Farms Rivers Markets
Rivers (Ecology)
Broken River System Literature Review

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1 Broken System Overview

The Broken River has a catchment area of approximately 389km2 (Goulburn-Murray Water 2007). Beginning in the Wellington-Tolmie highlands on the northern side of the Great Dividing Range in north-east Victoria it flows in a north-westerly direction to its confluence with the Goulburn River near Shepparton (Cottingham *et. al.* 2001) The main tributaries of the Broken River are Holland's Creek, Ryan's Creek and Lima East Creek. The upper reaches have high gradients, but lower reaches of the Broken River meander across a low-gradient floodplain (Strom 1962).

There are two storages on the Broken River- Lake Nillacootie and Lake Mokoan and three weirs: Broken weir at Benalla, Casey's weir at the confluence of the Mokoan off take and the Broken River and Gowangardie weir
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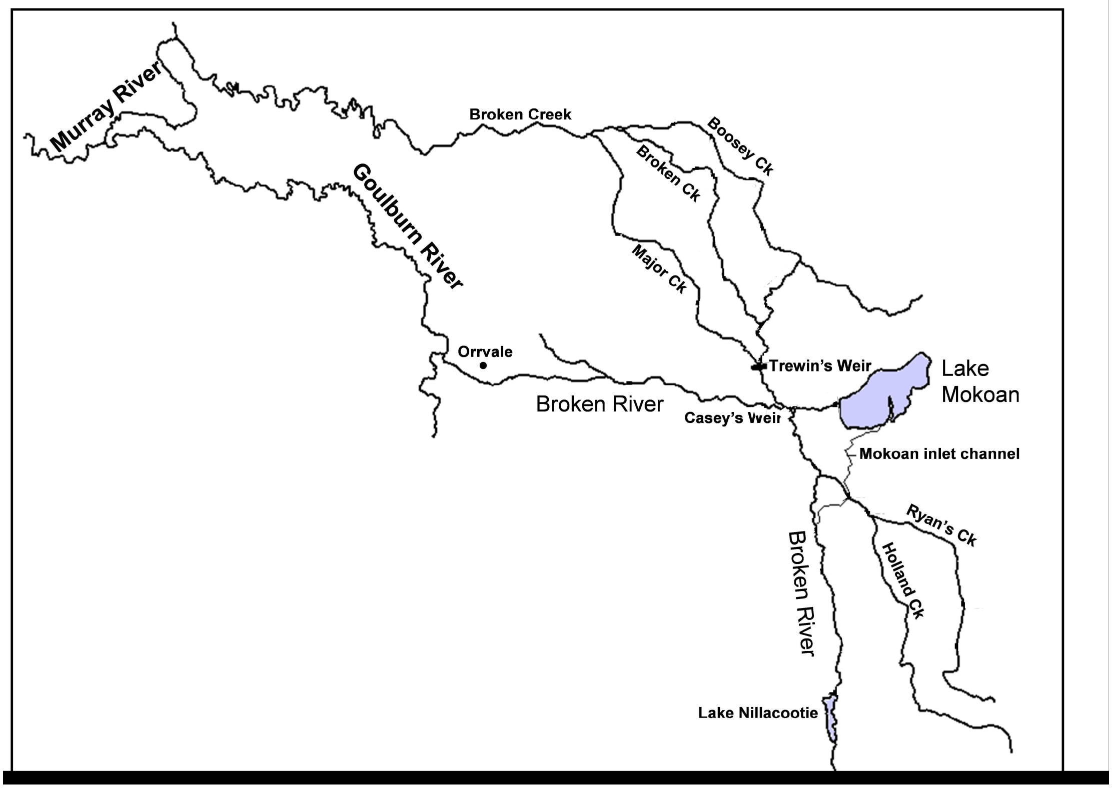

Figure 1). Lake Nillacootie constructed in 1967 (capacity of 40,000 ML) is located in the upper reaches to capture high winter flows and deliver irrigation flows in summer. This has resulted in a change of the flow regime with lower flows than would naturally occur in wetter months (May/June to October/November) and increased flows during drier months (January/February to April/May) (Cottingham *et al.* 2001). Average in-flows into Lake Nillacootie are 40,000ML/yr, compared to the 200,000 ML/yr at Casey's Weir. This signifies a much larger catchment downstream of Lake Nillacootie providing a fundamentally largely natural flow regime in the Lower Broken River.

Lake Mokoan, constructed in 1971, was a shallow off-river storage fed by Hollands Creek. Due to the shallow nature of this lake, it was deemed to be inefficient, losing up to 50,000 ML per annum through evaporation (URS 2003). In addition to the evaporative losses, water returning from Lake Mokoan was of poor water quality contributing to the deterioration in water quality in the Broken River downstream of Casey's weir (URS 2003). Lake Mokoan was subsequently decommissioned in 2008, with regular outputs to the Broken River ceasing during

January 2009. The decommissioning of Lake Mokoan will result in a decrease in the amount of water harvested, increasing winter/spring flows up to 2,400ML/day (Geoff Earl, *pers. comm*.). An increase from 70% to 87% of natural flows are estimated to reach Shepparton with the decommissioning of Lake Mokoan.

Broken Creek is an effluent stream that flows in a north-westerly direction towards Katamatite, where it is joined by Boosey Creek, before flowing into the River Murray near Barmah. Historically, the creek would have been naturally ephemeral receiving flood water from the Broken River. Broken Creek was turned into a predominantly permanently flowing stream for stock and domestic and irrigation, supplied from the Broken River at Casey's Weirs (Cottingham *et al.* 2001). As a result of the water saving Tungamah Pipeline project implemented in 2007, the need for stock and domestic water supplies to be delivered via the Broken Creek has been eliminated. Along with redundant weir removal, some flow intermittency has been returned to the Broken Creek.

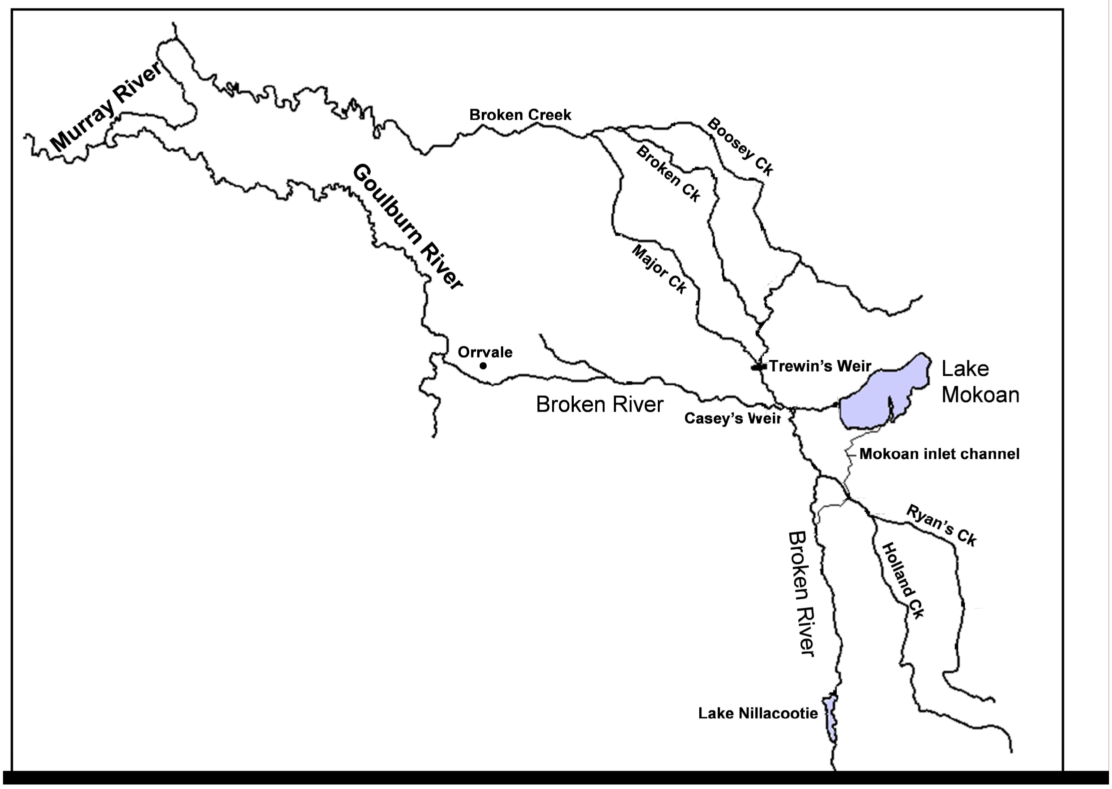

Figure 1 Map of the Broken River system.

2 Flow

A summary of available flow data, water balances, extractions, and losses can be found in the FRM Water Data and Background Working Paper (Adams *et al.* 2009).

In general, stream flow in the Broken River system is variable, both annually and seasonally, and has been modified by the following:

- The presence and operation of Lake Nillacootie;
- The presence and operation of Lake Mokoan;
- The construction of irrigation supply and drainage schemes;

- The presence and operation of numerous weirs, both on the Broken River and Broken Creek;
- Progressive extraction of water from the Broken River and Broken Creek for irrigation and stock and domestic water supply;
- Changes to the form of the channel due to channelisation and snag removal; and
- Changes to floodplain drainage through the construction of levees and drains (Cottingham *et al.* 2001).

Minimum environmental flows are required within the Broken systems as set out in the Bulk Entitlement (Broken System – Goulburn-Murray Water) Conversion Order 2004 (Table 1). These environmental flow requirements are less than the environmental flow recommendations outlined in Cottingham *et. al.* (2001).

Table 1. Minimum flow requirements for the Broken River

Reach	**Month**	**Flow (ML/d)**	**Calculated**
Broken River between Lake Nillacootie and Broken Weir	June-Nov	30 or natural (whatever the lesser)	Natural flow generated in all of catchment above Moorngag.
Broken River between Broken Weir and Casey's Weir	Dec-May	22 or natural (whatever the lesser)	Natural flow generated in all of catchment above Casey's Weir.
Holland Creek downstream of Holland weir	When water is being diverted from Broken River	12 or natural (whatever the lesser)	Natural flow generated in Holland Creek catchment
Broken River below Casey's Weir to Goulburn confluence	Dec-May	25 or natural (whatever the lesser)	Natural flow generated in all of catchment above Gowangardie Weir.

Although the only environmental flows currently being delivered within the Broken system are low flows, it should be noted that as this project is used on a broader scale, flows of differing magnitudes may be an option to other systems.

Other flow components are also partly provided within areas of the Broken system via natural inflows eg lower Broken River still has a largely natural flow regime due to a significant catchment area below Lake Nillacootie.

Across the system there is the ability to inundate wetlands (floodrunners, billabongs etc) through irrigation infrastructure, however the ability to deliver water to large scale floodplain environments (floodplain proper) is less likely.

3 Drought – the current situation

Over the past four years, there has been progressively less water in storage in Lake Nillacootie at the start of each irrigation season. Rights to water have been qualified by the Minister for Water under a declared water shortage for the 2009/2010 season, as was done in 2007-2009. This temporarily restricts the Minister for Environment's right to extract water as set out in the Bulk Water Entitlement (2004) from the Broken system, until the declared water shortage is revoked.

This Qualification of Rights (QoR) ensures that essential needs of towns, stock and domestic customers and rural industries are met under the continuing dry conditions. There are provisions within the qualification to re-instate environmental flows when an irrigation allocation is declared. Although, the QoR restricts any minimum environmental flows, catchment inflows are providing around 40ML/day of flow in the Broken River at the end of August 2009. It is estimated that by the end of Spring 2009, the Broken River system will cease to flow and become a series of disconnected pools. In previous years minimum flows were able to be provided to retain flows for the majority of the season (Geoff Earl, *pers. comm.*).

A scientific panel was contracted by Goulburn Broken CMA (Catchment Management Authority), Goulburn-Murray Water and the Department of Sustainability and Environment to look at the risks and best ways of deploying any available water. Cottingham *et al* (2009) adopted the following general principles (modified from Government of Victoria 2008) when considering threats (and associated risks) and priorities for action along the Broken system:

- Avoid critical loss of imperilled species (e.g. critically endangered species, at-risk remnant populations at a catchment or regional scale);
- Maintain viable populations of threatened species within the river system;
- Avoid irretrievable ecosystem damage or catastrophic events (e.g. large fish kills due to blackwater events);
- Provide refuges to allow recolonisation following drought or other disturbance;
- Maintain long-term perspective to maintain resilience and ecosystem functioning into the future.

Based on these principles, the Broken River below Casey's Weir and the Lower Broken Creek were judged as priorities for any available water in the system (Cottingham *et al.* 2009).

4 Flow Ecology Relationships

There have been a number of studies conducted which focus on the relationship between flow and ecology in the Broken River.

- ***Research on the Ecological Impacts of Flow Regime Reversal and Weir Removal in the Broken-Boosey Creek System*** **(**Monash University) has been assessing changes in ecological and physical condition in Broken and Boosey Creek associated with flow changes resulting from the construction of the Tungamah pipeline and removal of redundant structures. Clear differences were detected in geomorphology, water quality and biotic assemblages (macrophytes, macroinvertebrates and fish) within 2 yrs of the pipeline being operational as a result of changes in flow (McMaster *et al.* 2008).

- ***Campaspe Flow Manipulation Project*** (CRCFE) used the Broken River as a 'less regulated' control for the Campaspe River to assess changes associated with delivering environmental flows. Unfortunately, flows were never delivered to the Campaspe River, however the wealth of data collected has provided many insights into the instream communities of both rivers.

- ***The Lowland River Project*** (CRCFE) investigated flow-ecology relationships in lowland rivers of the Murray Darling Basin. The Broken River was selected for its low level of regulation compared to The Murray River (highly regulated) and the Ovens River (unregulated). Ecological processes within the three sites were compared.

- ***Broken River Rehabilitation Project*** **(2006 – ongoing)** (MDFRC) has been monitoring the effectiveness of instream habitat restoration (re-snagging). Findings included a clear difference in fish species composition above and below Casey's Weir (Nielson *et al.* 2009; Stoffels *et al.* 2009).

- ***Effect of Mokoan decommissioning on Broken River fish community structure*** **(2008- ongoing)** *(MDFRC)****.*** To date, the project has found that, as with the Broken River Rehabilitation Project, spatial patterns in fish community structure and decomposition are different above and below Casey's Weir. These differences may bee correlated with that of turbidity, and also with other aspects of habitat structure (Stoffels *et al.* 2009).

- As well as these large projects, many smaller projects have made important contributions towards flow-ecology relationships within the Broken River system. These include investigations into the importance of slackwater habitats for fish and shrimp at various life-stages, (Price 2007) and microinvertebrates (Ning 2008). King (2002) demonstrated that low flows and slackwaters were important for fish recruitment.

4.1 Fish

There has been a substantial amount of research and monitoring on fish populations in the Broken River System

Murray Cod

Murray Cod (*Maccullochella peelii peelii)* has a wide distribution through out the Murray-Darling basin and is listed as vulnerable under the federal EPBC act,1999 and listed under the Victorian Flora and Fauna Guarantee Act 1988 Generally Murray Cod are associated with deep holes in rivers, and prefer habitats with instream cover such as rocks, stumps, fallen trees or undercut banks (Linterman 2007).

The Broken River below Casey's weir has been found to contain a greater abundance of Murray Cod compared to reaches above Casey's weir (Nielson *et al.* 2009; Stoffels *et al.* 2009). Work is currently being undertaken to determine whether these differences are due in part to differences in turbidity or a lack of suitable habitat (Stoffels *et al.* 2009). In the Broken and Boosey Creek systems, two years of post pipeline surveys found the occurrence of Murray cod had been significantly reduced as flow intermittency increased (McMaster *et al.* 2009).

Research in the Broken, Ovens and Murray Rivers into the spawning and recruitment of Murray Cod have indicated that spawning occurs across a range of flow conditions and not related to discharge (Humphries 2005; Koehn *et al.* 2006). These results have led to the suggestion that river regulation has more of an impact on post-spawning recruitment than on spawning itself (Humphries *et al.* 2000).

Trout Cod

The Trout Cod (*Maccullochella macquariensis*) was once widespread throughout the southern tributaries of the Murray-Darling Basin including the Broken River (McDowall 1980). It has suffered a catastrophic decline in range and abundance. At present only two potentially sustainable, breeding populations of Trout Cod are known: a naturally occurring population in the Murray River (NSW) downstream of the Yarrawonga Weir and a translocated population in Seven Creeks, a tributary of the Goulburn River (Team 2008). Trout Cod are listed as endangered under both the under the federal EPBC act (1999) and the Victoria Flora and Fauna Guarantee Act (1988). In Victoria it is the only fish species listed as endangered.

The species is typically associated with deeper water (pools) and instream cover such as logs and boulders (Linterman 2007). An assessment of habitat critical to survival has been carried out on the Trout Cod population in the Murray River. Trout Cod used river positions where large woody debris is present in high quantity, close to deeper water and high surface velocity, further from the river bank (Koehn *et al*. 1998).

The environmental conditions and timing of spawning of Murray cod and Trout cod were investigated over three successive years in the regulated Murray River and in the nearby, unregulated Ovens (Koehn *et al.* 2006). Spawning occurred regularly under a range of flow conditions and it is likely that recruitment of these species in these rivers is driven by the subsequent survival of larvae and juveniles. Similarly, a field based experiment by Lake (1967) found flowing water was not required for gonad maturation or spawning.

Re-stocking of the Broken River has been undertaken with 11,400 hatchery-bred trout cod juveniles released above Benalla between 1990 and 1994 (Brown *et al.* 2002). Works to protect and restore Trout Cod habitat in the Broken River were also established by the Broken River Management Board (BRMB). To date, no evidence of self sustaining population has been found (ARI 2006; O'Connor *et al.* 2008; Ecowise 2009; Nielson *et al.* 2009; Stoffels *et al.* 2009).

Golden perch

Golden perch (*Macquaria ambigua ambigua*) are predominantly found in warm, turbid, slow flowing lowland rivers. In the Broken River they have been shown to prefer deep, slow flowing pool habitats and were often associated with snags and other cover (Crook *et al.* 2001).

Fish surveys for the Broken River Rehabilitation Project in 2008 found Golden Perch along the length of the Broken River, with the highest numbers between Casey's and Gowangardie Weirs (Nielson *et al.* 2009). ARI found similarly high numbers in May 2008, predominantly downstream of Casey's weir, as well as in the Lower Broken Creek, downstream of Walsh's bridge (O'Connor *et al.* 2008). Fish surveys conducted in October 2008 as part of the VEFMAP program found individuals along Broken River below Casey's Weir and along Broken Creek (Ecowise 2009). McMaster et al. (2009) have found that Golden perch populations in the Broken and Boosey Creek systems have reduced significantly in the two years of post pipeline surveying as flows have reduced.

Originally thought to spawn in floods during spring and summer (Lake 1967), they have been found to spawn during relatively stable bankfull irrigation flows in the

Murray River (Mallen-Cooper *et al.* 2003). Humphries and Lake (2000) also sampled Golden perch in both the Campaspe and the Broken Rivers in only one year out of three, coinciding with extremely poor winter rains before the breeding season and low daily discharge throughout summer. Despite this, spawning activity significantly increased during a flood and environmental water release in 2005 in the mid-Murray River (King *et al.* 2008).

Silver Perch

Silver perch (*Bidyanus bidyanus*) are found in similar habitats to Murray cod and Golden perch, i.e. lowland, turbid and slow-flowing rivers (Linterman 2007). Silver perch spawning and recruitment appears to occur during both within-channel flows and overbank floods (Mallen-Cooper *et al.* 2003). But whilst spawning can occur during non-flood conditions, spawning activity was significantly increased during a flood and environmental water release in 2005 in the mid-Murray River (King *et al.* 2008).

Silver perch appear to occur in low numbers in the Broken River System. Only two individuals were found below Gowangardie Weir during fish surveys in 2008 for the Broken River Rehabilitation Project (Nielson *et al.* 2009). None were sampled during surveys by ARI in 2005 or 2008 (O'Connor *et al.* 2008), nor in surveys as part of the VEFMAP program (Ecowise 2009).

Macquarie Perch

The Macquarie perch (*Macquaria australasica*) are listed as endangered under the under the federal EPBC act (1999) and vulnerable under Victoria Flora and Fauna Guarantee Act (1988). It is typically found in the cool, upper reaches of the Murray-Darling basin (Linterman 2007). During fish surveys to assess aquatic habitat restoration in the mid Broken River (below Swanpool) from 1995-98, 132 Macquarie perch were sampled (Brown *et al.* 2002). Surveys by ARI in 2005 and 2008 did not sample any Macquarie Perch (ARI 2006; O'Connor *et al.* 2008), neither did recent surveys for the VEFMAP project (Ecowise 2009). There has been some work conducted by ARI on Macquarie Perch in the Upper Broken, however this is outside the scope of this review.

River Blackfish

The River Blackfish (*Gadopsis marmoratus*) is found in a diverse range of stream types, from small upland and lowland creeks to large rivers. It prefers habitats with good instream cover such as woody debris, aquatic vegetation or boulders (Linterman 2007). Altered flows are likely to contribute to the build up of sediment which in turn smothers eggs and spawning sites, a major threat to the species.

During fish surveys to assess aquatic habitat restoration in the mid Broken River (below Swanpool) from 1995-1998, 144 River blackfish were sampled (Brown *et al.* 2002). Much greater numbers were found in Ryan's Creek, an upland unregulated stream. A more recent survey for the Broken River Rehabilitation Project sampled only 1 individual below Casey's Weir (Nielson *et al.* 2009). As flow intermittency was re-instated in the Broken and Boosey Creek systems, two years of post pipeline surveying found the occurrence of River blackfish was significantly reduced (McMaster *et al.* 2009).

Two-spined Blackfish

The Two-spined Blackfish (*Gadopsis bisinosus*) is restricted to cool, clear upland stream with abundant instream cover, usually in the form of boulders and cobbles (Linterman 2007). Although greater numbers were found in the upland Holland's Creek, several Two-spined Blackfish were sampled from the mid Broken River around the Swanpool area between 1995-98 (Brown *et al.* 2002). It has not been collected in any recent fish surveys (ARI 2006; O'Connor *et al.* 2008; Ecowise 2009; McMaster *et al.* 2009; Nielson *et al.* 2009).

Mountain Galaxias

Mountain Galaxias (*Galaxias oldius*) habituate medium to high altitude streams (up to 1,800 m) where water temperatures are cooler and streams smaller with rock, gravel or sand substrates. Also found over mud substrates in quieter stretches of water (DPI 1998). Mountain galaxias were found in the mid Broken River around the Swanpool area during an aquatic habitat restoration project between 1995-1998 (Brown *et al.* 2002). Recently collected in the Boosey Creek by McMaster *et al* (2009), but not in recent sampling of the Broken River (ARI 2006; O'Connor *et al.* 2008; Nielson *et al.* 2009; Stoffels *et al.* 2009).

Flat-headed Galaxias

Little is known about the ecology and habitat requirements of the Flat-headed galaxia (*Galaxias rostratus*). It has been historically collected from a variety of habitats, albeit patchily across the southern Murray-darling Basin including the Broken system (Linterman 2007). Most frequently found at low altitudes in still or slow-flowing warm waters such as lakes, lagoons, billabongs and backwaters (DPI 1998). No recent fish surveys within the Broken system have sampled this fish species (ARI 2006; O'Connor *et al.* 2008; McMaster *et al.* 2009; Nielson *et al.* 2009; Stoffels *et al.* 2009).

Crimson Spotted Rainbow Fish

Crimson-spotted rainbowfish or 'Murray-Darling Rainbowfish' (*Melanotaenia fluvilatilis*) are generally found in the lowland parts of the Basin, preferring slow flowing rivers, wetlands and billabongs.

Rainbow fish were one of two fish species to dominate during surveys for the Broken River Rehabilitation Project, and were primarily found above Casey's weir (Nielson *et al.* 2009). Surveys by Ecowise in October 2008 for the VEFMAP program found the fish in the Broken River, but not in Broken Creek however they were recorded in the Broken Creek in 2009 by McMaster (2009).

Carp Gudgeon

This group of species *(Hypseleotris spp.)* is found in slow-flowing or still waters, normally associated with macrophyte beds or other aquatic vegetation (Linterman 2007). They are widespread over the Basin including the Broken system.

Carp Gudgeons were one of two fish species to dominate fish surveys for the Broken River Rehabilitation Project, and were primarily found above Casey's weir (Nielson *et al.* 2009). These fish were also recorded at numerous sites and in high abundances throughout the Broken Creek system (McMaster *et al.* 2008).

Lowland River Project found the diet of the Carp gudgeon to be strongly influenced by flow conditions (Gawne *et al.* 2002).

Flat-headed Gudgeon

The Flat-headed gudgeon (*Philypnodon grandiceps*) has been found to prefer slow-flowing areas of lowland streams or lakes and dams and is often associated with muddy or weedy areas with abundant cover in the form of rocks or logs (Linterman 2007). Flow regime appears to play little part in breeding, and the species does not routinely utilise the floodplain for larval development (Humphries *et al.* 2002). The species was found during recent VEFMAP fish surveys (Ecowise 2009) in Broken Creek, but there is little evidence to suggest they occur in the Broken River (Humphries *et al.* 2004; ARI 2006; O'Connor *et al.* 2008; Ecowise 2009; Nielson *et al.* 2009; Stoffels *et al.* 2009).

It is possible that the extended spawning period of Flat-headed gudgeon in the Campaspe system – up to 10 months each year - is the key to their persistence. We speculate that this breeding pattern means that at least a proportion of hatchlings will encounter favourable conditions for recruitment during most breeding seasons (Humphries *et al.* 2004).

Australian Smelt

The Australian Smelt (*Retropinna semoni*) is one of the most widespread and abundant species at lower and mid altitudes in the southern parts of the Basin (Linterman 2007). Typically these fish are found in slow moving or still water (DPI 1998).

Recent work by McMaster et al (2008) found Australian Smelt to occur in high abundances across the Broken Creek System. However, during the Broken River Rehabilitation Project they were found primarily above Casey's Weir (Nielson *et al.* 2009). Australian smelt were the most abundant fish species sampled between Benalla Weir and Gowangardie Weir by ARI in 2005 (ARI 2006).

It is possible that the extended spawning period of flathead gudgeon and Australian smelt – up to 10 months each year - is the key to their persistence. It has been speculated that this breeding pattern means that at least a proportion of hatchlings will encounter favourable conditions for recruitment during most breeding seasons (Humphries *et al.* 2004).

Lowland River Project found the Smelt diet appears to be influenced by flow conditions (Gawne *et al.* 2002)

Opportunities to manage flows for fish

- One of the most significant results of the Campaspe Flow Manipulation Project (Humphries *et al.* 2004) was the observation that fish spawn each year, regardless of the flow conditions. However, river regulation created unfavourable conditions for recruitment, through an interaction between hydrology and habitat and food availability for the young stages of fish. As such, the management of flows for fish should be focused to favour recruitment.
- The CRCFE Lowland River Project II (Gawne *et al.* 2002) showed that the diet of Carp gudgeon and Australian smelt appeared to be strongly influenced by flow conditions (Gawne *et al.* 2002). Initial analysis indicated that fluctuations in flow are important to provide sufficient food resources, however

further investigation would be necessary to infer particular flow patterns necessary for other species.
- Flows to prevent the loss of lateral and longitudinal connectivity which may affect processes such as drift are a necessary step in the life history of some fish species.

Knowledge gaps

- Flows/habitats required for recruitment in different fish species, and critical timing
- Flow rate/height required for refuges. This is relevant for drought and also high flows.

4.2 Murray Crayfish

Murray crayfish (*Euastacus armatus*) is listed as threatened under the Victorian Flora and Fauna Gaurantee Act 1988 and also listed on the IUCN red list of Threatened Species as vulnerable. They occupy a wide range of habitat types ranging from small upland streams to large lowland rivers. The average size of individuals increases with the amount of habitat available. Clay banks, deep holes, woody debris and boulders are considered important habitat characteristics as they provide shelter.

In the 1800s and early 1900s, Murray crayfish were very abundant, including the Broken system (Gilligan *et al.* 1997). However, recreational fishermen, commercial fisherman and researchers noted that their distribution, abundance and average size began to decline during the 1950s. These declines continued through until the 1980s when fishing regulations and total fishing closures were introduced. Murray crayfish are now considered very rare or locally extinct in the Murray River downstream of Mildura and are reportedly very rare in several lowland river reaches.

Threatening processes postulated to have caused of these declines include; river regulation, pesticides and agrochemicals, commercial and recreational overfishing and to a lesser extent, thermal pollution and obstructed fish passage. The construction of weirs and subsequent river regulation and seasonal flow reversal, and the widespread use of agro-chemicals in the 1940s and 1950s are likely to be the two primary threatening processes responsible for the decline of the range and abundance of Murray crayfish. Commercial and recreational over-fishing also contributed to the decline in abundance and average size. Habitat degradation, thermal pollution, obstructed fish passage and predation by introduced fish also pose moderate threats to the sustainability of the population (Gilligan *et al.* 1997).

Between 1997 and 1999 the Victorian Department of Natural Resources and Environment (Raadik *et al.* 2001) collected data on fish and crayfish from throughout Victoria, including 506 Murray Crayfish from the Broken system (Raadik *et al.* 2001).

Opportunities and knowledge gaps
The ecology of the Murray Crayfish is largely unknown. Further work is required to determine the flow ecology relationship of this species, enabling a better understanding of the effects of managed flows.

4.3 Birds

One of the main impacts in the Murray-Darling basin on waterbirds since European settlement has been the changes to the flow regime of rivers and wetlands, which are both essential for waterbird breeding and survival (Scott 1997). Reduced flooding of wetlands and floodplain environments, creating permanent water supplies and changes in seasonality of flow are some of the compounding factors (Scott 1997).

Changes in flow regime of rivers and wetlands have impacted on some species more than others. Those that rely on the wetting and drying cycles of wetlands for food supply or breeding habitat, such as many waterfowl species, ibis, egrets and the waders, have probably suffered the most. Other species, which prefer a more permanent water supply such as the fish eating species, have in many areas increased in abundance (R. Kingsford, *pers. comm*. in Scott 1997).

During drought, surface water in either permanently inundated wetlands and waterholes in rivers can become a drought refuge for birds. Within rivers as the water recedes, new plants germinate in the exposed mud and waterbirds such as ibis and spoonbills feed in the shallow pools and mudflats. Birds will also predate on organisms concentrated in smaller areas of water (Scott *et al.*). Waterbirds fly many hundreds of kilometres to find more permanent water, such as coastal estuaries (Scott *et al.*)

Ecology Australia's flora and fauna survey of Lake Mokoan in 2006, found a number of notable bird species of State and/or National conservation significance, and one community of State significance was recorded (Ecology-Australia 2006). They included:

- *Lathams Snipe* (migratory species under EPBC Act, Near Threatened in Victoria)
- *Freckled Duck* (Endangered in Victoria; FFG listed)
- *Intermediate Egret* (Critically endangered in Victoria; FFG listed)
- *Great Egret* (Endangered in Victoria, FFG listed)
- *Australian Little Bittern* (Nationally Near Threatened; Endangered in Victoria, FFG listed)
- *White-bellied Sea-Eagle* (Vulnerable in Victoria; FFG listed)
- *Victorian Temperate Woodland Bird Community*- a number of species of this listed community were recorded: Black-chinned Honeyeater, Brown Treecreeper, Diamond Firetail, Painted Button Quail.
- *Colonial Breeding Waterbirds* - the presence of colonially nesting waterbirds breeding at least at two sites was noted (Little Black Cormorant and Little Pied Cormorant confirmed; Australian Pelican, Nankeen Night Heron, Great Egret and Intermediate Egret probable but unconfirmed).

There is little other information available for the Broken system. Although Broken Creek has a big influence on the flooding of Goose Swamp (Barmah Forest), it was seen as being outside the study area.

Opportunities to manage flows for birds

- Water allocations for wetlands

- During drought or restricted flows, remaining waterholes become refuges for birds. It is critical that these waterholes are retained ie not pumped dry when providing water for livestock.
- Floodplain flooding. Good redgum riparian zone exist alongside lower Broken Creek. This is not likely to be an option for the Broken system in the foreseeable future due to low water availability, but may have application in other systems.

Knowledge gaps

- The use and importance of river environs for terrestrial birds

4.4 Macroinvertebrates

There is some uncertainty about the direct link between flow and macroinvertebrates. Existing studies suggest complex interactions with other biological processes e.g. Hart & Finelli (1999).

Monitoring of the Broken River Catchment undertaken as part of the Sustainable Rivers Audit (SRA) in 2005 (Davies *et. al* 2008) deemed the Broken Valley macroinvertebrate community to be in poor condition, particularly within the lower reaches downstream of Benalla. Most sites lacked taxa which were expected in these areas as well as disturbance-sensitive families (Davies *et. al* 2008). The final VEFMAP report of 2008 found macroinvertebrates sampled from four sites in the Broken River typical of lowland, agriculturally disturbed river in northern Victoria (Ecowise 2009).

The Campaspe Flow Manipulation Project (Humphries *et al.* 2004) found that the Broken River had a macroinvertebrate fauna which varied seasonally in response to the periodicity of high and low flows and corresponding changes in biofilm structure. The macroinvertebrate assemblages within the Campaspe and Broken Rivers were relatively persistent during times of hydrological change over the seven years of sampling. Abundances of these taxa did, however, change with discharge throughout different seasons.

Filtering taxa appeared to respond consistently and rapidly to increases in the abundance of habitat and food following increased flow. In each case in the Broken River, when there was a substantial rise in discharge, an increase in relative abundance of filterers could be detected approximately four months later (Humphries *et al.* 2004)

The Lowland River Project (Gawne *et al.* 2002) found differences in the macroinvertebrate community structure of the Broken River compared two rivers with different flow regimes: the Murray (highly regulated) and the Ovens (unregulated). Macroinvertebrate functional feedings groups differed between the rivers as a result of sedimentation and scouring associated with flow regime (Gawne *et al.* 2002).

In the Broken and Boosey Creek system Reich *et al* (2009) found the unregulated site was characterized by highly mobile species tolerant of poor water quality. In contrast, heavily regulated sites harboured taxa that reflected an obvious response to perennial flows at these sites. There were significant differences in total taxa richness between flow groups with heavily regulated and moderately regulated sites comprising a greater number of taxa per site than the unregulated site on each sampling occasion.

Opportunities to manage flows for macroinvertebrates

- Flows that reduce sediment build up and subsequent smothering of biofilms
- Flow variability to ensure taxa variation. An increase in the quantity and diversity of habitats should increase assemblage diversity by allowing aquatic organisms with different habitat requirements to coexist.
- Flows for invertebrate dispersal. Loss of lateral and longitudinal connectivity may affect processes such as drift which are a necessary step in the life history of some macroinvertebrate species.
- River system should be operated to avoid rapid and prolonged exposure of habitat to decrease the risk of stranding or desiccation
- Flows that promote habitat and food sources for macroinvertebrates eg- macrophyte growth

Knowledge gaps

- Flow rates to reduce sedimentation and thereby increasing habitat
- Optimal flow velocity/height for biofilm development

4.5 Vegetation

Macrophytes

Generally speaking, most determinants of aquatic macrophyte assemblage are all flow related factors; flow extremes, flow regime, hydraulics, substrate composition, and stability (Bunn *et al.* 2002). Macrophytes also reduce flow velocity, stabilise sediments and provide habitat for micro-organisms, invertebrates and fish (Meschiatti *et al*. 2000; Pederson *et al*. 2004). Thus the structure of macrophytes, either as an individual plant or in bed formation, is important in the ecology of lowland rivers (Reid 2006).

The Broken River is one of the few lowland rivers within the Murray-Darling Basin with extensive macrophyte beds; predominantly the submerged macrophyte *Vallisneria americana.* A study of the lowland reaches of the Broken River by Reid (2006), found *V. americana* was located within shallow zones of depths < 0.6 m with shallow substrates of sand. These macrophytes also preferred the inner bends of the river which are generally slower flowing (Reid 2006).

Work by Bowen (2006) to develop a model of organic matter inputs from macrophytes to river channels, including the effects of these inputs on river functioning used a site on the Broken River at Benalla as one of three lowland river sites. This work contributed to the Lowland Rivers Project II (Gawne *et al.* 2002) which estimated the annual above ground production of macrophytes and the seasonal timing of the entry of this biomass to the water column, as influenced by flow conditions. Species studied included are *Vallisneria gigantea*, *Typha orientalis*, *Phragmites australis* and *Persicaria prostrata*.

The lower Broken Creek is characterised by the extensive growth of the floating fern *Azolla*. *Azolla* blooms can occur over many 100s of meters, up to kilometres and have the capacity to greatly alter the ecological condition of the creek and to have a major impact on the overall water quality of the creek (Rees *et al.* 2007). The system now undergoes regular growth and death cycles of *Azolla* and a large reserve of carbon and nutrient exists within the sediments. Poor water quality (low dissolved oxygen - DO) was considered a major factor that contributed to a fish death event in 2002. In addition, other consequences of anaerobic waters, namely, potential increase in hydrogen sulfide, ammonia and other products of microbial metabolism, also were considered as possible factors compounding the problems of low dissolved oxygen (Rees *et al.* 2007). As a result, flows on the lower Broken Creek are managed to disperse Azolla from the weir pools and discourage growth, as well as lifting DO to prevent further fish kills.

There have been reports of the introduced Cabomba (*Cabomba caroliniana*) in Benalla Weir pool and Casey's 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)* (Newall *et al.* 2008).

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 (Newall *et al.* 2008). Decommissioning of Mokoan may reduce turbidity levels in the upper parts of the creek, resulting in increased macrophyte growth.

As flow intermittency was re-instated in the Broken and Boosey Creek systems following pipeline implementation, no major changes in the species composition have been observed in the aquatic macrophyte assemblages. Significant encroachment into the channel by amphibious fluctuation tolerators (e.g. *Juncus and Cyperus spp.*) has however been detected. (Reich *et al.* 2009).

Riparian

The riparian vegetation along the Broken systems can be divided into 3 areas: (Cottingham *et al.* 2001)

- Broken River below Lake Nillacootie to Casey's Weir (Central Victorian Uplands bioregion): tree diversity high, with several *Eucalyptus* and *Acacia* species.
- Broken River below Casey's Weir (Victorian Riverina bioregion): intermediate tree diversity, with two dominant species (River Red Gum *Eucalyptus camaldulensis* and Silver Wattle *Acacia dealbata*)
- Broken Creek (Victorian Riverina bioregion): tree diversity low, mainly River Red Gum or Black Box *Eucalyptus largiflorens* sparse woodland.

Little is known about flow requirements for the Central Victorian Uplands Bioregion (Lake Nillacootie to Casey's Weir) riparian zone. For trees within the riparian zone typical of the Victorian Riverine bioregion (Broken River below Casey's Weir and the Broken Creek), flood frequency and duration have long been thought to be key factors for survival and growth of established Eucalyptus trees and the establishment of offspring .

There are some recent findings that both Red Gum and Black Box have shown a preference for saline groundwater (Overton *et al.* 2004) through an ability to switch their use of water sources via an extensive and deep root system. For Red Gums more saline groundwater preference can remain even where water is readily available from flooding (Dawson *et al.* 1991; Mensforth *et al.* 1994; Thorburn *et al.* 1994).

Opportunities to manage flows for vegetation

- Flow for Azolla disturbance, reduce optimal growing conditions and in turn improving water quality
- Ensure areas of low flow which are more conducive to colonisation eg slackwaters
- Ensure river is not consistently 'run' high limiting shallow areas with enough light penetration for submerged species
- Wetland inundation to promote both aquatic and riparian vegetation growth/reproduction
- High flows/overbank flows for riparian and floodplain vegetation. It should be noted that is very unlikely water would be available in the Broken system for any floodplain inundation, however this may be an option in other catchments.

Knowledge gaps

- Flow rates required to displace invasive species
- Preferred water source for riparian and floodplain vegetation along the Broken system, ie is groundwater adequate?
- Optimal colonisation conditions, especially for macrophytes

5 Flow Related Processes

This section discusses information that's available for some of the processes on which flow-ecology relationships are dependant.

5.1 Water Quality

Lake Mokoan has been the focus of many of the water quality issues within the Broken system; particularly high turbidity and nutrient levels. Improvements are therefore expected as decommissioning occurs. However, high turbidity and nutrient inputs have also been detected further downstream suggesting catchment inputs such as irrigation drainage, urban run-off and erosion (Cottingham *et al.* 2001; Newall *et al.* 2008).

The elevated turbidity concentrations in the waters of Caseys Weir do not correspond with higher suspended solids levels, suggesting that the turbidity inputs from Lake Mokoan do not necessarily indicate an increased threat of sedimentation downstream. The turbidity from the Lake is due to very fine colloidal material that will contribute little to sedimentation (Newall *et al.* 2008).

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 within Broken Creek may result in very low oxygen levels during prolonged dry periods where the pools develop substantial phytoplankton communities. Sediment oxygen demand may contribute to low DO, whilst macrophytes will increase oxygen in the water. (Newall *et al.* 2008).

Nutrient levels can be high downstream of Caseys Weir. Levels are high enough to promote excessive plant growth but turbidity is also very high which limits plant growth (Newall *et al.* 2008). 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 (Newall *et al.* 2008).

Upper Broken Creek and Lower Broken River have consistently failed to attain State Environment Protection Policy (Waters of Victoria) water quality objectives for nutrients, dissolved oxygen and turbidity (Newall *et al.* 2008). An Ecological Risk Assessment of was undertaken by Lloyd Environmental in 2008 using fish communities as end points.

Water quality monitoring already identified within the FRM Water Data and Background Working Paper (Adams *et al.* 2009) includes Victorian Water Quality Monitoring Network (VWQMN), and Waterwatch. Several key studies containing water quality data which have been conducted within the Broken system are listed in Appendix 1.

Opportunities to manage flows for water quality

- Returning Lake Mokoan to natural wetland system, and thereby improving turbidity downstream
- Freshening flows to improve water quality, most importantly dissolved oxygen where waterway has constricted to isolated pools

Knowledge gaps

- How downstream vegetation communities will respond with the decommissioning of Lake Mokoan if nutrients remain elevated and turbidity is reduced

5.2 Productivity

Patterns of productivity and sources of organic matter in the food webs of three Australian lowland rivers, including the Broken River were studied by Gawne et al (2003). Flow regime influenced organic inputs to the three sites. The Murray and Broken River sites were less variable (compared to the less regulated Ovens River) due to the regulation of flows, with organic matter inputs varying seasonally. The Broken River maintained shallower water with higher surface area to volume ratios which were associated with increased attached algal contributions. The steep banks and relatively narrow channel at the Broken River might have been expected to be associated with relatively high riparian inputs except that the riparian corridor had been extensively cleared. Where macrophyte beds were present, macrophyte organic matter represented a significant input. The major sources of organic carbon for the invertebrate community in the Murray, Broken and Ovens Rivers appear to be attached biofilms and phytoplankton. The isotopic analysis reveals that the diets of filtering invertebrates were dominated by phytoplankton while the diets of true bugs were dominated by biofilm.

Little more is known about how flow influences productivity in the Broken system, and opportunities are difficult to assess.

5.3 Habitat

Habitats are defined by a complex interaction of physical factors and the ecological requirements of aquatic flora and fauna, such as light, shelter, food and flow-mediated chemical exchanges (Chee *et al.* 2006).

Habitat patches in rivers are formed by interactions of hydrology, geomorphological features (e.g. pools, runs, bars, benches, overhanging banks and anabranches) and structural elements (e.g. boulders, tree roots, coarse woody debris and macrophytes). These habitat patches are dynamic and respond to various characteristics of the flow regime. For instance, freshes (freshening flows) can create new habitat patches through inundation where none existed previously and can alter the nature of a habitat patch from a pool to a run. The persistence of habitat patches depends on the temporal characteristics of the flow regime (e.g. timing, duration, frequency and variation of various flow features) (Chee *et al.* 2006).

Slackwater areas, typically small shallow areas of still water formed by sand bars, woody debris and bank morphology, have also been found to contain many more larval and smallbodied fish than flowing water patches in lowland rivers. In their study involving hydraulic manipulations to create slackwater and flowing water patches, an order of magnitude more fish and shrimp were collected from slackwaters, both created and natural (Humphries *et al.* 2006). Slackwaters have been hypothesized as providing refuge from current for the young stages of fish and shrimp and/or predation and as sites where food is abundant (Humphries *et al.* 1999, 2006, King 2004).

A pool excavation trial is currently being implemented by Monash University, with Goulburn-Broken CMA at three sites along the Broken and Boosey Creeks. This trial will attempt to restore the natural channel heterogeneity (which is currently heavily sedimented) as well as the functional role of providing refuge habitats for the biota during periods of low flow. This restoration will also involve the reinstatement of large wood to provide complementary habitat structure. The addition of timber may furthermore assist in preventing further sedimentation in the future by promoting local scour of sediments during high flows. If successful, such pool excavation has the potential to be extended to other locations within these creeks as well as to similar creek systems affected by sedimentation throughout Victoria.

Opportunities to manage flows for habitat

- Using flow to promote slackwater habitat, which is critical for a number of biota
- Flow to reduce sediment build-up which reduces available habitat
- Flow variation to promote a variety of habitat patches

6 Addressing the Environmental Flow Requirements of the Broken River System

6.1 How FRM will support achievement of ecological targets

The Ecology subproject in FRM will draw on the existing knowledge reviewed above to develop novel modelling approaches to predict ecological response to flow in both planning and operational contexts, thereby enabling improved environmental water management. It will also address some specific knowledge gaps associated with water management and ecological response related directly to clear opportunities to change management of water in the Broken. These include management of irrigation delivery flows and impacts on fish recruitment, which requires knowledge of flow-habitat linkages are relatively low flows, particularly slack water habitats, and the potential to use Billabongs in the lower catchment to achieve ecological outcomes while supplying water for consumptive purposes. The following sections outline these approaches.

6.2 Ecological Response Modelling and Environmental Flows

Determining and delivering the environmental flow requirements to sustain ecological processes is now regarded as an important and increasingly sophisticated aspect of river management and water allocation planning both in Australia and internationally. Numerous reviews (e.g. Arthington *et al.* 1998; Tharme 2003) have highlighted the large number of specific approaches that have been developed for establishing the flow requirements to achieve particular environmental and ecological objectives; for example Tharme (2003) identified 255 different unique approaches or methods that have been applied globally. Despite this diversity, in general the methods are well classified into 3-4 main groups; hydrologic, hydraulic, habitat based and holistic approaches (Tharme 2003). These methods range from relatively simple approaches, such as identifying the proportion of mean annual flow that can be diverted before ecosystem change (appropriately defined; Lancaster, 2002) would be expected, to complex holistic models of flow requirements incorporating multiple species and life history stages together with a range of flow dependent physical processes. Common to all approaches however is the requirement for some form of conceptual and ultimately quantitative model linking patterns of flow variability and alteration to the ecosystem response(s) of interest.

As part of the FRM project the rivers project team is looking to explore and further develop novel approaches to modelling the response of aquatic biota to patterns of flow variability, and hence water allocation and delivery decisions. Whilst focused initially on the Broken River, this aspect of the project is internally regarded as being of a relatively conceptual nature, and hence whilst the models will have practical relevance to the Broken River system and decision making therein, the greater long-term contribution of the work will be in advancing the suite of modelling approaches that can be used to inform environmental water management as well as our understanding of flow-ecology linkages more generally. In this section of the report we provide a brief review of the broad approaches to modelling flow-ecology relationships and outline the likely directions for work within the FRM project. Given the broad range of modelling approaches there are multiple ways in which they can be categorized. Here we explore to approaches to this classification.

6.3 Classifying Ecological Response Models (ERMs) used in e-flows planning

Process-based models

As with the more specific case of models specifically linking flow alteration to environmental and ecological change, there are many ways in which the full gamut of ERM's can be divided up. A common approach is to distinguish between process-based (mechanistic) and data-driven (statistical) models, although hybrid models employing elements of both approaches are also common.

Process based models are typically built from first principles based around a conceptual understanding of the key causal relationships between physical and ecological processes, and have been used to explore a wide range of problems at very different scales and levels of complexity including biogeochemical cycling, population dynamics and community composition. Because they are underpinned by first principles process based models are attractive from a causal perspective, but can frequently become relatively complex, making parameterisation difficult. In an environmental flows context, simple causal models are frequently used to predict or support expectations around ecological responses to specific flow components. For example, most holistic approaches to environmental flows setting are based around conceptual models linking various flow 'events' to specific physical and ecological processes (e.g. sediment scour, channel and habitat maintenance, fish spawning and migration, floodplain inundation), although as discussed below the occurrence of these 'events' is often used as a proxy for the response variable of interest.

In terms of examining the response of individual species, there are a number of recent examples from south eastern Australia in which process based models have been used to examine flow-ecology relationships. For example, most of the recent environmental flows studies conducted in Victoria have adopted the FLOWS method (SKM *et al.* 2002), which depends on the identification of causal linkages between flow components and desired objectives to arrive at a recommended flow regime. Such approaches are widely employed here and internationally (e.g. see Gippel *et al.* 2009). While we have not conducted a systematic review, experience with this approach suggests that most of these causal models are relatively crude, although in their defence they are also generally quite testable if monitoring programs are in place (Reich *et al.* in prep). There are however several examples in which more sophisticated modelling approaches have been employed to examine flow-population responses in Victorian rivers, primarily as part of applied research programs. For example, Todd et al (2005) and Sherman (2007) developed stage-structured population models for Murray Cod which allowed them to explore the influence of coldwater releases from Dartmouth and Hume Dams, which impact directly on the survival of Murray Cod eggs and larvae. These papers represent one of the few examples from Australia in which demographic population models have been employed in exploring the effects of flow management on aquatic species, although examples from overseas (particularly Salmon populations) are more common (e.g. SABATON *et al.* 1997). More recently Bayesian Network models have been used to examine the outcomes of a range of flow scenarios in the Latrobe River (Hart *et al.* 2009).

Statistical (data-driven) models

In contrast to process-based models, statistical models are built from the 'top-down' – essentially the model structure is inferred from the data rather than being defined a priori. Statistical models have been widely used in ecology to infer habitat relationships at a range of scales in rivers – from flow-mediated microhabitat associations (including in the Broken River Humphries *et al.* 2006) up to the influence of flow regimes at continental scales (e.g. Poff *et al.* 1995). In a specific environmental flows context statistical models have been strongly advocated by a number of researchers as a means of identifying the effects of flow alteration on aquatic ecosystems (e.g. Bunn *et al.* 2002; Arthington *et al.* 2003; POFF *et al.* 2009). Using this approach deviations in long-term flow characteristics are linked via statistical models to changes in ecological characteristics (structure and/or function). The nature of these relationships are subsequently used to define acceptable limits on various forms of hydrologic alteration (e.g. MAF, cease to flow duration etc.). A major issue in this approach is the need to collect data from a large number of rivers, over relatively long time scales in order to develop robust statistical relationships, although where strong flow gradients exist even basic indices of flow characteristics can be used to predict broad scale ecological change (Reich *et al.* 2009).

6.4 An alternative view of modelling approaches

Above we describe potential modelling approaches based on the frequently adopted distinction between process-based and statistical models. However, an important but rarely identified distinction between several different types of models is the distinction between temporally implicit and temporally explicit models. This approach focuses more on the way in which temporal dynamics are treated within the modelling framework, and is entirely analogous to the distinction between spatially implicit (*spatial*) and spatially explicit models. Surprisingly, there are few cases in the literature in which this distinction has been noted, although the distinction is common and applies equally to hydrologic models, which may focus simply on long-term yields (based on rainfall/catchment physiography), or explicitly consider the effects of climate variability on temporal dynamics of runoff. In the case of ecological response models, there are few cases in which statistical models explicitly consider temporal dynamics, although autoregressive modelling approaches make this possible.

6.5 Summary of approaches

While there are also many examples of process-based models (e.g. Bayesian Networks) that are poor at representing temporal dynamics (or feedbacks), some classes of model such as Markov-chain models, which are frequently used to model demographic processes (e.g. Todd, 2005; Sabaton, 1997) are when coupled with time-varying transition probabilities, well suited to modelling the temporal dynamics explicitly, such that population size at time t is a function of population size at t-1 (and t-2, t-3…etc). Modelling approaches such as these, which are capable of handling time explicitly, contrast strongly with the more widely used habitat suitability models (whether statistical or mechanistic), in which the specific sequencing of habitat availability over time is largely ignored – these models tend to focus more on how average (or extremes of) habitat conditions differ between flow scenarios when compared over the long-term. An important consequence of the different ways in which time is treated between the two models, is that it is generally difficult to reconcile planning and operational decision making decisions using the same model, because temporally implicit models are incapable of answering the question of how systems will respond to two different scenarios at any point in time. We therefore contend that temporally explicit modelling approaches, which hitherto have been used infrequently, have much to offer the future development of environmental flows methodologies. With this in mind, the following section outlines the proposed modelling work to be conducted within the FRM project. The specific details of what species (and/or processes) will become the focus of the modelling will be informed by a workshop discussion based around previous empirical studies and identification of species with strong flow-dependent aspects to their biology.

6.6 Questions to be addressed by the modelling activities.

The ecological modelling component of the FRM ‘Rivers’ project will address these three areas through the following activities.

- Incorporate stochastic input data and extreme events into existing e-flows plans. This will help identify periods when shortfalls in the availability of water to meet consumptive demands would impinge on the delivery of environmental allocations, and underpin subsequent risk-based planning and decision making.

- Explore the utility of demographic modelling approaches as an alternative to more widely used habitat suitability models. By explicitly considering survivorship and recruitment rates in response to changing river flows, these modelling approaches are arguably better suited to capturing the temporal dependencies between life-history stages, and their sensitivity to river flows. Whether the more complex parameterisation required will deem this type of model unsuitable for application in a management context is a key question for the study.

- Develop models to support operational decision-making under changing patterns of water availability and demand. There is a range of modelling approaches developed in the field of decision science (e.g. Stochastic Dynamic Programming), which guide operational decision making in cases where the future is uncertain. As an example, water managers may be faced with a scenario such as, given the time since the last winter fresh, the current volume of water available, and the possible inflows and hence availability of water in the next and subsequent years, is it preferable to deliver a fresh now, or carry the water over and release a larger or similar flow next year? Such questions can be evaluated by comparing the long-term outcomes of each possible set of decisions – in this and previous/future years (a decision tree), under a range of possible futures, to identify the most robust decision set capable of achieving the desired objective. The response models to underpin the decision science work will draw on elements of both 1&2 above.

6.7 Management of Ecological Impacts of Irrigation Deliveries

As outlined above, the Broken River has been the subject of considerable freshwater ecological research for the last two decades. The research that highlighted the importance of summer low flows was undertaken in the Broken R. This research lead to an investigation of the role of slackwaters as critical habitats within river channels.

Slackwaters have been recognized as critical habitat for microinvertebrates and the recruitment of several species of native fish and the adults of native species such as the rainbowfish. Slackwaters have been found to provide ideal hydraulic habitat and an abundant source of food for small fish. Changes in flow represent a significant disturbance through the creation, drying or scouring of slackwaters, however, slackwater communities appear to be relatively resilient to these disturbances. Constant flows may also affect the character of slackwaters as fine sediments accumulate changing the nature of biofilms, modifying nutrient cycles. What remains to be resolved is the influence that discharge has on the abundance, morphology and distribution of slackwaters and how this affects river function at the reach scale.

The effects of long term discharge patterns on the growth and recruitment of native fish is much less well understood. To date our examinations of slackwater dynamics have been relatively short term and have not enabled comparison of the outcomes of different flow regimes on fish populations.

Methods

The project will employ a hydrologist to undertake an examination of the effects of flow regime on the distribution and abundance of slackwaters in several reaches of the Broken River. Survey techniques for sampling slackwaters have been well established by MDFRC in the Broken River and these techniques will be employed in this component. The knowledge generated by the hydrological investigation will be integrated with a review of existing ecological knowledge of slackwaters generated by MDFRC as part of their in kind contribution to the project. The final product will be an evaluation of the effects of changing flow regimes on the ecology of slackwaters and their likely impacts on the river.

7 Operational Aspects of Environmental Flow Regimes

7.1 Assessment of potential for and impacts of temporary storage in billabongs and near stream wetlands

Optimising the trade-offs among water uses requires knowledge of the relationship between flow and ecology. This component of the sub-project will investigate the influence of flow regime on two significant habitats in the Broken River - wetlands and slackwaters. The wetland component will explore whether some wetland values could be restored by using wetlands as temporary off-river storages. Such a strategy would ensure that wetlands that may otherwise remain dry, receive water for at least some portion of the year. The NSW Murray Wetland Working Group has achieved considerable success restoring wetland environmental values through the use of irrigation infrastructure to deliver water to dry wetlands. This component will build on the NSW MWWG experience and evaluate environmental effects and outcomes from using on-farm wetlands as temporary storages in an attempt to provide both consumptive and environmental benefits within the system. This strategy could also contribute to alleviating ecological impacts associated with poorly timed high flows for irrigation.

In order to assess the potential environmental benefits of using wetlands as off-river storages, the impact of different management scenarios on wetland health – e.g. community changes, persistence and condition - will be investigated. This information will feed into the catchment ecological model to predict the effects of management change on the system.

More specifically, the project will determine:

- flow-ecology relationships under differing water regimes (timing, extent, duration), focusing on long-term flow scenarios for the Broken River (identified by Water Resources, Accounting and Hydrology subprojects) and managers capacity to influence aspects of the flow regime.

- the impact of water delivery (e.g. pumping, irrigation channel) on wetland health, utilising existing irrigation infrastructure
- effects of water extraction from wetlands on wetland health, compared to “natural” drawdown/drying events

A suite of wetland communities (e.g. fish, zooplankton and aquatic vegetation) and processes (e.g. decomposition) will be selected. While some information exists on flow-ecology relationships of wetland plants and zooplankton, for example, knowledge gaps need to be identified, particularly around water delivery and extraction. Wetlands located in the vicinity of Dookie farm will be selected and allocated treatments based on water delivery (natural flooding vs. inundation) and drying (natural vs. artificial drawdown).

7.2 Management of Slackwaters

The second major habitat is slackwaters. Slackwaters have been are recognized as critical habitat for recruitment of several species of native fish and the adults of native species such as the rainbowfish. Slackwaters have been found to provide ideal hydraulic habitat and an abundant source of food for small fish. Changes in flow represent a significant disturbance through the creation, drying or scouring of slackwaters. Constant flows may also affect the character of slackwaters as fine sediments accumulate changing the nature of biofilms, modifying nutrient cycles.

It is believed that flow management during periods of low flow have the potential to significantly affect the abundance, distribution and disturbance regime of slackwater habitats. Improving our understanding of the influence of flow on slackwater habitats will enable managers to improve management of low flows to optimise habitat in the Broken River. The slackwater component of the project will undertake a review of our knowledge of slackwater ecology and then integrate this knowledge with the hydrology component that will provide information on the influence of flow on the distribution and abundance of slackwaters. The project will generate guidelines on flow regimes that will optimise slackwater habitats in the Broken River and explore ways to transfer the information to rivers with different morphologies.

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9 Appendix 1

Key studies from the Broken system containing water quality data

- The Environmental Protection Agency's (EPA) ***Biological Monitoring of the Broken Catchment,*** previously known as the First National Assessment of River Health, Monitoring River Health Initiative, Sustainable Rivers Audit and National Action Plan, has evaluated river health across Victoria, including the Broken catchment using water quality, macroinvertebrates and habitat assessments. Sampling has taken place biannually since 1994. 43 sites have been sampled, with over 10 years of continuous data for 13 sites.

- The MDFRC's ***Campaspe Flow Manipulation Project*** included monthly to quarterly water quality sampling between1995-2005, totalling over 50 sampling events.

- The MDRFC's ***Broken River Rehabilitation Project*** has been monitoring the effectiveness of instream habitat restoration (re-snagging). Water quality sampling took place at 9 sites bi-monthly in the first 2 years, and quarterly in year 3. This project is on-going.

- The MDFRC's ***Monitoring the Effects of Drought*** project has focused on the Broken, as well as the Ovens, Murray and Kiewa rivers. Data extends from 2006 at 2 sites, and was sampled monthly through-out summer/autumn and reduced during winter/spring.

- The MDFRC's ***Effect of Mokoan Decommissioning on Broken River Fish Community Structure*** has been focusing particularly on turbidity.

- Monash University's ***Research on the Ecological Impacts of Flow Regime Reversal and Weir Removal in the Broken-Boosey Creek System*** has detected clear differences in water quality within 2 yrs of the pipeline being operational as a result of changes in flow (McMaster et al 2008).

- An ***Ecological Risk Assessment of Upper Broken Creek and Lower Broken River*** was undertaken in 2008 when these reaches consistently failed to attain State Environment Protection Policy (Waters of Victoria) water quality objectives for nutrients, dissolved oxygen and turbidity (Newall *et al.* 2008)

- The ***Lowland River Project*** was conducted by the MDFRC to determine flow-ecology relationships in lowland rivers of the Murray Darling Basin. Water quality was measured through-out the project.