GOULBURN BROKEN CATCHMENT MANAGEMENT AUTHORITY

Ecological Risk Assessment of Upper Broken Creek and Lower Broken River

Peter Newall*, David Tiller# & Lance Lloyd

Lloyd Environmental

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****Independent Consulting Aquatic Ecologist; #Karoo Consulting***

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Inquiries on this report can be made to:

Lance Lloyd,
Director,
Lloyd Environmental Pty Ltd,
ph: 03 9884 5559, Mob: 0412 007 997,
Fax: 03 9884 7405,
lance@lloydenviro.com.au,
PO Box 3014, SYNDAL, Victoria 3149

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Cover Photo: Caseys Weir, Broken Creek (David Tiller).

1. EXECUTIVE SUMMARY

This project examined risks to the environmental values of upper Broken Creek and lower Broken River due to the consistent failure of these waterways to attain State Environment Protection Policy (Waters of Victoria) [hereinafter referred to as SEPP (WoV)] water quality objectives for nutrients, dissolved oxygen and turbidity. The areas under investigation were:

- upper Broken Creek between its origin at Caseys Weir and its confluence with Boosey Creek near Katamatite; and,
- lower Broken River from its confluence with Holland Creek at Benalla, down to its confluence with the Goulburn River at Shepparton.

The process used for this assessment is known as Ecological Risk Assessment (ERA) which has been adopted by EPA Victoria and modified for this Goulburn Broken catchment application. GB CMA commissioned Lloyd Environmental to apply the process in the Broken Creek and Broken River, through the completion of ERAs within the context of identified threats and also considering issues more specific to these catchments, including consideration of the effects of decommissioning of Lake Mokoan, impacts of bushfires and fire control measures, and the interests and attitudes of local community and community groups. The ERA used the native fish community as the assessment endpoint for the ERAs.

The aim of this project was to undertake ecological risk assessments of threats to the environmental values of the upper Broken Creek and lower Broken River, using available information and local knowledge. A corollary aim was to present the information in a format that will assist with future development of a Bayesian network of the Broken Creek/River systems.

The values highlighted in the Regional River Health Strategy (RRHS) (GB CMA 2005) for the Broken Creek and Broken River are shown below:

Broken Creek Values	**Broken River Values**
○ Association with wetlands of national significance	○ Wetland of national significance (DIWA wetland, Lower Broken River)
○ Association with Broken Boosey State Park (a unique linear corridor along the Broken and Boosey Creeks, with substantial occurrences of high quality native vegetation	○ Large-bodied fish (Catfish, Murray Cod, Silver Perch, Golden Perch; Macquarie Perch)
○ Large-bodied native fish (Catfish, Murray cod, Silver perch, Golden perch)	○ Small fish (River Blackfish, Rainbowfish, Gudgeons, Australian Smelt, Hardyheads)
○ Small native fish (Rainbow fish, Gudgeons, Hardyheads)	○ Macroinvertebrate fauna
○ Macroinvertebrate fauna	○ Riparian zones
○ Riparian zones	○ aquatic macrophytes
○ Aquatic macrophytes	

Similarly, the threats identified in the RRHS (GB CMA 2005) and during the Scientific Workshop for the study area of Broken Creek:

Broken Creek Threats	Broken River Threats
○ Flow deviation	○ Flow deviation
○ Water quality (turbidity, dissolved oxygen, nutrients)	○ Water quality (turbidity, dissolved oxygen, nutrients)
○ Water quality (SIGNAL Score)	○ Stock access
○ Water quality trends (turbidity)	○ Introduced flora
○ Stock access	○ Introduced fauna
○ Introduced flora	○ Fish barriers
○ Introduced fauna	○ Land use (including potential irrigation runoff, erosion)
○ Fish barriers	○ Water extraction
○ Land use (including resultant irrigation runoff, erosion)	
○ Water extraction	

The highest risks to the fish community of the Broken Creek identified through the preliminary risk analysis were the impacts of fish barriers and introduced fish (both 'very high risk'). These were primarily a function of exposure, whereby both these threats impact on the fish community every day, and also a function of probability, with it being almost certain that the threats have an impact on the fish community. The next highest risks ('high to very high') were identified as flow regulation in the section of the Creek upstream of Flynn's Weir, and low dissolved oxygen and introduced macrophytes in the section of the Creek downstream of Flynn's Weir. Risks from introduced fish are probably the most difficult to manage. The remaining threats are more manageable, although at varying costs.

The highest risks to the fish community of the Broken River identified through the preliminary risk analysis were the same as for Broken Creek - the impacts of fish barriers and introduced fish (both 'very high risk'). These were similarly based on high exposure, whereby both these threats impact on the fish community every day, and also high probability, with it being almost certain that the threats have an impact on the fish community. The next highest risks ('high to very high') were identified as flow regulation in all three section of the River downstream of Caseys Weir, and introduced macrophytes, also in all three section of the River downstream of Caseys Weir. Risks from introduced fish are probably the most difficult to manage. The remaining threats are more manageable, although at varying costs.

Although this ERA has focused on the ecological values of the two stream systems, using the fish communities as endpoints, an additional component of the project brief required an assessment of the efficacy of proposed management actions to meet SEPP WoV objectives and the derivation of attainable targets and time lines. Specifically, the water quality indicators turbidity, nutrients, and dissolved oxygen need to be assessed in relation to their failure to meet SEPP WoV (see table below).

Parameter	Parameter	WoV Objective	Current status (approx.)	Resource Condition Target (75th percentile)	Time frame	Uncertainty (the confidence level to achieve target in timeframe)
Turbidity (NTU)	Broken Creek	<30	>100	<100 WoV Objective (<30)	5 years 15 years	Low to Moderate
	Broken River		>80	<50 WoV Objective (<30)	5 years 15 years	Moderate
Phosphorus (mg/L)	Broken Creek	<0.045	>0.15	0.1 0.045 (WoV Objective)	5 years 15 years	Low to Moderate Moderate
	Broken River			0.1 0.045 (WoV Objective)	2 years 15 years	Low to Moderate Moderate
DO (%sat)	Broken Creek	>85%<110%	60-100%	Maintain current conditions	ongoing	Moderate to high. High below Flynns Weir
	Broken River			Maintain current conditions	ongoing	Moderate

Management actions that have been recommended for the mitigation of the major risks include:

- removal of unnecessary fish barriers and installation of fishways (ladders, rock ramps, bypass channels) elsewhere;
- improvement of riparian and in-stream ecosystem conditions for native fish to, competitive advantage over exotic fish species;
- consider the potential for use of fish traps in fishways to remove exotic fish;
- management of storage discharges to reflect natural conditions as far as practical;
- an integrated weed control program with nutrient reduction management actions;
- monitoring of dissolved oxygen concentrations during low flow periods;
- provision of fresher flows as needed during dissolved oxygen risk periods;
- undertaking an investigation of potential nutrient and sediment inputs to the waterways downstream of Caseys Weir; and
- mapping of existing pools within Broken Creek and documenting potential for habitat improvement and/or deepening.

These management actions were derived assuming that the decommissioning of Lake Mokoan will proceed, as the decommissioning represents the removal of a major source of several risks identified.

In addition to the ERAs and resultant management recommendations, this study presents conceptual models in a way that may, in future, be used in the development of a Bayesian network. Section 5 of this document presents a Bayesian network structure derived from the outcomes of the ERA, and also presents the variables, their states and the data used for development of the structure. Conceptual examples of Conditional Probability Tables (CPTs) are also presented in Section 5. The CPTs are conceptual only and should not be used in an actual assessment.

2. INTRODUCTION

This report contains assessments of the risks to the environmental values of upper Broken Creek and lower Broken River. The consistent failure of these waterways to attain State Environment Protection Policy (Waters of Victoria) [hereinafter referred to as SEPP (WoV)] water quality objectives for nutrients, dissolved oxygen and turbidity has triggered these assessments (GB CMA 2005, 2008).

The study section of the upper Broken Creek is between its origin at Caseys Weir and its confluence with Boosey Creek near Katamatite (Figure 3). The study section of the lower Broken River is from its confluence with Holland Creek at Benalla, down to its confluence with the Goulburn River at Shepparton (Figure 8).

Victoria's Environment Protection Authority (EPA) has adopted a process for determining the risks to waterways. The process, known as Ecological Risk Assessment (ERA) has been adapted by the Goulburn Broken Catchment Management Authority (GB CMA) for application to the Goulburn Broken catchment. GB CMA commissioned Lloyd Environmental to apply the process in the Broken Creek and Broken River, through the completion of ERAs within the context of identified threats and also considering issues more specific to these catchments, including consideration of the effects of decommissioning of Lake Mokoan, impacts of bushfires and fire control measures, and the interests and attitudes of local community and community groups. In particular, GB CMA required:

- Identification of the **values** associated with the selected reaches of upper Broken Creek and lower Broken River;
- Identification of the **threats** posed to the values associated with the study reaches;
- Explicit **statements of investigation** for the ERAs;
- Development of **conceptual models** to assist in system description and assessment;
- **Preliminary risk assessments** using existing information and relevant local knowledge and including assumptions made during the process;
- Documentation of **gaps** in knowledge and understanding identified during the risk assessment;
- Recommendations for appropriate **management actions** to protect values within each waterway and reduce threats to these values; and
- Deriving attainable SEPP (WOV) **targets** and **time lines** and assessing the efficacy of recommended actions to meet these targets.

The GB CMA also requested that the conceptual models be built and presented in a way that may, in future, be used in the development of a Bayesian network (refer Section 5 of this report). If, at a later time, a Bayesian network is needed, the information collected can be easily adapted to contribute to the network.

2.1 Project Aim

The aim of this project was to undertake ecological risk assessments of threats to the environmental values of the upper Broken Creek and lower Broken River, using available information and local knowledge.

A corollary aim was to present the information in a format that will assist with future development of a Bayesian network of the Broken Creek/River systems.

2.2 SEPP WoV Review

A review of regional water quality data against SEPP trigger values undertaken by the GB CMA (2008) identified several sites within the Goulburn-Broken Catchment as triggering further investigations. Among the reaches examined, upper Broken Creek and lower Broken River were identified as being 'very degraded' and were allocated highest priority for further action. These two stream sections were recorded as triggering SEPP(WoV) for nutrients (total phosphorus and total nitrogen), dissolved oxygen and turbidity.

The review undertaken by GB CMA 2008 noted that regulated releases from Lake Mokoan are likely to have a major impact on water quality in both stream sections, and hence SEPP(WoV) attainments in each reach. For example, median turbidity in Lake Mokoan is approximately 130 NTU (GB CMA 2008), substantially above the 75th percentile trigger of 30 NTU for the two stream sections. In contrast, water in the Broken River upstream of the Lake Mokoan discharge (Pump House at Faithful Street) had a median turbidity of 25 NTU, less than 20% of the Lake Mokoan median.

2.3 Approach

The SEPP (WoV) states that: "The non-attainment of an objective will trigger further investigation to assess risks to beneficial uses" (Government of Victoria 2003, p. 13). Beneficial uses can cover a range of uses of a waterway, from social and economic through to ecological. Within an ERA, the focus is on the ecological uses (values) of the system. These ERAs have consequently focused on the ecological values of each waterway and the threats they face. Therefore, although water quality has been the trigger for the ERAs, the ensuing ERAs do not necessarily focus on the water quality indicators themselves. Rather, the focus is on the ecological values, the threats, and their management. However, the values selected for the ERAs must be affected by water quality changes. The connected nature of stream systems will often mean that mitigation of one threatening process results in mitigation of others. For example, implementation of a flow regime to improve the viability of the aquatic fish community may contribute to an improvement in water quality.

Although beyond the scope of this project, validation of management actions is an important component of ERA. This entails the monitoring, measurement, recording and evaluation of any effects from actions undertaken in the management of the waterways. Validation enables an assessment of the benefits of specific tasks, informing future decision-making.

2.4 Methods

A representation of the approach used in this study is presented in Figure 1. Following the project inception meeting and site visit, the problem formulation phase of the ERAs commenced. This included:

- defining the management context;

- identifying relevant values of upper Broken Creek and lower Broken River;
- identifying threats to those values;
- identifying endpoints to use in the assessment and measurement of condition for upper Broken Creek and lower Broken River;
- development of conceptual models; and
- culminated with the identification of an investigative question.

Within an ERA, the focus is on ecological values. Although other values (social and economic) were identified, these are not considered within the context of an ERA. Problem formulation included a scientific workshop held by the consultants and the GB CMA.

The investigative question stated the problem, the issue or value to be used for *assessing* the status of each waterway (**assessment endpoint**) and the aspect that is *measured* to provide the required information (**measurement endpoint**). The rationale behind the selection of endpoints is discussed further in Sections 2 and 3.

Corollary requirements of the study included the identification of **knowledge gaps** in the management needs for the values of each waterway, and listing of **assumptions** made in the implementation of the study.

Identification of the values, endpoints and investigative question enabled the construction of a conceptual model of the relevant components of the creek system and interactions between the value and threats.

Following problem formulation, the threats were qualitatively assessed as risks (preliminary analysis). The approach used a Risk Calculator (Hydro Environmental 2005) that incorporated Probability, Exposure and Consequence to derive a Risk Score. This was undertaken as a Workshop, by the authors of this report. The Risk Calculator is discussed further in the following sub-section (1.5) of this report.

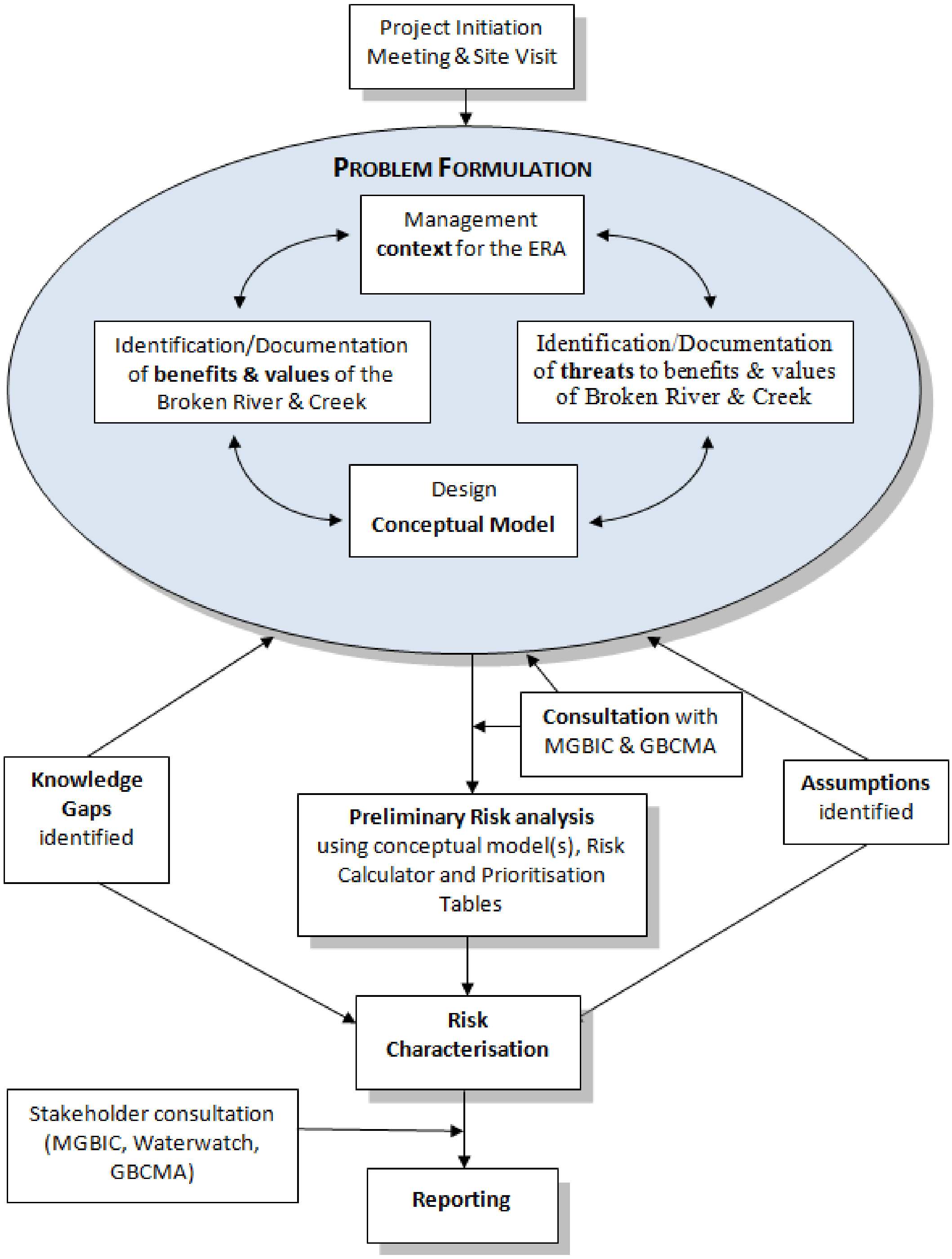


Figure 1: Approach to Ecological Risk Assessment of Broken River and Creek

2.5 The Risk Calculator

Risk calculators are nomographs relating probability and exposure to a hazard, through a tie line, to possible consequences and then to a risk score. They provide a simple, semi-quantitative method for assessing environmental risks and although originally designed for calculating environmental risks to humans, they have been adapted by natural resource management bodies in managing risks to waterways (Hart et al. 2005).

The risk calculator used in this study (Hydro Environmental 2005) is an output from a workshop attended by natural resource management agencies and authorities in northern Victoria, including the GB CMA. It is therefore familiar to the GB CMA and has been used in a previous ERA for GB CMA (Newall and Lloyd, 2007). It provides a readily interpretable output of risk scores ranging from below 'Low Risk' to above 'Very High Risk'.

Use of the Risk Analysis Calculator (Figure 2) (Hydro Environmental 2005) requires each identified threat to be evaluated against three criteria. The first criterion is the probability of the threat having an impact, and ranges from 'Almost Certain' to 'Practically Impossible'. In the example in Figure 2, a hypothetical threat has been given a probability of causing a consequence as 'Quite Possible'. The second category is the exposure, or frequency of an impact from the threat. In the hypothetical example presented, an exposure of 'Monthly' has been allocated. The next step in the process is to pass a line (in Figure 2 it is represented by the dashed line) from 'Quite Possible' on the probability scale, through 'Monthly' on the exposure scale, and extending to the 'Tie Line'. The dashed line reaches a point marked "A" on the Tie Line.

The third category for evaluation is the consequence of the threat occurring and ranges from 'insignificant impact' to 'Loss of Value'. In the example, 'Minor impact on value' was allocated as the consequence. The next action required is to draw a line from Point A, through the 'Minor impact on value' point on the consequence scale (in our example it is represented by the dotted line) and extending to the Risk Score Scale (represented by Point B in Figure 2). This example results in a Risk Score between 'Moderate' and 'Substantial'.

An explanation of the probability, exposure and consequence scales has been developed for this ERA (Table 1), to assist understanding of the allocation of rankings within each criterion.

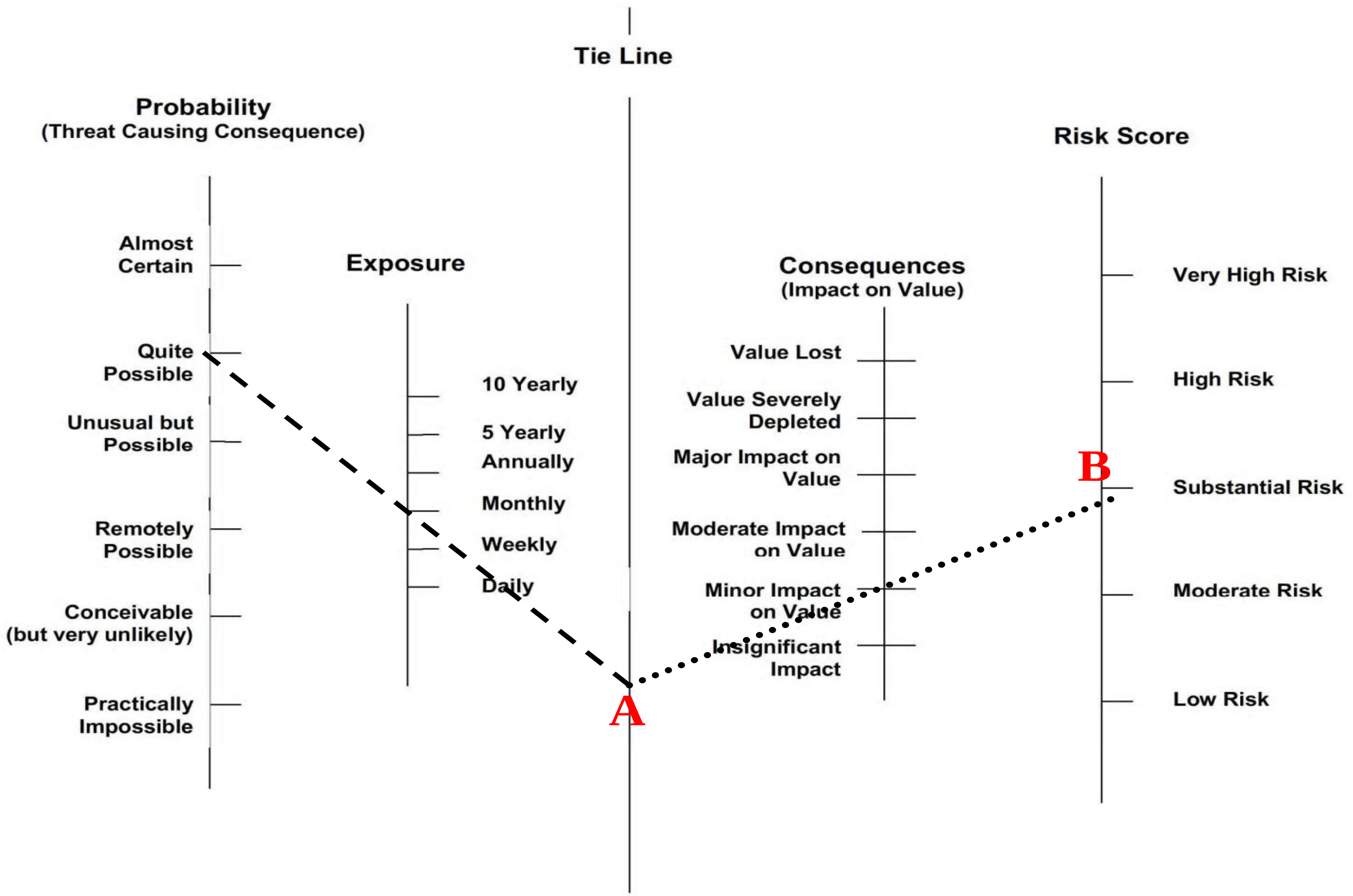


Figure 2: Risk Calculator (example only)

Table 1: Explanation of scales for the Risk Calculator Criteria

(a) Probability

Probability rating	Description
Almost Certain	It is expected that this threat will cause some consequence in almost all circumstances
Quite Possible	This threat is likely to cause some consequence in most circumstances
Unusual but Possible	This threat might cause some consequence at some time
Remotely Possible	This threat might cause some consequence, but not likely
Conceivable (but very unlikely)	This threat may cause some consequence but only in exceptional circumstances
Practically impossible	Almost inconceivable that this threat might cause some consequence

(b) Exposure

Exposure rating	Description
10 yearly	The ecosystem's exposure to any consequences from this threat will be very rare, at an estimated recurrence of approximately 10 years
5 yearly	The ecosystem's exposure to any consequences from this threat will be rare, at an estimated recurrence of approximately 5 years
Annually	The ecosystem's exposure to any consequences from this threat will be yearly, potentially as part of an annual cycle of the system (e.g. spring floods) or individual species (e.g. spawning)
Monthly	The ecosystem's exposure to any consequences from this threat will be relatively common, occurring approximately monthly.
Weekly	The ecosystem's exposure to any consequences from this threat will be common, occurring approximately weekly.
Daily	The ecosystem's exposure to any consequences from this threat will be continual or nearly so.

(c) Consequence

Consequence rating	Explanation of consequence upon a biological community
Biological Community Lost	Loss of all key species and impact sensitive species within a community. Recovery unlikely.
Biological Community severely depleted	Severe degradation of community diversity. Recovery possible with major management inputs.
Major impact on Biological Community	Severe degradation of community diversity. Recovery will require some management inputs.
Moderate impact on Biological Community	Some degradation of community diversity. Recovery will be assisted by some management inputs.
Minor impact on Biological Community	Threat to community diversity. If impact occurs, likely to be temporary.
Insignificant impact	No measurable impact on population or community.

2.6 Risk Characterisation

Risk characterisation is the final stage of the risk assessment. The evaluation and reporting of the problem formulation and risk analysis results that provides the information needed for decision-making and risk management (Suter 1993). Specifically, risk characterisation should:

- identify risks to values;
- assess levels of change or impact to the values;
- summarise assumptions, uncertainties and strength and limitations of the analysis;
- identify any other information gained during the risk assessment that would be useful in guiding decision making; and
- clearly communicate conclusions to managers.

3. BROKEN CREEK

3.1 Introduction

The Broken Creek lies within the Goulburn Broken Catchment, diverging from the Broken River at Caseys Weir west of Lake Mokoan and flowing north-west into the Murray River (Figure 3). The section of the Broken Creek assessed in this study extends from its point of divergence with the Broken River, down to its confluence with Boosey Creek near Katamatite.

Within this section, the Broken Creek is associated with nationally significant wetlands [the Muckatah Depression and Broken Creek itself have been listed by DIWA (2001)]. State and nationally threatened flora and fauna have been listed on the floodplain (DIWA 2001), which contains Public Land Water Frontage Reserves and the Moodie Swamp State Wildlife Reserve. A range of potential threats to the values of Broken Creek have been identified, including poor water quality (with declining trends), flow deviation and stock access (GB CMA 2005).

3.2 Background

The Broken Creek was identified in the Goulburn Broken Regional River Health Strategy (GB CMA 2005) as not attaining water quality objectives for total nitrogen, total phosphorus, dissolved oxygen and turbidity as defined in SEPP(WoV). The more recent review of water quality in the Goulburn Broken Catchment (GB CMA 2008), identified Broken Creek upstream of Katamatite as a high priority reach for an ecological risk assessment, based on the Creek's continuing failure to attain SEPP(WoV) objectives.

A potentially important impact on the water quality of Broken Creek is the discharge the creek receives from Lake Mokoan, via Casey's Weir. Generally, the discharge from Lake Mokoan forms all or most of the flow in the Broken Creek above Katamatite. Therefore, the quality and quantity of the flow in this stretch is almost entirely dependent upon the discharge from Lake Mokoan.

Lake Mokoan is scheduled to be decommissioned in mid 2009. The recent commissioning of the Caseys' Weir/Major Creek (Tungamah) pipline has reduced the role of the Broken Creek in delivering irrigation and stock and domestic water.

As a result of the water saving Tungamah Pipeline project, stock and domestic water has been supplied to landholders in the Tungamah system area eliminating the need for stock and domestic water supplies to be delivered via the Broken Creek.

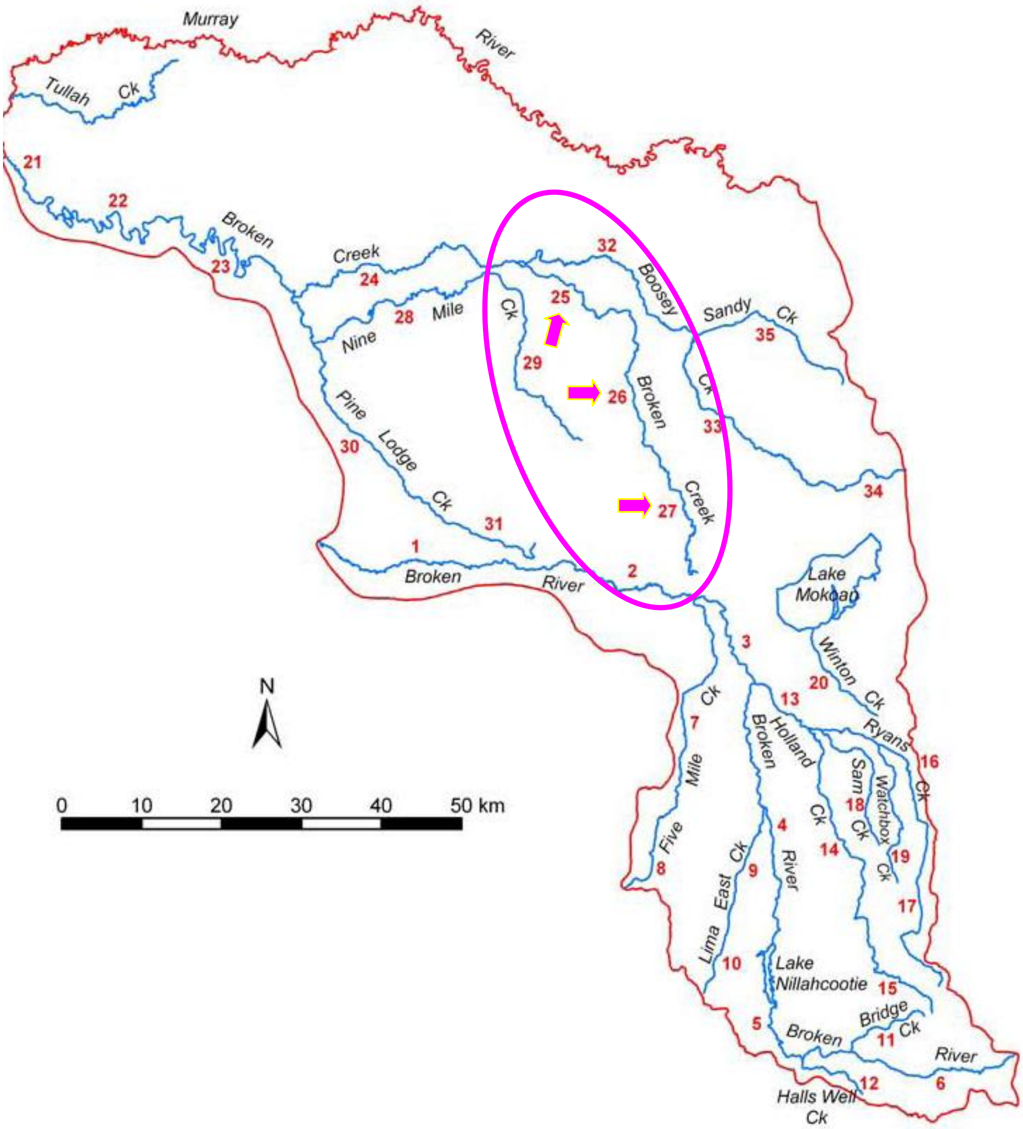


Figure 3: Map of the Broken Creek system, with Reaches 25 – 27 highlighted (Source: GB CMA 2005)

A detailed discussion of the decommissioning and pipelining is beyond the scope of this study. However, the following aspects of the new irrigation regime are relevant to the ecological risk assessment (ERA) of upper the Broken Creek:

- irrigation water discharged into Broken Creek will be sourced from the Broken River (and Lake Nillahcootie rather than from Lake Mokoan;
- irrigation water (from the Broken River) will only influence the uppermost reach (Reach 27) of Broken Creek, with most irrigation water inputs being diverted before Waggarandall Weir and the small excess water volumes being retained by the weir;

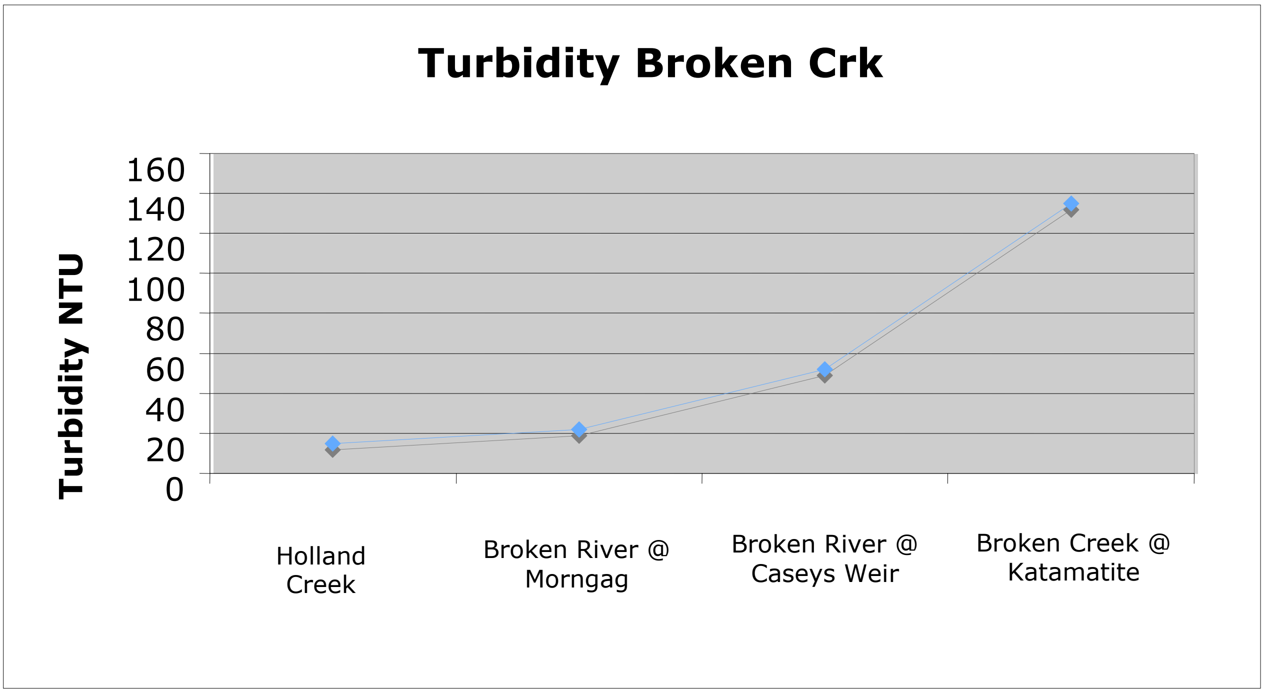
- Lower volumes of water will be delivered down the Broken Creek, as opposed to historic flows, as a result of the commissioning of Tungamah Pipeline. Irrigation water will still be delivered via Upper Broken Creek; and,
- downstream of Reach 27, Broken Creek will return to an ephemeral stream with regular cease-to-flow periods in drier months. Historically there has been an 'inversion' in the flow regime, with high summer flows for stock and domestic purposes, contrasting with the natural flow regime, which typically had low flows and regular cease-to-flow periods during the summer.

The decommissioning of Lake Mokoan offers the prospect of improved water quality within the study reach of the Broken Creek. Lake Mokoan has been noted (O'Brien et al. 1996, URS 2002) as having poor water quality in terms of turbidity and nutrient concentrations. An initial comparison of water quality data from Mokoan (at Casey's Weir), against Broken River water upstream of the Lake Mokoan discharge (Holland Creek and Broken River at Morngag) supports this (Figure 4), showing that the total phosphorus concentrations and turbidity levels in Casey's Weir are substantially higher than the upstream Broken River sites .This suggests that the input water from Mokoan impacts on the water from upstream.

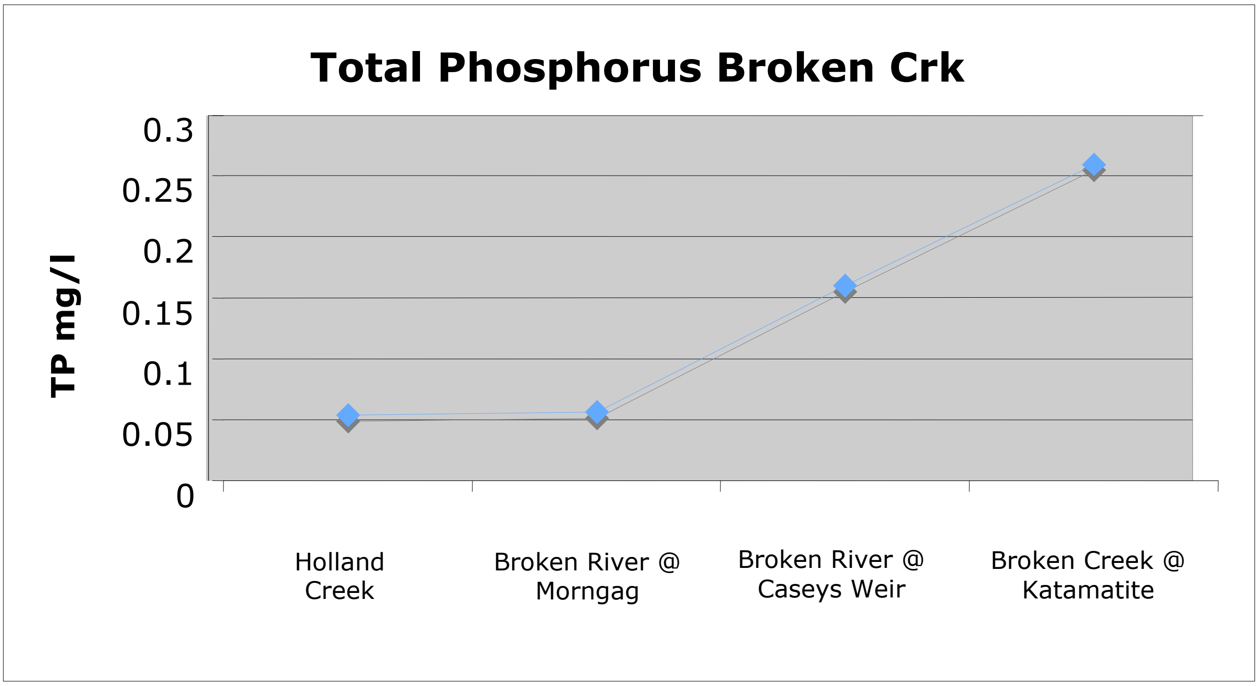
Although water from Lake Mokoan may be impacting on the quality of water in the Broken River, the data presented in Figure 4 also indicate that water quality continues to deteriorate downstream in the Broken Creek, reaching substantially higher turbidity levels and total phosphorus concentrations recorded at Katamatite. This is further supported by Waterwatch data, showing a trend of increasing turbidity levels and phosphorus concentrations at several sites between Casey's Weir and Katamatite (Figure 5). The data does not allow a statistical assessment but the rise in these levels are large and ecological significant. Seventy fifth percentile measures of total phosphorus and turbidity taken by Waterwatch at the Lake Mokoan outlet are almost identical to those measured at Goorambat, presented in Figure 5. These data strongly suggest that there are factors apart from Lake Mokoan impacting on the quality of water in the Broken Creek system between Casey's Weir and Katamatite.

The elevated turbidity concentrations in the waters of Caseys Weir do not correspond with higher suspended solids levels (refer Case Study 1, p17), suggesting that the turbidity inputs from Lake Mokoan do not necessarily indicate an increased threat of sedimentation in the Broken Creek.

Data in Figures 4 and 5 are presented as 75th percentiles as the SEPP (WoV) objectives are set as 75th percentiles for turbidity and total phosphorus. Data were obtained from the Victorian Data Warehouse, which contains results from approximately 1980 to present (Holland Creek and Broken River at Caseys Weir) or 1990 to present (Broken River at Morngag and Broken Creek at Katamatite) and incorporate at least 200 samples for each indicator at each site.

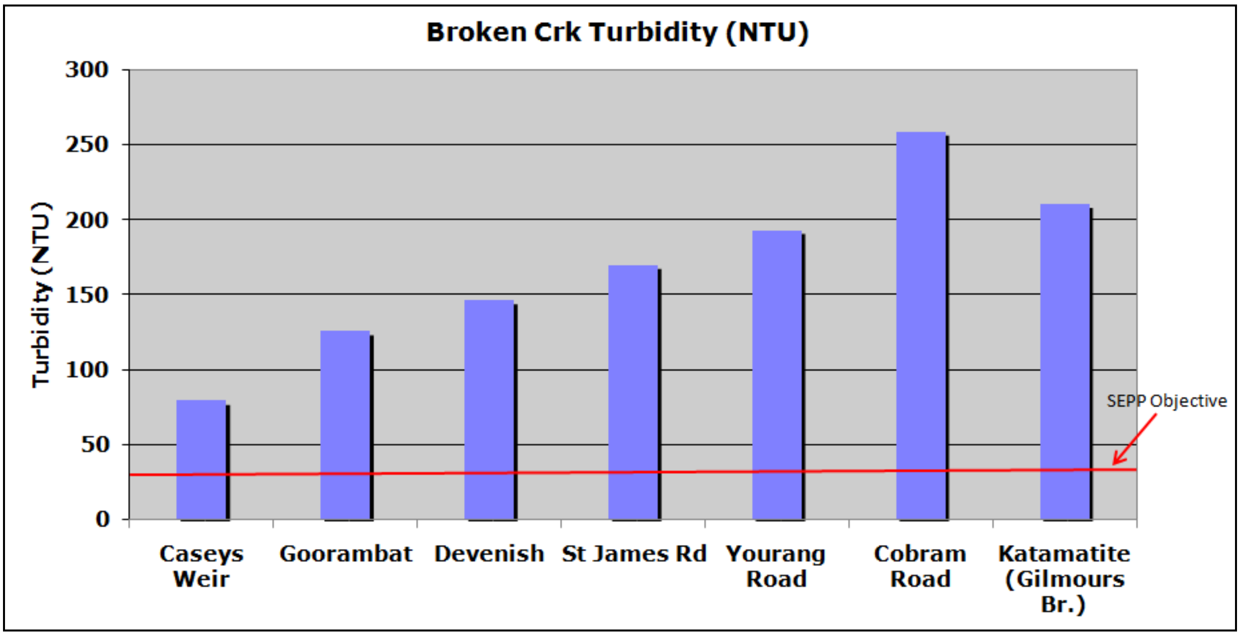


(a) Turbidity

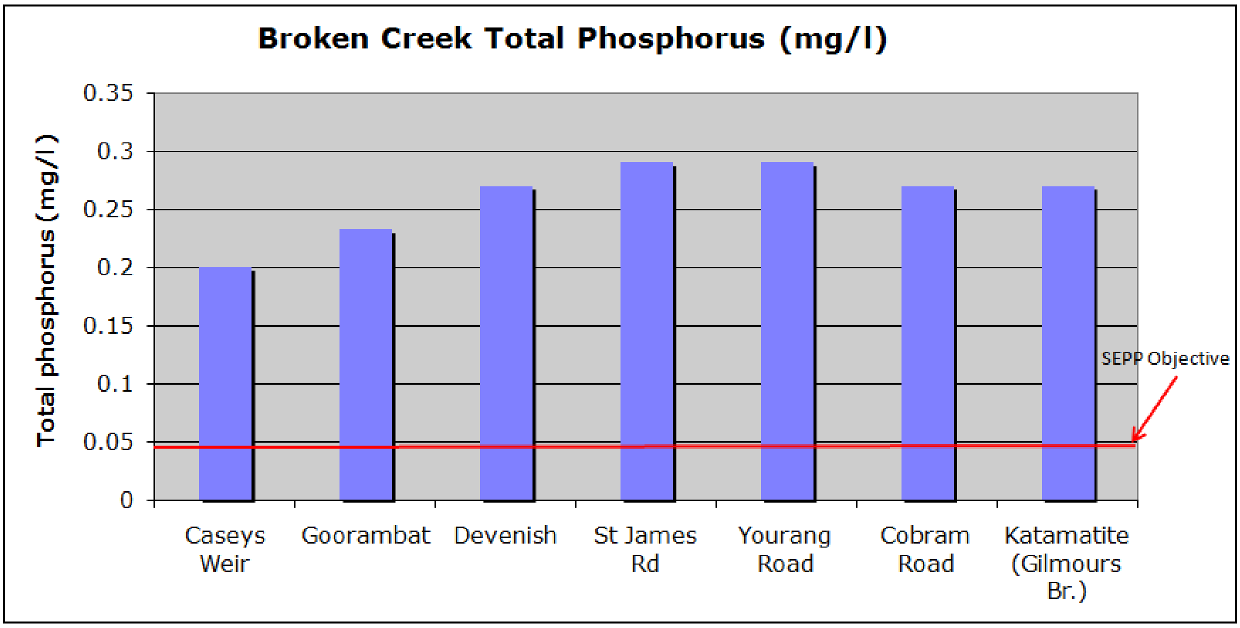


(b) Total Phosphorus

Figure 4: Turbidity and total phosphorus 75th percentile concentrations at Holland Creek and Morngag (upstream of the Lake Mokoan discharge), the discharge site (at Caseys Weir) and Katamatite (downstream of the discharge). Data source: VWQMN



(a) Turbidity



(b) Total Phosphorus

Figure 5: Turbidity and total phosphorus 75th percentile concentrations at sites on Broken Creek between Caseys Weir and Katamatite. Source: Goulburn-Broken Waterwatch

Case Study 1: Turbidity (NTU) versus Suspended Solids (mg/L) - 75th percentiles at Caseys Weir and Morngag in the Broken River and at Peechelba in the Ovens River (Source: VWQMN)

Years	Suspended solids 75th percentile (mg/l)	Turbidity 75th percentile (NTU)
Caseys Weir 1982 - 1996	33	37
Caseys Weir 1996 - 2008	22	84
Morngag 1990, - 1996	10	20
Morngag 1996 - 2008	11	32
Ovens River 1996 - 2008	23	17

Suspended solids (SS) concentrations in Broken Creek at Caseys Weir are similar to concentrations in the lower Ovens River (at Peechelba), which has relative natural flows and minimal impacts on water quality. In contrast, turbidity levels were considerably lower in the Ovens River compared to recent years at Casey Weir. SEPP (WoV) objective for turbidity is 30 NTU (annual 75th percentile), which is not being met at Caseys Weir. Interestingly, prior to 1996 the levels were close to meeting the objective. No SEPP (WoV) objective is available for suspended solids. While a concentration of 25 mg/L is known to affect Salmonids, in lowland Australian rivers this level is unlikely to have any impact on biota. These results show that although current turbidity in Broken River is high, suspended solid concentrations are low in comparison. This suggests that the turbidity mainly consists of fine clays, colloids and possibly algae, indicating that sedimentation is unlikely to be an issue with water entering from Lake Mokoan.

The decommissioning of Lake Mokoan is likely to result in substantially lower turbidity levels at Caseys Weir as the upstream turbidity levels are much lower, although it also has increased since the early 1990s. Suspended solid levels are low and have not changed since the early 1990s.

Changes in turbidity appear to be catchment wide and may not be associated only with changes in land-use but also changes in flow patterns and flow levels arising from climate change.

Case Study 2: Turbidity (NTU) versus Suspended Solids (mg/L) - 75th percentiles at Goorambat and Katamatite in the Broken Creek (Source: VWQMN)

	Suspended solids 75th percentile (mg/l)	Turbidity 75th percentile (NTU)
Goorambat 1982 - 1995	33	44
Goorambat 1996 - 2007	20	80.8
Katamatite 1990 - 1996	150	145
Katamatite 1996 - 2007	120	170

Similar to the water quality data presented for Caseys Weir and Morngag, suspended solids concentrations during the last decade have decreased in the Broken Creek at Goorambat and Katamatite, compared to earlier data. The decrease in suspended solids concentrations has been accompanied by an increase in turbidity readings. These data support the assertion in Case Study 1 that turbidity increases appear to be catchment-wide.

Despite the decrease in suspended solids over the last decade, the data continue to show large increases in suspended sediment concentrations and turbidity readings between Goorambat and Katamatite, suggesting substantial inputs are occurring from adjacent land-use and/or mobilisation of in-stream sediment.

Similar to the results from Case Study 1, Case Study 2 demonstrates an increase in turbidity over the last decade, accompanied by a decrease in suspended solids concentrations. However, this temporal decrease in suspended solids must be viewed within the context of a very large spatial (downstream) increase in both water quality indicators between Goorambat and Katamatite. Despite a decrease in suspended solids at Katamatite over the last decade, concentrations remain high.

3.3 Scope for Broken Creek ERA

The geographical scope of the project covers reaches 27, 26 and 25 (GB CMA 2005) of Broken Creek (Figure 3). These are defined as:

Reach 27: from the origin of Broken Creek at Casey's Weir, to Waggarandall Weir;

Reach 26: from Waggarandall Weir, to Reilly's Weir; and

Reach 25: from Reilly's Weir to the confluence of Broken Creek and Boosey Creek.

The temporal scope of the project focuses on the future (post-Mokoan) period to 2013 (i.e. 5 years from production of this report). This is because the decommissioning of Lake Mokoan has been confirmed and management recommendations arising from this study must be set within that context. This means that the current influences of Lake Mokoan discharges on the upper Broken Creek must be recognised and removed from the assessment of post-Mokoan risks.

3.4 Broken Creek Results Part 1: Problem Formulation

3.4.1 Values and Threats

The values highlighted in the Regional River Health Strategy (RRHS) (GB CMA 2005) for the Broken Creek study area were supplemented during the Problem Formulation Scientific Workshop. The resulting list of values was:

- Association with wetlands of national significance;
- Association with Broken Boosey State Park (a unique linear corridor along the Broken and Boosey Creeks, with substantial occurrences of high quality native vegetation;
- Large-bodied native fish (Catfish, Murray cod, Silver perch, Golden perch);
- Small native fish (Rainbow fish, Gudgeons, Hardyheads);
- Macroinvertebrate fauna;
- Riparian zones; and,
- Aquatic macrophytes.

Similarly, the threats identified in the RRHS (GB CMA 2005) and during the Scientific Workshop for the study area of Broken Creek were:

- Flow deviation;
- Water quality (turbidity, dissolved oxygen, nutrients);
- Water quality (SIGNAL Score);
- Water quality trends (pH, turbidity);
- Stock access;
- Introduced flora;
- Introduced fauna
- Fish barriers; and
- Land use (including resultant irrigation runoff, erosion); and,
- Water extraction.

During the Problem Formulation, the threat 'water quality (SIGNAL Score)' was identified as a condition of a value (macroinvertebrate community) rather than a threat and was removed from the list. The 'Water quality trend –pH' was identified as no longer occurring, with pH having effectively stabilised (Pat Feehan, personal communication) and was therefore also removed from the list.

3.4.2 Endpoints and Investigative Question

An '*assessment* endpoint' is a measurable feature of the stream reach that allows accurate assessment of that feature's condition or status. For example, phytoplankton may be a useful assessment endpoint (or assessment tool) for determining the condition or status of a water reservoir, due to their response to nutrient concentrations and their influence on water quality values such as taste and odour. A '*measurement* endpoint' is the critical aspect of the assessment endpoint that is measured to provide the required information. For example, 'phytoplankton biomass as indicated by chlorophyll-a concentration' would be a useful measurement endpoint for the reservoir.

The list of values for the study area contained several potential study endpoints, including macroinvertebrate community condition, wetland health and riparian zone condition. However, the Scientific Workshop determined that the native fish community (large-bodied and small fish) provide excellent endpoints for determining the condition of the Creek and assessing any changes due to management actions. This is supported by the following:

- fish are readily identifiable and are a valued component of river ecosystems;
- fish are sampled regularly within the Broken system
- the condition of the fish community relies on many aspects of ecosystem health, including several of the other identified values. For example: some species of fish require healthy wetlands and/or riparian zones for spawning; many species of fish require an adequate supply of macroinvertebrate fauna for food; the fish community composition will reflect the influences of flow regimes; and some species are noted as requiring adequate stands of macrophytes for general habitat and spawning purposes; and
- the fish community is directly and/or indirectly affected by all the water quality issues that triggered the ERA (turbidity, nutrients, dissolved oxygen).

For this ERA the assessment endpoint is therefore the fish community of the upper Broken Creek (Reaches 25 to 27 inclusive), and the measurement endpoint is Sustainable Rivers Fish Index (SR-FI) (MDBC 2004). The Sustainable Rivers Audit (SRA) for the Murray-Darling Basin established the SR-FI as an overall measure of fish community health. The index uses the composition and diversity of fish communities and is a good indicator of river health because it is representative of the quality and quantity of available habitat. Sampling is conducted in randomly selected 1km reaches on a regular basis. Analysis of the fish data focuses on fish community composition, including expected versus observed fish species, the relative abundance by number and weight of native and alien species, and the age structure of each fish species collected.

The investigative question for this ERA is:

> *What are the risks to the ecological condition of the native fish community of the upper Broken Creek (as measured by the SR-FI) from the major threats identified?*

The fish community of the Broken system has been sampled on several occasions (e.g. Close and Aland 2001, SKM 2008). Table 2 presents the fish species found in the study reaches and relevant associated ecological information.

The fauna of the Upper Broken Creek is dominated by exotic species (Eastern Gambusia, Redfin, Carp and Goldfish). The only native fish with high abundance and widespread distribution are the Australian Smelt and Carp Gudgeon but several are present within the system including Murray Cod, Golden Perch, Crimson-spotted Rainbowfish and River Blackfish (McMaster et al. 2008). A significant issue is that the recruitment of native fish within the system is poor, particularly in comparison to the exotic species. Murray Cod and Golden Perch populations have been stocked in large numbers (Close and Aland 2001, McMaster et al. 2008, SKM 2008) indicating these species are likely to be maintained from stocking and/or emigration from the Broken River rather than local recruitment. The fish fauna is missing species such as Southern Pygmy Perch, Mountain Galaxias and Flathead Gudgeon which thought to have been once present. This is not unusual for Southern Pygmy Perch which has undergone declines across the Murray-Darling Basin but the other species would be expected to be present. McMaster et al 2008 speculates whether large stocking of Murray Cod and Golden Perch has increased predation on these smaller species. It is generally assumed that these large fish being piscivorous may feed upon smaller fish species and in turn have adverse impacts on the smaller species' populations. The highly regulated flow environment is likely to be the cause of the lack of natural fish recruitment and a return to a more natural (ephemeral) flow regime will benefit native species and disadvantage exotic fish. This assumption is being tested by detailed work being undertaken by Monash University on behalf of GB CMA in the Broken Creek system.

Table 2: Fish species found in the study reaches of Broken Creek and associated ecological information

Reach	Large-bodied species	Small-bodied species	Ecological notes
27 (Casey's to Waggarandall Weir)	• Murray Cod • Golden Perch (Exotics: Carp)	• Australian Smelt • Carp Gudgeon • Rainbowfish • Blackfish (Exotics: Goldfish, Gambusia)	Moderate to good habitat with a variety of channel and weir pool habitats containing a moderate amount of large woody debris. Perennial flow retains permanent habitat for large bodied fish (e.g. Murray cod and Golden Perch) Threats include: Exotic fish, Stock access, poor water quality (such as high turbidity, high nutrients and low dissolved oxygen)
26 (Waggarandall to Reilly's Weir)	• Golden Perch (Exotics: Carp)	• Australian Smelt • Carp Gudgeon • Blackfish (Exotics: Carp, goldfish, Gambusia, Weatherloach)	Moderate habitat with a variety of channel and weir pool (McLaughlin's Weir & Reilly's) habitats containing a low amount of large woody debris. Currently* perennial flow (but lower than Reach 27) retains permanent habitat for golden perch but lack of deeper pools probably limits Murray cod. Post-Mokoan, more ephemeral flows will restrict large-bodied species and encourage smaller fish. Threats include: Exotic fish, significant flow deviation from natural, poor invertebrate communities (indicating poor water quality via Signal Score), fish barrier @ Reilly's, stock access, introduced flora and introduced fauna.
25 (Reilly's Weir to Katamatite)	• Golden Perch (Exotics: Carp)	• Australian Smelt • Carp Gudgeon (Exotics: Carp, Goldfish, Redfin, Gambusia, Weatherloach)	Moderate to poor habitat with a small uniform channel containing a low amount of large woody debris. Currently* perennial flow (but more natural than upstream reaches). Lack of pools probably limits larger fish. Post-Mokoan, more ephemeral flows will restrict large-bodied species and encourage smaller

			fish. Threats include: Exotic fish, poor water quality during prolonged cease-to-flow periods (high turbidity, low DO and high nutrients), flow deviation from natural, and poor invertebrate communities (indicating poor water quality via Signal Score).

***'Currently' refers to situation with Lake Mokoan operating**

3.4.3 Conceptual Model

Using the measurement endpoints and the threats to values presented in the previous Section, a conceptual model was derived for the fish community as an indicator of ecological condition (Figure 6). The threats to the fish community were divided into *direct* threats (those that have the potential to directly impact upon the native fish community); and *indirect* threats (those that contribute to the direct threats). For example, 'Physical habitat destruction' is a direct threat to the fish community. Factors that may contribute to Physical habitat destruction, such as stock access to the riparian zone or sedimentation are indirect threats. The direct threats are represented by the red text boxes in Figure 6 and include:

- flow regulation;
- barriers to fish movement;
- turbidity;
- sedimentation;
- dissolved oxygen;
- introduced pest fish;
- introduced plant species; and,
- physical habitat destruction.

Flow Regulation: There are two dams upstream of Caseys Weir, Lake Mokoan and Lake Nillahcootie, which currently regulate flows in the Broken Creek. Lake Mokoan will be decommissioned and it is expected that as part of changes to the system, flows will decrease downstream of Flynn's Weir, changing the Creek from perennial to ephemeral. Substantial irrigation pumping is undertaken from Broken Creek between Casey's Weir and Flynns Weir, but this is not expected to affect the perennial nature of the creek between Casey's Weir and Flynn's Weir.

Barriers to fish movement: All existing barriers in the Broken Creek downstream of Katamatite have had fish passage provision installed. In the reaches from Katamatite up to Casey's Weir, Irvine's, Reilly's, Waggarandall, and Flynn's Weirs have all been identified as fish barriers. Further, a gauging station within the Creek has also been identified as a potential fish barrier.

Turbidity: Turbidity levels are currently high downstream of Caseys Weir. Turbidity levels in the Broken River upstream of Caseys Weir are low, suggesting that when Lake Mokoan is decommissioned levels will decrease substantially. However, similar to nutrient levels, turbidity increases markedly in the Broken Creek downstream of Casey's Weir (Figure 5b), suggesting that there are other major sources of nutrients entering the stream between Casey's Weir and Katamatite.

Sedimentation: Current turbidity levels immediately downstream of Caseys Weir are high enough to suggest that a sedimentation threat may exist. However, suspended solids concentrations in this section are low, suggesting that the turbidity is due to very fine colloidal material from Lake Mokoan and will contribute little to sedimentation. In contrast, turbidity and suspended solids both increase to high levels downstream of Goorambat, indicating a potential threat from sedimentation.

In the past, upstream catchment erosion has been a major source of sediment. This has resulted in silting of pools and smothering of large woody debris in uppermost reach (Reach 27) of the Broken Creek (SKM 2006). Ongoing bank and riparian zone erosion are potential continuing sources of sediment within the Creek. Works are underway to assess the usefulness of reinstating deep pools and the effects of sediment load to the creek will need to be assessed.

Dissolved oxygen: Dissolved oxygen concentrations can be low at times, but measurements suggest these are not at levels dangerous to native fish. Changes in flow regime, especially the ephemeral reaches downstream of Flynn's Weir, may result in very low oxygen levels during prolonged dry periods where the pools develop substantial phytoplankton communities. Sediment oxygen demand may also result in pools with large, oxygen-consuming, organic loads during prolonged dry spells.

Macrophytes will also influence oxygen levels although macrophytes densities are generally low. However, the native species, *Azolla filliculoides* (a floating fern) does form thick mats on some pools. Macrophyte densities may increase if turbidity levels decrease.

Introduced fish species: Competition and predation by pest fish species is currently important, and changes in flow regime may, and water quality will, affect them and their relationships with native species. One mechanism is that Redfin have a competitive advantage under conditions of low turbidity in their predation ability. Other mechanisms include the hardiness of Carp and Gambusia under extreme water quality conditions (e.g. low DO) and these fish have a competitive advantage over natives in these conditions.

Introduced macrophytes: Currently there are no major impacts of introduced macrophytes on the fish community upstream of Katamatite. Cabomba (*Cabomba caroliniana*) has been observed in Casey's weir and is therefore a potential threat to Broken Creek, especially if flows are reduced. In the potentially ephemeral reaches downstream of Flynn's Weir, the potential risk is substantially higher.

Physical habitat destruction: Suitable physical habitat is critical for a healthy fish community and includes in-stream and riparian zone habitat. Submerged macrophytes in Broken Creek are generally restricted to scattered clumps, which is likely due to the high turbidity levels restricting light required for plant growth. Decommissioning of Mokoan may reduce turbidity levels in the upper parts of the creek, resulting in increased macrophyte growth. Large wood material is common in the creek and is the major physical habitat available to fish.

The riparian zones are the major source of organic matter, insects, shading and large woody debris to the creek. The creation of the Broken-Boosey State park recognises the value of the riparian zone in the Broken Creek. Grazing access to the riparian zone seriously impacts its integrity. Decreased sediment loads from the banks of the creek due to fencing (removing stock access) and revegetation works may reduce the sedimentation threat to the physical habitat.

Among the indirect threats, the major ones are:

Nutrients: Nutrients themselves do not pose a direct threat to the fish community. However, elevated nutrient concentrations may lead to excessive growths of algae and macrophytes. Nutrient concentrations downstream of Caseys Weir are currently high enough to promote excessive plant growth. However, turbidity is also very high which limits plant growth due to light limitation. Therefore, nutrients pose a threat to Broken Creek but the threat is not being activated due the turbidity. Nutrient levels in the Broken River upstream of Caseys Weir are low, suggesting that when Lake Mokoan is decommissioned these levels will decrease substantially in the Broken Creek at Caseys Weir. However, nutrient levels downstream in the Broken Creek increase substantially (Figure 5a), suggesting that there are other major sources of nutrients downstream of Caseys Weir. Irrigation return waters and bed and bank erosion are possible sources.

Land use: The adjacent land use will determine the level of sediment and nutrient transported to the creek. In general, broad-acre cropping and grazing are not considered to be a major source of sediment and nutrients to the creek except when they encroach on the riparian zone. Irrigation however, may deliver substantial quantities of sediment and nutrients to waterways via irrigation return waters. The increasing concentrations of total phosphorus and turbidity with distance downstream indicate that some forms of surrounding land use (including stock access) are contributing to water quality problems.

Direct stock access to streams: Stock access to riparian zones is major cause of erosion and subsequently a major source of sediment to waterways, and for this reason is a major focus of management actions. In general, the banks of the Broken Creek are relatively stable and the level of erosion low, therefore, as a source of sediment and nutrients the banks of the creek are likely to be low if stock access is removed.

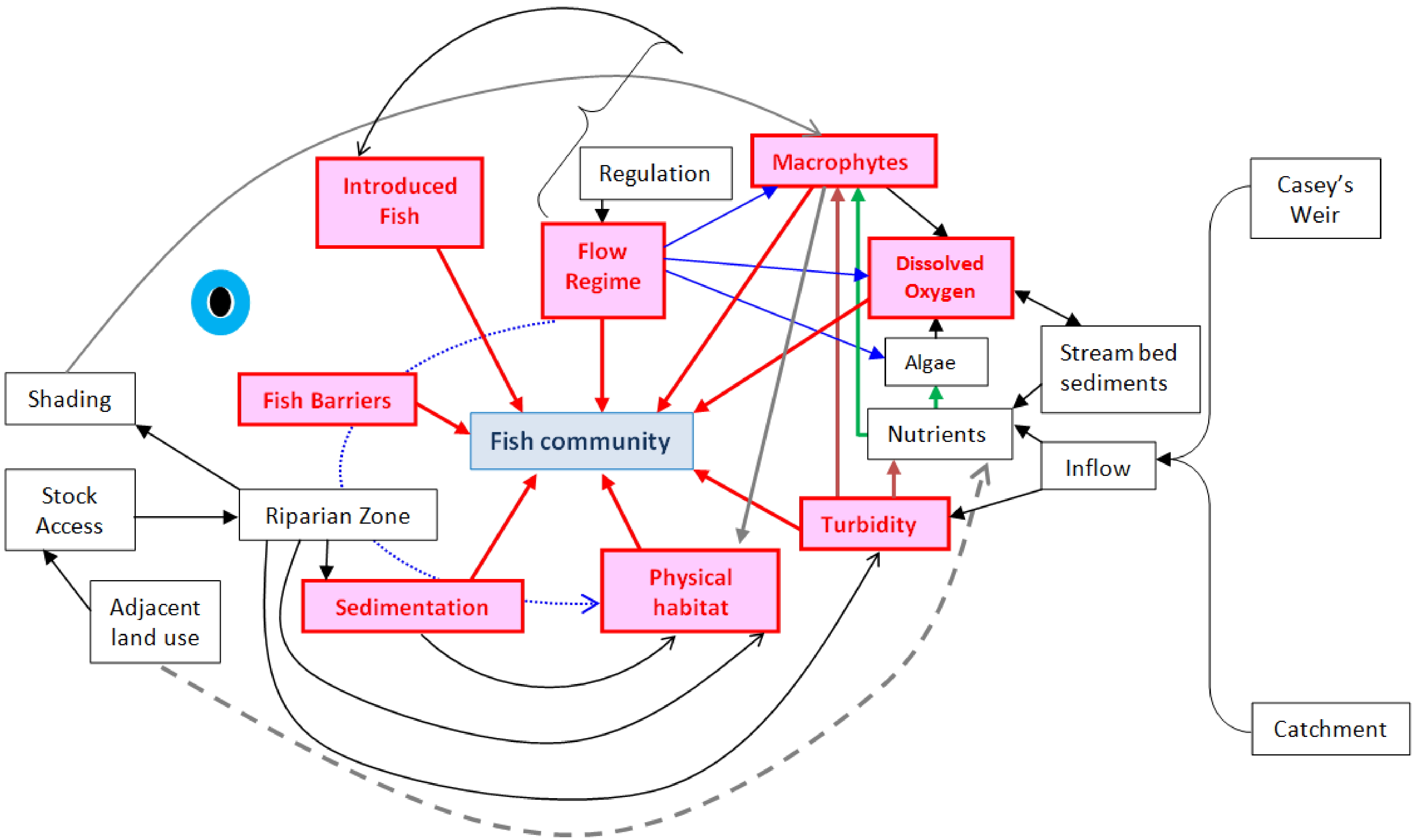


Figure 6: Conceptual Model of threats to the fish community in the upper Broken Creek

3.5 Broken Creek Results Part 2: Preliminary risk analyses

The preliminary risk analysis of the upper Broken Creek was undertaken as a workshop by the authors of this report. In addition to the authors' aquatic ecological expertise (including ecology of fish, algae, macrophytes and macroinvertebrates; water quality; impacts and management of high nutrients; and catchment management) and collective experience with the natural resource management issues of the Broken Creek, the analyses were informed by formal meetings and informal discussions with relevant staff of the GB CMA, members of the MGBIC and local/regional Waterwatch participants.

The preliminary risk analysis was undertaken for two separate zones within the Creek: (i) the zone upstream of Flynn's Weir; and (ii) the zone from Flynn's Weir to Katamatite. The first zone will continue to receive flows from Casey's Weir following the decommissioning of Lake Mokoan. As a result of the Tungemah pipeline, the second zone will not receive flows, resulting in several different assessment outcomes from the preliminary risk analyses. The results from the use of the risk calculator are tabulated and presented in Table 3.

While fish communities the Broken Creek may be better than in other locations in Victoria, they are still considered depauperate in relation to their original condition. Some species are missing or in very low numbers (Catfish, Purple-spotted Gudgeons, Pygmy Perch, Mountain Galaxias, Flathead Gudgeon & River Blackfish) and common fish are lower than historical levels (J.O. Langtry in Cadwallader 1977) reports very high levels of native fish present in Murray system). This risk assessment considered this information as it formed background information about the ability of the fish fauna to respond to threats and changed operating conditions.

Table 3: Risk Scores for the Preliminary and Qualitative Risk Assessment for ecological threats in Broken Creek Reaches 25 - 27

Threat	Source of potential threat	Probability	Exposure	Consequence	Risk Calculator Score
Flow regulation	Discharge from Casey's Weir u/s Flynns	Almost certain	Annual to monthly	**Moderate - Major** • No Cease to flow – predators remain • Breeding cues reduced • Habitat changed • Production reduced due to lack of flooding	**High to Very High**
	Discharge from Casey's Weir d/s Flynns	Conceivable (but very unlikely)	5 yearly	**Insignificant** • Little flow change on natural	Low
Fish barriers	Irvine & Reilly's Weir	Almost certain	Daily	**Moderate** • Prevent breeding migration • Prevent smaller fish to find mates, food resources and breeding habitat	**Very High**
Nutrients (note: not a direct threat; impact via macrophyte growth & algal blooms)	Upstream catchment	Conceivable (but very unlikely)	5 to 10 yearly	**Insignificant** • Short term event • Nutrient increase will be minor in relation to background levels	Low
	Bed Sediments • u/s Flynn's Weir	Conceivable to Practically Impossible	10 yearly	**Minor** • Short term event • Nutrient increase and algal response will be minor in relation to seasonal conditions (cold)	Low

Threat	Source of potential threat	Probability	Exposure	Consequence	Risk Calculator Score
	Bed Sediments • d/s Flynn's Weir	Quite Possible	Annual to 5 yearly	**Moderate** • DO sags of below 2mg/l • Initial major impact as large fish will be disadvantaged and small fish will thrive – moderate on small fish	Moderate to Substantial
	Stream banks	Quite Possible	Monthly	**Moderate** • Nutrients will cause DO sags of below 2mg/l • Initial major impact as large fish will be disadvantaged and small fish will thrive – moderate on small fish	**Substantial to High**
	Adjacent land use	Quite Possible	Monthly	**Moderate** • Nutrients will cause DO sags of below 2mg/l • Initial major impact as large fish will be disadvantaged and small fish will thrive – moderate on small fish	**Substantial to High**
Dissolved oxygen	Phytoplankton • u/s Flynn's Weir	Conceivable to Practically Impossible	10 yearly	**Minor** • Short term event • Nutrient increase and algal response will be minor in relation to seasonal conditions (cold)	Low
	• d/s Flynn's Weir	Quite Possible	Annual	**Moderate** • DO sags of below 2mg/l • Initial major impact as large fish will be disadvantaged and small fish will thrive – moderate on small fish	**High to Very High**

Threat	Source of potential threat	Probability	Exposure	Consequence	Risk Calculator Score
	Macrophytes • u/s Flynn's Weir	Conceivable to Practically Impossible	10 yearly	**Minor to Insignificant** • Short term event • Nutrient increase and macrophyte response will be slower than algae in relation to seasonal conditions (cold) • Cabomba might cause DO problems in weir pools but fish can avoid these pools	Low
	Macrophytes • d/s Flynn's Weir	Remotely Possible	Annual	**Moderate** • DO sags of below 2mg/l • Initial major impact as large fish will be disadvantaged but small fish will thrive – moderate impact on small fish • Pools will be isolated and fish can escape	Low to Moderate
	Sediment oxygen demand • u/s Flynn's Weir	Conceivable to Practically Impossible	10 yearly	**Minor** • Short term event • Nutrient increase and algal response will be minor in relation to seasonal conditions (cold)	Low
	Sediment oxygen demand • d/s Flynn's Weir	Quite Possible	Annual to 5 yearly	**Moderate** • DO sags of below 2mg/l • Initial major impact as large fish will be disadvantaged and small fish will thrive – moderate on small fish	Moderate to Substantial

Threat	**Source of potential threat**	**Probability**	**Exposure**	**Consequence**	**Risk Calculator Score**
Turbidity	Upstream catchment	Conceivable (but very unlikely)	5 to 10 yearly	**Insignificant** • Short term event • Turbidity increase will be minor in relation to background levels	Low
	Stream banks	Quite Possible	Monthly	**Minor** • Predation from exotics will be lower • Most native will not be affected significantly • Some macrophytes may be affected and have reduced habitat fish	Moderate to Substantial
	Adjacent land use	Quite Possible	Monthly	**Minor** • Predation from exotics will be lower • Most native will not be affected significantly • Some macrophytes may be affected and have reduced habitat fish	Moderate to Substantial
Sedimentation	Upstream catchment	Conceivable (but very unlikely)	5 to 10 yearly	**Insignificant** • Short term event • Sediment increase will be minor in relation to background levels • Sediment level needs to be very high to have impact	Low

Threat	Source of potential threat	Probability	Exposure	Consequence	Risk Calculator Score
	Stream banks	Quite Possible	Weekly	**Minor** • Threat to community diversity but likely to be temporary • Sediment increase will be minor in relation to background levels • Sediment level needs to be high to have impact	**Substantial to High**
	Adjacent land use	Quite Possible	Weekly	**Minor** • Threat to community diversity but likely to be temporary • Sediment increase will be minor in relation to background levels • Sediment level needs to be high to have impact	**Substantial to High**
Introduced fish		Almost Certain	Daily	**Moderate** Impacts – some species will decline – all species will have reduced impacts	**Very High**
Introduced macrophytes	• u/s Flynn's Weir	Remotely Possible	Annually	**Minor - Moderate** • Exotic macrophytes will reduce and change nature of habitat for fish and cause oxygen sags at times – not just minor consequence as some impacts will not be temporary	Low (to Moderate)
	• d/s Flynn's Weir	Quite Possible	Monthly to Annual	**Major** • Large infestation of Exotic macrophytes will significant reduce habitat and change nature of habitat for fish. Also will cause oxygen sags at times	**High to Very High**

The highest risks to the fish community identified through the preliminary risk analysis were the impacts of **fish barriers** and **introduced fish** (both 'very high risk'). These were primarily a function of exposure, whereby both these threats impact on the fish community every day, and also a function of probability, with it being almost certain that the threats have an impact on the fish community. The next highest risks ('high to very high') were identified as **flow regulation** in the section of the Creek upstream of Flynn's Weir, and **low dissolved oxygen** and **introduced macrophytes** in the section of the Creek downstream of Flynn's Weir. Risks from introduced fish are probably the most difficult to manage. The remaining threats are more manageable, although at varying costs.

Fish barriers create a variety of problems for individual fish species. For some species the major impact upon long term survival of the population is by stopping genetic exchange that would normally occur through finding new mating partners. Barriers to movement also restrict opportunities for finding new territories for migration and population expansion, as well as expanding hunting grounds.

Introduced fish - European carp uproot aquatic macrophytes, increasing turbidity and may compete for food and habitat. Eastern Gambusia also compete for food and habitat, with small bodied fish and juvenile large-bodied fish and prey on eggs and young of all native fish. Gambusia is also known to attack the fins of fish much larger than itself causing them stress and diseases (Lloyd et al. 1986). Small native fish such as Pygmy Perch are particularly vulnerable to Gambusia (Lloyd 1990). Impacts from Goldfish and Weatherloach are unknown but if large populations arise they may consume food and habitat resources of native fish.

The impacts of ongoing **flow regulation** on the fish population upstream of Flynn's Weir include reduced breeding cues for native species, less habitat heterogeneity from continual flows, predators remaining and a reduced flooding regime which reduces production within the system. Sliver and Golden Perch both require flow freshes to stimulate breeding and Murray Cod recruitment is also enhanced by flow freshes, especially those which connect marginal and floodplain wetlands. All these species also undertake pre and post-spawning migrations which if prevented will reduce the reproductive success of these large fish species. Murray Cod larvae drift downstream and if they are not able to migrate upstream, the larvae will be washed out of the reach (Koehn & Harrington 2006).

As displayed in the conceptual model (Figure 6), **dissolved oxygen** is influenced by many factors. The allocation of a 'high to very high' risk score for dissolved oxygen concentrations downstream of Flynn's Weir was based on the increased likelihood of cease-to-flow periods during dryer months, combined with high nutrient concentrations. Lack of flow reduces aeration of water bodies, particularly pools in warmer seasons. Lack of flow also promotes settling of suspended particulate matter, thereby increasing light transmission through the pools and promoting algal growth. Algal growth is already favoured by the high nutrients within the pools. High algal biomass contributes to dissolved oxygen stress through two mechanisms. Firstly, although the algae photosynthesise during the day (producing high dissolved oxygen concentrations), they also respire (consuming oxygen). During the night, the respiration is not balanced with oxygen production, leading to an oxygen trough (and a severe oxygen stress for the fish community) in the water body when algae are present in very high concentrations.

The second mechanism by which high algal concentrations create oxygen stress is through die-off at the end of their growing period. The decaying (oxidising) algal cells create an oxygen demand on the water body that can create oxygen troughs for days or even weeks, again stressing or even killing the fish community. When this impact occurs in a flowing system, the fish can often swim to more suitable habitats. However, when this occurs in pools, the fish are trapped.

The risks posed by **introduced macrophytes** (in particular, Cabomba) include substantial loss of physical habitat through prolific growth filling in most available space within a water body. A large biomass of aquatic weed would also contribute to a diurnal sag in dissolved oxygen, as described for algal blooms, and the risk will be increased during cease-to-flow periods.

3.6 Knowledge Gaps and Assumptions for Broken Creek ERA

Knowledge gaps: The major knowledge gaps identified during the development of this risk assessment, with emphasis on highest risks, include:

- quantitative information on the fish species in the study reach of the Broken Creek and data on the impacts of fish barriers to the native fish community;
- quantitative information on the abundance (and its variability) of introduced fish species and their impact on the distribution and abundances of native fish populations in the relevant study reaches of the Broken Creek;
- quantitative information on the influences of future flow regimes (particularly in the lower parts of the study) on dissolved oxygen regimes. This information can be gathered through field studies following the decommissioning of Lake Mokoan;
- information on nutrient and turbidity inputs to the Broken Creek downstream of Caseys Weir. Evidence suggests that there are other sources of nutrients and turbidity entering the creek downstream of the weir, further increasing the already elevated measures of these indicators;
- extent and rate of sediment inputs to the Broken Creek from adjacent catchment and riparian land use;
- data on the quality and volume of stormwater discharged to the river from Benalla is unknown. Nutrient and sediment levels increase in Benalla Lake and downstream (Figure 7) but there are no data on toxicants. It is likely that many of the toxicants entering Benalla Lake will settle out in the lake and are unlikely to have impacts further downstream (Hurl et al. 1999; Wong et al. 1999, 2003; Fletcher et al. 2004).

Uncertainties and assumptions: As with any study of lowland rivers, the complexity of the system can lead to substantial uncertainties, however, all effort has been made to reduce uncertainties through the identification and analysis of all identified threats. This is a strength of the ERA approach. A weakness in the process has been the lack of data or information on nutrient and sediment sources in the creek downstream of Caseys Weir. In particular, the influence of elevated suspended solids downstream of Goorambat is a high uncertainty in relation to the native fish community in the post-Mokoan period.

While many assumptions have been made concerning the needs of fish, particularly with respect to water quality, these are generally based on substantial expert knowledge, patterns of distribution or known cause effects relationships. Key assumptions include:

- Flows in Broken Creek below Flynns Weir will reduce to zero during annual dry periods
- Climate change will not lead to a situation where the majority of the Creek is completely dry for large periods of time

- dissolved oxygen concentrations around 85% saturation are unlikely to harm any native fish species and can in fact drop to 2-3ppm before native species are likely to be impacted (Hydro Environmental 2006), whereas some exotic species are more likely to withstand those conditions and only become stressed at almost anoxia (Lloyd et al. 1986).
- Fish barriers do prevent fish movement between reaches and no other natural barriers exist.
- That changes to flow regimes will benefit native fish more than exotic species.
- The introduced weed *Cabomba caroliniana* is currently found in Benalla Lake and Caseys Weir pool and while the extent and speed of spread is unknown it is believed to be able to infest all standing water bodies downstream.

4. BROKEN RIVER

4.1 Introduction

The Broken River originates on the north draining slopes of the Great Dividing Range, near Tolmie, and flows generally north then west to join the Goulburn River at Shepparton. The focus of this ecological risk assessment is the Broken River from its confluence with Holland Creek, down to its confluence with the Goulburn River at Shepparton. This section of river has high community value, is associated with wetlands of national significance and supports significant fauna and flora, including listed species (Silver Perch, Macquarie Perch and Murray Cod). In addition, the river has substantial social values (camping, fishing, passive recreation) and economic benefits (irrigation, domestic and stock water supply). The lower Broken River consistently triggers the SEPP (WoV) objectives for turbidity, nutrients and dissolved oxygen, indicating risk to the aquatic ecosystem.

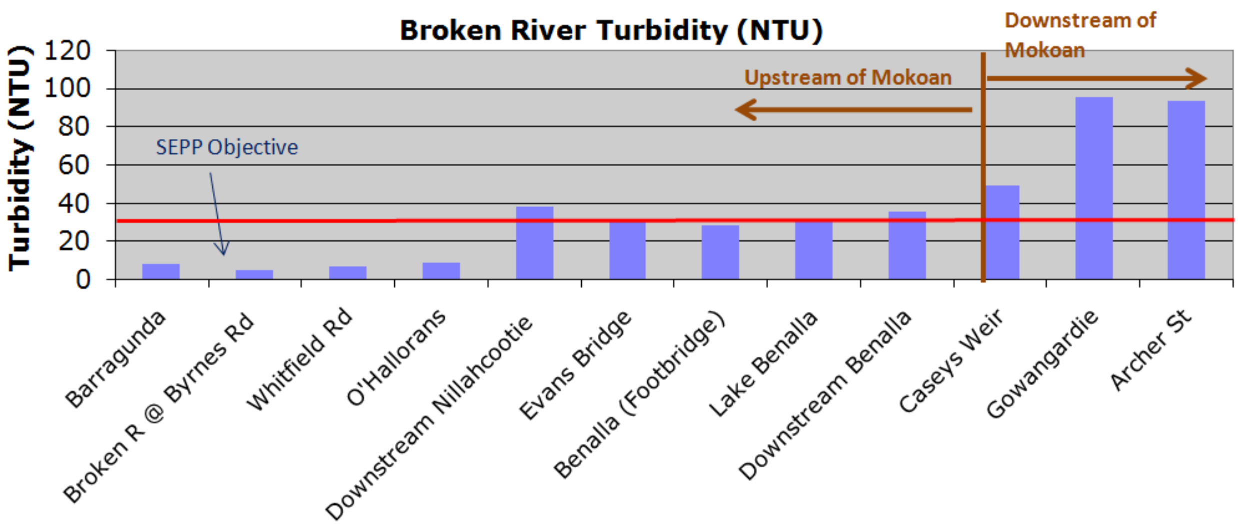
4.2 Background

The Broken River was identified in the Goulburn Broken Regional River Health Strategy (GB CMA 2005) as not attaining water quality objectives for total nitrogen, total phosphorus, dissolved oxygen and turbidity as defined in SEPP(WoV). In a more recent review of water quality in the Goulburn Broken Catchment (GB CMA 2008), Broken River between Benalla and Shepparton was identified as a high priority reach for an ecological risk assessment, based on the Creek's continuing failure to attain SEPP(WoV) objectives.

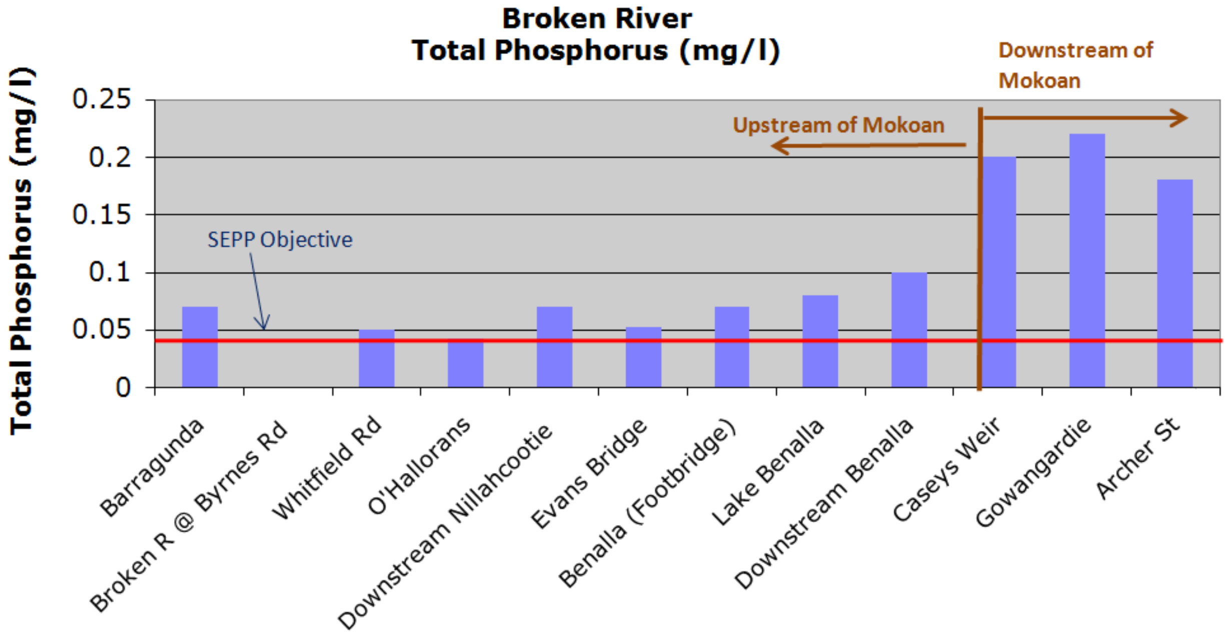
A potentially important impact on the water quality of Broken River is the discharge the River receives from Lake Mokoan, via Stockyard Creek above Casey's Weir. The discharge from Lake Mokoan mixes with waters from upstream in the Broken River (including inputs from tributaries such as Holland Creek and Ryans Creek) and forms a significant part of the flow in the Broken River. Therefore, the quality and quantity of the flow in this stretch is influenced by the discharge from Lake Mokoan.

Lake Mokoan is scheduled to be decommissioned in mid 2009. Upon the decommissioning, Broken River will return to near-natural flows (Broken River Scientific Panel, 2001), with the only river regulation coming from Lake Nillahcootie – a relatively small storage of only 40 GL.

The decommissioning of Lake Mokoan offers the prospect of improved water quality within the study reach of the Broken River. Lake Mokoan has been noted (O'Brien et al. 1996, URS 2002) as having poor water quality in terms of turbidity and nutrient concentrations. An initial comparison of water quality data from Mokoan (at Casey's Weir) supports this (Figure 4, Section 3), showing that the total phosphorus concentrations and turbidity levels in Casey's Weir are substantially higher than the Broken River sites upstream of Casey's Weir (Holland Creek and Morngag). This suggests that the input water from Mokoan impacts on the water from upstream. Although waters from Lake Mokoan may be impacting water quality of the water from Broken River, data presented in Figure 7 indicate that water quality continues to deteriorate downstream in Broken River, with water at Gowangardie having higher total phosphorus concentrations and turbidity levels than at Caseys Weir. The high turbidities recorded at Gowangardie Weir, however, are not matched by suspended solids concentrations (VWQMN 2008), indicating little potential risk of sedimentation impacts.



(a) Turbidity



(b) Total Phosphorus

Figure 7: Turbidity and total phosphorus concentrations at sites on Broken River from near the headwaters to Archer Street (Shepparton). Source: Goulburn-Broken Waterwatch

Data in Figure 7 are presented as 75th percentiles as the SEPP (WoV) objectives are set as 75th percentiles for turbidity and total phosphorus. Data were obtained from the Goulburn-Broken Waterwatch group and ranges from approximately 1996 to 2008. These data strongly suggest that there are ongoing impacts to water quality of the Broken River system between Casey's Weir and Gowangardie Weir. Interestingly, both turbidity and total phosphorus decline slightly between Gowangardie and Archer St. in Shepparton (Figure 7), but it is unsure whether this decline is significant.

4.3 Scope for Broken River ERA

The geographical scope of the project covers reaches 3, 2 and 1 (GB CMA 2005) of Broken River (Figure 8). These are defined as:

Reach 3: From the confluence of Broken River and Holland Creek, down to Caseys Weir;

Reach 2: From Caseys Weir, down to Gowangardie Weir; and

Reach 1: From Gowangardie Weir down to the confluence of Broken River and the Goulburn River.

The temporal scope of the project focuses on the future (post-Mokoan) period to 2013 (i.e. 5 years from production of this report). This is because the decommissioning of Lake Mokoan has been confirmed and management recommendations arising from this study must be set within that context. This means that the current influences of Lake Mokoan discharges on the lower Broken River must be recognised and removed from the assessment of post-Mokoan risks.

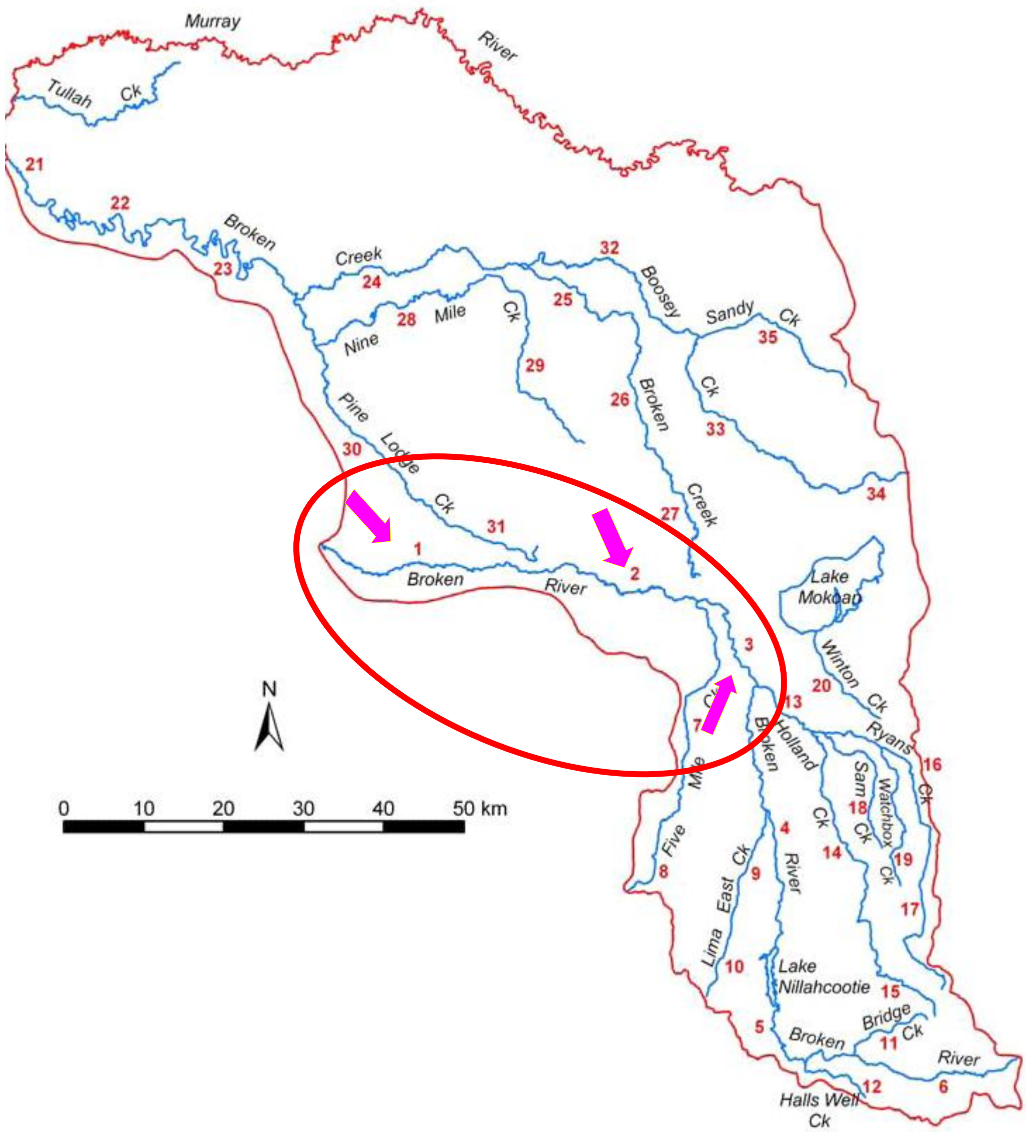


Figure 8: Map of the Broken River system, with Reaches 1 – 3 highlighted (Source: GB CMA 2005)

4.4 Broken River Results Part 1: Problem Formulation

4.4.1 Values and Threats

The values highlighted in the Regional River Health Strategy (RRHS) (GB CMA 2005) for the Broken River study area were similar to those identified for Broken Creek, and the examination of values and threats at the Problem Formulation Scientific Workshop produced similar lists:

Values

- Wetland of national significance (DIWA wetland, Lower Broken River)
- Large-bodied fish (Catfish, Murray Cod, Silver Perch, Golden Perch; Macquarie Perch);
- Small fish (River Blackfish, Rainbowfish, Gudgeons, Australian Smelt, Hardyheads);
- Macroinvertebrate fauna;
- Riparian zones; and,
- Aquatic macrophytes.

Threats

- Flow deviation;
- Water quality (turbidity, dissolved oxygen, nutrients);
- Stock access;
- Introduced flora;
- Introduced fauna
- Fish barriers;
- Land use (including potential irrigation runoff, erosion); and,
- Water extraction.

4.4.2 Endpoints and Investigative Question

The similarity in the list of values between the upper Broken Creek and the lower Broken River resulted in the same endpoints being selected – the native fish community. The native fish community (large-bodied and small fish) provides excellent endpoints for determining the condition of the River and assessing any changes due to management actions. This is supported by the following:

- fish are readily identifiable and valued component of river ecosystems
- fish are sampled regularly within the Broken system
- the condition of the fish community relies on many aspects of ecosystem health, including several of the other identified values. For example: some species of fish require healthy wetlands and/or riparian zones for spawning; many species of fish require an adequate supply of macroinvertebrate fauna for food; the fish community composition will reflect the influences of flow regimes; and some

species are noted as requiring adequate stands of macrophytes for general habitat and spawning purposes; and

- the fish community is directly or indirectly affected by all the water quality issues that triggered the ERA (turbidity, nutrients, dissolved oxygen).

For this ERA the assessment endpoint is therefore the fish community of the lower Broken River (Reaches 3 to 1 inclusive), and the measurement endpoint is Sustainable Rivers Fish Index (SR-FI) (MDBC 2004). The Sustainable Rivers Audit (SRA) for the Murray-Darling Basin established the SR-FI as an overall measure of fish community health. The index uses the composition and diversity of fish communities and is a good indicator of river health because it is representative of the quality and quantity of available habitat. Sampling is conducted in randomly selected 1km reaches on a regular basis. Analysis of the fish data focuses on fish community composition, including expected versus observed fish species, the relative abundance by number and weight of native and alien species, and the age structure of each fish species collected.

The investigative question for this ERA is:

> *What are the risks to the ecological condition of the native fish community of lower Broken River (as measured by the SR-FI) from the major threats identified?*

The fish community of the Broken system has been sampled on several occasions (e.g. Close and Aland 2001, SKM 2008). Table 4 presents the fish species found in the study reaches and relevant, associated ecological information. These surveys show that the Broken River has a reasonably diverse native fish fauna with seventeen native fish species of fish (Close and Aland 2001). Unfortunately, since European settlement, the Broken River now also supports eight species of exotic fish. Significantly, Australian Smelt, Southern Pygmy Perch, Mountain Galaxias, Flathead Galaxias and Carp Gudgeon are all common in the Broken River (Close and Aland 2001). The river also supports populations of listed large-bodied fish as well such as Trout Cod, Murray Cod, Macqurie Perch, and Silver Perch (though Trout Cod may be maintained by repeated stockings (DNRE 2001). The near natural flow regime of the Broken River means that breeding and recruitment of native fish occurs regularly and changes from the decommissioning of Lake Mokoan will only reinforce this healthy community.

4.4.3 Conceptual Model

Using the measurement endpoints and the threats to values presented in the previous Section, a conceptual model was derived for the fish community as an indicator of ecological condition. Again, the similarity between the Broken Creek study area and the Broken River study area has resulted in the same conceptual model being produced (Figure 6, repeated here as Figure 9).

Table 4: Fish species found in the study reaches of the lower Broken River, with associated ecological information

Reach	Large-bodied species	Small-bodied species	Ecological notes
3 (confluence of Broken River and Holland Creek, down to Caseys Weir)	• Murray Cod • Silver Perch • Golden Perch	• Australian Smelt • Gudgeon • Rainbowfish • Blackfish (Exotics: Carp, Goldfish, Gambusia)	Moderate to good habitat with a variety of channel and weir pool habitats containing a moderate amount of large woody debris. Perennial flow retains permanent habitat for large bodied fish (e.g. Murray Cod, Silver Perch and Golden Perch). The major threats are perceived to be water quality decline, stock access, flow regulation, and sedimentation (especially in pool habitat).
2 (Caseys Weir, down to Gowangardie Weir)	• Murray Cod • Golden Perch	• Australian Smelt • Gudgeon • Rainbowfish • Blackfish (Exotics: Carp, Goldfish, Gambusia)	Moderate to good habitat with a variety of channel and weir pool habitats containing a moderate amount of large woody debris. Perennial flow retains permanent habitat for large bodied fish (e.g. Murray Cod and Golden Perch). The major threats are perceived to be water quality decline, stock access, flow regulation, and sedimentation (especially in pool habitat).
1 (Gowangardie Weir down to the confluence of Broken River and the Goulburn River)	• Murray Cod • Macquarie Perch	• Australian smelt • Gudgeon • Blackfish (Exotics: Carp, Goldfish, Gambusia)	Moderate to good habitat with a variety of channel and weir pool habitats containing a moderate amount of large woody debris. Perennial flow retains permanent habitat for large bodied fish (e.g. Murray Cod and Macquarie Perch). The major threats are perceived to be water quality decline, stock access, flow regulation, and sedimentation (especially in pool habitat).

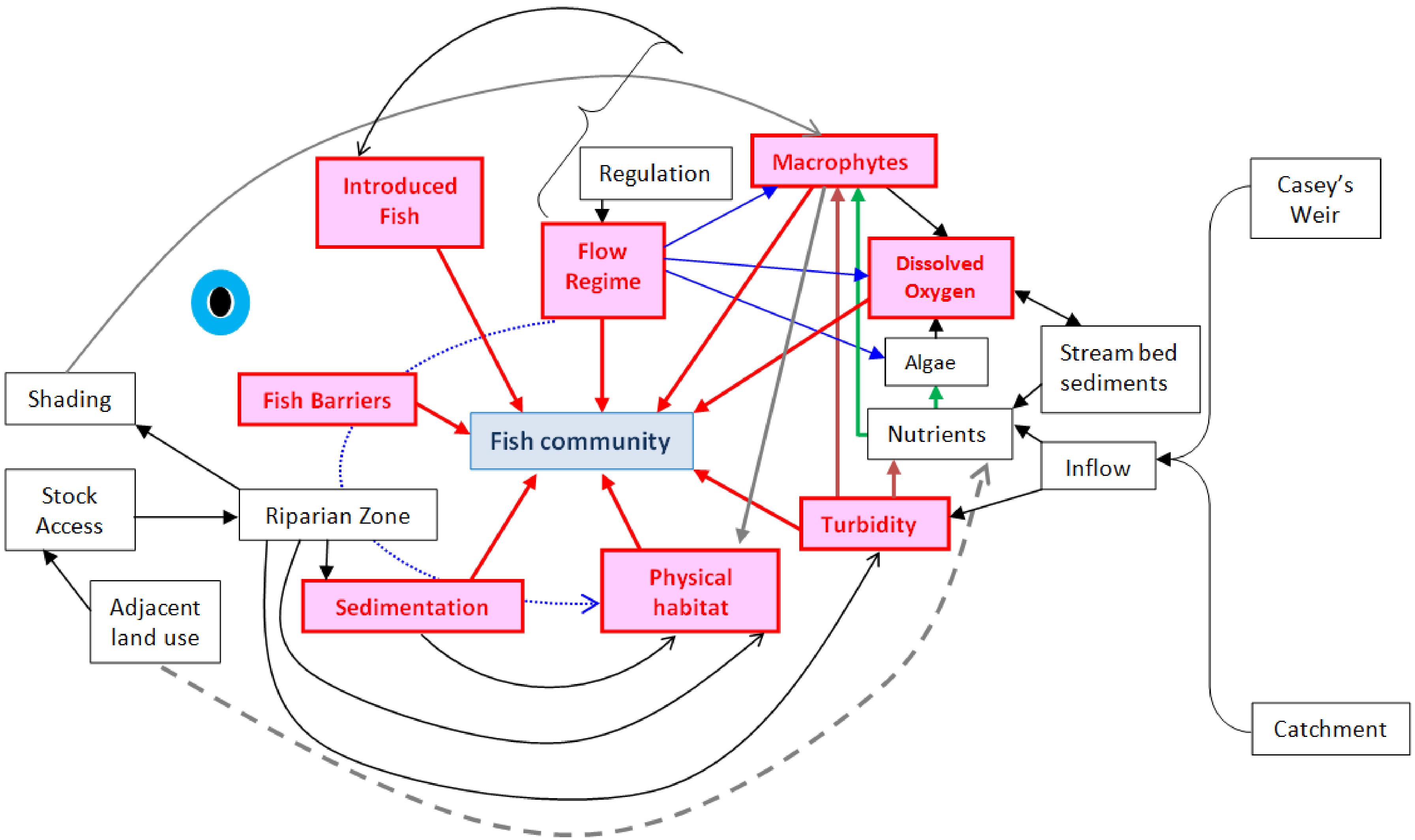


Figure 9: Conceptual Model of threats to the fish community in the lower Broken River

The threats to the fish community were divided into *direct* threats (those that have the potential to directly impact upon the native fish community); and *indirect* threats (those that contribute to the direct threats). For example, 'Physical habitat destruction' is a direct threat to the fish community. Factors that may contribute to Physical habitat destruction, such as stock access to the riparian zone or sedimentation are indirect threats. The direct threats are represented by the red text boxes in Figure 6 and include:

- flow regulation;
- barriers to fish movement;
- turbidity;
- sedimentation;
- dissolved oxygen;
- introduced pest fish;
- introduced plant species; and,
- physical habitat destruction.

Flow regulation: There are two dams upstream of Caseys Weir which currently regulate flows in the Broken River. It is expected that a lower flow deviation will occur in Broken River as a result of decommissioning Lake Mokoan i.e. a closer to natural flow regime. Irrigation pumping is undertaken downstream, but this is not expected to affect the flow regime of the river.

Barriers to fish movement: Gowangardie weir currently acts as a barrier to fish migration. Casey's weir and Lake Benalla have had fish passage provision installed.

Turbidity: Turbidity levels are currently high downstream of Caseys Weir. Turbidity levels in Broken River upstream of Caseys Weir are low, suggesting that when Mokoan is decommissioned levels will decrease substantially.

Sedimentation: Current turbidity levels downstream of Caseys Weir are high enough to suggest that a sedimentation threat exists. A major source of turbidity is Lake Mokoan, however the total suspended solids load is typically low in Lake Mokoan (refer Section 2.2), suggesting that the turbidity from the Lake is due to very fine colloidal material that will contribute little to sedimentation. Similarly, raised turbidities at Gowangardie Weir are not accompanied by high suspended solids concentrations (VWQMN 2008).

Dissolved oxygen: Dissolved oxygen levels can at times be low, but measurements suggest never at levels dangerous to native fish. Changes in flow regime are unlikely to change this unless the river dries to a series of pools. Macrophytes will also influence oxygen levels although macrophytes densities are currently low. However, this may change if macrophyte densities increase due to lower turbidity levels.

Introduced fish species: Competition and predation by pest fish species is currently important, and changes in flow regime may and water quality will affect them and their relationships with native species.

Introduced macrophytes: There is currently an impact from Cabomba (*Cabomba caroliniana*) in Benalla Weir pool and Cabomba has been observed in Caseys weir. Cabomba is a potential threat to all downstream reaches of Broken River. Flow reduces the impact of Cabomba, therefore the major risk is to the weir pools. If flow stop in the river for any appreciable period of time the risk would also increase outside the weir pools. Other pest plant species that have been found in the Broken River include the Yellow Water Lily (*Nymphaea mexicana*) and Lippia (*Phyla canescens*).

Physical habitat destruction: Suitable physical habitat is critical for a healthy fish community and includes in-stream and riparian zone habitat. Submerged macrophytes in Broken River are generally restricted to scattered clumps, which is likely due to the high turbidity levels restricting light required for plant growth. Decommissioning of Mokoan may reduce turbidity levels in the River, resulting in increased macrophyte growth. Large wood material is common in the River and is the major physical habitat available to fish. The riparian zones are a major source of organic matter, insects, shading and large woody debris to the River. Grazing access to the riparian zone seriously impacts its integrity. Decreased sediment loads from the banks of the creek due to fencing (removing stock access) and revegetation works may reduce the sedimentation threat to the physical habitat.

Among the indirect threats, the major ones are:

Nutrients: Nutrient levels are currently high downstream of Caseys Weir. Levels are high enough to promote excessive plant growth but turbidity is also very high which limits plant growth. Nutrient levels in the Broken River upstream of Caseys Weir are low, suggesting that when Mokoan is decommissioned levels will decrease substantially in Broken River at Caseys Weir. The influence of turbidity on plants however will also decrease. Nutrient levels downstream in Broken River increase substantially, suggesting that there are major sources of nutrients downstream of Caseys Weir. Irrigation return waters and bed and bank erosion are possible sources.

Stock access to riparian zone: Stock access to riparian zones is major cause of erosion and subsequently a major source of sediment to waterways, and for this reason is a major focus of management actions. In general, the banks of Broken River appear relatively stable and the level of erosion low, therefore, as a source of sediment and nutrients the banks of the creek are likely to be low unless stock can access the riparian zone. No geomorphic study has been undertaken to clarify the rate of bank erosion.

Land use: The adjacent land use will determine the level of sediment and nutrient transport to the river. In general, broad acre cropping and grazing are not considered to be a major source of sediment and nutrients to the River except when they encroach on the riparian zone. Irrigation however may deliver substantial quantities of sediment and nutrients to waterways via irrigation return waters.

Contaminated urban stormwater runoff to the river from Benalla and Shepparton may have substantial local impact.

4.5 Broken River Results Part 2: Preliminary Risk Analyses

The preliminary risk analysis of the lower Broken River was undertaken as a workshop by the authors of this report. In addition to the authors' aquatic ecological expertise (including ecology of fish, algae, macrophytes and macroinvertebrates; water quality; impacts and management of high nutrients; and catchment management) and collective experience with the natural resource management issues of the Broken River, the analyses were informed by formal meetings and informal discussions with relevant staff of the GB CMA, members of the MGBIC and local/regional Waterwatch participants.

The results from the use of the risk calculator in the preliminary risk analysis of lower Broken River are tabulated and presented in Table 5.

The fish communities in the Broken River are in an excellent condition and are better than in other locations in Victoria, though some species are not as abundant as in historical levels (J.O. Langtry in Cadwallader (1977). This risk assessment considered this information as it formed background information about the ability of the fish fauna to respond to threats and changed operating conditions.

Table 5: Risk Scores for the Preliminary and Qualitative Risk Assessment for ecological threats in Broken River Reaches 1 - 3

Threat	Source of potential threat	Probability	Exposure	Consequence	Risk Rating
Flow regulation	Discharge from Casey's Weir (Lake Nillahcootie)	Almost certain	Annual to monthly	**Moderate to- Major** • No Cease to flow – predators remain • Breeding cues reduced • Habitat changed • Production reduced due to lack of flooding	**High to Very High**
Fish barriers	Gowangardie Weir	Almost certain	Daily	**Moderate** • Prevent breeding migration • Prevent smaller fish to find mates, food resources and breeding habitat	**Very High**
Nutrients	Upstream catchment	Conceivable (but very unlikely)	5 to 10 yearly	**Insignificant** • Short term event • Nutrient increase will be minor in relation to background levels	Low
	Bed Sediments	Conceivable to Practically Impossible	10 yearly	**Minor** • Short term event • Nutrient increase and algal response will be minor in relation to seasonal conditions (cold)	Low

Threat	**Source of potential threat**	**Probability**	**Exposure**	**Consequence**	**Risk Rating**
	Stream banks	Quite Possible	Monthly	**Moderate** • Nutrients will cause DO sags of below 2mg/l • Initial major impact as large fish will be disadvantaged and small fish will thrive – moderate on small fish	**Substantial to High**
	Adjacent land use	Quite Possible	Monthly	**Moderate** • Nutrients will cause DO sags of below 2mg/l • Initial major impact as large fish will be disadvantaged and small fish will thrive – moderate on small fish	**Substantial to High**
Dissolved oxygen	Phytoplankton	Conceivable to Practically Impossible	10 yearly	**Minor** • Short term event • Nutrient increase and algal response will be minor in relation to seasonal conditions (cold)	Low
	Macrophytes	Conceivable to Practically Impossible	10 yearly	**Minor to Insignificant** • Short term event • Nutrient increase and macrophyte response will be slower than algae in relation to seasonal conditions (cold) • Cabomba might cause DO problems in weir pools but fish can avoid these pools	Low

Threat	Source of potential threat	Probability	Exposure	Consequence	Risk Rating
	Sediment oxygen demand	Conceivable to Practically Impossible	10 yearly	**Minor** • Short term event • Nutrient increase and algal response will be minor in relation to seasonal conditions (cold)	Low
Turbidity	Upstream catchment	Conceivable (but very unlikely)	5 to 10 yearly	**Insignificant** • Short term event • Turbidity increase will be minor in relation to background levels	Low
	Stream banks	Quite Possible	Monthly	**Minor** • Predation from exotics will be lower • Most native will not be affected significantly • Some macrophytes may be affected and have reduced habitat fish	Moderate to Substantial
	Adjacent land use	Quite Possible	Monthly	**Minor** • Predation from exotics will be lower • Most native will not be affected significantly • Some macrophytes may be affected and have reduced habitat fish	Moderate to Substantial
Sedimentation	Upstream catchment	Conceivable (but very unlikely)	5 to 10 yearly	**Insignificant** • Short term event • Sediment increase will be minor in relation to background levels • Sediment level needs to be very high to have impact	Low

Threat	Source of potential threat	Probability	Exposure	Consequence	Risk Rating
	Stream banks	Quite Possible	Monthly	**Insignificant** • Short term event • Sediment increase will be minor in relation to background levels • Sediment level needs to be high to have impact	Low to Moderate
	Adjacent land use	Quite Possible	Monthly	**Insignificant** • Short term event • Sediment increase will be minor in relation to background levels • Sediment level needs to be high to have impact	Low to Moderate
Introduced fish		Almost Certain	Daily	**Moderate** Impacts – some species will decline – all species will have reduced impacts	**Very High**
Introduced macrophytes		Almost Certain	Monthly to Annual	**Major** Large infestation of exotic macrophytes will significantly reduce habitat and change nature of habitat for fish. Also will cause oxygen sags at times	**High to Very High**

The highest risks to the fish community identified through the preliminary risk analysis were the impacts of **fish barriers** and **introduced fish** (both 'very high risk'). These were primarily a function of exposure, whereby both these threats impact on the fish community every day, and also a function of probability, with it being almost certain that the threats have an impact on the fish community. The next highest risks ('high to very high') were identified as **flow regulation** in all three section of the River downstream of Caseys Weir, and **introduced macrophytes**, also in all three section of the River downstream of Caseys Weir. Risks from introduced fish are probably the most difficult to manage. The remaining threats are more manageable, although at varying costs.

Fish barriers create a variety of problems for individual fish species. For some species the major impact upon long term survival of the population is by stopping genetic exchange that would normally occur through finding new mating partners. Barriers to movement also restrict opportunities for finding new territories for migration and population expansion, as well as expanding hunting grounds. Gowangardie Weir was identified as the barrier to fish movement in the study reach of Broken River.

Introduced fish - European carp uproot aquatic macrophytes, increasing turbidity and may compete for food and habitat. Eastern Gambusia also compete for food and habitat, with small bodied fish and juvenile large-bodied fish and prey on eggs and young of all native fish. Gambusia is also known to attack the fins of fish much larger than itself causing them stress and diseases (Lloyd et al. 1986). Small native fish such as Pygmy Perch are particularly vulnerable to Gambusia (Lloyd 1990). Impacts from Goldfish and Weatherloach are unknown but if large populations arise they may consume food and habitat resources of native fish.

The impacts of ongoing **flow regulation** on the fish population due to Lake Nillahcootie and Caseys Weir include reduced breeding cues for native species, less habitat heterogeneity from continual flows, predators remaining due to no cease-to-flow periods, and a reduced flooding regime which reduces production within the system. Sliver and Golden Perch both require flow freshes to stimulate breeding and Murray Cod recruitment is also enhanced by flow freshes, especially those which connect marginal and floodplain wetlands. All these species also undertake pre and post-spawning migrations which if prevented will reduce the reproductive success of these large fish species. Murray Cod larvae drift downstream and if they are not able to migrate upstream, the larvae will be washed out of the reach (Koehn & Harrington 2006).

The risks posed by **introduced macrophytes** (in particular, Cabomba) include substantial loss of physical habitat through prolific growth filling in most available space within a water body. A large biomass of aquatic weed would also contribute to a diurnal sag in dissolved oxygen. In contrast to Broken Creek where it is a potential threat, Cabomba is a clear threat in the Broken River, as it has been recorded in the River.

4.6 Knowledge Gaps and Assumptions for Broken River ERA

Knowledge gaps: A major knowledge gap was identified during the development of this risk assessment; what is causing the increases in turbidity and total phosphorus in Broken River downstream of Caseys Weir? Two issues need to be investigated:

1. The extent of riparian zone and stream bed and bank damage as a result of stock access or other impacts.
2. The extent and quality of any irrigation return water inputs to the River.

A recommended assessment study is detailed in Section 4.4 of this report.

Uncertainties and assumptions: As with any study of lowland rivers, the complexity of the system can lead to substantial uncertainties, however, all effort has been made to reduce uncertainties through the identification and analysis of all identified threats. This is a strength of the ERA approach. A weakness in the process has been the lack of data or information on nutrient and sediment sources in the river downstream of Caseys Weir.

While many assumptions have been made concerning the needs of fish, particularly with respect to water quality, these are generally based on substantial expert knowledge, patterns of distribution or known cause effects relationships.

The introduced weed *Cabomba* (*Cabomba caroliniana*) is currently found in Benalla Lake and Caseys Weir pool and while the extent and speed of spread is unknown it is believed to be able to infest all standing water bodies downstream.

5. SYNTHESIS OF THE RESULTS FROM UPPER BROKEN CREEK AND LOWER BROKEN RIVER

5.1 Ecological Risk Assessment

The Broken Creek and the Broken River are high value ecosystems with many acknowledged values. The Broken Creek is associated with nationally significant wetlands [the Muckatah Depression and Broken Creek itself have been listed by DIWA (2001)]. State and nationally threatened flora and fauna have been listed on the Broken Creek floodplain (DIWA 2001), which contains Public Land Water Frontage Reserves and the Moodie Swamp State Wildlife Reserve.

The Broken River also has high ecological value. It is associated with wetlands of national significance and supports a significant fauna and flora, including listed species (Silver Perch, Macquarie Perch and Murray Cod).

Preliminary risk assessments using existing information and relevant local knowledge have identified the most significant threats to the native fish of upper Broken Creek and lower Broken River. These are summarised in Table 6, with their risk ratings, recommended management actions, knowledge gaps and assumptions used in their assessments.

Fish barriers and introduced fish species were allocated the highest risk score (Very High) in both waterways. For fish barriers, provision of upstream and downstream fish access an important management action. Important management actions for reducing this threat would include reviewing the necessity of existing barriers and weirs, followed by removal of unnecessary structures and installation of fishways (ladders, rock ramps, bypass channels) in other locations. Management of exotic fish species should focus on native ecosystem management, including improvement of ecosystem conditions (riparian and in-stream) for native fish, thereby providing some competitive advantage to native fish. Also, use of fish traps in fishways to remove exotic fish should be explored.

Flow regulation was rated as a High to Very High risk in both stream systems. Flow management is the key management action for mitigation of this risk. This would include management of upstream storages to reflect conditions upstream of the storages. In part, this will occur through changes already planned and underway to reconfigure the system with the decommissioning of Lake Mokoan.

Introduced macrophytes were also rated a High to Very High risk along the Broken River and in the reaches of the Broken Creek downstream of Flynns Weir. The species *Cabomba caroliniana* has been found in the Broken River, including Caseys Weir, which means it has a reasonable chance of spreading to the Broken Creek. This weed is hardy and resistant to management controls and a comprehensive integrated program will be required including spraying, removal, and drying. The floating fern *Azolla filiculoides* has been observed to form thick mats at locations along Broken Creek, particularly within weir pools. The formation of these thick mats can create a barrier between the water surface and the atmosphere, impeding aeration of the water and also light penetration within the water. Similar to *Cabomba caroliniana* management of *Azolla filiculoides* will require an integrated program and may be assisted by nutrient reduction management actions.

Table 6: Threats rated substantial or higher to the native fish communities of upper Broken Creek and lower Broken River, with identified knowledge gaps and assumptions, and recommended management actions.

Threat	Risk Rating	Knowledge Gaps and Assumptions	Recommended Management Actions
Fish Barriers	Very high	*Assumption*: Daily exposure to effects of barriers *Knowledge Gaps:* Possible existence of private weirs acting as barriers	• Review barriers to fish movement; • remove where possible or install fishways
Introduced Fish	Very high	*Assumption*: Daily exposure to effects of introduced species	• Using riparian management practices (fencing, revegetation) to improve ecosystem conditions for native fish; • use fish traps in fishways to remove exotic fish where possible
Flow Regulation: B. Creek (Caseys Weir to Flynn's Weir); B. River (via Lake Nillahcootie)	High to Very high	*Assumption*: no worsening of drought/climate conditions *Knowledge Gap*: proposed post-Mokoan flow regime (including flow components – only partly known)	• examine optimizing environmental requirements for irrigation flow regime;
Introduced Macrophytes B River & B Creek (downstream of Flynns Weir)	High to Very high	*Assumption*: slow to still waters will promote conditions for some macrophyte species to flourish	• Develop and implement a comprehensive integrated weed control program; • nutrient reduction to reduce bloom potential
Dissolved Oxygen (B. Creek only - downstream of Flynn's Weir)	High to Very high	*Assumption*: slow to still flows reduces oxygenation and promotes phytoplankton blooms *Knowledge Gaps:* extent to which historical inputs of sediment may restrict pool depths	• Regular monitoring of D.O., particularly in summer/low flow period • Explore opportunities for periodic fresher flows when D.O. reaches minimum threshold; • map existing pools and document needs for improvement/deepening
Nutrients (from stream banks and/or adjacent land	Substantial to high	*Assumption*: primary impact via eutrophic reduction of dissolved oxygen	• investigation of nutrient inputs (use approach described in this report) • manage inputs based on

uses). Downstream of Caseys Weir for Creek & River		*Knowledge Gap*: Source of nutrients entering the Creek downstream of Caseys Weir	investigation outcomes
Sedimentation (B. Creek only)	Substantial to high	*Assumption:* High TSS does indicate significant deposition *Knowledge Gap*: Source of sediment entering the Creek	• investigation of sediment inputs (use approach described for turbidity investigation in this report)

Dissolved oxygen was also rated as a High to Very High risk, although only within Broken Creek downstream of Flynns Weir, based on predicted low flows and cease-to-flow events. Currently there are no adverse outcomes from dissolved oxygen concentrations on the fish community. This is unlikely to change in the sections of the Creek above Flynn's Weir, as the system will remain perennial. However, downstream of Flynn's weir, the system will become ephemeral, leading to concentration of nutrients and a building up of algae and macrophytes, with subsequent decomposition of organic matter and resultant dissolved oxygen reductions, likely to affect the fish community. Sand accumulation in pools may exacerbate the impacts of reduced flows, by reducing the depth and number of deep pools that would normally provide refuge during low flow periods. Recommended management actions for mitigation of this threat focus on reconnaissance (mapping of existing pools and documenting potential for improvement and/or deepening); monitoring of dissolved oxygen concentrations (especially during low flow periods); and provision of fresher flows during high risk periods.

Elevated nutrient concentrations (Broken River and Creek) and sedimentation (Broken Creek only) were both rated as Substantial to High risks. Ceasing releases from Lake Mokoan will mean that a point source of nutrients and sediment is eliminated. This will reduce nutrient concentrations at Casey's Weir, however data show that there are substantial sources of turbidity (Figures 5a and 7a) and nutrients (Figures 5b and 7b) downstream of Casey's Weir, so these reductions will be limited. An investigation as described in Section 4.4 (below) is recommended for determining the source(s) of the nutrients and sediments. Fencing stock out from riparian zones will lead to reduced erosion and this will in turn reduce sediment and nutrient inputs. Similarly, revegetation of riparian zones – including fencing and some direct seeding or selected planting – will also lead to reduced nutrient and sediment inputs.

5.2 Achieving SEPP WoV: Management Actions & Timelines

Although this ERA has focused on the ecological values of the two stream systems, using the fish communities as endpoints, an additional component of the project brief required an assessment of the efficacy of proposed management actions to meet SEPP WoV objectives and the derivation of attainable targets and time lines. Specifically, the water quality indicators turbidity, nutrients, and dissolved oxygen need to be assessed in relation to their failure to meet SEPP WoV.

Turbidities upstream of Lake Mokoan and in the nearby Ovens River meet the SEPP WoV objectives (discussed further in Section 4.3, below). This suggests that the current objective for turbidity (30 NTU) is achievable and should remain. However, substantial increases in turbidity downstream of Caseys Weir, particularly in the Broken Creek (> 100 NTU) and to a lesser extent in Broken River (>80 NTU), suggest that SEPP objectives are not likely to be achieved within these reaches in the near future, despite the planned decommissioning of Lake Mokoan. Therefore, development of regional Resource Condition Targets (RCTs) (EPA 2003c clause 24 (2)) is warranted. Achievable RCTs are suggested in Tables 7 and 8. Undertaking an investigation into the source of the high turbidities, as proposed in Tables 7 and 8, can be completed reasonably quickly. A possible approach is described further in Section 4.4. However, remedial actions may take longer to implement and produce results. For that reason a time frame of 5 years has been suggested for achieving the interim turbidity targets.

The nutrients identified as triggering SEPP are total nitrogen and total phosphorus. Phosphorus is generally a more important nutrient in freshwater systems, in terms of nutrient impacts. Further, actions undertaken to reduce turbidity and total phosphorus typically lead to reductions in total nitrogen concentrations. Therefore, the focus of in this document is directed towards total phosphorus. The total phosphorus objective in SEPP WoV (0.045 mg/L) was determined using cause-effect information and reference site data (EPA 2003b, Newall and Tiller 2002).

Concentrations of total phosphorus around 0.1 mg/L in lowland rivers are likely to lead to a risk of algal blooms (EPA 2003b). These facts suggest that the current objective for total phosphorus (0.045 mg/L) is a necessary goal for ecological condition and that an interim target of 0.1 mg/L should be a reasonable interim target. Available data (e.g. Figures 5 and 7) indicate that the discharge from Lake Mokoan is a major contributor to total phosphorus concentrations in Broken River, whereas Broken Creek clearly suffers from further inputs downstream of the Lake Mokoan discharge. For this reason, the timeline for achieving the interim target of 0.1 mg/L in Broken River is set at 2 years (allowing time for the decommissioning of Lake Mokoan) (Table 8) and 5 years for Broken Creek, to coincide with the combined 'turbidity-phosphorus' investigations and follow-up actions.

The dissolved oxygen objective was determined using reference site data (EPA 2003). No reliable cause-effect data was available however many native fish can tolerate low dissolved oxygen levels (Treadwell & Hardwick 2003). The current levels are therefore unlikely to have measurable effects on lowland river biota. The SEPP WoV objective of 85% saturation is likely to be difficult to achieve in slow flowing lowland rivers and consideration could be given to revise this level using reference sites which have characteristics much closer to Broken Creek and Broken River. Until any further revisions, the interim RCT should be to maintain current levels. This may prove difficult in the Broken Creek downstream of Flynns Weir, where the Creek will dry to a series of pools during low flow and cease-to-flow periods. The uncertainty has therefore been rated as high for dissolved oxygen in this section of the Creek (Table 7).

Table 7: Management actions and targets for triggered SEPP WoV objectives in Broken Creek

Parameter	WoV Objective	Current status (approx.)	Management actions	Resource Condition Target (75th percentile)	Time frame	Uncertainty (the confidence level to achieve target in timeframe)
Turbidity (NTU)	<30	>100 BC	Remove Mokoan Discharge Identify and manage sources in BC d/s Caseys	<100 WoV Objective (<30)	5 years 15 years	Low to Moderate
Phosphorus (mg/L)	<0.045	>0.15	Remove Mokoan Discharge Identify and manage sources in Broken Ck downstream of Caseys Weir	0.1 0.045 (WoV Objective)	5 years 15 years	Low to Moderate Moderate
DO (%sat)	>85%<110%	60-100%	Reduce nutrients downstream of Flynns Weir BC to avoid algal blooms in pools	Maintain current conditions	ongoing	Moderate to high. High below Flynns Weir

Table 8: Management actions and targets for triggered SEPP WoV objectives in Broken River

Parameter	WoV Objective	Current status (approx.)	Management actions	Resource Condition Target (75th percentile)	Time frame	Uncertainty (the confidence level to achieve target in timeframe)
Turbidity (NTU)	<30	>80 BR	Remove Mokoan Discharge Identify and manage sources between Caseys & Gowangardie Weirs	<50 WoV Objective (<30)	5 years 15 years	Moderate
Phosphorus (mg/L)	<0.045	>0.15	Remove Mokoan Discharge Identify and manage sources between Caseys & Gowangardie Weirs	0.1 0.045 (WoV Objective)	2 years 15 years	Low to Moderate Moderate
DO (%sat)	>85%<110%	60-100%	Reduce nutrients downstream of Flynns Weir BC to avoid algal blooms in pools	Maintain current conditions	ongoing	Moderate

5.3 Suitability of WoV Objectives

A recent review of water quality in Broken Creek and Broken River identified several indicators that triggered the SEPP WoV objectives (GB CMA 2008). The question is whether these triggers were warranted, that is, 'Does a real risk exist in the creek and/or river?'.

SEPP WoV objectives (annual 75th percentile of monthly data) for the relevant reaches are:

- Turbidity 30 NTU
- Total phosphorus 0.045 mg/l
- Dissolved oxygen 85% saturation

Turbidity: The turbidity objective in SEPP WoV was determined using reference site data (EPA 2003) as there was no cause-effect data available. Although turbidity levels are currently high in both the creek and the river, levels are partly elevated as a result of the discharge from Lake Mokoan, and would be expected to decrease after it is decommissioned. Levels upstream are considerably lower, and generally meet the SEPP WoV objective. Levels in the lowland reaches of the nearby Ovens River also meet the objectives. These results suggest that the aspirational target for turbidity (30 NTU) should remain. The development of a regional resource condition target (EPA 2003c clause 24 (2)) would be warranted. An interim level can be aligned to regional management actions that lead to the achievement of targets.

Total Phosphorus: The total phosphorus (TP) objective was determined using cause-effect information and reference site data (EPA 2003b, Newall and Tiller 2002). While TP concentrations are currently high in both the Creek and the River, concentrations in part are elevated as a result of the discharge from Lake Mokoan, and would be expected to decrease after it is decommissioned. Concentrations upstream are considerably lower, and either meet or come close to meeting the SEPP WoV objective. In addition, concentrations of total phosphorus around 0.1 mg/L in lowland rivers are likely to lead to a risk of algal blooms (EPA 2003b). The current objective therefore should remain. As with turbidity, consideration should be given to setting a resource condition target for TP. Currently, with TP concentrations downstream of Casey's weir in both the creek and river well in excess of 0.1 mg/L, a resource condition target of 0.1 mg/L is recommended.

Dissolved oxygen: As described in Section 4.2, above, the SEPP WoV objective of 85% saturation is likely to be difficult to achieve in slow flowing lowland rivers and consideration could be given to revise this level using reference sites which have characteristics much closer to Broken Creek and Broken River. The current dissolved oxygen concentrations are unlikely to have measurable effects on lowland river biota, with many native fish tolerating low concentrations (Treadwell & Hardwick 2003).

5.4 Monitoring to Fill Knowledge Gaps

Among the knowledge gaps, the increases in total phosphorus and turbidity beyond the discharge from Caseys weir presents a gap that is fundamental to the initiation of this project, potentially a major risk to the Creek ecosystem and may be relatively easily (and cheaply) resolved.

Assessment of sources of phosphorus and turbidity in Broken Creek: High levels are being measured in Broken Creek downstream of Caseys Weir and keep increasing downstream to Katamatite (Figures 4 and 5, Section 3.2). These results suggest that there are multiple sources of phosphorus and sediment between Caseys Weir and Katamatite. The most likely sources would be bank erosion and irrigation return waters, however expert opinion suggested these sources would contribute little to the creek load of phosphorus and sediment. A small, targeted project is recommended to investigate this issue.

Aim: Assess phosphorus and turbidity levels in Broken Creek and inputs and evaluate these results with respect to land use and quality of the riparian zone.

Approach: Turbidity and phosphorus both show the same pattern in the Broken Creek downstream of Caseys Weir. Therefore it is likely that both have the same sources. Turbidity is recommended as the primary indicator for this assessment. Measuring bank stability, vegetation cover and adjacent land use in conjunction with the water quality, should resolve the sources of both turbidity and phosphorus.

Method:

- One dry-weather and one wet-weather sampling trip.
- Sample as many locations as possible between Casey's Weir and Katamatite.
- Measure turbidity at all selected creek sites and also all inflowing waters, using a field turbidity meter.
- Consider total phosphorus sampling only where a substantial input is identified.
- Target likely source areas, in particular known erosion hot spots and irrigation return drains.
- Assess bank stability and vegetation cover using ISC approach.

Outcomes:

- Map turbidity levels and bank stability and vegetation scores
- Assess results against water quality data already collected (VWQMN and WaterWatch data).
- Determine likely source area.
- Determine whether further investigations are required.
- Data can also be used to assist in informing a Bayesian network.

Other issues: The approach described above can also include measurements of dissolved oxygen and flow regime (from nearby gauges and also in-stream flow measurements). The approach could also be used in a similar study along the lower Broken River if nutrient and turbidity measures do not decrease along this part of the River in the post-Mokoan period.

6. EXTENDING THE ERA OUTPUTS: POTENTIAL USE IN BAYESIAN MODELS

As presented in the Introduction to this report (Section 1.1), the GB CMA requested that the outputs of this project be presented in a form that will contribute in the development of a Bayesian network/model. A Bayesian network is a model that assesses the relationships between variables in complex systems and how they interact. Bayesian networks are able to bring together and incorporate all available types of data, information and knowledge. The aim of a network is to provide predictions of the overall risk posed to ecological values and the likely outcomes of different management scenarios. They not only provide quantitative predictions but explicitly state where the uncertainties are in the information. The models can be easily updated when more data or information becomes available, improving the predictions.

Bayesian approaches are now used in many areas of natural resource management (Hart and Pollino 2008), with aims ranging from:

- Determining risks to aquatic ecosystems from multiple threats, such as flow changes, excessive nutrients, degradation of in-stream habitat, changes to riparian vegetation, and potential impacts of pest fauna and flora;
- Integrating qualitative and quantitative information across a range of disciplines (such as hydrology, hydraulic and ecological response modelling) and stakeholders;
- Evaluating the benefits of management activities (such as maintaining or restoring certain part of the flow regime), within an adaptive management context, and prioritising actions to achieve the best outcomes when resources (either capital or natural) are limited,
- Linking investments to resource condition outcomes; and
- Informing risk management strategies via scenario analysis.

6.1 Structure of the network

Developing the graphical structure of the network requires the identification of the key variables (nodes) influencing the endpoint, and the interactions (linkages) between them. The conceptual models developed during problem formulation for Broken River and Broken Creek provided the starting point for the network structures. The initial network is overly complicated and well-substantiated decisions need to be made on what are the key variables to include in the network. Bayesian networks shouldn’t be too complex as this reduces their ability to predict well.

The structure of the Broken River and Broken Creek Bayesian networks was finalized through focus on the key values and threats identified in the problem formulation workshops, the analysis of data and information and consultation with ecological experts and the GB CMA. A single network has been developed for both waterways as it covers the same key variables in both systems.

Several factors originally identified as potential influences were assessed as having no substantial impact on native fish community diversity. For example, although shading is important it was considered to have minor influence and this influence is likely to be included within the riparian zone variable.

The final structure of the combined Broken River and Broken Creek network is provided in Figure 10. It represents the key cause-effect relationships determining a diverse native fish community in both systems.

6.2 Definition of variables and their states

Network variables (or nodes) need to be clearly defined. They must also be observable and measurable. The definitions of variables and their states were established using the relevant literature, data analysis and consultation with ecological experts and the GB CMA. Definitions of variables, finalised states, data used in finalising states, and parent variables are provided in Table 9.

The network also contains one ***integrative*** variable: 'Physical habitat quality', (Figure 10). This variable is not directly observable or measurable. The purpose of integrative variables is to reduce the number of linkages to a particular variable primarily thereby reducing network complexity. An added benefit of integrative variables is that they also enhance the predictive accuracy of the network. The states of the integrative variables are more difficult to define than other variables, as they are qualitative expressions of condition, e.g. Good, Moderate and Poor (Table 9). During expert elicitation workshops, it is crucial to discuss the ecological meaning of the states of these variables, arriving at a group consensus.

Once finalized, ecological experts and GB CMA staff can review the definitions and states for each variable, and verify their applicability to the Broken River and Broken Creek.

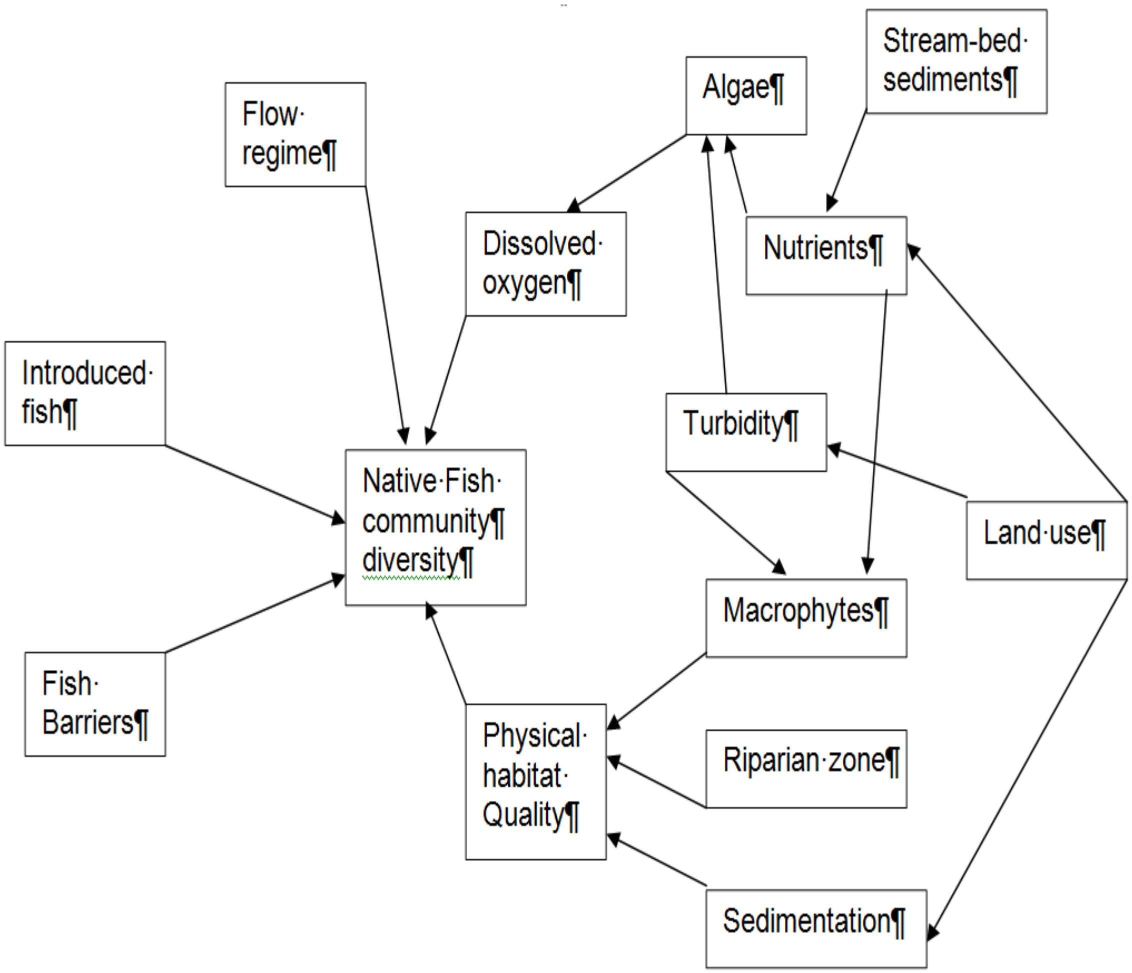


Figure 10: Bayesian network structure for Broken River and Broken Creek.

Table 9: Definitions of variables, their states and the data used for Broken Creek Bayesian Network development

Variable (Nodes)	Parent nodes (variables)	States	Method for defining variables, states and calculating prior probabilities in CPT	Data Source
DO% surface	Flow regime Macrophytes Algae Stream bed sediments	Poor: < 2 mg/l Moderate: > 2 <6 mg/l Good: > 6 mg/l	States were determined by expert opinion. The CPT can completed using historical and current water quality data	Expert opinion (Ecological experts) Water quality monitoring data (VWQMN and WW)
Nutrients	Adjacent land use Stream bed sediment	Poor: >0.1 mg/l total phosphorus Moderate: >0.5<0.1 mg/l total phosphorus Good: <0.5 mg/l total phosphorus	States have been determined by comparison to SEPP (WoV) turbidity objectives and expert opinion. The CPT can be completed using historical and current water quality data.	VWQMN data WW data
Stream bed sediments nutrient mobilisation	None	Yes: Surface DO <2mg/l No: Surface DO greater than 2 mg/l	States have been determined by expert opinion as no data are available on streambed sediment condition (such as redox potential). Dissolved oxygen levels less than 2 mg/l are likely to result in the releases of nutrients form bottom sediments. The CPT can be completed using historical and current water quality data.	VWQMN data WW data

Variable (Nodes)	**Parent nodes (variables)**	**States**	**Method for defining variables, states and calculating prior probabilities in CPT**	**Data Source**
Turbidity	Riparian zone quality Land use	Poor - >70 NTU annual 75th percentile Okay - >30<70 NTU annual 75th percentile Good - <30 NTU annual 75th percentile	States have been determined by comparison to SEPP (WoV) turbidity objectives and expert opinion. The CPT can be completed using historical and current water quality data.	VWQMN data WW data
Sedimentation	Land use	*To be determined*. High - > 'X' mg/l SS annual 75th percentile Low - < 'Y' mg/l SS annual 75th percentile	States will be determined by comparison to fish effects data and expert opinion. The CPT can be completed using historical and current water quality data.	VWQMN data
Flow regime	None	*To be determined.* Poor: High deviation from natural Good: Low deviation from natural	Integrative variable, states will be determined by expert opinion concerning the states of base-flow, freshes and cease-to-flow that provide a good or poor amount of flow for the fish community.	Expert opinion (Ecological expert panel) Flow recommendations
Macrophyte Habitat quality	Turbidity Flow Shading	*To be determined.* Macrophyte abundance and sub-structures	States will be defined using site data on macrophyte abundance and diversity of structural components. States will be defined by cover and the number of macrophyte substructure groups present (EPA 2003).	Macrophyte survey data

Variable (Nodes)	Parent nodes (variables)	States	Method for defining variables, states and calculating prior probabilities in CPT	Data Source
Quality physical in-stream habitat	Macrophyte habitat quality Riparian zone quality Sedimentation	Poor Moderate Good	Integrative variable, states will be determined by expert opinion concerning the states of macrophyte habitat, riparian zone and sedimentation to determine poor, moderate and good physical in-stream habitat.	Expert opinion (Ecological expert panel) ISC data monitoring data
Quality of riparian zone	None	*To be determined.* Good: > ISC sub-component score Poor: < ISC sub-component score	States will be determined by expert opinion based on ISC scores	ISC scores
Land use	None	Poor: Substantial cattle access and/or runoff from farms, e.g. irrigation return drains Good: no cattle access or runoff from farms	Difficult to quantify as little data are available to assess levels of runoff from farms therefore the states must be determined by expert opinion.	Maps of drains and local knowledge from GB CMA

Variable (Nodes)	Parent nodes (variables)	States	Method for defining variables, states and calculating prior probabilities in CPT	Data Source
Fish barriers	None	Presence Absence	GB CMA information and knowledge	GB CMA data base and expert opinion Literature
Introduced pest fish species	None	Poor: Composition and number > 'X' Good: Composition and number < 'X'	States will be determined by expert opinion on the effects of the relative abundance of introduced pest species.	GB CMA fish survey data
Native fish community diversity	DO surface Quality physical habitat Flow regime Barriers Introduced pest fish species	At or near natural condition Minor modification Moderate modification Major modification Extreme modification	States will be defined using the SRA SR-FI index (MDBC 2003). The CPT will be completed through expert elicitation.	Fish community composition and abundance data and SRA index score information.

6.3 Conditional probability tables

The relationship between variables needs to be quantified after the states of the variables have been defined. Parent variables lead into child variables, and the outcomes of child variables are conditional on how the parent variables combine. These relationships are defined using conditional probability tables (CPTs) (see conceptual examples in Tables 10 and 11).

We emphasise that Tables 10 and 11 have no status as real CPTs within any Bayesian Network – they are provided to demonstrate the approach and concept of CPT design and filling.

Table 10: Conceptual conditional probability table (CPT) for the variable 'Physical Habitat' based on the model presented in Figure 10

			Habitat Condition		
Macrophyte Habitat	Riparian zone	Sedimentation	Poor	Moderate	Good
Poor	Good	low	20	30	50
Poor	Good	high	90	5	5
Poor	Poor	low	40	30	30
Poor	Poor	high	99	1	0
Good	Good	low	0	1	99
Good	Good	high	60	35	5
Good	Poor	low	5	30	65
Good	Poor	high	70	25	5

This table is provided to display the concept of Conditional Probability Tables and is not designed for quantitative modelling purposes.

Table 11: Conceptual conditional probability table (CPT) for the variable 'Native Fish Community' based on the model presented in Figure 10. Note missing variable 'Introduced Fish' due to lack of information at this time.

			Native Fish Community		
Habitat Condition	**Dissolved oxygen**	**Flow**	Poor	Moderate	Good
Poor	Poor	Poor	90	10	0
Poor	Poor	Good	80	20	0
Poor	Moderate	Poor	70	30	0
Poor	Moderate	Good	70	30	0
Poor	Good	Poor	20	70	10
Poor	Good	Good	20	70	10
Moderate	poor	Poor	50	50	0
Moderate	poor	Good	30	70	0
Moderate	Moderate	Poor	30	70	0
Moderate	Moderate	Good	10	60	30
Moderate	Good	Poor	20	70	10
Moderate	Good	Good	10	50	40
Good	poor	Poor	30	70	0
Good	poor	Good	30	70	0
Good	Moderate	Poor	20	70	10
Good	Moderate	Good	10	20	70
Good	Good	Poor	10	40	50
Good	Good	Good	0	10	90

This table is provided to display the concept of Conditional Probability Tables and is not designed for quantitative modelling purposes.

The development of CPTs beyond the conceptual examples provided above, and the subsequent building of a meaningful and operational Bayesian network, would require substantial resources (in the order of two or three months). This is largely because few networks have been built that could be taken and adapted specifically for the reaches in question. Once networks are built that could be adapted for use from similar regions and reaches, the time required will drop substantially (to as little as a few weeks).

The alternative, used in this project, is to gather the available information, build conceptual models that reflect Bayesian network structures, and use a semi-quantitative (ordinal) approach to assessing the influencing of threats and other factors (nodes) on the listed values. If, at a later time a Bayesian network is needed, the information collected can be easily adapted to build a quantitative network.

7. CONCLUSION

This study used the Victorian EPA's adopted process for Ecological Risk Assessment (ERA), to determine and evaluate the risks to selected reaches of upper Broken Creek and lower Broken River. Using the native fish community as the assessment endpoint for the ERAs, The following major risks to the waterways were identified:

- barriers to fish movement and migration;
- presence of exotic fish species;
- flow regulation/'unnatural' flow regime;
- introduced species of macrophytes;
- reduced dissolved oxygen concentrations (Broken Creek only);
- elevated nutrient concentrations; and
- sedimentation (Broken Creek only).

The sources and magnitudes of nutrient and turbidity inputs to the waterways downstream of Caseys Weir were identified as major knowledge gap. A specific monitoring plan has been designed to fill this gap and is presented within this report.

Management actions that have been recommended for the mitigation of the major risks include:

- removal of unnecessary fish barriers and installation of fishways (ladders, rock ramps, bypass channels) elsewhere;
- improvement of riparian and in-stream ecosystem conditions for native fish to, competitive advantage over exotic fish species;
- consider the potential for use of fish traps in fishways to remove exotic fish;
- management of storage discharges to reflect natural conditions as far as practical;
- an integrated weed control program with nutrient reduction management actions;
- monitoring of dissolved oxygen concentrations during low flow periods;
- provision of fresher flows as needed during dissolved oxygen risk periods;
- undertaking an investigation of potential nutrient and sediment inputs to the waterways downstream of Caseys Weir; and
- mapping of existing pools within Broken Creek and documenting potential for habitat improvement and/or deepening.

These management actions were derived assuming that the decommissioning of Lake Mokoan will proceed, as the decommissioning represents the removal of a major source of several risks identified.

In addition to the ERAs and resultant management recommendations, this study had the following objectives of:

1. Setting attainable SEPP (WOV) targets and time lines and assessing the efficacy of recommended actions to meet these targets. Interim targets were presented for turbidity and phosphorus, and a revised objective was proposed dissolved oxygen in both waterways. The turbidity and phosphorus targets included interim targets (two to five years) and a long-term (fifteen year) target of achieving SEPP (WoV). The proposed revised objective for dissolved oxygen was maintenance of current conditions and is based on an expectation that current conditions are not detrimental to native fish species.

2. Presentation of conceptual models in a way that may, in future, be used in the development of a Bayesian network. Section 5 of this document presents a Bayesian network structure derived from the outcomes of the ERA, and also presents the variables, their states and the data used for development of the structure. Conceptual examples of Conditional Probability Tables (CPTs) are also presented in Section 5. The CPTs are conceptual only and should not be used in an actual assessment.

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