Report of the Broken River Scientific Panel on the environmental condition and flows of the Broken River and Broken Creek

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The Cooperative Research Centre for Freshwater Ecology is a national research centre specialising in river and wetland ecology. The CRC for Freshwater Ecology provides the ecological knowledge needed to help manage the rivers in a sustainable way. The CRC was established in 1993 under the Australian Government's Cooperative Research Centre Program and is a joint venture between:

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Executive Summary

The Department of Natural Resources and Environment (DNRE) is overseeing a Bulk Entitlement conversion process for the Broken River Basin, with the aim of converting current water authority rights to water to Bulk Entitlements under the provisions of the Water Act (1989). A key feature of this process involves an assessment of current environmental conditions and identification of any current or potential impacts on environmental values associated with the regulation of flow within the river system. The broad environmental objective of the Bulk Entitlement conversion process is to ensure that current environmental values are protected and, where possible, enhanced.

The Broken Basin Bulk Entitlement Project Group appointed a Scientific Panel (convened by the Cooperative Research Centre for Freshwater Ecology) to consider environmental issues and to provide independent advice on the opportunities that exist through the Bulk Entitlement Conversion Process to better protect and enhance existing environmental values associated with regulated waterways in the Broken River Basin. The Scientific Panel had two objectives:

1. To specify a regulated flow regime that will sustain and where possible improve the current environmental values, dependent on water flows in the Broken River Basin; and
2. Provide advice to the Project Group on the environmental benefits of a variety of management options and operational scenarios.

This report meets the first of these objectives. The Scientific Panel has focussed its attention on the factors that contribute to current environmental conditions, and developed recommendations that aim to preserve or enhance the key ecological attributes of the river system. The advice of the Scientific Panel on management options and operational scenarios will be addressed separately.

The Scientific Panel based its recommendations on:

- An understanding of ecosystem health, including important river and floodplain ecosystem components (e.g. fish or vegetation biodiversity or community structure), that may be affected by management decisions;
- Principles for assessing river condition and making recommendations to improve river health within a water management context, focussing on:
    - The diversity of natural habitats and biota within the river channel, riparian zone and floodplain should be maintained (and where possible enhanced);
    - The natural linkages between the river and the floodplain should be maintained;
    - Natural metabolic functioning of aquatic ecosystems, such as primary productivity and respiration, should be suported.
- Assessing the river as a whole and operation of the river at the largest possible scale.

Some of the major tasks completed by the Broken Scientific Panel while undertaking this project included:

- Integration of knowledge of the historical and current environmental condition of streams in the study area (including the considerable experience and knowledge of the Broken system held by Panel members);

- Consultation with Goulburn Murray Water to clarify the operation of the system and aspects of its current condition;
- An intensive field trip, used to assess environmental conditions at 20 sites across the study area;
- Limited consultation with local landholders to gain their perspective of the river system;
- Analysis of hydrological data to identify changes to stream hydrology that have occurred since the regulation and diversion of water for agriculture and urban supply;
- Hydraulic modelling of sites representative of each reach of the Broken River;
- A series of workshops so that Panel members could develop a common understanding of the river system, important environmental values to be protected and how these values may have been affected by regulation and other catchment activities;
- The development of recommendations for a flow regime that will protect or enhance the environmental values identified for the Broken River system.

The representative reaches considered by the Scientific Panel were:

1. Broken River – Lake Nillahcootie to Broken Weir;
2. Broken River –Broken Weir to Casey's Weir;
3. Broken River – Casey's Weir to the Goulburn River;
4. Broken Creek – Casey's Weir to Katamatite;
5. Broken Creek – Katamatite to the Murray River.

Flow Regulation

Streamflow in the Broken River system is variable, both annually and seasonally, and is modified by the following processes:

- The presence and operation of Lake Nillahcootie;
- Diversion of water from the Broken River and Holland's Creek to supply Lake Mokoan, and operation of Lake Mokoan;
- The construction of irrigation supply and drainage schemes;
- The presence and operation of numerous weirs, both on the Broken River and Broken Creek;
- Progressive extraction of water from the Broken River and Broken Creek for irrigation and stock and domestic water supply;
- Changes to the form of the channel due to channelisation and snag removal; and
- Changes to floodplain drainage through the construction of levees and drains.

There are four major points at which flows in the Broken River are regulated:

- Lake Nillahcootie releases;
- Lake Mokoan diversions;
- Lake Mokoan releases; and
- Casey's Weir diversions.

Flow regulation has increased median monthly flow during drier months (February to April) and reduced flows in the wetter months (May to November). Median flows in December and January are reduced in Reach 1 and Reach 2, but increased in Reach 3. Irrigation demands in December and January are met by releases from Lake Mokoan, which discharges downstream of Reaches 1 and 2.

The effect on flood frequencies is small in all three reaches, with Reach 2 being most affected. At this site, recurrence intervals of small flow peaks (flows up to a 1-year return interval) are decreased by approximately 50%, presumably due to diversions to Lake Mokoan.

Summary of environmental values associated with the Broken River system
The Scientific Panel identified the following environmental values associated with the Broken River system, recommending that they should be protected in the future:

- The largely natural pattern of the flow regime in the lower reaches of the Broken River and lower Holland's Creek (including both high and low flows) as it maintains geomorphological, biological and ecological processes;
- Habitat diversity in the lower reaches of the Broken River, including in-stream features such as large woody debris, riffles, pools, bars, anabranches, the littoral fringe, flood runners, and floodplain and wetland/billabong features in the nearby landscape;
- Threatened species (flora and fauna), including up to ten native fish species of State and national conservation significance and icon species such as Murray cod;
- Riparian vegetation, especially in the lower Broken River and along Broken Creek. The remnant riparian and floodplain vegetation also provides important habitat for threatened species (fish, birds, amphibians) whose natural habitat in the region has been greatly reduced since European settlement;
- Connectivity between the river channel and its floodplain that maintains floodplain function;
- Links with the Goulburn and Murray Rivers, with the Broken River and Broken Creek being important for water yield and fish migration.

Summary of threats to environmental values
A large number of activities and processes pose threats of varying degrees to the environmental condition of the Broken River system. This is not surprising given the broad range of activities and land use that occur across the study area. The threats to environmental values include those associated with flow and river management, agricultural and industrial practices and activity, natural ecological processes, and invasion by pest plant and animal species:

- Altered flow regime;
- Altered floodplain drainage patterns;
- Potential cold water releases;
- Introduced fish species;
- Barriers to fish migration;
- Clearing of riparian vegetation;
- Weed invasion (terrestrial or aquatic);
- Bed and bank erosion;
- Channel realignment and excavation;
- Sediment inputs from tributaries and due to past river management works
- Livestock access;
- Stormwater pollution;
- Septic tank contamination;
- Poor water quality from Lake Mokoan;
- Impact of algal blooms;
- Contaminants carried in road runoff;

- Discharge of irrigation drainage.

Summary of the environmental effects of flow regulation
The effects of flow regulation on the ecological components of the river system may be summarised as:

- River hydrology has been altered, with a reduction in higher flows as a result of regulation at all three reaches of the Broken River. Low flows are now greater than natural in the upper two reaches but are reduced in Reach 3. The effect on flood frequencies is small at all three sites, with Reach 2 being most affected.
- River geomorphology remains largely unaffected by flow regulation;
- Water quality has been affected by inputs of nutrients, sediments and turbidity, including irrigation drainage, runoff from agricultural land and releases from Lake Mokoan.
- Riparian and aquatic vegetation has been affected by wetter conditions in upper reach of Broken River and by disturbances such as clearance and livestock access across the catchments. Floodplain wetlands are likely to have been affected by isolation form the river channels (due to levees) and land management practices (e.g. livestock access);
- Macroinvertebrates are unaffected by river regulation in upstream areas. The decline in macroinvertebrate communities in downstream areas is probably due to multiple catchment impacts;
- Dams and weirs that act as barriers to migration have affected native fish populations, including threatened species. The extent of reduced habitat availability due to lower than natural flows in the lower Broken River reach needs to be confirmed. The potential effect of cold water releases from Lake Nillahcootie also requires confirmation, although flows from Back Creek are likely to dampen the extent of temperature depression when cold water releases occur.
- The connection between the river channel and its floodplain has been largely unaffected by flow regulation from the dams. However, river-floodplain connections have been altered by the presence of levees in the vicinity of Benalla and along the lower Broken Creek.

Environmental flow recommendations
The Broken River and Broken Creek systems have been treated separately in terms of environmental flow recommendations. Environmental flow recommendations have been developed for the Broken River, while management recommendations have been supplied for Broken Creek, complementing those recommendations developed by other projects and initiatives. This recognises the fact that the current flow regime in Broken Creek will remain largely unnatural and that there was insufficient hydrological and hydraulic data available to quantify environmental flow requirements. The use of Broken Creek as a water supply channel and as a receiving water for irrigation drainage and channel outfalls means that what was once an intermittently flowing stream is now a permanent stream. Any detailed environmental flow regime would be an artificial construct for much of Broken Creek. The exception is for the section of Broken Creek between Waggarandall Weir and Katamatite. This section of the creek still retains some measure of ephemerality, which will be enhanced should the proposed pipeline for the Casey’s Weir and Major Creek Waterworks District go ahead.

The following flow rules are recommended to protect or enhance the current environmental values associated with the Broken River. Given that existing knowledge of the ecology of the

Broken River is limited, these recommendations should be considered as part of an adaptive management experiment, where the delivery of flows and any ecological responses are monitored and assessed. This will lead to the optimisation of environmental flow releases in the future. The recommendations mostly focus on minimum flows and rates of rise and fall in the flow regime. The Scientific Panel recognises the potential ecological impact of higher than normal summer flows down the Broken River (e.g. section 7.1.7 and 7.6), but felt there was insufficient information to recommend maximum flows. The potential geomorphological and ecological effects of higher than natural summer flows is an area requiring additional research.

Broken River from Lake Nillahcootie to Broken Weir:

- Maintain minimum winter flow of 30 ML/d or natural at Moorngag while Lake Nillahcootie fills or when water is being transferred to Lake Mokoan. This flow is to pass along the rest of the reach and over Broken Weir;
- Apply a flow reduction target of $Q_2 > 0.65Q_1$[1] when reducing regulated releases (e.g. when reducing flows from Lake Nillahcootie when filling the dam);
- Apply a rule of $Q_2 < 2.1Q_1$ when increasing regulated releases from Lake Nillahcootie.

Broken River from Broken Weir to Casey's Weir:

- Maintain summer flow above a minimum of 22 ML/d or natural. This will be sufficient to maintain slow water habitat for juvenile fish also (20 ML/d). Compliance should be measured at Broken Weir and include the 22 ML/d (or natural) and additional flow to meet diversion needs along the reach;
- Apply flow reduction target of $Q_2 > 0.7Q_1$ when adjusting flows (e.g. when diverting to Lake Mokoan; when reducing flows during the irrigation season).
- Apply a rule of $Q_2 < 1.5Q_1$ when increasing regulated releases.

Broken River from Casey's Weir to the Goulburn River:

- Maintain flow above a minimum of 25 ML/d or natural downstream of Casey's Weir. This will be sufficient to maintain slow water habitat for juvenile fish also (20 ML/d). Compliance should be measured at Gowangardie Weir and include the 25 ML/d (or natural) plus flows to meet diversion demands downstream of Gowangardie Weir;
- Apply flow reduction target of $Q_2 > 0.55Q_1$ when adjusting flows (e.g. when diverting to Lake Mokoan; when reducing flows at the end of the irrigation season).
- Apply a rule of $Q_2 < 1.8Q_1$ when increasing regulated releases.

Holland's Creek from Holland's Weir to the Broken River:

- Maintain flow above a minimum of 12 ML/d or natural downstream of Holland's Weir when Lake Mokoan is being filled.

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[1] (Q_2 = flow on day 2, Q_1 = flow on day 1)

Implications of changed operation of Lake Mokoan

The Scientific Panel was asked to consider the impact on the Broken River system of the future management of Lake Mokoan. The management options considered were:

- Existing management of Lake Mokoan continues according to current levels of demand, current diversion and release patterns, and the reservoir being closed in summer-autumn months for 9 years in 10 (the basis of previous discussion on environmental values and environmental flows);
- Decommissioning the reservoir, where Lake Mokoan is no longer used as a supply of irrigation water and there are no diversions to, or releases from the reservoir to meet downstream demand;
- Unconstrained operation of the reservoir, where diversions to, and releases from the reservoir are unconstrained by water quality and algal bloom problems, the reservoir remains open all year round and there is a full uptake of existing licenses.

There are no formal plans to decommission Lake Mokoan as an irrigation supply. Any decommissioning scenario would necessarily include the removal or modification of the dam wall to eliminate the risk of future failure and flooding. How the site currently occupied by the reservoir would be managed under some future decommissioning scenario is unclear, although a number of options would be available (e.g. management of the area as a recreational lake, return to the flow regime of Winton Swamp). No assumptions were made on the future management of the Lake Mokoan site for this assessment, other than that decommissioning would result in a cessation of diversions from the Broken River and Holland's Creek and a cessation of water released from the reservoir to meet downstream demand.

The unconstrained use of Lake Mokoan assumes that current water quality and algal blooms problems in the reservoir are overcome, that there are no constraints on storage levels in the reservoir and that diversions into and out of the reservoir occur when required in all years. This scenario also assumes full uptake of existing diversion and irrigation licenses.

Assessment of the different scenarios was made by examining the level of deviation from natural flow regime each of the management scenarios represents. Such an approach assumes that moving to more natural hydrology will result in more natural environmental conditions and ecological processes. However, whether such perceived ecological benefits actually arise with the implementation of any of the scenarios will depend on many factors, such as habitat quality, successional patterns, competition and opportunities for migration, amongst many others. Predicting the order and final outcome in terms of ecological response to any of the management scenarios is extremely difficult, and requires more detailed consideration than that afforded to the Scientific Panel in this project.

On balance, the Scientific Panel supports the decommissioning scenario as it poses less risk to the Broken River system than the unconstrained development scenario (both scenarios offered advantages compared with the current situation). The reasons for this include:

- The lower Broken River is an example of a lowland river that generally is in good health. This is a relatively rare thing and considered to be of greater ecological value than the upper reach of the Broken River, which is a foothill stream of moderate to good condition.

- Reach 3 is more likely to support an abundant and a diverse range of native fish species than is Reach 1, including Murray cod, trout cod, golden perch and blackfish. Any move to enhance native fish populations in this reach would be valuable. Reach 3 is also much longer than Reach 2 and is closest to the Goulburn and Murray Rivers. Most fish migrations from these rivers will occur along Reach 3.
- Relatively little is known about the ecology of the river upstream of Benalla. At this stage, priority should go to those reaches known to have a high conservation value.
- The decommissioning scenario poses fewer risks to the health of the Goulburn and Murray Rivers, as the largely natural winter/spring flows resulting from this scenario are complementary to the natural flow regime of these rivers.

The Scientific Panel acknowledges that the decommissioning scenario has significant socio-economic implications for local stakeholders and the community that were beyond the scope of this project to address. An Environmental Impact Study is recommended to consider future management options for the lake if decomissioning is considered as a viable option.

Management of Broken Creek

The Casey's Weir and Major Creek Waterworks District provides year-round water for stock and domestic supply, and irrigation supply in summer-autumn. The existing system involves the Broken River and Broken (particularly between Waggarandall Weir and Katamatite), Major, Back and Boosey Creeks. Water is supplied via earthen channels constructed on drainage pathways. It is proposed that this system be replaced with a reticulated pipeline system. In addition to water savings, the environmental benefits associated with installation of the pipeline are expected to include:

- Reduction in unnatural overflows to wetlands such as Moodies Swamp and Lake Rowan;
- Changes to geomorphic processes and increased habitat diversity in the long term;
- Increased native vegetation both in the creek channel and in the riparian zone;
- Conditions less favourable to weeds species such as willows;

The installation of a pipeline will alter the current flow regime in the Broken Creek between Casey's Weir and Katamatite, particularly below Waggarandall Weir. Given the relatively poor water quality in the creek (high turbidity, high suspended sediment, high nutrient levels) significant reductions or cessation in flows, although approaching a more natural condition, are likely to increase the risk of detrimental effects on in-stream communities because current flows help to ameliorate the effects of habitat degradation and poor water quality. There is a risk that managing this reach as an ephemeral stream may exacerbate the impacts of surrounding land use.

It is recommended that a performance management plan be developed for the creek in the event that the pipeline is constructed. This plan should include monitoring of the responses of water quality, native fish and invertebrates, and pest fish and plants. Recovery of the creek system may only become apparent after many years; realisation of the benefits of the altered flow regime will require a long-term commitment.

Broken Creek downstream of Katamatite has significant problems caused by an altered flow regime, poor water quality and degraded in-stream habitat. Efforts made to improve water quality and habitat are likely to have greater effects on improving conditions for invertebrates than alterations to the current flow regime.

The following management recommendations are intended to complement the goals and objectives already articulated by initiatives such as the Goulburn-Broken CMA's river health strategy and management plans developed previously for the Broken Creek:

- Develop clear rehabilitation objectives for Broken Creek. Given that the current condition of instream values in Broken Creek is poor, rehabilitation should be directed towards maximising/improving landscape values.
- Return the Broken Creek to an ephemeral stream between Waggarandall Weir and Katamatite. Potential benefits include extending the range of native fish, control of carp and the management of willows.
- Control livestock access to Broken Creek.
- Revegetate stream with native (indigenous) species.
- Support the move to include high value riparian areas in a proposed State park.
- Develop carp control strategy to complement the carp control plan for Barmah.
- Continue willow removal program.
- Continue the fish passage/weir removal program after reviewing weir pools with apparent good environmental values.
- Continue and possibly increase the rate of investment in water quality and river health initiatives in line with the Goulburn Broken CMA's waterway health program and water quality strategy.
- Review the benefits of weir draw down trials being conducted elsewhere in the Murray Darling Basin.
- Support the call for monitoring the effects of management actions (ISC, WQ, length of stream fenced of and revegetated, increased native fish populations etc.). If moves to return intermittency of flow to the stream are acted upon, then monitoring ecological responses will be critical.
- Develop and implement a pest and fire management plans to complement rehabilitation plans.
- Cessation of any further channelisation works. If in-stream works such as sediment removal are carried out (e.g. from weir pools), care must be taken to minimise sediment input and transport in the stream as current levels of suspended particulate matter are unacceptably high.
- Ban of removal of wood from the riparian zone.
- Closely monitor ecological responses to the changed flow regime that accompanies installation of the Tungemah pipeline.

Other management recommendations

The environmental condition of the Broken River system can be improved by actions that complement the environmental flow recommendations. These include habitat rehabilitation works, implementation of existing catchment management and water quality strategies and the provision of fish passage past in-stream barriers:

- Continued efforts to reduce nutrients, sediment and turbidity in releases from Lake Nillahcootie and Lake Mokoan;
- Rehabilitation of native vegetation in the riparian zone of Reach 1 and Reach 2;
- Prevent further small weir building within the main channel of the Broken River;
- Evaluation of the potential to reinstate in-stream habitat such as snags in areas previously cleared by 'river improvement' works;
- Investigating the significance of slugs of sand to altered habitat diversity (Reaches 2 and 3);

- Limiting livestock access to waterways;
- Implementing pest control strategies, for example for carp;
- Continue the program of providing fish passage past barriers such as weirs. Priority should go to Gowangardie Weir, Casey's Weir and Broken Weir on the Broken River, Holland's Weir on Holland's Creek, and continuation of the fish passage program on Broken Creek;
- Ensure proper maintenance of existing fishways;
- Encouraging responsible recreational fishing for native species.

Key knowledge gaps

The regulation of flows from Lake Nillahcootie has resulted in higher than natural summer/autumn flows in the Broken River below the dam. This poses a number of potential threats to the ecosystem of the river:

- More constant water levels that favour invasive species such as willows and carp;
- Potential cold water releases that affect the biology of riverine biota;
- Change in macroinvertebrate abundance and species composition;
- Increased potential for washout of larval and juvenile fish;
- Less habitat for submerged aquatic macrophytes and, as a consequence, less habitat for macroinvertebrates and small fish;
- Increased sediment movement that disrupts biofilms and microphytobenthos that are a potential source of food for other biota;
- Increased bank erosion due to increased saturation of the bed and banks.

However, there was insufficient information available to assess the degree to which the higher than natural summer flows may have impacted on biological and ecological processes in the Broken River, if at all. While acknowledging higher summer flows as a potential threat, the Scientific Panel felt that it could not make environmental flow recommendations at this stage. The ecological effects of higher than natural summer/autumn flows is an area requiring further investigation. Factors to consider when investigating the impact of higher than natural summer flows in the Broken River between Lake Nillahcootie and Broken Weir are listed in section 7.6.

A performance monitoring and assessment program will be an important consideration when implementing any of the initiatives listed in this report. This will ensure that environmental values are protected and highlight the response of the river system to management actions. Responsibility for undertaking the various management actions and for assessing their effect will require negotiation between stakeholders such as the GBCMA, DNRE, GMW, EPA and local communities.

Contents

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1 INTRODUCTION

The Department of Natural Resources and Environment (DNRE) is overseeing a Bulk Entitlement conversion process for the Broken Basin, with the aim of converting current water authority rights to water to Bulk Entitlements under the provisions of the Water Act (1989). A key feature of this process involves an assessment of current environmental conditions and identification of any current or potential impacts on environmental values associated with the regulation of flow within the river system. The broad environmental objective of the Bulk Entitlement conversion process is to ensure that current environmental values are to be protected and, where possible, enhanced.

The Broken Basin Bulk Entitlement Project Group considered that a Scientific Panel should be convened to consider the environmental issues and provide independent advice on the opportunities that exist through the Bulk Entitlement Conversion Process to better protect and enhance existing environmental values associated with the waterways. DNRE approached the Cooperative Research Centre for Freshwater Ecology (CRCFE) to convene and manage the Scientific Panel, which has identified the flows necessary to maintain or improve key environmental values. The Project Group will consider the scientific panel's advice, along with economic and social factors, when it determines the Bulk Entitlement for the Broken Basin.

1.1 Project Objectives

The Scientific Panel had two main objectives:

1. To specify a regulated flow regime that will sustain and where possible improve the current environmental values, dependent on water flows in the Broken Basin; and
2. Provide advice to the Project Group on the environmental benefits of a variety of management options and operational scenarios.

This report meets the first of these objectives. The Scientific Panel has focussed its attention on the factors that contribute to current environmental conditions, and has developed recommendations that aim to preserve or enhance the key ecological attributes of the river system, with emphasis on an environmental flow regime for the Broken River system. The Scientific Panel has also considered the implications of proposed developments of the water supply system, in particular the future management of Lake Mokoan and the replacement of the current Casey's Weir & Major's Creek Waterworks District supply system with a reticulated pipeline.

For the second objective, the advice of the Scientific Panel on the management options and operational scenarios developed by the Broken Basin Bulk Entitlement Project Group will be reported separately during the Bulk Entitlement conversion process.

1.2 Structure of this report

Chapter 2 of this report provides an overview of the study area. The general approach used by the Scientific Panel to assess river and floodplain condition in the study area is outlined in Chapter 3. The history of flow regulation across the study area is summarised in Chapter 4, while the impact of flow regulation on the flow regime is provided in Chapter 5. Flow-related river ecology in the study area is summarised in Chapter 6, along with summaries of environmental values to be protected or enhanced and the threats to the environmental values. The recommendations of the Scientific Panel are presented in Chapter 7.

2 OVERVIEW OF THE STUDY AREA

The Broken River rises in the Wellington-Tolmie highlands and flows in a westerly direction to Lake Nillahcootie. The river then flows north to Benalla and then west again, before it discharges to the Goulburn River near Shepparton. The main tributaries of the Broken River include Holland's Creek, Ryan's Creek, and Lima East Creek (formerly Moonee's Creek). The gradient of the river is relatively steep in upstream areas, before becoming flat downstream of Swanpool (Strom 1962).

Much of the study area has been cleared for agriculture, including dryland (livestock grazing and cereal cropping) and irrigated agriculture (dairy, fruit, livestock). Major urban areas in the study include Benalla, Dookie, Katamatite, Tungamah, Numurkah and Nathalia.

Broken Creek is an effluent stream that receives overflows and water diverted from the Broken River at Casey's Weir. The creek flows north-west from the Broken River to Katamatite, where it is joined by Boosey Creek. Broken Creek then flows west until it reaches the Murray River near Barmah. Broken Creek was an ephemeral stream prior to regulation of the Broken River, but now flows continuously in its upstream reaches as a consequence of flow diversions into Broken Creek from the Broken River at Casey's Weir. The creek carries irrigation and stock and domestic supply between Casey's Weir and Katamatite, and receives water from the East Goulburn Main channel and numerous irrigation return drains between Katamatite and the Murray River.

Lake Nillahcootie and Lake Mokoan are the two main water storages in the study area. Lake Nillahcootie was constructed on the Broken River in the south of the catchment in 1967. Lake Mokoan is an off-river storage constructed with the damming of Winton Swamp in 1971. There are three major weirs on the river downstream of Lake Nillahcootie:

- Broken Weir, which is used to divert water to Lake Mokoan;
- Casey's Weir, which is used to divert water to the Casey's Weir and Major's Creek Waterworks District; and
- Gowangardie Weir, which is used to divert water to the Pine Lodge and Shepparton Waterworks Trust.

An additional diversion weir for Lake Mokoan is located on Holland Creek, a major tributary of the Broken River

The Scientific Panel assigned the study area to five representative reaches (Figure 1) based on hydrology and geography:

1. Broken River – Lake Nillahcootie to Broken Weir;
2. Broken River –Broken Weir to Casey's Weir;
3. Broken River – Casey's Weir to the Goulburn River;
4. Broken Creek – Casey's Weir to Katamatite;
5. Broken Creek – Katamatite to the Murray River.

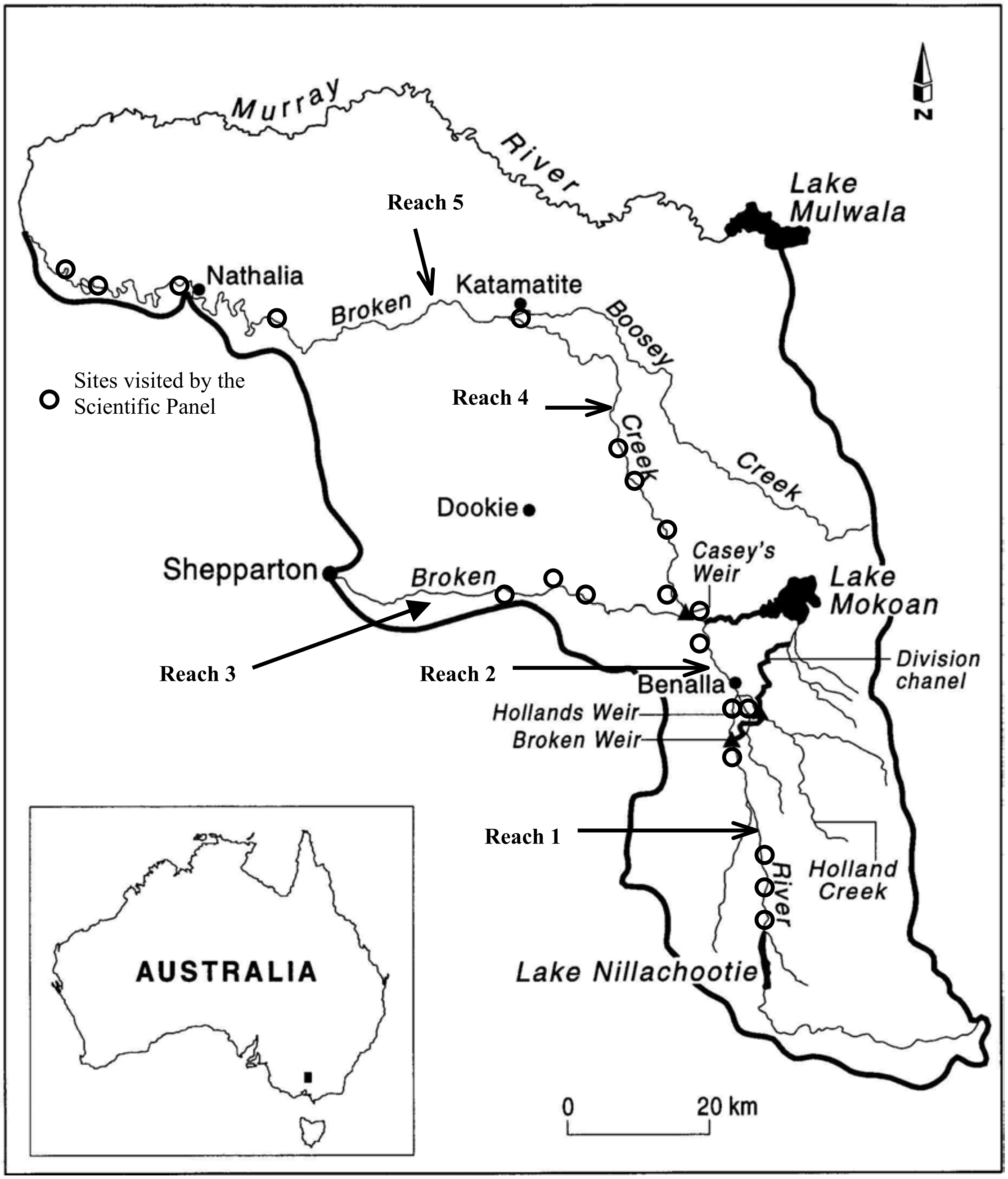

Figure 1: Broken River representative reaches and sites visited by the Scientific Panel

3 SCIENTIFIC PANEL APPROACH

The Scientific Panel approach includes a rapid appraisal of the geomorphological and ecological condition of a riverine ecosystem by an interdisciplinary team that includes both local and scientific expertise. This approach has been employed within the Murray-Darling Basin on the Darling and Murray Rivers (Thoms *et al.* 1996 and 2000), the Murrumbidgee River (NSW EPA 1997; Hillman *et al.* 2000), and on the Campaspe River (Marchant *et al*. 1997), the Ovens River (Cottingham *et al*. 2001) and the Snowy River in Victoria (SGCMC 1996). Arthington and Zalucki (1998), the NSW EPA (1997) and Swales and Harris (1995) have reviewed the advantages and limitations of the expert panel method. Key strengths include:

- Synergies are gained from the interaction across scientific disciplines, and between scientists and managers;
- The process is relatively quick and inexpensive compared to many other environmental assessment methods;
- Relatively few field measurements are required;
- The process provides an opportunity for collaborative decision-making for river management within a framework of adaptive management;
- Opportunity for direct interaction between researchers and managers resulting in time efficiencies.

Shortcomings of the Scientific Panel approach include:

- The method is often qualitative, so additional investigations may be required to confirm findings;
- Assessment is restricted to a limited number of sites that must be representative of the river system;
- Limited to data already available or already collected
- The method can be limited by the expertise of the Panel members;
- As it is based on a brief view of the system at only one point in time (snap shot) Panel members must be aware of the variability of the system.

3.1 Broken Scientific Panel assessment framework

The experience and expertise of the Broken Scientific Panel is summarised in Appendix 1. All the Panel members have considerable experience in assessing the environmental condition of rivers in the Murray Darling Basin, including the Broken River.

In order to undertake the assessment required by the project brief, the Scientific Panel developed a framework in which recommendations could be developed in a way that was consistent, easily understood, environmentally defensible and scientifically valid. This framework was based on:

- An understanding of ecosystem health, including important river and floodplain ecosystem components (e.g. fish or vegetation biodiversity or community structure), that may be affected by management decisions;
- Principles for assessing river condition and making recommendations to improve river health within a water management context, focussing on:

  - ➢ The natural diversity of habitats and biota within the river channel, riparian zone and floodplain should be maintained (and where possible improved);
  - ➢ The natural linkages between the river and the floodplain should be maintained;
  - ➢ Natural metabolic functioning of aquatic ecosystems, such as primary productivity and respiration, should be maintained.
- Assessing the river as a whole and operation of the river at the largest possible scale.

Further, elements of the natural flow regime, especially seasonality, should be retained as far as possible in order to provide or maintain a niche for native species and maintain the natural functions of the river system.

3.2 Approach to developing environmental flow recommendations

Some of the major tasks completed by the Broken Scientific Panel while undertaking this project included:

- Integration of knowledge of the historical and current environmental condition of streams in the study area (including the considerable experience and knowledge of the Broken system held by Panel members);
- Consultation with Goulburn Murray Water to clarify the operation of the system;
- An intensive field trip, used to assess environmental conditions at 20 sites across the study area (Table 1 and Figure 1);
- Limited consultation with local landholders to gain their perspective of the river system;
- Analysis of hydrological data to identify changes to stream hydrology that have occurred since the regulation and diversion of water for agriculture and urban supply;
- Hydraulic modelling of sites representative of each reach of the Broken River;
- A series of workshops so that Panel members could develop a common understanding of the river system, important environmental values to be protected and how these values may have been affected by regulation and other catchment activities;
- The development of recommendations for a flow regime that will protect or enhance the environmental values identified for the Broken River system, assisted by the Flow Events Method (Stewardson 2001). This method is described in section 3.2.1.

3.2.1 The Flow Events Method

The Flow Events Method (FEM) has been developed as a tool for integrating various techniques and expert opinion when determining environmental flows for regulated rivers (Stewardson 2001). The method can be used for purposes such as assessing the ecological impact of changes to the flow regime, specifying environmental flow targets or optimising environmental flow rules to maximise ecological benefits. As it was applied to the Broken River system, the FEM was used to:

- Identify the habitat potentially affected by flow variation, particularly for native fish, macroinverterbates and in-stream and riparian vegetation;
- Characterise flow events to be considered;
- Assess changes to ecologically important aspects of the flow regime, based on changes to flow event recurrence interval;
- Set environmental flow targets.

This process was aided by the construction of daily flow models and data sets, and hydraulic modelling of representative sites within the three reaches of the Broken River.

Table 1: Sites visited by the Scientific Panel, 30th April – 2nd May 2001.

Reach	Site	Location
1. Broken River – Lake Nillahcootie to Broken Weir	Broken River 1 Broken River 2 Broken River 3	Lake Nillahcootie William Rd Swanpool (Butter Factory Bridge)
2. Broken River – Broken Weir to Casey's Weir	Broken River 4 Broken River 5 Broken River 9 Broken River 10	O'Farrell Rd (Goldings Weir) Broken Weir Scholes Rd Casey's Weir
3. Broken River – Casey's Weir to Goulburn River	Broken River 6 Broken River 7 Broken River 8	Gowangardie Weir Goomalibee Ballantine Rd
4. Broken Creek – Casey's Weir to Katamatite	Broken River 11 Broken River 12 Broken River 13 Broken River 14 Broken River 15	Midland Highway Flynn's Weir Boxwood Rd Oliver Rd McLaughlin's Weir
5. Broken Creek – Katamatite – Murray River	Broken River 16 Broken River 17 Broken River 18 Broken River 19	Fairman's Bridge Downstream of Nathalia Walsh's Bridge Follets Bridge
6. Holland's Creek – Holland's Weir to Broken River	Broken River 20	Tatong Rd

The first step examines key aspects of the flow regime that influence the stream ecosystem. These aspects are referred to as flow events and each flow event is associated with a particular ecological response. Where ecological knowledge is poor, the flow event and response can be considered an hypothesis that might be tested through monitoring or further research. The Scientific Panel identified aspects of the flow regime that potentially influence important components of the river ecosystem, including:

- Geomorphology,
- River-floodplain connectivity, including wetlands and anabranches,
- Macrophyte, macroinvertebrate and fish communities, and
- Water quality.

The flow events that were considered important for setting environmental flow targets in the Broken River were:

- Stranding of fish during rapid flow reductions;
- Washout of young fish during rapid flow increases;
- Loss of slow-water habitat for fish larvae;
- Drying of the streambed;
- Loss of shallow water for macrophytes; and
- Changes in river bench inundation.

These flow events were identified by the Scientific Panel in light of changes to the flow regime of the Broken River and the potential for adverse ecological effects. Operation of the dams and flow regulation can potentially alter the rate of rise and fall, minimum flows and the frequency of inundation of in-channel features such as river benches and bank vegetation (regulation has not altered the frequency of large flow events such as floods - see section 5.2).

The flow events were evaluated using hydraulic parameters that measured the severity of the event. For example, drying of the streambed was characterised by the area of wetted perimeter of the channel. The Scientific Panel also considered the time sequence of flow events, for example:

- The months in which the events are ecologically important;
- Whether extreme events, more frequent events or average conditions are important; and
- What degree of change in the ecologically important flow events is acceptable.

The results of this analysis are considered in detail in Chapters 5 and 6.

4 HISTORY OF FLOW REGULATION IN THE BROKEN RIVER SYSTEM

4.1 Overview of the system

Mean annual streamflow for the Broken Basin is approximately 325 GL, with an average flow of approximately 236 GL in the Broken River below Casey's Weir and an average flow of approximately 71 GL in Broken Creek at Rice's Weir (DWR 1989). Streamflow is variable, both annually and seasonally, and is modified by the following processes:

- The presence and operation of Lake Nillahcootie;
- Diversion of water from the Broken River and Holland's Creek to supply Lake Mokoan, and operation of Lake Mokoan;
- The construction of irrigation supply and drainage schemes;
- The presence and operation of numerous weirs, both on the Broken River and Broken Creek;
- Progressive extraction of water from the Broken River and Broken Creek for irrigation and stock and domestic water supply;
- Changes to the form of the channel due to channelisation and snag removal; and
- Changes to floodplain drainage through he construction of levees and drains.

The operation of Lake Nillahcootie and Lake Mokoan to provide irrigation, stock & domestic, and town water supply are discussed in the following sections. Changes to river form (geomorphology) and the effect of flood levees are discussed in Chapter 5.

4.2 Lake Nillahcootie and Lake Mokoan

There are 44 licences but only 6 active diverters along the Broken River to Benalla and 73 diverters between Benalla and the Goulburn River, licensed to divert approximately 27,000 ML annually (27,859 ML was diverted 2000/01). There are 38 irrigators on the Broken and Majors Creek system with entitlements to approximately 9,000 ML annually, supplied via diversion to Broken Creek from Casey's Weir. Water usage in 2000/01 was about 6,100 ML. Both Lake Nillahcootie and Lake Mokoan are operated by GMW to meet demand, which is usually less than entitlement and varies with climatic conditions. The utilisation of licensed volume varies from reach to reach, with typically lower usage in the reach from Lake Nillahcootie to Benalla and from Lake Mokoan.

4.2.1 Operation of Lake Nillahcootie

Lake Nillahcootie is located on the Broken River approximately 31 km south of Benalla. The dam was completed in 1967 and has a capacity of 40,000 ML and a surface area of 530 hectares at Full Supply Level (FSL). The dam has an earth and rockfill embankment that is 34 metres high and two spillways, an Ogee Crested concrete spillway (capacity of 110,000 ML/d at imminent flood failure) and an uncontrolled fuse plug.

Lake Nillahcootie fills in most years, as the dam capacity is approximately half of the mean annual flow of that section of the Broken River, and is regularly drawn down to less than 30% capacity by the end of the annual irrigation season. The storage does not have a formal filling curve, and is allowed to fill according to available inflows. Prior to the onset of regular blue-green algae outbreaks in Lake Mokoan, formal guidelines permitted the transfer of water to Lake Mokoan if Lake Nillahcootie was approaching full supply level and Lake Mokoan still had airspace.

Releases from the dam are via a single outlet controlled by two cone valves (one 1350 mm diameter, one 450 mm diameter) with a combined capacity of approximately 800 ML/d. The top of the outlet is approximately 16 m below FSL. Water is released to meet downstream demand up to 300 ML/d and to ensure a minimum 'riparian flow' of 30 ML/d at Moorngag. Releases from the dam may be less than 30 ML/d as tributary inflows (e.g. Back Creek) can supply much of the flow required. Releases from the valves are adjusted manually on Mondays, Wednesdays and Fridays. Flow rates can be changed up to three times per week but are generally constant over much of the irrigation season. The system is expected to be automated in 2002 to allow remote operation and the fine-tuning of releases.

4.2.2 Operation of Lake Mokoan

Lake Mokoan is an off-stream storage constructed on what was Winton Swamp, north of Benalla. The dam was complete in 1971 and has a capacity of 365,000 ML and a surface area of 7,890 hectares at FSL. The dam is an earthen bank approximately 11 m high and 7,500 m long. There is no spillway as the risk of water levels overtopping the dam is very low.

The dam supplies approximately 22,000 ML to downstream diverters and irrigators annually, although more water would be available if water quality/algal bloom problems were overcome. Persistently poor water quality and the regular occurrence of potentially toxic algal blooms have resulted in closure of Lake Mokoan over summer-autumn in 9 out of 10 years over the past decade.

Lake Mokoan is filled by diversions from Holland's Creek and the Broken River each year. Storage levels are managed to achieve a target level of 70% capacity and are drawn down to 42% capacity during the irrigation season. This operating range represents a depth variation of approximately 1.5 m, and was considered as a compromise between the amount of lake bed exposed to encourage regrowth of vegetation and the needs of lake diverters (AWT 2000).

4.3 Operation of Casey's Weir and Gowangardie Weir

4.3.1 Casey's Weir

Casey's Weir is located 15 km downstream of Benalla on the Broken River. It was constructed in 1885 to divert the low flows into the Broken Creek system. It is founded on sand drift and clay and consists of a buttressed concrete wall supported by three rows of piling. After being originally controlled by the constructing rural waterworks trusts, then State Rivers and Water Supply Commission, it is now operated by Goulburn-Murray Water. Water is diverted at Casey's Weir to supply the irrigation requirements on Broken Creek and the Casey's Weir and Majors Creek Domestic and Stock system. The weir also supplies to North East Regional Water Authority for the towns of Devenish, St. James and Tungamah.

4.3.2 Gowangardie Weir

Gowangardie Weir is located 30 km downstream from Benalla on the Broken River. It was built to replace the original Pine Lodge Weir (1884) which was washed away by floods due to an unsuitable site. The site of Gowangardie Weir 5 km upstream from the old weir has a foundation of slatey stone. The structure is a concrete 'gravity' type founded on rock. The maximum height from the natural riverbed to the spillway crest is 3.5 meters. Gowangardie Weir diverts water to supply the Shepparton East Community Water Supply Scheme. Annual diversion in recent years has been approximately 750 ML.

4.4 Modifications to floodplain drainage

Flow from the floodplain of the Broken River and Broken Creek has been extensively modified by agriculture and urban development, and especially the construction of irrigation water supply channels and return drains. For example, approximately 34% of the Broken Creek catchment lies within the Murray Valley and Shepparton irrigation districts (SKM 1998). Irrigation drainage systems include both public and private schemes. The largest drains in the Shepparton Irrigation District are the Shepparton Drains 11 and 12, which outfall to Nine Mile Creek downstream of Wunghnu. Other Shepparton drains include Drains 13A, 15 and 16; all discharge to Nine Mile Creek.

Drain 13 and Drain 18 are the two largest drains in the Murray Valley Irrigation District, outfalling to the Broken Creek downstream of Nathalia and south of Waaia respectively. Other Murray valley drains include Drains 17, 19 and 20; all discharge to Broken Creek.

Irrigation water is mainly supplied from the East Goulburn Main Channel and from Lake Mulwala. The East Goulburn Main Channel outfalls to the Broken Creek and Nine Mile Creek at Katandra Weir downstream of Katamatite

The interaction between Broken River and Broken Creek and their respective floodplains has also been modified by practices such as landforming and the construction of levees to protect public and private assets (SKM 1998).

4.5 Potential developments in flow regulation

4.5.1 Tungamah pipeline

It is proposed that the existing system of earthen channels that supply water to the Casey's Weir and Major Creek Waterworks District should be replaced with a reticulated pipeline network (AWT 2001). It is anticipated that a pipeline system will result in water savings ranging from approximately 3,500 to approximately 8,900 ML per year, depending on the level of bulk entitlement set for the district.

The Scientific Panel was requested to consider the ecological implications for Broken Creek should the Tungamah pipeline go ahead. The pipeline development is most relevant to the section of Broken Creek between Flynn's Weir and Katamatite and particularly the section downstream of Waggarandall Weir, as this reach will receive significantly lower flows after being managed as a permanent waterway for over 100 years. AWT (2001) suggested that complete flow cessation would occur rarely along Broken Creek. The Scientific Panel's recommendations for Broken Creek are outlined in Chapter 7.

4.5.2 Future of Lake Mokoan

The DNRE is reviewing the operation of large dams across northern Victoria to assess potential water savings and efficiencies and meet Victoria's commitment and contribution that will return flow in the upper Snowy River to 28% of natural. The future of Lake Mokoan is being considered within this context, and in view of its recent history of poor water quality (high turbidity, high nutrient concentration) and closure of the lake due to potentially toxic algal blooms in the summer of most years. Lake Mokoan is also being considered in a feasibility study to supply water to a proposed irrigation district near the Warby Ranges.

The Scientific Panel was requested to consider the ecological implications of different management scenarios for Lake Mokoan on the environmental values associated with the Broken River system, including:

- Current operation (water levels maintained within a target range, closure due to algal blooms in most summers, water supplied to the Murray River in dry years if the lake has not been closed due to algal blooms);
- Operation of Lake Mokoan at its full potential (unconstrained operation - assumes no restriction on storage levels, no closure due to algal blooms, full uptake of licenses, supply of water to the Murray River in dry years);
- Decommissioning of Lake Mokoan (future management of the lake unclear).

The implications of changed management of Lake Mokoan are discussed in Chapter 7.

4.5.3 Potential long-term changes to stream flow

Long-term changes to climate and landuse in the Broken catchment may have the potential to affect streamflow in the future. For example, increased temperature due to global warming may result in reduced streamflow in southern areas of the Murray Darling Basin. Modelling reported by Bennett (1999) suggested that flows in the rivers of north-east Victoria may decrease by up to 36% over the next 30 years (worst case scenario), and that the frequency of flooding would decrease while the frequency of drought would increase (Tables 2 and 3). These are the upper limits of changes modelled in the studies reported by Bennett (1999) and while modelling predictions about the sustainability of water resources and agriculture should be treated with caution (Henderson-Sellers, 1996), they suggest that climate change may significantly alter flows in the Broken and nearby catchments. Any reduction in rainfall and streamflow may affect the water yield available for irrigation, consumptive and environmental purposes.

Table 2: Scenarios for the year 2030 on the effect of climate change on precipitation and streamflow in snow-free catchments (Goulburn and Broken Rivers) in Victoria (from Schreider *et al.* (1997) reported in Bennett, 1999)

Scenario	Precipitation (% change)	Streamflow (% change)
Most dry	-7	-36
Most wet	+13	0

Table 3: Scenarios for the year 2030 on the effect of climate change on floods and drought in snow free catchments (Goulburn and Broken Rivers) in Victoria (from Schreider *et al.* (1997) reported in Bennett, 1999)

Scenario	August – October floods (% frequency)	January – March drought (% frequency)
Most dry	-82	+36
Most wet	+41	+5

The Victorian Government intends to invest $8 million in the Replanting Victoria 2020 program (DNRE, 1999) as part of its response to Greenhouse effects and other land and water management issues. Much of the new plantation areas are expected to replace what is currently grassland. Given that evapotranspiration rates in plantations are higher than in cleared areas such as grasslands, extensive reforestation has the potential to significantly reduce stream flows from afforested catchments (Vertessy, 1999). The implications of these broad regional scenarios for the Broken River system are not yet clear.

There is insufficient information available to assess the combined effects of climate and landuse change on stream flow in the Broken catchment. However, it would be prudent for the farming community and waterway managers to consider the implications of afforestation and global warming on their respective operations. Given the broad scale at which climate and landuse changes may potentially impact on water yield, it is likely that negotiations will be required at State, regional and local levels. It is unrealistic to expect that water entitlements will simply be increased to offset any loss of reliability at the expense of maintaining environmental condition or health of streams. It is timely to consider the potential impacts on climate change and reafforestation on water resource availability, and in particular how environmental flows might be affected.

5 HYDROLGICAL IMPACTS OF FLOW REGULATION

5.1 System Operation

There are four major points at which flows in the Broken River are regulated:

1. **Lake Nillahcootie Releases**: The Lake Nillahcootie outlet is operated during the irrigation season to meet downstream demand (Figure 2a). During the irrigation season there is a general increase in releases to meet an increasing demand with some periods of lower releases when demand reduces as a result of rain events. At the end of the irrigation season, the minimum flows are released to ensure that flows downstream of Moorngag are at least 30 ML/d. If it is appears that the dam will fill before the end of winter, flows are released from Lake Nillahcootie to fill Lake Mokoan.

2. **Lake Mokoan Diversions:** Lake Mokoan is a large off-stream storage that is filled during the wetter months by diversions from the Broken River and Holland's Creek via Broken Weir and Holland's Weir. The capacity of the diversion channel from Broken Weir to Holland's Weir is 1,800 ML/d. The capacity of the diversion channel from Holland's Weir to Lake Mokoan is 2,500 ML/d. During periods of operation, approximately 90% of flow in the Broken river is diverted at Broken Weir and up to 100% of flow is diverted at Holland Weir. However, a minimum release of 12 ML/d from the Holland's Weir has been applied in recent years to maintain flow in lower Holland's Creek. Diversions are not usually undertaken when flow in Broken River exceeds 2,500 ML/d or Holland's Creek flow exceeds approximately 4,000 ML/d (Figure 3).

3. **Lake Mokoan Releases:** Water is released from Lake Mokoan to meet downstream agricultural demands in the drier portion of the year, and enters the Broken River upstream of Casey's Weir. Since 1984, releases have not been possible in the latter part of the irrigation season because of algal blooms in the Lake. Releases of up to 2,160 ML/d have been recorded and the average release is 500 ML/d (Figure 2b and Figure 4). Since Lake Mokoan was commissioned, releases have occurred for 25% of the time and there is an average of three release periods in each year.

4. **Casey's Weir Diversions:** Flow is diverted from Broken River into Broken Creek via a diversion channel at Casey's Weir. These diversions are undertaken all year round to meet stock and domestic demands and in the drier months to meet irrigation demands. Diversions are also undertaken at Gowangardie weir, downstream of Casey's Weir on the Broken River.

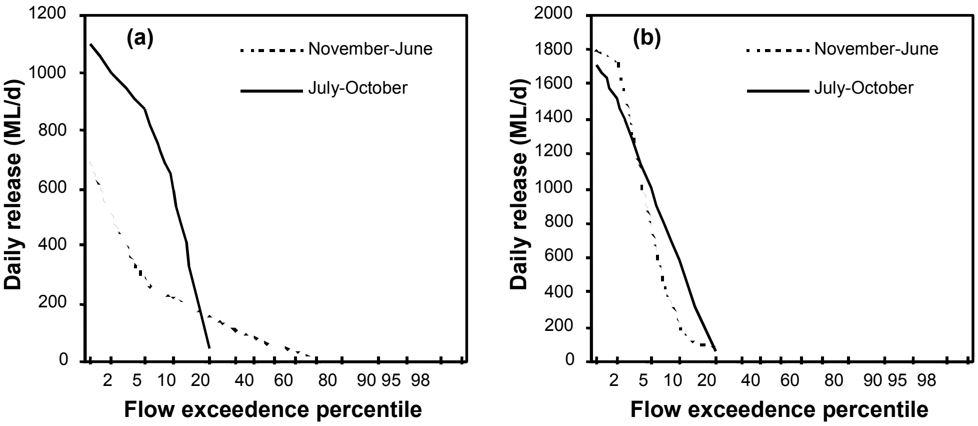

Figure 2: Flow duration curves for daily flows released from (a) Lake Nillahcootie and (b) Lake Mokoan

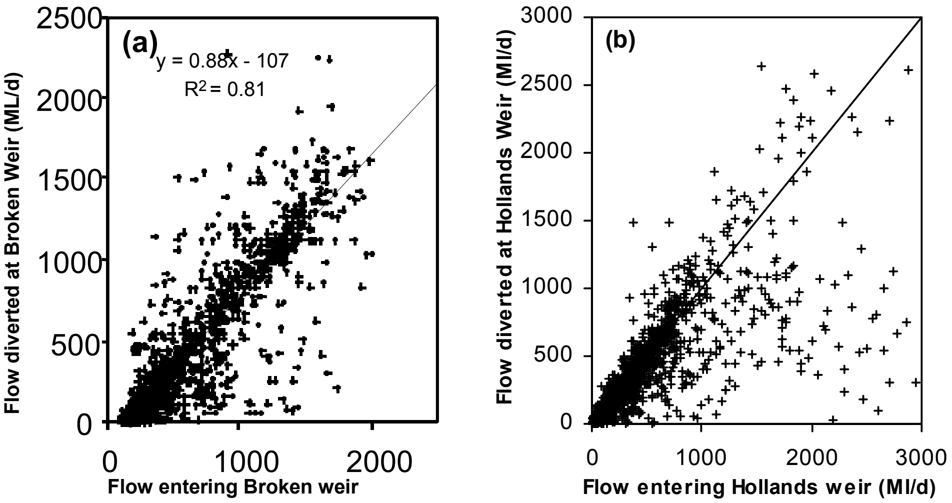

Figure 3: Plots showing river inflow and diversions at (a) Broken Weir and (b) Holland's Weir

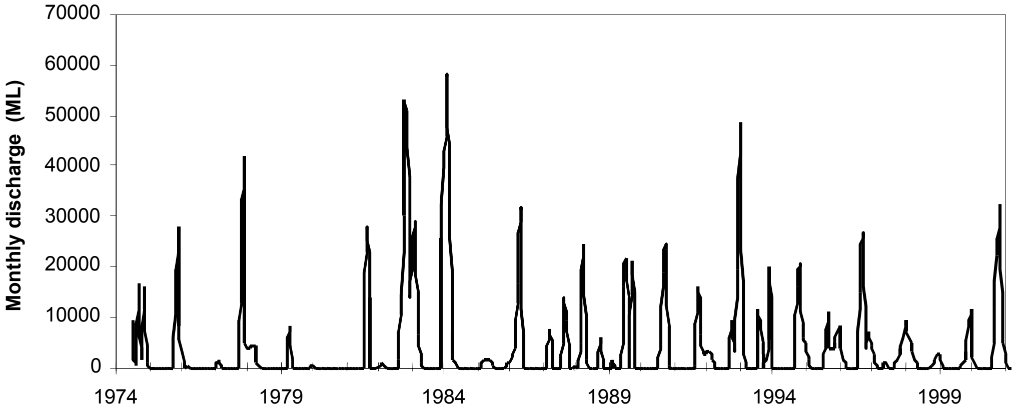

Figure 4: Monthly releases from Lake Mokoan

5.2 Impact of current regulation on the Broken River flow regime

This section describes the impact of historical operation of the Lake Nillahcootie and Lake Mokoan. This description is based on a comparison of:

1. Flows recorded for the period 1/7/74 to 30/4/98; and
2. Flows modelled for this period without the effects of flow regulation.

In some cases historical flow records for this period were incomplete. Procedures for infilling data and modelling flows without the effect of regulation are described in Appendix 2. It should be noted that flow management policy has changed since these storages began operation. In particular, Lake Mokoan operation changed in 1984 following the onset of annual algal blooms. The comparison is used to evaluate the impact of historical operation. Future management scenarios are considered in the following section.

A comparison of regulated and unregulated flows was made at three sites, one in each of the representative reaches of the Broken River:

Reach 1: Swanpool Rd (close to the Moorngag streamflow gauge);
Reach 2: Riverview Drive (downstream of Broken Weir); and
Reach 3: Goomalibee Rd (downstream of Casey's Weir).

These sites were chosen because, being immediately downstream of diversion or release points, they are likely to be the most heavily impacted sites along river and each is affected differently by the operation of diversions and releases. Unregulated tributary inflows and summer diversions result in a more natural flow regime further downstream from these points.

Flow duration curves, flood frequency curves and monthly median flows[2] are shown for each site in Figures 5 to 7. The impact of flow regulation is most apparent in the monthly median flows (Figure 5). Median flows are increased in the drier months (February to April) and reduced in the wetter months (May to November). Median flows in December and January are reduced at the Swanpool and Riverview sites, but increased at the Goomalibee site. During

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[2] Monthly median flows are obtained from a monthly REALM model developed by DNRE and are medians for the period July 1891 to June 2000.

these two months irrigation demands in December and January are met by releases from Lake Mokoan, which discharges downstream of the Swanpool and Riverview sites.

The flow duration curves (Figure 6) show a reduction in higher flows as a result of regulation at all three sites. Low flows are now greater than natural at the upper two sites. Surprisingly low flows are reduced at the Goomalibee site. The effect on flood frequencies is small at all three sites (Figure 7), with the Riverview site being most affected. At this site, recurrence intervals of small flow peaks (flows up to a 1-year return interval) are decreased by approximately 50%, presumably due to diversions to Lake Mokoan.

MEDIAN MONTHLY FLOWS

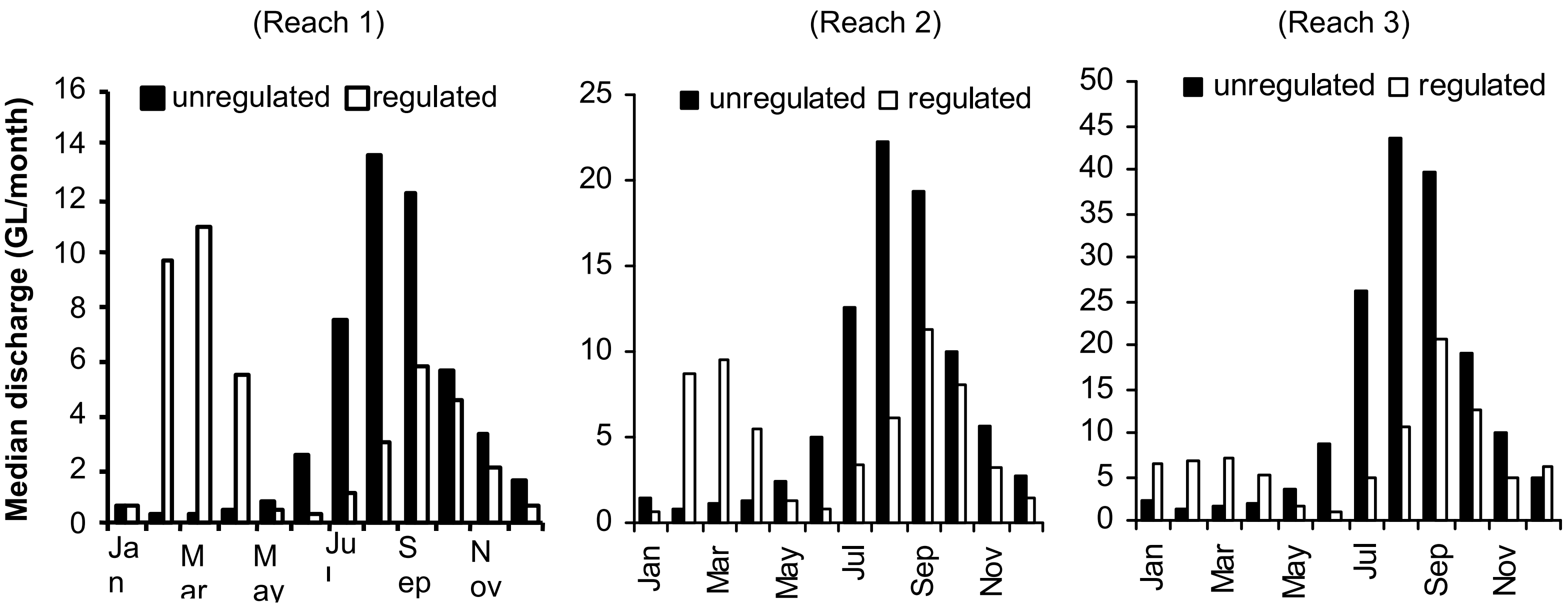

Figure 5: **Comparison of modelled regulated and unregulated monthly flows at three sites along the Broken River**

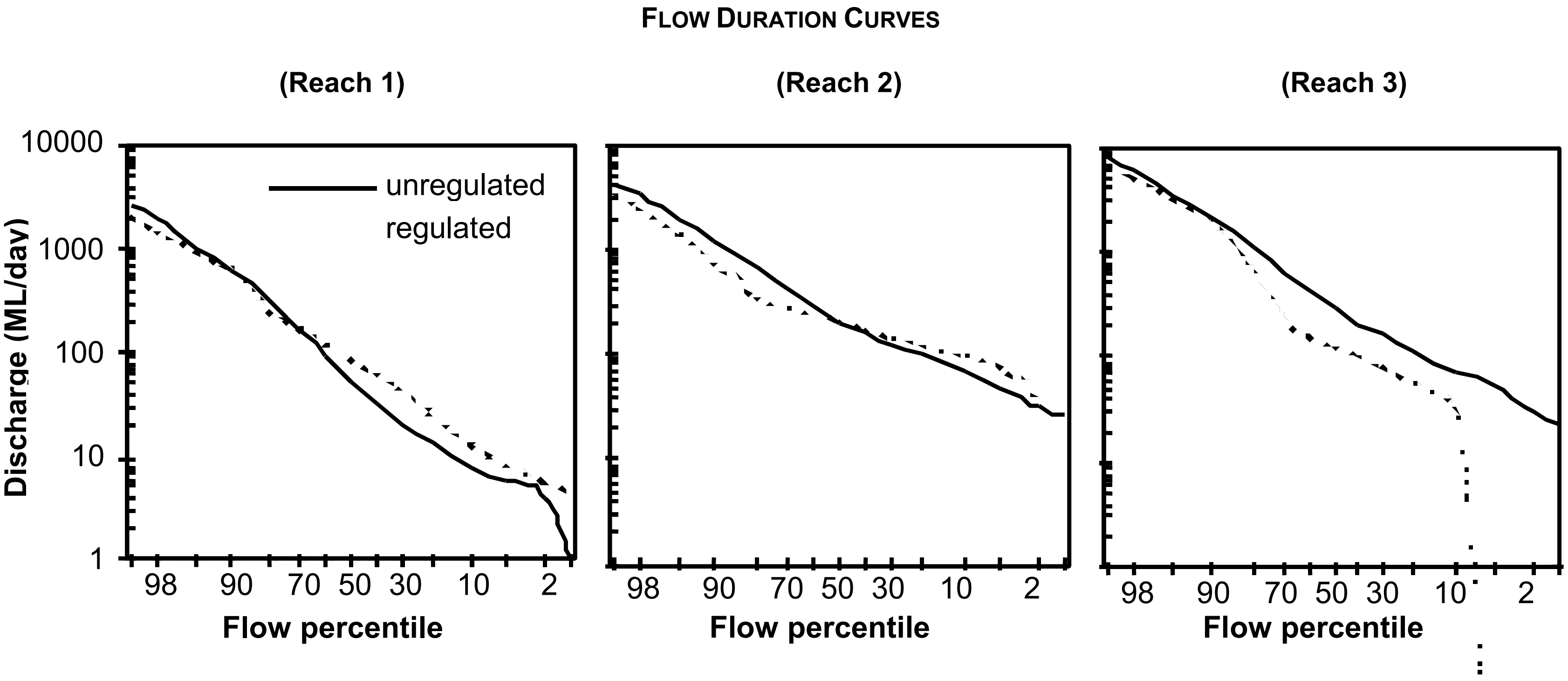

Figure 6: **Comparison of flow duration curves for the modelled regulated and unregulated flow regimes in the Broken River**

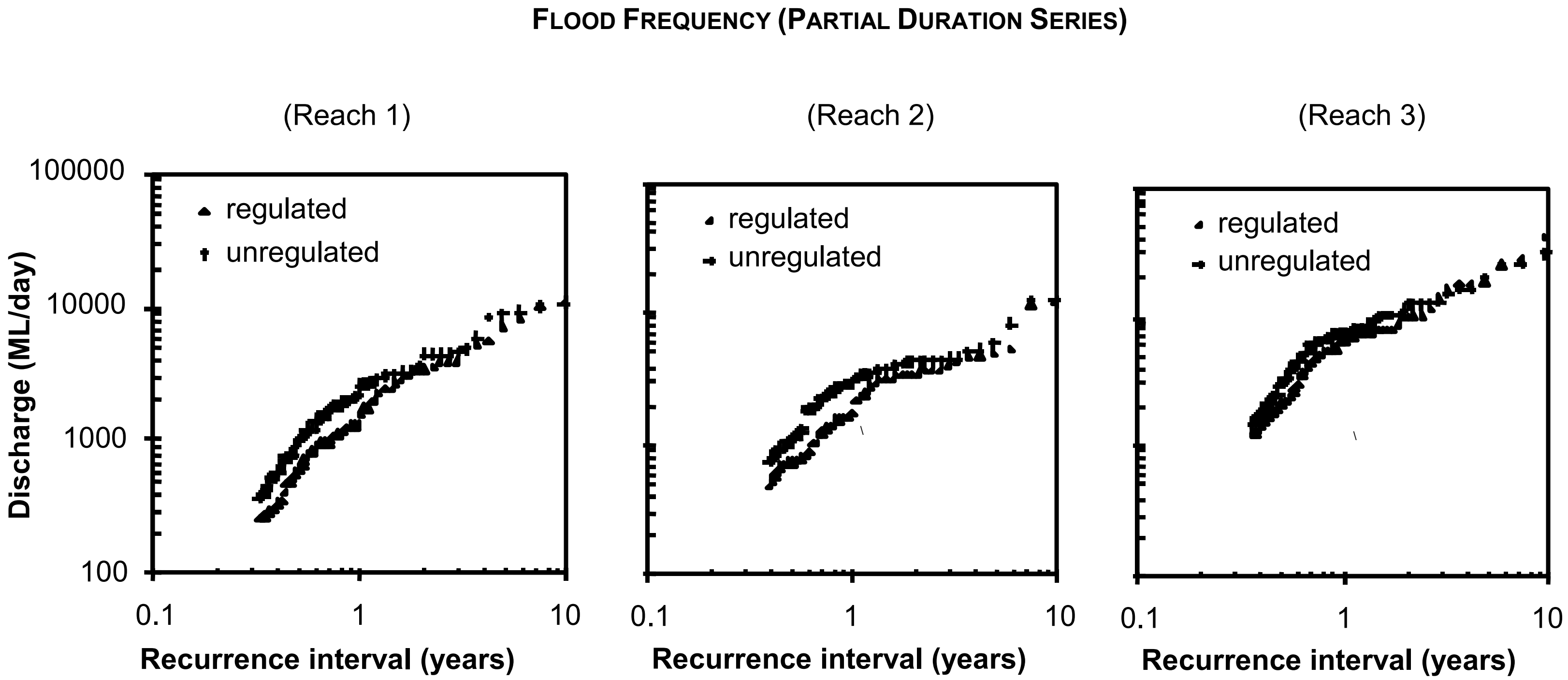

Figure 7: Comparison of partial duration series for modelled regulated and unregulated flows in the Broken River

5.3 Impact of future water management scenarios on the Broken River flow regime

The DNRE is reviewing the operation of large dams across northern Victoria to assess potential water savings and efficiencies and meet Victoria's commitment and contribution that will return flow in the upper Snowy River to 28% of natural. The future of Lake Mokoan is being considered within this context, and in view of its recent history of poor water quality (high turbidity, high nutrient concentration) and closure of the lake due to potentially toxic algal blooms in the summer of most years. Lake Mokoan is also being considered in a feasibility study to supply water to a proposed irrigation district near the Warby Ranges.

The Scientific Panel was requested to consider the ecological implications of different management scenarios for Lake Mokoan on the environmental values associated with the Broken River system, including:

- Current operation (water levels maintained within a target range, closure due to algal blooms in 9 out of 10 years, water supplied to the Murray River in dry years if the lake has not been closed due to algal blooms);
- Operation of Lake Mokoan at its full potential (i.e. unconstrained operation - assumes no restriction on storage levels, no closure due to algal blooms, full uptake of licenses, supply of water to the Murray River in dry years);
- Decommissioning of Lake Mokoan (future management of the lake unclear).

These three scenarios are compared to the unregulated flows using monthly flows modelled DNRE using REALM for each scenario for the period July 1981 to June 2000 (Figure 8). Initially it was hoped that each scenario could be considered based on changes in daily flows. It was decided to use monthly flows for the following because:

- The result of any assessment based on modelled daily flows for each scenario was highly sensitive to assumptions regarding the operation of diversions and releases and there is no sound basis for making these assumptions;
- The daily flows would have been disagregated from the modelled monthly flows and so would not have provided any additional information on variability in the flow regime; and
- The monthly flows were considered adequate when combined with more detailed information on the historic operation of diversions and releases (section 5.1) and an analysis of the impact of historic management practices on daily flows (section 5.2).

The possible ecological effects of flow changes associated with these three scenarios are described in section 7.3.

The hydrological impact of decommissioning Mokoan is complex and varies between sites and seasons (Figure 8). In operational terms, if Mokoan were decommissioned all irrigation (and other water) demands would need to be met by natural flows or releases from Lake Nillahcootie. With operation of Lake Mokoan median monthly flows in December and January upstream of Casey's Weir are close to natural as irrigation demands are met by releases from Lake Mokoan in these months. Decommissioning Lake Mokoan brings forward the start of the irrigation releases from Lake Nillahcootie to December and introduces higher flows for the January-December period in Reach 1 and Reach 2. The start of the irrigation season is unaffected in Reach 3. Decommissioning Mokoan is likely to result in greater water restrictions, particularly towards the end of the irrigation season. As a consequence, decommissioning is expected to result in a reduction in irrigation releases in May at all sites, bringing May flows closer to natural levels.

If we consider the impact of decommissioning on flows in the wetter months, the picture becomes slightly more complicated. Decommissioning reduces median flows in the winter period in Reach 1 but results in a substantial increase in winter flows in Reach 2 and Reach 3 because the diversions to Lake Mokoan in winter months would no longer be required. A more subtle impact of decommissioning is a further delay in the peak winter flow in Reach 1. The peak unregulated (Natural) median monthly flow in Reach 1 occurs in August; with current practices this peak is delayed until September and decommissioning Lake Mokoan further delays the peak until October.

The effect of full development is also rather complicated. With full operation of Lake Mokoan, irrigation releases can be made from Lake Mokoan throughout the irrigation season. As a consequence, summer flows upstream of Casey's Weir can return to natural or lower levels. The REALM model predictions are likely to be sensitive to assumptions regarding the operation of the system under this scenario but under the assumptions used in this case, releases from Lake Nillahcootie late in the irrigation season will result in enhanced median flows in Reach 1 and Reach 2. Summer flows downstream of Casey's Weir are slightly increased in the full development scenario.

In the winter months, full development is expected to result in closer to natural flows in Reach 1. This is presumably because of the requirement to make releases or allow spills from Lake Nillahcootie to fill Lake Mokoan. The wetter months at Reach 2 and Reach 3 are affected in a similar way to current operation, with a reduction in flows and a delay in the seasonal peak.

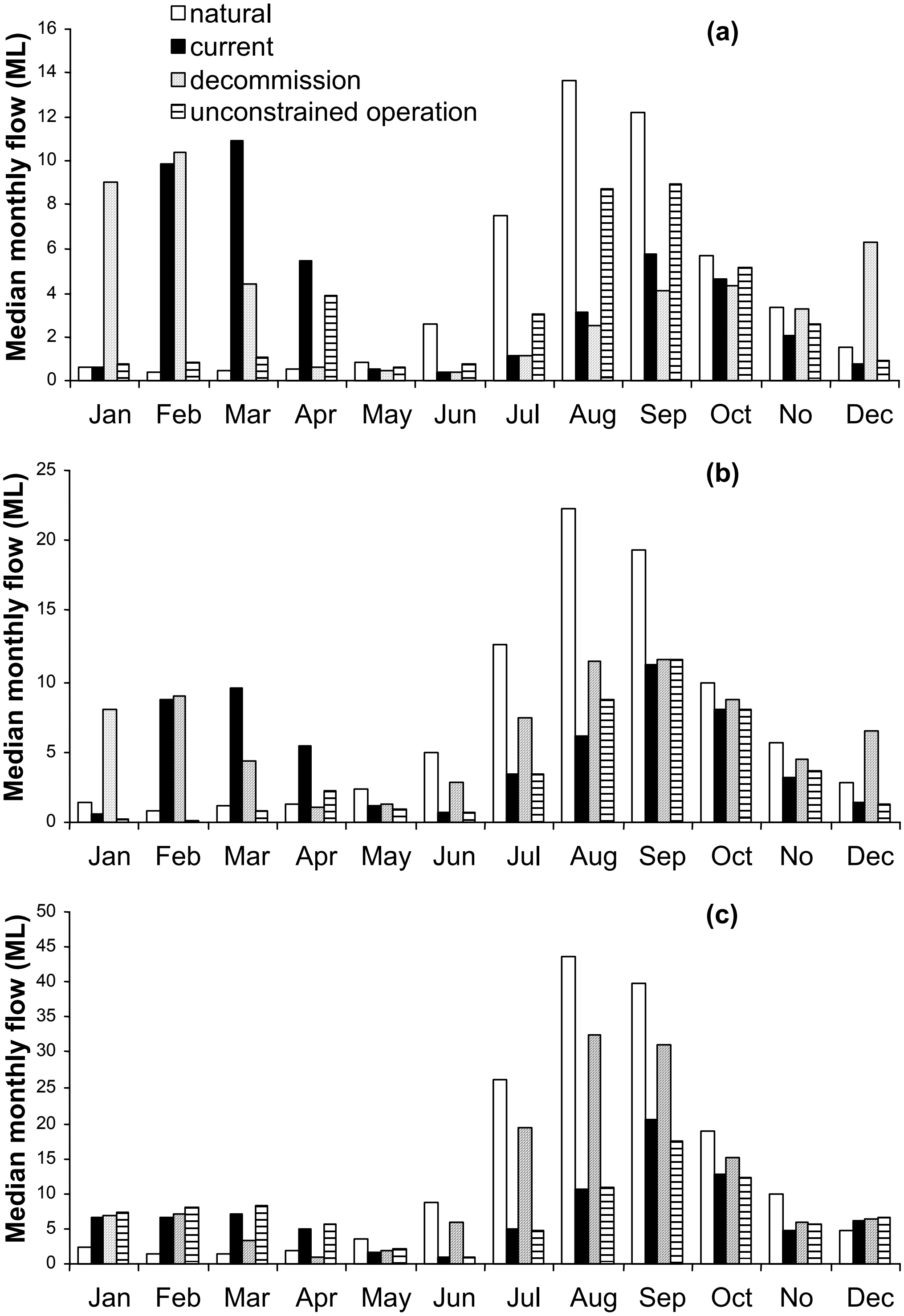

Figure 8: **Median monthly flows generated by REALM for the period July 1891 to June 2000 for four scenarios (i) natural flows, (ii) current management, (iii) decommissioning Mokoan and (iv) full development of the existing water resource scheme at three sites in the Broken River (a) Reach 1 (b) Reach 2 and (c) Reach 3.**

5.4 Impact of current regulation and future water management scenarios on the Broken Creek flow regime

Flow records are inadequate to model daily flows along the Broken Creek. Flows are only recorded at the Casey's Weir diversion and at Katamatite, just upstream of the Boosey Creek confluence. Flow is diverted at Casey's Weir to provide for summer irrigation demand and stock and domestic demand; the latter persist along Broken Creek throughout the year. There are several points at which flow is diverted for both stock and domestic and irrigation uses. Diversions to all water users occur at or upstream of Waggarandall Weir. Where possible, these demands are met by runoff from the Broken Creek catchment. When runoff does not meet demand, water is diverted at Casey's Weir along the Broken Creek Diversion Cannel to provide additional water. There is no requirement for G-M Water to provide flows downstream of Waggarandall Weir although, in practice, a relatively small volume of water spills over the weir during dry periods.

Flow records at Katamatite give the best indication of the natural flow regime available. However, this record is likely to be somewhat modified by irrigation drainage and regulations of flows upstream of Waggarandall Weir. The record indicates that Broken Creek ceases to flow in some years in the drier months (i.e. December to March) (Figure 9; see Appendix 5 for details of how flow was estimated)). Peak flow occurs in July to December.

We might assume that the natural flow regime upstream of Waggarandall Weir would resemble that recorded at Katamatite but with lower flows corresponding to the smaller catchment area. At the upper end of Broken Creek, just downstream of the outlet for the diversion channel from Casey's Weir, natural runoff will be negligible. Only extreme floods spill from the Broken River into Broken Creek and spills are reported to have occurred less than once every ten years. Diversions of flow into Broken Creek peak in March and are at a minimum in the winter months when demands are at their lowest. The diversions results in a (i) a reversal of the seasonal flow pattern, (ii) elimination of cease-to-flow periods, and (iii) substantially increased flows all-year-round. This pattern persists to Waggarandall Weir although its scale will reduce further downstream of Casey's Weir as a consequence of flow diversions and tributary inflows in the winter months.

It is proposed that the existing system of earthen channels that supply water to the Casey's Weir and Major Creek Waterworks District be replaced with a reticulated pipeline network (AWT 2000). The preferred option for the pipeline is to divert water from Flynn's Weir. The pipeline will provide water stock and domestic uses in the region. However, the irrigation demands along Broken Creek will continue to be met by diversions directly from the Creek. Since the bulk of summer diversions into Broken Creek are to meet irrigation demands, pipelining will not eliminate high summer flows. It will result in lower winter flows downstream of Flynn's Weir. It is anticipated that a pipeline system will result in water savings ranging from approximately 3,500 to approximately 8,900 ML per year, depending on the level of bulk entitlement set for the district which means less water will be diverted at Casey's Weir. Detailed analysis of the hydrological impact of the proposed pipeline is difficult because of the lack of reliable information on the location, magnitude and purpose of flow diversions in the current system.

The Scientific Panel was requested to consider the ecological implications for Broken Creek should the Tungamah pipeline go ahead. The pipeline development is most relevant to the section of Broken Creek between Flynn's Weir and Katamatite and particularly the section downstream of Waggarandall Weir, as it is this section of the creek that is most likely to return to an ephemeral creek system after being managed as a permanent stream for over 100 years. The Scientific Panel's recommendations for Broken Creek are outlined in Chapter 7.

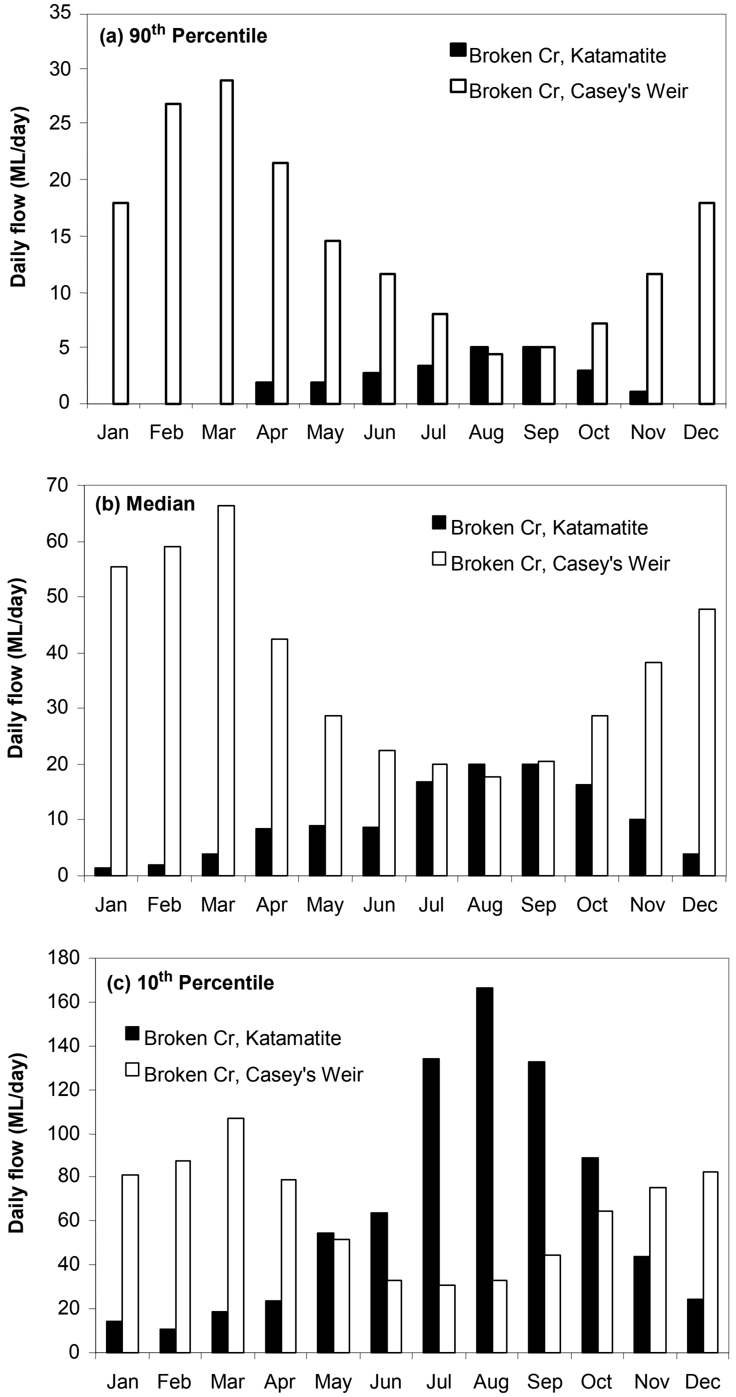

Figure 9: Daily flow percentiles for each month based on streamflow records at the Casey's Weir diversion channel and Broken Creek at Katamatite. Graphs show the (a) 90th percentile daily flow (low flows) (b) median daily flow (c) 10th percentile daily flow (high flows) in each month.

6 RIVER GEOMORPHOLOGY AND ECOLOGY

This chapter provides an overview of the important geomorphological and ecological features of the study area, and considers the environmental values that should be maintained or protected to ensure that the Broken River remains a functioning and diverse ecosystem. The environmental threats to the Broken River system are also considered.

6.1 Geomorphology

There have been no formal studies of the geomorphology the Broken River and Broken Creek and an assessment of how geomorphology has changed since European settlement (especially observations of how flow regulation has affected river geomorphology) is not possible with the available data.

However, limited published information and anecdotal reports suggests that the geomorphology of the Broken River and Broken Creek have been affected by development in the region. Previous ‘river improvement’ works were aimed at reducing flood frequency and included the removal of snags, channel works to decrease roughness and the construction of levees to protect nearby private land. Such works are thought to have contributed to bank erosion and reduced in-stream and floodplain (including wetland) habitat conditions (CCV 1977).

It is likely that flow regulation has had little impact on river geomorphology, as the larger flow events that are important drivers of geomorphology have been little changed by regulation (see chapter 5). These flow events are likely to be important for maintaining habitat diversity in the river, for example by mobilising the sand deposited in the river as a result of anthropogenic activities.

6.2 Water Quality

Water quality issues such as high nutrient concentration and high turbidity have been the focus of numerous studies over the past decade and a catchment based water quality management strategy has been developed to achieve nutrient load reductions that will reduce the frequency and duration of nuisance algal blooms (GBWQWG 1997). Specific water quality management plans have also been prepared to address issues in standing waters such as Lake Benalla (IDA 1995, TBLD 2000). Lake Mokoan has also been the focus of rehabilitation efforts (AWT 2000), with a view to reducing the turbidity and nutrient concentration in the water column, promote the growth of aquatic macrophytes, and ultimately a reduction of the frequency of algal blooms that lead to the closure of the lake in most years.

Water quality data obtained from the Victorian Data Warehouse for representative sites across the study area (Tables 4-6; Appendix 2) were compared with recognised water quality guidelines and criteria (ANZECC 2000, Government of Victoria 1983, Tiller and Newall 1995). Nutrient concentration in the Broken River increased with distance downstream from Lake Nillahcootie. Nutrient concentration was highest in the lower sections of the river, resulting from the combined inputs of runoff from agricultural and urban areas, and discharge from Lake Mokoan. There were also instances of high turbidity in the lower sections of the river. The other water quality parameters tested in the Broken River generally met recognised guidelines.

Table 4: Water quality monitoring stations across the study area

Site Code	Site Name
404206	Broken River at Moorngag
404210	Broken Creek at Rices Weir
404214	Broken Creek at Katamatite
404216	Broken River at Goorambat (Casey Weir head gauge)
404219	Lake Mokoan at head gauge
404222	Broken River at Orrvale
404224	Broken River at Gowangardie

Water quality in Broken Creek and Lake Mokoan was generally poor, with high nutrient and suspended sediment concentrations and high turbidity. The water quality in the creek reflected that of the Broken River at Casey’s Weir combined with runoff from adjacent agricultural land. In the lower reaches of the creek, irrigation return drains and urban runoff were additional sources of contaminants.

Poor water quality in the Broken River and Broken Creek was the result of many catchment activities and inputs, including the discharge of water from Lake Mokoan and from irrigation channels and drains. Thus, regulation of the river system has contributed to the decline of water quality in the study area but this effect is often difficult to separate from that of other catchment activities and processes.

Table 5: Summary of water quality data for the Broken River and exceedance of recognised guidelines (shaded)

Parameter	Number of Data	Minimum	Mean	Maximum	Standard deviation	Percentiles				
						10	25	50	75	90
Broken River at Moorngag										
Nitrate and Nitrite (mg/L)	106	0.008	0.318	3.0000	0.373	0.078	0.140	**0.225**	0.360	0.540
Total Kjeldahl Nitrogen (mg/L)	106	0.14	0.59	1.20	0.17	0.40	0.50	**0.60**	0.70	0.80
Total Phosphorus (mg/L)	106	0.020	0.047	0.130	0.017	0.030	0.034	**0.044**	0.054	0.067
Broken River at Goorambat										
Nitrate and Nitrite (mg/L)	137	0.022	0.265	2.300	0.249	0.074	0.130	**0.210**	0.330	0.450
Total Kjeldahl Nitrogen (mg/L)	137	0.100	0.783	2.200	0.359	0.480	0.510	**0.690**	0.910	1.300
Total Phosphorus (mg/L)	136	0.032	0.102	0.260	0.051	0.048	0.064	**0.091**	0.130	0.180
Turbidity (Field) (NTU)	241	2.00	32.53	130.00	26.6	9.0	15.0	**23.0**	40.0	76.0
Broken River at Gowangardie Weir										
Nitrate and Nitrite (mg/L)	67	0.003	0.190	0.600	0.142	0.023	0.048	**0.190**	0.250	0.410
Total Kjeldahl Nitrogen (mg/L)	67	0.300	0.722	1.700	0.308	0.400	0.500	**0.630**	0.910	1.100
Total Phosphorus (mg/L)	67	0.037	0.103	0.210	0.047	0.055	0.067	**0.090**	0.130	0.180
Turbidity (field) (NTU)	71	8.0	45.6	130.0	29.9	15.0	21.0	**40.0**	61.0	85.0
pH (field) (pH units)	71	5.0	6.8	7.0	0.4	6.0	7.0	**7.00**	7.0	7.0

Table 6: Summary of water quality data for the Broken Creek and Lake Mokoan and exceedance of recognised guidelines (shaded)

	No. of Data	Minimum	Mean	Maximum	Standard deviation	Percentiles				
						10	25	50	75	90
Broken Creek at Katamatite										
Dissolved Oxygen (mg/L)	250	?	6.9	11.0	2.3	3.5	5.0	**7.0**	9.0	10.0
Nitrate and Nitrite (mg/L)	106	0.003	0.037	0.390	0.061	0.003	0.004	**0.013**	0.038	0.110
Suspended Sediment (mg/L)	106	15.00	127.5	400.0	76.7	53.0	72.0	**120.0**	160.0	230.0
Total Kjeldahl Nitrogen (mg/L)	106	0.60	1.52	2.90	0.59	0.80	1.10	**1.40**	1.90	2.40
Total Phosphorus (mg/L)	106	0.071	0.204	0.570	0.097	0.100	0.130	**0.180**	0.250	0.330
Turbidity (Field) (NTU)	253	1.0	75.7	220.0	53.1	8.0	30.0	**74.0**	110.0	149.0
Broken Creek at Rice's Weir										
Nitrate and Nitrite (mg/L)	665	?	0.20	0.74	0.003	0.003	0.004	**0.0**		
Suspended Sediment (mg/L)	29	?	39.4	210.0	30.0	40.0	58.0	**81**		
Total Kjeldahl Nitrogen (mg/L)	664	?	0.50	4.10	0.30	0.80	1.00	**1.3**		
Total Phosphorus (mg/L)	663	?	0.28	5.70	0.03	0.19	0.25	**0.3**		
Turbidity (Field) (NTU)	1177	?	35.0	330.0	0.0	55.0	68.0	**88**		
Lake Mokoan										
Nitrate and Nitrite (mg/L)	110	0.015	0.303	0.520	0.116	0.130	0.240	**0.290**	0.400	0.460
Total Kjeldahl Nitrogen (mg/L)	110	0.600	3.701	?	10.426	0.850	0.920	**1.100**	1.400	5.150
Total Phosphorus (mg/L)	110	0.092	0.314	3.900	0.526	0.110	0.130	**0.160**	0.230	0.445
Turbidity (Lab) (NTU)	110	18.0	170.9	1500.0	183.1	110.0	120.0	**140.0**	170.0	195.0

6.3 Riparian and In-channel vegetation

There have been no specific studies on the native species of in-channel, riverbank or riparian plant habitats in the Broken River and Creek system, such as mapping riverine vegetation and its distribution or ecology studies (e.g. assessing the water requirements of key species during different stages of their life cycles). The EPA (Victoria) has collected information on in-channel macrophytes as part of its habitat description for its routine bio-assessment of water quality based on macro-invertebrates (Metzeling 2001, pers. comm.); but unfortunately, the taxonomic resolution and correctness of these repeated and extensive observations are too variable in quality to be useful as a source of information on in-channel macrophytes.

The riparian and in-channel plant communities existing in the study area can be divided into three areas, based on terrestrially defined bioregions[3] and landscape-scale geomorphic features and flow regime:

[1] Upper reach of the Broken River downstream of Lake Nillahcootie;
[2] Lower reaches of the Broken River to the Goulburn River; and
[3] The Broken Creek system.

The presumed natural characteristics (i.e. pre-European settlement) of the riparian and in-channel species, and plant habitats of these three macro-reaches are summarised in Table 7.

The upper sections of the Broken River between Lake Nillahcootie and Broken Weir (i.e. most of Reach 1) flows through the Central Victorian Uplands bioregion. Habitat diversity is mainly associated with in-channel features such as narrow benches, bars of mainly coarse material (sands, gravels), small pools, the littoral zone, and the riverbank.

Areas [2] and [3] lie in the Victorian Riverina bioregion but reflect different aspects of that bioregion. They differ in their geomorphic features and natural flow regime, factors that are strong determinants of riparian and riverine vegetation in terms of its characteristic perennial species, structure, life histories, and type and range of plant habitats available. The Riverina bioregion has been extensively cleared and is one of the most depleted bioregions in Australia. Along the Broken River, the vegetation type characteristic of this riparian zone is riverine grassy woodland, dominated by River Red gum *Eucalyptus camaldulensis*, with a shrubby-form of silver wattle *Acacia dealbata* and an understorey of sedges and grasses. Characteristic in-channel macrophytes include common reed *Phragmites australis* occurring in patches at the water line and on river banks, and the occasional occurrence of macrophytes such as the emergent water ribbons *Triglochin* sp. and the submerged macrophyte ribbon weed *Vallisneria* sp in slow-flowing patches near the channel margin. The Broken River downstream of Casey's Weir has been listed as a wetland of significance (ANCA 1996).

Land-based activities such as timber removal, stock access and invasion by terrestrial weed species onto the floodplain and the adjacent riverbank are the principal threats to the riparian woodland. In-channel structures such as weirs and regulators have created new aquatic habitats within the river channel, characterised by stable water levels, extensive growths of willows *Salix* spp. and/or common reed *Phragmites australis*.

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[3] **Bioregions**: The application of terrestrially-defined bioregions to aquatic and in-channel fauna has proved problematic, and as a result a set of five aquatic bioregions, empirically defined by community composition of macro-invertebrates, has been identified for Victoria. However, as riparian vegetation is influenced in part by regional factors such as soil types and prevailing climate that affect terrestrial species, and in part by flow regime, bioregions were considered appropriate here for such broad-scale vegetation definition.

Broken Creek flows through the Riverina bioregion throughout its length. The riparian zone is narrower than on the Broken River and the riparian vegetation, where it exists, includes remnant *Eucalyptus camaldulensis* woodland or blackbox woodland (Table 7). Although in-channel habitat diversity is low because of low in-channel geomorphic complexity (compounded by channel clearing and shaping), floodplain habitat diversity is high due to the presence of fluvial features such as deflation basins, flood-out areas and wetland depressions. However, the ephemeral and intermittent wetlands of the Broken Creek system, like others throughout the Riverina bioregion, have been severely impacted by agricultural expansion, water resource development and landscape changes to surface hydrology. As a result these ephemeral and intermittent wetlands, and their associated flora (such as canegrasses) and fauna (such as waders, brolgas) are also severely impacted. In addition, the water regime of surviving and residual wetlands tends to be considerably modified: in such a flat landscape, structures that affect and deflect surface hydrology such as roads and culverts can have a dramatic effect on flood frequency and flood retention times. Thus the value of these wetlands needs to be examined on a case by case basis.

Flow in Broken Creek prior to development and regulation was intermittent and variable (Section 5.2). The ephemeral nature of the stream included periods of flow followed by periods of no-flow, after which water would have ponded in deeper holes until lost by evaporation. During this ‘pool’ phase, it is likely that macrophytes would have become more abundant, water cleared and such ponds would have become drought refugia. The alternating conditions of wet and dry, of flowing and standing water habitat, of flood waters clearing, would have made Broken Creek a dynamic system, and very much in contrast to its modern character. In the lowest parts of the Broken Creek, flows were probably influenced by the Murray River.

Use of the Broken Creek as a water supply conduit and the installation of regulatory structures has changed the Creek into a ‘new’ type of habitat on the landscape. The weir pools formed behind regulatory structures provide atypical permanent pond-like aquatic habitats, some of which have become the foci for plant (and animal) biodiversity within the agricultural landscape. The habitat resulting from this means the vegetation existing along Broken Creek has a high conservation value (and hence its listing as a wetland of significance (ANCA 1996) which is partly due to the extensive clearing of previous floodplain vegetation.

6.3.1 Evaluating effects of flow modifications on riverine vegetation

The impact of river regulation on riverine vegetation can be evaluated using different approaches, the choice being dependent on information available. Possible approaches include:

- A species approach, focusing on certain species selected for scientific and/or pragmatic reasons;
- A growth-form approach, using growth-form as a generalization of a set of ecological responses that can be inferred from scientific literature;
- A functional group and/or ecological strategy approach, using identifiable groups of plants known to have similar responses to water regime or flow regime.

These plant-based approaches can be complemented by habitat approaches, using spatially defined or geomorphic features and/or prevailing water regime such FEM (Section 3.2.1). In practice, the data and knowledge for the plant-based approaches are usually severely constrained by lack of knowledge about species responses and, in this case, by lack of description of riparian and in-channel plant communities of the Broken River system. Thus, elements of all of these approaches may be used, as done here, resulting in a hybrid approach. As a guide, however, critical features of water regime for particular plant groups are summarised in Table 8:

- For the species approach, information on native species was drawn from published reviews and compendiums, such as Young (2000), Roberts and Marston (2000), and Ward (unpublished data), and supplemented by scientific papers.
- For the growth-form approach, general sets of plant responses and tolerances are inferred from scientific literature of plants of similar growth-form. There is no universal standard description of growth-forms and the ones used here are trees, shrubs, emergent and submerged macrophytes.
- For functional types, plants with similar responses to a specific aspect of their environment (such as water regime) are said to be a functional type. The wetland functional groups developed by Brock and Casanova (1997) are based on experimental and published information of over 60 wetland species of the New England tablelands. For ecological strategies, individual species are recognised as being one of several types based on their characteristics, and how types are defined. In Grime's C-S-R approach, where C is for Competitor (species that capture resources effectively), S for Stress tolerators and R for Ruderals, types are defined in terms of their (presumed) capacity to tolerate disturbance and to acquire resources (Begon *et al*. 1996).

The effects of regulation and development on flow regimes of different parts of the Broken River system have been described in Chapter 5. The following discussion examines how these changes affect riverine and riparian vegetation, by relating them to species, life-forms, functional types and habitats, as appropriate and feasible. The hydrologic effects are grouped into two broad categories: (i) seasonal flow inversion, and (ii) shift from variable & intermittent to predictable & permanent.

(i) Seasonal flow inversion

Seasonal flow inversion can result in a package of different effects; for riparian and in-channel macrophytes, the most important are the seasonal shift in high and low flow periods, and changes to flow predictability (reliability).

High summer flows: These create a spatial niche at or close to the water line, for summer-growing species that are intolerant of water stress. Species adapted to these conditions may be summer-growing native and introduced plants such as emergent macrophytes (eg *Cyperus eragrostis*), or species introduced from temperate zones. Creation of this niche results in the displacement of species previously occurring on this part of the bank, such as disturbance-tolerant ruderals, which typically are short-lived and poor competitors. The disappearance of these is a loss to biodiversity. Habitats most affected in the Broken River are lower part of banks, in-channel bars and low-level benches.

A reliable resource-rich environment: Resources in question here are those needed for vigorous plant growth, including a combination of reliable water availability, fertile substrate, warm temperatures and long days. Such conditions are favourable for establishment and persistence of resource-capturing species, whether native or introduced, such as Typha spp.

Low-level benches: Under regulated flows, many of these do not dry out in summer; some are periodically flooded by summer irrigation flows. These conditions may guarantee the post-germination survival of seedlings germinating in spring and summer; and may also flush away accumulated detritus, with consequences for carbon fluxes. Thus the bench habitat becomes suitable for plants tolerant of moist aerated conditions and/or shallow anoxic conditions (e.g. moisture-loving terrestrial plants, amphibious plants, emergent macrophytes, riparian trees and shrubs, and seedlings from all these). Existing conditions on the Broken River, especially in Reach 1, are particularly favourable for summer-growing species. With time, benches likely to be dominated by C-type species (e.g. willows).

Summer habitat of slow-shallow water: Persistently higher flows in summer means deeper-than-natural water conditions and this reduces the extent of shallow-water slow-flowing habitat from parts of the river. Affected macrophytes are most likely to be ruderals such as small, fine submerged macrophytes (e.g. Characeae and fine milfoils) and possibly short-medium height weakly-competitive floating-leafed macrophytes, especially (in both cases) short-lived or annual species.

Overtopping

Deeper flows during spring-summer, a time when flows would naturally be receding, means there is potential for winter-spring-growing species to be over-topped and thus suffer oxygen deficiency. Examples of species that grow in winter-spring period are some *Triglochin* species and *Damasonium minus*.

(ii) Variability & Duration

The provision of water for stock and domestic purposes and for irrigation has caused the flow regime to shift from one that lacks specific intermittent and variable characteristics to one that is permanent and predictable. The implications for plants of losing this dynamic component to water regime are as follows.

Reducing variability and increasing duration. Changing the in-channel water regime, from intermittent to near-permanent and predictable, changes the pattern of plant resource availability. Temporarily available resources favour short-lived macrophytes and ruderals, while resource-capturing species are favoured when resources are persistently available. Persistent conditions lead to dominance by competitors such as *Typha* and willows *Salix* spp.

Mudflat and recession niches. Mudflats exposed by falling water levels are shallow and moist, nutrient rich and (initially, at least) lack competitors. Mudflats are important germination and establishment sites for emergent macrophytes and for short-lived ruderals. Permanent water levels, or water levels that are stable over long periods, reduce and sometimes eliminate this transient habitat. The impact of this habitat loss is greatest on short-lived ruderals, and their continued persistence in the region depends on maintaining viable seedbanks. At least two species recorded along the Broken Creek as regionally significant, *Myriophyllum porcatum* and Swamp millet *Panicum decompositum* (Robinson and Mann 1996) may be impacted in this way. Swamp millet is important for seed-eating water birds.

Lack of drying out. Persistent high flows result in a saturated soil layer in the channel bank, extending under the riparian zone. Access to water may favour shallow-rooted species in the riparian zone, such as grasses, herbs and sedges, but deep-rooted species such as shrubs and trees will be stressed through lack of oxygen in the rhizosphere for most of their root systems. The effect can be a structural change in riparian vegetation.

Seasonal flow inversion is characteristic of the Broken River. The effect is generally strongest immediately downstream of Lake Nillahcootie and becomes gradually attenuated downstream. The exception to this trend is the loss of summer slow-water habitat, which is most pronounced below Broken Weir. The Broken Creek is characterised by shift to permanence and, probably, seasonal flow inversion.

Table 7: Selected natural attributes of vegetation in the study area

River Reach	Broken River D/s Lake Nillahcootie	Broken River D/s Casey's Weir	Broken Creek
Bio-Region	Central Victorian Uplands (CVU)	Victorian Riverina (VR)	Victorian Riverina (VR)
Dominance & Diversity of native riparian trees	Tree diversity relatively high, with several *Eucalyptus* and *Acacia* species.	Tree diversity intermediate, with two main dominants: River Red gum *E. camaldulensis* & Silver Wattle *A. dealbata*	Tree diversity low, mainly River Red Gum or Black Box *E. largiflorens* sparse woodland. Other species now occur where channel has been deflected.
Habitat diversity (for plants) in/ associated with river	Habitat diversity low, being restricted to small in-channel features such as benches, substrate (gravels, sands), pools and shallows.	Habitat diversity relatively high, due to geomorphic complexity such as floodplain, islands, anabranches, river banks, benches, in-channel variations substrate (sands, silts).	Habitat diversity in-channel probably low but hard to discern due to extensive changes. Overall habitat diversity is relatively high due to flow-connected geomorphic features such as flood-out areas, depressions, playas, deflation basins, distributaries and effluent creeks.
Natural hydrological characteristics	Peak flows in winter and spring, with increased flows beginning in autumn.	Peak flows in winter and spring, with increased flows beginning in autumn.	Flow regime intermittent and ephemeral, being driven by rain events on the nearby ranges, and / or overbank flows out of the Broken River. Wetlands receive local run-off, direct rainfall and / or flows from Broken Creek have intermittent water regime.
Bio-diversity issues	Invasive tree and shrubs (*Salix*, *Rubus*) dominate parts of riparian zone	Invasive species, native and exotic, readily establish where water levels are relatively stable such as weir pools.	In a landscape highly modified through extensive clearing, channel modifications and changes to flow, and new attitudes required to recognise that modified habitats do have specific bio-diversity and functional values.
Bio-diversity values	Diverse woody riparian species, diverse in-channel macrophytes	Continuous riparian fringe with native trees dominant, very important for riparian fauna such as gliders and possums.	Species of conservation significance at state level

Table 8: Native and Introduced Riverine Vegetation: Growth-forms and water requirements

Plant Growth-forms	Plant Habitats in the Broken system	Important aspects of water regime	Other aspects of water regime
Riparian Trees In VR bioregion, *Eucalyptus camaldulensis* and *Eucalyptus largiflorens*	Floodplain above and adjacent to river channel (BR), river banks (BR, BC). Introduced trees establish on in-channel benches (BR), at water's edge in weir pools (BR, BC) and on some banks (BR).	For trees typical of VR bio-region: Flood frequency and duration are key factors for survival and growth of established *Eucalyptus* trees; flood events, flood timing and flow regime in following years are relevant to establishment of new cohorts. For other tree species and trees associated with CVU bioregion, little hard information.	Some species occurring on bank habitats such as *Acacia dealbata* are tolerant of flood-related mechanical disturbance, and have capacity to sucker or re-sprout.
Riparian Shrubs Silver Wattle *Acacia dealbata* sometimes included as a shrub	Sloping river banks of main channel (BR), islands (BR) Introduced shrubs establishing on the floodplain are not linked to water regime but to land management practices and numerous vectors.	Almost nothing known about life history , water regime or water requirements of native riparian shrubs.	
Emergent macrophytes	Base of banks in-channel (BR, BC). In shallow-medium deep water of weir pools (BR, BC)	Water depth (up to 1.5 m depending on plant size) and duration of flooding, and timing (season), for established plants. Regeneration usually requires fall in water level, followed by slowly increasing water depth: time of year relevant.	Established plants with leaves in air are little influenced by turbid water. Turbidity may restrict species that have part of their establishment phase under water. Depth is relevant but the absolute value depends on plant height and hence on species, possibly ranging from 30 cm to 3 m tall. Few species are tolerant of being overtopped for long periods.
Floating-leafed macrophytes	In slow-flowing shallow-medium deep water in of river pools, in-channel, in weir pools.	Rate of change, if too fast, will result in overtopping; if slower, then plants can extend and keep leaf on surface.	Velocity: persistent high flows can cause mechanical damage.
Submerged macrophytes	In slow-flowing shallow-medium deep water in of river pools, in-channel, in weir pools,	Robust perennial species can grow in slow-flowing water up to 1.5 m deep, but probably need favourable growing conditions for at least 2-3 months for persistence. Annual and small fine species probably require slow-flowing shallow water during the growing season.	Turbid water will restrict light reaching submerged leaves: sustained periods of high turbidity or water that is persistently deep and turbid in the growing season will eventually eliminate submerged macrophytes.

6.4 Macroinvertebrates

Many biological monitoring programs include the sampling of aquatic macroinvertebrates. Macroinvertebrates provide an 'integrated' record of environmental stress (e.g. pollution effects over time). For example, the presence or absence of particular species provides information about water quality; some species are known to have particular tolerances to environmental factors such as temperature or levels of dissolved oxygen. Other information can be obtained from the number of species found at a site (biological diversity), the number of animals found at a site (abundance) and aspects of community structure such as trophic interactions and relative abundance. Macroinvertebrates are also responsive to changes in habitat (i.e. communities will be different in stony riffles compared with sand or clay bottomed pools or amongst aquatic plants). As stream flows are an important feature of stream habitat, macroinvertebrate communities can also be markedly different under different flow regimes.

The National River Health Program is a nationally consistent biological assessment scheme for evaluating river health across Australia. Data on macroinvertebrates and environmental variables from approximately 200 reference sites (sites that are relatively unimpacted or otherwise desirable) were used to build AUSRIVAS models (Davies 2000; EPA 2001) that predict the macroinvertebrates that should be present in specific stream habitats under reference conditions. The models do this by comparing a test site with a group of reference sites, which are as free as possible of environmental impacts but have similar physical and chemical characteristics to those found at the test site. The ratio of observed versus expected taxa provides a measure of stream health.

The Victorian EPA has sampled over 600 sites across Victoria as part of the First National Assessment of River Health, 10 of which were located within the study area downstream of Lake Nillahcootie (EPA 1999). Macroinvertebrate communities at the 10 sites were assessed using AUSRIVAS scores, as well as the number of macroinvertebrate families recorded and SIGNAL scores, a biotic index that is particularly sensitive to organic pollution (Chessman 1995). The use of a number of indicators to assess ecosystem health improves the robustness and reliability of the conclusions. When different measures are in accord, greater confidence may be placed on the outcome, and differences between assessment measures can be used to indicate particular types of environmental stressors.

6.4.1 Broken River

The Broken River between Lake Nillahcootie and Broken Weir (Reach 1) is a typical foothill stream, generally with a cobble substrate and a moderate gradient. Riffles are common, and along with river runs and shallow pools provide a diversity of in-stream habitat for invertebrates. Water quality in this reach poses little risk for macroinvertebrates (e.g. nutrient concentrations are at moderate levels and salinity is low, although turbidity can be high on occasion), as the invertebrates assessed at three sites were generally in Band A in AUSRIVAS (equivalent to reference condition) and the number of families was high (18 – 26 families in single samples), particularly in the littoral margins. SIGNAL scores were between 5.3 – 5.8, indicating mild pollution. This is not unusual in agricultural areas, where catchment runoff and an altered riparian zone affects the input of organic matter.

The maintenance of higher than normal flows over the summer months is likely to have had some effect on the invertebrate fauna although flows are not high enough to scour the substrate, nor is there any indication of thermal impact. Community composition has been changed, with some families favoured by the altered flow conditions more than others.

Families commonly found downstream of dams (blackflies – Simuliidae, and net-spinning caddis-fly larvae - Hydropsychidae) were very abundant at one site in this reach. The riffle at the Swanpool-Moorngag Road (downstream of Lake Nillahcootie) scored B in AUSRIVAS and had relatively few families (18 families; Table 9). As the SIGNAL score (5.8) suggested that water quality was not a major limiting factor, habitat features, including the flow regime, may have contributed more to the poor AUSRIVAS score. In support of this, the mayfly family Leptophlebiidae, which was moderately abundant upstream of the dam, was considerably less common at the two downstream sites. This family contains some species that are sensitive to flow alterations and its reduced abundance may reflect the flow changes downstream of the dam.

The Broken River from Broken Weir to the Goulburn River (Reaches 2 and 3) has the characteristics of a lowland stream, with a wide channel incised into the floodplain and a more meandering pattern. Riffles are generally absent (except downstream of weirs), and pools and shallow runs dominate. The stream bed is predominantly sand, which provides poor habitat for invertebrates. The primary habitat for invertebrates is large woody debris (LWD or snags) and aquatic macrophytes such as *Vallisineria, Phragmites* and sedges.

Invertebrate sites in these reaches (Table 9) rate as either Bands A or B in AUSRIVAS, with SIGNAL scores ranging from 4.8 to 5.7 (moderate levels of organic pollution). As the invertebrate families used to calculate SIGNAL scores favour upland streams, a score of 5.5 for a lowland stream is generally considered good (EPA unpublished data). Numbers of families from single samples ranged from 18 – 30. The fauna collected in the littoral habitat was dominated by water bugs (Corixidae), caddis-fly larvae (Leptoceridae), mayflies (Baetidae) and midge larvae (Chironomidae). Several other families of true bugs (Hemiptera) were also common, as were Simuliidae and Hydropsychidae that are thought to be common on snags (from J. Growns, unpublished data).

Water quality may have had some effect on the invertebrate fauna, with nutrient levels above recommended concentrations. However, the effects of poor water quality appear to be minor. Under the regulated flow regime, the general pattern of monthly flows are similar to the natural pattern, but system operation may lead to periods of very low flow occurring more frequently. Flows would have ceased from time to time under natural conditions and low flows need not necessarily be viewed as a major problem to the invertebrate fauna. However, if unnaturally rapid drops in flow results in large areas of the stream bed being exposed, then the risk of stranding sedentary invertebrate species increases, as does the risk of decreased species richness and faunal abundance.

Table 9: Number of families (from combined autumn and spring samples), AUSRIVAS combined seasons and SIGNAL scores for sites in the Broken catchment. Exceedences of the nutrient guidelines are shaded.

Site	Site code	Edge number of families	Edge SIGNAL	Edge AUSRIVAS	Riffle number of families	Riffle SIGNAL	Riffle AUSRIVAS	TN (mg/L)	TP (mg/L)
Upstream sites									
Holland Creek upstream of Fords Bridge	DCB	33	6.22	X	39	6.57	X	0.10	0.04
Ryan's Creek at Madhouse Track Crossing	DCC	30	6.89	A	37	6.69	A	0.20	0.02
Moonee Creek upstream of Lima East	DCH	29	6.61	A	30	6.90	A	0.11	0.10
Broken River at Bridge Creek	DCA	29	5.52	X	17	5.63	A	0.40	0.04
Broken River at Lake Nillahcootie Road	DCI	30	5.32	A	19	5.12	B**	0.46	0.02
Reach 1									
Broken River at Williams Road	DCN	33	5.42	A	31	5.41	A	0.76	0.04
Broken River at Swanpool-Moorngag Road	DCJ	27	5.42	A	18	5.82	B**	0.66	0.03
Reach 2									
Broken River downstream Benalla at Faithful St	DCL	29	5.69	A				0.56	0.05
Broken River at Scholes Road	DCK	30	5.42	A				0.52	0.05
Reach 3									
Broken River at Goomalibee 1994/5	DCF	23	5.57	A				1.17	0.18
Broken River at Goomalibee 1997	DCF	18	4.82	B	17	5.27*	B*		
Broken River upstream Shepparton on Euroa Road	DCD	20	5.37**	B**				0.83	0.10
Reach 4									
Broken Ck at Ligerwood Rd	DCQ	30	4.96	A				1.06	0.16
Broken Creek at Katamatite 1995/96	DCG	22	5.62	B				1.30	0.27
Broken Creek at Katamatite 1998	DCG	27	5.00	A					
Reach 5									
Broken Creek at Carlands Bridge	DCM	13	5.46	B				1.20	0.35
Broken Creek downstream Nathalia 1994/95	DCE	18	5.00	B				1.50	0.43
Broken Creek downstream Nathalia 1995/96	DCE	11	5.05	C					

* = autumn only

** = spring only

6.4.2 Broken Creek

Broken Creek between Casey's Weir and Katamatite was an intermittently flowing stream prior to regulation. The invertebrate fauna expected in such a stream would reflect this intermittency, favouring opportunistic species with mobile life stages (e.g. beetles and water bugs). As the creek has been managed as a permanent stream for many decades, the nature of the invertebrate community is expected to have changed. For example, less mobile species present in the Broken River may become established. The permanent water supply has helped to support a narrow riparian zone that varies in condition from moderate to poor quality and generally lacks an understorey. The trees contribute LWD to the stream, providing better habitat for invertebrates than the sand, silt or mud substrate of the stream. Macrophytes are present (*Triglochin, Vallisineria, Potamogeton, Cyperus, Typha*), although not extensive in area, and provide another important habitat for invertebrates. However, invertebrate diversity is still likely to be relatively low, due partly to the small size of the creek (i.e. limited habitat). Moderate to poor water quality (e.g. high turbidity and high nutrient concentrations) is also likely to have direct and indirect effects on the fauna.

The invertebrate fauna was good at two sites in this reach (Table 9). Both sites rated as Band A in AUSRIVAS (suggesting habitat is good) but had SIGNAL scores (4.9 to 5.6) suggesting that there are water quality problems. The number of invertebrate families in samples has been very low on occasion but was generally low to moderate (10 – 14 families from single samples). Hardy, widespread taxa dominate including Corixidae (water boatmen), Leptoceridae (caddisfly larvae), Coenagrionidae (damsel-fly nymphs), Atyidae (shrimps) and Notonectidae (back swimmers). The creek in its current condition is far from natural and the artificial flow regime has created conditions that can support a different style of invertebrate community than would have occurred naturally.

Flows in Broken Creek between Katamatite and the Murray River are now larger and more permanent than would have occurred naturally. The riparian zone along the creek is variable, but often of poor quality and the channel and banks have been scoured or straightened in many places, presumably to increase channel capacity. Water quality is poor, with high levels of nutrients and turbidity; The combination of poor in-stream habitat (with relatively few snags or macrophytes) and poor water quality is likely to have contributed to the very limited invertebrate communities present in the creek. The invertebrate communities at 2 sites in this reach (Table 9) both rated below reference in AUSRIVAS (Bands B or C), and SIGNAL scores of 5.0 – 5.5 indicated mild to moderate levels of pollution. Fewer than 5% of the 600 sites sampled by EPA between 1997-99 have been rated in Band C or below, indicating the poor condition of the creek relative to the many other streams in Victoria. The number of invertebrate families was generally very low (less than 10 families in a single sample), with water bugs dominating (Corixidae, Notonectidae and Veliidae). Atyid shrimps are also common. All families found were hardy and widespread. The very low diversity in this reach suggests a combination of habitat degradation and water quality problems.

6.4.3 Effects of regulation on invertebrates

River regulation and diversion has resulted in a pronounced seasonal shift in flow between Lake Nillahcootie and Broken Weir during February and March. However, the higher summer-autumn flows do not appear to have caused excessive scouring of the substrate and there was no evidence of thermal impacts associated with cold water releases from Lake Nillahcootie. With the possible exception of a decreased abundance of the mayfly family Leptophlebiidae, the impact of flow regulation on macroinvertebrate communities in Reach 1 is slight.

The Broken River between Broken Weir and the Goulburn River (Reaches 2 and 3) contains a relatively high diversity of in-stream and riparian habitat for a regulated lowland river and the invertebrate communities appear to reflect this. Flow regulation has had a relatively small impact on the seasonal pattern of flows compared with Reach 1. Many of the invertebrate families present are tolerant of short-term variability in flow and the current flow regime is unlikely to have affected invertebrate communities significantly. However, the river system should be operated with care to avoid the risk of rapid and prolonged exposure of in-stream habitat and thus the stranding or desiccation of invertebrates. This may occur, for example, when filling Lake Nillahcootie or diverting water to Lake Mokoan.

The supply of irrigation, stock and domestic water via the Broken Creek has changed what was an intermittent stream into a permanently flowing stream. This is likely to have changed invertebrate community composition from one dominated by mobile, rapid colonisers to one that supports less mobile and persistent taxa. Nevertheless, the invertebrate communities have far fewer taxa that expected, probably reflecting the combined impacts of flow regulation, poor in-stream habitat and poor water quality. These stresses persist or increase along Broken Creek downstream of Katamatite to the Murray River.

6.5 Fish

6.5.1 Fish species across the study area

Of the 33 native fish species recorded in the Murray Darling Basin, 16 species have been recorded in the Broken River and Broken Creek reaches of the study area. Seven alien fish species, including carp and gambusia (mosquito fish) that are listed as noxious species in Victoria, have also been recorded across the study area. All 16 native and 7 alien species have been recorded in the Broken River, while 8 native and 5 alien species have been recorded from Broken Creek. Although there are no records of fish species from Holland's Creek, it is likely that up to 8 native species and 5 alien species occur, based on the known range of species in the area.

Ten native species are noted for their conservation significance (Table 10), 5 of which are listed under the Flora and Fauna Guarantee Act (1988). The Broken River between Broken Weir and the Goulburn River, and the Broken Creek between Numurkah and the Murray River, are of particular importance for key native species such as Murray cod and Golden perch.

Broken River

Fish populations occurring in Reach 1 are less studied than the populations in the lower reaches of the Broken River. Based on limited knowledge, it is likely that there are fewer species in this reach than in the rest of the Broken River, since the river is relatively narrow (10-15 m across) and, being characterised by series of fast-flowing riffles and relatively shallow pools, does not have the same level of habitat diversity evident in downstream reaches. The sites visited in May 2001 (see Table 1) are unlikely to support large individuals of some species, such as Murray cod and golden perch, although the presence of weirs provide habitat for larger fish. Unfortunately, weir pools are also ideal habitat for introduced species such as common carp and European perch (redfin). Cool, relatively high flows during summer can also provide suitable conditions for brown trout, a species that cannot tolerate temperatures in excess of 28 ^{o}C. This species would naturally be excluded from downstream reaches during the summer period, but the current flow regime may provide a degree of refuge for this introduced species. Reach 1 would naturally have supported native species such as mountain galaxias (and perhaps several other species, including the climbing galaxias,

Galaxias brevipinnis), southern pygmy perch, rainbowfish, species of carp gudgeon, river blackfish and, almost certainly, trout cod (Cadwallader and Backhouse 1983). With river regulation, barriers to fish migration, habitat alteration and the presence of introduced species, the current status of native fish species is unclear.

Investigations undertaken by the CRCFE in the Broken River between Broken Weir and Casey's Weir (Humphries and Lake, 2000; Humphries *et al*., in press) indicate that this reach is in good physical condition and supports a diverse fish fauna (Table 10). Most of the species that occur in the river are present in sufficient numbers to sustain viable populations, as spawning has been recorded for the majority of species between 1995 and 2000. A notable exception is golden perch and, although this species clearly occurs in large numbers and in a range of sizes (based on CRCFE sampling and reports by anglers), few larvae have been collected. This suggests that spawning is poor and that a large proportion of the extant golden perch population is made up of stocked fish (for example 20,000 golden perch were released into each of the Broken River and Lake Mokoan in 2001 – www.nre.vic.gov.au). Of note is the occurrence of crimson-spotted rainbowfish and Murray cod, and reports of trout cod in this reach; all are Flora and Fauna Guarantee listed species. Large numbers of carp and gambusia are present in this reach, along with smaller, but still significant, numbers of European perch. Each of these species will be having a deleterious effect on the native fish population through mechanisms such as competition, predation and the introduction of disease.

Broken River between Casey's Weir and the Goulburn River also contains a good diversity of physical habitat and supports a relatively diverse fish fauna (Table 11). Of note are reports of Macquarie perch and silver perch in this reach (D. Crook and A. King, pers. comm.). There is evidence that most native fish species are breeding each year (Humphries and Lake, 2000; Humphries *et al*., in press) and recruitment of juveniles into populations is likely. However, golden perch are again an exception, although larvae and a small number of juveniles have been recorded. This reach supports a healthy population of Murray cod, and CRCFE research indicates that this species breeds every year. As Reach 3 runs into the Goulburn River, it is a significant passage for fish travelling between the Murray River and the upper reaches of the Broken River. Alien species such as common carp, gambusia and European perch are common and their eradication should be pursued should effective eradication measures be developed.

Table 10: List of species of fish, their conservation status in Victoria, their movement patterns recorded from the Broken River and Broken Creek systems. See text for definition of reaches.

Species	Conservation Status	Movement	Broken R	Reach 1	Reach 2	Reach 3	Broken Ck	Reach 4	Reach 5	Holland's Ck
Australian smelt		L	C	?	C	C	M,S	M?	M,S	?
Crimson-spotted rainbowfish	FFG	?	C	?	C	C	A,M	M?	M	?
Murray cod	T,FFG	Ad, L	C	O	C	C	M	?	M	?
Trout cod	T,FFG	L	M	?	M					
Golden perch	T	Ad, L	C,M	O	C	C	M	?	M	?
Macquarie perch	T,FFG	Ad, L	O		O					
Southern pygmy perch		?	?				S		S	?
River blackfish	T	?	C	O	C	C				?
Silver perch	T	Ad, L	O		O					
River catfish	T,FFG	?	?							
Western carp gudgeon		No	C	O	C	C	A,M,S	M?	?	?
Midgley's carp gudgeon		No	C	?	C	C				
Lake's carp gudgeon		No	C	?	C	C				
Flathead gudgeon		L	?							
Mountain galaxias	T	?	C	O	C	C	S	?	?	?
Flat headed galaxias	T	?	?				S			
Brown trout		Ad	?							
Common carp		Ad, L	C	?	C	C	A,M,S	MS	M,S	?
Goldfish		?	C	?	?	?	A,M,S	M?	M,S	?
Gambusia		?	C	?	C	C	A,M,S	M?	M,S	?
European perch		?	C	?	C	C	A,M,S	MS	M,S	?
Tench		No	?							
Oriental weatherloach		?	?				M	?	M	?

T = listed as threatened in Victoria, FFG = listed under Fauna and Flora Guarantee act in Victoria, 1988; Ad = Adult, L = larvae/juveniles. ? = not recorded but likely to occur; A = Australian Water Technologies (AWT, 2000b); C = Campaspe Flow Manipulation Project (Humphries and Lake, 2000; Humphries et al., in press), M = MAFRI (Douglas, 2000), S = Streamline (McGuckin, 1997), O = other (D. Crook, A. King and angler personal communication)

Broken Creek

Ten species of fish have been recorded in Reach 4, which includes the Broken /Boosey /Major Creeks system. Six species are native and four are introduced species (Table 10). Native fish recorded from Boosey and Major Creeks include flatheaded galaxias, southern pygmy perch and crimson-spotted rainbowfish and it is also likely that these species occur in the upper Broken Creek, albeit in small numbers due to limited available habitat for these species. The permanent nature of Broken Creek probably enhances conditions for introduced species, especially carp, and restoration of a periodic wetting and drying cycle may make conditions inhospitable for this and other introduced species. However, the benefits of such an approach when managing introduced species is likely to be offset by the presence of numerous permanent weir pools along Broken Creek.

Eleven fish species are thought to occur in Reach 5 (Table 10). The reach is notable for its sizeable populations of crimson-spotted rainbowfish and as a breeding area for Murray cod (Douglas, 2000). The potential for this reach to be a corridor for movement of fish from the Murray River into the upper Broken Creek (and even into the Broken River during high flows), and Boosey Creek means that it may be a significant stretch of stream in the overall system.

Holland's Creek

There is no data on fish species occurring in Reach 6. However, based on known distributions, species likely to occur are crimson-spotted rainbowfish, southern pygmy perch, Australian smelt, carp gudgeons and river blackfish. (Table 10). The ubiquitous common carp, European perch, goldfish and gambusia undoubtedly also occur. Larger bodied native species, such as golden perch and Murray cod, could possibly move up into Holland's Creek during periods of high flow.

6.5.2 Habitat availability

The reach downstream of Lake Nillahcootie contains a substantial amount of exotic vegetation, including willow and blackberry, very little of which provides good in-stream habitat for fish. Willows do not have the same rate of limb drop as native trees, such as river red gum, and, together with their faster rate of decomposition and their contribution to erosion, provide inferior overall habitat for fish than do native tree species. Catchment works to remove exotic species and replace with native species will eventually help to improve in-stream habitat for fish. Experiments aiming to improve in-stream habitat should continue and be designed rigorously.

The Broken River between Broken Weir and the Goulburn River has a form typical of lowland streams. Broad pools (20-30 m wide and 3-5 m deep) are interspersed with narrower (10-15 m), shallow runs, and meander between banks supporting predominantly native trees, understorey and aquatic vegetation. Aquatic macrophytes are dominated by common reed, *Phragmites australis*, although occasional patches of submerged macrophytes, such as *Triglochin* sp. and *Vallisneria* sp. can be found. Anecdotal reports suggest that these plants may have been in much greater abundance in the past, and therefore contributed significantly to fish habitat. The dominant in-stream habitat is now coarse woody debris, derived mostly from river red gums. Overall, habitat diversity for fish in this reach is relatively good, although there are pressures associated with current and past river and catchment management (e.g. previous snag removal, sedimentation associated with previous catchment erosion).

Slugs of sand occur within the main channel of the Broken River between Broken Weir and the Goulburn River. The source of this sand is unclear but experience in nearby catchments (e.g. Ovens, Campaspe) suggests that previous land clearing and river management works were likely to have been involved. The sand mobilised in the Broken River has the potential to fill in deeper holes in the river bed and effectively 'homogenise' the habitat (P.S. Lake, pers. comm.). Anecdotal evidence suggests that habitat reduction because of the deposition of sand was exacerbated by the removal of woody debris as part of previous 'river improvement' works (T. Cochran, pers. comm.), which resulted in a decrease in hydraulic diversity and scouring. Changes to the flow regime can also increase the risk of habitat 'homogenisation' if the frequency of flows that scour sand from the stream bed is reduced. The infilling of pools with sand can reduce the habitat available for species such as golden perch, which preferentially inhabit deep sections of the river (Crook *et al.*2001). Sand deposition may also result in sub-optimal substrate for the growth of food for small fish (A. King, pers. comm.).

Access to the river by livestock can also affect fish habitat availability or quality, for example by creating localised erosion and poor water quality. The edge habitats important for rearing of young fish are most at risk.

The channel of Broken Creek between Casey's Weir and Katamatite is highly variable; in places it can be up to 15 m wide and 1 m deep, while in others the creek is barely 3 m wide and only a few centimetres deep. Modification to the channel (SKM 1998) and reduction of the riparian zone have decreased in-stream habitat diversity. Weir pools provide some habitat for deeper bodied fish and may serve as foci for angling, but they also provide relatively constant, benign conditions for introduced species, such as carp and European perch. Overall, fish habitat is poor. Snags provide some structure, but sedimentation will almost certainly have filled in deeper parts of the creek. The presence of *Typha* sp. will not provide any great benefits as fish habitat. This reach of the creek provides only limited habitat for native species, such as Australian smelt, mountain galaxias and carp gudgeons.

Much of the Broken Creek between Katamatite and the Murray River is wider (up to 60 m) than upstream areas because of inputs from Boosey Creek, from discharges from irrigation channels and drains, and because of channel modifications. Snag habitat did not appear abundant, but high water turbidity in the creek made visual assessment of snag habitat very difficult. Observations at sites which visited by the Scientific Panel, together with the weir pools, suggests there is habitat for larger bodied native (Murray cod) and introduced species (carp), as well as some smaller species, such as Australian smelt and gambusia.

Holland's Creek downstream of Holland's Weir is a small stream, running through agricultural land. At low flow, when visited, it was narrow (3-8 m wide) and appeared relatively shallow (less than 1 m). In-stream vegetation and snags were among a variety of potential habitats noted in the creek.

6.5.3 Fish movement and fish passage

Many native fish species present across the study area are known to move at some stage during their life cycle. The adults of species such as Murray cod, golden perch, Macquarie perch and silver perch have been known to move for tens and even hundreds of kilometres (Reynolds 1983). Upstream movement mainly occurs during rises in river flow but may also occur at other times. For example, the upstream movement of juvenile golden perch may occur during small rises in flow at various times of the year (Mallen-Cooper *et al.*, 1995). Downstream drift of fish larvae, such as that of Murray cod and golden perch, can take place during late spring/early summer. Recent estimates are that larvae of Murray cod are able to drift at least 2 km in one night, and so may drift considerable distances over several days.

Barriers to fish movements, such as dams, weir and culverts can restrict the movement of fish (both upstream and downstream), thus affecting distribution and recruitment. Larvae are likely to be more susceptible to damage when passing weirs and other structures than older stages of fish.

The success of environmental flows and other measures implemented to promote native fish populations across the study area will require effective fish passage past barriers such as those listed in Table 11. A study by Marine and Freshwater Resources Institute (Douglas, 2000) indicated that fishways installed in Broken Creek were effective in allowing fish movement. DNRE and the GBCMA is currently implementing a program of progressive installation of fish passage across the study area and this should be continued. The design of future fish passage should provide two-way passage past barriers for a range of fish sizes.

Priorities for fish passage for the Broken River include Gowangardie, Casey's and Broken weirs, and eventually Lake Nillahcootie.

Table 11: Major fish barriers and passage across the study area

Reach	Barrier	Fish Passage
Reach 1	Lake Nillahcootie Low level weirs and fords (multiple, built by landholders) Broken Weir	None None None
Reach 2	Lake Benalla Low level weirs (built by landholders) Casey's Weir	Fishway installed None Fishway proposed
Reach 3	Low level weirs (built by landholders) Gowangardie Weir	None Weir removal being assessed
Reach 4	Casey's Weir Flynn's Weir McLaughlan's Weir Waggarandall Weir	Fishway proposed None Weir removal being assessed None
Reach 5	Rice's Weir Kennedy's Weir Schler's Weir Harding's Weir Luckes Weir Ball's Weir Chinaman's Weir Nathalia Weir	Fishway installed Fishway installed Fishway proposed Fishway proposed Fishway proposed Fishway proposed Fishway proposed Fishway proposed
Reach 6	Holland's Weir	None

6.5.4 Stocking of fish

Native fish such as Murray cod and golden perch are sought-after species by recreational anglers. The DNRE fish stocking program (www.nre.vic.gov.au) is designed to enhance native fish populations or establish new populations. Releases of native fish have two objectives: (i) as a conservation measure and, (ii) to provide recreational fishing opportunities. In the year 1996/97 for example, golden perch were stocked into Broken Creek (10,000), the Broken River (20,000) and Lake Mokoan (20,000). The lack of natural golden perch recruitment was noted in previous discussion. It must be realised, however, that stocking is only a short-term solution and that sustainable 'natural' populations of fish can only be achieved if the threatening processes are addressed and redressed.

While stocking native species can maintain populations in areas where they might otherwise disappear, stocking fish on an ongoing basis poses risks to natural populations. Stocked fish are likely to be sourced from a narrow genetic base and when released can reduce the genetic variability of wild populations. Hatchery reared fish may also be less robust than wild populations and so be less able to survive the variable conditions that will be encountered in the wild. When measures such as the removal of barriers to fish migration are implemented (e.g. installation of fishways at weirs), it is hoped that the natural recruitment of golden perch will improve, thus removing the need for restocking across the study area.

6.5.5 Relationship with flow

The changes to the flow regime of both the Broken River and Broken Creek have almost certainly been detrimental to fish fauna across the study area. For example, high summer flows can displace eggs and larvae from spawning and rearing habitat, thus reducing recruitment. High summer flows and less annual flow variability also provides habitat conditions favourable for introduced species such as carp and gambusia. Reduced flows during winter and early spring can prevent movement of fish upstream and downstream across riffles and other small barriers. Lower winter flows also means that there is less habitat and food available for native fish at a time that may be critical for reproductive development prior to spawning. Overall, the 'flow inversion' pattern (higher summer flows, lower winter flows) established by flow regulation tends to create a more homogeneous channel and provide fewer backwater and still littoral habitats for larval and juvenile fish of large species and adult fish of small species. Also, water released from Lake Mokoan (and to a lesser extent from Lake Nillahcootie) is generally more turbid than the Broken River water would have been naturally. This is likely to have an effect on algal biofilm growth, and in turn affect production of larval fish food (either the algae itself or microfauna which grazes the algae). Reduced water clarity may also reduce the foraging efficiency of fish larvae, which feed visually.

The impact of changed flow regime is likely to be most pronounced in Reach 1 (the Broken River between Lake Nillahcootie to Broken Weir), where flows are seasonally reversed and flow variability has been altered substantially from natural. Short-term (over several days) changes in flow from 50 to 300 ML/day are not uncommon during the summer irrigation season, resulting in changes to river height in the order of 25-30 cm.

The pattern of seasonal shift in flow is increasingly attenuated downstream of Broken Weir because of tributary inputs and the diversion of water to Lake Mokoan. As the flow regime in the Broken River below Broken Weir is less affected that in Reach 1, native fish communities in Reach 2 and 3 (Broken Weir to the Goulburn River) are likely to be less affected. The differences in fish communities between the reaches are difficult to assess, since historical records are only reliable for noting the presence/absence of species and not abundance. It is likely that flow conditions in Reaches 2 and 3 are sufficient for fish to complete their life cycles, although a sudden rise in flow with the shut down of Lake Mokoan in January increases the risk that eggs and larvae of species of fish breeding at this time may be displaced. A sudden decrease in flow when diversions to Lake Mokoan commence or when Lake Nillahcootie is filled can increase the risk of fish strandings.

The Broken Creek between Casey's Weir and Katamatite is currently operated as a supply channel for irrigation and stock and domestic water supply. The creek is now a permanent stream rather than ephemeral. The significance of these changes for native fish species is uncertain. Flooding episodes would undoubtedly have been important occurrences and the ecology of the Broken Creek and associated wetlands would once have been unique to this area. It is speculated that native fish moved into the Broken Creek system from the Murray River following large floods (W. O'Connor, pers. comm.), potentially as far as the Broken River. However, numerous weirs act as barriers to fish migration along the creek.

The Broken from Katamatite to the Murray River (Reach 5) has also been profoundly affected by flow regulation. Flow in this section of Broken Creek is greatly influenced by discharge from the East Goulburn Main Channel and a series of irrigation drains associated with the Murray Valley and Shepparton irrigation districts, and creek heights are maintained at high levels due to the presence of a series of weirs. As the creek in this reach is wider and deeper than upstream, it has more habitat for larger, deeper bodied native fish such as Murray cod and golden perch. However, the relatively constant water levels in the weir pools favours alien species such as carp.

The seasonal flow pattern in lower Holland's Creek (Reach 6) is largely unchanged, although magnitude of flows has decreased considerably, especially in late winter and early spring as water is diverted to Lake Mokoan. Holland's Weir acts as a barrier to fish migration from the Broken River into the Holland's and Ryan's Creek systems.

6.6 Threatened species

A number of flora and fauna surveys have been conducted across the study area, particularly in the Broken Creek catchment as part of management strategy development and environmental impact statements (SKM 1998a and b, AWT 2001). For example, 407 plant species have been recorded across the Broken Creek catchment, 25 of which are listed as threatened in Victoria (SKM 1998b). Examination of more recent records indicates that 33 fauna species (including 7 fish and 20 bird species) and 31 flora species with a high conservation value have been recorded in and adjacent to the Broken River and Broken Creek (DNRE, unpublished data; Appendix 4). The large number of threatened species, particularly that of plants and birds, indicates the importance of the remnant habitat provided by riparian areas that exist along the major waterways in the study area.

6.7 River channel – floodplain linkages

Floodplains play an essential functional role in riverine ecosystems. It is important that these functions are recognised and supported if river health is to be maintained in the long term. It is also important to recognise that floodplains are valuable ecosystems in their own right, and contribute significantly to regional diversity.

Floodplains present an array of habitats for species, many of which are aquatic organisms adapted to the non-flowing, but often temporary, billabongs and backwaters. Floodplain ecosystems are often present as a mosaic of habitats based largely on the frequency and duration of flooding. For example, work on the Barmah-Millewa forests has identified many sub-habitats and the threats posed to them by changes in water management (Anon. 2000).

Each of these sub-units can be characterised by the specific plant communities they support, which can in turn be identified by other faunal groups. For example, Parkinson (1996) indicated that diversity of bush-bird species on the Ovens floodplain near Peechelba was strongly correlated to the proximity of ephemeral wetlands.

Carbon is the basis of all food chains and its synthesis into organic forms (photosynthesis; primary production) and the ways in which it is exchanged through the food web determines the vigour, biodiversity, and robustness of the ecosystem. The sources and forms of carbon in river ecosystems are many and include leaves and litter from upper catchments, in-channel production (aquatic plants, algae, and biofilm) in middle reaches, and the products of production on the floodplain (litter, other terrestrial sources, and floodplain wetlands) in the lowland reaches. In upland reaches, carbon is delivered either by direct input from riparian vegetation or by transport in surface runoff. In floodplain reaches, a delivery system is also required but, as rainfall runoff is much reduced in force and quantity, the process is dependant on connections between the river and floodplain wetlands (billabongs and temporary anabranches) and/or the sweeping of floodplain areas by over-bank flow. Resource management can threaten and damage this relationship in several ways:

- The reduction of floodplain productivity (in the ecological sense) by clearing, heavy grazing etc. in areas likely to be inundated.
- Degradation of floodplain wetlands (eg draining, blocking, abstraction, heavy stock use).
- Alienation of floodplain by levees
- Flow regulation/water use which changes the timing, frequency, or extent (space or time) of over-bank flows.

Floodplain systems supply more than carbon and nutrients to river ecosystems. For example, billabongs support microbial communities that are more diverse than in the associated river systems. Billabong zooplankton communities are also more diverse and dense (often by two orders of magnitude) than those of the parent river. As well as a massive contribution to biodiversity, floodplain wetlands may serve to inoculate the parent system during high flow events.

In the current study, the major floodplain zones of floodplain are located downstream of where the Broken River valley broadens and stream gradients (downstream of Swanpool) and the areas northwest of the Broken River.

The floodplains in these areas have been significantly modified for agricultural production, including dryland and irrigated areas. In an ecological sense this has greatly reduced the productivity of these areas and also increased the risk of contamination from grazing stock, applied fertilisers, and the physical effects of rainfall runoff from relatively poorly protected floodplain (note the high maximum levels of turbidity).

As floodplain areas are developed, increased land values support intensive ‘river management’ activities to resist bank erosion and avoid floodplain inundation (e.g. levees) even at flows well within the normal range. This severely curtails the ecological role of the floodplain. Of all land management actions on the floodplain, levees are the most basin-wide in their effect. Prevention of a flood in one area must increase pressures elsewhere and (like dryland salinity) cause and effect are often separated by some distance.

6.7.1 Impact of river regulation on floodplains

The overbank flows that are important for connecting the river system with its floodplains have not been altered by flow regulation from the dams. However, floodplain connectivity has been affected by the presence of levees constructed to protect public and private assets. These are mostly located near towns such as Benalla, Numurkah and Nathalia.

6.8 Summary of environmental values and threats

Environmental values that should be protected have been highlighted in previous sections but are presented in an integrated way in Table 12, based on the previous discussion of the river system and observations made by the Scientific Panel during its field visit in May 2001. Particularly important values include:

- The largely natural pattern of the flow regime in the lower reaches of the Broken River and lower Holland's Creek (including both high and low flows) as it maintains geomorphological, biological and ecological processes (although there are instances of relatively constant and turbid flows each year);
- Habitat diversity in the lower reaches of the Broken River, including in-stream features such as large woody debris, riffles, pools, bars, anabranches, the littoral fringe, flood runners and floodplain and wetland/billabong features in the nearby landscape;
- Threatened species (flora and fauna), including up to ten native fish species of State and national conservation significance and icon species such as Murray cod;
- Riparian vegetation, especially in the lower Broken River and along Broken Creek. The remnant riparian and floodplain vegetation also provides important habitat for threatened species (fish, birds, amphibians) whose natural habitat in the region has been greatly reduced since European settlement;
- Connectivity between the river channel and its floodplain that maintains floodplain function, except in the case of Broken River/Broken Creek interactions;
- Links with the Goulburn and Murray Rivers, with the Broken River and Broken Creek being important for water yield and potentially for fish movement.

A large number of activities and processes pose threats of varying degrees to the environmental condition of the Broken River system (Table 13). This is not surprising given the broad range of activities and land use that occur across the study area. The threats to environmental values include those associated with flow and river management, agricultural and industrial practices and activity, natural ecological processes, and invasion by pest plant and animal species.

6.9 Summary of the environmental effects of flow regulation

The effects of flow regulation on the ecological components of the river system may be summarised as:

- River hydrology has been altered, with a reduction in higher flows as a result of regulation at all three reaches of the Broken River. Low flows are now greater than natural in the upper two reaches but are reduced in Reach 3. The effect on flood frequencies is small at all three sites, with Reach 2 being most affected.
- River geomorphology appears largely unaffected by flow regulation, although specific studies are required to confirm this;

- Water quality has been affected by inputs of nutrients, sediments and turbidity, including irrigation drainage, runoff from agricultural land and releases from Lake Mokoan.
- Riparian and aquatic vegetation has been affected by wetter conditions in upper reach of Broken River and by disturbances such as clearance and livestock access across the catchments. Floodplain wetlands are likely to have been affected by isolation form the river channels (due to levees) and land management practices (e.g. livestock access);
- Macroinvertebrates are unaffected by river regulation in upstream areas. The decline in macroinvertebrate communities in downstream areas is probably due to multiple catchment impacts;
- Native fish population, including threatened species, are likely to have been affected by dams and weirs that act as barriers to movement. Rapid changes in flow and seasonal reversal in flow are potentially detrimental to fish recruitment and adult fish habitat. The potential effect of cold water releases from Lake Nillahcootie also requires confirmation, although flows from Back Creek are likely to dampen the extent of cold water releases when they occur.
- The connection between the river channel and its floodplain has been largely unaffected by flow regulation from the dams, with the exception of the link between Broken River and Broken Creek. However, river-floodplain connections have been altered by the presence of levees in the vicinity of Benalla and along the lower Broken Creek.

Principles for assessing river condition and making recommendations to improve river health within a water management context were presented in section 2. These principles can also be used as rehabilitation objectives that serve as the basis of environmental flow recommendations:

- To maintain or enhance the natural diversity of habitats and biota within the river channel, riparian zone and floodplain;
- To maintain or enhance the natural linkages between the river and the floodplain;
- To maintain the natural metabolic functioning of aquatic ecosystems in the study area.

Flow and other management recommendations in Chapter 7 will therefore focus on ensuring sufficient flow to maintain or improve existing habitat for native fish (particularly threatened species), macroinvertebrates, aquatic and riparian vegetation, and natural linkages between the river and its floodplain. Other management actions that maintain, reinstate of improve habitat available for river and wetland biota will also be considered.

Table 12: Summary of environmental values associated with the study area

Environmental Value	Broken River (Reach 1)	Broken River (Reach 2)	Broken River (Reach 3)	Broken Creek (Reach 4)	Broken Creek (Reach 5)	Lake Mokoan	Holland’s Creek
Largely natural pattern of the flow regime		✔✔	✔✔				✔✔
Macroinvertebrate populations indicative of good river health	✔✔	✔✔	✔✔	✔			
Riparian vegetation species richness and habitat	✔✔	✔✔	✔✔				
In-stream habitat diversity	✔	✔✔✔	✔✔✔				✔✔
Presence of threatened flora or fauna	✔✔	✔✔✔	✔✔			✔*	✔
Remnant native vegetation (riparian and floodplain)	✔	✔✔	✔✔	✔✔	✔✔✔		
Water quality	✔✔	✔	✔				✔✔
Rehabilitation potential (vegetation or fish)	✔✔	✔✔	✔✔				✔✔
Lack of weeds		✔✔	✔✔✔				
Demonstration of fishway success					✔✔		

✔ fair ✔✔good ✔✔✔ high * stocked species

Table 13: Summary of threats to environmental values

Environmental Value	Broken River (Reach 1)	Broken River (Reach 2)	Broken River (Reach 3)	Broken Creek (Reach 4)	Broken Creek (Reach 5)	Lake Mokoan	Holland's Creek
Altered flow regime	✔	✔	✔	✔	✔	✔	✔
Altered drainage patterns (floodplain)		✔		✔	✔	✔	
Potential cold water releases	✔						
Introduced fish species	✔	✔	✔	✔	✔	✔	✔
Barriers to fish movement	✔	✔	✔			✔	
Clearing of riparian vegetation	✔	✔	✔				
Weed invasion (terrestrial or aquatic)	✔	✔	✔	✔	✔	✔	✔
Bed and bank erosion	✔	✔	✔				
Channel realignment and excavation				✔	✔		
Sediment inputs from tributaries and due to past river management works	✔	✔	✔	✔		✔	
Livestock access	✔	✔	✔	✔	✔		✔
Stormwater pollution		✔					
Septic tank contamination		✔					
Poor water quality from Lake Mokoan			✔				
Impact of algal blooms				✔	✔	✔	
Road runoff		✔		✔	✔		
Discharge of irrigation drainage				✔	✔		

7 MANAGEMENT RECOMMENDATIONS

The following flow and river management recommendations have been developed to maintain the current environmental or ecological value of the Broken River system and to address a number of the threats to environmental values.

The Broken River and Broken Creek systems have been treated separately in recognition that the current flow regime in Broken Creek is largely unnatural. Environmental flow recommendations have been developed for the Broken River, while management recommendations have been supplied for Broken Creek, complementing those recommendations developed by other projects (SKM 1996; AWT 2001). The use of Broken Creek as a water supply channel and as a receiving water for irrigation drainage and channel outfalls means that what was once an intermittently flowing stream is now mostly a permanent stream (See Appendix 5 for indicative flow regime at sites along the creek). There was insufficient flow data available for the Scientific Panel to properly assess aspects of the flow regime that would permit detailed environmental flow recommendations. In addition, any environmental flow regime would be an artificial construct for much of Broken Creek, given its use as a water supply channel. The exception is for the section of Broken Creek between Waggarandall Weir and Katamatite. This section of the creek still retains some measure of ephemerality, and this would be enhanced should the proposed pipeline for the Casey's Weir and Major Creek Waterworks District go ahead.

~~6.1~~7.1 Environmental flow recommendations for the Broken River

The hydraulic characteristics of the three study sites were modelled using HEC-RAS, a one-dimensional gradually varied flow analysis software package produced by the US Army Corps of Engineers. The three sites were:

- Upstream of the Swanpool Rd bridge;
- Adjacent to Riverview Drive, Benalla; and
- Upstream of the Goomalibee Bridge.

To obtain a representative sample of conditions at each site, 15 or more evenly spaced (at approx. 65 m) cross-sections were included in this model (see Appendix 2). Additional cross-sections were added to improve model performance where required. Cross-sections were surveyed during a period of low flows. The model provided water surface profiles for a 1 km reach for a range of discharges. Model output included the wetted perimeter, surface width and area for each cross-section for a range of discharges.

7.1.1 Potentially important flow events

After considering how regulation had impacted on river hydrology, the Scientific Panel investigated the following flow events that were considered ecologically important:

- Fish
  - Rapid reductions in discharge with system operation that increase the risk of stranding fish;
  - Rapid increases in discharge associated with system operation that may wash out larval and juvenile fish from rearing habitats;
  - A reduction in areas with slow-water velocity that serve as refuge and rearing habitat, particularly for young stages of fish.

- Invertebrates
    - Increased rates of drying of the streambed that lead to a loss of invertebrate habitat;
    - Rapid increases in discharge associated with system operation that may increase catastrophic drift in invertebrates, washout of microfaunal invertebrates from littoral and backwater habitats, and increased scour of biofilm from hard surfaces such as rocks and snags;
    - Rapid reductions in discharge with system operation that increase the risk of stranding invertebrates.

- Plants
    - Excess and/or seasonally shifted inundation of plants growing on in-channel benches;
    - Loss of shallow water area for aquatic macrophytes;
    - Loss of flow into anabranches.

Although these flow events can occur naturally, large changes in their frequency and magnitude can alter aspects of the stream ecosystem. Environmental flow targets have been developed to restrict the effect of regulation on these flow events and minimise the risk of adverse ecological impacts. Changes in the frequency of these flow events were evaluated using hydraulic parameters that measure the severity of the event (Figure 10). For example, drying of the streambed was characterised by the area of wetted perimeter of the channel. The project team also selected a method of characterising the time sequence of flow events. In designing this time-series analysis it was necessary to consider:

a) The months in which the events are ecologically important,
b) Whether extreme events, more frequent events or average conditions are important, and
c) What degree of change in these flow events is acceptable.

For the Broken River, the flow events analysis was developed progressively through meetings of the scientific panel. The initial meeting included a two-day field trip to sites along the river and presentations by the local water authority and community representatives. The event definitions are discussed in the following sections.

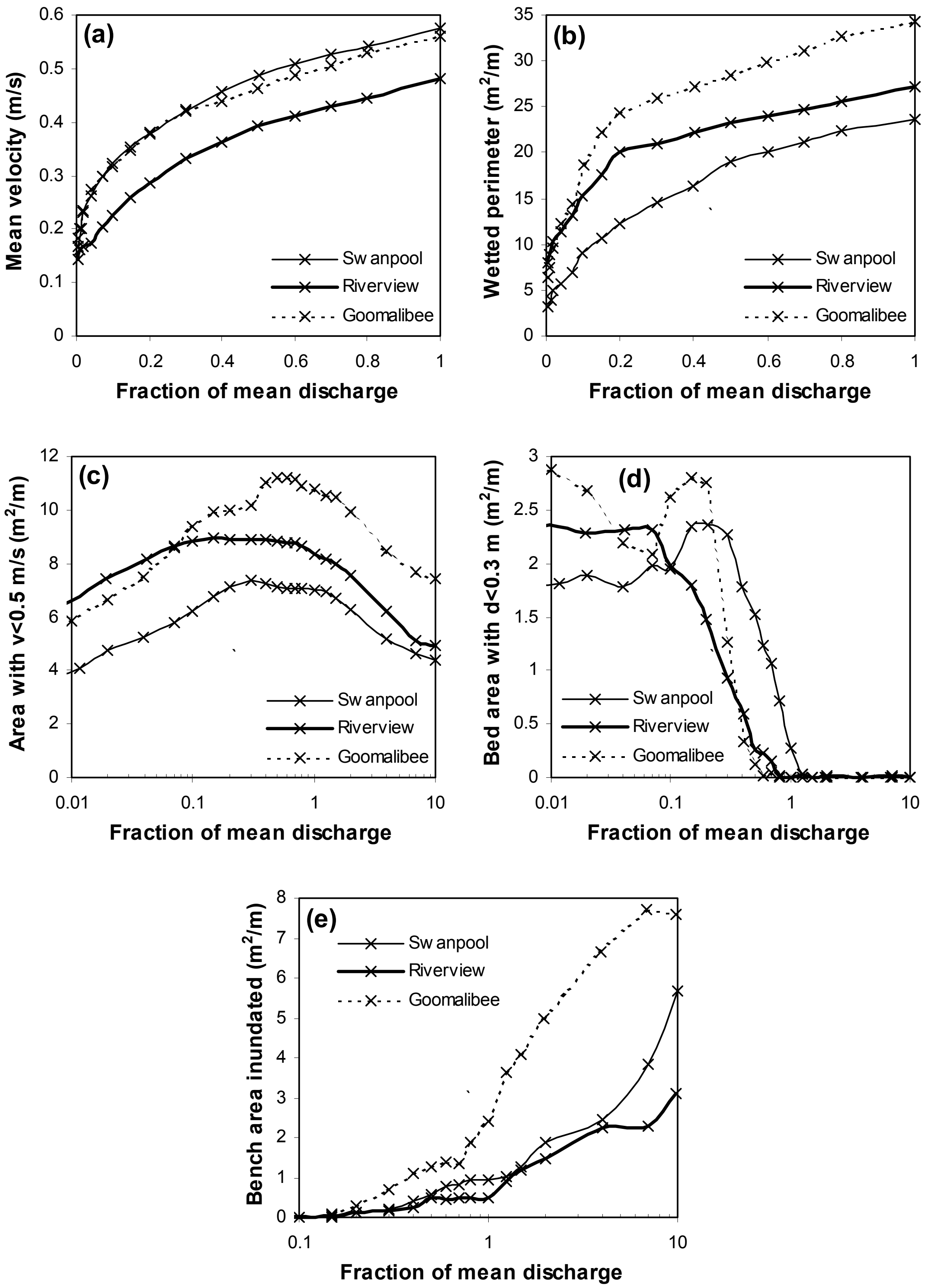

Figure 10: **Relations between discharge and (a) wetted perimeter, (b) mean velocity, (c) slow velocity area, (d) shallow bed area, and (e) area of inundated benches at three reaches of the Broken River. The natural mean daily discharges at Reach 1(Swanpool), Reach 2 (Riverview) and Reach 3 (Goomalibee) are 220 ML/d, 360 ML/d and 700 ML/d respectively.**

7.1.2 Rapid flow reductions

Biota such as fish and invertebrates face an increased risk of stranding due to rapid reductions in flow as a result of regulation. The rate of reduction in wetted perimeter (m/day) was used as a measure of the probability of stranding in the key periods December-February, March-May, June-August and September-October. Regulation was found to increase the recurrence of rapid flow reductions in all reaches of the Broken River (Figure 11), especially in the period March-May. This effect was most pronounced in Reach 2 (and occurred all year round), presumably due to diversions from Broken Weir to Lake Mokoan and decreased flow in the river as Lake Nillahcootie is filled. Rapid flow reductions are also apparent in Reach 1 in the period March-May, probably associated with either the cessation of the irrigation season or a temporary cessation of releases during a wet period.

Environmental flow rules that reduce the risk of rapid decreases in flow are required to address this issue, rather than specific minimum flow recommendations. Figure 12 shows daily flows plotted against flow on the previous day, for all days in the natural flow record (i.e. flows on consecutive days are shown as an XY plots). Not surprisingly, the data show a strong linear correlation, and flow reductions are generally less than flow increases for any flow range. It was decided that a practical and effective rule for restricting rates of flow reduction, to ensure they do not exceed natural rates, takes the form:

$$Q_2 > k \times Q_1$$

Where Q_1 and Q_2 are daily flows on consecutive days and k is some constant for the reach (where $k < 1$). The constant, k, was selected so that only 5% of the points in Figure 12 lay below the lines representing this rule. That is, this rule is only violated on 5% of days in the natural flow regime. The panel recommends this rule as suitable for periods when flows are regulated. Clearly, during periods when flows are not regulated (i.e. Nillahcootie spillway is operating and there is no diversions to or releases from Mokoan) natural flows reductions will not always conform to this rule. The advantage of this rule is that it allows rapid flow reductions at high flows but slower flow reductions at lower flows when flow changes have a greater influence on habitat conditions. The constants, k, derived for the Swanpool, Riverview and Goomalibee sites are 0.65, 0.7 and 0.65 respectively.

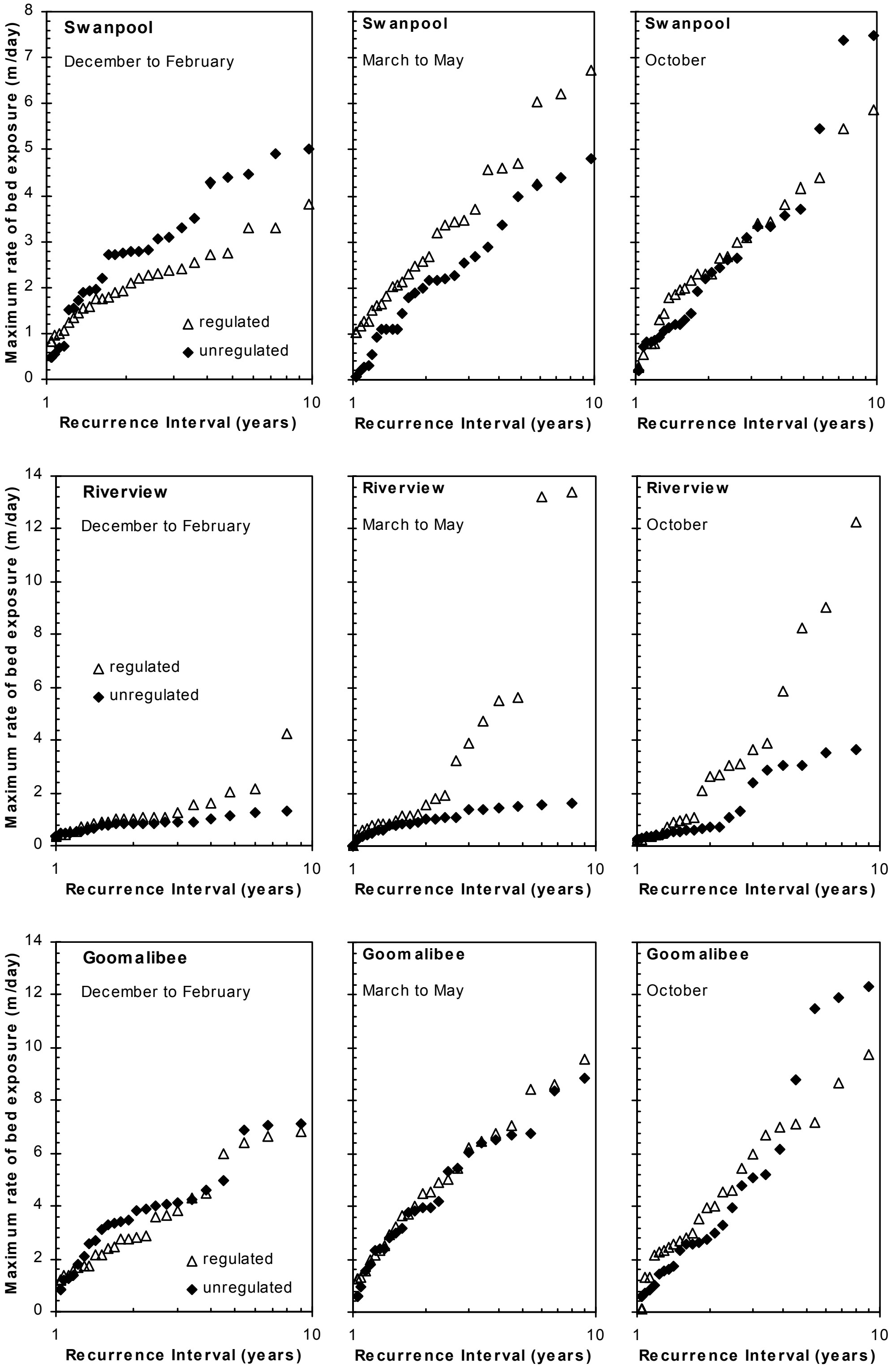

Figure 11: Comparison of rates of bed exposure in Reach 1 (Swanpool), Reach 2 (Riverview) and Reach 3 (Goomalibee) with regulated and unregulated flow regimes.

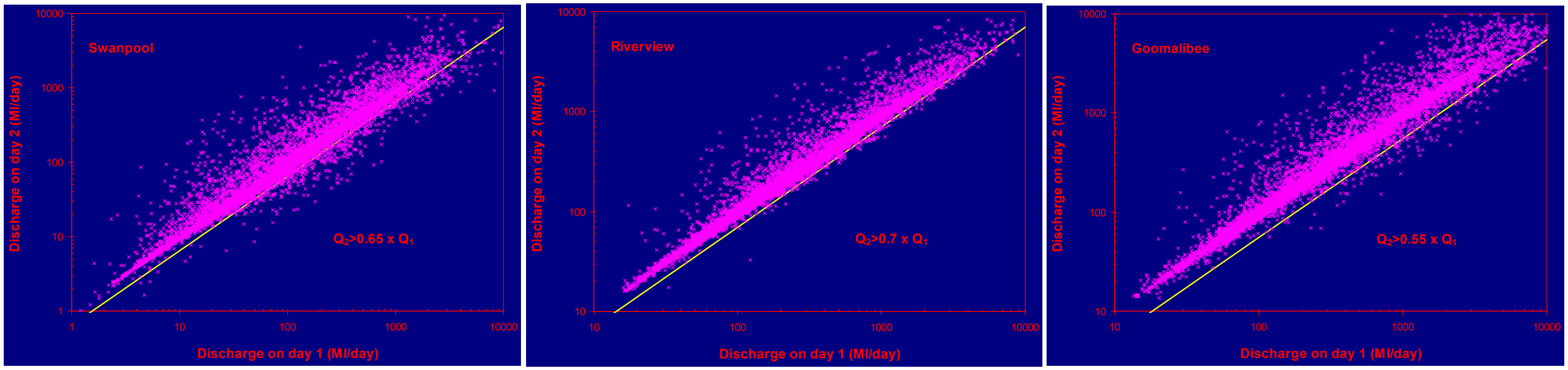

Figure 12: Development of flow reduction rules for the representative reaches of the Broken River

7.1.3 Rapid flow increases

Rapid changes to flow from Lake Nillahcootie to meet increasing downstream demand increases the risk of biota such as larval and juvenile fish being washed downstream, potentially reducing recruitment to the river. The risk of washout was considered for the periods December-February, March-May and October, known to be key time of breeding and migration for native fish. The maximum increase in velocity (m/s) was used as a measure of the probability of washout of larval and juvenile fish.

It was found that flow regulation was more likely to dampen, rather than exacerbate rapid flow increases (Figure 13), or that rapid flow increases for the regulated regime were still within the range experienced with the unregulated regime. This is not surprising, since rapid increase in discharge are a natural feature of most rivers and regulation and dam storage capacity tend to attenuate peak discharges. No environmental flow target was required to address this potential threat at this stage.

GMW proposes to automate the operation of Lake Nillahcootie by installing a SCADA system. This will give GMW better and more responsive control of releases. In order to avoid any increased risk of rapid increases in flow with automated operation, a flow rule similar to that proposed to avoid rapid decreases in flow has been developed. In this case, the 95th percentile value can be used to set the maximum rate of flow increase (cf 5th percentile used for rate of fall). In this case the criteria for the maximum rate of rise for the three sites is:

$$Q_2 < k \times Q_1$$

Where Q_1 and Q_2 are daily flows on consecutive days and k is the constant for the reach, calculated to be 2.1, 1.5 and 1.8 for the Swanpool, Riverview and Goomalibee reaches respectively. Given the greater control afforded by automation, it should be possible to increase flows gradually (e.g. over a 24 hour period), rather than as a step change.

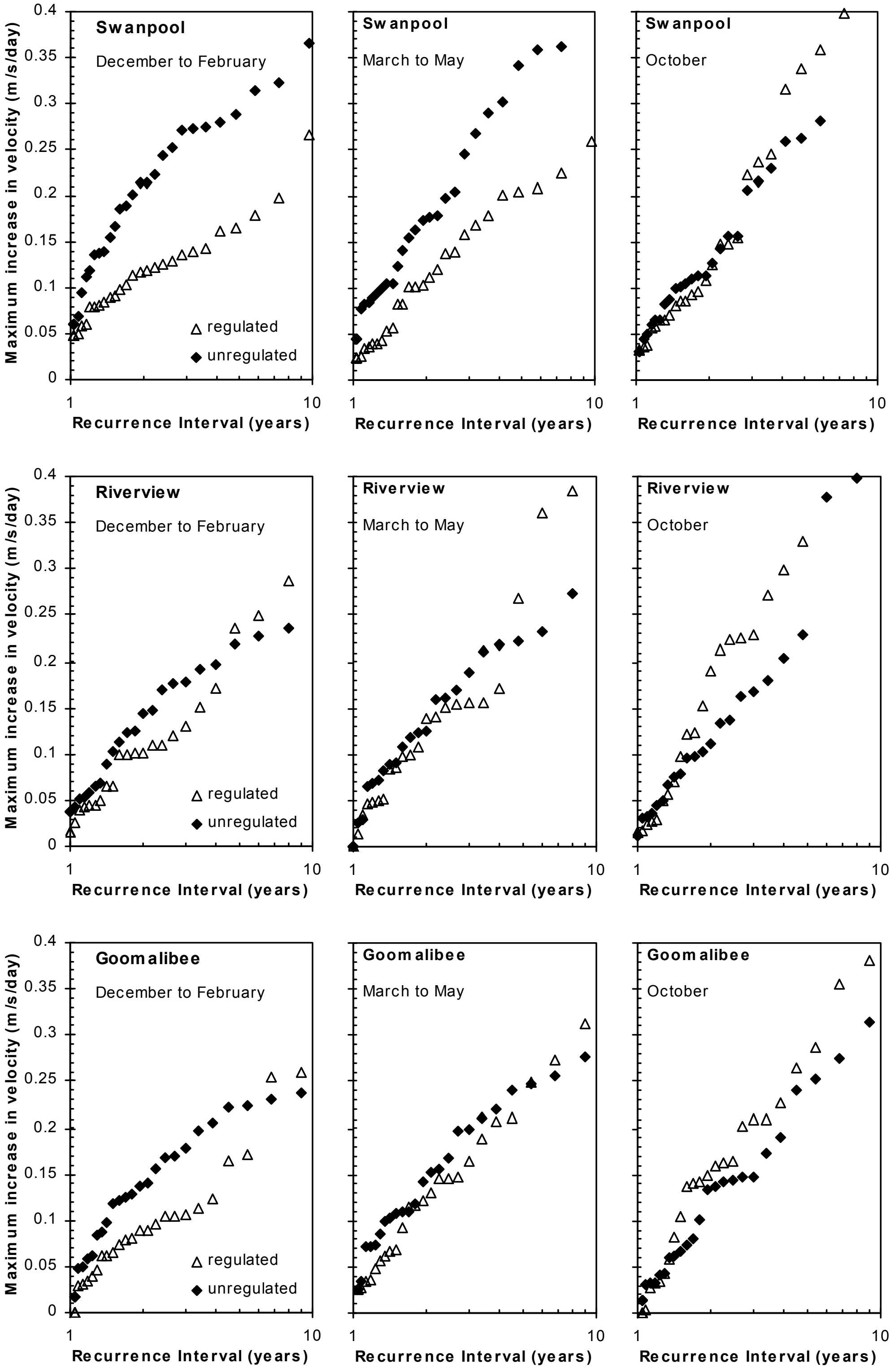

Figure 13: Comparison of maximum increase in velocity in Reach 1 (Swanpool), Reach 2 (Riverview) and Reach 3 (Goomalibee) with regulated and unregulated flow regimes.

7.1.4 Slow water habitat

Slow water habitat provides refuge and rearing habitat for larval and juvenile fishes. Two values were considered as representing slow flow conditions for the key native fish rearing periods of December-February, March-May and October:

- The stream bed area with velocity <0.05 m/s, and
- The stream bed area with velocity <0.01 m/s.

Changes to slow water habitat with regulation were only apparent in Reach 3, particularly in the period of March-May (Figure 14). Here, the amount of habitat was found to be relatively independent of the velocity that was chosen to represent slow flow conditions (<0.05 and <0.01 m/s), with a maximum habitat area in Reach 3 recorded at a flow of approximately 350 ML/d. However, this flow has a 20-30 percentile exceedance (Figure 3) and is not 'typical' of the flows encountered in March-May. The loss of slow water habitat at Goomalibee is the result of low flows during this time rather than elevated flows associated with irrigation releases.

Based on professional judgement in this and similar studies (Davies and Humphries 1996), a reduction of up to 15% in available slow flow habitat was considered to represent a low risk to fish rearing habitat in the period March-May. A 15% departure from natural occurred at approximately the 2-year recurrence interval in the regulated regime (Figure 14), equivalent to a wetted area of approximately 7.4 m. A discharge-wetted area relationship was used to convert the minimum wetted area to a daily flow of 20 ML/d, which was adopted as the minimum wetted area required to preserve slow water habitat.

There are a number of assumptions related to adoption of a minimum flow of 20 ML/d in Reach 3. The modelling data and ecological information about the Broken River system is limited. It is assumed that the available slow water habitat indicated by the hydraulic modelling is distributed in a manner that native fish can use. For example, it is assumed that the slow flow habitat is distributed through pools and along the edge of riffles and runs, and is longitudinally connected. This assumption needs to be validated but requires additional survey work and modelling that was not available to this project. It is recommended that this work be undertaken in the future to support our recommendations and to inform similar work elsewhere. The adoption of a 15% reduction in slow water habitat as a low risk to fish migration is based on limited observations and professional judgement, including observations made from systems outside the Broken River. While this figure is based on best available ecological information, further investigation is required to confirm or refine what constitutes 'low risk' in terms of change to slow flow habitat.

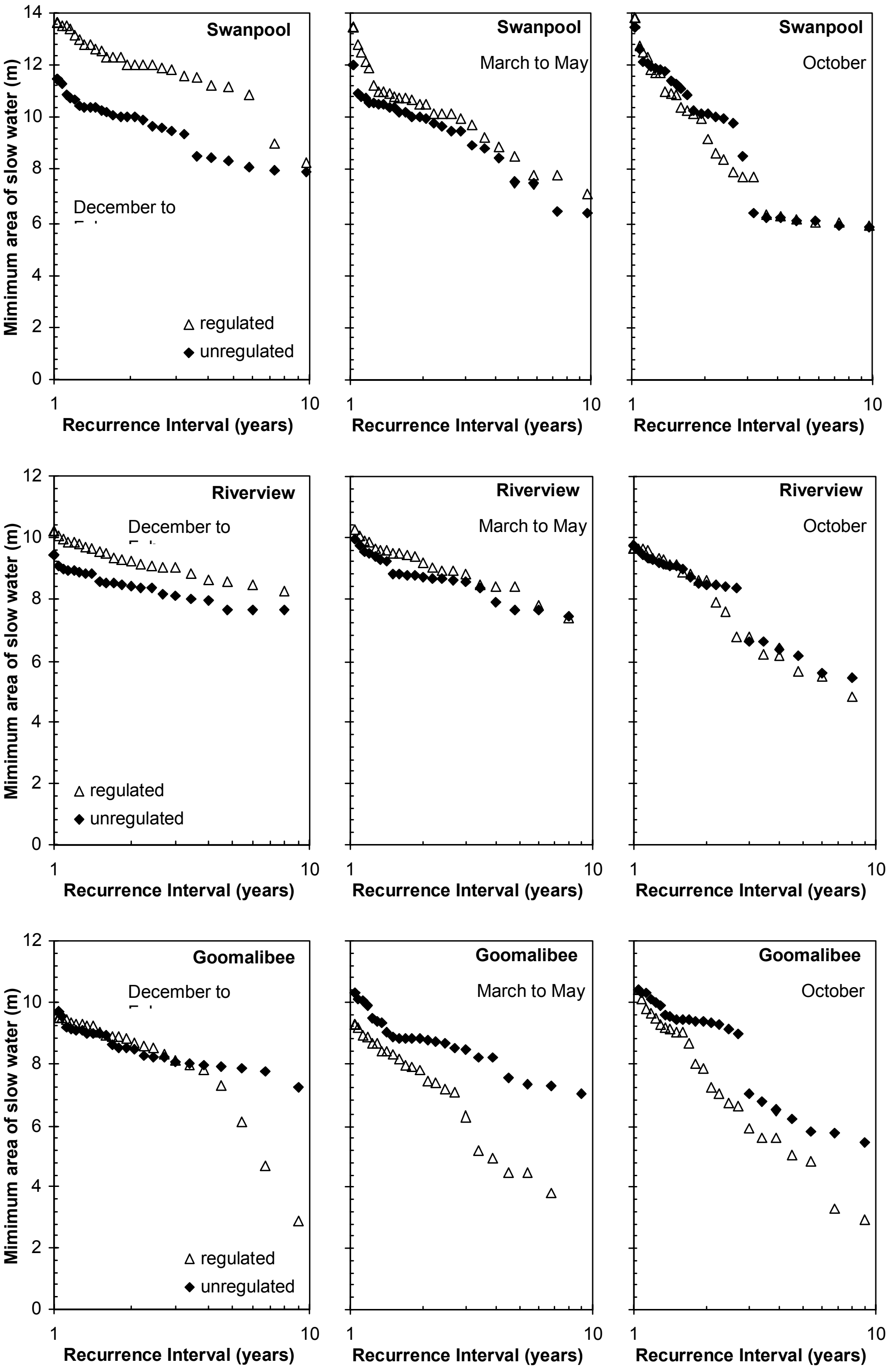

Figure 14: Minimum area of slow water habitat at three reaches of the Broken River with regulated and unregulated flow regimes in three different seasons

7.1.5 Drying of the stream bed

Diversion of water from the river increases the risk of unnatural rates of bed exposure. This will affect biota such as sedentary macroinvertebrates and will risk desiccating macrophytes. The impact of regulation on bed drying events was assessed by examining changes to the minimum wetted width of the channel, particularly in the periods December-May and June-November (Figure 15). Low flow events during which the streambed is exposed have become more frequent as a result of flow regulation. This occurs from June to November in Reach 1 and all year round in reaches 2 and 3.

Regulation has resulted in a decrease of up to 20% in wetted width in Reach 1, downstream of Lake Nillahcootie (Figure 9). However, biological monitoring (section 6.5) indicates that macroinvertebrate communities in Reach 1 are generally in good health. This suggests that a reductions of up to 20% in wetted area poses a low risk to invertebrate fauna in the Broken River, particularly as there is a diversity of habitat in Reaches 2 and 3. The effect on in-stream macrophytes, if any, is uncertain due to poor knowledge of pre-regulation flora.

Regulation has resulted in decreases in minimum bed area in excess of 20% in Reaches 3 during the low-flow period of December-May. Decreases greater than 20% occurred at flows equivalent to a 2-year recurrence interval for the regulated regime. This is equivalent to a minimum wetted perimeter of 13 m and 8.4 m for Reach 2 and Reach 3 respectively, and equates to a flow 22 ML/d and 25 ML/d respectively; these values were adopted as the minimum flow required to protect in-stream habitat for macroinvertebrates.

In recent years, GMW has maintained a minimum flow of 30 ML/d at Moorngag in Reach 1 of the Broken River below Lake Nillahcootie, equivalent to a wetted perimeter of 14.5 m. This minimum flow should be maintained along the river to minimise bed exposure as Lake Nillahcootie fills.

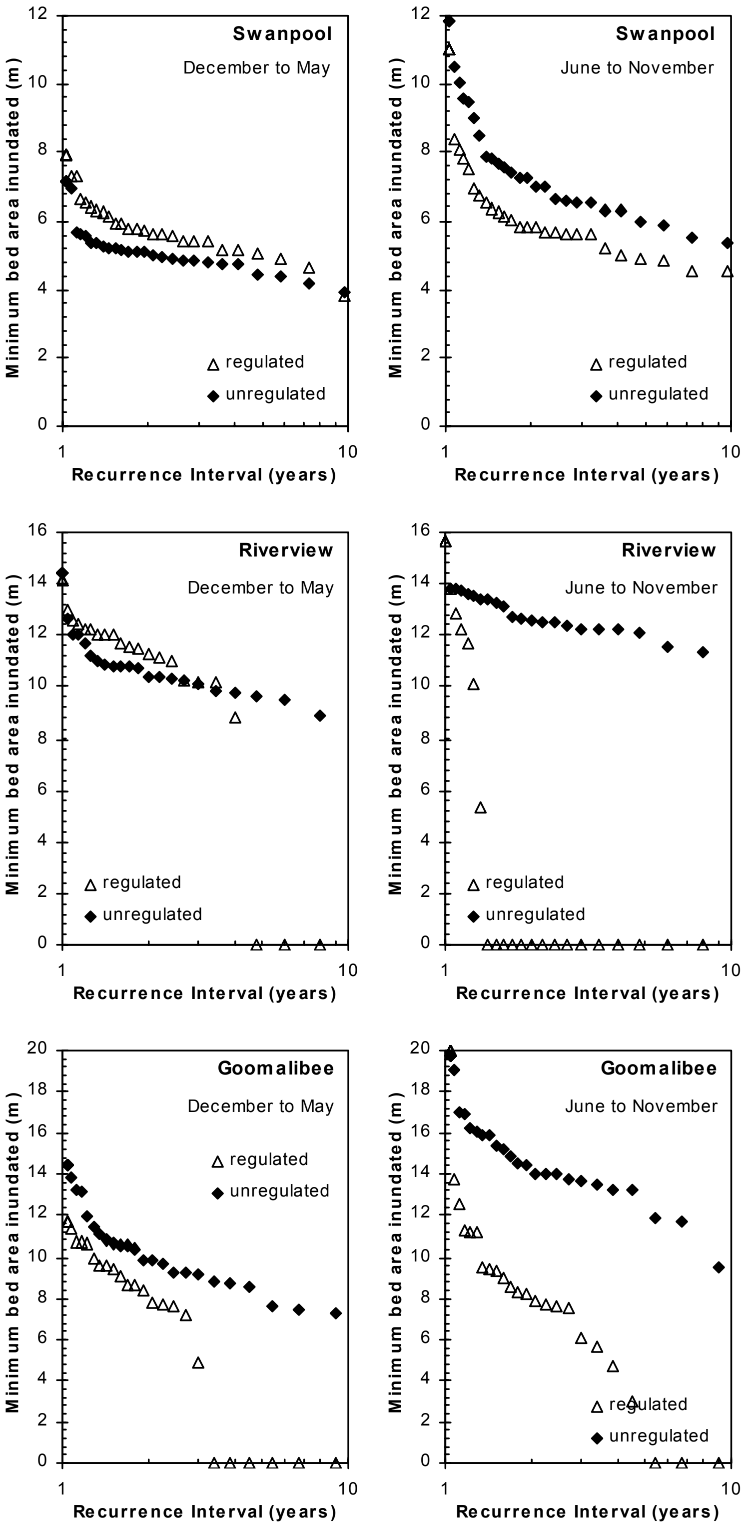

Figure 15: Comparison of streambed exposure events in the 3 reaches of the Broken River

7.1.6 Inundation of channel benches

Changes to the frequency and duration of bench inundation can alter the composition of bank and riparian vegetation, and changes to carbon quality and fluxes. Benches are defined as areas of the channel, with lateral gradient less than 0.1, which are not part of the low flow channel bed.

Higher summer flows with regulation mean that many benches in Reach 1 and Reach 2 are now wet at a time when they would naturally have been dry (Figure 16). This tends to shift the benches from ephemeral to permanently wet, and can affect the mix of aquatic/terrestrial species and increase the risk of weed invasion (e.g. willows). Detritus from the benches is also likely to be swept into the river more frequently than would occur naturally. However, benches in the Broken River form a far smaller proportion of the river and their distribution is far more variable than expected by the scientific panel. This makes quantifying the importance of benches and how they might respond to changes in the flow regime very difficult. The Scientific Panel agreed that no meaningful environmental flow rule could be set for bench inundation at this stage.

7.1.7 Shallow water habitat

Shallow water areas (i.e. with depth < 0.3 m depth) provide growing conditions suitable for the smaller submerged and floating leafed aquatic macrophytes during the warmer months between January and April. This hydrological niche is also likely to favour macroinvertebrates and possibly small fish species.

Changes to the flow regime have seen a substantial loss of habitat area < 0.3 m deep in Reach 1 and Reach 2 (Figure 17), as higher than normal flows are released to supply downstream demand. However, the lack of biological information on aquatic plant species in the Broken River, and the lack of information on the nature and extent of changes to populations since regulation (if any) means that species-targeted environmental flow rules cannot be set at this time. There are potential benefits to be gained from maintaining habitat for aquatic macrophytes (and other biota) and the impact of higher than normal flows on biota is an area requiring further research (see section 7.6). Part of this research should also focus on alternative release strategies to increase the variability of flows in summer/autumn (e.g. pulsed release of water for downstream users or supplementary flows for the Murray River).

Indicative flows required to maintain between 75% and 85% of the ‘natural’ area of < 0.3 m habitat at Swanpool (varying levels that might represent a low risk) require flow maximums of between 120 ML/d and 110 ML/d, respectively. It was acknowledged that flow maxima of this order would have significant impacts on security of supply for downstream diverters.

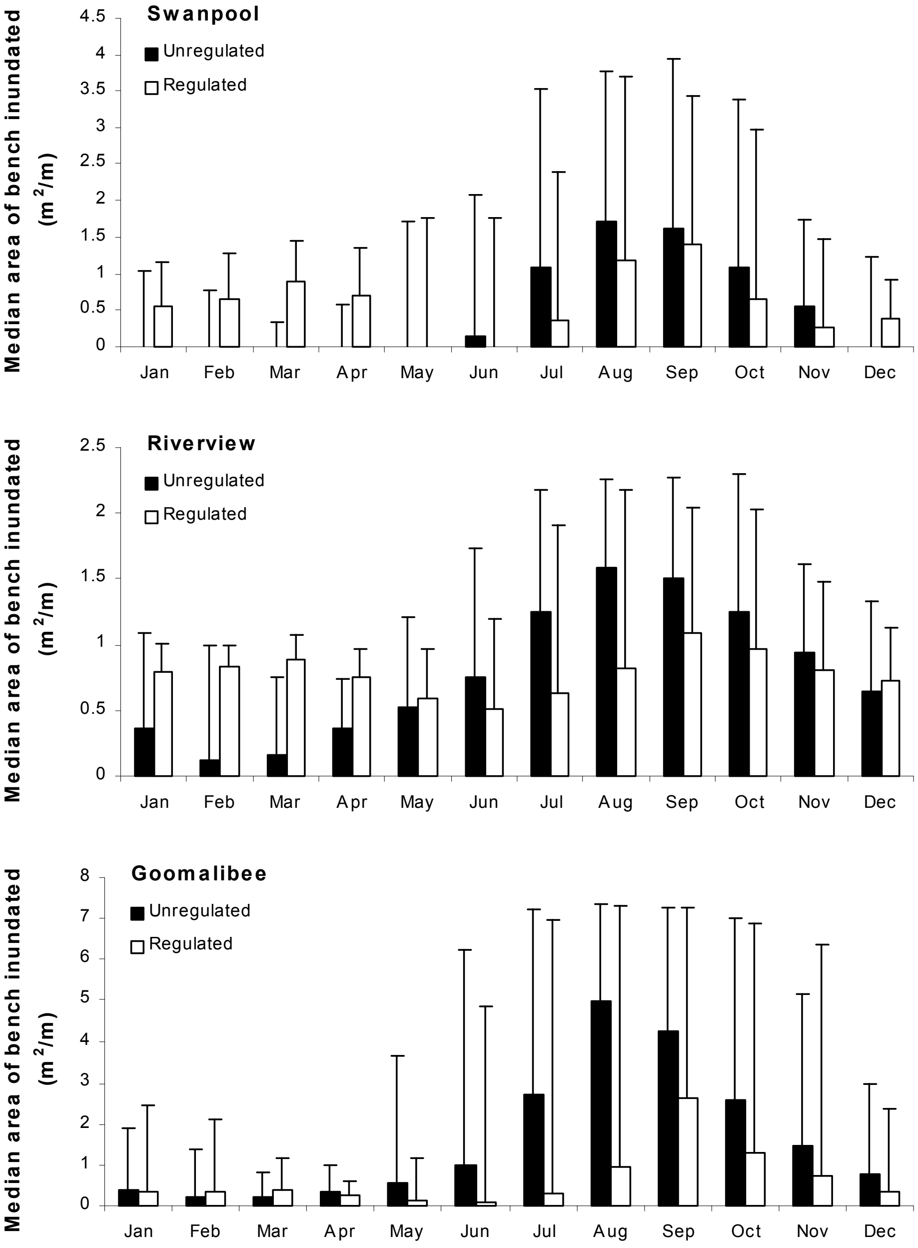

Figure 16: **Median (bar) and 90th percentile (error bar) of area of bench inundated for Reach 1 (Swanpool), Reach 2 (Riverview) and Reach 3 (Goomalibee)**

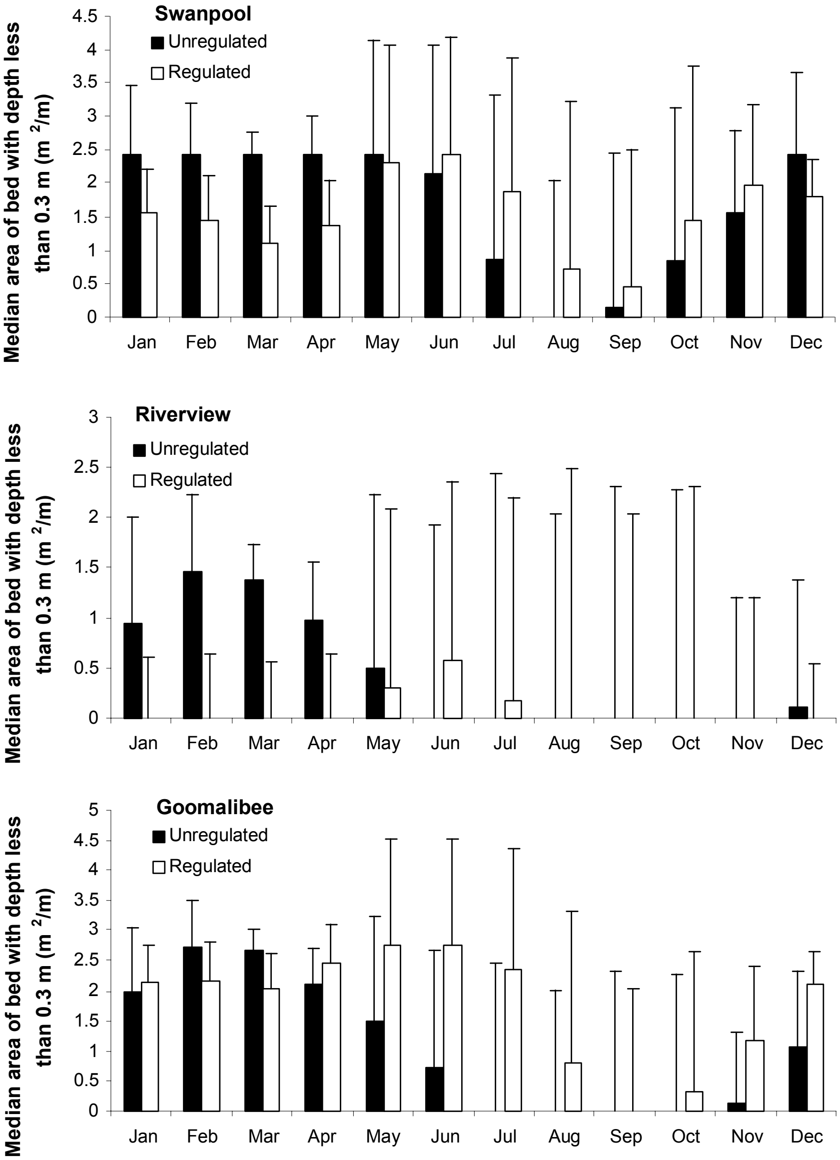

Figure 17: Comparison of median monthly shallow water habitat in Reach 1 (Swanpool), Reach 2 (Riverview) and Reach 3 (Goomalibee). Bars indicate 10th percentile values.

7.1.8 Flow into anabranches and floodplain inundation

Anabranches depart and re-enter the Broken River at numerous points. For example, there are four anabranches located along the lower Broken River (Reach 3). However, flow in excess of 1100 ML/d is generally required for water to enter the anabranches. The frequency and duration of events of this magnitude are unaffected by regulation and no environmental flow target is required.

Similarly, the flows required to reach the floodplain have not been affected by regulation (section 5) and no environmental flow target is required.

7.2 Summary of flow recommendations

The following flow rules are recommended to protect or enhance the current environmental values associated with the Broken River. Given that existing knowledge of the ecology of the Broken River is limited, these recommendations should also be considered as part of an adaptive management experiment, where the delivery of flows and any ecological responses are monitored and assessed. This will lead to the optimisation of environmental flow releases in the future.

The recommendations mostly focus on minimum flows and rates of rise and fall in the flow regime. The Scientific Panel recognises the potential ecological impact of higher than normal summer flows down the Broken River (e.g. section 7.1.7 and 7.6), but felt there was insufficient information upon which to base maximum flow recommendations at this stage. The potential geomorphological and ecological effects of higher summer flows is an area requiring additional research.

Broken River from Lake Nillahcootie to Broken Weir:

- Maintain minimum winter flow of 30 ML/d or natural at Moorngag while Lake Nillahcootie fills or water is transferred to Lake Mokoan. This flow is to pass along the remainder of the reach and over Broken Wier;
- Apply a flow reduction target of $Q_2 > 0.65Q_1$[4] when reducing regulated releases (e.g. when reducing flows from Lake Nillahcootie when filling the dam);
- Apply a rule of $Q_2 < 2.1Q_1$ when increasing regulated releases from Lake Nillahcootie.

Broken River from Broken Weir to Casey's Weir:

- Maintain summer flow above a minimum of 22 ML/d or natural. This will be sufficient to maintain slow water habitat for juvenile fish also (20 ML/d). Compliance should be measured at Broken Weir and include the 22 ML/d (or natural) and additional flow to meet diversion needs along the reach;
- Apply flow reduction target of $Q_2 > 0.7Q_1$ when adjusting flows (e.g. when diverting to Lake Mokoan; when reducing flows during the irrigation season).
- Apply a rule of $Q_2 < 1.5Q_1$ when increasing regulated releases.

Broken River from Casey's Weir to the Goulburn River:

- Maintain flow above a minimum of 25 ML/d or natural downstream of Casey's Weir. This will be sufficient to maintain slow water habitat for juvenile fish also (20 ML/d). Compliance should be measured at Gowangardie Weir and include the 25 ML/d (or natural) plus flows to meet diversion demands downstream of Gowangardie Weir;
- Apply flow reduction target of $Q_2 > 0.55Q_1$ when adjusting flows (e.g. when diverting to Lake Mokoan; when reducing flows at the end of the irrigation season).
- Apply a rule of $Q_2 < 1.8Q_1$ when increasing regulated releases.

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[4] (Q_2 = flow on day 2, Q_1 = flow on day 1)

It is also recommended that the current practice of maintaining flow above a minimum of 12 ML/d or natural in Holland's Creek downstream of Holland's Weir continue when Lake Mokoan is being filled.

7.2.1 Hypotheses linking flow recommendations to measurable outcomes

The implementation of an environmental flow program should be conducted as part of an adaptive management experiment, where recommendations are linked to specific hypotheses that are tested and evaluated. The results can then be used to inform the management of the system in the future. Potential hypotheses to consider as part of an adaptive management program for the Broken River are presented in Table 14.

Table 14: Potential hypotheses to be considered under an adaptive management framework

Flow Issue	Hypotheses	Action	Outcome	Monitoring
Increased rate of bed exposure	• Faster than natural rates of bed exposure decrease macroinvertebrate abundance and reduce AUSRIVAS O/E scores. • Faster than natural rates of flow reduction cause fish to be isolated from the main channel	• Rate of fall in river flows in accordance with flow reduction rules.	• Rate of bed exposure within natural range • Macroinvertebrate abundance not significantly increased from pre-drawdown conditions. • AUSRIVAS scores maintained or increased from current levels. • Orderly retreat of fish in the main channel as flow recedes.	• Continuous flow monitoring to ensure compliance with flow reduction rules • Macroinvertebrate populations twice annually (riffle and edge) • Fish populations in pools. • Visual observation of stream during discharge reduction
Increased rate of discharge	• Faster than natural rates of increased flow will reduce larval and juvenile fish survival due to loss of appropriate habitats • Faster than natural increases in flow result in uncompensated drift in microfauna from riffle and slow-flow areas • Faster than natural increases in flow scour biofilms from hard surfaces in the river channel	• Restrict increase in dam releases in accordance with flow increase rules	• Loss of larval and juvenile fish due to rapid increases in flow reduced • Reduced loss of microfauna • Reduced rate of scour of biofilm	• Larval/juvenile fish using traps and nets immediately before and 3 days after large increases in flow. • Microfauna associated with riffles and backwaters before and during rapid increases in flow. • Biofilm on rocks before and during rapid flow increases
Loss of slow water habitat	• A reduction in areas with slow-water velocity reduces the refuge and rearing habitat, particularly for young stages of fish	• Maintain greater than 80% of natural slow water habitat (< 0.05 m/s)	• Refuge and rearing habitat for native fish increased	• Water velocity • Confirmation of modelled slow water habitat
Higher than natural summer flows	• Higher than natural summer flows result in a shift in vegetation on benches from stress-tolerant to competitive invading species • Higher summer flows change the bed environment from an opportunity for summer-growing annual/perennial herbaceous forms and short benthic submerged macrophytes, to one that is too challenging for these weakly-growing and non-robust species. This restricts their abundance and range.	• Manage summer flows to prevent constant saturation of channel benches • Manage summer flows to provide increased shallow, slow water habitat	• Increased proportion of stress-intolerant species rather channel vegetation comprised of than competitors that require water during the growing season (e.g. willows) • Increased abundance and range of summer growing annual and perrenial herbs and submerged macrophytes	• Floristic and structure of aquatic and riparian vegetation

~~6.1~~7.3 Implications of changes to the operation of Lake Mokoan

The Scientific Panel was asked to consider the impact on the Broken River system of the future management of Lake Mokoan. The management options considered were:

- Existing management of Lake Mokoan continues according to current levels of demand, current diversion and release patterns, and the reservoir being closed in summer-autumn months for 9 years in 10 (the basis of previous discussion on environmental values and environmental flows);
- Decommissioning the reservoir, where Lake Mokoan is no longer used as a supply of irrigation water and there are no diversions to, or releases from the reservoir to meet downstream demand;
- Unconstrained operation of the reservoir, where diversions to, and releases from the reservoir are unconstrained by water quality and algal bloom problems, the reservoir remains open all year round and there is a full uptake of existing licenses.

The implications of the existing management of Lake Mokoan have been discussed in previous chapters. The impact of the decommissioning and unconstrained development scenarios on the representative reaches of the Broken River, and on the Murray and Goulburn Rivers is considered in this section.

There are no formal plans to decommission Lake Mokoan as an irrigation supply. Any decommissioning scenario would necessarily include the removal or modification of the dam wall to eliminate the risk of future failure and flooding. How the site currently occupied by the reservoir would be managed under some future decommissioning scenario is unclear, although a number of options would be available (e.g. management of the area as a recreational lake, return to the flow regime of Winton Swamp). No assumptions were made on the future management of the Lake Mokoan site for this assessment, other than that decommissioning would result in a cessation of diversions from the Broken River and Holland's Creek and a cessation of water released from the reservoir to meet downstream demand.

The unconstrained use of Lake Mokoan assumes that current water quality and algal blooms problems in the reservoir are overcome, that there are no constraints on storage levels in the reservoir and that diversions into and out of the reservoir occur when required in all years. This scenario also assumes full uptake of existing diversion and irrigation licenses.

Water savings associated with the decommissioning scenario are assumed to provide major environmental benefits, although it is recognised that delivery of these environmental benefits depends on how the water savings are delivered across the system and, to some extent, the use to which the lake is put. The following discussion assumes that water savings will lead to environmental benefits and that the unconstrained development scenario forgoes this benefit. Assessments are based on modelled median monthly flows provided by DNRE from the REALM model of the Broken River system (see section 5.3, Figure 8). The benefits and disbenefits associated with each scenario are summarised in Table 15. Assessment has been made on the basis of the level of deviation from natural represented by each of the management scenarios. Such an approach assumes that moving to more natural hydrology will result in more natural environmental conditions and ecological processes. However, whether such perceived ecological benefits actually arise with the implementation of any of the scenarios will depend on many factors, such as habitat quality, successional patterns, competition and opportunities for migration, amongst many others. Predicting the order and final outcome in terms of ecological response to any of the management scenarios is extremely difficult, and requires more detailed consideration than that afforded to the Scientific Panel in this project.

Table 15: Summary of benefits associated with decommissioning and unconstrained development scenarios

	Reach 1	Reach 2	Reach 3
Decommissioning Scenario			
Benefits			
Water savings	✔	✔	✔
Autumn flows closer to natural than existing management (although still high)	✔		
Autumn low flows closer to natural than existing management or unconstrained development		✔	
Autumn-winter-spring pattern similar to natural (although reduced)			✔
Improved annual flow variability (better than both existing regime and unconstrained development)		✔	✔
The timing of winter flow peaks returns to natural		✔	
Better water quality with absence of Lake Mokoan water			✔
Disbenefits (costs)			
Higher and more extensive summer flows (4 months cf 3 months currently)	✔		
Seasonal flow inversion maintained or extended (4 months rather than 3)	✔		
Higher than natural summer and early autumn flows (although the same or better than the existing situation for late summer and early autumn)		✔	
Higher summer flows than natural (but similar to existing regime)			✔
Unconstrained Development Scenario			
Benefits			
Summer flows close to natural	✔		
Peak flows in winter/spring (offset from natural by one month)	✔		
Reduction in winter flows less than existing regime	✔		
Summer-autumn flows similar to natural (although flows would be less than natural in some months)		✔	
Disbenefits (costs)			
Foregone water savings	✔	✔	✔
Spike in autumn flows (April) when flow is naturally low	✔		
Reduced annual flow variability, especially when compared with the decommissioning scenario		✔	
Peak flows in spring rather than winter		✔	
Very large loss of winter flows (but similar to existing situation)		✔	
Slightly higher summer flows than current			✔
Reduced annual flow variability			✔
Very low winter flows			✔
Peak flows shifted from winter to spring			✔

The potential impact of each scenario varies from reach to reach and season to season. Based on deviation from natural, the existing flow regime would appear to pose the highest risk to environmental values of the three scenarios being considered. Given that the general condition of the Broken River is good (although there are many opportunities for improvement), then changes that might be expected with the adoption of either of the alternative scenarios are likely to be incremental, rather than some large step change.

The unconstrained development scenario appears likely to pose less risk to existing environmental conditions in the Broken River between Lake Nillahcootie and Broken Weir

(Reach 1) than the decommissioning scenario. Conversely, the decommissioning scenario appears likely to pose less risk to environmental values in the Broken River below Casey's Weir (Reach 3) than the unconstrained development scenario. The scenario best suited to the Broken River between Broken Weir and Casey's Weir (Reach 2) is less clear.

If the future management of Lake Mokoan were considered as a rehabilitation project, then highest priority would go to the protection of the reach with the highest existing environmental values (protect the best first) (Rutherfurd *et al*. 2000). The next highest priority should go to protecting the next best reach or developing links between reaches of high value. Reaches 2 and 3 have been identified as having the best environmental values of the 3 reaches in the study area. Thus the assessment of the two Lake Mokoan scenarios should be based in the first instance on protecting or enhancing Reach 2 and Reach 3.

As the decommissioning scenario has already been identified as best suited to Reach 3, what then is the best scenario for Reach 2 and its linkages with Reach 3? The unconstrained development scenario for Reach 2 has the benefit of summer-autumn flows being similar to natural (care would be needed to ensure minimum flows are delivered but this should not be insurmountable). While the decommissioning scenario keeps summer flows higher than natural (although similar to current levels), it has the benefit of autumn-winter-spring patterns being closer to natural, the timing of flow peaks being the same as natural and annual flow variability that is much closer to natural than the unconstrained development scenario. The question then becomes "Is the more natural summer-autumn flows achieved with the unconstrained development scenario more important ecologically to Reach 2 (or the Broken River as a whole) than the improved flow variability and natural autumn-winter-spring pattern achieved with decommissioning?" Another way to look at it might be "Is the loss of winter flows, the shift to peak flows in spring and relatively low flow variability associated with the unconstrained development scenario likely to be more detrimental to the ecology of the Broken River than the high summer flows associated with decommissioning?"

On balance, the Scientific Panel supports the decommissioning scenario for Reach 2 (and Reach 3) as it poses less risk to the Broken River system than the unconstrained development scenario. The reasons for this include:

- The lower Broken River is an example of a lowland river that generally is in good health. This is a relatively rare thing and considered to be of greater ecological value than the upper reach of the Broken River, which is a foothill stream of moderate to good condition.
- Reach 3 is more likely to support an abundant and diverse range of native fish species than is Reach 1, including Murray cod, trout cod, golden perch and blackfish. Any move to enhance native fish populations in this reach would be valuable. Reach 3 is also much longer than Reach 2 and is closest to the Goulburn and Murray Rivers. Most fish movement from these rivers will occur along Reach 3.
- Relatively little is known about the ecology of the river upstream of Benalla. At this stage, priority should go to those reaches known to have a high conservation value.
- The decommissioning scenario also poses fewer risks to the health of the Goulburn and Murray Rivers, as the largely natural winter/spring flows resulting from this scenario is complementary to the natural flow regime of these rivers.

The potential risks to Reach 1 of the Broken River may be reduced by evaluating different flow delivery scenarios to the Goulburn and Murray Rivers. For example, flow may be delivered in pulses rather than as constant flows. The delivery of water in an ecologically sensitive fashion with the decommissioning of Lake Mokoan requires further evaluation.

The Scientific Panel acknowledges that the decommissioning scenario has significant socio-economic implications for local stakeholders and the community. However, socio-economic implications were were beyond the scope of this project and an Environmental Impact Study is recommended to consider future management options for the lake if decomissioning is considered as a viable option.

~~6.1~~7.4 Management of Broken Creek

7.4.1 Proposed Tungamah pipeline

The Casey's Weir and Major Creek Waterworks District provides water for stock and domestic supply. The existing system involves the Broken River and Broken (particularly between Waggarandall Weir and Katamatite), Major, Back and Boosey Creeks over an area of approximately 1,140 km^2 (AWT 2001). Water is supplied via earthen channels constructed on drainage pathways.

It is proposed that this system be replaced with a reticulated pipeline system. In addition to water savings, the environmental benefits associated with installation of the pipeline are expected to include:

- Potential reduction in any unnatural overflows to wetlands such as Moodies Swamp and Lake Rowan;
- Changes to geomorphic processes and increased habitat diversity in the long term;
- Increased native vegetation both in the creek channel and in the riparian zone;
- Conditions less favourable to weeds species such as willows and Typha.

The installation of a pipeline will alter the current flow regime in the Broken Creek between Casey's Weir and Katamatite, particularly below Flynns Weir. It would be desirable to attempt to restore a degree of ephemerality to the Broken Creek, as this was its state prior to regulation. Ephemeral water bodies are known to be highly productive and periodic inundation may provide cues for movement and, perhaps, spawning of native fish in Broken Creek and through it into the Broken River. However, given the relatively poor water quality in the creek (high turbidity, high suspended sediment, high nutrient levels), it is uncertain what the effects of a return to ephemerality on water quality and instream values will be. Thus, it must be recognised that there is a risk that managing this reach as an ephemeral stream may exacerbate the impacts of surrounding land use.

It is recommended that a performance management plan be developed for the creek in the event that the pipeline is constructed (i.e. returning ephemerality to the creek should be conducted as an adaptive management experiment). The development of such a plan is also consistent with the recommendations of AWT (2001). This plan should include monitoring of the responses of water quality, native fish and invertebrates, and pest fish and plants. Flexibility for delivering water will be required during this process so that additional releases can be made in the event that water quality/habitat problems arise. The performance management plan should also contain provision to reinstate flows to the creek should the increase in ephemerality fail to deliver ecological benefits.

Recovery of the creek system may only become apparent after many years, especially as the pipeline is likely to increase the variability of flow in the creek between Casey's Weir and

Katamatite; realisation of the benefits of the altered flow regime will require a long term commitment.

Broken Creek downstream of Katamatite has significant problems caused by an altered flow regime, poor water quality and degraded in-stream habitat. Efforts made to improve water quality and habitat are likely to have greater effects on improving conditions for invertebrates than alterations to the current flow regime.

7.4.2 Management Recommendations

The following management recommendations are intended to complement the goals and objectives already articulated by initiatives such as the Goulburn Broken CMA's river health strategy and management plans already identified for the Broken Creek (SKM 1998, AWT 2001).

- Develop clear rehabilitation objectives for Broken Creek. Given that the current condition of instream values in Broken Creek is poor, rehabilitation should be directed towards maximising/improving landscape values.
- Return the Broken Creek to an ephemeral stream between Waggarandall Weir and Katamatite. Potential benefits include extending the range of native fish, control of carp and the management of willows.
- Control stock access to Broken Creek
- Revegetate stream with native (indigenous) species
- Support the move to include high value riparian areas in proposed State park
- Develop carp control strategy to complement the carp control plan for Barmah
- Continue willow removal program
- Continue the fish passage/ weir removal program after reviewing weir pools with apparent good environmental values
- Continue and possibly increase the rate of investment in water quality and river health initiatives in line with the Goulburn Broken CMA's waterway health program and water quality strategy;
- Review the benefits of weir draw down trials being conducted elsewhere in the Murray Darling Basin;
- Support the call for monitoring the effects of management actions (ISC, WQ, length of stream fenced of and revegetated, increased native fish populations etc.). If moves to return intermittency of flow to the stream are acted upon, then monitoring ecological responses will be critical.
- Develop and implement a pest and fire management plans to complement rehabilitation plans
- Cessation of any further channelisation works. If in-stream works such as sediment removal are carried out (e.g. from weir pools), care must be taken to minimise sediment input and transport in the stream as current levels of suspended particulate matter are unacceptably high.
- Ban of removal of wood from the riparian zone.
- Closely monitor ecological responses to the changed flow regime that accompanies installation of the Tungemah pipeline.

7.5 Other Management Recommendations

The environmental condition of the Broken River system can be improved by actions that complement the environmental flow recommendations. These include habitat rehabilitation works, implementation of existing catchment management and water quality strategies and the provision of fish passage past in-stream barriers. The ongoing maintenance or improvement to environmental conditions in the Broken River system will be bolstered by:

- Continued efforts to reduce nutrients, sediment and turbidity in releases from Lake Nillahcootie and Lake Mokoan;
- Rehabilitation of native vegetation in the riparian zone of Reach 1 and Reach 2;
- Prevent further small weir building within the main channel
- Evaluation of the potential to replace in-stream habitat such as snags in areas previously cleared by ‘river improvement’ works;
- Investigating the significance of slugs of sand to altered habitat diversity (Reaches 2 and 3)
- Limiting livestock access to waterways;
- Implementing pest control strategies, for example for carp;
- Continue the program of providing fish passage past barriers such as weirs. Priority should go to Gowangardie Weir, Casey’s Weir and Broken Weir on the Broken River, Holland’s Weir on Holland’s Creek, and continuation of the fish passage program on Broken Creek;
- Ensure proper maintenance of existing fishways;
- Encouraging responsible recreational fishing for native species.

7.6 Key knowledge gaps

High summer flows

The regulation of flows from Lake Nillahcootie has resulted in higher than natural summer/autumn flows in the Broken River below the dam. This poses a number of potential threats to the ecosystem of the river:

- More constant water levels that favour invasive species such as willows and carp;
- Potential cold water releases that affect the biology of riverine biota;
- Change in macroinvertebrate abundance and species composition;
- Increased potential for washout of larval and juvenile fish;
- Less habitat for submerged aquatic macrophytes and, as a consequence, less habitat for macroinvertebrates and small fish;
- Increased sediment movement that disrupts biofilms and microphytobenthos that are a potential source of food for other biota;
- Increased bank erosion due to increased saturation of the bed and banks.

However, there was insufficient information available to assess how the higher than natural summer flows may have impacted on biological and ecological processes in the Broken River, if at all. Although acknowledging the higher summer flows as a potential threat, the Scientific Panel felt that it could not make environmental flow recommendations at this stage. This would require important information, such as the macrophyte species and their distribution prior to regulation of the river system, which could serve as the basis of quantifying flow recommendations. The ecological effects of higher than natural summer/autumn flows is an area requiring further investigation. Factors to consider when investigating the impact of higher than natural summer flows in the Broken River between Lake Nillahcootie and Broken Weir include:

- Cold water releases from Lake Nillahcootie that may affect the biology of riverine biota
- Presence and distribution of submerged and emergent aquatic macrophytes;
- Presence and distribution of riparian vegetation, particularly invasive species such as willows;
- Distribution of channel benches and their relative proportion in terms of total in-channel habitat;
- Sediment initiation of movement;
- Biofilms and microphytobenthos;
- Rates of gross primary production and community respiration;
- Macroinvertebrate abundance and community composition and changes from reference condition;
- Fish abundance and community composition; and
- Fish habitat and how it s afected by changes to the fow regime.

Monitoring and evaluation
An important consideration for the implementation of any or all of the initiatives listed in sections 7.1 to 7.5 will be the establishment of a performance monitoring and assessment program. This will ensure that environmental values are protected and allow assessment of the response of the river system to future management actions (e.g. riparian rehabilitation, additional winter diversion should this occur). While important components of the river system are already monitored (e.g. hydrology, water quality), there is no routine monitoring for components such as geomorphological changes, fish, macroinvertebrate and aquatic or riparian vegetation communities. A number of factor to consider when developing a monitoring program are listed in Table 14, along with the hypotheses that underpin the environmental flow recommendations of the Scientific Panel.

Responsibility for undertaking the various management actions and for assessing their effect will require negotiation between stakeholders such as the GBCMA, DNRE, GMW, EPA and local communities.

Groundtruthing of the hydraulic model
Hydraulic modelling was a valuable tool that was used by the Scientific Panel when determining environmental flows for the Broken River. An investigation of the hydraulic characteristics of the river under different flows scenarios (e.g. very low flow or flows common when water is released to support summer irrigation) can provide useful information for optimising the hydraulic model and refining environmental flow recommendations in the future.

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APPENDIX 1 EXPERIENCE OF THE BROKEN SCIENTIFIC PANEL

The Scientific Panel established for this project is listed in Table 17. The team combines expertise in:

- Hydrology and geomorphology;
- Macroinvertebrate community ecology;
- Fish biology and ecology;
- Macrophyte, riparian and wetland ecology;
- Water quality; and
- River operations.

Table 16: Broken Scientific Panel

	Organisation
Terry Hillman	CRC for Freshwater Ecology (Chairperson)
Paul Humphries	CRC for Freshwater Ecology
Leon Metzeling	Environment Protection Authority
Mike Stewardson	Melbourne University
Graham Hannan	Goulburn Murray Water
Jane Roberts	Jane Roberts & Associates
Peter Cottingham	CRC for Freshwater Ecology (Project Manager)

Dr Terry Hilllman chaired the Scientific Panel and lead it through its deliberations. The Scientific Panel will was supported by Peter Cottingham, who served as Project Manager to coordinate Panel activities and liaise with DNRE and the Bulk Water Project Group. A brief description of the experience and skills of the Scientific Panel is presented below.

Dr Terry Hillman is the Director of the Murray Darling Freshwater Research Centre and Deputy Director of the CRC for Freshwater Ecology, in which he has also been leader of the Floodplain and Wetland Ecology program. Terry has over 35 years experience as a researcher providing advice on the management of inland waters, especially floodplain wetlands. Investigations of wetlands on the lower Broken River have formed a key part of Terry's research on river-floodplain interactions. Terry's many activities include serving on subcommittees related to water quality and biological monitoring for the Murray Darling Basin Commission, as a member of an expert panel examining ecological responses to flow management along the River Murray, as a Board Member of the North-East Catchment Management Authority, and as Chair of the Scientific Expert Panel on ecological flows for the Barling-Darling River. Together with John Whittington, Terry authored the CRCFE report' Sustainable Rivers: The Cap and Environmental Flows' as a communication document explaining the importance of the Cap in maintaining river health in the Murray Darling Basin. Terry has recently secured funding for rehabilitation work in the Kiewa River catchment through the Natural Heritage Trust.

Leon Metzeling is a Senior Ecologist in the Catchment and Marine Studies group of the Victorian Environment Protection Authority. Leon is also a research scientist in the Cooperative Research Centre for Freshwater Ecology, working on projects related to long-term variability of benthic invertebrate communities, statewide monitoring using AUSRIVAS, and the taxonomic resolution required for monitoring purposes water quality and river health. Leon's EPA activities have included investigations of salinity, fish farming, metal contamination of lakes and streams, biological monitoring and urban lake ecology. He has also prepared expert witness statements for prosecutions and advice on policy issues. Leon has played a leading role in monitoring the health of rivers across the Broken catchment as part of statewide initiatives.

Graeme Hannan is the Production Manager at Goulburn Murray Water, which he has represented in a range of state and national forums. Graeme's project work has included flood studies and drainage design projects requiring a significant degree of consultation with the affected public. It has also included water resource evaluation, water quality management, master planning and detailed design of water supply, sewerage and drainage infrastructure for large development projects in Australia, Indonesia, Malaysia and Papua New Guinea. Graeme's previous experience included preparation of master plans and numeric modelling for a variety of flood and drainage studies, and design work for water supply, drainage and wastewater projects. He has international experience in office and project management and in urban infrastructure development for appraisal for multi-lateral funding and recent experience in water resource management, bulk water supply system operations, modelling and business impact analysis of water reform proposals.

Dr Paul Humphries has over 16 years experience as a researcher of freshwater and marine fishes and currently manages the Campaspe River Environmental Flows project on behalf of the CRC for Freshwater Ecology. This project examines the effect of river regulation on the fish and invertebrate populations of the Campaspe River, northern Victoria, and will assist in developing new flow management rules to enhance conditions for riverine biota. The Broken River plays an important part in the project by serving as a reference against which changes in the Campaspe River may be assessed. Paul's previous work has also included environmental flow assessments for the Inland Fisheries Commission, Tasmania, where he used several methods for determining environmental flows, including the Instream Flow Incremental Methodology. Paul has also studied the habitat preference of selected freshwater and marine fish species and has played a major role in promoting the use of fish larvae as a tool for assessing the effectiveness of environmental flows. He has recently conducted a review of the role of flow and floodplains in the biology of Murray-Darling fishes. Paul sits on several steering and advisory committees related to environmental water allocations and riverine ecology.

Dr Jane Roberts is an ecologist, specialising in plants and water regime of riverine and associated aquatic habitats, with 10 years research and practical experience of lowland rivers and wetlands of the Murray-Darling Basin. Her technical knowledge of ecology, growth and life history covers a number of plant species and communities and includes different growth forms, such as woody and non-woody as well as aquatic and semi-terrestrial plant species. This technical knowledge is for rivers, wetlands and floodplains, and covers highly modified and constructed habitats such as regulated rivers, storages, drains, irrigation systems, dams and evaporation basins. She has a good knowledge of key widespread problem or nuisance species within these environments, and has experience in assessing impacts, evaluating controls and working towards minimising ecological or production costs. She believes that understanding the present and working towards the future also requires reaching back into the past, hence her interest in environmental history where she has pioneered the scientific use of 'soft' information such as oral history in relation to a lowland river. Ten years field and regional experience in inland south-eastern Australia has made her familiar with ecological issues resulting from development and use of natural water resources for irrigated agriculture and domestic use. As a research scientist, she has lead and participated in applied scientific research in a range of aspects of water management (river, tailwater, water regime, drainage) and their environmental consequences, often within the context of the Murray-Darling Basin.

Peter Cottingham joined the CRC Freshwater Ecology in a technology transfer and consultant role. Peter has been responsible for preparing major technology exchange strategies and plans for the various CRCFE programs and projects. Peter's position is the first application of the 'knowledge broker' concept developed by the CRCFE to facilitate knowledge exchange between environmental researchers and the end-users of the knowledge generated by the CRCFE. In this role he has also led a number of consulting projects focussed on future investigations and the management of inland water resources, one of which was the *Riverine Management and Rehabilitation Scoping Study* undertaken for the MDBC. Peter was also involved in a CRCFE project that identified interim environmental flows for the Thomson and Macalister Rivers in Gippsland, and in the review of the ecological sustainability of the Cap on diversions in the Murray Darling Basin, and the review of performance monitoring of environmental flows proposed for the Woronora River, NSW. Prior to this, he had accumulated 14 years experience as an environmental consultant and researcher of inland and coastal waters. Peters' research has focused on the effectiveness of using constructed wetlands for the treatment wastewater. In recent years, his work has focussed on the development of catchment based nutrient management strategies and water quality investigations of rivers, lakes and wetlands.

APPENDIX 2 DAILY FLOW AND HYDRAULIC MODELLING

Flow modelling

Daily flow series were constructed for representative reaches in the Broken River under the regulated and unregulated conditions and used to evaluate how regulation has affected the flow regime. The simplest approach would be to use recorded flow series for periods (i) prior to and (ii) since regulation. However, as flow records were not always available for the pre-regulation period and some records had significant gaps, daily flow series were simulated for the same period with and without the effects of regulation. The available data was most complete between 1/7/74 to 30/4/98 (Table 4), so historical flows for this period was chosen as representing the regulated condition.

Table 17: Streamflow data for the upper Broken River

Station	Data Record	Percentage of the record missing
404218 Nillahcootie spillway[1]	Jan-70-Mar-01	3
404220 Nillahcootie outlet[2]	May-68-May-00	0
404206 Moorngag on Broken R[1]	May-57-Sep-00	0
404213 U/S Broken Weir[1]	Jun-72-Dec-74	0
Diversions at Broken Weir[2]	Jul-74-Apr-01	0
404208 Lima on Moonee Cr[1]	May-55-Jun-00	17
Nillahcootie storage leve[1]	Dec-93-Mar-01	0
Nillahcootie storage volume[2]	May-68-Apr-01	50

[1] Data supplied by Thiess Environmental Services
[2] Data supplied by Goulburn-Murray Water

Natural flows at the study site were modelled for the same period using two steps:

a) Modelling inflows to Lake Nillahcootie; and
b) Routing modelled and gauged tributary flows downstream.

The availability of streamflow data for calibrating these models is typical of regulated rivers in south-east Australia, in that records were discontinuous and collected at daily and weekly timesteps, rather than continuously, and it is not common practice to monitor dam inflows. For much of the modelled period, storage levels in Lake Nillahcootie were recorded on a weekly basis, rather than daily. Inflows to Lake Nillahcootie were estimated using a different method for times when the spillway was and was not operating. During times when the dam was full, inflows were calculated from spillway and outlet flows using a reverse routing procedure. At other times, a rainfall runoff model was used to estimate inflows. The reverse routing procedure, used for periods when the spillway was operating, predicted the daily inflow $I(t)$ for day t as:

$$I(t) = Q(h(t)) + A(h(t))\frac{dh(t)}{dt}$$

Where $Q(h(t))$ is the outflow as a function of storage level h, and $A(h)$ is the surface area of the storage. The derivative was approximated using:

$$\frac{dh(t)}{dt} = \frac{h(t+\Delta) - h(t-\Delta)}{2\Delta}$$

Where Δ is the time step, one day in this case. These relations were derived using the reverse routing analysis of Zoppou (1999) applied to Fenton's (1992) reservoir routing equation. The reverse routing procedure was applied to every day that the spillway was operating except days on which spillway flows began or ended. At times when the spillway was not operating, a lumped conceptual model was used to represent reservoir inflows. This model used pan evaporation and rainfall as input and represented changes in storage within the reservoir by accounting for flow releases and evaporative and rainfall fluxes at the reservoir surface. Rainfall and pan evaporation are recorded at a station by the reservoir. The model parameters were calibrated to provide the best fit with observed changes in storage level.

As there is no gauge downstream of Broken Weir, a flow routing model was used to estimate flows between Broken Weir and Casey's Weir for the regulated and unregulated condition. The routing model took the form of a linear transfer function. The flow at the downstream end of the reach on the i^{th} day (Q'_i) was expressed as linear function of the current and last n days flow at the upstream end of the reach ($Q_{,u,i}$). Multiple input flow series ($u = 1$ to p) were used to account for tributary inflows. The routing model can be expressed as

$$Q'_i = \sum_{u=1}^{p} \sum_{j=0}^{n} k_{u,j} Q_{u,i-j}$$

Where $k_{u,j}$ is the transfer function coefficient for the u^{th} inflow series and a lag time of j days. The routing model accounted for ungauged tributary inflows by using coefficients for a particular inflow series that summed to greater than 1.

For the regulated condition, flows recorded at Moorngag on the Broken River and at Lima on Moonee Creek (now called Lima East Creek) were routed to upstream of Broken Weir. Flows below Broken Weir were then estimated by subtracting recorded diversions at the weir from weir inflows estimated using the routing model. The transfer function coefficients were calibrated for this reach using the available flow records at these three sites between June 1972 and December 1974.

To simulate natural flows at the study site, a streamflow record for ungauged tributary inflows between Lake Nillahcootie and Moorngag was generated by subtracting dam releases and spills from flows recorded at Moorngag. Simulated inflows to Lake Nillahcootie were added to this generated flow series to simulate a natural flow series at Moorngag. Routing effects between the dam and Moorngag were ignored because of the relatively short reach length. The calibrated routing model was then used to estimate natural flows at the study site.

Hydraulic Model

The hydraulic characteristics of the three reaches of the Broken River were modelled by Sinclair Knight Merz P/L using HEC-RAS, a one-dimensional gradually varied flow analysis software package produced by the US Army Corps of Engineers (Sinclair Knight Merz, 2001). To obtain a representative sample of conditions at the site, 15 or more evenly spaced (at approximately 60 m intervals) cross-sections were included in the model. Additional cross-sections were added to improve model performance where required. The three sites were surveyed by Goulburn Valley Irrigation Services P/L between May 23 and May 31

2001. Plans showing site features, the longitudinal bed, water surface and bank profiles, and each cross-section for each of the three sites were provided to DNRE . Flows were low at the time of these surveys . The model provided water surface profiles for the reach for a range of discharges, as well as wetted perimeter, surface width and area for each cross-section for a range of discharges.

Representativeness of the modelled flow period

Decadal periods of higher and lower flood magnitude and frequency have been identified in southeast Australian streams (Brizga *et al*., 1993; Erskine and Warner, 1988). Robinson (1993) examined the occurrence of drought and flood dominated sequences in the years between the mid 1940s and the early 1990s in the Ovens River catchment. The period of 1974 to 1998 used to develop daily times series for this study coincided with a period that was flood dominated. Assuming that the pattern of flood and drought dominated sequences recorded in the nearby Ovens catchment was also reflected in the Broken catchment, then we can conclude that the Broken River flow record is highly variable from decade to decade, and that the period of record used for flow modelling was characterised by more frequent flooding than normal. Monthly streamflow was simulated for the Broken River using REALM for the unregulated condition. Analysis of flow duration curves at Moorngag generated using these data show that the daily flow-modelling period is not atypical of the longer record (Figure 21). However, The 80th and higher flow exceedence percentiles have increased slightly indicating higher baseflows in the daily flow-modelling period.

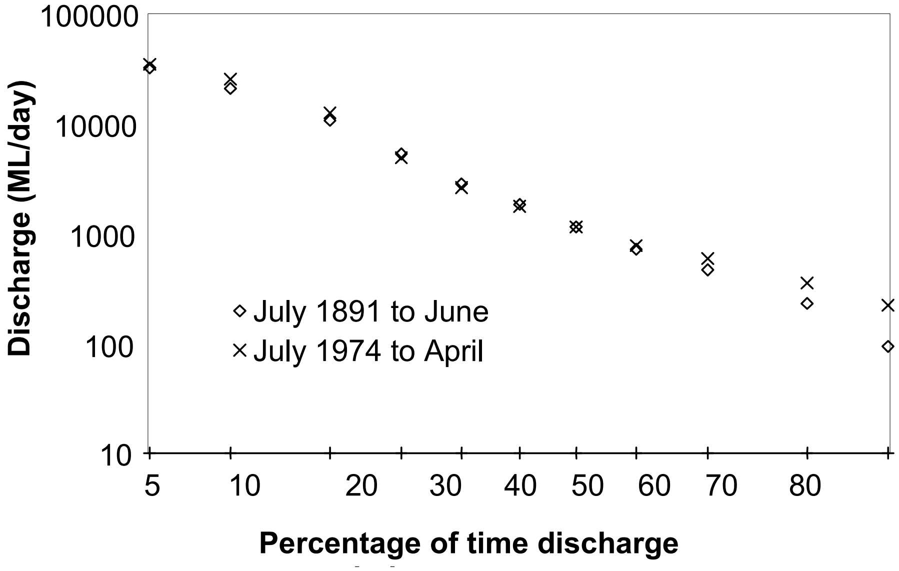


Figure 18: Flow duration curves for monthly data generated by Realm for the unregulated condition at Moorngag. The two data sets are for the periods 1891 to 2000 the period for which REALM data is available, and 1974 to 1998 the period used for daily flow modelling.

APPENDIX 3 WATER QUALITY STATISTICS

Broken River at Moorngag (Site 404206) November 1976 – May 1999

Parameter	**Number of Data**	**Minimum**	**Mean**	**Maximum**	**Standard deviation**	**Percentiles**				
						10	**25**	50	**75**	**90**
Colour (Filt.) (Pt/Co Units)	106	15.00	76.20	160.00	31.21	40.00	52.00	**71.00**	100.00	120.00
Dissolved Oxygen (mg/L)	242	7.00	9.67	13.00	1.29	8.00	9.00	**10.00**	11.00	11.00
Electrical Conductivity (µs/Cm)	258	35.00	116.24	890.00	63.99	77.00	93.00	**110.00**	130.00	140.00
Nitrate and Nitrite (mg/L)	106	0.0080	0.3183	3.0000	0.3729	0.0780	0.1400	**0.2250**	0.3600	0.5400
Reactive Phosphorus (Filt) (mg/L)	106	0.0030	0.0085	0.0350	0.0068	0.0030	0.0040	**0.0060**	0.0090	0.0190
Suspended Solids (mg/L)	106	1.00	8.33	39.00	6.60	4.00	4.00	**6.00**	10.00	15.00
Temperature (°C)	261	4.00	14.72	25.00	4.71	8.00	10.00	**16.00**	18.00	20.00
Total Kjeldahl Nitrogen (mg/L)	106	0.140	0.587	1.200	0.166	0.400	0.500	**0.600**	0.700	0.800
Total Phosphorus (mg/L)	106	0.0200	0.0465	0.1300	0.0166	0.0300	0.0340	**0.0440**	0.0540	0.0670
Turbidity (Field) (NTU)	257	1.00	13.66	71.00	11.64	4.00	6.00	**10.00**	17.00	28.00
pH (Field) (pH)	254	6.00	7.17	9.00	0.65	6.00	7.00	**7.00**	8.00	8.00

Broken River at Goorambat (Site 404216), July 1979 – May 1999

Parameter	Number of Data	Minimum	Mean	Maximum	Standard deviation	Percentiles				
						10	25	50	75	90
Alkalinity (mg/L CaCO3)	31	20.00	34.10	96.00	15.80	23.00	24.00	**31.00**	34.00	45.00
Calcium (mg/L)	31	3.60	5.70	15.00	2.33	3.80	4.10	**5.10**	6.50	7.30
Chloride (mg/L)	31	11.00	22.61	55.00	9.51	14.00	17.00	**19.00**	26.00	39.00
Colour (Filt.) (Pt/Co Units)	106	25.00	95.14	240.00	50.62	42.00	60.00	**80.00**	120.00	180.00
Dissolved Oxygen (Mg/L)	232	4.00	8.47	13.00	1.62	6.00	7.00	**8.00**	10.00	11.00
Electrical Conductivity (Field) (µs/Cm)	243	47.00	156.77	430.00	47.29	110.00	130.00	**150.00**	180.00	210.00
Iron (mg/L)	31	0.49	2.48	4.70	1.00	1.50	1.80	**2.20**	3.20	4.10
Hardness (mg/L)	30	17.00	29.33	69.00	11.31	19.50	22.00	**26.50**	33.00	37.50
Potassium (mg/L)	31	0.90	2.87	6.70	1.31	1.80	2.00	**2.40**	3.40	4.90
Magnesium (mg/L)	31	2.3	3.9	10.0	1.5	2.8	3.1	**3.6**	4.4	4.9
Manganese (mg/L)	31	0.03	0.08	0.30	0.05	0.04	0.05	**0.06**	0.09	0.10
Nitrate and Nitrite (mg/L)	137	0.0220	0.2646	2.3000	0.2485	0.0740	0.1300	**0.2100**	0.3300	0.4500
Sodium (mg/L)	31	9.90	18.90	52.00	8.52	11.00	14.00	**16.00**	22.00	28.00
Reactive Phosphorus (Filt) (mg/L)	106	0.0030	0.0245	0.1400	0.0252	0.0050	0.0080	**0.0145**	0.0350	0.0670
Sulphate (mg/l)	31	1.60	3.58	9.00	1.62	2.10	2.40	**3.10**	4.10	5.30
Suspended Solids (mg/L)	137	9.00	25.39	98.00	14.04	13.00	16.00	**21.00**	31.00	41.00
Silica (mg/L)	31	0.6	11.4	17.0	3.8	6.1	9.6	**12.0**	14.0	16.0
Temperature (°C)	243	6.00	16.49	28.00	5.63	9.00	12.00	**16.00**	22.00	24.00
Total Dissolved Solids (mg/L)	29	85.00	124.97	240.00	34.71	91.00	100.00	**120.00**	140.00	180.00
Total Kjeldahl Nitrogen (mg/L)	137	0.100	0.783	2.200	0.359	0.480	0.510	**0.690**	0.910	1.300
Total Organic Carbon (mg/L)	29	3.0	9.4	20.0	4.3	5.0	6.0	**9.0**	12.0	17.0
Total Phosphorus (mg/L)	136	0.0320	0.1023	0.2600	0.0514	0.0480	0.0635	**0.0905**	0.1300	0.1800
Turbidity (Field) (NTU)	241	2.00	32.53	130.00	26.61	9.00	15.00	**23.00**	40.00	76.00
Colour (Pt/Co)	31	20.00	81.77	180.00	39.59	50.00	60.00	**70.00**	100.00	160.00
pH (Field) (pH)	237	6.00	7.06	9.00	0.65	6.00	7.00	**7.00**	7.00	8.00

Broken River at Gowangardie (Site 404224), August 1993 – Jun 1999

Parameter	Number of Data	Minimum	Mean	Maximum	Standard deviation	Percentiles				
						10	25	50	75	90
COLOUR (FILT.) (Pt/Co Units)	67	20.00	107.36	250.00	56.86	45.00	60.00	**95.00**	140.00	200.00
DISSOLVED OXYGEN (mg/L)	70	6.00	8.67	12.00	1.45	7.00	7.00	**9.00**	10.00	10.00
ELECTRICAL CONDUCTIVITY (FIELD) (uS/cm)	71	66.00	217.11	2100.00	232.76	130.00	160.00	**180.00**	230.00	260.00
NITRATES AND NITRITES (mg/l)	67	0.0030	0.1899	0.6000	0.1422	0.0230	0.0480	**0.1900**	0.2500	0.4100
REACT. PHOSPHORUS (FILT) (mg/l)	67	0.0030	0.0143	0.0410	0.0093	0.0040	0.0060	**0.0110**	0.0210	0.0290
SUSPENDED SOLIDS (mg/l)	67	7.00	28.16	170.00	23.89	11.00	16.00	**20.00**	31.00	55.00
TEMPERATURE (°C)	71	6.00	15.66	26.00	5.84	8.00	10.00	**16.00**	21.00	24.00
TOTAL KJELDAHL NITROGEN (mg/l)	67	0.300	0.722	1.700	0.308	0.400	0.500	**0.630**	0.910	1.100
TOTAL PHOSPHORUS (mg/l)	67	0.0370	0.1031	0.2100	0.0466	0.0550	0.0670	**0.0900**	0.1300	0.1800
TURBIDITY (FIELD) (NTU)	71	8.00	45.59	130.00	29.90	15.00	21.00	**40.00**	61.00	85.00
pH (FIELD) (pH)	71	5.00	6.82	7.00	0.42	6.00	7.00	**7.00**	7.00	7.00

Broken River at Orrvale (Site 404222), January 1991 – July 1993

Parameter	Number of Data	Minimum	Mean	Maximum	Standard deviation	Percentiles				
						10	25	50	75	90
Dissolved Oxygen (mg/L)	32	7.00	9.50	11.00	1.24	8.00	8.50	**10.00**	10.50	11.00
Electrical Conductivity (Field) (µs/cm)	32	82.00	201.00	320.00	56.96	140.00	160.00	**190.00**	230.00	280.00
Temperature (°C)	32	8.00	16.00	25.00	5.49	9.00	10.00	**16.50**	20.50	23.00
Turbidity (Field) (NTU)	32	8.00	45.22	120.00	33.99	12.00	17.50	**26.50**	79.00	97.00
pH (Field) (pH units)	30	6.00	7.00	8.00	0.45	6.50	7.00	**7.00**	7.00	7.50

Holland Creek at Kelfeera (Site 404207), November 1976 – May 1999

Parameter	Number of Data	Minimum	Mean	Maximum	Standard deviation.	Percentiles				
						10	25	50	75	90
Alkalinity (mg/L CaCO3)	45	10.00	32.11	90.00	14.93	17.00	20.00	**31.00**	39.00	45.00
Calcium (mg/L)	45	2.70	5.41	20.00	2.86	3.20	3.40	**5.10**	6.50	7.10
Chloride (mg/L)	45	7.60	26.37	110.00	20.20	12.00	13.00	**22.00**	31.00	40.00
Colour (Filt.) (Pt/Co units)	106	15.00	48.04	120.00	22.62	25.00	33.00	**42.00**	60.00	80.00
Dissolved Oxygen (mg/L)	259	3.00	8.88	13.00	1.72	7.00	8.00	**9.00**	10.00	11.00
Electrical Conductivity (Field) (µs/Cm)	279	36.00	157.76	910.00	99.30	81.00	98.00	**130.00**	180.00	280.00
Iron (mg/L)	45	0.84	1.57	6.62	0.90	1.00	1.10	**1.38**	1.65	2.38
Hardness (mg/L)	44	15.00	28.77	88.00	12.48	18.00	20.00	**27.50**	36.00	40.00
Potassium (mg/L)	45	1.10	2.20	8.50	1.31	1.30	1.50	**2.00**	2.40	3.00
Magnesium (mg/L)	45	1.9	3.9	11.0	1.9	2.3	2.5	**3.5**	4.7	5.7
Manganese (mg/L)	45	0.02	0.10	0.70	0.12	0.03	0.05	**0.07**	0.11	0.16
Nitrate and Nitrite (mg/L)	151	0.0030	0.1838	2.3000	0.2436	0.0560	0.0760	**0.1100**	0.2000	0.3700
Sodium (mg/L)	45	4.50	19.11	77.00	14.64	8.30	10.00	**16.00**	22.00	29.00
Reactive Phosphorus (Filt) (mg/L)	105	0.0030	0.0063	0.0410	0.0058	0.0030	0.0030	**0.0040**	0.0070	0.0140
Sulphate (mg/L)	44	1.00	3.48	12.00	2.12	1.70	2.00	**3.00**	4.55	5.90
Suspended Solids (mg/L)	151	1.00	18.52	280.00	28.72	6.00	8.00	**10.00**	18.00	34.00
Silica (mg/L)	45	8.1	14.6	20.0	2.4	12.0	13.0	**14.0**	16.0	18.0
Temperature (°C)	281	6.00	15.71	30.00	5.66	8.00	10.00	**16.00**	20.00	24.00
Total Dissolved Solids (mg/L)	42	65.00	107.17	280.00	40.08	69.00	78.00	**97.50**	130.00	140.00
Total Kjeldahl Nitrogen (mg/L)	151	0.180	0.458	2.100	0.265	0.200	0.300	**0.400**	0.600	0.760
Total Organic Carbon (mg/L)	44	2.0	5.9	12.0	2.7	3.0	4.0	**5.0**	8.0	10.0
Total Phosphorus (mg/L)	150	0.0130	0.0452	0.3800	0.0381	0.0210	0.0260	**0.0340**	0.0500	0.0835
Turbidity (Field) (NTU)	277	1.00	12.05	105.00	12.81	4.00	6.00	**8.00**	13.00	21.00
Colour (Pt/Co units)	45	20.00	65.56	200.00	35.98	30.00	45.00	**60.00**	70.00	100.00
pH (Field) (pH units)	275	6.00	7.12	10.00	0.64	6.00	7.00	**7.00**	8.00	8.00

Lake Mokoan head gauge (Site 404219), July 1992 – September 1997

Parameter	Number of Data	Minimum	Mean	Maximum	Standard deviation.	Percentiles				
						10	25	50	75	90
Alkalinity (mg/L CaCO3)	6	39.00	41.00	49.00	3.95	39.00	39.00	**39.50**	40.00	49.00
Chlorophyll-A (µg/L)	103	0.5	14.6	510.0	51.6	1.2	2.1	**4.0**	8.8	33.0
Electrical Conductivity (Lab) (µs/Cm)	110	180.00	228.55	300.00	28.54	190.00	210.00	**225.00**	250.00	260.00
Nitrates And Nitrites (mg/L)	110	0.0150	0.3028	0.5200	0.1163	0.1300	0.2400	**0.2900**	0.4000	0.4600
React. Phosphorus (Filt) (mg/L)	110	0.0050	0.0305	0.0970	0.0210	0.0140	0.0170	**0.0230**	0.0360	0.0650
Phaeophytin (µg/L)	102	0.5	59.8	2600.0	301.1	1.0	1.6	**2.9**	6.6	27.0
Total Kjeldahl Nitrogen (mg/L)	110	0.600	3.701	85.000	10.426	0.850	0.920	**1.100**	1.400	5.150
Total Phosphorus (mg/L)	110	0.0920	0.3136	3.9000	0.5260	0.1100	0.1300	**0.1600**	0.2300	0.4450
Turbidity (Lab) (NTU)	110	18.0	170.9	1500.0	183.1	110.0	120.0	**140.0**	170.0	195.0
pH (Lab) (pH)	110	5.70	7.65	8.60	0.41	7.25	7.50	**7.70**	7.90	8.10

Broken Creek at Katamatite (Site 404214), October 1976 – May 1999

Parameter	No. of Data	Minimum	Mean	Maximum	Standard deviation	Percentiles				
						10	25	50	75	90
Colour (Filt.) (Pt/Co units)	106	25.00	127.64	450.00	62.40	60.00	90.00	**120.00**	160.00	200.00
Dissolved Oxygen (mg/L)	250	1.00	6.89	11.00	2.30	3.50	5.00	**7.00**	9.00	10.00
Electrical Conductivity (Field) (µs/Cm)	261	67.00	201.92	700.00	90.15	120.00	140.00	**180.00**	240.00	310.00
Nitrate and Nitrite (mg/L)	106	0.0030	0.0368	0.3900	0.0612	0.0030	0.0040	**0.0130**	0.0380	0.1100
Reactive Phosphorus (Filt) (mg/L)	106	0.0030	0.0133	0.0580	0.0119	0.0030	0.0050	**0.0095**	0.0180	0.0270
Suspended Solids (mg/L)	106	15.00	127.51	400.00	76.70	53.00	72.00	**120.00**	160.00	230.00
Temperature (°C)	260	5.00	15.11	30.00	5.27	8.00	10.00	**15.00**	19.50	22.00
Total Kjeldahl Nitrogen (mg/L)	106	0.600	1.517	2.900	0.588	0.800	1.100	**1.400**	1.900	2.400
Total Phosphorus (mg/L)	106	0.0710	0.2042	0.5700	0.0971	0.1000	0.1300	**0.1800**	0.2500	0.3300
Turbidity (Field) (NTU)	253	1.00	75.70	220.00	53.11	8.00	30.00	**74.00**	110.00	149.00
pH (Field) (pH)	244	6.00	6.98	8.00	0.61	6.00	7.00	**7.00**	7.00	8.00

Broken Creek at Rice’s Weir (Site 40421), December 1976 – June 2001

Parameter	Number of data	Mean	Std Dev	Maximum	Minimum	Percentiles				
						P10	P25	P50	P75	P90
Alkalinity (mg/l CaCO3)	232	43.3	9.6	73.0	24.0	32.0	37.0	43.0	48.0	57.0
Calcium (mg/L)	231	7.5	2.1	21.0	0.5	5.5	6.0	7.3	8.4	9.9
Chlorophyll-A (ug/L)	27	31.5	23.1	106.0	6.6	7.6	14.0	27.0	41.0	57.0
Chloride (mg/L)	279	22.5	10.0	82.0	7.9	13.0	16.0	19.0	27.0	35.0
Colour (Filt.) (Pt/Co Units)	203	106.3	62.3	320.0	10.0	45.0	60.0	85.0	140.0	200.0
Dissolved Oxygen (mg/L)	133	9.0	1.6	12.2	5.8	6.7	8.0	8.9	10.3	11.4
Dissolved Organic Carbon (mg/L)	204	10.1	5.0	27.0	2.0	5.0	6.0	9.0	13.0	18.0
Discharge (ML/d)	1169	358.3	408.8	4698.0	0.0	43.0	116.0	252.0	444.0	738.0
Electrical Conductivity (Field) (uS/cm)	1193	175.2	53.1	464.0	29.0	120.0	140.0	170.0	200.0	240.0
Iron (mg/L)	29	7.2	3.6	19.0	2.7	3.5	5.0	6.4	7.8	14.0
Hardness (mg/L)	29	36.6	7.8	58.0	24.0	26.0	32.0	35.0	40.0	46.0
Potassium (mg/L)	232	6.3	2.0	12.0	2.5	3.9	4.9	6.2	7.4	8.9
Magnesium (mg/L)	232	5.2	1.2	11.0	3.2	3.9	4.4	5.0	5.7	6.7
Manganese (mg/L)	29	0.1	0.0	0.19	0.04	0.06	0.08	0.11	0.13	0.17
Nitrates And Nitrites (mg/L)	665	0.1	0.2	0.74	0.003	0.003	0.004	0.023	0.18	0.35
Sodium (mg/L)	232	19.9	7.8	62.0	8.8	13.0	15.0	18.0	23.0	29.0
React. Phosphorus (Filt) (mg/L)	633	0.086	0.090	0.850	0.000	0.027	0.041	0.060	0.094	0.170
Phaeophytin (ug/L)	27	4.71	11.46	60.00	0.05	0.05	0.20	1.40	5.20	7.60
Sulphate (mg/L)	229	8.2	3.8	29.0	2.0	5.0	6.0	7.1	9.0	12.0
Suspended Solids (mg/L)	29	87.3	39.4	210.0	30.0	40.0	58.0	81.0	120.0	132.0
Silica (mg/L)	662	3.0	2.9	11.0	0.0	0.2	0.4	2.0	5.0	7.4
Temperature °C	1196	16.8	5.8	32.0	0.0	9.5	11.5	16.5	22.0	24.5
Total Dissolved Solids (mg/L)	29	181.0	66.2	390.0	100.0	120.0	140.0	160.0	200.0	300.0
Total Kjeldahl Nitrogen (mg/L)	664	1.4	0.5	4.1	0.3	0.8	1.0	1.3	1.7	2.0
Total Organic Carbon (mg/L)	28	12.6	5.1	26.0	6.0	6.0	9.5	12.0	14.5	22.0
Total Phosphorus (mg/L)	663	0.38	0.28	5.70	0.03	0.19	0.25	0.33	0.45	0.59
Turbidity (Field) (NTU)	1177	93.2	35.0	330.0	0.0	55.0	68.0	88.0	115.0	140.0
Colour Pt/Co units	29	161.0	83.4	320.0	60.0	70.0	80.0	160.0	200.0	320.0
pH (Field) (pH units)	1182	7.0	0.3	8.3	6.0	6.6	6.8	7.0	7.2	7.4

APPENDIX 4 THREATENED SPECIES

Common Name	Species	FFG	AROTS	VROTS	TWV	ESP
Reach 1 Lake Nillahcootie to Broken Weir						
Murray cod	*Maccullochella peelii peelii*	L			Vul	
Macquarie perch	*Macquaria australasica*	L			End	
River blackfish	*Gadopsis marmoratus*				DD	
Mountain galaxias	*Galaxias olidus*	L			DD	
Crimson spotted rainbow fish	*Melanotaenia fluviatilis*	L			DD	
Golden perch	*Macquaria ambigua*				Vul	
Squirrel glider	*Petaurus norfolcensis*	L			End	
Powerful owl	*Ninox strenua*	L			End	
Reach 2 Broken Weir to Casey's Weir						
Murray cod	*Maccullochella peelii peelii*	L			Vul	
Macquarie perch	*Macquaria australasica*	L			End	
River blackfish	*Gadopsis marmoratus*				DD	
Mountain galaxias	*Galaxias olidus*	L			DD	
Crimson spotted rainbow fish	*Melanotaenia fluviatilis*	L			DD	
Golden perch	*Macquaria ambigua*				Vul	
Trout cod	*Maccullochella maquariensis*	L			CEn	
Nankeen night heron	*Nicticorax caledonicus*				Vul	
Great egret	*Ardea alba*	L			End	
Royal spoonbill	*Platalea regia*				Vul	
Regent honey eater	*Xanthomyza phrygia*	L			Cen	End
Australasion shoveller	*Anas rhynchotis*				Vul	
Musk duck	*Biziura lobata*				Vul	
Hardhead	*Aythya australis*				Vul	
Carpet python	*Morelia spilota variegata*	L			End	
Woodland blind snake	*Pamphotyphlops proximus*				Vul	
Southern Myotis	*Myotis macropus*				LR	
Grey headed flying fox	*Pteropus poliocephalus*				Vul	
Downy swainson pea	*Swainsonia swainsonoides*	N		e		
Red swainson pea	*Swainsonia plagiotrapis*	L	V	e		V
Reach 3 Casey's Weir to the Goulburn River						
Murray cod	*Maccullochella peelii peelii*	L			Vul	
Golden perch	*Macquaria ambigua*				Vul	
River blackfish	*Gadopsis marmoratus*				DD	
Crimson spotted rainbow fish	*Melanotaenia fluviatilis*	L			DD	
Mountain galaxias	*Galaxias olidus*	L			DD	
Great Egret	*Ardea alba*	L			End	
Royal spoonbill	*Platalea regia*				Vul	
Australasian shoveller	*Anas rhynchotis*					
Bush stone curlew	*Burhinus grallarius*	L			End	
Striped legless lizard	*Delma impar*	L			End	Vul
Reach 4 Broken Creek from Casey's Weir to Katamatite						
Bush stone curlew	*Burhinus grallarius*				DD	
Nankeen night heron	*Nicticorax caledonicus*				Vul	
Brolga	*Grus rubicunda*	L			Vul	
Little button quail	*Turnix velox*				DD	
Forde poa	*Poa fordeana*			*k*		
Neat spear grass	*Austostripa mundula*			*r*		
Reach 5 Broken Creek – Katamatite to the Murray River.						
Murray cod	*Maccullochella peelii peelii*	L			Vul	
Golden perch	*Macquaria ambigua*				Vul	
Crimson spotted rainbow fish	*Melanotaenia fluviatilis*	L			DD	

Common Name	Species	FFG	AROTS	VROTS	TWV	ESP
Black falcon	*Falco subniger*				End	
Eastern curlew	*Numenius madagascariensis*				LR	
Great Egret	*Ardea alba*	L			End	
Intermediate egret	*Ardea intermedia*	L			CEn	
Bush stone curlew	*Burhinus Grallarius*	L			End	
Blue-billed duck	*Oxyura australis*	L			Vul	
Little button quail	*Turnix velox*				DD	
Bluish raspwort	*Haloragis blauca cf glauca*			k		
Common joyweed	*Alternanthea nodiflora*			k		
Forde poa	*Poa fordeana*			k		
Waterbush	*Myoporum montanum*			r		
Smooth minuria	*Minuria integerrima*			r		
Ridged water milfoil	*Myriophyllum porcatum*		V	v		V
Mallee golden wattle	*Acacia notabilis*			v		
Spinyfruit saltbush	*Atriplex spinibractea*			e		
Austral trefoil	*Lotus australis*			k		
Yellow tongue daisy	*Brachyscome chrysoglossa*		N	v		
Spurred spear grass	*Austrostipa gibbosa*			r		
Island celery	*Apium insulare*			r		
Small scurf pea	*Cullen parvum*	L	E	e		E
Narrow leaf sida	*Sida tricopoda*			r		
Tough scruf ea	*Cullen tenax*	L		e		
Small burr grass	*Tragus australianus*			r		
Boosey Creek below Lake Rowan						
Royal spoonbill	*Platalea regia*				Vul	
Australiasian shoveller	*Anas rhynchootis*				Vul	
Fat tailed dunnart	*Sminthopsis crassicaudata*				DD	
Little button quail	*Turnix velox*				DD	
Slender tick trefoil	*Desmodium varians*			k		
Spurred spear grass	*Austrostipa gibbosa*			r		
Forde poa	*Poa fordeana*			k		
Common joyweed	*Alternanthea nodiflora*			k		
Bluish raspwort	*Haloragis glauca cf glauca*			k		
Pale spike sedge	*Eleocharis plana*			v		
Native peppercress	*Lepidium psuedohyssopifolium*			k		
Pin sida	*Sida fibulifera*			v		
Leafless bluebush	*Maireana aphylla*			v		
Black roly poly	*Sclerolaena muricata*			k		
Lake Rowan						
Red chested button quail	*Turnix pyrrhothrax*				Vul	
Brolga	*Grus rubicunda*	L			Vul	
Hardhead	*Aythya australis*				Vul	
Australasian shoveller	*Anas rhynchotis*				Vul	
Tufted club sedge	*Isolepsi wakefieldiana*			r		
Swamp star	*Hypoxis elixis*			v		
Small scurf pea	*Cullen parvum*	L	E	e		E
Australian millet	*Panicum decompositum*			k		
Slender tick trefoil	*Desmodium varians*			k		
Flat sedge	*Cyperus victoriensis*			k		
Lake Wallace						
Little egret	*Egretta garzetta*	L			CEn	
Great egret	*Ardea alba*	L			End	
Intermediate egret	*Ardea intermedia*	L			CEn	
Royal spoonbill	*Platalea regia*				Vul	
Hardhead	*Aythya australis*				Vul	
Wiskered tern	*Chlidonias hybridus*				LR	
Blue billed duck	*Oxyura australis*	L			Vul	
Freckled duck	*Stictonetta naevosa*	L			End	
Australasian bittern	*Botaurus poiciloptilus*				End	

Common Name	Species	FFG	AROTS	VROTS	TWV	ESP
Tree goanna	*Varanus varius*				DD	
Forde poa	*Poa fordeana*			k		
Matted water starwort	*Callitriche sonderi*			k		
Spurred prear grass	*Austrostipa gibbosa*			r		
Cotton panic grass	*Digitaria brownii*			k		

APPENDIX 5 INDICATIVE FLOW REGIME OF BROKEN CREEK BETWEEN CASEY'S WEIR AND KATAMATITE

An **indicative** flow regime for Broken Creek between Casey's Weir and Katamatite was preprared using monthly flow information provided by DNRE. Stock and domestic and irrigation demands (based on current diversion patterns) were subtracted from the monthly flows entering Broken Creek from Casey's Weir. The monthly flows were divided by the days of the respective month to estimate daily flow including median, low(90th percentile) and high flow conditions (10th percentile) (Figure 19). The same approach was used to provide indicative flows for Broken Creek, with and without the Tungamah pipeline (Figure 20).

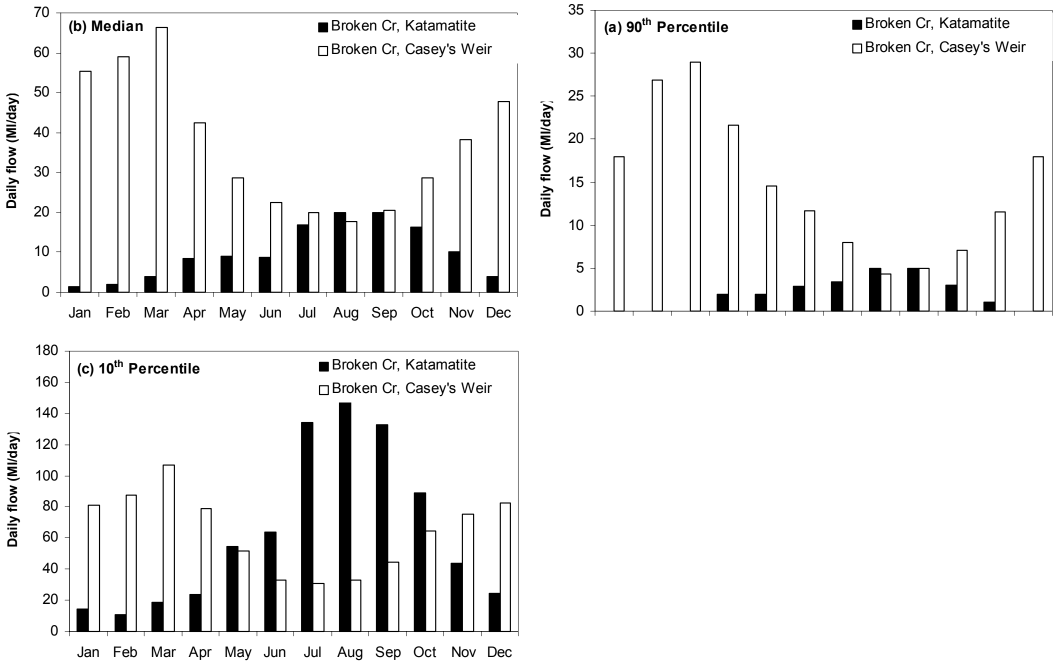
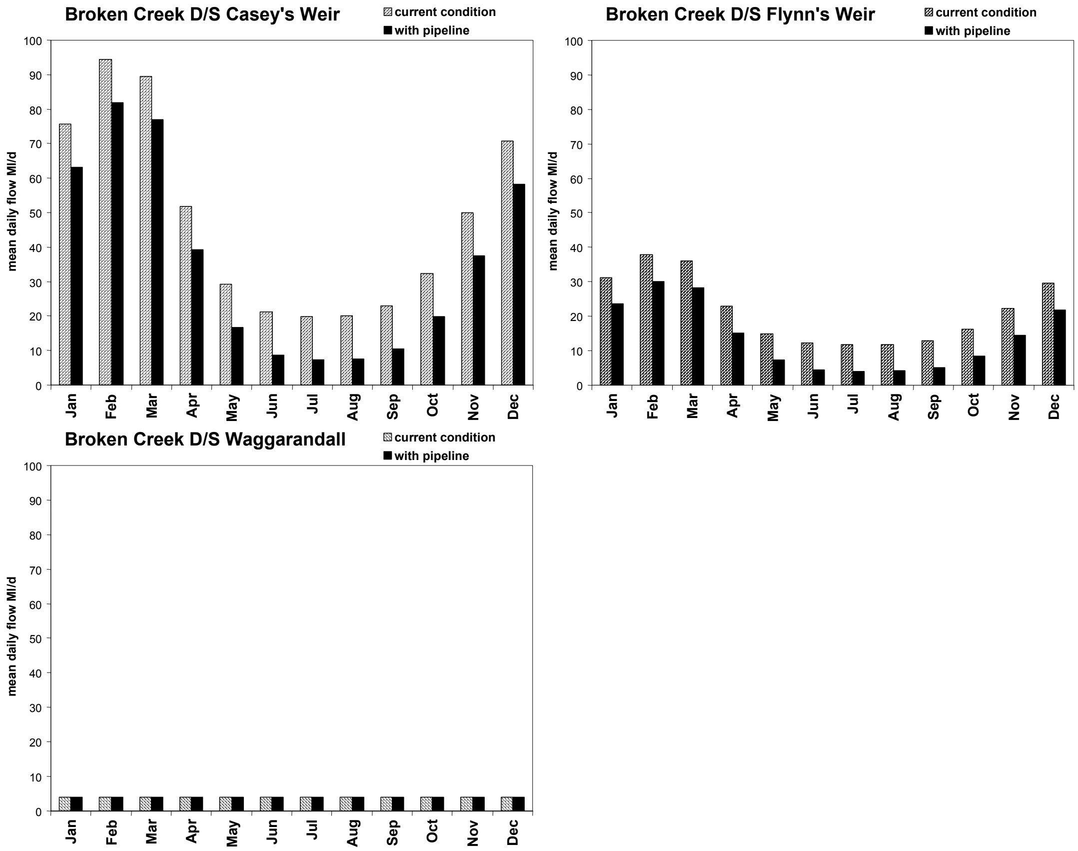


Figure 19: Indicative flow regime for Broken Creek at Casey's Weir and at Katamatite



Broken Creek D/S Casey's Weir

Broken Creek D/S Flynn's Weir

Broken Creek D/S Waggarandall

Figure 20: **Comparison of the flow regime in Broken Creek with and without the Tungamah pipeline**