Goulburn Broken Catchment Management Authority

Lower Broken Creek Waterway Management Strategy

Final Report – Volume I

July 2005

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1. Introduction

1.1 Location and Scope

This Waterway Management Strategy has been developed to address the key threats to the environmental values of the Lower Broken Creek. The majority of the environmental values and key threats to the Broken Creek occur within the Lower Broken Creek System, and therefore this strategy was developed focusing on this area. For the purposes of this strategy, the Lower Broken Creek is defined as the waterways of the Broken Creek downstream of the confluence of the Boosey Creek, including Nine Mile Creek. This covers the five Index of Stream Condition (ISC) Reaches numbers 21, 22, 23, 24 on the Broken Creek (all downstream of the Boosey Ck confluence) and Reach 28 on the Nine Mile Creek. Figure 1 shows the Lower Broken Creek within the study area, while Figure 2 shows the broader catchment with the five relevant ISC reaches. Many of the issues identified in the 1998 Strategy for the upper Broken Creek catchment still stand, and the original strategy remains current for this part of the Broken Creek system.

1.2 Need for a Revised Strategy

The management of the physical condition of the creeks, water quality and significant flora and fauna are central to the Management Strategy for Broken Creek.

Degradation of the creek environment has not only resulted in a loss of value perceived by those who live along the creek, but also by visitors and tourist who come to enjoy the specific values retained by the environment. Broken Creek is highly prized as one of the best remaining habitats for the Murray Cod and other native fishes, and the four reaches on the Broken Creek are defined as High Priority Waterways within the Goulburn Broken Regional River Health Strategy as a result of their notable high environmental values.

The quality of the water is vital to the residents who live and work near the creek, since it has become a key supplier of water for domestic, stock, urban and irrigation purposes. To a very large degree, the water quality depends on the preservation of the condition of the stream bed, banks and the riparian zone and the management of water flowing into the creek system from adjacent waterway and land systems.

A Management Strategy for the Broken Creek was first developed in 1998. As part of the development of the current 2005 Strategy, the current status and effectiveness of the 1998 strategy was reviewed. This review indicated that many of the actions set out in the 1998 strategy to address the priority issues at the time have been implemented, however there are some ongoing and emerging issues in the Lower Broken Creek system that have not been adequately addressed or were not covered by the 1998 Strategy. In addition, adequate resource condition targets were not provided to fully measure the success of the original strategy, and so the revised strategy will need to provide measurable resource condition targets. Further information on the 1998 Strategy and the review outcomes are provided in Chapter 3. The full review is provided in Appendix A.

Legend

- Towns
- G-MW Drains
- Streams
- Rivers
- Roads
- SIR
- Weirs

Rices Weir
Kennedys Weir
Schiers Weir
Hardings Weir
Lukes Weir
Magnussons Weir
Chinamans Weir
Town Weir
Melville Street Weir
Station Street Weir
Ratandra Weir

Barmah
Picola
Barwo
Nathalia
Baulkamaugh North
Vaaia
Numurkah
Katunga
Strathmerton
Koonoomoo
Bearii
Barooga
Yarroweyah
Cobram
Cobram East
Yarroweyah South
Sandmount
Muckatah
Naringaningalook
Ratamatite
Dunbulbalane
Drumanure
Wunghnu
Invergorden North
Youanmite
Marungi
Yabba North
Ratandra West
Tallygaroopna
Katandra
Marionvale
Yabba South
Zeerust
Bunbartha
Undera North
Undera
Saint Germains
Wyuna East
Wyuna
Barep
Pederick
Tongala
Tongala East
Kotupna
Yambuna
Kanyapella
Kaarimba
Mundoona

Broken Creek
Broken Creek
Nine Mile Creek

0 5 10 15
Kilometres

N
W E
S

DATA SOURCE:

Prepared.	SLP		17/08/04	Workspace	Fig 1 - Lower Broken Creek.WOR
Checked.	AWR		17/08/04	Location	G:\31\15069\GIS\Workspaces
Approved.	AWR		17/08/04	Map Grid	MGA94 Zone 55

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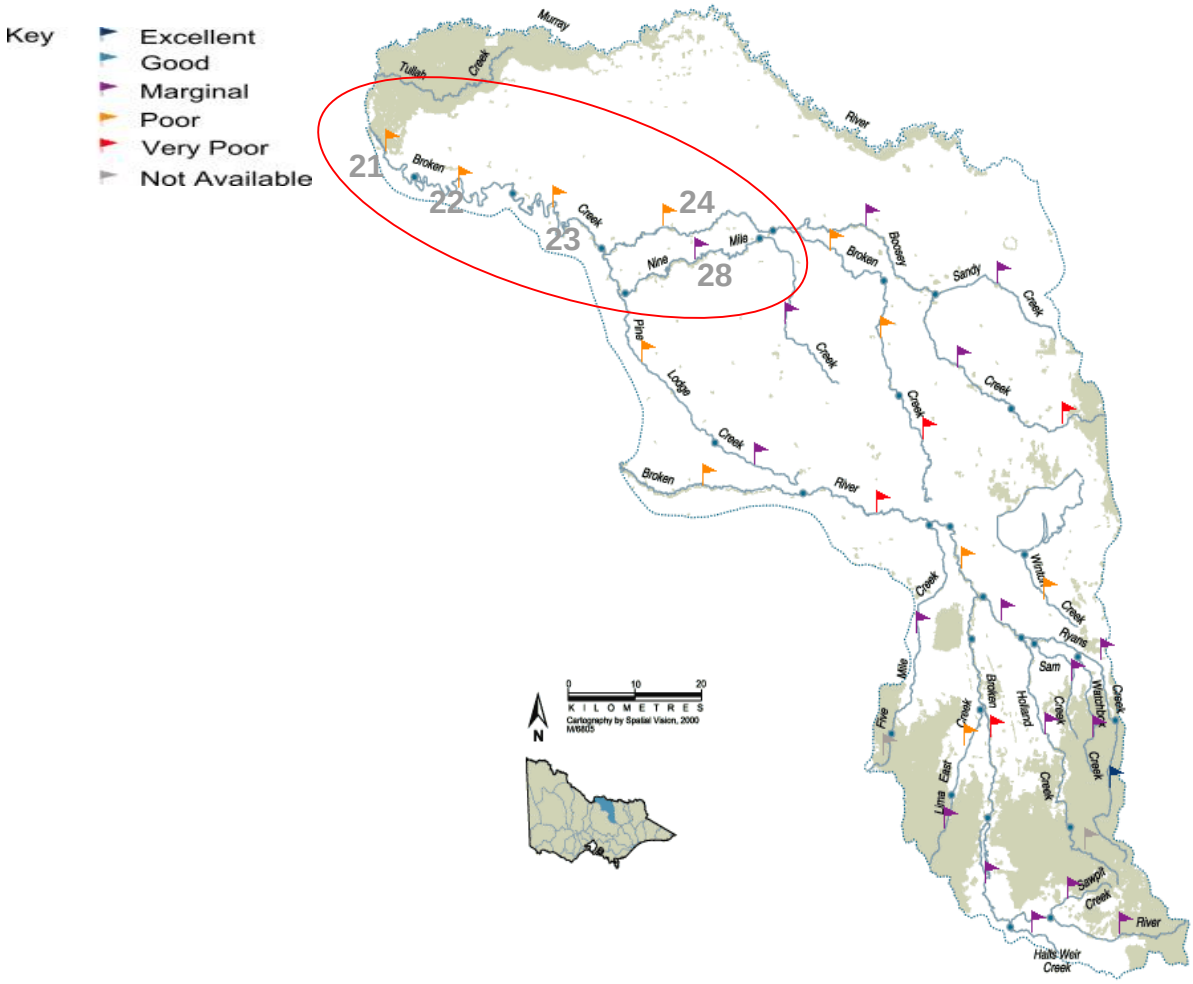
Project: Review of the Broken Creek Management Strategy

TITLE: **Figure1: The Lower Broken Creek**

Project No.	Date.	Scale			
3115069	17/08/04	Scale: 1:195000	A3	Sh 1 of 1	Rev. O

Figure 2 Broken Creek catchment and relevant ISC reaches



Reach 21 Confluence with River Murray to Schiers Weir

Reach 22 Schiers Weir to Chinamans Weir (Nathalia)

Reach 23 Chinamans Weir (Nathalia) to Nine Mile Creek confluence

Reach 24 Nine Mile Creek confluence to Boosey Creek confluence (downstream of Katamatite)

Reach 28 Nine Mile Creek

1.3 Aim

The aims of this management strategy were to:

- Enhance the health of the Lower Broken Creek, taking into consideration impacts on it by adjacent waterway and land systems; and
- Establish simple, clear management objectives and targets that can be implemented, monitored and reported on by responsible agencies and the community.

1.4 Approach

The approach taken to develop the 2005 Lower Broken Creek Management Strategy is listed below:

- A comprehensive review of 1998 Broken Creek Strategy to determine:
  - The degree to which the action items identified within the 1998 strategy had been implemented within the timeframe established;
  - The degree to which the strategy has been successful in meeting its original objectives, through assessment against the identified performance criteria or other relevant criteria; and
  - The ongoing relevance of the 1998 Strategy for addressing current and emerging issues in the Broken Creek.

  The results of the review are reported in a separate report (GHD / URS 2005a), which is summarised in Chapter 3 and presented in full in Appendix A.
- A review of relevant available literature to the Broken Creek system, including management plans, strategies and scientific reports. A full list of documentation is included in the references listed in Chapter 14;
- A review of the key values, threats and priority risks to the Broken Creek identified in the River Values and Environmental Risk System (RiVERS) database, and the application of an asset based risk assessment process to identify the key management responses. It is recognised that scale on which RiVERS is based (ISC reach scale) is too large for this project, so other processes such as field visits and Steering Committee and stakeholder input have also been introduced to ensure values and threats are identified at an appropriate scale;
- Field inspections were undertaken by the project team and representatives of the Steering Committee over two days in April 2004. The aim of carrying out field inspections were to:
  - Verify and ground truth data in RiVERS to determine if it reflected the current environmental status;
  - Ground check the level of values and threats and the resultant risk ranking provided by RiVERS to determine if they reflect the current status;
  - Identify other threats and values that may not be included in the RiVERS database application;
  - Identify hot spots[1] throughout the five ISC reaches;

[1] The term 'hot spots' refers to site specific issues within a reach. 'Hot spots' may not be reflected in the RiVERS database because RiVERS collates information on a reach scale, not a site specific scale.

- Discuss and contribute to the review of the 1998 Broken Creek Strategy; and
- Familiarise the consulting team with the Broken Creek environment to provide a better understanding of the key issues for inclusion into the Strategy review.

Please note that there was no formal data collection conducted at each site.

- A cost-benefit analysis was used to assist in prioritising management responses for the Lower Broken Creek. A three staged process was used for this assessment of the benefits and costs of the Broken Creek Management Strategy:
  - ***Identify Priority Actions*** – Firstly, a benefit cost analysis (BCA) was used to assess the costs and benefits of management actions that were identified as part of a risk assessment using RiVERS;
  - ***Determine Strategy Actions/Programs*** – Secondly, these costs and benefits were one of the inputs used by the project steering committee to determine priority management actions to be included within the Revised Broken Creek Management Strategy; and
  - ***BCA for Strategy*** – Finally, the overall costs and benefits of the Strategy were assessed for those management actions and programs included within the revised Strategy.

  The results of the benefit cost analysis are summarised in Section 9.4, and the full report is provided in Appendix B.

1.5 Consultation

It was recognised that wide public and landowner consultation is important for the community to gain an understanding and ownership of the Broken Creek Management Strategy. In order to involve the community in the review process, the following community consultation activities were undertaken to allow participation and input by all stakeholders in decision-making:

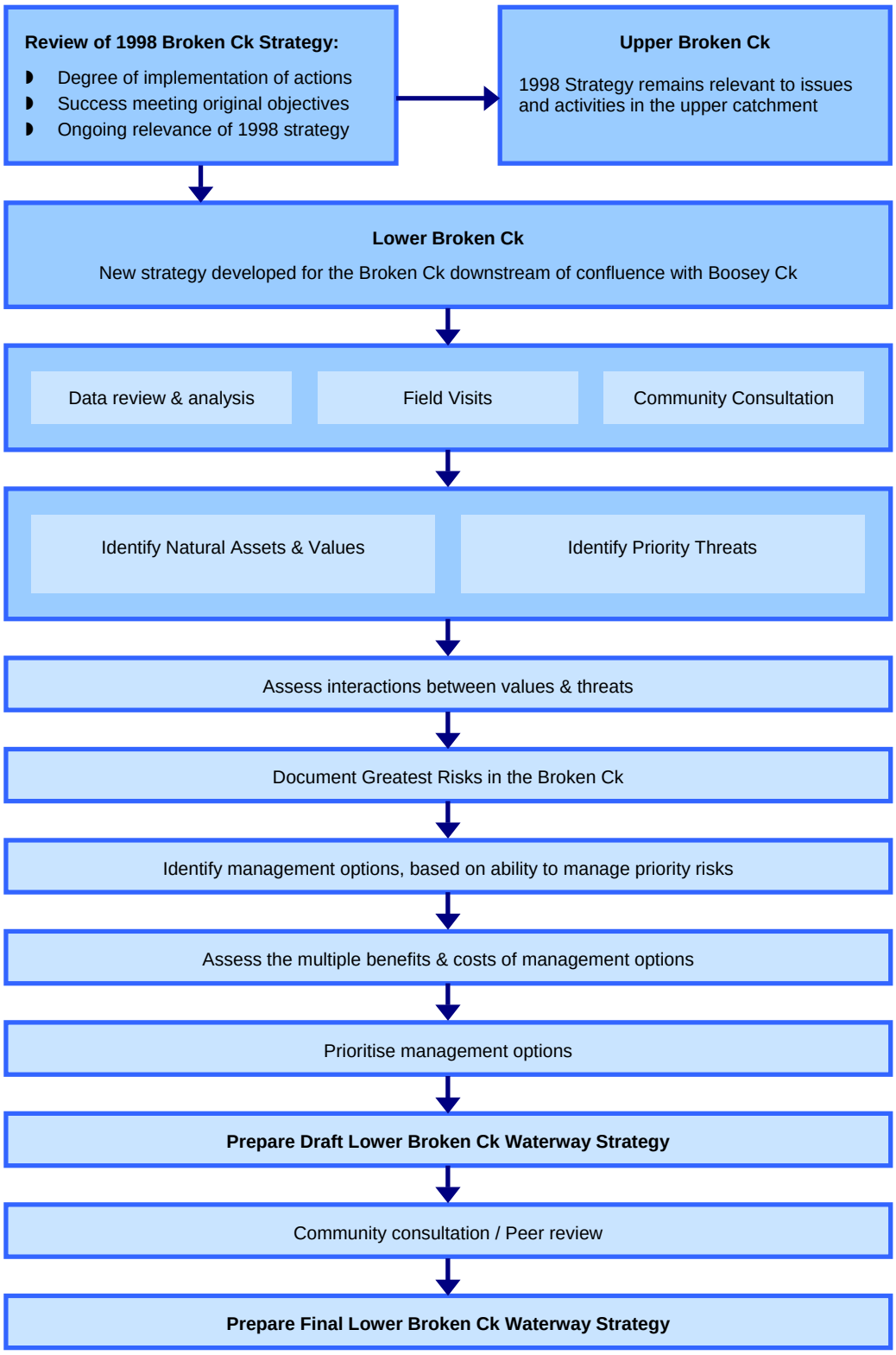
- Preparation and distribution of a community newsletter providing background information and updates on the review process;
- A total of three community drop-in sessions were held in different geographical parts of the catchment: Nathalia, Numurkah and Katamatite. At these sessions, the values of and threats to the Broken Creek identified by the RiVERS database were presented, and community input was sought to identify any additional values and threats and their views on proposed management responses; and
- Three stakeholder workshops were held, with participation drawn from an existing network developed as part of the Broken Creek Operational Review Committee, plus additional representatives from across the lower Broken Creek catchment. This Community Reference Group had 16 members representing a variety of interests. The purpose of these workshops was to seek input to the development of the revised Strategy.

1.6 Accompanying Reports

Three supplementary documents are associated with this Strategy:

- GHD / URS (2004), Field Notes and RiVERS summary; for Steering Committee Comment, Report;
- GHD / URS (2005a), Review of the Broken Creek Management Strategy, Review of 1998 Strategy, Final Report; and
- GHD / URS (2005b) Broken Creek Management Strategy - Setting Priorities for Investment using a Benefit Cost Analysis, *Final Report.*

Figure 3 Process for the review and development of the Broken Creek Strategy



1.7 Structure

The Management Strategy is divided into twelve main chapters:

1. Introduction – introduces the plan, its purpose and approach.
2. The Lower Broken Creek – provides background information on the Lower Broken Creek system.
3. Management Context – outlines the history and management framework for the region.
4. Vision and Management Objectives –identifies the community vision and objectives for the Lower Broken Creek.
5. Natural Assets and Values – describes the natural assets and values of the Lower Broken Creek.
6. Major Threats – describes the major threats to the identified natural assets and values.
7. Priority Risks – describes the priority risks based on the assessment of values and threats.
8. Assessment of Multiple Benefits and Costs - employs benefit-cost analysis to assess the benefits and costs of management alternatives in monetary terms.
9. Management Program – presents the management responses and actions available to address the identified priority risks that threatened the natural assets and values of the Lower Broken Creek.
10. Monitoring, Evaluation and Reporting – describes the broad monitoring, review and evaluation activities required to determine the success of the strategy in meeting its identified objectives and targets, including identification of knowledge gaps.
11. Knowledge Gaps and Research – describes current knowledge gaps and areas where further research is required.
12. Cost Sharing Principles – recommends the funding and partnership arrangements required for the implementation of the Strategy, based on the principles used in the GB Regional River Health Strategy.
13. Implementation and Review – describes the implementation process and the timeframe for ongoing and timely review of the 2005 strategy.

2. The Lower Broken Creek

2.1 The Broken Creek Catchment

The Broken Creek catchment occupies approximately 3 300 km^2 of the Murray Valley Riverine Plains in northern Victoria, and provides regional drainage for the Muckatah, Shepparton, Kaarimba, Invergordon, and Nathalia-Barmah sub catchments. The creek branches from the Broken River north west of Benalla and flows to the north west where it outfalls to the Murray River in the Barmah-Millewa Forest, a RAMSAR listed wetland 210 km downstream (GBCMA, 2002a). Figure 1 shows the Lower Broken Creek catchment within the study area.

Main towns along the creek include Nathalia and Numurkah. Within the catchment, Katamatite and Tungamah are located on the Boosey Creek and Wunghnu is located on the Nine Mile Creek.

Most of the land in the catchment is used for grazing, with dairying being the predominant industry. The western parts of the catchment are irrigated, with the Shepparton Irrigation District to the south of Broken Creek and the Murray Valley irrigation district to the north of the Broken Creek. Well-developed drainage systems and arterial drains are a feature of the Murray Valley and Shepparton irrigation districts, and many of these drains outfall to the Broken Creek and Nine Mile Creek (SKM, 1998). There are also substantial constructed drainage systems in dryland areas, including the Drain Road outfall into Boosey Creek upstream of Katamatite and Kreck Road / Sandy Creek near Tungamah. There are also roadside drains, smaller drains, and laser graded drainage lines in the dryland areas of the upper catchment, which may be contributing significant flows to the Broken Creek following rain events (P. Mapletoft, pers comm.).

The Broken Creek catchment lies within the Shepparton Irrigation Region, which is known as the food bowl of Australia, and generates 25 per cent of Victoria's annual rural export earnings. Much of this area falls within Moira Shire, where a population of 25 856 people rely on a regular source of irrigation water that contributes to the Farm Gate Gross Value of Production (GVP) of over $3 million in Moira Shire (Young, 2000). The three irrigation Shires of the Goulburn Broken Catchment (City of Greater Shepparton, Moira and Campaspe) produce 77% of the farm gate GVP in the Goulburn Broken Catchment. This reflects the intensity and diversity of agricultural production that irrigation permits in a relatively low rainfall area. The Broken Creek system is a key source of irrigation water within the Goulburn Broken catchment. More than twenty major food processing companies have located in the Shepparton Irrigation Region, due to the ready access to large volumes of reliably produced raw materials for their production lines and a concentration of infrastructure and services that support their businesses (Young, 2000).

Prior to clearing for agriculture, the Broken Creek catchment was largely open woodland, with extensive areas of box eucalypts. Stands of River Red Gums were found in well-watered areas and along waterways (SKM, 1998).

2.2 Hydrology and Water Use

The Broken Creek system has been used as a source of water for domestic and stock watering purposes since the earliest days of settlement. A number of low timber weirs were constructed on the lower Broken Creek early last century to improve the reliability of supply (SKM, 1996a). Irrigation in the Broken Creek catchment first commenced on a large scale following construction of the East Goulburn Main Channel (EGMC) in 1911, which imports water from the Goulburn Weir near Nagambie. In 1929 the EGMC was enlarged and extended to Nine Mile Creek, and assumed its current form (SKM, 1996a). Diversion from the Broken Creek occurred on a relatively *ad hoc* basis up until the 1940s, when the first channel outfalls were constructed (SKM, 1996a). After a Parliamentary inquiry in 1961, works were conducted to upgrade and replace a number of the weirs (the presence of the weirs on Broken Creek has altered the creek from free flowing to a series of stepped pools). Also, at this time, parts of Nine Mile Creek and Broken Creek were regraded to facilitate effective outfall for irrigation drainage schemes (SKM, 1996a). A number of drainage schemes were constructed in the Broken Creek catchment during the 1960s, allowing removal of excess irrigation water and nuisance flooding (SKM, 1998). This development coincided with delivery of significant volumes of irrigation water from the EGMC outfall.

Water from the EGMC outfalls to the Broken Creek and Nine Mile Creek at Katandra Weir, and both of these creeks are used as irrigation carriers to permit riparian landholders to pump water from the waterways. The combined entitlement along the Lower Broken Creek and Nine Mile Creek system downstream of Katandra Weir is 26 400 ML per annum (SKM, 1998). Total diversions and Channel Outfall volumes within the Broken Creek System are presented in Tables 1 and 2 respectively. The EGMC outfall at Katandra Weir has a standing order of 200 ML/d during the irrigation season (SKM, 1998). The weirs on Broken Creek and Nine Mile Creek downstream of the EGMC outfall help facilitate delivery of water for irrigation and domestic/stock water supply (SKM, 1998). Prior to the upgrade of these weirs in the late 1990s, many of them leaked, and flows well in excess of demands had to be passed downstream in summer and autumn in order to maintain the weir pool levels (SKM, 1996b). In the mid-1990s, SKM (1996a) reported anecdotal evidence that an increasing volume of water was being supplied to irrigators along this system. The water was provided via outfall channel outfalls to the creek, and from drain flows entering the creek from the irrigation area.

Table 1 Broken Ck System – Diversions within the Broken Creek System

Location	Total Diversion Entitlement (ML)	Supply Source
Boosey Ck	359	-
Upper Broken Ck	7 044	Casey's Weir
Lower Broken Ck (Katandra Weir to Walshes Bridge)	4 811	EGMC
Lower Broken Ck (Walshes Bridge to Rices Weir)	14 342	EGMC
Nine Mile Ck	7 245	EGMC

Source: SKM, 1998

Table 2 Broken Creek Systems Channel Outfall Volumes

Location	Flow (ML/d)
MV Channel 3 Outfall	10
East Goulburn Main Channel	
Broken Ck component	60
Nine Mile Ck component	115
Combined Drain Inflow (all drains upstream of and including M.V. Drain 13)	180
MV Channel No. 4 Outfall	5
Outfall at Rice's Weir	170

Source: SKM, 1996c.

Flows in the Broken Creek catchment are gauged at Boosey Creek at Tungamah, Broken Creek at Katamatite and Broken Creek at Rices Weir. The sites at Tungamah and Katamatite are in the upper part of the catchment, and are upstream of the main irrigation area. Flows in the upper catchment show a marked seasonal variation, with highest average monthly flows occurring in August and September and the lowest in March, which follows the natural seasonal variation in rainfall and evaporation (SKM, 1998). The site at Rices Weir is located at the downstream end of Broken Creek. The usefulness of the Rices Weir record is compromised by the effect of backwater from the River Murray when the Murray is flowing at high stage. There are no permanent gauges with which to measure flows in the middle part of the catchment, downstream of the EGMC outfall at Katandra, and where flows are divided between Nine Mile Creek and Broken Creek (SKM, 1998). Thus, the hydrology of the middle part of the catchment has to be evaluated qualitatively or modelled.

While the hydrology of the lower Broken Creek has been subjected to a number of regulating influences over the past century, the major changes occurred in the 1960s, following construction of irrigation drains and delivery of significant volumes of water via the EGMC outfall. Use of the Broken Creek as an irrigation conduit has transformed it from a winter/early spring flowing ephemeral stream to a series of permanent weir pools with summer flow maxima. During the irrigation season, flows are now dominated by irrigation deliveries from the Goulburn system; drain discharges from adjacent irrigation areas and River Murray system channel outfalls. During the winter, flows are dominated by drain discharges from both irrigation areas. On a seasonal basis, contributions from the largely un-irrigated catchment above Katamatite are less than approximately 8% of the total river flow (Butcher, 2004). Some proportion of current drainage flows and all of the irrigation deliveries and channel outfalls are artificial supplements to natural catchment flows. This would apply to at least 30% of winter flows and at least 80% of irrigation season flows (Butcher, 2004). Anecdotal evidence reported by SKM (1998) suggests that agricultural drains have increased the frequency and duration of low to intermediate flow events on Broken Creek.

As part of a weir replacement program for the weirs on the lower Broken Creek, undertaken during the late 1990s, gates were installed on the weirs together with remote sensing control (SCADA) to facilitate better water management. The upgrade has almost completely eliminated weir leakage, and the gates permit better management of water variations in weir pools. SKM (1996b) predicted that the weir upgrade could lead to reduced flows along Broken Creek during the irrigation season because of reduced drain outfalls to Broken Creek or reduced outfalls from the EGMC. Butcher (2004) noted that programs designed to improve water delivery efficiency and to improve regional water quality have reduced creek flows, especially during the late winter/early spring period. This tendency has been exacerbated in recent years by drought. While the general objective has been to maintain relatively constant weir pool levels at all times, it is possible that a few electrically operated pumps operating together to take advantage of off-peak prices could drain a weir pool very quickly.

Minor flooding along the Lower Broken Creek is not uncommon and the new weir structures can be operated to help reduce the peak flood levels for a given flow. Minor nuisance flooding would occur when flows below Hardings Weir exceeded 2 160 ML/d. In the past all flows had to go over the top of the weirs and water levels would rise with increases in flow. With the new gate arrangements, up to 1 000 ML/d can be passed without causing a noticeable rise in water level at the weir. Therefore, for any given flow, it is expected that there will be a reduction in water level to that previously experienced within the reach influenced by the weir pool (Goulburn-Murray Water, 2003). While an improved ability to manage weir level improves the opportunity to enhance ecological benefits, as well as reducing nuisance flooding for landholders, the lower frequency of minor floods could have detrimental ecological consequences.

By the late winter and spring of 2002 catchment inflows to Broken Creek were insignificant, and severe water quality problems occurred in November 2002. A fish-kill occurred at this time, resulting in the death of 179 Murray Cod (*Maccullochella peeli*) and six Carp (*Cyprinus carpio*) in Rices weirpool. Lack of flows associated with prolonged fishway closures and build up of the floating fern azolla (*Azolla filiculoides* and *A. pinnata*) are believed to be implicated (Butcher, 2004). Recently, G-MW and River Murray Water have provided a return flushing flow of between 40 and 120 ML/d from the River Murray, via G-MW's irrigation channels on the northern side of Broken Creek (there are legal constraints in doing so from the channels supplied from the Goulburn System on the southern side of the creek). This flow was implemented to prevent a fish kill recurrence while the strategy review comes up with a long term solution (Butcher, 2004). The flushing flow is returned to the River Murray at Rices Weir, ensuring in the process that all of the fishways are kept open, that azolla does not build up to dangerous levels, and that there is sufficient through flow to oxygenate the weir pools (Butcher, 2004).

The flushing flow has so far proved worthwhile in preventing catastrophic azolla build up, but when a significant accumulation does occur, sustained flows in excess of 300 ML/d are required to flush the azolla (Butcher, 2004). There are considerable travel times involved in delivering such a flush. It takes four days for water to travel from Lake Eildon to the EGMC outfall, a further four days to travel from the EGMC outfall to Nathalia Weir and a further six days for it to reach Rices Weir (Butcher, 2004).

2.3 Geomorphology

The Lower and Middle Broken Creek catchment can be divided into two distinct geomorphic zones (SKM, 1996a). From a point near Waaia approximately 2 km downstream of Walsh's Bridge (the arbitrary boundary of the Middle and Lower Broken catchment), to just upstream of its junction with the River Murray, Broken Creek occupies the channel of an ancestral river. This so-called Tallygaroopna channel, abandoned between 25 000 years and 30 000 years BP, had a much larger meander wavelength and wider meander belt than both the present-day Murray and Goulburn River channels. Thus, the Broken Creek downstream of Waaia owes much of its current broad plan form to inheritance, but it also contains some tighter meanders within the larger inherited meanders. The second zone extends from Waaia upstream to Katamatite (the arbitrary boundary of the Middle and Upper Broken Creek), and has a more sinuous course.

2.4 Water Quality

Good water quality is essential for enhancing the social, economic and environmental values of the Broken Creek system. In addition to being vital for life within the Broken Creek, water is used by local communities for domestic, stock, urban and irrigation supply, and provides important aesthetic and recreational values. Water quality in the Broken Creek is considered degraded mainly due to high turbidity and nutrient levels, which is a threat to these values. The quality of water quality data is limited in terms of statistical validity, having been obtained from only two monitoring stations: one at the upper end of the study area at Katamatite; and one at the lower end at Rice's Weir. However, it does provide a broad picture of the overall water quality of the system. Analysis of this water quality data is provided in Section 6.6.

There are some other data available for the Broken Creek and drains from studies undertaken by SKM (SKM, 2004), which indicates that water quality could be worse in some locations where drains outfall to the Creek. It is expected that water quality would improve downstream of each outfall due to dilution and self-purification processes, in a step-like downstream trend. Improved drainage management has the potential to improve instream water quality, through reducing drainage inputs or by improving drainage water quality.

2.5 Flora

The Broken Creek is rated as "high significance" in terms of significant flora throughout the length of the reaches covered by this report. This reflects the presence of endangered and depleted Ecological Vegetation Classes along most of the length of the creek, in a landscape that is largely cleared and intensively farmed. There is almost continuous riparian woodland along the Broken, Boosey and Nine-mile Creeks, although the width of the tree community and intactness of the understorey varies.

The value of this vegetation has been increased by the recent inclusion of the creeks in a State Park. A number of rare and threatened plant species have been recorded in each of the reaches covered by this report (Robinson and Mann, 1996), and while these records refer to a larger area than the creek riparian zone, the surrounding farmland is largely cleared, and it is likely that the rare species are mostly found along the creeks.

The longitudinal continuity of the riparian vegetation is generally good. Even where the woodland is narrow, it will provide a corridor that connects the wider sections. This corridor is particularly valuable at a landscape scale across a largely cleared landscape (Robinson and Mann, 1996). The aquatic vegetation of the Broken Creek is in a degraded condition. Robinson and Mann recorded aquatic vegetation as common at only 5% of their survey sites. The most common emergent aquatic vegetation along the creek is the exotic weed Arrowhead. The high turbidity of the water is probably a major factor in the rarity of submerged aquatic species.

2.6 Fauna

The fauna of the Broken Creek is diverse and represents a range of species due to a complex of habitats available. These include aquatic, riparian and woodland areas that provide habitat to many animal species including some listed species. In the waterway corridor (defined as being within 100 m of the creek) at least 13 significant listed fauna species have been identified, including three fish, a frog, two reptiles, five waterbirds and a mammal species (SKM, 1996).

The connectivity of the riparian and aquatic habitat from the upper zones within the Broken-Boosey State Park linking down to the Barmah-Forest system ensures species are able to disperse throughout the system. This connectivity is a major factor in providing the relatively high conservation significance and biodiversity for the system.

The value of the woodland as fauna habitat varies with the width, intactness of the understorey and the age of the trees. Where the creek has widened in the past, or where weir pools have inundated the former bank, trees that have been permanently inundated have been killed. These dead trees still provide valuable habitat for bats and hollow nesting birds. The rarity of old hollow-bearing trees in some reaches increases the importance of all dead trees.

Macroinvertebrates are monitored in two reaches of the lower Broken Creek (Broken Creek, Reach 23 and Nine Mile Ck, Reach 28). The SIGNAL scores indicate that Nine Mile Creek has a low level of macroinvertebrate biodiversity consisting of hardy or pollution tolerant species. Reach 23 has moderate levels of biodiversity.

3. Management Context

3.1 1998 Broken Creek Management Strategy

3.1.1 Background

A management strategy for the Broken Creek was released in 1998 (SKM, 1998) to provide a framework for addressing the issues affecting the management of the creek and its environs. This included the effects of land use practice and other management strategies on the physical and biological conditions of the Broken Creek, its water quality, and flooding and drainage issues. The original strategy was part of a broader project initiated in 1995 that assessed the floodplain impacts of proposed drainage works as part of the surface drainage strategy of the Shepparton Irrigation Region. The strategy was developed for the Lower Goulburn Waterway (LGW) by Sinclair Knight Merz in association with Neil Craigie & Associates, Sandra Brizga & Associates and Streamline Research Pty Ltd. In 1997 the LGW became a coordinating committee of the then newly formed Goulburn Broken Catchment Management Authority.

To gauge the level of implementation and success of the 1998 Broken Creek Strategy and to bring it up to date, the Goulburn Broken Catchment Management Authority commissioned a review of the 1998 strategy. The key findings of the review of the 1998 Strategy are described below. Detailed results of this review are described in a separate report (GHD / URS, 2005a).

3.1.2 Findings of the Review of the 1998 Strategy

The majority of the actions in the 1998 Strategy had been implemented, as measured by the following actions:

- Removal of approximately 90-95% of willows downstream of Katamatite;
- Improved riparian zone management through 82 km of fencing and 155 off-stream watering points;
- Removal of in-stream barriers through weir replacement and the installation of 12 vertical slot fishways downstream of Katamatite;
- Gazetting of Broken-Boosey State Park, and creation of the Nathalia and Numurkah Natural Features Reserve;
- Best practice drain design and construction;
- Best practice drainage management for Kinnairds wetland;
- Best practice drain management, including improved monitoring, Drainage Diversion Plans (DDPs) and Drainage Management Plans (DAMPs);
- Improved farm management through landholder investment, irrigation extension and the development of guidelines and incentive schemes;
- Development of best practice guidelines, such as:
  - Lower Broken Creek Operational Guidelines;
  - Best Practice Principles of Drainage in Dryland Catchments;

- Dairy Shed Effluent & Nutrient Mgmt on Dairy Farm Guidelines;
- NE Planning Guidelines for Water Quality;
- Best Practice Drain Management, including improved monitoring, development of Drainage Diversion Plans (DDPs) and Drainage Management Plans (DAMPs);
- Best Practice Drain Design and Construction;

- Improved management framework:
  - Key role of the CMA since strategy developed;
  - Good coordination with other agencies via SIRTech and RHWQC; and
- Enhanced monitoring of drains discharging to the Broken Creek.

However, there were some key actions identified that had not been implemented, including:

- Water quality and flow monitoring - the recommendation in the 1998 strategy that *'water quality (and flow) should be monitored in at least three other locations'* in addition to the permanent gauging stations at Katamatite and Rices Weir has not been implemented. Improved data will assist in better defining the condition of the Broken Creek, and assist with developing targeted management actions and in measuring the success of those actions for improving water quality;
- Limitations for the improvement to in-stream habitat due to the limited availability of large woody debris; and
- Constraints with variation in weir pool levels for management of siltation.

Most importantly, 1998 Strategy had not yet been successful in meeting all its original objectives, in particular the prevention of further degradation and an improvement the environmental condition of the Broken Creek Catchment, although it was recognised that the plans 10 year timeframe had not yet elapsed. This was highlighted by a number of key ongoing issues:

- A fish-kill in Rices Weir pool in November 2002 resulted in the death of 179 Murray Cod (*Maccullochella peeli*) and six Carp (*Cyprinus carpio)*. Lack of flows associated with prolonged fishway closures and build up of the floating fern azolla (*Azolla filiculoides* and *A. pinnata*) have been identified as the likely cause;
- Weed infestations such as azolla and arrowhead are significant issues requiring targeted and ongoing management;
- There is ongoing poor water quality, particularly turbidity and nutrients. There is evidence of some improvements, however the lack of sufficient monitoring data and the ability to separate out the effect of the drought on reduced nutrient loads is difficult; and
- Weir upgrades have almost completely eliminated weir leakage, which in the past have provided a proxy environmental flow for the Broken Creek. This is likely to have led to reduced flows along Lower Broken Creek, which has been exacerbated in recent years by drought. This loss of flow may potentially impact on important native fish communities in the Lower Broken Creek. It is therefore important to determine and provide an environmental flow to achieve improved protection of in-stream ecological values.

In many instances it was difficult to assess the success of the 1998 Strategy, due to lack of clear targets and measurement criteria. The 1998 Strategy did identify nine Performance Criteria to measure the success and review the progress of the Management Strategy, however these were "starting points for debate" and while there was significant agency input to the development of the strategy, it appears that these performance criteria were not endorsed. More importantly, in some instances the baseline value against which these criteria were to be measured was not identified, and there was insufficient monitoring data collected to measure improvement.

In addition to these issues:

- There have been significant institutional, policy and strategic changes since the 1998 Strategy was finalised, such that the context of the 1998 Strategy is no longer relevant; and
- Approaches to the development and structure of waterway management plans have evolved, and an opportunity exists to provide a more user-friendly document.

As a result of these outstanding and emerging issues, it was identified that further work was required to ensure the Lower Broken Creek continues to provide a water supply and drainage function, while protecting and enhancing its ecological values. In preparing a revised Strategy for the Broken Creek, therefore, the following were considered important:

- Provide a structure and content that is consistent with the current regional policies and strategies, particularly the Regional River Health Strategy and the Regional Catchment Strategy;
- Develop a clear and concise vision for the Broken Creek and clear objectives for the Broken Creek Strategy against which the success of the Strategy can be assessed in the future;
- Present the Management Programs and Actions in a clear and concise format that can stand alone and be easily referred to by those responsible for implementing the strategy;
- Develop meaningful and measurable performance criteria, including both Management Action Targets and Resource Condition Targets, against which the success of the Strategy can be measured;
- Outline a monitoring program that will allow the collection and analysis of appropriate data to determine baseline conditions and measure whether the performance criteria have been met;
- Provide a clear overview of the process that was followed to develop the revised strategy, including stakeholder consultation for the development of key components such as the vision, objections and management actions;
- Clearly present any assumptions made, information gaps, and limitations of the revised strategy; and
- Outline the process for review and updating of the revised strategy in the future.

3.2 Legislation

A number of international, commonwealth and state legislation relevant to the protection of riverine health and water quality need to be considered in the implementation of the revised Broken Creek Strategy. This legislation is summarised in Table 3 and key legislation, policies, strategies and guidelines are described in more detail below.

Table 3 Relevant International, Commonwealth and State Legislation

International	Commonwealth	State
RAMSAR (Directory of Important Wetlands)	Environment Protection & Biodiversity Conservation Act 1999	Flora and Fauna Guarantee Act 1998
	Aboriginal and Torres Strait Islander Heritage Protection Act 1984	Water Act 1989
		Fisheries Act 1995
	Native Title Act 1993	Environment Protection Act 1970
		State Environment Protection Policy (Waters of Victoria) 2003
		Catchment and Land Protection Act 1994
		Planning and Environment Act 1978
		National Parks Act 1975
		Crown Land Reserves Act 1978

3.2.1 State Environment Protection Policy (Waters of Victoria) (Victorian Government Gazette, 2003)

State environment protection policy – SEPP - Waters of Victoria (WoV), subordinate legislation under the *Environment Protection Act 1970*, was updated in June 2003 to reflect current scientific approaches and Victoria's catchment management arrangements, replacing the first policy from 1988. The 1988 SEPP focused mainly on the key problems facing waterways in the 1980s, particularly point source discharges. The new policy recognised that, since 1988, a partnership approach for protecting the environment has been developed where government, businesses and community members are working together. The new policy also recognises that catchment management authorities and the regional coastal boards are central to coordinating these partnerships.

The 2003 SEPP also provides a statutory framework for the next 10 years to protect the uses and values of Victoria's fresh and marine water environments. As required by the *Environment Protection Act 1970*, the SEPP includes:

- The uses and values of the water environment that the community and government want to protect – these are known as beneficial uses;
- The objectives and indicators which describe the environmental quality required to protect beneficial uses; and
- Guidance to catchment management authorities, coastal boards, water authorities, communities, businesses and local government and state government agencies to protect and rehabilitate water environments to a level where environmental objectives are met and beneficial uses are protected (the attainment program).

Objectives and indicators of environmental quality have been updated from the original SEPP. The 2003 SEPP includes objectives and targets to provide the ultimate goal and to encourage and drive continuous improvement towards that goal. The 2003 SEPP also supports the need for the development of appropriate targets that drive progressive rehabilitation of environmental quality and refers to and is structured around the use of new assessment approaches such as Ecological Risk Assessment. Guidelines for Environmental Management (GEM's) are being developed to support the implementation of the SEPP, and a GEM on risk based assessment of ecosystem protection in ambient waters has recently (November 2004) been released.

The SEPP includes a number of specific clauses relevant to the Broken Creek system including:

Water Management;

- Clause 40 – Water Conservation
- Clause 41 – Water allocations and environmental flows
- Clause 42 – Releases from water storages
- Clause 43 – Surface water management and works
- Clause 46 – Urban Stormwater Management

Catchment Management;

- Clause 50 – Agricultural Activities
- Clause 51 – Irrigation Channels and Drains
- Clause 53 – Vegetation protection and rehabilitation
- Clause 54 - Recreational Activities

Many of these clauses require state government agencies, catchment management authorities, water authorities, industry and the community to work together minimise pollution and protect surface waters, with some specific roles clearly defined. Please refer to State environment protection policy – SEPP (Waters of Victoria) for further details.

3.3 Policies, Strategies and Guidelines

A number of policies, strategies and codes of practice or guidelines relevant to the protection of riverine health and water quality need to be considered in the implementation of the revised Broken Creek Strategy. These are summarised in Table 4, and key policies are described in more detail below.

Table 4 Relevant Policies, Strategies and Guidelines

Policies, Strategies & Management Plans	Codes of Practice/Guidelines
White Paper, Securing Our Water Future	Irrigation Drainage Memorandum of Understanding
Victorian River Health Strategy (2003)	Lower Broken Creek Operational Guidelines
Draft Goulburn Broken Regional River Health Strategy (2004)	Best Practice Management Principles and Standards for Dryland Drainage
Goulburn Broken Regional Catchment Strategy (2003)	Nutrient Best Practice Guidelines for Horticulture
Goulburn Broken Water Quality Strategy 2002	Nutrient Best Practice Guidelines for Irrigated Pasture
Victorian Biodiversity Strategy (1997)	Best Practice Guidelines for Construction of Surface Water Management Schemes
Victoria's Native Vegetation Management Framework	

Policies, Strategies & Management Plans	Codes of Practice/Guidelines
Victorian State Fishway Program (1999)	Automatic Irrigation Incentive Scheme: Guidelines for the Shepparton Irrigation Region Catchment Strategy
Murray Darling Basin Salinity Management Strategy	Drainage Reuse Incentive Scheme: Guidelines for the Shepparton Irrigation Region Catchment Strategy.
Draft Murray Darling Basin Commission – Fish Management Plan (2003)	Whole Farm Plan Incentive Scheme: Guidelines for the Shepparton Irrigation Region Catchment Strategy
Murray Daring Basin Salinity Management Strategy (2001)	Community Surface Drainage Guidelines
Moira Shire Urban Stormwater Management Plan	Environmental Assessment Procedure for Integrated Catchment Management
SIR Catchment Strategy	Environmental Assessment Procedure for Integrated Surface Water Management
SIR Surface Water Management Strategy Review	Guidelines for the Protection of Water Quality (NE Victoria Planning Referrals Committee, 2000)
SIR Sub Surface Drainage Review	Current Recommended Practices for the Goulburn Broken Catchment 2004
Farm Strategy Review	Concentrated Dairy Effluent Guidelines
Muckatah Depression Drain Stage 1, Draft Drain Management Plan	AgNote 0435 and 0430 for Dairy Shed Effluent
Kinnairds Wetland Environmental Management Plan	Dairy Cattle Feedpad Guidelines for the Goulburn Broken Catchment
Irrigation Drainage Memorandum of Understanding (IDMOU)	Managing Nutrients on Irrigated Dairy Farms

3.3.1 The White Paper – Securing Our Water Our Future (Victorian Government, 2004)

In June 2004, the Minister for Water John Thwaites released the White Paper*, Securing Our Water Future,* an action program including 110 new initiatives to secure Victoria's water for the next 50 years.

Since the White Paper is a key policy document guiding water management in Victoria into the future, relevant initiatives need to be considered in the development of the revised Lower Broken Creek Strategy. These initiatives include:

- Releasing 165 000 ML environmental water for Murray and Victorian tributaries;
- Improved environmental flows in Goulburn and Broken Rivers;
- River Murray icon site gains water – Barmah Forest;
- Lake Mokoan to be returned to wetlands;
- Making 'sales' water into secure, tradeable entitlements;
- Irrigation channel upgrade and new technology for Tatura;
- Projects to improve farm water efficiencies and reuse systems;
- Pipeline for efficiency of Tungamah supply, saving 4 000 ML;
- Water recycling projects;
- $30 million for dam safety and $50 million for irrigation system improvements;

- Improvement of the Eildon Dam wall; and
- Raising the height of the Lake Nillahcootie dam wall.

3.3.2 Victorian River Health Strategy (DNRE, 2002)

The Victorian River Health Strategy (VRHS) outlines the government's long-term direction for the management of Victoria's rivers. It provides a vision for the management of rivers in Victoria, policy direction on issues affecting river health and a blueprint for integrating protective efforts on rivers and ensuring that river health benefits are achieved for the resources invested. A key philosophical change in this policy is the approach of "protecting the best", rather than spreading limited resources across all environmental issues affecting river health.

The VRHS provides a framework for regional communities to make decisions on river protection and restoration and to find the balance between using rivers and maintaining their ecological condition. The VRHS therefore provides an overall policy framework that needs to be considered when identifying management directions for the Broken Creek.

3.3.3 Goulburn Broken Regional Catchment Strategy (GBCMA, 2003)

The Goulburn Broken Regional Catchment Strategy provides the context in which the Goulburn Broken catchment community will work with the Commonwealth and State agencies, rural and urban water authorities, landholders, the broader community and local government to achieve the regional vision for the catchment. It sets the context for the Catchment's sub-strategies and action plans.

The Goulburn Broken RCS 2003 features an updated vision and a reassessment of the catchment's natural assets and current and emerging threats to land and water assets such as increasing salinity and declining water quality. The RCS prioritises the actions and works that must occur to address these threats so that effort and funding can be directed where they are most needed. A key element of the strategy is the whole of catchment approach that promotes investment that offers benefits to the natural environment, the social fabric and the economy of the region. This 2005 Broken Creek Strategy has been developed consistent with the framework provided in the RCS.

3.3.4 Draft Goulburn Broken Regional River Health Strategy (GBCMA, 2004)

The Goulburn Broken Regional River Health Strategy (2004 – 2014) was prepared by the River Health and Water Quality Committee of the Goulburn Broken Catchment Management Authority. The Goulburn Broken Regional River Health Strategy builds on existing river-related action plans, implementation plans and strategic documents and is supported by a series of sub-strategies and discussion papers. The Regional River Health Strategy provides a framework for the integration of actions that will enable rivers of high quality to be protected and others to be improved in quality for current and future generations. The Strategy sets on four key objectives:

- Protect the rivers that are of highest community value from any decline in condition;
- Maintain the condition of ecologically healthy rivers;
- Achieve an 'overall improvement' in the environmental condition of the remainder of rivers; and

- Prevent damage from future management activities.

The strategy identifies a number of high priority waterways within the Goulburn Broken catchment. These include rivers that are "of greatest value to the community", and rivers that are currently "ecologically healthy". It also identifies waterways within the catchment that can potentially be improved to ecologically healthy condition. Reaches 21 to 24 in the Broken Creek are defined as High Priority Waterways as a result of the notable high value assets they contain. These high value assets are listed below:

- Reach 21 — Associated with Ramsar Wetland
- Reaches 21 -23 — Murray Cod
- Reaches 22 -24 — Associated wetlands of national significance

Key threats to high value assets in the Goulburn Broken Catchment waterways are identified in the strategy using an asset based risk assessment process as applied in the RiVERS database. It identifies programs or management responses from existing sub-strategies that seek to address key threatening processes or restore and improve environmental conditions, as well as developing new programs where they do not already exist. It sets five year implementation targets and 10 year resource condition targets for major river reaches and river health objectives for major river management units, as well as outlining a monitoring program to measure the success of the Strategy.

As the Goulburn Broken Regional River Health Strategy is the main overarching strategy with most direct relevance to the Broken Creek Waterway Management Strategy, we have aimed to make our approach and framework consistent with the Regional River Health Strategy. However, it is important that this is balanced with the implementation of management strategies, such as the Land and Water Salinity Management Plans, which aim to protect and enhance the land resources.

3.3.5 SIR Surface Water Management Strategy 2002 (SMEC, 2002)

The Shepparton Irrigation Region Surface Water Management Strategy was reviewed in 2002, to examine changes in design and construction practices, and changes in the legislative, administrative and business environment since the strategy was last reviewed in 1995.

The primary goal of the Surface Water Management Strategy is:

"By 2020, improve the health of natural resources and reduce the risk to investment in the Shepparton Irrigation Region, by providing appropriate Surface Water Management service in areas where the total benefits, including economic, social and environmental benefits, exceeds the costs".

Sub-goals of the Surface Water Management Strategy include:

1. *Minimising adverse impacts on the biodiversity and quality of water in streams receiving water from drains;*
2. *Providing an opportunity for enhancement of high value wetlands and other areas of high conservation value;*
3. *Reducing groundwater accessions, thus reducing the need for subsurface drainage and salt disposal from the region in the longer term;*

4. *Providing a mechanism for the conveyance and distribution of subsurface and surface drainage water within the Region and, as necessary disposal from the Region;*
5. *Reducing the adverse impact of waterlogging on the productivity of pastures and horticultural plantings;*
6. *Providing a catalyst for landholders to undertake positive salinity control activities and improve farm productivity on their properties;*
7. *Incorporating current design features in existing drains to deliver a better mix of beneficial outcomes;*
8. *Ensuring Surface Water Management projects are financially equitable and affordable;*
9. *Reducing road construction and maintenance costs; and*
10. *Ensuring surface drains do not intensify downstream flooding.*

Of relevance to the Broken Creek Waterway Management Strategy, the Surface Water Management Strategy contains the Goulburn Broken Water Quality Strategy objectives to reduce and manage nutrients through reducing water outfalling from drains, the promotion and adoption of Best Management Practices (BMPs) including whole farm plans, drainage re-use and drainage diversion, and action plans to concentrate on the management of drainage water during the summer irrigation season for target catchments, including the Broken Creek. The Surface Water Management Strategy also includes the development of Drain Management Plans to promote BMPs such as retention of vegetation to assist with nutrient stripping, as well as promoting research into appropriate BMPs.

The Surface Water Management Strategy contains costs for works in the Broken Creek catchment. These costs include those for the replacement of some of the weirs on the Lower Broken Creek that have been completed, as well as those for works in the Muckutah drainage area for the construction of the Browning's Road Diversion Drain.

3.3.6 Sub-service Drainage Review 2002 (SKM, 2002)

The Sub-Surface Drainage Program is part of the Shepparton Irrigation Region Land and Water Salinity Management Plan, and at the time of its review in 2002 was in its tenth year of implementation.

The overall objective of the Sub-Surface Drainage Program is, where possible and justified, to protect and reclaim the Shepparton Irrigation Region's land and water resources from salinisation.

The preferred package of works adopted by the Draft Plan (1989) aimed to serve some 213 000 ha by the year 2020 through:

- Implementation of management arrangements for 395 existing (i.e. entirely landholder funded) and 365 new private pumps to serve 85 000 ha of current and future high groundwater level areas; and
- Installation of approximately 425 public pumps and some 50 disposal basins to serve a further 85 000 ha in areas where private pumping and farm reuse was not feasible.

A review of areas subject to high groundwater levels since 1982 and the results of further investigations indicate that the preferred package (1989) is still appropriate for strategic planning purposes.

The review presents a forecast of Future Works Program through to 2023. The program assumes the priority for the private program will be retained and largely completed by 2010, 10 years ahead of schedule. The timeline for public works was extended to 2023 to offset the relatively low rate of implementation at the time, and the program has been accelerated to meet this revised timeline.

Groundwater management and salt disposal is fundamental to the implementation of the Sub-Surface Drainage Program. This will require a significant salt disposal requirement under the Murray River Salt Disposal Entitlement (SDE), and probably the most critical long term issue for the Plan is to secure SDEs for future implementation and establish groundwater reuse options that minimise SDE requirements.

In 1993, a range of salt disposal guidelines were suggested for the Region's streams and wetlands, with a maximum salinity limit of 300 EC set for the Broken Creek (SKM, 2002). Salt disposal guidelines have since been established for the Broken Creek (SKM, 1996c), which are discussed within the Sub-Surface Drainage Program. There are two current guidelines for out of season disposal to the Broken Creek:

- River Murray trigger flows must be met; and
- Flows at Rice's Weir should be on a rising trend and exceed 300 ML/d for seven consecutive days.

Modelling of average salinity of 230 EC in Broken Creek by the year 2020 indicates there will be little impact on disposal opportunities; however this will need to be re-assessed if monitoring indicates a significant change from the base conditions.

3.3.7 Memorandum of Understanding for Irrigation Drainage Management and Water Quality, 2004

The Memorandum of Understanding for Irrigation Drainage Management and Water Quality, which is commonly referred to as the Irrigation Drainage Memorandum of Understanding (IDMOU), is intended to articulate the day-to-day portfolio responsibilities and intentions of the Parties (Department of Sustainability and Environment, Goulburn Broken Catchment Management Authority, North Central Catchment Management Authority, Environment Protection Authority and Goulburn Murray Water) to work cooperatively and in partnership to deliver sustainable surface water management in the Irrigation Districts in northern Victoria.

The IDMOU provides a framework for target setting and adaptive management. Targets are set as Resource Condition Key Performance Indicators (KPIs) within the relevant Land and Water Management Strategy/Plan and Management Action Performance Indicators (Pis) within the relevant Surface Water Implementation Plans. The IDMOU provides for a risk based decision support process to assist decision-making with respect to the selection of Resource Condition KPIs and Management Action PIs.

The IDMOU also provides for Performance Reviews of Resource Condition KPIs, Management Action PIs, and a Process Audit of the five yearly Performance Reviews and the five yearly Target Setting processes.

3.4 Management Roles and Responsibilities

Key management roles and responsibilities of the regional stakeholders are described in the Goulburn Broken Regional Catchment Strategy and the Regional River Health Strategy. These roles and responsibilities are equally relevant to sub-strategies such as the Broken Creek Management Strategy, and are therefore adopted here. These are summarised in Table 5 below.

Table 5 Roles of Regional Stakeholders

Goulburn Broken Catchment Management Authority (GBCMA)

The Goulburn Broken Catchment Management Authority was formed in 1997, and is responsible for works on waterways, regional drainage and floodplain management, and co-ordination of Commonwealth and State natural resource management investment in the region. GBCMA is responsible for the development and review the Regional Catchment Strategy, as well as input to its implementation. Through its Implementation Committees, the GB CMA provides strong community ownership and input to the Strategy.

Department of Sustainability and Environment (DSE)

The DSE, through its responsibilities to the Minister under the Water Act and the CALP Act, provides financial, policy and strategic support for the development and implementation of regional waterway strategies. The department is also responsible for statewide land use planning and the implementation of the Planning and Environment Act.

Department of Primary Industries (DPI)

DPI provides technical and extension support for developing and implementing regional catchment strategies. These services are provided through the Northern Irrigation and North East regional offices. Of particular importance is the research and development input provided by the department's research institutes.

Local government

The Catchment includes the municipalities of Moira, Campaspe and the City of Greater Shepparton in the SIR and the Benalla Rural City and shires of Mitchell, Mansfield, Murrindindi and Strathbogie in the dryland part of the Catchment. Local governments are central to the Strategy's implementation through their responsibilities for land use planning, development approvals, rates and a variety of services such as road construction and maintenance.

Goulburn Murray Water (G-MW)

G-MW contributes to irrigation, drainage, water supply and management of specific water supply catchments. It licenses surface and groundwater extractions, and plays a major role in irrigation salinity management, water quality management and regional economic development. It also contributes significantly to other riverine health outcomes.

Urban water authorities

Goulburn Valley Water and North East Water provide water and wastewater services to urban communities in the region. These authorities manage specific water supply catchments and contribute to the water quality outcomes of the region by investment in improved wastewater management services.

Environment Protection Authority (EPA)

The EPA co-ordinates all activities relating to the discharge of waste into the environment and the generation, storage treatment, transport and disposal of industrial waste. It seeks to control pollution and protect the quality of the environment. The EPA's efforts are guided by the State Environment Protection Policy (Waters of Victoria).

Landholders

Achieving the Strategy outcomes requires changes in the way we manage our natural assets. Under the Catchment and Land Protection Act Landholders are required to: 1) avoid causing or contributing to land degradation which

causes or may cause damage to land of another owner; 2) conserve soil; 3) protect water resources; 4) eradicate regionally prohibited weeds; 5) prevent the growth and spread of regionally controlled weeds; and 6) prevent the spread of and, as far as possible, eradicate established pest animals.

Landcare Groups

Landcare groups enable the community to participate directly in natural resource management, particularly by identifying and setting direction for on-ground works and mobilising community involvement in their local area. Landcare groups and networks will continue to play a major role in implementing regional strategies.

Parks Victoria

Parks Victoria manages state and National parks within the Goulburn Broken Catchment, including the Broken Boosey State Park. Its primary role is to ensure the conservation values of the parks and reserves network is protected.

Aboriginal Groups

The Aboriginal community possess knowledge of their cultural history and the natural environment that is valuable in the development and implementation of natural resource management programs. Over the coming five years the CMA will build on existing arrangements to create an environment that promotes indigenous involvement, ownership and input.

Universities and TAFE

Universities and TAFE Colleges operating in the region must continue to provide a high level of service and to produce graduates with an extensive knowledge of natural resource management issues. They have an ongoing role in providing support to natural resource managers through student and staff involvement in Catchment initiatives.

Industry

Through its operating practices and peak industry groups, such as Murray Dairy and the Victorian Farmers Federation (VFF), industry is able to exert strong influence over natural resource management outcomes.

Environment groups

These groups are major contributors to the outcomes of the RCS by either involvement in shaping its direction or delivering onground works. The groups include the region's Environment Alliance Network, and the Goulburn Valley Environment Group.

4. Vision and Management Objectives

4.1 Vision

The following Community Vision for the Broken Creek has been identified through consultation with the Community Reference Group:

"A healthy system that provides water for human and agricultural use, protects and enhances our social, economic and cultural values, and sustains a vibrant range and abundance of native flora and fauna."

4.2 Management Objective

The following management objectives have been identified in consultation with the Project Steering Committee and stakeholders:

1. Conserve existing genetic diversity.
2. Provide effective water supply that meets the needs of users.
3. Provide regional and irrigation drainage.
4. Maintain and enhance existing riparian vegetation structure and intactness.
5. Enhance in-stream ecological values.
6. Improve the quality of recreational fishing and other recreation opportunities.
7. Improve in-stream water quality to ensure that the above objectives can be met.

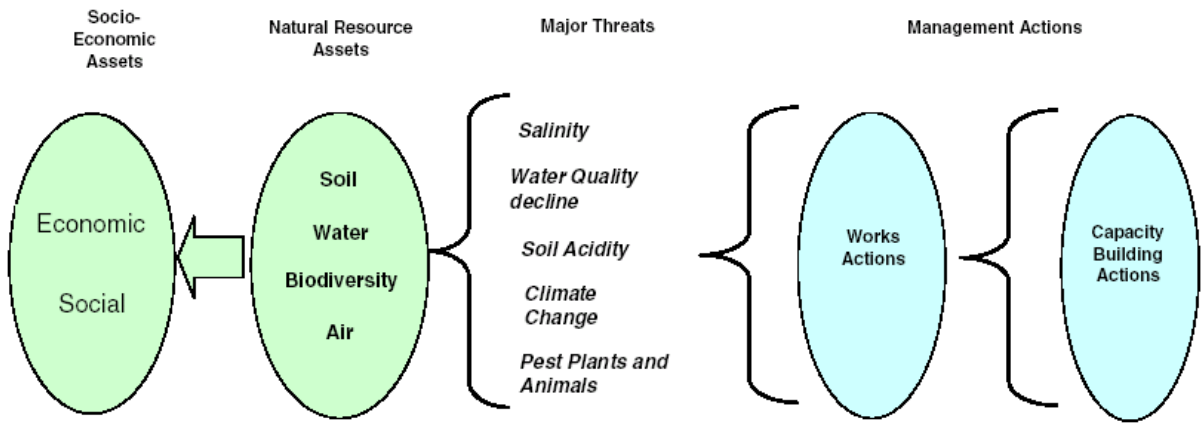
It needs to be recognised that achieving these objectives will require some trade-offs, as in many instances there may be conflict between competing objectives. For example, the provision of irrigation and drainage services may have an impact on genetic diversity, or instream ecological values for some species. The role of this management strategy is to find a balance between sustainable use and conservation.

5. Natural Assets and Values

5.1 Asset-based Approach to Natural Resource Management

This Strategy has been developed consistent with the asset-based approach to natural resource management described in the Goulburn Broken Regional Catchment Strategy (GBCMA, 2003). The Strategy recognises that as our understanding of natural resource management improves we can target our investments so that our environmental, economic and social assets are more efficiently protected. This asset-based framework is diagrammatically represented in Figure 4.

Figure 4 Assets, threat and action framework – Works Actions target both past and present causes that impact on natural assets



The region's **social assets**, consisting of its people (individuals and as communities of interest) and its **economic assets** (physical and financial assets) depend on ecosystem services provided by our **natural assets**.

Major threats include water quality decline arising from nutrients and sedimentation, pest plants and animals and loss of biodiversity. The major threats to the Broken Creek are described in Chapter 6.

5.2 Environmental Values of the Lower Broken Creek

The environmental values of the Lower Broken Creek were identified initially via the RiVERS database method, which is based on expert and community consultation, field assessments and collation of information from a range of environmental databases. The values identified within the RiVERS database were then validated by field assessment, and through the community consultation process undertaken for the development of this strategy. The values are identified and assessed considering significant flora and fauna, invertebrate and fish diversity, structural intactness, significant sites, wetlands attributes and significance listings as shown in Table 6. Environmental Value scoring protocols are presented in Appendix C.

Table 6 Environmental values from RiVERS

Stream Name	Reach No	Significant fauna	Significant flora	Invertebrate O/E	Ecological Vegetation Class	Structural intactness	Longitudinal Continuity	Fish Migration	Fish O/E	Proportion Introduced fish	Wetland Significance	Wetland Rarity	Width vegetation	Sites of significance	Heritage River	Ecologically healthy river	Environmental rating
Broken Creek	**21**	5	5	0	5	3	5	4	4	2	5	5	3	1	1	1	3 Moderate
Broken Creek	**22**	5	5	0	5	4	2	4	4	2	4	5	3	1	1	1	3 Moderate
Broken Creek	**23**	5	5	3	5	4	3	1	3	2	4	5	2	1	1	1	3 Moderate
Broken Creek	**24**	1	5	0	5	4	4	1	3	2	4	5	3	1	1	1	3 Moderate
Nine Mile Creek	**28**	5	5	2	5	4	3	1	2	1	1	1	5	1	1	1	2 Low

Note: Invertebrate O/E score of '0' equates to the absence of data, not a rating of 0.

5.2.1 Significant Fauna

Significant fauna included for this project has been identified within 100 m of the waterway. Most information has been provided by the RiVERS database application analysis, which was used to develop the Goulburn Broken River Health Strategy. Table 7 presents the significant fauna listed within the waterway and 100 m either side.

Table 7 Significant fauna of the Reaches of the Lower Broken Creek

Scientific Name	Common Name	Conservation Status[1]	FFG[2]	ANZECC[3]
Ardea alba	Great Egret	e	L	
Aythya australis	Hardhead	v		
Burhinus grallarius	Bush Stone-curlew	e	L	
Limnodynastes fletcheri	Barking Marsh Frog	k		
*Maccullochella macquariensis**	Bluenose(Trout) cod	e	L	
Maccullochella peelii peelii	Murray cod	v	L	
*Macquaria australasica***	Macquarie perch	e	L	
Nycticorax caledonicus	Nankeen Night Heron	v		
Petaurus norfolcensis	Squirrel Glider	e	L	

Scientific Name	Common Name	Conservation Status[1]	FFG[2]	ANZECC[3]
Ramphotyphlops proximus	Woodland Blind Snake	v		
Stagonopleura guttata	Diamond Firetail		L	
*Tandanus tandanus**	Freshwater catfish	v	L	
Varanus varius	Tree Goanna	k		

1. Conservation Status is identified as: e = endangered; v = vulnerable; k = indeterminant; r = rare.

2. FFG = Flora and Fauna Guarantee Act, 1988. L = listed

3. ANZECC = Australian and New Zealand Environment Conservation Council. E=endangered

* Have been recorded in lower reaches of Broken Creek (Kennedy's Weir 2000) and other anecdotal recordings. Possibly not self-sustaining population but migrating from Murray River. (J. McGuckin, pers comm 2004)

** Have not been recorded in Lower Broken Creek for over 50 years, but may still inhabit creek (J. McGuckin, pers comm 2004).

5.2.2 Significant Flora

The Broken Creek is rated as being of high significance throughout the length of the reaches covered by this report for significant flora. This reflects the presence of endangered and depleted Ecological Vegetation Classes along most of the length of the creek, in a landscape that is largely cleared and intensively farmed. There is almost continuous riparian woodland along the Broken, Boosey and Nine-mile Creeks, although the width of the tree community and intactness of the understorey varies.

Significant flora included for this project has been identified within 100 m of the waterway. Information has been provided by the RiVERS database application analysis, which was used to develop the Goulburn Broken River Health Strategy. Table 8 presents the list of significant fauna listed within the waterway and 100 m either side as identified in RiVERS database.

Table 8 Significant flora identified in RiVERS database

Scientific Name	Common Name	Conservation Status[1]	FFG[2]	ANZECC[3]
Acacia notabilis	Mallee Golden Wattle	v		
Allocasuarina luehmannii	Buloke		L	
Alternanthera nodiflora	Common Joyweed	k		
Atriplex spinibractea	Spiny-fruit Saltbush	e		
Austrostipa gibbosa	Spurred Spear-grass	r		
Callitriche sonderi	Matted Water-starwort	k		
Cullen parvum	Small Scurf-pea	e	L	E
Cullen tenax	Tough Scurf-pea	e	L	
Eulalia aurea	Silky Browntop	r		

Scientific Name	Common Name	Conservation Status[1]	FFG[2]	ANZECC[3]
Haloragis glauca f. glauca	Bluish Raspwort	k		
Lotus australis	Austral Trefoil	k		
Minuria integerrima	Smooth Minuria	r		
Myoporum montanum	Waterbush	r		
Poa fordeana	Forde Poa	k		
Templetonia stenophylla	Leafy Templetonia	r		
Ixiolaena sp. 1	Woolly Buttons	r		
Eleocharis pallens	Pale Spike-sedge	v		

1. Conservation Status is identified as: e = endangered; v = vulnerable; k = indeterminant; r = rare.

2. FFG = Flora and Fauna Guarantee Act, 1988. L = listed

3. ANZECC = Australian and New Zealand Environment Conservation Council. E=endangered

5.2.3 Invertebrate Observed / Expected

This measure examines the presence of invertebrate families (observed) against those that occur in similar systems (expected). This ratio is derived from the National River Health Program conducted by the Victorian EPA and indicates the ecological condition of the stream. This information is limited to two reaches of the lower Broken Creek (Broken Creek, Reach 23 and Nine Mile Ck, Reach 28), which indicates that the macroinvertebrate community is generally depleted against expected levels.

5.2.4 Ecological Vegetation Class

Fifteen different Ecological Vegetation Classes (EVCs) and mosaics of some of these have been identified from EVC mapping of the reaches of the Broken, Boosey and Nine-mile Creeks under discussion. Of these, 11 are listed as endangered, three are depleted and one is vulnerable. This reflects the widespread loss of native vegetation across the Northern Plains of Victoria, and the significance of the remnant vegetation along the creeks.

5.2.5 Structural Intactness

The values for structural intactness provided by the Index of Stream Condition (ISC) data are widely varied for the reaches under consideration. The scoring system in RiVERS gives high scores to multiple vegetation layers. The low values reflects the degraded condition of the riparian vegetation at many sites where grazing has removed the shrub layer. Along the Broken Creek system, the shrub layer is the component of the vegetation that has suffered greatest decline (Robinson and Mann 1996). Shrubs were recorded at less than 40% of their sites, and only 15 of the 473 surveyed sections had an extensive shrub layer. While tree-felling is prohibited on Crown Reserves, the almost universal grazing resulted in the early destruction of the shrub layer. Additionally, EVCs such as high quality Northern Plains Grassy Woodland could be given a low score in the RiVERS process as in these EVCs the shrub layer can be discontinuous and sparse, or absent.

5.2.6 Longitudinal Continuity

The continuity of the creek line vegetation is a significant factor in assessing the ecological value of this vegetation. In an extensively cleared landscape such as the northern plains of Victoria, the isolation of native vegetation remnants is a cause of the gradual decline in biodiversity of such patches over time, as many plant and animal populations cannot readily move between remnants and they are susceptible to species loss. The longitudinal continuity of creek line vegetation provides a corridor for movement or gene flow between larger blocks of vegetation, and opportunities for species to recolonise degraded plant communities if the habitat improves (eg. by fencing). Good continuity also provides corridor habitat for daily and seasonal movements of birds, feeding and migrating between the riverine forests of the Murray and foothills and box-ironbark forests near Benalla and Wangaratta (Robinson and Mann 1996).

The ISC data analysis gives low scores for some reaches of the creeks. This does not fit with a general perception of fairly continuous tree cover in the crown reserve. It may be that even where trees are fairly continuous, the absence of a shrub layer at many sites may reduce the score. The narrowness of the tree corridor in some sections and the occurrence of small gaps in the canopy will also reduce the score, as commonly the trees are the only native component of the vegetation. The ISC data scoring process may not adequately cater for woodland communities, where tree canopies commonly do not touch.

5.2.7 Fish Migration

Several of the fish found within the Broken Creek need to move from one location to another to undertake some biological functions (breeding, feeding, etc). Many of the threatened fish in this system are migrating species and the upland areas of the Broken Catchments are linked to the significant Murray River and Barmah Forest wetland areas. The value of this connection has been recognised by the extensive fishway construction that has been undertaken. These fishways ensure fish of all sizes have passage past each weir along the length of the system (Lance Lloyd pers. comm. 2004).

5.2.8 Fish Observed/Expected

There is a high level of observed fish species compared to those expected within the Broken Creek. This is probably due to a combination of the excellent fish passage, the diverse habitats within the system and the longitudinal connectedness from the Murray River to upland areas.

5.2.9 Proportion of Introduced Fish

Many of the fish present within the Broken Creek are native fish but as with most Murray-Darling rivers there is a relatively high proportion of introduced species such as carp, Eastern Gambusia and redfin. The presence of these species, sometimes in high numbers, is reflected in the scores for this environmental value.

5.2.10 Wetland Significance

The wetlands of the Broken are mostly confined to narrow riparian zones which are inundated frequently and which contribute the habitat complexity of the system. Some significant sites exist in the lower reaches such as those present adjacent to, or within, the Barmah Forest, which is a wetland of international significance (Commonwealth of Australia, 2003).

5.2.11 Wetland Rarity

The wetlands of the Broken Creek are highly valued as other wetlands have been alienated from rivers and creeks due to the construction of levees. This alienation has occurred in a few locations on the Broken Creek, which could be re-engineered to allow high flows to inundate these sites. The engineering works required to do this might be relatively simple but discussions with landholders will be necessary to allow this to happen, and landholders would require assurance that these works would not result in an increased flood risk.

5.2.12 Width of Vegetation

The tree cover along the creeks largely reflects the width of the Crown Land Reserve. Robinson and Mann (19996) calculated that in their study area (including the whole length of the Broken-Boosey Creek system) 28% of the sections recorded had a crown reserve width of less than 30 metres while 21% had a tree width less than 30 metres. Although tree removal is not allowed on a crown reserve, there has been significant attrition over the 150 years of settlement and as the majority of frontages are grazed, no compensatory regeneration has occurred in most reaches. The width of remnant vegetation is a strong predictor of species diversity and abundance of birds, and native plant species diversity. Along the Broken Creek, low values for width may then be more important for environmental rating than structure or continuity in the RiVERS analysis.

5.2.13 Sites of Significance

There are no sites of significance in the Lower Broken Creek.

5.2.14 Heritage River

The Lower Broken Creek is not listed as a heritage river.

5.2.15 Ecologically healthy rivers

There are no reaches that meet the “ecologically healthy rivers” criteria in the lower Broken Creek study area (GBCMA 2004).

5.3 Community Identified Values

In addition to the values identified through the development of the RiVERS database, which in itself involved extensive stakeholder input, a range of values was identified by the community through the community consultation process (Community Drop-In Sessions and the Community Reference Group meetings) specifically undertaken as part of the strategy review. These are summarised in Table 9.

Table 9 Community Identified Values

Values	◗ High value native vegetation. ◗ Awareness of conservation values of creek. ◗ Rare and threatened flora and fauna ◗ Fauna habitat. ◗ Potential for trout cod to travel up creek (recently recorded at Barmah). ◗ Catfish. ◗ Shade value for stock. ◗ Road access to properties via the riparian zone has meant these areas are not grazed. ◗ Town aesthetics, urban enhancement (Numurkah & Nathalia). ◗ Tourism in Numurkah and Nathalia (economic value). ◗ Nice place to live. ◗ Recreation – walking / fishing / hunting. ◗ Improved fishing from Katandra weir half way to Katamatite, primarily due to release of fish and reduction in carp. ◗ Water supply for urban water supply, domestic, stock and irrigation use. ◗ Cultural / historical values.

Community identified values include a range of environmental, social and economic values, which are consistent with the range of values identified within the RiVERS database. As indicated in Figure 4, there is a direct relationship between natural assets / values and social or economic asset / values, such that a threat to a natural asset / value often results in a threat to a related social asset / value. This highlights the importance of protecting and enhancing the natural assets of the Broken Creek. While the strategy has focused on the environmental assets and values, a full list of the RiVERS environmental, social and economic assets / values was incorporated within the risk assessment framework presented in Appendix D.

6. Major Threats

The sixteen major threats identified in the RiVERS database are presented in Table 10 and discussed in general below. Chapter 7 then presents an assessment of the hazard of the threats to the environmental values described in Chapter 5, to identify the key management responses required to protect and enhance the Lower Broken Creek. Threat value ranking scores are presented in Appendix C.

Table 10 Threats Rated in RiVERS Database

Stream Name	Reach No	Bank stability	Bed stability	Barriers to fish	Channel Modification	Flow deviation	Water quality trend	Water quality level	Water quality signal	Exotic flora	Exotic fauna	Loss of instream habitat	Loss of riparian	Change to water temperature	Algal blooms	Loss of wetland connectivity	Stock access	Threat rating
Broken Creek	**21**	2	1	1	2	5	5	5	0	2	0	2	3	0	5	3	5	3 Moderate
Broken Creek	**22**	2	1	1	2	5	0	0	0	2	0	3	3	0	1	2	5	2 Low
Broken Creek	**23**	3	2	1	2	5	0	0	1	3	0	2	3	0	5	2	5	3 Moderate
Broken Creek	**24**	1	1	1	2	5	0	0	0	2	0	3	3	0	1	2	5	2 Low
Nine Mile Creek	**28**	2	2	1	2	1	0	0	5	3	0	3	2	0	1	2	5	2 Low

Note: Scores of '0' equates to the absence of data, not a rating of 0. Water quality is considered to be a significant threat; hence the need for further data collection and analysis is highlighted as a priority.

6.1 Bank Stability

SKM (1996a) reported that the 1961 aerial photographs revealed only localised bank erosion. HydroTechnology (1994) reported that landowners on the Lower Broken Creek were concerned about trees falling into the Creek from bank erosion, and some localised rock beaching work has been conducted in recent times to prevent what is known locally as "green tree fall". There has never been any systematic survey of bank stability along the length of Broken Creek (SKM, 1996a), although ISC surveys attempt to report on this process. Stakeholder input indicates that green tree falls are an ongoing issue within the Lower Broken Creek.

Apparently, the regulated flows in the Broken Creek system were higher in the early years of operation of Lake Nillahcootie (on the Broken River, upstream of the study area) during the early 1970s (Mark Bailey, GM-W, pers, comm. 2000), but no data are available to confirm this. Certainly, imposition of long periods of near-banktop flows for long periods of the year is known to result in channel widening, as the channel adjusts to the higher flow volume. Weir pools are also susceptible to widening, due to the relatively constant water levels resulting in fretting of a notch in the bank. Carp may have been involved in stream channel degradation, but they are unlikely to be the main explanation for significant channel widening.

Bank erosion has been noted in some parts of Broken Creek, but mostly in the lower reaches. Reach 24 and Reach 28 (Nine Mile Creek) do not have bank erosion problems (SKM, 1998). Further downstream, in Reach 22, bank erosion is more prevalent than further upstream, but SKM (1996a) regarded this as of "minor concern". SKM (1996a) reported some slumping of banks in Magnussons Weir pool due to saturation from long periods of high water levels. Within the weir pool near Nathalia township, rock beaching was recently incorporated into works in some places on the left bank. This is known locally as a "green tree fall" area where the perception is that it is undesirable for living trees to fall into the creek.

Downstream of Rices Weir some minor scour is apparent. This is to be expected, and would not normally be regarded as a serious problem. However, this is close to the site of a midden, which makes the erosion undesirable.

Nine Mile Creek suffered bed instability and resultant bank slumping following dredging in the 1960s, but this was largely controlled by the installation of sheet pile weirs. SKM (1998) noted minor bank erosion still occurring, explained by the fact that the channel capacity is still less than the combined capacities of Drains 11 and 12.

6.2 Bed Instability

The weirs along the middle and lower Broken Creek were constructed in the early 1900s. The impact of these weirs on siltation of the creek bed, and hence flood levels, has been the subject of previous and ongoing debate. The earliest channel survey was undertaken in 1961 as a series of cross-sections of lower Broken Creek channel. Unfortunately the surveyors failed to record whether they surveyed the upper level of a silt surface (presuming it was present), or the level of the hard bed (SKM, 1996b, 31). Thus, comparison of cross-sections surveyed in 1961 and 1994 were equivocal (1996a). SKM (1996b) and SKM (1996a) found no evidence for a net build up of sediment since 1961, but they did find evidence for bed degradation downstream of many weirs. Apparently, aerial photographs show that silt was present at time of the 1961 survey (SKM, 1996b). Potential sources of silt in the lower Goulburn Creek at that time include erosion of material in the upper catchment area (gullies and surface erosion) and channel bank erosion.

AWT (2001) found that the Back/Boosey Creek system (part of the upper Goulburn Creek catchment, draining the Warby Ranges) showed evidence of aggradation by silt. Soon after settlement and clearing of the Goulburn-Broken catchment, sediment would have been delivered from slopes to channels through land clearing, and other sediment would have been delivered from channels through tributary degradation (incision resulting from channel destabilisation). The process of accelerated mobilization of sediment from the landscape appears to have begun soon after clearing, and peaked during the early part of the 1900s. While this process mobilized sediment, the delivery of high quantities of sediment to the streams in the Goulburn-Broken catchment appears to have been delayed until the 1940s-1950s (Erskine et al., 1993), explained by temporary storage of sediment in morphological sink areas in the landscape, and slow delivery rates. Streams in the Broken Creek catchment also probably widened in response to regulated flows from 1900 onwards, which would have contributed further sediment to the channels, and also reduced the stream power, thereby reducing the capacity of the streams to transport the additional sediment being supplied.

Previous field inspection of streams in the Upper Broken Creek catchment suggested that Nine Mile Creek, Broken Creek and Major Creek do not have an excessive sedimentation problem (AWT Victoria, 2001). They are low-lying streams connected to the Broken River system, and do not have a nearby high elevation sediment source area. However, they are low gradient lowland streams, and natural deposition areas. Streams such as this do not necessarily have clearly defined pool-riffle morphology, especially in areas with naturally high sediment loads. It could not be determined in the field that these streams had excessive sedimentation; nor could it be definitively determined if a deep pool habitat was previously a characteristic feature of these streams.

A previous survey by Fluvial Systems Pty Ltd of sediment depth behind weirs on upper Goulburn Creek catchment channels (AWT, 2001) generally found minimal sediment build up immediately behind weir walls on Broken and Major Creeks. Flynn's Weir on Broken Creek had 0.75 m of silt deposited behind the weir wall, but the surface level of this deposit was at the same elevation as the downstream sill of the weir. It would appear that in this case, the hard bed of the channel behind the weir wall is deeper than the bed of the channel downstream of the weir wall, so it was not unexpected to find that this pool had filled with sediment up to at least the level of the stream bed (making the bed profile continuous). No sediment was detected behind the wall of Reilly's Weir on the Broken Creek. Back Creek was previously observed to have a considerable siltation (aggradation) problem (also reported by locals). While Back Creek showed evidence of aggradation by silt, Boosey Creek (same channel, but further downstream) did not. Major Creek showed no evidence of accelerated sedimentation being caused by the weir structures. This study concluded that Broken, Back/Boosey and Major Creeks are currently relatively stable systems. In general the streams carried fine-grained sediment, but there appeared to be localised sand sources available as well.

While confirming that the Back/Boosey Creek system had much more fine sediment deposited in the bed than the upper Broken Creek and Major/Nine Mile Creek systems, Gippel (2001) concluded that the main disturbance to the catchment and channel has ceased. Therefore most of the deposit is an artefact. However, some of the tributary streams are reported to be still delivering sediment to the lower floodplain areas (Wayne Tennant, GB-CMA, pers. comm., 2000). Sandy Creek is reported to be a problem in this respect (SKM, 1998). SKM (1998) reported sedimentation of former pools in Broken Creek upstream of Numurkah. Sedimentation downstream of discharge locations for drainage channels, such as MV drain 13, has also been identified as an issue through the community consultation process.

In the 1960s, dredging was undertaken in the lower Nine Mile Creek and the section of Broken Creek upstream of Walsh's Bridge to Nine Mile Creek in preparation for implementation of Drains 11 and 12. It is possible that this activity released some sediment to the channel that was deposited downstream (SKM, 1996b).

The Broken Creek downstream of Walsh's Bridge occupies a large channel shaped by a former watercourse. Its capacity is in excess of the hydraulic requirements of the existing creek, so it is naturally prone to deposition of sediment (aggradation). This aggradation is a natural process that has been occurring since the course change occurred some 25 000 years to 30 000 years BP and will continue until the channel dimensions are in balance with the flow regime (SKM, 1998).

In conclusion, the threat to stream values in the Lower and Middle Broken Creek system from bed instability is not considered to be great. This is based on the lack of evidence for bed aggradation since surveys were undertaken in 1961, and the general lack of sediment build-up in weirs in the upper catchment. The Back/Boosey system, which drains the Warby Ranges, is a source of sediment to the Broken Creek, but most of the sediment in this system accumulated long ago.

6.3 Barriers to Fish

Barriers to fish are generally artificially created by humans through the construction of weirs and levees. The recent upgrade of the eight weirs along the Broken Creek with state-of-the-art SCADA controlled overshot gated structures with fishways has meant that the numbers of barriers has been largely reduced throughout the system. Issues still exist in the Nine Mile Creek where weirs, drop structures and a lack of suitable habitat may effectively contribute to fish movement barriers through this anabranch.

6.4 Channel Modification

Channelisation works have been undertaken on 32 km of the Middle and Lower Broken Creek and Nine Mile Creek up to the Drain 12 confluence. These include localised straightening, removal of excessive macrophyte growth, bed deepening and cutting a channel through wetlands. Dredging was significant, being up to 1 m in Broken Creek and up to 2 m in Nine Mile Creek (SKM, 1996a). Diversion of flows by willows has caused some bank erosion in some reaches of Broken Creek.

In Reach 24, minor excavations have been made to achieve relatively constant low flow channel capacity, and there has been considerable effort since prior to the 1960s on cumbungi control (SKM, 1996a). More recently Arrowhead has been recognised as a major aquatic weed problem, and this has also required management. Weed growth causes blockage of the low flow channel and loss of capacity.

With respect to location of pump offtakes, the past practice was to modify the Creek through the Crown frontage so it could be taken to the pump shed, located on private land (this is not current practice). The modified area can suffer siltation, and required occasional dredging.

In Reach 23, from the junction of Nine Mile Creek to Carlands Bridge, the creek bed was regraded in the 1960s using a cutter-suction dredge to improve drainage outfall capacity. This dredging lowered the bed by up to 1 m, and would have removed some components of physical habitat, such as large woody debris. Cumbungi control was also undertaken in this reach following channelisation.

Reach 22, from Carlands Road to Barmah Forest, was not dredged, because here the Creek flows through the larger ancestral channel. However, the effects of weir construction and de-snagging would have been similarly detrimental to the physical form of the channel (SKM, 1996a). In Reach 21, large woody debris (LWD) has been realigned to increase flow velocities as a method for clearing Azolla.

Sheet pile weirs were installed in the lower Nine Mile Creek to control bed erosion and resultant bank slumping that followed dredging performed in the 1960s. In 2003, six grade control structures were built in an effort to introduce variability in the long profile as a means of improving instream habitat. Some rock beaching was performed fairly recently near Wunghnu to protect “significant” trees from falling in the creek.

The eight weirs from Melville Street Weir downstream have recently either been replaced with a new structure comprising of SCADA controlled overshot gated openings and rock faced earthen bank secondary spillway, or had SCADA controlled overshot gated openings installed in the existing structure (except at Station Street). Each of these structures has had fishways incorporated into its design.

Weir pools have very low velocities, which encourage the deposition of fine silt on the bed, reducing biodiversity, degrading habitat, and producing conditions favourable to introduced or opportunistic species such as carp, willows, *Typha* and Arrowhead. Excessive growth of nuisance aquatic plants can lead to lowered channel capacities, exacerbating minor floods.

6.5 Flow Deviation

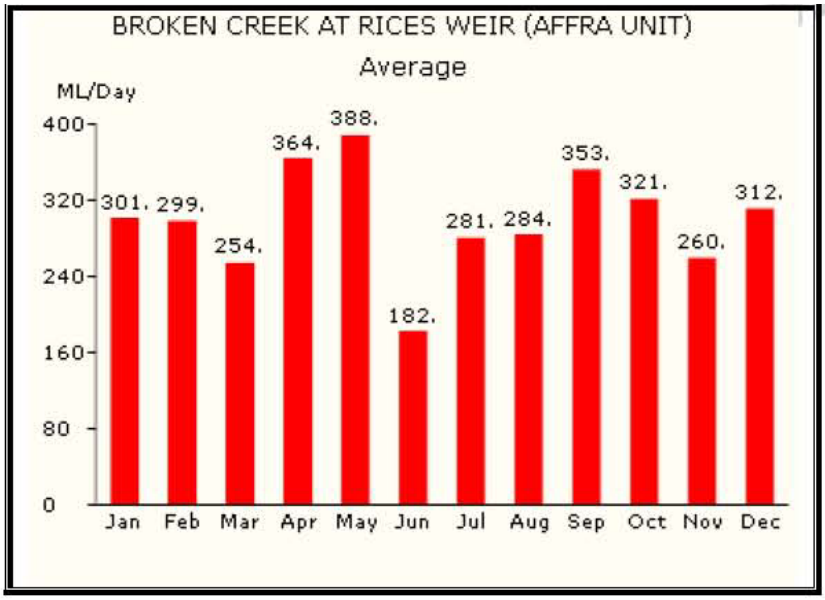
A change in the hydrology of the formerly seasonal or intermittent Broken Creek system to a lentic system of stepped weir pools and relatively high and constant water levels during the irrigation season (as described in Section 2.2) is likely to change vegetation composition. The dominant Grey Box communities of the riparian vegetation reflect the dry conditions that regularly prevailed in this environment prior to settlement. Red Gums, which typically fringe more permanent rivers and streams, are only found on the Broken where the water table was high enough to sustain them (Robinson and Mann 1996). Increased flows in summer and a higher regional water table could gradually enable Red Gum to spread beyond its former distribution on the creeks and replace Grey Box. Robinson and Mann note that Lignum appears to have become more common along the creeks in the last 50 years, possibly as a response to increased water availability. High water levels in summer also favour Cumbungi and exotic aquatic weeds, particularly Arrowhead.

The annual flow pattern at this site is illustrated in Figure 5 which indicates that while flows deviate from a natural flow regime substantially, there are some elements of the flow regime which mimic natural flows. In particular, there is a small rise in flows in spring that may allow breeding and recruitment of many native fish including Murray Cod. It appears that an unintended consequence of the altered flow regime in the lower Broken Creek and the provision of weirs is that the environment is attractive to deeper bodied native fish, to the point where DSE regards it as the third most important Murray Cod spawning ground in Victoria [Terry Bailley, DSE, pers. comm., as reported in Butcher (2004)]. Despite the significance of this waterway to a listed endangered species, there has been no environmental flow allocated to the creek. G-MW and River Murray Water have provided a return flushing flow of between 40 and 120 ML/d from the River Murray, via G-MW's irrigation channels on the northern side of Broken Creek to prevent a fish kill recurrence while the strategy review comes up with a long term solution (Butcher, 2004).

It is likely that attempts to restrict the sources of artificial flows in Broken Creek will meet with continued success in future, leading to more frequent low flow events at Rices Weir (where a fish kill occurred in Nov 2002). As the Murray System seasonal allocation increases, it will become progressively more difficult for G-MW to pass the flushing flow through the creek without impacting on customer service levels. There may come a point where G-MW's obligations under the Water Act 1989 to supply entitlement holders will prevent G-MW from supplying the flushing flow (Butcher, 2004). The pressure on flows in Broken Creek will most likely manifest in reduced creek flows in winter in average flow years, with recent experience suggesting the problem could extend into spring and intensify in drought years with low allocations (Butcher, 2004). In addition, the impact of the disposal of saline groundwater to the creek from public and private pumps on hydrology, water quality and fish populations may exacerbate this problem. This suggests that the risk of another fish kill is increasing.

The statewide Index of Stream Condition (ISC) measures flow deviation from natural as an indicator of stream condition and the RiVERS database applies the same measure to evaluate flow as a threat. Given that there have been substantial changes in the flow regime in the Broken Creek, the threat is rated as high. This does not translate to recommending the Broken Creek return to its natural flow regime, this is unachievable if the system is to carry water for consumptive purposes and may even result in environmental degradation within such an altered system. It does mean that it is important to assess the risk the current flow regime poses on the environmental, social and economic values and to recommend management options to reduce the flow threat in the existing system. The risks flow poses to environmental values are evaluated in Chapter 7. Some changes to flow patterns may result in environmental benefits but pose low impacts on economic and social values.

Figure 5 Annual Flow Patterns in Broken Creek



6.6 Water Quality

Water quality has three components in the RiVERS database - level, trend and signal. Water Quality Level is the pattern of concentrations and loads of nutrients over time and is usually measured against water quality criteria such as SEPP objectives. Water Quality Trend is the measure of the rate of change of water quality level. Water Quality SIGNAL (Stream Invertebrate Grade Number Average Level) is a biotic index that uses the fact that each family of macroinvertebrates has a different sensitivity to pollution. SIGNAL scores below 4 indicate probable severe pollution, scores of 4-5 indicate probable moderate pollution, scores of 5-6 indicate doubtful water quality, possible mild pollution and scores greater than 6 suggest clean water status.

The poor water quality of the Broken Creek is not reflected in the RiVERS threat scores, and so the values and threats for water quality are principally based on an assessment of the available water quality data.

6.6.1 Water Quality Level

The common water quality parameters monitored within Victorian waterways are presented in Table 11.

Table 11 Common Water Quality Parameters Monitored Within Victorian Waterways

Parameter Type	Parameter	Reason for measuring
Physico-Chemical Parameters	Turbidity	Direct impacts from smothering and changes to the light environment. Samples can be taken on site with simple equipment – can be used as an early alert system for other changes.
	Dissolved Oxygen (DO)	Oxygen dissolved in water is important for the survival of fauna (fish, macroinvertebrates, zooplankton). Low dissolved oxygen can not only be stressful/lethal to fauna but can result in chemical changes at the sediment-water interface, causing the undesirable release of sediment-stored nutrients.
	Electrical Conductivity (EC)	Electrical conductivity is an indication of the salinity of the water. High salinity in freshwater systems can be detrimental to flora and fauna.
	pH	Changes in pH outside the specified range will cause loss of the more sensitive species of flora and fauna.
Nutrients	Nitrite and Nitrate (NOx)	NOx is an inorganic form of nitrogen within the water that is potentially available to plants. Nitrogen is a nutrient for plants that promotes growth. It also promotes undesirable algal growth (e.g. blue-green algae) and, therefore, elevated levels of NOx are undesirable.
	Total Kjeldahl Nitrogen (TKN)	TKN is the organic nitrogen within the water. It is nitrogen that is bound to other chemicals, forming biological material (i.e. as part of flora and fauna) and is only available for plant uptake if broken down into simpler components.
	Total Nitrogen (TN = TKN + NOx)	TN is the total nitrogen that is in the water.
	Reactive Phosphorus (FRP)	FRP is essentially the dissolved fraction of Phosphorus and is readily uptaken by aquatic plants and algae, even in very low concentrations.

Parameter Type	Parameter	Reason for measuring
	Total Phosphorus (TP)	TP is the total phosphorus that is in the water. Like nitrogen, it is a plant nutrient that can promote algal growth.
Bioassessment	Macroinvertebrates	This is standard EPA monitoring protocol (EPA 1998a) that measures macroinvertebrate abundance and diversity. These results give an indication of stream health, provide an impact assessment tool and allow comparison against SEPP Objectives.

As a lowland river, the Broken Creek is likely to have had naturally high turbidity levels for much of the year, but land use changes in the catchment have resulted in higher turbidity, nutrient and salinity levels. Increased level of turbidity and nutrients along with low flows and warm water have resulted in increased frequency of algal blooms and nuisance aquatic plant growths. These are key problems in the lower Broken Creek, which are exacerbated by low flows, and require ongoing management.

A long term monitoring station has been established by the Murray-Darling Basin Commission at Rices Weir since 1978. Results of key water quality parameters measured in the laboratory for this site are summarised in Table 12, and the SEPP water quality objectives (Victorian Government, 2003) are shown in Table 13 for comparison.

Table 12 Long term monitoring data from Broken Creek at Rices Weir

Parameter	Minimum	25th Percentile	Median (50th Percentile)	75th Percentile	Maximum
Turbidity (NTU) (lab)	7.4	82	87	120	240
Electrical Conductivity (EC) (lab)	70	140	170	200	480
Total Nitrogen (mg/l)	0.333	1.007	1.332	1.81	4.89
Total Phosphorus (mg/l)	0.032	0.250	0.330	0.460	5.700
Dissolved Oxygen (% Saturation)	0	80	89	103	122
pH	0.00	6.80	7.00	7.20	8.3

*Source: summarised from the www.vicwater.data.net Data Warehouse website

Table 13 SEPP (WoV) water quality objectives

SEPP Objective	Parameters					
	Dissolved Oxygen	Turbidity	Electrical Conductivity	pH	Total Phosphorus	Total Nitrogen
Criteria	25th %ile / Max	75th %ile	75th %ile	25th/75th %ile	75th %ile	75th %ile
Murray & Western Plains	85/110 % saturation	30 NTU	500 EC units	6.4/7.7	0.045 mg/l	0.9 mg/l

Shaded cells in Table 12 show water quality levels that do not meet corresponding water quality objectives in State Environment Protection Policy (SEPP) – Waters of Victoria (WoV).

Comparison with SEPP levels shows that dissolved oxygen and turbidity do not meet SEPP objectives. However, it is known that spot samples of dissolved oxygen do not necessarily accurately or reliably report the true levels of fluctuations. Information available from the recent work commissioned by G-MW (Butcher, 2004), which examines dissolved oxygen and temperature over a 24 hour period, will provide a more reliable picture of the dissolved oxygen environment at Rices Weir.

Electrical conductivity and pH almost always meet the SEPP objectives. Nutrient levels are extremely high with both phosphorus and nitrogen levels almost always exceeding the SEPP objectives. Dissolved oxygen levels are also relatively low indicating high algal and aquatic populations using oxygen within the water column as a response to high nutrient levels.

In addition to this data, there are additional field measurements (available from the Data Warehouse website) from this site, which indicate that turbidity ranges from as low of 7 NTU (field measurement shows 0 but laboratory assessment is 7 NTU) to as high as 330 NTU, and the median level of 100 NTU. Salinity ranges from a low of 70 EC to a maximum of 480 EC with a median of 170 EC.

While salinity in the Broken Creek currently meets SEPP environmental quality objectives, salinity is of increasing concern, especially on the Riverine Plains, where the watertable is rising at an alarming rate. It is predicted that there will be significant increases in salinity in particular areas of the Goulburn-Broken catchment over the next 20-30 years if major management interventions are not implemented. This may result in the degradation of aquatic environments. At present, 45% of the Shepparton Irrigation Region is underlain by shallow watertables and this will rise to 60% if nothing is done (Hart et al, 2002). The annual economic losses are expected to rise from the current $30M to $47M by 2000 and $90M by 2020 (MDBC, 1999, Hart et al, 2002).

6.6.2 Water Quality Trend

The nutrient target set in the 1998 Broken Creek Management Strategy - “Nutrient concentration should not increase in the next 10 years, and nutrient loads should decline by 20% within 10 years” - is unlikely to be achieved given the likelihood of nutrients being stored within the system and slowly released over time (CMPS&F Environmental, 1995).

In the Goulburn Broken catchment, much of the sediment in the stream network is the result of erosion in the period not long after initial European settlement, and remobilised in the period of the 1940s and 1950s (Erskine et al., 1993). It is likely that these sediments still act as a phosphorus source (CMPS&F Environmental, 1995). Other sources of nutrients arise from current day farming practices, grazing of stream banks, storm water from townships and direct discharges. Sediment samples were taken from 10 sites within the Broken Creek in June 2003 and analysed for nutrients and organics. All organics were below detection limits. It is difficult to assess the nutrient results, as no sediment guidelines exist for nutrients. The ANZECC water quality guidelines indicate that further research is required before nutrient guidelines can be developed.

Each year the data of the nutrient monitoring program is summarised and an assessment made of the impact of irrigation drainage on nutrient loads exported from the Goulburn and Broken catchments to the Murray River. Trend analysis were conducted on a statewide basis in 1999 (Smith and Nathan 1999) indicating that significant water quality degradation was evident with respect to increases in turbidity and total phosphorus at the Rices Weir site. Other parameters assessed included pH, EC and Total Nitrogen but no significant trends were observed. The only other site within the Broken Creek that had sufficient water quality data for trend analysis is upstream at Katamatite. This analysis did show a small decrease in pH and significant increases in turbidity, with other parameters showing no steady fluctuation in levels.

More recently, SKM (2004) provides an updated analysis of trends in flow, nutrient concentrations and nutrient loads in irrigation drains in the Shepparton Irrigation District, which includes the Broken Creek at Rices Weir and Shepparton Drains 11 and 12. Data collated as part of the analysis includes rainfall data, irrigation delivery data, load data and concentration data, and was trend was analysed using the Generalised Additive Model (GAM). Variation in nutrient concentration with time was tested independent of the variability of flow, whilst the trend in flow was tested after removing the effects of rainfall variability. Both of these parameters were also tested independent of seasonality and, if found to be a significant indicator, irrigation deliveries. The trend analyses for the river monitoring sites, including Broken Creek were carried out for TP and TN concentrations only. If a statistically significant trend was identified at a site for any of the parameters analysed, a trend analysis of load was also undertaken. This parameter was tested independent of rainfall, irrigation deliveries and season (SKM, 2004).

The results show no significant trend for total nitrogen concentration for Shepparton Drains 11 and 12, and Broken Creek at Rices Weir. For Broken Creek, the increasing total nitrogen trend has been reduced since last measured two years earlier. This indicates that the downstream sites are receiving less TN than previously. For Total Phosphorus concentration there was no significant trend for Shepparton Drain 11, a significant downward trend for Shepparton Drain 12, and a very significant upward trend for Broken Creek at Rices Weir. For TN and TP load a very significant downward trend is evident for both Shepparton Drains 11 and 12. Broken Creek at Rices Weir was not analysed for load. This result indicates that flow rather than concentration is the current driver affecting nutrient loads, and the influence of flow on load data is believed to be considerable.

Trend plots from the GAM analysis are presented in the Appendix of the SKM 2004 report, but raw data is not provided.

6.6.3 Water Quality SIGNAL

Water Quality SIGNAL data is only available for two reaches of the Broken Creek, Reach 23 and Nine Mile Creek (Reach 28). The SIGNAL score indicates that Nine Mile Creek has a moderate to significant levels of pollution but Reach 23 has good water quality.

6.7 Exotic Flora

The invasion of weeds – terrestrial, riparian and aquatic, remains a serious threat to riparian vegetation, which may be exacerbated in some areas by the removal of grazing. The long continuous boundary with farmland makes this vegetation particularly vulnerable to weed incursions. Terrestrial agricultural species such as Phalaris are likely to invade from adjacent paddocks, particularly if soil disturbance occurs. Riparian species such as *Lippia* are a growing threat. This species already occurs on the Broken Creek, and has the potential to spread. It is a particularly difficult species to control.

The most significant aquatic weed species at the present is Arrowhead, which has spread rapidly in the last few years until it now presents a very difficult control problem. It is probable that it has not yet reached its full expression in the Broken Creek system, and will continue to spread into all suitable habitats. The impact of arrowhead is greatest in shallow reaches, and it is likely to increase the siltation rate in areas where it is established. As a result, it may sometimes be able to spread further by modifying the profile of the creek or weir pool.

Azolla is a native floating plant which under some conditions can increase prolifically, creating dense floating mats that accumulate in still water, and cause a serious oxygen deficiency when it dies. It has been associated with significant impacts on the health of the Broken Creek, most notably the November 2002 fish kill.

Likewise Cumbungi is a problem in the creek, particularly upstream of Numurkah where it is impacting on the operation of Kinnairds wetland, where spraying would be problematic, and similarly upstream of Wunghnu on the Nine Mile creek where it is interfering with the provision of water to of Black Swamp (Shane Papworth, G-MW, pers comm.). This native plant is valuable habitat in the creek, particularly where other structural habitat features such as large woody debris is absent. It benefits from high water levels in summer and accumulation of silt.

There are other potentially serious aquatic weeds present in low numbers in the upper and mid Goulburn Catchment, and it is important that a rapid response be implemented as soon as any of these species are detected. The most conspicuous exotic species along the creeks has been willows. The removal program has been effective in most reaches, and it is likely that this species may no longer be a serious threat. A number of other exotic weeds were mentioned in the community consultation meetings, including blackberries, olives, date palms, briars and peppercorns. They may all behave as environmental weeds.

The most common exotic flora is introduced grasses and forbs, including weeds and common agricultural species such as Rye Grass, Barley Grasses and brome grasses, which dominate much of the understorey in the riparian woodlands. Only in a few very high quality remnants would native grasses and forbs comprise most of the biomass, even if there are more native than introduced species present. This is a result of the long history of grazing and disturbance of the creek frontage. Removal of grazing by fencing may exacerbate this for some time and it may be appropriate to use some controlled grazing to reduce the dominance of introduced grasses in some sites.

6.8 Exotic Fauna

Exotic fauna is not given as a value in the ISC data analysis. Rabbits and foxes would be expected to be present in varying numbers along the creek reserve, depending on the control activities carried out by adjoining landholders. Foxes are a continual threat to a number of ground dwelling and breeding species such as lizards and Bush Stone Curlews. Fox populations may be favoured by the fencing of the creek frontage because of increased shelter provided by vegetation growth. Exotic fish are prevalent within the system, notably Carp, Eastern Gambusia and redfin perch would dominate the fish fauna. EHN virus has resulted in declines of redfin perch but the other two species are well established. These are likely to be reduced if flows regimes are altered to favour native fish and support improved river health. Carp and Eastern Gambusia are unlikely to be removed from the system unless the Daughterless Gene technology, current being trailed, is successfully applied to both species. In optimistic scenarios this has a 30-50 year timeframe. Therefore habitat and flow improvements are critical to support native fish to survive in the short term and flourish in the longer term.

6.9 Loss of Instream Habitat

Instream habitat is all the biophysical aspects of the environment that are required by aquatic organisms for shelter, feeding and breeding. The main elements of instream habitat are:

- Substrate or sediment type;
- Flows;
- Water quality;
- Structural elements (Large Woody Debris, LWD, in lowland systems, rocks and boulders in higher order streams); and
- Aquatic plants (which act as critical habitat for many fish and invertebrate species but are also dependant upon the elements above).

All of these elements interact, are spatially and temporally variable, and various ecological feedback mechanisms are driven by and dependent upon them.

However, various management responses can cause a loss of instream habitat. Dredging that may be carried out in weirs or channels for silt removal presents a threat to riparian vegetation, from both mechanical disturbance (resulting in damage, removal and disease of vegetation) and from the dumping of silt (resulting in smothering and death of plants). De-snagging removes LWD and disturbs the sediment and changes local flow patterns and can cause silting and erosion. Sedimentation and highly turbid flows can cause loss of aquatic vegetation and eutrophication, through the nutrients attached to the sediment. Changes in the flow regimes can change the aquatic vegetation; affect water quality and substrate type.

6.10 Loss of Riparian Vegetation

Riparian vegetation is a very important part of the ecology of streams as it provides valuable “services” such as shade, woody debris (a habitat and energy source), invertebrates as a food source for some fish, and habitat for amphibians, aquatic reptiles and waterbirds. However, it is also easily lost due to grazing, riparian developments, recreational use, changes in stream flows and many other surrounding activities.

6.11 Change to Water Temperature

Changes to water temperature regimes are recognised as a serious threat to the ecology of rivers and streams, which alter the natural cues to native organisms and sometime providing an additional advantage to exotic species. Referred to as “thermal pollution” cold-water releases from dams and hot water releases from power stations often disrupt local ecological conditions such that complete new ecosystems develop. However, these new systems are frequently dominated by exotic fish, have lower biodiversity and few natural values. While drainage water may have a higher temperature than the receiving waters of the Broken Creek, the relatively small volume of discharge means that this impact is likely to be minimal, as indicated by the zero threat rating in Table 10.

6.12 Algal Blooms

Algal blooms are natural phenomena that occur when the right conditions coincide – these conditions tend to be low flows, high nutrient levels and warm water. However, historical landuse and water use changes have resulted in these conditions coinciding more often and algal blooms have become more frequent and intense across Australia. Impacts of algal blooms can include major fish kills; reduced recreation and tourism; farmers being unable to divert stock and irrigation water; and the costs to manage the bloom.

Water managers report that algal blooms have not been a major issue in the Broken Creek system but the RiVERS database records significant threats in reaches 21 and 23. Routine algal monitoring is not undertaken in Broken Creek, although ad-hoc monitoring is often initiated by G-MW in response to blooms or likely bloom conditions. This indicates that historically blue-green algae has not been a major problem in the creek, with the exception of an Alert 3 bloom (Microcystis aeruginosa) in 1991, and an Alert 2 bloom in 1999 (Microcystis) (Kevin Preece, G-MW, pers. Comm.).

6.13 Loss of Wetland Connectivity

Wetlands are integral components of riverine and floodplain ecosystems and wetlands provide many benefits to the biodiversity and functioning of rivers and streams. There are also many benefits provided back to the waterway by reinstating connectivity of wetlands and the Broken Creek. Wetlands can act as nurseries for native fish, sources of invertebrates, provide opportunities for breeding birds and provide carbon and sediment sources to the waterway.

The loss of wetland connectivity isolates wetlands from their rivers and can result in significant degradation of the ecological condition of the river or stream system. The loss of wetland connectivity is determined by the changes to the systems hydrology and channel modifications.

6.14 Stock Access

Grazing has historically been the major threat to vegetation diversity and structure. This is becoming less so with creation of the Broken-Boosey State Park with associated fencing and changes in land management. However the removal of grazing may in some areas present a threat to surviving native species if weedy species become more vigorous and widespread as a result. The response to grazing removal depends on the species composition of the vegetation at the site. Frontages that have been recently fenced will require some monitoring to ensure that there is no adverse response to sudden removal of grazing.

Incentives have been the main mechanism that has allowed an increase in riparian fencing in recent years, however other mechanisms will be required in those areas where landholders are reluctant to remove stock from riparian areas. Through the Crown Frontages review along the Lower Broken Creek other mechanisms such as reviewing grazing licences, putting protection conditions on new licences and providing advice to Crown Land Management should be considered.

6.15 Community Identified Threats

In addition to the threats identified through the development of the RiVERS database, which in itself involved extensive stakeholder input, a range of threats was identified by the community through the community consultation process (Community Drop-In Sessions and the Community Reference Group meetings) specifically undertaken as part of the strategy review. These are summarised in Table 14.

Table 14 Community Identified Threats

Threats	◗ Lack of clarity of agency roles – within and between agencies – communication of these roles to the community. ◗ Poor agency response to issues. ◗ Lack of adoption of new technologies to report problems in the Creek. ◗ Siltation of the Creek and the impact on Urban Water Supply (Numurkah). ◗ Lack of winter flow for Urban Water Supply. ◗ No permanent environmental flow.No delivery mechanism for environmental flow. ◗ Loss of production due to flooding. ◗ Variation of pool levels – up and down to quickly causing trees to fall. ◗ Powerlines – Powercor lopping of trees on one side increasing tendency of trees falling into stream. ◗ Trees falling across stream and causing major blockages. ◗ Maintaining abnormally high water levels has changed the vegetation types.

- Bank slumping due to flow variations, carp and overgrazing.
- Inappropriate operation of Broken Creek Fishways.
- Use of creek as irrigation channel.
- Dryland drainage (flow rates / water quality).
- Poor water quality from irrigation drains.
- Flow from Drains 11 and 12.
- Construction of more community drains upstream will lead to increased nutrients and flows downstream.
- Effluent disposal especially from dairy farms, especially after a large rainfall event following irrigation.
- Permanent transfer of irrigation water out of region.
- Rubbish and debris blocking the openings of fishways.
- Rubbish Dumping.
- Carp.
- Blue green algae
- Bardi Grubbing.
- Firewood removal.
- Increased fire risk by fencing off creek.
- Stock grazing on Crown Frontages.
- Ongoing woody weed management / insufficient follow up control.
- Weed control – Arrowhead, Patterson's Curse, Tomato Weed, Bathurst Burr.
- Cumbungi in stream.
- Emerging environmental weeds – blackberries / briar / date palms / olives.
- Vermin – foxes, rabbits, hares.
- Camping – rubbish, fires and other impacts.
- Climate change – what will Broken Creek look like in 100 years.

These community identified threats are largely consistent with the threats identified in the RiVERS database. These additional threats were also incorporated within the risk assessment process to determine the priority risks and management responses.

7. Risk Assessment

The basic aim of the risk assessment is to provide a systematic approach to measure the hazard of a particular threat impacting on a particular asset (environmental, social or economic). Risk analysis is expressed as a function of "likelihood", "consequence" and the level of the threat. Further details of the risk assessment process, and definitions were provided in the background field report (GHD / URS, 2004).

Risk assessment was conducted for combinations of threat and value in each reach as part of the Goulburn Broken Regional River Health Strategy, and the results for the Lower Broken Creek were reviewed as part of the development of this Strategy. The risk assessment results are presented in Tables B1 to B5 in Appendix D.

Within the Risk Assessment Result tables the resultant risk level is interpreted into a management response priority for the threat value combination. The management response priority (Table 15) provides a practical guide to highlighting priority threats.

Table 15 Key to management response priority

Very High	Urgent need to reduce threat level
High 1	First priority for threat reduction
High 2	Second priority for threat reduction
Medium 1	Third priority for threat reduction: Monitor asset level for decline: Opportunistic threat reduction
Medium 2	Monitor asset level for decline; Do not allow threat level to increase
Low 1	Do not allow increase in threat levels
Low 2	Assess whether threat is the cause of low value and act accordingly

7.1 Priority Threats

The RiVERS database identifies the following priority threats to be managed to protect the environmental values of the Lower Broken Creek:

- Stock Access;
- Water Quality; and
- Hydrology.

In addition to this, information gathered from literature review, field visits and the consultation process also highlights several additional threats requiring management. These are listed below:

- Exotic vegetation;
- Loss of aquatic habitat and fauna; and
- Loss of wetland connectivity.

These priority threats are summarised and described below.

7.1.1 Stock Access

While identified as a priority threat in the RiVERS database, stock access has been reduced due to significant works meaning much of the Lower Broken Creek has been fenced, so this risk should be decreasing along the creek. However there are still hotspot areas for fencing and revegetation where landholders are unwilling to fence off the creek to stock access. In addition, the need to fence channel systems where they enter the creek to control stock access, which is a threat to in-stream water quality, is considered a high priority by the community. Any management response in relation to stock control and fencing needs to concentrate on key locations to complete the fencing program.

7.1.2 Water Quality

Poor water quality reflects unfavourable drainage from irrigation areas, urban stormwater runoff, stock access and potential sewerage pollution. This poor water quality is exacerbated by stored nutrients and fine sediments on the bed of the creek coupled with low flows. Improving management of drainage has meant that water quality has improved to some degree but seasonal low flows mean that nutrients and other pollutants are released from sediments under conditions of low oxygen level. Even if further inputs of nutrient and sediment are controlled, it is likely that the accumulated store of nutrients and sediments within the Broken Creek will continue to influence water quality for many years to come. As a result, management efforts to address water quality may not be reflected in the water quality trend data for some time.

In addition, without significant ongoing management action, salinity in the Broken Creek is predicted to increase significantly in the next 20 – 30 years (GBCMA, 2002b). This will require catchment wide approach to reduce the salinity threat, however the Goulburn Broken Dryland Salinity Management Plan recognises that little that be done to manage the development of discharge on the Riverine Plains area due to the large area involved, and the slow response time of the regional groundwater flow systems (GBCMA, 2002b). Instead, efforts will need to focus on adapting to increasing salinity levels in this area.

7.1.3 Hydrology

With respect to hydrology, the flow regime has been altered from natural for around 50 years. Over this time period, it is likely that the creek ecosystem would have adjusted to the regulated regime, as reflected in changed abundance and diversity, and changed structure of the flora and fauna community. The precise nature of the change cannot be determined because of the lack of pre-regulation data. Also, the lower sections of the creek reportedly are havens for native fish, especially Murray cod, meaning some aspect/s of the flows and/or habitat are supporting these fish. A thorough investigation of the aspects of the current flow regime and the response of the ecosystem to this flow regime should be undertaken before substantial changes are made. Currently a return flushing flow of between 80 – 120 ML/d is being provided from the Murray system to prevent azolla build up, freshen weir pools and keep fishways open. Irrigation channels in the Murray Valley Irrigation Area on the northern side of Broken Creek are being used to supply this flushing flow during the irrigation season. However, there are likely to be constraints on the capacity of these channels to deliver these flows at critical times in the future (Butcher, 2004). Attention must be paid to determining and supplying suitable environmental flows for Broken Creek. The Ecological Risk Assessments (ERAs) undertaken by the Cooperative Research Centre for Freshwater Ecology in this catchment (Feehan et al., 2004) may be an appropriate approach to this issue.

7.1.4 Terrestrial weeds

Terrestrial weeds are rated as a relatively low risk in most reaches. The willow risk has been greatly reduced by the work that has been done over the last few years. However, other terrestrial weeds including peppercorn, desert ash, canary island date palm, olive, boxthorn, sweet briar have been recorded and are likely to spread without some effort to control them. It has been estimated that without management, terrestrial weeds in particular willows will again become abundant within the Broken Creek.

7.1.5 Aquatic Weeds

Aquatic weeds such as arrowhead, cumbungi and azolla are becoming an increasingly serious problem in irrigation areas. Without future management, it is likely that the risks proposed by aquatic weeds will become substantially worse. The risk from Arrowhead is high and likely to increase, particularly if siltation reduces the depth of the creek bed or weir pools. Lippia also presents a serious potential threat to riparian diversity. It is relatively insignificant in appearance but can dominate the ground cover and reduce diversity. Azolla has become a weed of serious concern following the attribution of the 2002 fish kill to a build up of this species. This native plant is favoured by the still water provided by weirs and low flow. The maintenance of sufficient flow in the system in the last couple of years has been successful in preventing a dangerous increase in the mass of Azolla. This will be an on-going requirement in the growing season if further major build-ups are to be avoided. If the phosphorous levels of the water can be significantly lowered over time this may reduce the vigour of this species Azolla management is difficult. It is a mobile native species that can't be managed by spraying or removal except in exceptional circumstances, and management usually involves manipulation of aquatic environment to provide conditions that do not favour this species.

The appearance of any other aquatic weeds should be treated as a high priority for removal before they spread and become expensive and difficult to control. However, it should also be noted that aquatic weeds are a symptom of a range of water quality and instream attributes. While weed removal is a useful short-term management option, in the long term, managing siltation, flow and instream and catchment nutrients are likely to be more important for preventing ongoing aquatic weed infestations.

7.1.6 Loss of Wetland Connectivity

Wetland health is one of the major aims of the Goulburn Broken Regional River Health Strategy. Some confirmation of significant unpriced values on the Broken Creek is provided by the fact that the 2 500 ha the Broken Creek floodplain is regarded as a "nationally important" wetland (ANCA 1996).

There are likely to be a number of sites, which if "opened up" would allow floodwaters or high flow to enter the floodplain wetlands and improve their condition (as long as grazing was controlled). These sites could vary in size from a few hectares in size to tens of hectares at any one site where works might be able to be of benefit.

Presently no information is available to determine the area of wetlands in the lower Broken Creek that would benefit from being opened up and therefore no benefits have been assessed. The RiVERS database indicates this is a moderate risk across the lower Broken Creek.

7.2 Association Between Threats and Values

The association is a measure of the theoretical potential for a threat to have an impact on the value. For many threats, there is a direct and obvious "association" with a particular value. For example, the presence of a barrier to fish migration has a high potential (or strong association) to have an impact on the fish community upstream; bank erosion has a strong association with riparian vegetation width; bed instability has a strong association with the macroinvertebrate community; and water temperature has a strong association with the social value of swimming.

For other threat/value combinations, there is no obvious association. The same barrier to fish migration, for example, has no association with passive recreational values upstream (i.e. the recreation values are completely independent as to whether or not there is a barrier to fish migration downstream).

Other threat/value associations are not so obvious. For examples, exotic riparian flora may, or may not, have an association with a significant fish species (depending on the species itself, and perhaps the location in the catchment); and bank erosion may or may not have an impact on European heritage values (being different, say, between an historic bridge and an historic farmhouse well away from the river bank). These association values are, therefore, site specific.

Association values were evaluated on a 1-5 scale (where 1 represents no association and 5 represents a strong association) for each possible combination of the 16 threats and 29 values (environmental, social and economic). The ratings between 1 and 5 were based on definitions and criteria outlined in Table 16.

Rather than allocate association values in each and every reach, the Technical Panel determined that a number of association values could be applied across the catchment. That is, the relationship between a threat and a value was constant, irrespective of the location in the catchment, or the specific nature of the value. Hence, a generic table of association values was established (Table 17) for a number of specific threat/value combinations.

Table 16 Association values adopted for the Riverine Health Strategy

Value	Meaning	Clarifier
1	Practically Impossible	Practically impossible that the threat will impact on the value.
2	Remotely possible	No evidence of threat impacting on value, but it is remotely possible.
3	Unusual but possible	Evidence in a few isolated cases where threat has impacted on the value
4	Quite possible	Some evidence that threat has an impact on the value
5	Almost certain	Good evidence that the threat always impacts on the value

Table 17 Generic association values for different threat/value combinations

	Bank erosion	Bed instability	Barriers to migration	Channel modification	Flow deviation	WQ trend	WQ level	WQ SIGNAL	Temperature	Exotic Flora	Exotic Fauna	Loss of Instream habitat	Algal Blooms	Degraded Streamside Zone	Wetland Connectivity	Stock access
Environmental Value																
Significant Flora	ss[2]	ss	1	ss	ss	ss	ss	ss	ss	ss	ss	ss	ss	ss	ss	ss
Significant EVC	ss	ss	1	ss	ss	ss	ss	ss	ss	ss	ss	ss	ss	ss	ss	ss
Significant Fauna	ss	ss	ss	ss	ss	ss	ss	ss	ss	ss	ss	ss	ss	ss	ss	ss
Significant Wetland	2	2	1	2	5	4	4	4	2	5	4	1	1	2	5	3
Wetland Rarity	2	2	1	2	5	4	4	4	2	4	4	1	1	2	5	4
Heritage River	ss	ss	ss	ss	ss	ss	ss	ss	ss	ss	ss	ss	ss	ss	ss	ss
Sites of Significance	ss	ss	ss	ss	ss	ss	ss	ss	ss	ss	ss	ss	ss	ss	ss	ss
Ecologically healthy	5	5	ss	5	5	4	4	4	4	5	5	5	4	5	4	4
Riparian Width	5	2	1	3	3	1	1	1	1	5	4	1	1	5	2	5
Riparian Continuity	5	2	1	1	3	1	1	1	1	5	4	1	1	5	2	5
Riparian intactness	4	2	1	1	4	1	1	1	2	5	5	1	1	5	2	5
Invertebrate O/E	4	5	1	4	3	4	5	5	5	4	2	5	4	5	4	4
Native Fish O/E	4	4	ss	5	5	4	4	4	5	3	4	5	2	4	4	4
Native Fish Proportion	4	4	4	5	5	4	4	4	5	3	4	5	2	4	4	3
Fish migration	2	2	5	4	4	3	4	4	4	1	2	4	2	2	ss	2

[2] **Note: ss – values are site specific**

7.3 Management Responses to Address Priority Risks

Table 18 presents the key management responses to address the priority risks to the Lower Broken Creek. The ● symbol represents a more direct or significant effect on the threat, whereas the ○ symbol represent an indirect or less significant effect. A description of each Management Response is outlined in Table 19.

Table 18 Management Responses to Address Priority Risks

	THREATS WHICH MAKE UP MAJOR RISKS											
MANAGEMENT RESPONSE	**Stock Access**	**Water Quality**	**Hydrology**	**Terrestrial weeds**	**Aquatic Weeds**	**Loss of Instream Habitat**	**Loss of Wetland Connectivity**	**Algal Blooms**	**Instream Barriers**	**Bank Erosion**	**Loss of Heritage Values**	**Recreation / People**
Fencing & Revegetation	●	○				○		○		○		
Enhance Instream Habitat		○				●						
Improve Flow Regime		●	●		●	○	○	●	○			
Water Quality Management		●			○	○		●				
Catchment Management		●	●					●		○		○
Drainage Management		●			○	○		●				
Terrestrial Weed Management				●								
Aquatic Weed Management					●							
Bank Erosion & Habitat – Nine Mile Ck		○				●		○		●		
Fish Passage									●			
Wetland Connectivity		○				○	●	○	○			
Cultural Heritage											●	
Planning	○	○	●	○	○	○	●	○	○	○	○	●
Communication	○	○	○	○	○	○	○	○	○	○	○	○
Monitoring & Evaluation	○	●	●	○	○	○	○	○	○	○	○	●
Research & Development		○		○		○		○		○		○

Table 19 Description of Management Responses

Management Response	Description
Fencing & Revegetation	Fencing off of priority riparian areas and channels, the provision of off-stream watering points for watering stock and revegetation of the riparian zone
Enhance Instream Habitat	Provision of Large Woody Debris (LWD) to enhance instream habitat.
Improve Flow Regime	Undertake an environmental flow assessment to guide decisions on changes to the hydrological regime to enhance ecological health, while protecting other social and economic benefits.
Water Quality Management	Stabilisation of bed and banks, riparian vegetation enhancement and management of algal blooms. Maintenance of dissolved oxygen levels to sustain native fish populations.
Catchment Management	While not the main focus of the management strategy, the importance of integrated catchment management to the health of the Lower Broken Creek needs to be considered. This issue is covered more broadly by existing strategies such as the Regional Catchment Strategy, SIR Surface Water Management Strategy, SIR Subsurface Drainage Strategy and the 1998 Broken Ck strategy for the upper catchment.
Drainage Management	Supporting the implementation of the Regional Water Quality and Drainage Strategies, and managing catchment and drain water quality and flow. The IDMOU is developing a decision support system that is a framework to identify drainage issues and develop monitoring to assess them.
Terrestrial Weed Management	Identifying and controlling priority terrestrial weeds infestations.
Aquatic Weed Management	Identifying and controlling priority aquatic weed infestations.
Bank Erosion & Habitat Management- Nine Mile Ck	Assessment of potential erosion risks associated with proposed works to enhance instream habitat within Nine Mile Creek.
Fish Passage	Evaluation and management of barriers to fish passage within Nine Mile Creek.
Wetland Connectivity	Assessment and implementation of options to enhance wetland connectivity in the Lower Broken Creek.
Cultural Heritage	Protection of aboriginal middens from bank erosion in Reach 21.
Planning	Development of a Fish Action Plan to combine and co-ordinates the range of management responses that will produce greater benefits for fish populations and reduce the risk of future fish kills; Undertake an Environmental Flow Assessment; Development of a Rapid Response Procedure to control weeds.
Communication	Provides actions for enhancing communication of information about the Broken Creek, and improving communication between agencies and the community.
Monitoring & Evaluation	Establishes monitoring and evaluation requirements to evaluate the effectiveness of the Strategy.
Research & Development	Identifies areas where further research will assist in enhancing our understanding of the Broken Creek and improve management responses.

8. Prioritisation of Management Responses

The investment prioritisation framework used within the project takes the priority risks and management responses identified and then uses benefit-cost analysis to assess the benefits and costs of those management alternatives in monetary terms.

Key issues for management were identified based on field visits and risk assessments data of RiVERS. The key issues identified ranged from those that affected the entire Broken Creek study area to those that only affected hotspot areas. As part of our assessment of the costs and benefits of management responses, we have described a number of case studies to assess site-specific (hot spot) river health issues.

Case studies have been used to assess the benefits and costs of:

- Riparian fencing and revegetation;
- Willow and aquatic weed management (including large woody debris);
- Enhancement of instream habitat;
- Increasing wetland connectivity; and
- Increasing base flows over Rices Weir.

For some management actions such as modifying flow regimes, the multiple benefits and costs of management cannot be assessed at a case study scale, but rather need to be assessed from a whole of river point of view. Management actions that fall into this category include:

- Flow management;
- Catchment management;
- Capacity building (Land Care, Water Watch and education programs);
- Planning activities (environmental flow strategy);
- Heritage management;
- Program management; and
- Monitoring, evaluation and reporting.

These management actions have not been prioritised independently, however they have been included within the overall economic assessment of the Broken Creek Strategy.

The benefits and costs that were assessed as part of the investment prioritisation framework are described in Table 20.

Table 20 The multiple benefits and costs of management responses within the Broken Creek

Management response	Benefits	Costs	Limitations
Fencing & Revegetation	◗ Improved healthy native vegetation ◗ Improved instream habitat ◗ Improved water quality ◗ Reduced sedimentation	◗ Materials to fence & revegetate ◗ Stock watering points ◗ Loss of grazing land ◗ Weed and pest management	◗ Limited landholder cooperation & investment
Terrestrial Weed Management	◗ Improved healthy native vegetation	◗ Labour costs to physically remove and manage terrestrial weeds	◗ Community opposition to weed removal in some areas (eg willows in townships)
Aquatic Weed Management	◗ Improved healthy native vegetation ◗ Improved instream habitat ◗ Improved amenity ◗ Reduced clogging of pumps and filters	◗ Labour and materials cost ◗ Cost of passing water flows	◗ Community perceptions of impacts of biocide use in waterways
Enhance Instream Habitat (LWD)	◗ Improved instream habitat ◗ Increased number and abundance of native fish species ◗ Increase recreational fishing ◗ Improved water quality	◗ Cost to source and install large woody debris	◗ Limited availability of LWD
Increase Wetland Connectivity	◗ Improved abundance and health of native vegetation	◗ Loss of grazing land ◗ Removal of levees	◗ Community opposition to flooding of wetland areas
Flow Management	◗ Reduced weed infestations ◗ Improved instream habitat ◗ Increased number and abundance of native fish species ◗ Improved water quality conditions within water column	◗ Potential impacts on stock, domestic and irrigation water users	◗ Implications of white paper for water trading ◗ Difficulty in obtaining permanent water allocation

Management response	Benefits	Costs	Limitations
Planning (Fish Action Plan)	◗ Increased number and abundance of native fish species ◗ Improved fish stocks (increased recreational fishing opportunities) ◗ Improved conservation status of listed species ◗ Improved instream habitat ◗ Improved co-ordination of fish related actions ◗ Fewer and less severe fish kills	◗ Potential impacts on stock, domestic and irrigation water users	
Catchment Management / Water Quality Management	◗ Reduced drainage discharge ◗ Reduced sedimentation ◗ Improved water quality and reduced algal blooms ◗ Increased efficiency of water use & improvement of instream values	◗ Farm management costs ◗ Drainage management costs ◗ Capital costs ◗ Monitoring costs	◗ Limited landholder uptake

8.1 Summary of Findings

The benefits and costs for different management actions are summarised in Table 21. The results are shown using net present values (NPV) and benefit cost ratios (BCR). Where investment dollars are limiting, and the aim is to maximise returns, the highest BCR shows which actions should be priorities. The highest BCRs are associated with *Terrestrial weeds Management* and *Aquatic Weed Management*. However, the highest NPVs are associated with *Fencing and Revegetation* and *Aquatic Weed Management*.

Table 21 Summary of the Costs and Benefits for Different Management Actions

	Best Outcome		Most Likely Outcome		Worst Outcome	
	NPV	BCR	NPV	BCR	NPV	BCR
Fencing & Revegetation	$4 884 689	6	$1 997 162	3	$264 646	1.3
Terrestrial weeds Management	$1 702 579	9	$559 368	4	-$202 772	0
Aquatic Weed Management	$4 434 675	10	$1 480 591	4.0	-$488 798	0.0
Improve Instream Habitat	$179 310	1.3	-$249 799	0.6	-$563 805	0.01
Increase Wetland Connectivity	Not Assessed					
Increase Base Flows over Rices Weir	$2 506 977	2.5	$309 325	1.2	-$1 323 863	0.18
Flow Management	Not Assessed					
Catchment Management	Not Assessed					

Note that for a number of management actions, the benefits include improved aquatic habitat, which should lead to an increase in the number and abundance of native fish species. Presently no economic data exists for determining the value of species abundance. Where such values exist, it is likely that the benefits of Improving *Instream Management* and *Increasing Base Flows over Rices Weir*, would prove to be substantially better.

9. Management Program

9.1 Introduction

To address the key threats identified for the Lower Broken Creek, specific management responses have been developed, as introduced in Chapter 8. These include planning, works, communication, monitoring and evaluation components. These management responses are set out in Section 9.2.

Against each management program the responsible agency and indicative cost of the action has been identified.

In addition, both a management action target and a resource condition target has been set to allow the implementation of the action and its effectiveness in improving the condition of the natural asset of value to be measured. This was a key recommendation from the review of the 1998 Strategy.

Many of these management responses will have benefits (reduced risks) for more than one natural asset or value. Table 22 attempts to demonstrate the multiple benefits of each of the management responses.

9.2 Management Responses per Reach

A summary of the key management responses to address the priority risks identified, per Reach of the lower Broken Creek is provided in Table 22.

Table 22 Multiple Benefits of Priority Management responses

Management Response	Reach				
	21	22	23	24	28
Fencing & Revegetation	✓	✓	✓	✓	✓
Enhancement LWD	✓	✓	✓	✓	✓
Improved flow regime	✓	✓	✓	✓	✓
Flow over Rices Weir (all weirs)	✓	✓	✓	✓	✓
Water Quality Management	✓	✓	✓		✓
Catchment Management	✓	✓	✓	✓	✓
Drainage Management	✓	✓	✓		
Aquatic Weed Management	✓	✓		✓	✓
Terrestrial weeds Management	✓	✓		✓	✓
Aquatic Weed Mgt (esp. Arrowhead)	✓	✓		✓	✓
Bank erosion					✓
Fish Passage					✓
Wetland Connectivity		✓			

Management Response	Reach				
	21	22	23	24	28
Heritage Management	✓				
Fish Action Plan	✓	✓	✓	✓	✓
Communication	✓	✓	✓	✓	✓
Monitoring & Evaluation	✓	✓	✓	✓	✓
Education	✓	✓	✓	✓	✓

9.3 Specific Monitoring Programs

Specific NRM Programs and key tasks are set out in Table 23. The program has a structure consistent with that used for the Regional River Health Strategy, including the establishment of both management action targets and resource condition targets, to allow for future monitoring and evaluation of the strategy. Where possible, costs have been based on estimates provided in the regional strategy, which are presented in Appendix E.

Table 23 Specific NRM Programs for the Lower Broken Creek

Management Response	Reach	Actions		Responsible Agency	Indicative Cost	Timeframe	Management Action Target	Resource Condition Target
1. Fencing & Revegetation	All	1.1	Identify & map lengths of Broken & Nine Mile Ck that require fencing and revegetation.	GBCMA	$15 000	Jan 2006	Priority areas identified on GIS based maps	Improve condition of ISC Streamside Zone sub-index by 1-2 points over 62 km river
		1.2	Identify & map sections of channel entering the creek that should be fenced to limit stock access to improve water quality.	G-MW, GBCMA	$5 000	Jan 2006	Priority areas identified on GIS based maps	Maintain condition of riparian vegetation over 61 km of river Improved aquatic invertebrate condition Improvement in surface feeding fish species (Galaxiids, and smelt) abundance & diversity compared to 2005 baseline
		1.3	Assess & develop appropriate delivery mechanisms (eg incentive schemes, others) to maximise fencing & revegetation.	GBCMA; Landholders	$20 000	Jun 2006	Delivery mechanism developed & implemented	
		1.4	Implement the priorities identified in 1.1 and 1.2 using the mechanism identified in 1.3.	GBCMA; Landholders	$1 M See Table 31, Ch 13.	Dec 2006 to Dec 2010 (8 km/yr)	305 km frontage fenced as: 245 km Broken Ck[5] 60 km Nine Mile Ck	
		1.5	Encourage land managers to adopt Current Recommended Practices (CRP) for "Managing grazing in riparian zone" [3]	GBCMA; DPI	See Table 31, Ch 13.		305 km frontage under CRP	
		1.6	Control grazing on public waterfronts [4]	DSE / Parks Vic			305 km frontage controlled	

[3] refer to Table 9.5 in GB Regional River Health Strategy

[4] refer to Table 9.5 in GB Regional River Health Strategy

[5] 245 km represents the total length of Broken Ck. It needs to be recognised that 82.5 km of the Broken Ck was fenced under the 1998 Strategy, some areas have been fenced historically, and other areas may not require fencing (eg where the riparian corridor includes property access roads). These targets could therefore be further refined if further information can be obtained.

Management Response	Reach	Actions	Responsible Agency	Indicative Cost	Timeframe	Management Action Target	Resource Condition Target
2. Enhance Instream Habitat	All	2.1 Assess the benefits and risks of enhancing LWD in Nine Mile Ck	GBCMA	$5 000	June 2007	Assessment complete	Improved channel stability over Nine Mile Creek
		2.2 Depending on the outcomes of 2.1, introduce large woody debris into most reaches of the Nine Mile Creek.	GBCMA	$700 000	Jun 2007 to Jun 2008	LWD installed along 10 km of Nine-Mile Ck	Improvement in snag loving fish species (Murray Cod, Golden Perch and gudgeons) abundance & diversity compared to 2005 baseline
3. Improve Flow Regime	All	3.1 Undertake an environmental flow assessment for the Broken Creek to determine an appropriate flow regime, giving particular attention to: – assessing the flow requirements for particular fish populations of the creeks system; – identifying options for improved ecological health.	GBCMA; G-MW	$150 000	Jan 2006 to Jul 2006	Environmental flow assessment complete	Improvement in fish species abundance & diversity compared to 2005 baseline by 2010 Additional resource condition targets for other parameters (eg water quality, hydraulics, other ecological parameters) should be identified and developed as part of the environmental flows assessment.
		3.2 Based on the outcome of the environmental flow assessment, obtain a secure environmental flow for the Broken Creek	GBCMA; G-MW	To be determined	Dec 2006	Environmental flow secured.	
4. Water Quality Management	21, 22, 23, 28	4.1 Investigate benefits / cost of options to manage excessive azolla grow at Rice's Weir, including current practice of providing passing flows (also refer to 3.1).	GBCMA; G-MW	$5 000	Dec 2007	Investigation complete	Compliance with SEPP dissolved oxygen objectives; no excessive azolla growth at Rices Weir; Flows targets met.
		4.2 Identify & develop appropriate options for managing excessive azolla growth, giving consideration to social, environmental & economic costs & benefits.	GBCMA; G-MW	$10 000	Dec 2007	Guidelines developed	When they become available, adopt targets under the IDMOU, however in the interim, improve nutrient and turbidity water quality attainment towards SEPP (WoV) requirements.

[6] Refer to GBRRHS Table 9.5.

Management Response	Reach	Actions	Responsible Agency	Indicative Cost	Timeframe	Management Action Target	Resource Condition Target
		4.3 Assess the impact of current legal practices within riparian areas (such as grazing, recreation) on river health and water quality, and identify appropriate action to manage.	GBCMA, DSE, DPI	$20 000	Dec 2008	Assessment complete	Consider developing site specific trigger values based on 80th percentile of existing water quality data. Target achieved within identified timeframe.
		4.4 Develop targets for water quality as defined by the Irrigation Drainage Memorandum of Understanding Rapid Decision Support Scheme (also see Section 10 – Monitoring)	GBCMA	$$15 000	Dec 2006	Water quality targets developed in accordance with IDMOU Rapid Decision Support Scheme	
		4.5 Encourage implementation of the GB Water Quality Strategy in the Broken Creek.	GBCMA	See Table 31, Ch 13.	Ongoing	Relevant actions to Broken Ck implemented	
		4.6 Encourage land managers to adopt CRP for “Stabilising Bed and Banks”6	GBCMA	See Table 31, Ch 13.	Ongoing	40 km of stream under CRP	
		4.7 Stablise instream and near stream erosion (Reach 23)	GBCMA	$50 000 (10 km @ $5000/km)	Dec 2008	Banks stabilised over 10 km of stream	
		Also see actions under Fencing & Revegetation, and Wetland Connectivity					
5. Catchment Management		5.1 Support the implementation of actions relevant to the Broken Creek identified within broader strategies such as: – Regional Catchment Strategy – SIR Subsurface Drainage Strategy – SIR Surface Water Management Strategy	GBCMA	See Table 31, Ch 13	Ongoing	Programs implemented	Not applicable, as covered by more specific resource condition targets set for other Management Responses.

Management Response	Reach	Actions	Responsible Agency	Indicative Cost	Timeframe	Management Action Target	Resource Condition Target
6. Drainage Management	21, 22, 23	6.1 Encourage implementation of existing water quality and drainage strategies in the Broken Creek, giving consideration, as appropriate, to: – managing farm nutrient run-off to reduce volumes & improve quality – managing drains to re-use drainage water to reduce run-off to Broken Creek & Nine Mile Creek; and – constructing new drains according to existing best practice and implementing the strategy of retrofitting existing drains to reduce nutrient loads. This may include establishing in-line or off-line wetlands along irrigation drains to reduce nutrients and manage outflows to high flow events in the Creek.	DPI, GBCMA; Landholders	See Table 31, Ch 13.	Ongoing	Programs implemented	When they become available, adopt targets under the IDMOU, however in the interim, improve nutrient and turbidity water quality attainment towards SEPP (WoV) requirements
7. Terrestrial weeds management	21, 22, 24, 28	7.1 Identify & map terrestrial weeds species & priority management areas within the riparian zone of the Lower Broken Creek system	GBCMA	$20 000	Dec 2006	Terrestrial weeds mapped and prioritised	Terrestrial weed infestations controlled (specific targets to be developed after initial survey).
		7.2 Conduct targeted control programs (Willows, other known species)	GBCMA	$20 000/yr (4 km/yr @ $5000/km)	Dec 2006 and Ongoing	Target control program developed & implemented	
		7.3 Maintain areas of previous terrestrial weeds removal	GBCMA	$5 000/yr	Ongoing	Previously treated areas managed	
		7.4 Maintain good information resources on potential weeds for the local community, who are most likely to detect new infestations	GBCMA; DSE	See Mgmt Resp 13	See Mgmt Resp 13	See Mgmt Resp 13 - Communication .	
		Also see actions under Management Response No. 1 - Fencing & Revegetation					

Management Response	Reach	Actions	Responsible Agency	Indicative Cost	Timeframe	Management Action Target	Resource Condition Target
8. Aquatic Weed Management	21, 22, 24, 28	8.1 Assess and map the present extent of aquatic weed infestations (Arrowhead, Azolla, Lippia and other identified weedy species) & identify priorities for management, which may include: – trials of water level regimes to control arrowhead; and – increased variability of flows to provide low flow periods, particularly in autumn periods.	GBCMA; G-MW	$20 000	Jun 2006	Aquatic weeds mapped.	50% reduction in weed infestations of highest risk (Arrowhead, Azolla) compared to 2006 baseline (to be determined); other weeds monitored and controlled as required.
		8.2 Implement an appropriate targeted control programs to control aquatic weed species.	G-MW	$80 000/yr for 3 years	Jan 2009	Target control program developed & implemented (extent to be determined)	
		8.3 Implement a maintenance program to manage aquatic weeds controlled in 8.3.	G-MW	$50 000/yr	Ongoing	Maintenance program developed & implemented	
		8.4 Maintain good information resources on potential aquatic weeds for the local community, who are most likely to detect new infestations.	GBCMA; G-MW	See Mgmt Resp 13.	See Mgmt Resp 13	See Mgmt Resp 13 – Communication	
		8.5 Develop a rapid response procedure for any new weed species that may be likely to become a threat to the Broken Creek environment.	GBCMA; DSE	$10 000	Dec 2006	Rapid response procedure complete Staff trained	
9. Bank Erosion & Habitat Management - Nine Mile Ck	28	9.1 Undertake an assessment of erosion risks in the Nine Mile Ck and ensure bed and bank stability is taken into account when plans for habitat improvement are implemented (Refer also to Mgmt Response 2 – LWD)	GBCMA	$10 000	Prior to works starting	Assessment complete & documented	Banks stabilised over 30 km of Nine Mile Creek. Reducing turbidity in Nine Mile Creek towards achieving SEPP (WoV) requirements
		9.2 Encourage land managers to adopt CRP for "Stabilising Bed and Banks" [7]	GBCMA	See Table 31, Ch 13.		30 km of Nine Mile Ck under CRP	

[7] From GBRRHS Table 9.5

Management Response	Reach	Actions	Responsible Agency	Indicative Cost	Timeframe	Management Action Target	Resource Condition Target
10. Enhance Fish Passage	28	10.1 Assess the structures and barriers present within Nine Mile Creek & develop options to improve fish passage	GBCMA	$15 000	Jun 2010	Study of barriers to fish movement in Nine Mile Ck completed	Improvement in fish species abundance & diversity compared to 2005 baseline (see Mgmt Resp 14 - Monitoring & Evaluation)
		10.2 Provide fish passage, including simple rock structures (not necessarily complex fishways), as required	GBCMA	$100 000/ barrier		Removal of barriers to fish movement complete, where deemed to be cost-effective.	
11. Enhance Wetland connectivity	22	11.1 Explore & assess opportunities to re-connect cut-off meander loop wetlands (Billabongs), which have been previously alienated from creek flows, including mapping of all potential wetlands & benefit/cost analysis of relative options	GBCMA	$60 000	Dec 2008	Potential wetlands mapped, and options for reconnection to the Broken Ck assessed.	To be determined, but to include a river & wetland target relative to baseline (including water quality, habitat, riparian vegetation)
		11.2 Based on the outcome of the above study, re-connect two cut-off meander loop wetlands where deemed to be cost-effective.	GBCMA	$120 000	Jun 2010	Two wetlands re-connected, as appropriate.	
		11.3 Continue to develop and implement wetland management plans for Kinnairds Swamp, Green Swamp, and other significant wetlands associated with the Broken Ck	GBCMA	$20 000	Ongoing	Two wetland management plans developed by 2010	
12. Protect Cultural heritage	21	12.1 Undertake specific works in Reach 21 (downstream of Rices Weir) to protect Aboriginal middens	GBCMA	$ 10 000	Dec 2006	Works completed	Aboriginal middens protected
13. Planning	All	13.1 Develop Fish Action Plan to co-ordinate and communicate activities aimed at benefiting fish, Including recreation and tourism	GBCMA	$10 000	Dec 2006	Plans / Procedures developed	Improvement in fish species abundance & diversity compared to 2005 baseline.
		13.2 Develop a policy and guidelines for managing camping and recreation in areas outside Nature Feature Reserves and the State Park.	GBCMA	$10 000	Jun 2007		Prevention of establishment of any new weed species along the Broken Ck.

Management Response	Reach	Actions	Responsible Agency	Indicative Cost	Timeframe	Management Action Target	Resource Condition Target
		13.3 Develop a regional policy and program for addressing illegal recreation and grazing	Community reps, DPI, DSE, GBCMA, Parks Vic	$15 000	Dec 2007		
		13.4 Develop a Waterway Action Plan for the Lower Broken Creek to link strategic issues identified in this strategy to local issues, and to provide a specific works program.	GBCMA	$ 15 000	Dec 2005		
		13.5 Develop a Rapid Response Procedure for Aquatic Weed Management (see Mgmt Resp 7)	See Mgmt Resp 7	See Mgmt Resp 7	See Mgmt Resp 7		
		13.6 Undertake an Environmental Flow Assessment (see Mgmt Resp 3)	See Mgmt Resp 3	See Mgmt Resp 3	See Mgmt Resp 3		
14. Communication	All	14.1 Ensure the Communication Strategy for Riverine Health from the RRHS and the SIR Communication Strategy are implemented to clarify agency roles and responsibilities and gain community input to managing threats and improving the environmental values of the Broken Ck	GBCMA	$15 000	Dec 2006	Communication Strategy developed & implemented; Community action enhanced	Not Applicable
		14.2 Provide local community with information of the creeks ecology and water quality including the elements they can assist with management (riparian vegetation; spills and run-off; flow management) of the creek	GBCMA	$10 000	Jun 2007	Information resources developed; community aware of issues.	
		14.3 Maintain good information resources on potential weeds for the local community, who are most likely to detect new infestations		$11 000, Also see Chapter 12	Dec 2007	Information resources developed; community aware of issues.	

Management Response	Reach	Actions	Responsible Agency	Indicative Cost	Timeframe	Management Action Target	Resource Condition Target
15. Monitoring & Evaluation	All	15.1 Continue ongoing monitoring and assessment of water quality in the Broken Creek at Rices Weir and Katamatite to allow assessment of management responses and allow for adaptive management of the system. This should be consistent with the approaches within the ID MOU	GBCMA; G-MW	$50 000/yr	Ongoing / Annual to 2015	Annual report on water quality monitoring results and trends completed.	Not Applicable
		15.2 Collect baseline data on fish, macroinvertebrates, instream and riparian condition	GBCMA; DPI	$30 000 (for 10 sites)	Jun 2006	Baseline data collected and reported.	
		15.3 Establish appropriate resource condition targets for fish etc based on baseline data	GBCMA; DPI		Dec 2006	Targeted resource condition targets developed.	
		15.4 Establish an ongoing monitoring program for fish, macroinvertebrates, instream and riparian condition to allow assessment of management responses and allow for adaptive management of the system.	GBCMA; DPI	$30 000	Jun 2007	Report of resource conditions against baseline provided every 5 years.	
16. Research & Development		16.1 Investigate other approaches for riparian revegetation, such as: – Use direct seeding to re-establish more native vegetation. – Use fire management to stimulate germination of native vegetation. – Use direct seeding to re-establish more native vegetation 16.3 Use fire management to stimulate germination of native vegetation	GBCMA, DPI	$10 000	Jun 2007	Approaches assessed and documented.	Not Applicable

9.4 Benefits and Cost of Management Responses

Within this section, the overall benefits and costs of the revised Broken Creek Strategy are compared.

Current management responses in the Strategy have been categorised under the following headings that have been taken from the statewide Regional Catchment Investment Plan (RCIP) Guidelines:

- Resource Assessments;
- Planning;
- Capacity Building; and
- On-ground works.

It is difficult to assess the relative merits of isolated management options due to the synergies created when programs are developed and subsequently implemented. For example, it would not make sense to assess an environmental flows study (Planning), without assessing what management responses will be implemented to manage flows. For this reason, the costs and benefits of the overall strategy are assessed as a whole.

9.5 Costs of the Strategy

The management responses that have been costed in this benefit cost analysis are outlined in Table 23 and Table 31. The cash flow budget for the management responses is shown in the full Benefit Cost Analysis report provided in Appendix B. A summary of these costs is shown in Table 24 and Table 25.

Table 24 Summary of Strategy Costs by Management Type

Management Response	PV Costs	% of PV Total Costs
Resource Assessment	$563 512	12%
Planning	$333 581	7%
Works	$2 293 762	48%
Capacity Building	$53 846	1%
Implementation	$1 488 224	31%
Total	**$4 732 925**	**100%**

Table 24 shows that almost 50 per cent of the Strategy costs are associated with on-ground works. Over 30 per cent of the costs are associated with implementing the Strategy.

Table 25 Summary of Strategy Costs by Management Program

No	Management Response	PV Costs	Total Cost	% of PV Total Costs
1	Fencing & Revegetation	$965 210	$1 040 000	20%
2	Enhance Instream Habitat	$595 096	$705 000	13%
3	Improve Flow Regime	$144 231	$150 000	3%
4	Water Quality Management	$94 148	$100 000	2%
5	Catchment Management	$0	$0	0%
6	Drainage Management	$0	$0	0%
7	Terrestrial Weed Management	$230 114	$270 000	5%
8	Aquatic Weed Management	$537 965	$620 000	11%
9	Bank Erosion & Habitat Management	$9 615	$10 000	0%
10	Enhance Fish Passage	$13 335	$15 000	0%
11	Enhance Wetlands Connectivity	$71 475	$60 000	2%
12	Protect Cultural Heritage	$10 000	$10 000	0%
13	Planning	$49 038	$50 000	1%
14	Communication	$34 615	$36 000	1%
15	Monitoring and Evaluation	$480 613	$560 000	10%
16	Research & Development	$9 246	$10 000	0%
All	Implementation Costs	$1 488 224	$1 760 000	31%
	Total	**$4 732 925**	**$5 396 000**	**100%**

Apart from Implementation Costs Table 25 shows that the greatest costs are associated with the Fencing and Revegetation, Enhance Instream Habitat, Aquatic Weed Management and Monitoring and Evaluation Strategy Programs.

9.6 Benefits of the Strategy

The benefits of the Strategy are shown in Table 26.

Table 26 Summary of Strategy Benefits

	Best Outcome	Most Likely Outcome	Worst Outcome
Present value of benefits at 4 per cent over 30 years			
Fencing & Revegetation	$5 775 054	$2 887 527	$1 155 011
Terrestrial Weed Management	$1 905 351	$762 140	$0
Aquatic Weed Management	$4 923 473	$1 969 389	$0
Improve Instream Habitat	$747 072	$317 963	$3 958
Increase Wetland Connectivity	$0	$0	$0
Increase Base Flows over Rices Weir	$2 506 977	$309 325	-$1 323 863
Flow Management	$0	$0	$0
Catchment Management	$0	$0	$0
Total Benefits	**$15 857 926**	**$6 246 345**	**-$164 894**

The greatest benefits are associated with Fencing and Revegetation and Aquatic Weed Management. The benefits that have been quantified vary between $15.9 million for the best outcome and minus $165 000 for the wost outcome. The most likely benefits are estimated at $6.2 million.

The assessment of benefits was not able to quantify all of the benefits of the Broken Creek Strategy. For example, no benefits were quantified due to an increase in the abundance of native fish species associated with improved water quality and instream habitat.

9.7 Comparison of Benefits and Costs

The comparison of benefits and costs is shown in Table 27.

Table 27 Comparison of Benefits and Costs (discounted at 4% over 30 years)

	Best Outcome	Most Likely Outcome	Worst Outcome
Present value of benefits at 4 per cent over 30 years	$15 857 926	$6 246 345	-$164 894
Present value of costs at 4 per cent over 30 years	$4 732 925	$4 732 925	$4 732 925
NPV	$11 125 001	$1 513 419	-$4 897 820
BCR	3.4	1.3	0.0

For the most likely outcome the Broken Creek Strategy has a NPV of $1.5 million and a BCR of 1.3. If however, the best environmental outcomes of the Strategy are achieved, the NPV increases to $11.2 million and the BCR increases to 3.4. Alternatively, should the worst environmental outcomes be realised, the NPV of the Strategy is minus $4.9 million.

Where a discount rate of 8 per cent is used, the net benefits of the Broken Creek Strategy are slightly improved (see Table 28).

Table 28 Comparison of Benefits and Costs (discounted at 8% over 30 years)

	Best Outcome	Most Likely Outcome	Worst Outcome
Present value of benefits at 4 per cent over 30 years	$15 857 926	$6 246 345	-$164 894
Present value of costs at 4 per cent over 30 years	$4 132 258	$4 132 258	$4 132 258
NPV	$11 725 668	$2 114 086	-$4 297 152
BCR	3.8	1.5	0.0

9.8 Conclusion

The Broken Creek Strategy is economic using both a four per cent and eight per cent discount rate. At a four per cent discount rate, the most likely NPV for the Strategy is $1.5 million with a BCR of 1.3. The main benefits quantified in the analysis were associated with improvements in the health of riparian zones, increases in tourism and reductions in toxic algal blooms. No benefits were quantified for the increase in the abundance of native fish species associated with improved water quality. Where such benefits could be quantified, it is likely that the Strategy would be substantially more attractive regarding benefits and costs.

10. Monitoring, Evaluation and Reporting

10.1 Monitoring and Evaluation

Monitoring and evaluation are critical parts of any management strategy. Monitoring provides the feedback on the performance of management responses implemented, which allows management responses to be improved. This is referred to as adaptive management and is regarded as a leading edge approach to environmental management.

Monitoring programs are often overlooked, despite their importance, perhaps due to their costs and perceived lack of relevance to the management strategy. The approach used to develop the monitoring program has been focussed on performance measurement against the resource targets, which are listed in the Specific NRM Programs (Table 23). Measuring against the resource condition targets will allow the development of a cost effective and relevant monitoring program, as well as allowing an adaptive management to be implemented.

In the implementation of a monitoring and evaluation program, the following major tasks have been identified (see Table 31 for details):

- Continuation of ongoing monitoring and assessment of water quality in the Broken Creek at Rices Weir and Katamatite to assess the performance of management responses and allow for adaptive management of the system;
- Collection of baseline data on fish, macroinvertebrates, instream habitat and riparian condition; and
- Establishment of an ongoing monitoring program for fish, macroinvertebrates, instream habitat and riparian condition to assess the performance of management responses and allow for adaptive management of the system.

Monitoring will need to be consistent with the Irrigation Drainage Memorandum of Understanding (IDMOU) – Rapid Decision Support Scheme and the Goulburn Broken Monitoring Evaluation and Reporting Strategy. However, the monitoring program for the Broken Creek Management Strategy will be different and has wider objectives than the monitoring required under the IDMOU. The Broken Creek Management Strategy monitoring is aimed at evaluating the effectiveness of the Strategy's actions when implemented and will, by necessity, cover a wide range of parameters (i.e. complete water quality and biological parameters – fish, vegetation & macroinvertebrates). The IDMOU monitoring will be focused on the single highest risk for receiving waters in irrigation reaches. Further, the IDMOU process is still in the development phase, and the project team for the IDMOU will be using the Broken Creek as a pilot program for the Decision Support Tool. Once this pilot project has been reported, then the monitoring requirements in this Strategy, and those from the IDMOU project, will need to be compared so that the programs can be aligned and any overlap or inconsistencies minimised.

The detail of the monitoring program is presented in Table 29. The table documents the class of monitoring tasks, parameters, sites selected, frequency of monitoring and which resource condition target the parameters measure.

Table 29 Monitoring Program for the Broken Creek

Monitoring Class	Parameters	Sites	Frequency	Monitoring Rationale – Resource Condition Target Measured
Flow	Streamflow (& stage height)	At each weir	Daily	◗ Flows targets met
Physical Form	Channel cross sections	At selected site(s) within each reach	Annually	◗ Improved channel stability over Nine Mile Creek ◗ Banks stabilised over 30 km of Nine Mile Creek.
Water Quality	Turbidity DO* EC PH Colour NOx (Nitrite and Nitrate) Total Kjeldahl Nitrogen (TKN) Total Nitrogen (TN = TKN + NOx) Reactive Phosphorus (FRP) Total Phosphorus (TP) Temperature*	At each weir	Monthly**	◗ Compliance with SEPP dissolved oxygen objectives; no excessive azolla growth below Rices Weir ◗ Improve nutrient and turbidity water quality attainment towards achieving SEPP (WoV) requirements ◗ Improving turbidity in Nine Mile Creek towards SEPP (WoV) requirements

Monitoring Class	Parameters	Sites	Frequency	Monitoring Rationale – Resource Condition Target Measured
Vegetation	Native and exotic species diversity and abundance	At representative sites within each weir pool (away from weir structure)	Annually	◗ Maintain condition of riparian vegetation over 61 km of river ◗ Terrestrial weed infestations controlled ◗ 50% reduction in weed infestations of highest risk (Arrowhead, Azolla) compared to 2005 baseline (to be determined); other weeds monitored and controlled as required. Azolla is a native species that floats freely on the water surface and is not really controllable except by manipulation of its environment.
Aquatic invertebrates	Macro-invertebrate species diversity and abundance	At representative sites within each weir pool (away from weir structure)	Twice a year – according to EPA protocol	◗ Improve condition of ISC Aquatic Life sub-index by 1-2 points over the length of the River
Fish	Fish species diversity and abundance	At representative sites within each weir pool (away from weir structure)	Annually	◗ Improvement in abundance of surface feeding fish species (Galaxiids, hardyheads and smelt) compared to 2005 baseline ◗ Improvement in abundance of snag loving fish species (Murray Cod, Golden Perch and Gudgeons) compared to 2005 baseline ◗ Improvement in fish species abundance & diversity compared to 2005 baseline
Wetland and Floodplains	Time when flow commences	Along total length of Lower Broken	Initial survey and follow-up surveys	◗ Two re-connected wetlands enhanced with improve environmental values (water quality, habitat, riparian vegetation)
Overall Condition	Index of Stream Condition	One site per reach	Every five years	◗ Improve condition of ISC Streamside Zone sub-index by 1-2 points over 62 km river

* G-MW currently have a continuous monitoring probe installed at Rices Weir to monitor DO and temperature.

** Weekly monitoring currently undertaken at Rices Weir under the MDBC statutory monitoring program.

10.2 Reporting

Monitoring and evaluation provides little value for improving management if the results are not adequately reported, and the important role of reporting has been highlighted in the Goulburn Broken Monitoring, Evaluation and Reporting Strategy (Garret and McLennan, 2004). It is therefore recommended that monitoring and evaluation results be collated and reported annually, where appropriate, to provide sufficient feedback into the decision making process. If monitoring is recommended to occur less frequently than annually (e.g. every five years), then reporting should coincide with the monitoring frequency. Reporting of the status of the key threats identified in this strategy should be undertaken annually.

11. Knowledge Gaps and Research

Identifying knowledge gaps is critical to a successful and complete management strategy. Unless some attempt is made to understand the knowledge gaps, it will not be possible to ensure that all issues are addressed within the system being managed over the life of the management strategy. Investment in research and development allows these knowledge gaps to be addressed and ultimately improves management of the system under consideration, and other areas under the management organisations' responsibility. These investigations can be conducted by consultancies, contracted research, research partnerships with universities and other institutions.

During the work to audit the previous management strategy and develop a new strategy, the following knowledge gaps and issues were identified and discussed in the following section:

- Aquatic and riparian vegetation;
- Weeds;
- Fish Ecology and Flow Requirements;
- Water Quality and Management of Excessive Azolla Growth;
- Erosion; and
- Wetland Ecology and Connectivity.

11.1 Aquatic and Riparian Vegetation

- The distribution and abundance of native aquatic and riparian vegetation is unknown. A survey is required to assess the aquatic plants of the lower Broken to identify those species present, their flow and environmental requirements to develop strategies to improve their abundance and diversity;
- Knowledge is needed on alternative approaches for riparian revegetation that may work in the Broken Catchment. This knowledge is related to:
  - Direct seeding to re-establish more native vegetation; and
  - Fire management to stimulate germination of native vegetation.
- Knowledge is also needed with respect to the current regime of crown frontage management in order to identify mechanisms that will improve the ecology of and biodiversity within riparian zones.

11.2 Weeds

- The ecology and management of excessive azolla growth is poorly known. The following investigations may provide for a greater understand and management capability in the future:
  - Investigate benefits / cost of options to manage excessive azolla growth at Rice's Weir, including current practice of providing passing flows;
- Identify and develop appropriate options for managing excessive azolla growth, giving consideration to social, environmental & economic costs & benefits;

- Assess and map the present extent of aquatic weed infestations (Arrowhead, Azolla, Lippia and other identified exotic species) & identify priorities for management, which may include:
  - Trials of water level regimes to control arrowhead; and
  - Increased variability of flows to provide low flow periods, particularly in autumn periods.
- Investigate and develop an understanding of impact and potential spread of the important weed, Arrowhead. For example what type of instream habitat does Arrowhead (and other aquatic weeds) provide compared with native aquatic species (given these are now rare)?

11.3 Fish Ecology and Flow Requirements

- Investigate the distribution and abundance of fish within the Lower Broken in order to develop an understanding of the values of the fish community and what environmental conditions contribute to the community;
- Assess the environmental conditions and fish populations, in particular, of the creeks system in order to determine the environmental water requirements of the system;
- Assess the effectiveness of current fishways within the Lower Broken and identify flow conditions most conducive to fish movement of all species; and
- Assess the structures and barriers present within Nine Mile Creek & develop options to improve fish passage.

11.4 Water Quality & Management of Excessive Azolla Growth

- The dynamics and forms of nutrients and other water quality parameters are poorly known especially in terms of interactions with and impacts on the ecological functions of the lower Broken Creek. The following investigations may provide for a greater understand and management capability in the future:
  - Investigate the forms of nutrients in drains and the creek in both water column and sediment deposits;
  - Map extent of sedimentation in weir pools and understand nutrient levels in these sediments;
  - Assess the dissolved oxygen and temperature data from Rices Weir continuous probes in relation to nutrient levels in the water column, and assess whether nutrient fluxing is occurring during low DO periods;
  - Develop a nutrient budget for the creek and the various inputs (drains, upstream sources, Instream, riparian zone, floodplain and wetlands) and impacts on receiving waters (the Murray, Barmah wetlands);
  - Investigate benefits, cost and effectiveness of options to manage poor water quality at Rice's Weir, including the current practice of providing passing flows; and
  - Identify & develop appropriate options for managing poor water quality, giving consideration to social, environmental & economic costs & benefits.

11.5 Erosion

- The extent of erosion and stream channel instability is poorly known, especially when stream works are undertaken to change current conditions that may trigger further instability. Undertake an assessment of erosion risks in Nine Mile Ck and ensure bed and bank stability is taken into account when plans for habitat improvement are implemented.

11.6 Wetland Ecology and Connectivity

- Explore and assess opportunities to re-connect cut-off meander loop wetlands (Billabongs), which have been previously alienated from creek flows, including mapping of all potential wetlands and benefit/cost analysis of options.

12. Cost Sharing Principles

This Broken Creek Management Strategy recommends that resources be directed to the areas of highest priority, and to the most efficient means of achieving resource condition targets for these priorities. To achieve these targets, a long-term commitment is required from all stakeholders including the State and Federal Governments, and the local community.

Within this strategy, cost-sharing negotiations between stakeholders will only proceed for management responses that have passed the benefit–cost test. There is little point arguing about sharing of costs for inefficient projects. The benefit–cost methodology used within this strategy for ranking projects essentially tells us whether or not a particular project is likely to increase community welfare. In addition, the benefit–cost analysis identifies the stakeholders between whom costs should be shared.

Three sources of funding can be considered:

- Private entities or local agencies whose actions are causing the degradation that is giving rise to the need for the implementation of the strategy (i.e. the 'polluters pay');
- Private entities or local agencies who would benefit from the implementation of the plan (i.e. the 'beneficiaries pay'); and
- Government.

It is important that funding for the strategy reflects the general cost-sharing principles for natural resource management. The following cost sharing principles will be adopted where appropriate:

12.1 Polluters Pay (Duty of Care)

It has been a long-standing code of human conduct that if you make a mess you clean it up. This notion has been enshrined in the 'polluter-pays' principle for environmental protection. With respect to river health, polluters are those who cause damage to the physical, biological or chemical characteristics of the waterbodies and waterways. Demanding that polluters pay is often society's policy of first choice because it is regarded as being the fairest and most equitable policy. It is also the most efficient policy when the principle can be applied to stop pollution before it occurs, or to control it within acceptable limits.

Therefore, where the polluter-pays principle is appropriate and the polluters can be identified and their pollution measured, monitored and levied, it is sensible that that polluter-pays principle should take precedence over the beneficiary-pays principle for sharing the funding of management actions. To do otherwise runs the risk that the pollution may continue unabated.

The polluter-pays principle, therefore, is a principle, which provides an economic disincentive to pollute.

12.2 Beneficiaries Pay

The main convention by which commercial affairs are conducted is that the 'user' or 'beneficiary' of some service pays for that service. By paying prices that reflect the social value of these goods and services, an economically efficient allocation of resources can be ensured. Governments and public authorities have come to realise that it is important for the efficient use of scarce resources that the services provided by public authorities also be paid for by the users or beneficiaries of those services. Thus, the beneficiary-pays principle has been adopted by many authorities for determining who should meet the costs of the works undertaken as part of land and water planning and management.

A distinction can be made between direct and indirect beneficiaries, but it is appropriate that both groups pay. That is, even if the benefits are indirect or intangible, those enjoying the benefits should also contribute. This includes those whose use of a river and its environs is non-consumptive. An example would be recreational anglers who, unlike irrigators, do not pay any charges for the use of increased quantities of water or improved quality, but benefit from the improved quality because the habitat for a sport fishery is improved.

12.3 Government Pays

Government contributions to the funding of on-ground works can be justified in situations where there would be too little investment if it were left entirely to the free market. The reasons for this proposition are:

- The polluters are blissfully unaware of the effects of their actions on other parties ('externalities');
- Enjoyment of the benefits cannot be restricted to a particular group of private entities (that is, the benefits represent 'public goods'); and
- The costs of collecting contributions from each private beneficiary or polluter would be too large relative to the contributions required from those entities (that is, the 'transaction costs' are excessive when collecting contributions from the private entities).

13. Implementation and Review

There are four types of activity needed to implement the strategy:

1. Development of an implementation structure.
2. Acquisition and deployment of resources.
3. Establishment of implementation systems.
4. Development of a strategy supporting culture.

13.1 Implementation Structure

Implementation structure includes:

- Who is to lead the process of implementation;
- Who does what;
- To whom are they responsible; and
- How are they accountable.

Many of these structures have already been established and outlined through the Regional Catchment Strategy and the Regional River Health Strategy. Implementation of the Broken Creek Strategy will need to take advantage of these existing cooperative partnerships and networks, and build on these where any limitations are identified. Table 5 sets out the broad roles and responsibilities of regional stakeholders, and Table 14.2 of the Regional River Health Strategy sets out the Roles and Responsibilities for River Health. This is directly relevant for the Lower Broken Creek, and is presented again in Table 30.

The Goulburn Broken Catchment Management Authority should be the lead agency responsible for the overall coordination of the Broken Creek Management Strategy. The CMA will be supported by the Shepparton Irrigation Region Implementation Committee, particularly for community engagement and on the ground implementation of the action items. The Goulburn Broken River Health and Water Quality Committee should provide the forum for regional coordination of actions, and as outlined in the Regional River Health Strategy, develop the initial stages of implementation. These stages include monitoring and integrating implementation into the broader activities within the catchment through Implementation Committees and the Waterway Working Groups.

The Management Strategy identifies the responsibility for the implementation of each action. The first agency listed will have primary responsibility for coordinating and implementing the action. Agencies with secondary responsibility will need to provide support, and will contribute to some proportion of the costs, to be developed under the Cost Sharing arrangement set out in Chapter 12. In addition, there is a clear role for the broader community to assist with implementing many of the actions, and providing funds under the polluter pays or beneficiary pays principles.

During the review of the 1998 Broken Creek Strategy, some deficiencies were noted in reporting and accountability structures. It is recommended that regular reporting of the implementation of the strategy against the management response and resource condition targets is undertaken, and responsible organisations are held accountable for the success of the strategy.

Table 30 Roles and Responsibilities for River Health (from GB Regional River Health Strategy)

Regional

Agency / Group	Roles (General)
Goulburn Broken Catchment Management Authority	Develop, in partnership with the community and other stakeholders, the Regional River Health Strategy and other action plans which define the vision for the catchment and set targets for land and water management. Provide advice to the State Government on both Federal and State resourcing priorities at a regional level. Develop and implement measures for river protection and restoration to implement. Encourage community involvement in river and catchment management. Undertake floodplain management in accordance with the Victoria Flood Management Strategy. Develop partnerships between resource managers in the catchment, and coordinate activities impacting on river health. Provide a focus for regional investment in river and catchment management. Monitor and report on the condition and management of the river and water resources in their region. Provide community education. Act as a communication conduit between regional communities and Government on issues relating to river and water management. Prepare annual works and activity programs for the protection and enhancement of river systems.
Regional Resource Managers (DSE, DPI, GMW and urban Water Authorities	Participate (as partners) in the development and implementation of the regional RHS. Undertake all activities which can potentially impact on rivers to best practice. Recognise their dependence on a healthy resource base and their potential impact on it. Develop and support partnerships with other resource managers in the catchment to enhance project coordination and implementation.
Local Government	Work in partnership with CMAs to set priorities and implement the regional RHS. Incorporate river restoration and catchment management objectives, priorities and actions into statutory planning processes. Undertake floodplain management and flood warning in accordance with the Victoria Flood Management Strategy. Develop and implement urban stormwater plans. Manage rural drainage schemes where appropriate. Facilitate local industry involvement in river restoration and catchment management activities. Provide local support for local action groups. Undertake all activities which can potentially impact on rivers to best practice.
Industry	Manage in accordance with the principles of ecologically sustainable development. Minimise their impact on the environment by the implementation of best management practices.

Individuals and Groups	Participate in regional planning, priority setting and the implementation of work programs related to river management and restoration. Participate in community groups aimed at monitoring river health or undertaking restoration projects in priority areas. Manage their own enterprises and actions in ways that acknowledge their 'duty of care' and their role in the stewardship of natural resources.

State and Federal

Agency / Group	Roles (General)
Commonwealth Government	Contribute funding to States, regional authorities, groups and individuals to achieve national objectives for river restoration and catchment management. Facilitate national or interstate coordination where this is necessary. Invest in the development of better management principles, tools and systems. Improve the knowledge base through strategic research and development. Provide incentives in areas of Commonwealth responsibility. Ensure that the wider Australian community is well informed about natural resource management issues. Facilitate the monitoring of the effectiveness of natural resource management at appropriate scales. Oversee the implementation of relevant Commonwealth legislation including the Environment Protection and Biodiversity Conservation Act 1999. Ensure that Australia meets its obligations under international agreements. Identify issues of national significance.
State Government	Set statewide policy and strategic directions for river restoration and for catchment and environmental protection. Establish legislative frameworks. Establish effective and efficient catchment / regional institutional arrangements. Provide funding to achieve State and regional priorities. Provide relevant advice, and undertake research and monitoring, planning, extension, on-ground works and some referral and enforcement functions to support regional communities. Participate in effective intergovernmental processes and national approaches where necessary, and implement State responsibilities under nationally agreed strategies.

13.2 Implementation Resources

Strategy implementation requires time, effort and money. It is important to determine where these resources will come from and how will they be deployed.

The following are some of the issues that need to be addressed (Neil Sturgess, URS, pers. comm.).

- How much is required and how distributed?
- How are resources to be acquired? Internally or externally?
- How will the use of resources be coordinated and controlled? (N. Sturgess, URS, pers. comm.).

In addition to the costs of specific works highlighted within Table 23 in Section 9.3, staff resources will be required to implement the Broken Creek Strategy. The Regional River Health Strategy provides a framework for these implementation costs, which has been used as the basis for the estimation of Implementation Costs shown in Table 31.

Table 31 Implementation Costs for the Broken Creek Management Strategy

Best Practice Standard Objective	Action	10 year Cost	Priority	Milestone Time frame	Responsibility
People Partnerships supported (agency & community);	Employ one full time staff member within the CMA to coordinate the implementation of management responses within the Strategy; coordinate activities with key people in other partnership agencies.	$700K	1	2005	GBCMA, RH&WQC[8], DPI/DSE, EPA, Local Govt, GMW
	Implement RRHS Communications Strategy of the Regional River Health Strategy within the Broken Creek.	$5K/yr for 10 yrs	1	2015	RH&WQC (with support of IC's/ WWG's)
	Review Broken Creek Strategy, & revise as required.	$100K	1	2015	RH&WQC
	Community Education & Extension – especially highlighting issues of concern to the Broken Ck, as identified in Chapter 9.	$20K/yr over 10 yrs	1	2015	All
Fairness Equitable sharing of costs and benefits	Address identified knowledge gaps and maintain an understanding of progress towards meeting Strategy targets. Integrate into program as new information is available.	$5K/yr over 10 yrs	1	Ongoing	RH&WQC, GBCMA
Cultural Heritage valued & considered in managing natural resources	Manage protection of aboriginal midden in Reach 23, identify other sites of significance within the Lower Broken Creek.	$10K/yr over 10 yrs	1	2015	RH&WQC
Technically Rigorous Ensure decisions are made based on best available economic, sociological, & scientific understanding of the Catchment.	Undertake an environmental flow assessment for the Broken Creek to determine hydrological requirements for ecological health. Collect baseline data on fish, macroinvertebrates, instream and riparian condition. Establish appropriate resource condition targets for fish etc based on baseline data. Establish an ongoing monitoring program for fish, macroinvertebrates, instream and riparian condition to assess performance of management responses and allow for adaptive management of the system. Maintain good information resources on potential weeds for the local community, who are most likely to detect new infestations.	$50K/yr over 10 yrs	1	Ongoing; Review 2010	RH&WQC

[8] RH&WQC = River Health and Water Quality Committee.

Best Practice Standard Objective	Action	10 year Cost	Priority	Milestone Time frame	Responsibility
Accountable Report progress in natural resource management in a clear and meaningful way.	Promote a reporting framework that emphasises the link between those making the changes (implementers) and those at catchment, State and national levels.	$1K/yr over 10 yrs	2	Annually	GBCMA; IC
Continuous Improvement Ensure Strategy implementation is monitored and underlying assumptions are regularly reviewed and appropriate modifications made.	Establish a program that monitors via Implementation Committees – resource (or catchment) condition changes; – management objectives and strategies achievement; – management task (output) achievement; and – physical target (output) achievement. Evaluate the Broken Creek Strategies implementation at least annually (Implementation Targets), and prepare an Annual Report that shows progress on issues. Evaluate the Broken Creek Strategies effectiveness every five years (Resource Condition Targets).	$5K/yr over 10 yrs	1	2015	GBCMA, RH&WQC & IC

13.3 Implementation Systems

Strategy supportive systems need to be established. There will be a need for:

- Direction and coordination systems; and
- Activating and controlling systems.

As discussed in Section 13.1, many of the management and coordination systems are already well established via the GBCMA, its Implementation Committees, the River Health and Water Quality Committee and the Waterway Working Groups. More specific activating and controlling systems have been outlined in Table 31, including staff coordination requirements, accountability structures and continuous improvement.

13.4 Strategy Supporting Culture

Culture may be said to include attitudes, philosophy and shared values that determine behaviour patterns. Regional stakeholders will need to adopt a strategy supportive culture if the strategy is to succeed (N. Sturgess, URS, pers. comm.).

The strategy development process to date, through the identification of shared visions and common issues, has started to produce a strategy supportive culture. Striving for a strategy supporting culture will be an ongoing and challenging task. Ongoing active involvement by the local community will be crucial to the success of the Broken Creek Strategy.

13.5 Review

As outlined in Table 31, the Broken Creek Strategy should be an evolving document, which is implemented under a model of continuous improvement. In some instance it has not been possible to set specific resource condition targets as insufficient information exists. In these instances, the first step in the management response has been to undertake sufficient monitoring to identify the baseline conditions, after which resource condition targets should be set.

Under the continuous improvement model, the Broken Creek Strategy's implementation should be evaluated at least annually against its Management Action Targets, and an Annual Report prepared that shows progress on management issues.

The Strategy has been developed with a ten year timeframe to be consistent with the Regional River Health Strategy, however the Broken Creek Strategy's effectiveness in achieving the Resource Condition Targets should be evaluated every five years, consistent with the review of the Regional Catchment Strategy.

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15. Acknowledgements

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- Peter Butcher — Goulburn Murray Water
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