Lower Broken Creek and Nine Mile Creek Environmental Watering Plan

April 2010

Update - July 2015

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PROJECT DETAILS

Project Name	Lower Broken Creek and Nine Mile Creek EWP (2015 Update)
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LAND MANAGEMENT AGREEMENT

I agree to the management actions and responsibilities as described in this EWP.

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1. EXECUTIVE SUMMARY

The Broken, Boosey and Nine Mile Creek system lies within the Broken River Basin in the Goulburn Broken catchment in northern Victoria. The flow regime of Broken Creek and its anabranch, Nine Mile Creek is highly modified with irrigation development commencing over 100 years ago. Broken Creek and Nine Mile Creek now carry irrigation water, with drains and outfalls from the Shepparton Irrigation Area and the Murray Valley Irrigation area within the Goulburn-Murray Irrigation District discharging directly to both waterways. Broken Creek and Nine Mile Creek have been altered from ephemeral systems, commonly ceasing to flow during summer and autumn, to perennial streams with significant flows maintained through summer and autumn to supply water for irrigation, stock and domestic use.

Despite (and in some cases because of) the hydrologic change, the Broken-Boosey Creek system including Nine Mile Creek is recognised for locally and regionally significant environmental values including:

- The presence of Victorian and nationally threatened flora and fauna species dependent on the aquatic ecosystem including the nationally Vulnerable Murray Cod (*Maccullochella peelii peelii).*
- The presence of significant wetlands, with Broken Creek listed in the Directory of Important Wetlands in Australia and the Ramsar listed Barmah Forest on the Murray River at the downstream end of Broken Creek.
- The Broken-Boosey State Park system covering approximately 60% of the stream frontage downstream of Katamatite. The park system provides habitat for a range of threatened flora and fauna, contains stands of threatened Ecological Vegetation Classes and provides an important vegetated linear corridor across a generally cleared agricultural landscape.

The Goulburn-Murray Water Connections Project (GMW Connections Project), previously known as the Northern Victoria Irrigation Renewal Project (NVIRP), is proposed to upgrade existing irrigation infrastructure in the Goulburn-Murray Irrigation District (GMID) to achieve water savings. The GMW Connections Project proposes to rationalise and re-configure the existing outfalls from the Murray Valley Irrigation Area to Broken Creek downstream of Katamatite, resulting in an expected reduction of 85% in the total volume of outfalls in excess of orders. The Shepparton Irrigation Area which has previously been upgraded will not be further modified under the GMW Connections Project.

This Environmental Watering Plan assesses the hydrologic impact of the implementation of the GMW Connections Project on the stream system downstream of Katamatite and reviews the need for mitigation water to account for the hydrological modification of the system.

The hydrologic assessment indicates that the majority of inflows to the system (more than 60% in most years) come through channel outfall structures that connect directly to the creeks. Inflows through outfall structures are comprised of two parts – inflows ordered by local diverters or environmental managers, and inflows in excess of orders. However, the contribution of this 'excess' to total inflows is minor, especially post 2002/03. As only the volume of outfalls in excess of orders is to be reduced by the GMW Connections Project monthly inflows are expected to reduce by less than 4% for all environmental flow reaches based on the 2004/05 base case.

While identified high value environmental assets are dependent on the in-stream environment the flow requirements are generally met by the regulated flow regime. The magnitude of the hydrologic change resulting from the GMW Connections Project is small relative to the degree of certainty for determination of the environmental water requirements of the assets. As such, according to the GMW Connections Project Water Change Management Framework, "mitigation water" is not required to protect the condition of these assets. A range of complementary actions to protect the environmental assets from any poorly understood impacts of the GMW Connections Project or other future impacts are identified.

2. PURPOSE OF THE PLAN

The Broken Creek system in northern Victoria currently conveys water used for irrigation within the Goulburn-Murray Irrigation District (GMID). The hydrology of the Broken Creek system has been significantly modified. However the system supports a range of high value environmental assets, some of which are dependent on the modified hydrologic regime resulting from the delivery of irrigation water. The implementation of the GMW Connections Project is intended to improve the efficiency of the GMID and will result in hydrologic modification due to reduced outfall volumes to the Broken Creek system.

This Environmental Watering Plan (EWP) has been prepared as a component of the Water Change Management Framework (WCMF) which is the means by which the effects of implementation of the GMW Connections Project on aquatic and riparian ecological values will be assessed, managed and mitigated (NVIRP 2010). The need for an EWP for the Broken Creek system was determined following a short-listing process which identified the presence of high value environmental assets comprising threatened flora and fauna species potentially impacted by a change in outfall water volumes (Feehan Consulting 2009).

This EWP documents the current aquatic and riparian ecological values within those reaches of the Broken Creek system likely to experience hydrologic modification as a result of implementation of the GMW Connections Project. The likely impact of the hydrologic modification on these assets is considered and where necessary means to mitigate these impacts, either through the delivery of "mitigation water[1]" or the implementation of complementary actions are identified. The EWP focuses on identifying and mitigating negative impacts of the GMW Connections Project and does not specifically consider any positive environmental outcomes which may result, albeit that none have been identified during the EWP development process.

The EWP specifically relates to the impact of the GMW Connections Project on the regulated flow regime which, within the subject reaches of the Broken Creek system, comprises in channel flows. The GMW Connections Project is not expected to have any impact on the occurrence or passage of flood events which may inundate riparian and floodplain zones and thus the EWP does not relate to or discuss environmental assets which are reliant on watering in events larger than those managed by system regulation.

The EWP is only a component of the overall management framework for the Broken Creek system. The EWP will be implemented in the context of broader strategies which provide for the integrated management of the waterway and catchment, along with the hydrologic regime, including:

- Overarching waterway and catchment management plans (that consider integrated land, water and biodiversity management of the waterway) such as the Lower Broken Creek Waterway Management Strategy (GHD / URS 2005), Biodiversity Action Plans (Heard 2007 and DSE 2008) and the Broken-Boosey State Park Management Plan (Parks Victoria 2006).
- Agency roles and responsibilities documented in the NVIRP Water Change Management Framework (WCMF) (NVIRP 2010), the Northern Region Sustainable Water Strategy (DSE 2009) and the Lower Broken Creek operational guidelines (GMW 2003).
- Victorian and regional strategies for healthy rivers, estuaries and waterways (still in development but likely to contain details of how environmental water is to be managed in regions).

[1] Mitigation water is defined as the water that is required to ensure no net impacts due to GMW Connections Project on high environmental values (NVIRP 2010).

3. BACKGROUND

3.1 GMW Connections Project

The GMW Connections Project proposes to upgrade existing irrigation infrastructure in the GMID. The upgrade works will improve the efficiency of water delivery through automation, remediation and reconfiguration of the channel system and implementation of modern metering and control systems. The resultant water savings from Stage 1 of the GMW Connections Project will be shared equally between the environment, irrigators and consumption in Melbourne (NVIRP 2010).

In relation to the Broken Creek system, the GMW Connections Project will rationalise and re-configure the existing outfalls to Broken Creek. Through the system rationalisation and improved system operation, the total volume of outfalls in excess of orders is expected to reduce by 85%.

3.2 EES decision

In February 2009, GMW Connections Project submitted a referral to the Victorian Minister for Planning seeking advice as to the requirement for preparation of an Environment Effects Statement (EES) under the Environment Effects Act 1978. The Minister for Planning's decision (14 April 2009) stated that the GMW Connections Project did not require an EES subject to the Connections Project complying with certain conditions. Full details of the referral and the Minister for Planning's decision are available at DPCD (2010). Of the five conditions, two related directly to the protection of wetlands and waterways, as outlined below.

> **Condition 3** – *Before operation of the relevant works commences, the GMW Connections Project must prepare a framework for protection of aquatic and riparian ecological values through management of water allocations and flows within the modified GMID system to the satisfaction of the Minister for Water...*

A Water Change Management Framework (WCMF) (NVIRP 2010) has been developed by the GMW Connections Project to address the requirements of Condition 3 of the Minister for Planning's decision as discussed in Section 3.3.

> **Condition 5** – *Before operation of relevant works commences, an approved Environmental Watering Plan is required for 'at risk' waterways and wetlands ... Approval of an Environmental Watering Plan is required prior to operation of modified irrigation infrastructure that could affect 'at risk' waterways or wetlands.*

Broken Creek is identified in the Minister for Planning's decision as an 'at risk' waterway and thus development and approval of an EWP is required prior to operation of modified irrigation infrastructure. This document (Lower Broken Creek and Nine Mile Creek Environmental Watering Plan) has been prepared to address Condition 5 of the Minister for Planning's decision.

3.3 WCMF

A Water Change Management Framework (WCMF) has been developed by the GMW Connections Project to satisfy the requirements of Condition 3 of the Minister for Planning's decision as outlined in Section 3.2. The WCMF was first approved in August 2009 and revised and approved in 2013. The WCMF (GMW 2013) identifies the following key environmental principles for operation of the modified GMID:

- GMW Connections Project will strive for efficiency in both water supply and farm watering systems.

- GMW Connections Project will design and construct the modernised GMID system to comply with environmental requirements as specified in the no-EES conditions.
- GMW Connections Project will develop management and mitigation measures consistent with established environmental policies and programs in place in the GMID.
- Renewal or refurbishment of water infrastructure will be undertaken to the current best environmental practice, including any requirements to better provide environmental water. Best environmental practice will require irrigation infrastructure required to deliver environmental water to be retained (no rationalisation at these waterways or wetlands) or upgraded to allow for future use.
- Management and mitigation measures will be maintained into the future through establishment of or modification to operating protocols and operational arrangements.

Additionally, the WCMF (GMW 2013) identifies additional environmental principles guiding the development of the WCMF:

- GMW Connections Project will adopt a risk management approach and will aim to:
    - Avoid and mitigate the adverse effects of GMW Connections Project's implementation on high environmental values associated with wetlands and waterways.
    - Avoid adverse effects on other environmental values where practicable.
    - Retain infrastructure, and improving it where practicable, where it will be required for delivering environmental water by others, either now or in the future.
- GMW Connections Project will actively seek to coordinate with relevant agencies to identify and assess impacts and to deliver effective management and mitigation measures.
- GMW Connections Project will consult with relevant environment and land managers to identify infrastructure requirements for environmental watering.
- GMW Connections Project will adopt an adaptive management approach (assess, design, implement, monitor, evaluate and adjust) to ensure that it is responsive to changing conditions.
- GMW Connections Project will ensure that adequate resources are provided to implement, monitor and review mitigation measures.

As required by the Minister for Planning's decision (refer Section 3.2), the WCMF establishes the process and methodology for preparation of EWPs to mitigate potential impacts of wetlands and waterways at risk from the implementation of the GMW Connections Project through adaptive water management. This EWP for Lower Broken Creek and Nine Mile Creek has been prepared in accordance with the WCMF (GMW 2013).

3.4 Short listing process

The identification of wetlands and waterways potentially at risk from the implementation of the GMW Connections Project has been undertaken in stages as outlined below:

- A desktop assessment (SKM 2008) was undertaken to inform the referral submitted to the Minister for Planning under the Environment Effects Act 1978. This desktop assessment process included (NVIRP 2010):
    - Identification of wetlands / waterways in the GMID.
    - Identification of high environmental values.
    - Assessment of type of connection to the irrigation system.
    - Assessment of the relative contribution of irrigation water to the flow regime of the wetland / waterway.

The desktop assessment resulted in the identification of a preliminary list of wetlands and waterways with high environmental values whose water regime is likely to be altered by implementation of the GMW Connections Project or where insufficient data are available to determine if the water regime is likely to be altered by the implementation of the GMW Connections Project.

Broken Creek was included in the list of waterways with high environmental values potentially exposed to a change in hydrology as a result of implementation of the GMW Connections Project.

- The Minister for Planning's decision (DPCD 2010) identified 17 wetlands and 15 waterways as potentially 'at risk' from implementation of the GMW Connections Project.

  The Minister for Planning's decision required the development of an EWP (refer Section 3.2) for 'at risk' waterways unless subsequent investigation revealed that specific waterways were not at risk.

  Broken Creek was one of the listed 'at risk' waterways[2].

- A Waterway Short-Listing Report (Feehan Consulting 2009) was prepared to further investigate the exposure of the 17 wetlands and 15 waterways listed in the Minister for Planning's decision to significant impacts from implementation of the GMW Connections Project. The method for the Waterway Short-Listing Report comprised (Feehan Consulting 2009):
  - Reviewing the Desktop report and recommendations relevant to the waterways assessed.
  - Documenting environmental values of candidate waterways by undertaking a review of relevant reports and literature, discussions with key staff and site field visits
  - Documenting more detailed information about channel outfalls and the hydrological regime of candidate waterways (if available)
  - Assessing the likelihood for significant negative impacts to be caused by a reduction in outfalls to waterways, and whether or not further work, or the development of an EWP, was warranted.

  Broken Creek (including a short reach of Boosey Creek downstream of Katamatite) was identified as one of five waterway systems 'at risk' from the implementation of the GMW Connections Project and therefore requiring the development of an EWP.

3.5 2015 Update

This report has been commissioned to provide an update to the environmental values and hydrological data from existing documentation for the EWP project area as of June 2015. Updates have been incorporated within the original 2010 report or added as additional sub-sections however the original report has been not been substantially altered. GMW were contacted for all available outfall data and that data was provided, however the dataset was significantly smaller compared to the data that was made available for the original 2010 report. We understand that all available data was supplied. Estimates were made using relationships developed in the original project for the outfall locations for where data was not available.

This document will be updated if further changes to the outfalls occur.

[2] Nine Mile Creek discussed in this EWP is an anabranch of Broken Creek and forms part of the Broken Creek system referred to in the Minister for Planning's decision. The Nine Mile Creek referred to in Attachment A to the Minister for Planning's decision is a part of the Serpentine Creek system in the Loddon catchment.

4. WATERWAY DESCRIPTION – THE BROKEN CREEK STREAM SYSTEM

The Broken, Boosey and Nine Mile Creek system lies within the Broken River Basin in the Goulburn-Broken catchment in northern Victoria. Broken Creek discharges to the Murray River upstream of Barmah while the Broken River discharges to the Goulburn River at Shepparton.

Broken Creek is a distributary channel of the Broken River, commencing at Casey's Weir on the Broken River approximately 10 km north of Benalla. From Caseys Weir, Broken Creek flows generally north and north-west for approximately 84 km to its confluence with Boosey Creek south-west of Katamatite. Broken Creek then trends generally west and north-west, flowing through Numurkah and Nathalia before entering the Murray River approximately 12 km upstream of the township of Barmah within the Barmah-Millewa Forest (SKM 1996).

Tributaries of Broken Creek include Boosey Creek, the Majors Creek and Nine Mile Creek system and Pine Lodge Creek. Boosey Creek drains the western slopes of the Warby Ranges near Wangaratta and enters Broken Creek at Katamatite. Majors Creek and Nine Mile Creek drain the area from Dookie to Youanmite before entering Broken Creek to the west of Katamatite immediately upstream of the Katandra or East Goulburn Main Channel weir. Downstream of the weir, Nine Mile Creek forms a regulated anabranch of Broken Creek over a length of approximately 50 km. Pine Lodge Creek enters Nine Mile Creek upstream from the confluence with Broken Creek. The arrangement of the major watercourses of the region is shown in Figure 4-1. The waterway reaches covered by this EWP (refer Section 4.2) are highlighted in Figure 4-1.

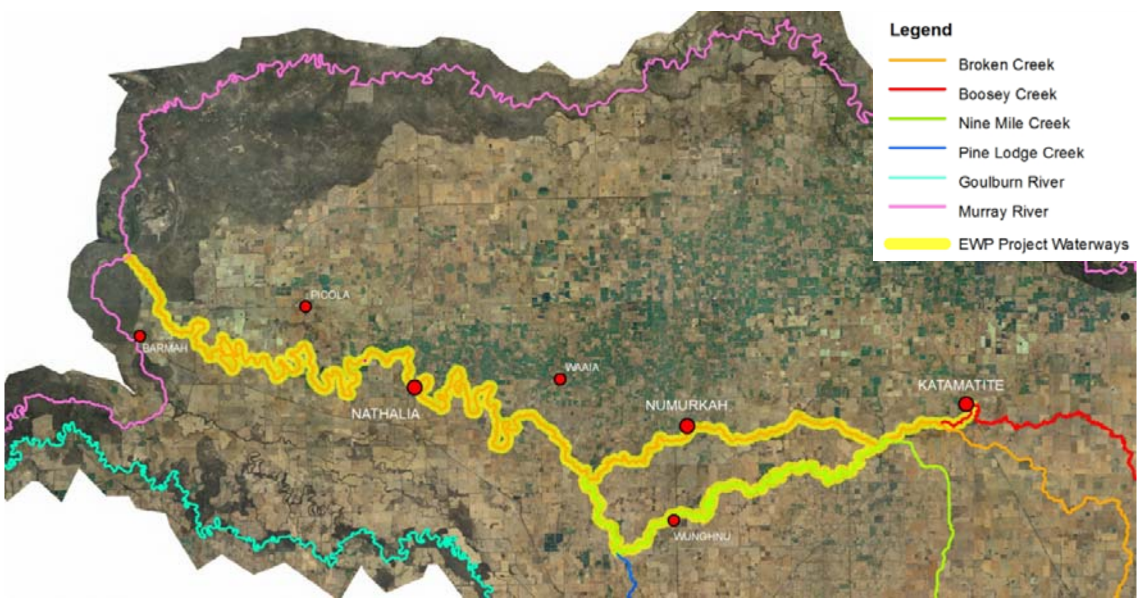

Figure 4-1 The Broken Creek waterway system

4.1 Spatial information and catchment setting

4.1.1 Catchment

The catchment area of Broken Creek covers approximately 3300 km^2 of the Murray Valley Riverine Plains (SKM 1996), encompassing the western slopes of the Warby Ranges and northern slopes of the foothills around Dookie. In addition to flows from the immediate catchment, Broken Creek historically received floodwaters from the catchment of the Broken River upstream of the present location of Caseys Weir in approximately 1 year in 5 (Reich *et al.* 2009) however the regulation of the system for irrigation has significantly modified the hydrologic regime in Broken Creek (refer Section 7).

Much of the catchment is cleared for grazing, with dairy farming the dominant land use in irrigated areas (SKM 1998). The Murray Valley and Shepparton irrigation districts lie generally to the north and south of Broken Creek within the current project area and cover 34% of the Broken Creek catchment (SKM 1998). Well developed drainage systems and arterial drains are features of these irrigation districts with numerous outfalls to Broken Creek and Nine Mile Creek (SKM 1998).

The project area lies within the Victorian Riverina and Murray Fans Bioregions.

4.1.2 Land use and management

The Broken Creek catchment lies in an area of intensive agricultural production, dominated by grazing in the south and mixed cereal and dryland grazing in the central region. The northern part of the catchment lies within the Murray Valley irrigation district where intensive horticultural, dairy and livestock production occurs (GBCMA 2005). The history of agricultural development has resulted in large scale land clearing and less than 3% of pre-European vegetation cover remains, with the majority of this located along the creeks and in Public Land reserves (DSE 2008). A significant portion of the stream frontage within the project area lies within State Park and Natural Features Reserves managed by Parks Victoria, namely:

- Broken Boosey State Park : 43.7 km of frontage within EWP project area
- Numurkah Natural Features Reserve : 50 km of frontage within EWP project area
- Nathalia Natural Features Reserve : 27.1 km of frontage within EWP project area
- Barmah National Park : 5.4 km of frontage (both sides of Broken Creek down to Rices Bridge, only east side between Rices Bridge to Murray River) within EWP project area

4.1.3 History and impact of river regulation

Prior to the development of irrigation infrastructure, Broken Creek was an ephemeral system with flows dominantly occurring in winter and early spring. The current irrigation infrastructure and management has transformed the system to a largely perennial system with dominant summer flows and permanent weir pools (GHD / URS 2005). Irrigation within the project area occurs by pumping from the Broken Creek and Nine Mile Creek waterways. Annual diversion entitlement volumes for the Broken Creek system are summarised in Table 4-1. The diversion entitlements are dominantly located in the Lower Broken Creek system (EWP reaches 3 and 4 as discussed in Section 4.2).

Table 4-1 Broken Creek system – Diversion entitlements (GHD / URS 2005 after SKM 1998)

Waterway	Total diversion entitlement (ML/yr)	Supply source
Boosey Creek	359	–
Upper Broken Creek (above Katandra)	7044	Caseys Weir
Lower Broken Creek (Katandra Weir to Walshs Bridge[(1)])	4811	East Goulburn Main Channel (EGMC)
Lower Broken Creek (Walshs Bridge[(1)] to Rices Weir)	14342	
Nine Mile Creek	7245	

1. Walshs Bridge is located approximately 3 km downstream of the confluence of Broken Creek and Nine Mile Creek.

Irrigation development has occurred in stages, with the most significant impacts of regulation occurring since the 1960s when delivery of significant quantities of water via the EGMC from Goulburn Weir commenced. The principal stages of development, as documented in SKM (1996) (cited in GHD / URS 2005) included:

- Broken Creek used to supply stock and domestic water since the earliest days of settlement.
- Low timber weirs constructed in the lower Broken Creek in the late 1800s to improve the reliability of supply.
- East Goulburn Main Channel (EGMC) from Goulburn Weir constructed in 1911.
- EGMC extended to Nine Mile Creek at Katandra Weir (near the Broken Creek confluence), assuming its current form in 1929.
- Relatively small scale diversions of water from Broken Creek continued until the 1940s when the first channel outfalls were constructed.
- Yarrawonga Weir on the Murray River constructed in 1939, enabling the development of the Murray Valley irrigation area and associated drainage outfalls to the north of Broken Creek (SKM 1998).
- Weirs on the Broken Creek system were upgraded and parts of Nine Mile Creek and Broken Creek were regraded (re-aligned?) in the 1960s to facilitate drainage outfalls for irrigation development.
- Delivery of significant volumes of water via the EGMC commenced in the 1960s.
- Significant upgrading and automation of weirs and installation of fishways occurred between 1997 and 2003.

Broken Creek has thus been subject to a regulated flow regime for over 100 years, with peak irrigation development having occurred in the last 50 years. The in-channel ecosystems and communities present within the Broken Creek system within the EWP project area are thus significantly modified from those occurring under pre-regulation conditions.

4.2 Proposed EWP reaches

The project area for the current EWP covers the reaches of the Broken Creek system where the hydrologic regime is likely to be impacted by the modifications to the channel and drainage network proposed under the GMW Connections Project. The current EWP thus relates to a short reach of Boosey Creek downstream of the 7/3 Channel Outfall in Katamatite to its confluence with Broken Creek, Broken Creek downstream of its confluence with Boosey Creek and the length of Nine Mile Creek downstream of the EGMC Weir at Katandra.

Reach breaks for the EWP have been identified based on consideration of the hydrologic regime (determined by the location of tributaries, channel outfalls and drain outfalls), system operation and channel morphology. Four reaches are proposed:

- Reach 1 – 42.6 km
    - Boosey Creek downstream of the 7/3 Channel Outfall through to the confluence with Broken Creek (4.1 km).
    - Broken Creek from the confluence with Boosey Creek to the confluence with Nine Mile Creek west of Numurkah (38.5 km).
- Reach 2 – 49.8 km
    - Nine Mile Creek downstream from the EGMC Weir at Katandra (the offtake from Broken Creek) to the confluence with Broken Creek west of Numurkah.
- Reach 3 – 37.9 km
    - Broken Creek downstream of the confluence with Nine Mile Creek to the Nathalia town weir.
- Reach 4 – 65.8 km
    - Broken Creek downstream of the Nathalia town weir through to the confluence with the Murray River.

Reach extents are indicated in Figure 4-2. More detailed aerial imagery for each reach is provided in Figure 4-3 to Figure 4-6 while detailed project reach maps are provided in Appendix A.

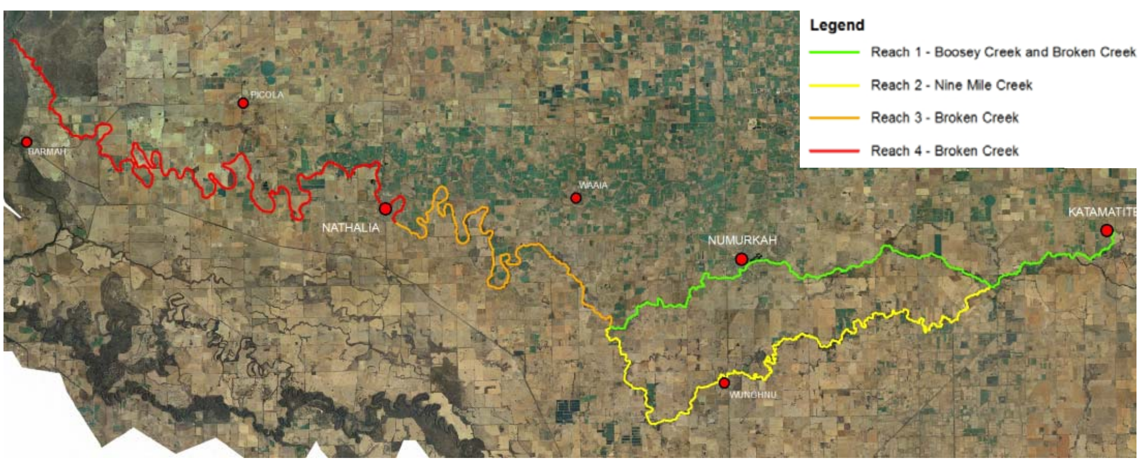

Figure 4-2 EWP project area and project reaches

4.2.1 Reach 1 – General description

Reach 1 comprises a short length (4.1 km) of Boosey Creek between Katamatite and Broken Creek and a 38.5 km reach of Broken Creek between Boosey Creek and the confluence of Broken Creek and Nine Mile Creek (refer Figure 4-3). The majority of the riparian land adjoining the streams in Reach 1 lies within the Broken-Boosey State Park (Boosey Creek) and the Numurkah Natural Features Reserve (Broken Creek) and is managed by Parks Victoria (refer Section 4.1.2).

Significant features within Reach 1 include:

- Discharge from the 7/3 channel outfall at Katamatite, defining the upstream end of Reach 1.
- The township of Katamatite located generally on the north-west bank of Boosey Creek.
- The offtake of Nine Mile Creek. The EGMC enters Nine Mile Creek a short distance downstream of Broken Creek. The flow distribution between Nine Mile Creek and Broken Creek is managed by a weir on each stream immediately downstream of the Nine Mile Creek offtake.
- The township of Numurkah located on both banks of Broken Creek near the downstream end of the reach.
- Two weirs (Station Street and Melville Street) located on Broken Creek within Numurkah
- Kinnairds Swamp located on the north bank of Broken Creek immediately upstream of Numurkah. Kinnairds Swamp is a part-public and part-privately owned wetland complex at the confluence of the Muckatah Depression and Broken Creek. Along with a suite of environmental attributes, Kinnairds Swamp also serves as a retardation basin and water quality improvement system for the Muckatah Surface Water Management Scheme (DPI 2003).

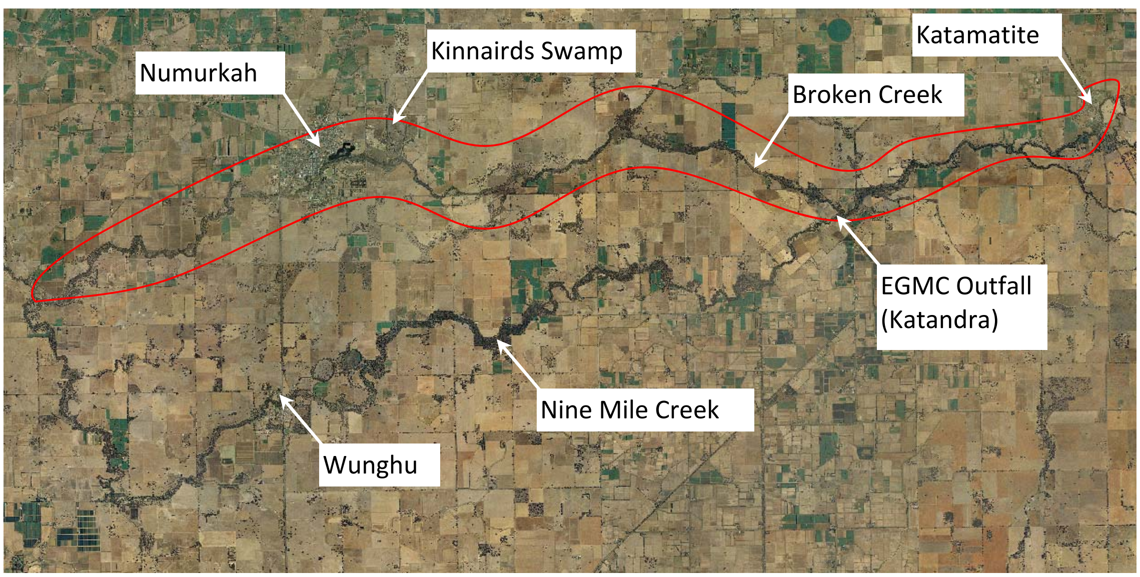

Figure 4-3 Reach 1 extent and aerial image

4.2.2 Reach 2 – General description

Reach 2 comprises a 49.8 km length of Nine Mile Creek between the EGMC Weir and the downstream confluence of Nine Mile Creek and Broken Creek (refer Figure 4-4). Nine Mile Creek in Reach 2 forms a regulated anabranch of Broken Creek, with a 70:30 flow distribution between Nine Mile Creek and Broken Creek. The EGMC weir is used to regulate the distribution of flows delivered to the system via the EGMC.

The entire length of Nine Mile Creek in Reach 2 upstream of Wunghu lies within the Broken-Boosey State Park managed by Parks Victoria (refer Section 4.1.2). Frontage over the remainder of the stream (between Wunghu and the confluence with Broken Creek) lies within public land water frontage.

Significant features within Reach 2 include:

- The outfall from the EGMC and the associated EGMC Weir on Nine Mile Creek immediately downstream of the offtake from Broken Creek.
- The township of Wunghu, located generally on the south bank of Nine Mile Creek.
- The Black Swamp and Purdies Swamp system lying to the north of Broken Creek immediately upstream of Wunghu.
- The confluence with Pine Lodge Creek near the downstream end of Reach 2. The lower reaches of Pine Lodge Creek are modified and form the outfall of Shepparton Irrigation District Drain 11.

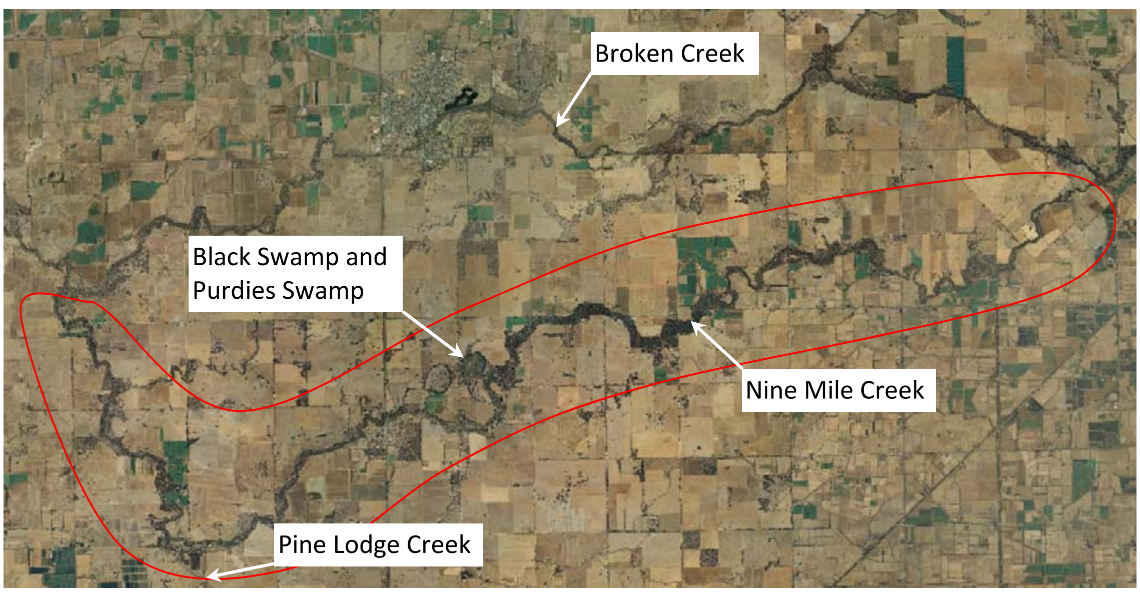

Figure 4-4 Reach 2 extent and aerial image

4.2.3 Reach 3 – General description

Reach 3 comprises a 37.8 km length of Broken Creek between the Nine Mile Creek confluence and Nathalia Weir (refer Figure 4-5). Apart from the Nathalia Weir defining the downstream end of the reach there are no other weirs on Broken Creek within this reach. The morphology of the stream changes mid-reach (approximately in the middle of Figure 4-5) where Broken Creek enters the Tallygaroopna Channel (a relic feature of the Goulburn River) and adopts significantly different meander geometry.

The stream frontage over the majority of this reach lies within the Numurkah Natural Features Reserve managed by Parks Victoria (refer Section 4.1.2). The remaining length (extending for approximately 11 km upstream of Nathalia) lies within public land water frontage.

Carlands Swamp is located to the south of Broken Creek approximately mid-reach.

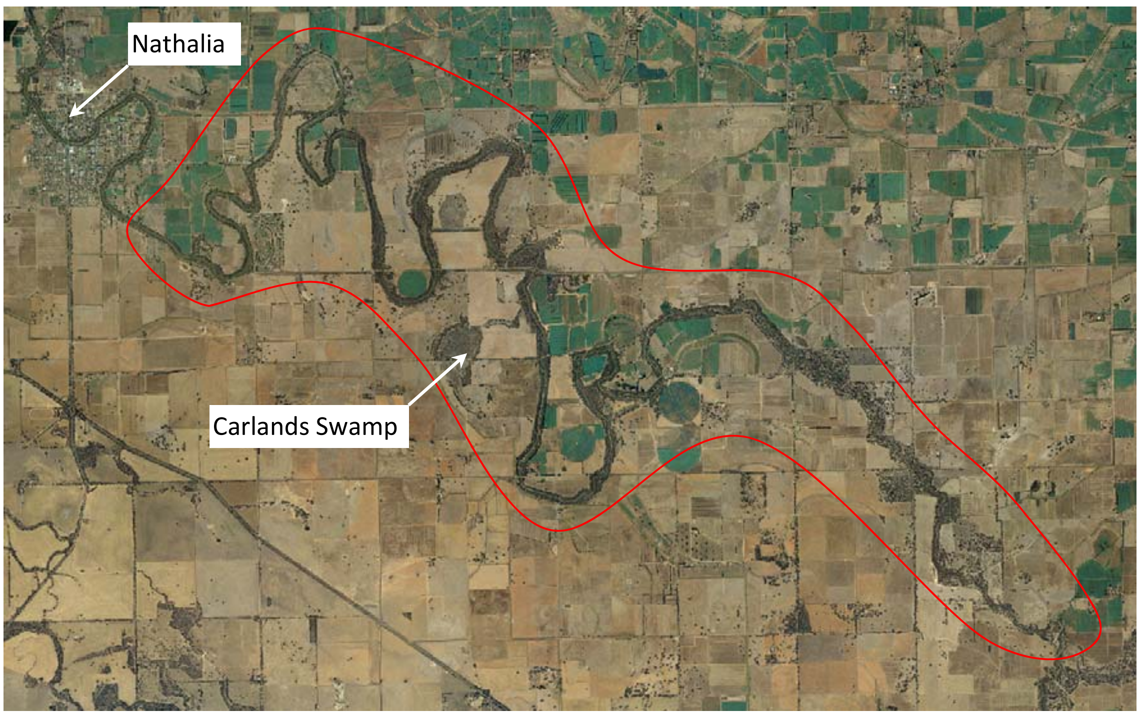

Figure 4-5 Reach 3 extent and aerial image

Reach 3 crosses the boundary between the Victorian Riverina bioregion and Murray Fans bioregion.

4.2.4 Reach 4 – General description

Reach 4 comprises a 65.8 km length of Broken Creek downstream of Nathalia Weir. Broken Creek within this reach occupies the ancestral Tallygaroopna Channel (refer Section 6.2) resulting in a larger meander wavelength and amplitude than that in upstream reaches. The character of this reach is however largely determined by the regulated flow regime and the presence of eight low weirs managed to provide a near-constant water level over the entire length of the stream, facilitating the extraction of irrigation water by pumping. The distance and drop in pool level between adjacent weirs is summarised in Table 4-2. The location of each weir is shown in the reach map in Appendix A.

Rices Weir is the most downstream weir on Broken Creek and is located approximately 1 km upstream of the confluence of the Murray River and Broken Creek within the Barmah National Park.

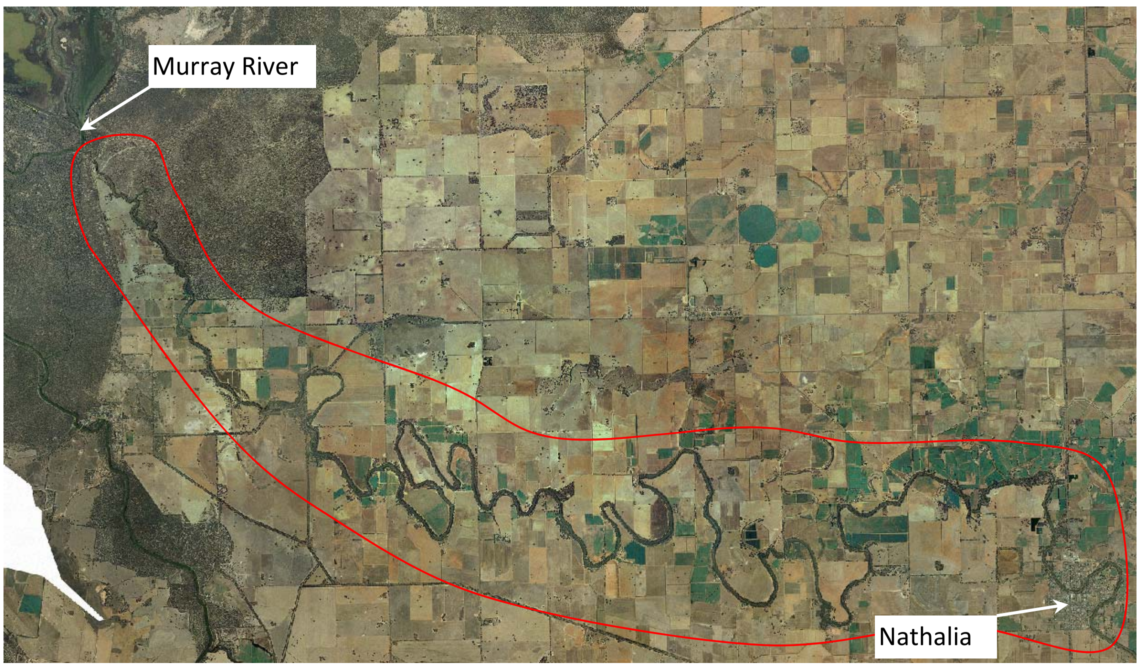

Figure 4-6 Reach 4 extent and aerial image

Table 4-2 Reach 4 weir details

Upstream weir	Downstream weir	Distance [1] (km)	Drop in pool level [2] (m)
Nathalia (Town)	Chinamans	4.8	0.69
Chinamans	Balls	6.1	0.95
Balls	Lukes	8.9	0.92
Lukes	Hardings	13.7	1.05
Hardings	Schiers	9.6	0.38
Schiers	Kennedys	8.9	0.66
Kennedys	Rices	12.8	1.1
Rices	Murray River	1.0	

Notes:
1. Stream length based on supplied GIS information
2. At maximum operating level, based on SKM (2003)

4.3 Previous relevant studies

The Broken-Boosey Creek system is highly modified from its natural condition, largely as a result of the altered flow regime brought about through regulation and use of the system to convey irrigation flows. Values and studies of particular relevance to the EWP process are briefly discussed in the following sections.

4.3.1 The Goulburn Broken Regional River Health Strategy

The Goulburn Broken Regional River Health Strategy 2005-2015 (GBCMA 2005) provides the strategic framework for the protection and enhancement of river health and water quality within the Goulburn Broken catchment, including water-related values, and aims to achieve four main objectives for the rivers and streams of the Goulburn Broken catchment:

- "Enhance and protect the rivers that are of highest community value (environmental, social and economic) from any decline in condition;
- Maintaining the condition of ecologically healthy rivers;
- Achieving an 'overall improvement' in the environmental condition of the remainder of rivers;
- Preventing damage from inappropriate development and activities." (GBCMA 2005)

The majority of the project area for development of the current EWP lies within Management Unit L2 (Lower Broken Creek) as identified in the Regional River Health Strategy (GBCMA 2005) and shown in Figure 4-7. The lower section of Boosey Creek and the short reach of Broken Creek upstream of Katandra Weir lie within Management Unit M6 (Upper Broken and Boosey Creeks). The Regional River Health Strategy adopts the reach breaks defined by the statewide Index of Stream Condition (ISC) program as shown in Figure 4-8. While the ISC reach breaks do not correspond exactly with the reach breaks proposed for the EWP process, the ISC reaches associated with each EWP reach are summarised in Table 4-3.

Table 4-3 Reach summary

	EWP Reach 1	EWP Reach 2	EWP Reach 3	EWP Reach 4
RRHS Management Unit	M6 (Broken Creek and Boosey Creek) L2 (Broken Creek D/S of Katandra Weir)	L2 (Nine Mile Creek D/S of Katandra Weir)	L2 (Broken Creek D/S of Katandra Weir)	L2 (Broken Creek D/S of Katandra Weir)
ISC Reaches	32 (Boosey Creek) 24 (Broken Creek)	28 (Nine Mile Creek)	23 (Broken Creek)	21 (Broken Creek) 22 (Broken Creek)

GBCMA (2005) identifies the following reaches of Broken Creek within the current project area as High Priority reaches within the Goulburn Broken catchment, based on their value to the community, namely:

- Association with significant wetlands:
    - Broken Creek – Reach 21 (part of EWP Reach 4) – associated with the Ramsar listed Barmah-Millewa Forest wetland
    - Broken Creek – Reaches 22-26 (EWP Reaches 1, 3 and 4) – associated with various wetlands (Broken Creek, Muckatah Depression) listed in the Directory of Important Wetlands in Australia (refer Section 4.3.3). The wetland listing

extends from 8 km NNW of Benalla to the Barmah Forest, covering an area of 2500 ha.

- Presence of fauna listed under the Federal Environment Protection and Biodiversity Act, 1999 (EPBC) and Australian Rare or Threatened (AROT) flora critically dependent on stream environments
  - Broken Creek – Reaches 21, 22 and 23 (EWP Reaches 3 and 4) – presence of Murray cod (Murray cod are also known to be present in the Katandra Weir pool (upstream end of Reach 24 (O'Connor 2008)

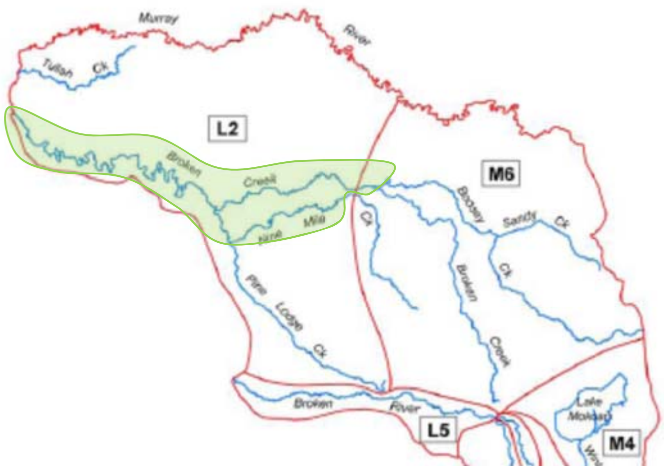

Figure 4-7 Regional River Health Strategy (GBCMA 2005) – Broken Basin Management Units (EWP project area highlighted)

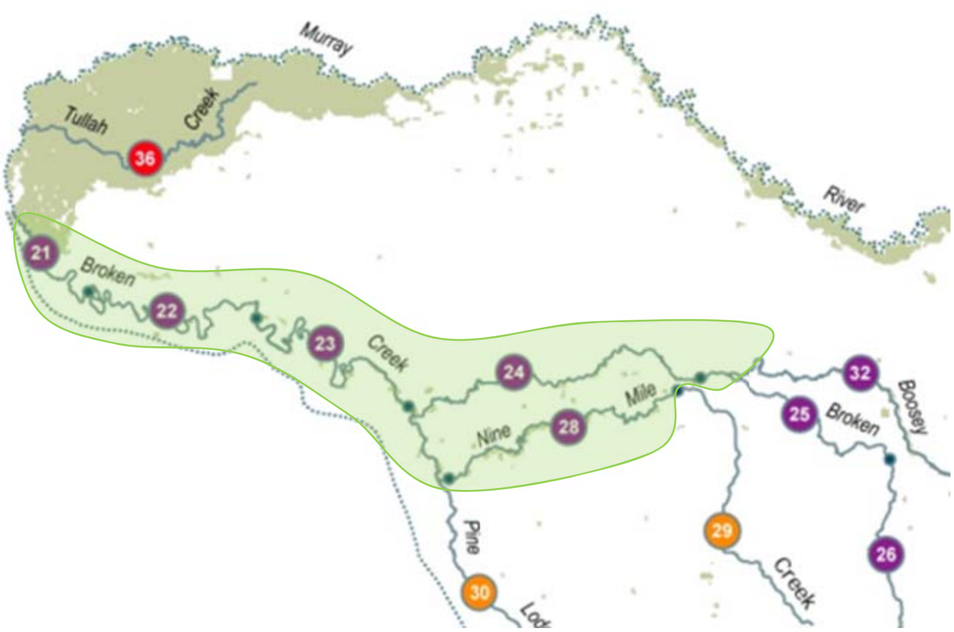

Figure 4-8 ISC Reach location map (EWP project area highlighted)

4.3.2 Box dominated grassy woodland

Approximately 61% of the Broken-Boosey Creek system within the area of the current EWP lies within public land managed by Parks Victoria (Broken-Boosey State Park, Numurkah Natural Features Reserve and Nathalia Natural Features Reserve). This park and reserve system was proclaimed in October 2002 based on recommendations of the Environment Conservation Council (ECC) Box Ironbark Forests and Woodlands Investigation (Parks Victoria 2006). Much of the land now forming the park and reserve system was formerly held in various public land reserves (i.e. Bushland, Town and Streamside Reserves) and public land water frontage (Parks Victoria 2006). The Broken-Boosey State Park is "managed primarily for conservation of specific natural features" (under IUCN Category III) while the natural features reserves are "managed primarily for the sustainable use of natural ecosystems" (under IUCN Category VI) (Parks Victoria 2006).

The Broken-Boosey State Park and associated Natural Features Reserves protect stands of remnant Box-dominated grassy woodland and includes important habitat for many rare and threatened flora and fauna species. Noted natural values identified in Parks Victoria (2006) include:

- The largest remaining example of grassy woodland on the eastern Northern Plains.
- One of the few surviving patches of remnant vegetation in the Northern Plains landscape (Robinson & Mann 1996).
- Approximately 30% of Victoria's endangered Plains Grassy Woodland / Gilgai Plains Woodland / Wetland Mosaic Ecological Vegetation Classes.
- Ecologically distinctive riparian Grey Box vegetation compared to most other Victorian rivers and creeks (Robinson & Mann 1996).
- The only known site for the endangered Amulla (*Eremophila debilis*) and one of only two known sites in Victoria for the endangered Spiny-fruit Saltbush (*Atriplex spinibractea*).
- Broken Creek – Provides habitat for Murray Cod (*Maccullochella peelii peelii*) and Freshwater Catfish (*Tandanus tandanus*) (Robinson & Mann 1996).
- Habitat for a significant number of woodland-dependent bird species associated with the Victorian temperate-woodland bird community listed under the Flora and Fauna Guarantee Act 1988 (Vic.), including the Bush Stone-curlew (*Burhinus grallarius*), Brown Treecreeper (*Climacteris picumnus*)and Black-chinned Honeyeater (*Melithripterus gularis*).
- Habitat for threatened fauna including the Growling Grass Frog (*Litoria raniformis*), Swift Parrot (*Lathamus discolor*) and Tree Goanna (*Varanus varius*), and supplementary feeding ground for the threatened Brolga (*Grus rubicund*).

Importantly the park and reserve system forms a linear corridor extending approximately 140 km across agricultural land (Parks Victoria 2006).

These box dominated grassy woodlands provide an important ecological buffer to the creek system, however the woodlands are mostly unaffected by any in-channel flow manipulation that may be specified in this EWP.

4.3.3 Wetland systems

Broken Creek between Caseys Weir and Barmah Forest is listed In the Directory of Important Wetlands in Australia (Environment Australia 2001). The criteria for listing of Broken Creek are:

- Criterion 1 – It is a good example of a wetland type occurring within a biogeographic region in Australia.
- Criterion 2 – It is a wetland which plays an important ecological or hydrological role in the natural functioning of a major wetland system/complex.
- Criterion 3 – It is a wetland which is important as the habitat for animal taxa at a vulnerable stage in their life cycles, or provides a refuge when adverse conditions such as drought prevail.

The spatial coverage of the listing is shown in Figure 4-9. The listing does not cover Nine Mile Creek or some of the main floodplain wetlands within the EWP project area (Black Swamp, Purdies Swamp, Kinnairds Swamp discussed in Section 6.4.2).

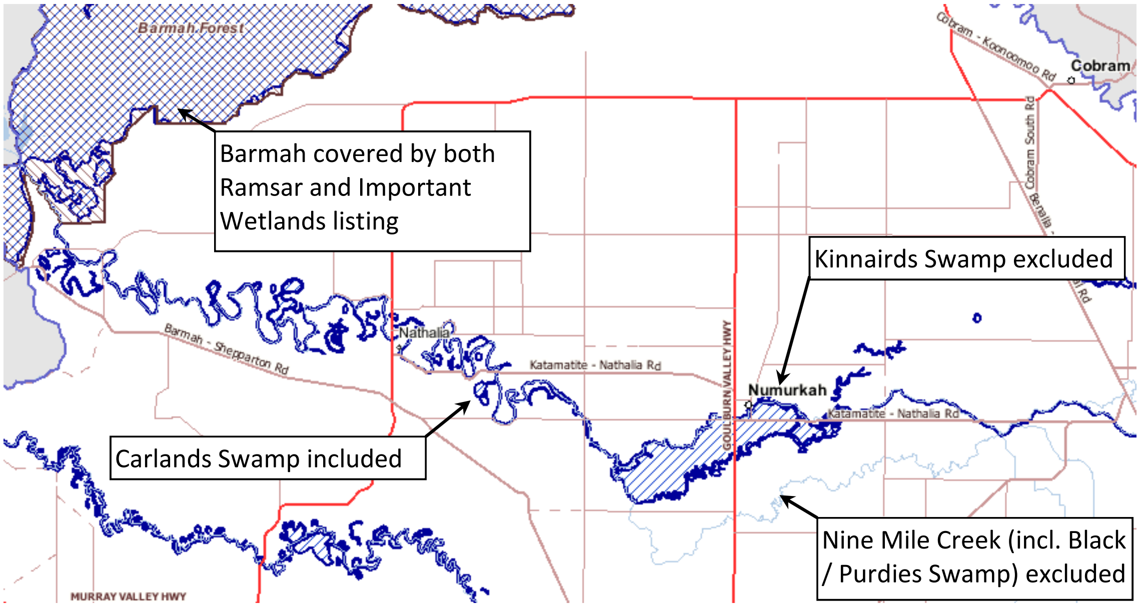

Figure 4-9 Spatial coverage of Broken Creek Directory of Important Wetlands listing (from DSE 2010)

Barmah Forest, located around the Murray River at the downstream end of the EWP project area, is a Ramsar listed wetland. The Ramsar listing includes the Barmah National Park which cover the northern bank of Broken Creek over at the downstream end of EWP Reach 4 however the hydrologic regime of the Barmah Forest system is dominated by flows in the Murray River, not Broken Creek.

4.4 2010 - 2015 Update – Relevant studies

A number of relevant documents and studies have been produced since the 2010 report was released. The following sections provide a summary of relevant information

4.4.1 The Third Benchmark of Victorian River Condition, ISC3

The Index of Stream Condition (ISC) provides information on five key aspects of river condition: Hydrology, Streamside Zone, Physical Form, Water Quality and Aquatic Life. The ISC benchmarking process remains the only ongoing statewide assessment of river condition in Australia. The first benchmark was undertaken in 1999, the second in 2004 and most recent in 2010 (i.e. after the original EWP was released). Of the reaches completely contained within the EWP area, most retained the same condition rating of Moderate compared with the 2004 results, while Reach 22 showed a decline in condition from Moderate to Poor. However, due to the modifications to the ISC approach between 2004 and 2010, it is conceivable that no substantial decline in condition has actually occurred over that 6 year period.

4.4.2 Analysis of fish assemblage data from the Goulburn-Broken Catchment (2008-2014), (McCasker et al. 2015)

The Victorian Environmental Flows Monitoring and Assessment Program (VEFMAP) was established in 2005 to provide a scientifically defensible approach to monitor the ecological responses of environmental water releases across the state of Victoria (Cottingham et al. 2005). The VEFMAP includes a fish monitoring component and separate assessments relating to riparian and in-channel vegetation, hydrology, physical habitat and macro-invertebrates (McCasker et al. 2015). There are a total of eight fish monitoring sites on the Broken Creek, six of which are within the EWP area.

Results:

Abundance: A total of 4041 fish were collected from the Broken Creek. Carp gudgeon sp. (n=1517) and common carp (n=617) were the most abundant, and trout cod and bony herring were absent. A total of nine native and alien species were collected. Notable increases in the percent composition of common carp occurred in 2011-12 and 2012-13, at which times, this species comprised nearly half of all fish collected.

Biomass: Common carp made up between 40% (2010-11) and 90% (2012-13) of the weight of all fish collected. In 2010-11, the contribution of Murray cod was similar to that of common carp.

Species presence/absence (six annual surveys 2009-2014):
Small-bodied native species – Australian smelt, Carp gudgeon complex and Flathead gudgeon were present in each of the six years surveyed, Murray River rainbowfish was present in 2014 and Unspeckled hardyhead was present in 2010 and 2014 only.
Large-bodied native species – Murray cod and Golden perch were present in each of the six years surveyed, while River blackfish, which is consistently found further upstream, was identified in 2011 only.
Alien species – Carp, Goldfish and Oriental weatherloach were present in each of the six years surveyed, while Gambusia and Redfin perch were both identified in four of the six years.

Summary:

The analysis indicated no evidence of consistent changes in abundance or number of native fish species collected in any of the rivers or reaches between 2008-09 to 2013-14. Equally, no new alien species were collected in the catchment, but some pre-existing alien species appeared to increase in abundance. Overall there was little change in the fish fauna throughout the study period, with the exception of the abundance of common carp (McCasker et al. 2015).

4.4.3 Commonwealth Environmental Water Office Short-term Intervention Monitoring Program (Webb et al. 2014)

The Commonwealth Environmental Water Office short-term intervention monitoring program for the lower Goulburn River and Broken Creek in 2013/14 was able to detect beneficial effects of environmental watering for all monitoring activities undertaken.

Golden perch and Murray cod in Broken Creek showed different levels of activity with changing dissolved oxygen levels and undertook movements correlated with higher flows in this system. Movement is a hypothesized positive short-term response to environmental flows as part of connectivity (Level 2 objective) within ecosystem function (Level 1 objective). Murray cod reduced their level of physical activity in response to low dissolved oxygen, while golden perch showed the opposite response, increasing levels of activity. A lack of mortality of tagged fish demonstrates that both species can readily cope with the short-term low levels of dissolved oxygen that occurred during this monitoring period. Both species showed increased movement through the lower Broken Creek system in response to higher flows, mirroring the movement results observed for adult golden perch in the Goulburn River. Discharge patterns in Broken Creek are quite stable at present. If fish movement is an objective for environmental managers, then they may need to deliver more variable flows in Broken Creek (Webb et al. 2014).

5. MANAGEMENT OBJECTIVES

Broad management objectives for the subject reaches of Boosey Creek, Broken Creek and Nine Mile Creek have been established in existing strategies and documents including:

- The Scientific Panel report on the environmental condition and flow in the Broken River and Broken Creek (Cottingham *et al.* 2001).
- The Regional River Health Strategy (GBCMA 2005).
- The Lower Broken Creek Waterway Management Strategy (GHD / URS 2005).
- Broken Boosey and Nine Mile Creeks Wetland Implementation Plan (Hale *et al.* 2006).
- Interim environmental flow objectives for Lower Broken Creek and Nine Mile Creek (GBCMA 2008).
- The Northern Region Sustainable Water Strategy (DSE 2009).

The range of objectives and their relevance to the current project are briefly discussed in the following sections.

Site or asset specific objectives are documented in other management plans including:

- Black Swamp (SKM 2007);
- Kinnairds Swamp (DPI 2003);
- Broken-Boosey State Park and Nathalia, Numurkah, Tungamah and Youarang Natural Features Reserves (Parks Victoria 2006).

5.1 Scientific Panel report on the environmental condition and flow in the Broken River and Broken Creek

A Scientific Panel was appointed by the Broken Basin Bulk Entitlement Project Group in 2001 to "consider environmental issues and to provide independent advice on the opportunities that exist through the Bulk Entitlement Conversion Process to better protect and enhance existing environmental values associated with the regulated waterways in the Broken River Basin". The investigation and recommendations from the Scientific Panel are documented in Cottingham *et al.* (2001). The Scientific Panel's deliberations included four reaches on the Broken River and a single reach on Broken Creek from Katamatite to the Murray River (encompassing EWP reaches 1, 3 and 4).

The study method did not specifically result in the establishment of objectives for management of the Broken Creek reach however the overall objective for the Bulk Entitlement conversion process was identified as "to ensure that current environmental values are to be protected and, where possible, enhanced." The Scientific Panel identified the significant environmental values in the subject reaches and, making use of the Flow Events Method (FEM) (Stewardson 2001), developed a recommended flow regime to protect and enhance the identified values in the Broken River reaches.

The Scientific Panel report did not include specific environmental objectives or flow regime recommendations for the Broken Creek reach, but provided management recommendations to improve environmental conditions. Despite the absence of detailed environmental objectives for Broken Creek, the discussion and justification of recommended flow regimes for the other reaches provides some useful information for the current EWP process.

5.2 Regional River Health Strategy

The four broad objectives of the Regional River Health Strategy (GBCMA 2005) for management of the rivers and streams of the Goulburn Broken catchment are presented in Section 4.3.1. In relation to the Broken River (including Broken Creek), the following specific river reach objective is identified:

> "to allocate water resources in a way that balances the needs of the environment with those of water users and to improve the ecological health of Broken River, and associated wetlands and floodplains."

Within the EWP project area, the entire length of Broken Creek is identified as a High Priority Reach (refer Section 4.3.1). This designation applies to EWP Reach 1 (excluding Boosey Creek), Reach 3 and Reach 4. The majority of the EWP project area (excluding Nine Mile Creek) thus lies within identified High Priority Reaches, with management and works to be implemented under RRHS Program A – Protection and enhancement of high priority reaches.

5.3 The Lower Broken Creek Waterway Management Strategy

The Lower Broken Creek Waterway Management Strategy (GHD / URS 2005) covers the full extent of the current EWP project excluding Boosey Creek (part of EWP Reach 1). The Waterway Management Strategy adopts the asset-based approach to natural resource management applied in development of the Regional River Health Strategy (GBCMA 2005). The following vision for the subject reach of Broken Creek was developed though consultation with the project Community Reference Group:

> "A healthy system that provides water for human and agricultural use, protects and enhances our social, economic and cultural values, and sustains a vibrant range and abundance of native flora and fauna." (GHD / URS 2005)

The following management objectives were identified:

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

GHD / URS (2005) recognises the potential for conflict between objectives and seeks to find a balance between sustainable use and environmental outcomes.

5.4 Broken Boosey and Nine Mile Creeks Wetland Implementation Plan

The Broken Boosey and Nine Mile Creeks Wetland Implementation Plan (Hale *et al.* 2006) covers the entire EWP project area and identifies the ecological values of the wetland systems, including the waterway channels and discrete floodplain wetlands. The following management goals for the Wetland Implementation Plan were developed with reference to the Regional Catchment Strategy (GBCMA 2003) and the 2004 draft of the Regional River Health Strategy GBCMA (2005):

- Maintain or improve the condition of wetlands of the highest ecological value;
- Maintain or improve the condition of ecologically healthy wetlands;
- Achieve "overall improvement" in the ecological condition of remaining wetlands
- Protect a diverse range of wetland habitats; and
- Prevent damage from future management activities.

Hale *et al.* (2006) recommended that "all remaining wetlands within the Planning Area should be considered of high conservation value and given the small amount of native vegetation remaining in this area, all remnant vegetation patches should be considered ecologically significant."

5.5 Interim Environmental Flow Recommendations

5.5.1 Background

Interim environmental flow recommendations were developed by Goulburn Broken Catchment Management Authority (Goulburn Broken CMA) at the request of the Department of Sustainability and Environment to inform the development of the Northern Region Sustainable Water Strategy. The interim recommendations and the process followed in their development are documented in GBCMA (2008). The interim recommendations were developed using an approach consistent with the FLOWS methodology (NRE 2002) but excluded field assessments and hydraulic modelling, relying instead on existing knowledge held by the project team.

5.5.2 Reaches

Three reaches were used in development of the interim environmental flow recommendations:

- Reach 1 – Broken Creek downstream of the Boosey Creek confluence to the Nine Mile Creek confluence (Equivalent to EWP Reach 1 however EWP Reach 1 also includes a short length of Boosey Creek between the 7/3 channel outfall and Broken Creek).
- Reach 2 – Nine Mile Creek and Broken Creek between the Nine Mile Creek confluence and the upstream end of the Nathalia Weir pool (covers EWP Reaches 2 and 3).
- Reach 3 – Broken Creek from the Nathalia Weir pool to the Murray River (equivalent to EWP Reach 4).

5.5.3 Assets, threats and objectives

Riparian environmental assets and threats within the project area were identified as geomorphology, native fish, riparian vegetation, in-channel vegetation, wetlands, aquatic macroinvertebrates and water quality. Of these, only on-stream wetlands, native fish and water quality were identified as subject to influence by the regulated flow regime of Broken and Nine Mile Creeks. The following objectives were identified:

- Native Fish (F1) – Improve native fish habitat and passage
    - Ensure persistence of aquatic habitats during migration and breeding seasons particularly for Murray Cod.
    - Supply sufficient flow to operate the fishways and provide fish access to appropriate habitat all year.
- Wetlands (W1) – Restore a more natural flood regime to Black and Purdies Swamp
- Low Dissolved Oxygen (DO1) – Maintain dissolved oxygen concentrations above 5 mg/L (based on ANZECC guidelines to maintain suitable conditions for oxygen dependent species
    - Dissolved oxygen levels maintained above 5 mg/L.
- Algal and azolla blooms (AB1) – Minimise the growth of azolla and algae
    - Reduced azolla and algal blooms and dissolved oxygen levels maintained above 5 mg/L.

Native fish habitat and native fish passage objectives (F1) were applied to all reaches while low dissolved oxygen (DO1) and algal and azolla bloom (AB1) objectives were applied only to Reach 3. The wetland objective (W1) applied only to Reach 2 but was phrased in terms of an annual or biannual inundation rather than a daily flow recommendation.

5.6 Northern Region Sustainable Water Strategy

The Northern Region Sustainable Water Strategy (DSE 2009) examines water availability and allocations for consumptive use and the environment in northern Victoria, including the Broken River basin. The strategy considers the impacts of drought and climate change and identifies short and medium term actions to secure water supplies for the region over the next 50 years. The strategy discusses targeted recovery and efficient use of environmental water to sustain and protect high value rivers, wetlands and floodplains. Priorities for environmental water recovery have been proposed for river and wetland systems within the Northern region using a system of six categories of expected environmental outcome. Environmental health is expected to progressively improve from Category one, representing a survival regime through to Category six where the majority of natural connections between the river and its floodplain wetlands are retained and full scientific environmental flow recommendations are met (DSE 2009). In this context, the following water recovery targets have been set for Broken Creek:

- Category 4 (or higher) under base case (current conditions) climate scenario
- Category 2 (or higher) under climate change Scenario D (continuation of low inflows as for July 1997 – June 2007)

The associated environmental outcomes and flow components for these categories are summarised in Table 5-1

Table 5-1 Categories guiding investment in water recovery and works (after DSE 2009)

Category	Environmental outcome	Flow component
2	Protection of drought refuge plus dry spell breaking	Summer minimums throughout the year and every third year deliver winter minimums and freshes
4	Sustainable population of all in-stream species	All summer and winter minimums and freshes at recommended frequency and bankfull flows at recommended frequency

Application of the water recovery categories from DSE (2009) for Broken Creek in the context of the EWP process suggests that adoption of “protect and enhance” objectives for all identified in-stream species is appropriate.

5.7 Relevance of existing objectives to the EWP process

The existing literature does not provide a strong or consistent base for identifying appropriate flow related environmental objectives for the Broken-Boosey system in the current EWP process. The objectives are generally phrased around maintaining or enhancing existing environmental assets but do not identify specific species or asset classes. GBCMA (2008) and DSE (2009) provide the most relevant objectives in relation to actions required to sustain assets with identified flow dependence. More specific objectives for management of key environmental assets have been developed during the preparation of this EWP. These objectives are shown in Table 8-1.

6. ENVIRONMENTAL VALUES AND CONDITION

6.1 Introduction

The current condition of Broken Creek and Nine Mile Creek within the project area is described in the following sections based on information from available literature and inputs from the Scientific Reference Group. Where relevant, conditions within each of the EWP reaches (refer Section 4.2) are discussed separately to assist in identification of the stream values, assets and threats within each reach.

This discussion of current condition and assets is focussed on water dependent in-stream and riparian assets influenced by the regulated flow regime as these assets are most likely to experience impacts as a result of implementation of modified irrigation drainage and outfalls. Broader floodplain assets which are impacted by flood events are discussed only briefly. The main assets thus considered in this review are:

- Geomorphology;
- Riparian and in-channel vegetation;
- Wetlands;
- Fish;
- Threatened flora and fauna found in the immediate riparian zone;
- Macroinvertebrates.

Many of these assets are potentially directly impacted by a change in flow regime. The impact of a flow regime modification resulting from implementation of the GMW Connections Project on these assets is discussed in Section 8. Other indirect threats to the condition of identified environmental values, as impacted by the flow regime within the creek system, are discussed in Section 6.8 and include:

- Poor water quality – high turbidity, high nutrient, low dissolved oxygen.
- Altered geomorphic processes – i.e. increased sedimentation in weir pools and channel reaches.
- Aquatic weeds – particularly those favoured by permanent water and low flow velocity conditions.

Changes in surface water / groundwater interaction as a result of the GMW Connections Project have potential impacts on the identified environmental assets. The impacts of the GMW Connections Project on regional groundwater, with resultant local impact on waterways are documented in other studies (i.e. SKM 2008) prepared in support of the GMW Connections Project approvals process and are not specifically considered in this EWP.

6.2 Geomorphology

6.2.1 Introduction

Cottingham *et al.* (2001) and GBCMA (2005) indicate that there has been no formal study of the geomorphic character of the Broken Creek system. GHD / URS (2005) provides a brief discussion of the overall planform, while SKM (1998) briefly describes the channel morphology and its association with the natural and modified hydrology. Cottingham *et al.* (2001) indicates that flow regulation is likely to have had little impact on river geomorphology as regulation has not significantly altered the occurrence of larger flow events in the system however this assessment is likely to relate principally to the large scale geomorphic character of the system. For the purposes of the current EWP project, channel morphology is considered to have been significantly impacted by regulation, both due to the modification of the low flow components of the flow regime and through the construction of in-channel weirs, floodplain levees, channel re-alignments and removal of in-stream habitat (snags).

6.2.2 Reach scale morphology

SKM (1996) cited in GHD / URS (2005) identifies two distinct geomorphic zones along Broken Creek within the project area. Upstream of Waaia (EWP Reaches 1 and 2 and upstream portion of EWP Reach 3), the channel is sinuous with a small meander amplitude and wavelength. Downstream of Waaia, Broken Creek occupies the channel of an ancestral river, the Tallygaroopna Channel, with a much larger meander wavelength and wider meander belt than the current Murray and Goulburn Rivers (Bowler 1978 and SKM 1998). The planform of Broken Creek downstream of Waaia (i.e. the downstream end of EWP Reach 3 and all of Reach 4) is therefore largely determined by the character of this ancestral channel (GHD / URS 2005). Adopting the terminology of Rosengren (1987), the Tallygaroopna Channel would be identified as a site of State geological and geomorphological significance on the basis that it includes “features which are important in the context of developing an understanding of the geological and geomorphological development of Victoria”.

6.2.3 In channel morphology

SKM (1998) describes the natural channel morphology of the streams upstream of the current project area as typical of those found in lowland, low gradient settings, consisting of poorly incised, low capacity creek-lines or depressions, drying seasonally to waterholes in the summer months but spilling to the adjacent broad floodplain following heavy rains. Downstream of Katamatite (i.e within the EWP project area) the degree of incision increases but other characteristics are as described for the upstream reaches.

While not describing directly the streams within the project area, Reich *et al.* (2009) reviews the impacts of returning an ephemeral flow regime to the Broken and Boosey Creek systems upstream of Katamatite (following implementation of the Tungamah Pipeline). A total of ten study sites across the hydrologic regime (from unregulated to heavily regulated) were assessed to describe the current condition of the streams. None of the study sites in Reich *et al.* (2009) were located in weir pools. Geomorphic characteristics considered included channel width and bank slope, pool depth, sediment depth and degree of wiggliness (variation in bed elevation along the thalweg). Highly regulated sites were found to exhibit greater depths of unconsolidated benthic sediment and less variation in thalweg depth than found at unregulated sites. The reduction in bed variability at the regulated sites was considered likely to result from two factors:

- the delivery of high suspended sediment loads in water diverted from Lake Mokoan; and
- the lack of wetting and drying cycles at the highly regulated sites limiting sediment consolidation and breakdown of organic material, leading to greater depths of unconsolidated sediment.

A reduction in the frequency and duration of flow events exporting sediments from pools is also likely to contibute

The situation within Broken and Nine Mile Creeks within the EWP project area is likely to be similar to that documented in Reich *et al.* (2009). The presence of significant weir pools, particularly in EWP Reach 4 is likely to exacerbate the sediment accumulation.

Significant channel modification works have been undertaken historically, as outlined in GHD / URS (2005), including:

- Channelization works on 32 km of Broken Creek and Nine Mile Creek downstream of Shepparton Irrigation District Drain 12.
- Excavations and control of Cumbungi growth in Broken Creek (EWP Reach 1) to achieve a relatively constant low flow channel capacity.
- Regrading and dredging of Broken Creek (EWP Reach 3) to improve drainage outfall capacity, resulting in lowering of the bed by up to 1 m and associated removal of large woody debris.

- Re-alignment of large woody debris in the lower reaches of Broken Creek (EWP Reach 4)
- Construction of weirs, especially in EWP Reach 4.

The cumulative result of these channel modifications is a reduction in bed and channel geomorphic diversity throughout much of the EWP project area.

6.3 Riparian and in-channel vegetation

6.3.1 Ecological Vegetation Class (EVC) mapping in the riparian zone

Ecological Vegetation Class (EVC) mapping is a vegetation classification system, derived from groupings of vegetation communities based on floristic, structural and ecological functions. Mosaics (combinations of EVCs) are a mapping unit, where the individual EVCs could not be separated, at the scale of 1:100,000 (Berwick 2003, cited in DSE 2008).

Current EVC mapping (based on 2005 extents) within the EWP project area has been reviewed. EVCs identified along the waterway (based on a 20 m buffer around the mapped waterway alignment) are summarised for each reach in Table 6-1 to Table 6-4. EVC maps for each reach, highlighting the EVCs found in proximity to the EWP waterways are provided in Appendix B. The greatest variation in EVC occurrence is around and downstream of Nathalia (EWP Reach 4) where there is greater geomorphic variability associated with the Tallygaroopna Channel features.

Four dominant EVCs / EVC mosaics (indicated in bold in the tables) are noted along the waterway frontage within the EWP project area, namely:

- EVC68 – Creekline Grassy Woodland is dominant throughout all reaches
- EVC168 – Drainage Line Aggregate occurs along substantial lengths of Reaches 1 and 4
- EVC259 – Plains Grassy Woodland / Gilgai Wetland Mosaic occurs commonly on the broader floodplain but occupies substantial lengths of stream frontage in Reaches 1 and 2
- EVC803 – Plains Woodland occurs commonly on the broader floodplain but occupies substantial lengths of stream frontage in Reaches 3 and 4

EVC68 and EVC168 are likely to be directly affected by EWP watering recommendations, while EVC259 and EVC 803 are less likely to be influenced by high level in-channel flows.

The conservation significance of EVCs is assessed on a bioregional status (Table 6-5), with the conservation status reflecting the rarity or degree of depletion of each EVC within a given bioregion. Three of the four dominant EVCs/mosaics along the waterway frontage in the project area are classified as Endangered while the fourth (EVC168 – Drainage Line Aggregate) is considered Vulnerable. The occurrence of significant stands of these endangered and vulnerable EVCs along the Broken Creek system, within the broader context of a generally cleared agricultural landscape, highlights their bioregional environmental significance. GBCMA (2008) indicates that the dominant EVCs (Plains Woodland and Creekline Grassy Woodland) are not flood dependent.

The dominant overstorey species in EWP Reaches 1 and 2 is Grey Box with occasional Yellow Box, River Red Gum and Buloke while Yellow Box are more dominant in EWP Reaches 3 and 4 (GBCMA 2008). The presence of riparian Grey Box vegetation within the Broken-Boosey system is recognised as ecologically distinctive compared to most other Victorian rivers and creeks (Robinson and Mann 1996, cited in Parks Victoria 2006) and reflect the frequently dry conditions prevailing in the stream prior to regulation (GHD / URS 2005). Robinson and Mann (1996) cited in Hale *et al.* (2006) suggest that waterlogging associated with flow regulation in these systems may lead to a replacement of Grey Box communities with more inundation tolerant Red Gum communities.

Table 6-1 EVCs in the immediate riparian zone within EWP Reach 1

EVC	EVC Name	Bioregional conservation status [1]	Occurrence in EWP Reach
68	**Creekline Grassy Woodland**	**E**	**Dominant along Boosey and Broken Creeks upstream of Numurkah**
74	Wetland Formation	E	Isolated occurrence near Nine Mile Creek offtake
168	**Drainage-line Aggregate**	**E**	**Along Broken Creek (and Box Creek) upstream of Numurkah**
259	**Plains Grassy Woodland/Gilgai Wetland Mosaic**	**E**	**Dominant on the floodplain throughout the reach and commonly adjacent the channel around and downstream of Numurkah**
803	Plains Woodland	E	Localised occurrence along Boosey Creek downstream of Katamatite and on Broken Creek around Nine Mile Creek offtake

1. For Victorian Riverina bioregion

Table 6-2 EVCs in the immediate riparian zone within EWP Reach 2

EVC	EVC Name	Bioregional conservation status [1]	Occurrence in EWP Reach
68	**Creekline Grassy Woodland**	**E**	**Near continuous along Nine Mile Creek, except downstream of Pine Lodge Creek**
259	**Plains Grassy Woodland/Gilgai Wetland Mosaic**	**E**	**Dominant on the floodplain throughout the reach and commonly adjacent the channel**
292	Red Gum Swamp	V	Black Swamp and Purdies Swamp and isolated occurrence near confluence with Broken Creek
803	Plains Woodland	E	On floodplain and locally near channel near confluence with Broken Creek
869	Creekline Grassy Woodland/Red Gum Swamp Mosaic	E	Along Nine Mile Creek downstream of Pine Lodge Creek

1. For Victorian Riverina bioregion

Table 6-3 EVCs in the immediate riparian zone within EWP Reach 3

EVC	EVC Name	Bioregional conservation status [(1)]		Occurrence in EWP Reach
		Vic Riv	Mur Fans	
68	**Creekline Grassy Woodland**	**E**	**E**	**Continuous along Broken Creek**
125	Plains Grassy Wetland		E	Floodplain wetland features with isolated occurrences adjoining Broken Creek
259	Plains Grassy Woodland/Gilgai Wetland Mosaic	E		Floodplain north of Broken Creek near upstream end of reach, with isolated occurrences near Broken Creek
333	Red Gum Swamp/Plains Grassy Wetland Mosaic		E	Carlands Swamp and other floodplain wetland features
803	**Plains Woodland**	**E**	**E**	**Southern floodplain of Broken Creek with significant occurrences along creek frontage**
873	Riverine Grassy Woodland/Riverine Chenopod Woodland/Wetland Mosaic		V	Adjacent Nathalia weir pool
882	Shallow Sands Woodland		V	Isolated occurrences near Broken Creek

1. Reach 3 crosses the boundary between the Victorian Riverina bioregion and Murray Fans bioregion. Bioregional conservation status is shown for each bioregion in which the EVC occurs within EWP Reach 3

Table 6-4 EVCs in the immediate riparian zone within EWP Reach 4

EVC	EVC Name	Bioregional conservation status (1)	Occurrence in EWP Reach
56	Floodplain Riparian Woodland	D	Localised occurrences adjacent Broken Creek downstream of Kennedys Weir
68	**Creekline Grassy Woodland**	**E**	**Dominant along Broken Creek upstream of Kennedys Weir**
106	Grassy Riverine Forest	D	Barmah National Park upstream and downstream of Rices Weir
125	Plains Grassy Wetland	E	Isolated floodplain occurrences with minor stands around Schiers Weir
168	**Drainage-line Aggregate**	**V**	**Abandoned channel meanders (Tallygaroopna Channel) and Broken Creek downstream of Kennedys Weir**
264	Sand Ridge Woodland	E	Isolated occurrences adjacent channel (inside bends)
295	Riverine Grassy Woodland	V	Barmah National Park
803	**Plains Woodland**	**E**	**Broad floodplain occurrences with significant Broken Creek frontage throughout reach**
814	Riverine Swamp Forest	D	Barmah National Park
816	Sedgy Riverine Forest	D	Localised occurrence upstream of Rices Weir
817	Sedgy Riverine Forest/Riverine Swamp Forest Complex	D	Localised occurrence downstream of Rices Weir
867	Shallow Sands Woodland/Plains Woodland Mosaic	E	Northern floodplain of Broken Creek upstream of Picola, with local occurrences along Broken Creek frontage
873	Riverine Grassy Woodland/Riverine Chenopod Woodland/Wetland Mosaic	V	Localised occurrences along Broken Creek frontage around Nathalia
882	Shallow Sands Woodland	V	On frontage between Hardings Weir and Chinamans Weir
1040	Riverine Grassy Woodland/Riverine Swampy Woodland Mosaic	V	Barmah National Park upstream and downstream of Rices Weir
1050	Mosaic of Floodplain Grassy Wetland/Grassy Riverine Forest-Riverine Swamp Forest Complex	E	Isolated occurrence downstream of Rices Weir
1068	Riverine Swamp Forest/Sedgy Riverine Forest Mosaic	D	Isolated occurrence between Rices Weir and Kennedys Weir

1. For Murray Fans bioregion

Table 6-5 EVC bioregional conservation status (from 2007_EVC_bioreg_bcs_gps.xls)

Code	Status	Definition
X	Presumed extinct	Probably no longer present in the bioregion OR if present, below the resolution of available mapping.
E	Endangered	Less than 10% of former range OR less than 10% of pre-European extent remains (or a combination of depletion, loss of quality, current threats and rarity that gives a comparable status e.g. 10 to 30% pre-European extent remains and severely degraded over a majority of this area).
V	Vulnerable	10 to 30% of pre-European extent remains (or a combination of depletion, loss of quality, current threats and rarity that gives a comparable status e.g. greater than 30% and up to 50% pre-European extent remains and moderately degraded over a majority of this area).
D	Depleted	Greater than 30% and up to 50% of pre-European extent remains (or a combination of depletion, loss of quality, current threats and rarity that gives a comparable status e.g. greater than 50% pre-European extent remains and moderately degraded over a majority of this area).
R	Rare	Rare (as defined by geographic occurrence) but neither depleted, degraded nor currently threatened to an extent that would qualify as endangered, vulnerable or depleted.
LC	Least concern	Greater than 50% or pre-European extent exists and subject to little to no degradation over a majority of this area.
na	Not applicable	The map unit is not a distinct native vegetation type and conservation status is not applicable.

6.3.2 Riparian vegetation condition

Hale *et al.* (2006) summarises riparian condition based on the results of 2004 Index of Stream Condition (ISC) assessments at 12 sites and Habitat-Hectares assessments at four riparian sites. While this review included reaches outside of the EWP project area (notably Boosey Creek and the upper reaches of Nine Mile and Broken Creeks) the general conclusion that the riparian condition is average to good, with a mature overstorey (often regrowth) but degraded understorey (reduced structural complexity, reduced species richness, little or no recruitment and an understorey of non-native species) is likely to reflect current condition within the EWP project area. The degraded understorey is attributed to past and present stock grazing pressures (GBCMA 2008) and timber removal for firewood (Hale *et al.* 2006). While large portions of the stream frontage within the EWP project area lie within the Broken-Boosey State Park and associated Natural Features Reserves, grazing, either under licence or illegally, continues in approximately 50% of the reserve area (Parks Victoria 2006).

6.3.3 In-channel vegetation

The distribution and character of in-channel vegetation within the EWP project area is dominated by the regulated flow regime within the Broken Creek system. Under natural conditions, flows in the system were ephemeral (refer Section 4.1.3) and would have provided habitat for a range of perennial and annual macrophytes adapted to wetting and drying cycles (GBCMA 2008). The modified flow regime favours robust perennial species adapted to permanent or near-permanent inundation and low flow velocity, with Cumbungi (Typha) and Common Reed (*Phragmites australis*) now dominating (GBCMA 2008). Localised patches of other species occur including Water milfoil (*Myriophyllum* sp), Water primrose (*Ludwigea peploides*), Water ribbons (*Triglochin* sp) and Ribbon weed (*Vallisneria* sp) (GBCMA 2008). Monitoring of Kinnairds Swamp after delivery of environmental water in 2008 located large populations of the nationally vulnerable Ridged Water Milfoil (*Myriophyllum porcatum*) and endangered (in Victoria) Slender Water Milfoil (*Myriopyllum gracile* var. *lineare*) (Australian Ecosystems 2009).

Aquatic weeds are becoming an increasing problem, favoured by high nutrient, low velocity flows (GBCMA 2008), as discussed in Section 6.8.2.

6.4 Wetlands

The Broken- Boosey and Nine Mile Creeks Wetland Implementation Plan (Hale *et al.* 2006) covers the entire EWP project area and provides the most complete review of current wetland condition within the project area. Hale *et al.* (2006) included assessment at two scales:

- "The floodplain / riparian zone associated with the creeks as a single connected wetland system; and
- The discrete wetlands within the floodplain."

The same classification of wetland assets has been adopted for the EWP process as discussed in the following sections.

6.4.1 Riparian wetland assets

As discussed in Section 4.3.3, Broken Creek within EWP Reaches 1, 3 and 4 is listed in the Directory of Important Wetlands in Australia (Environment Australia 2001). The listing covers the immediate riparian zone of Broken Creek however a number of floodplain features around and downstream of Nathalia (generally relic features within the Tallygaroopna channel meanders, refer Section 6.2.2) are also included in the listing. This is consistent with GHD / URS (2005) which identifies that the wetlands of the Broken River are "mostly confined to narrow riparian zones which are inundated frequently and which contribute to the habitat complexity of the system".

Hale *et al.* (2006) note that there is "little information available on the condition of wetlands within the Project Area. Previous investigations were limited to the larger wetlands with conservation reserves (Kinnairds, Black, Moodie and Rowan Swamps)". Hale *et al.* (2006) documents the presence and conservation status of EVCs within the wetland implementation plan project area (extending well outside of the area inundated by regulated flows) but does not provide a breakdown for those associated with the riparian wetland environment as distinct from the broader floodplain.

While there has been some subsequent assessment of wetland condition and hydrology within the project area (i.e. Australian Ecosystems 2009, SKM 2007) the value and condition of the riparian wetland asset is still generally poorly documented.

6.4.2 Floodplain wetland assets

A number of floodplain wetland features are associated with the Broken Creek system within the EWP project area. The distribution of wetlands, based on the DSE Wetlands 1994 layer (DSE 1994), is shown in Figure 6-2. Wetlands are classified into six categories (Corrick and Norman 1980) according to water depth, duration of inundation, salinity and dominant vegetation (Hale *et al.* 2006) as below:

- Deep freshwater marshes – deep freshwater wetlands that remain flooded for most of the year but may dry occasionally;

- Freshwater meadows – shallow freshwater wetlands holding water for less than four months of the year;
- Permanent open freshwater wetlands – deep freshwater wetlands that hold water permanently;
- Permanent saline wetlands – saline wetlands that rarely dry out, including tidal areas and saline inland lakes;
- Semi-permanent saline wetlands – saline wetlands flooded for less than eight months of the year, including salt pans and salt meadows; and
- Shallow freshwater marshes – shallow freshwater wetlands that usually dry out in mid-summer and refill with the onset of winter rains

The Freshwater Meadow, Shallow Freshwater Marsh, Deep Freshwater Marsh and Permanent Open Freshwater Wetlands categories occur within the EWP project area. All of the wetland features in proximity to Broken and Nine Mile Creeks within DSE (1994) lie within the Directory of Important Wetlands listing (Environment Australia 2001) discussed in Section 4.3.3.

Hale *et al.* (2006) reviewed the distribution and conservation significance of wetlands within the Broken, Boosey and Nine Mile Creek systems, encompassing (but extending beyond) the EWP project area. With reference to DSE (1994), the extent of wetlands in all wetland categories excluding Permanent Open Water (after Corrick and Norman 1980) have declined significantly in area since settlement. Based on review of 2001 aerial photography, Hale *et al.* (2006) conclude that this decline continued between the 1994 mapping (DSE 1994) and 2001. The greatest decline (in number and area of wetlands) has been in the "Freshwater Meadow" and "Shallow Freshwater Marsh" categories however the "Permanent Open Water" category has increased as a result of construction of dams and impoundments.

There are no Ramsar listed wetlands within the Broken Boosey and Nine Mile Creek systems, although Broken Creek discharges to the Barmah Forest Ramsar Site. The Black Swamp / Purdies Swamp system (see below) is listed as bioregionally significant within the National Land and Water Resources Audit (NLWRA 2002).

The largest discrete wetland systems in proximity to the Broken and Nine Mile Creek systems are:

- **Black Swamp and Purdies Swamp** – Located to the north of Nine Mile Creek near Wunghu in EWP Reach 2, discussed in further detail below.
- **Kinnairds Wetland** – Located near Numurkah in EWP Reach1, Kinnairds Wetland is a 93 ha terminal wetland complex near Numurkah. DPI (2003) describes the wetland as a Deep Freshwater Marsh in a prior stream depression (the Muckhatah Depression) with a vegetation community of sparse mature River Red Gum over Common Spike-Sedge, Water Milfoil and Moira Grass. Historically the wetland has been subject to waterlogging due to catchment clearing and irrigation development in the Muckatah catchment. More recently (approximately 2000 onwards) a more natural flooding regime has been reinstated.
- **Carlands Swamp** – Located approximately 20 km upstream of Nathalia on Broken Creek in EWP Reach 3, is identified as a Freshwater Meadow in the DSE Wetland 1994 layer but little other information is available on its condition or hydrology.

With the exception of the Black Swamp and Purdies Swamp system near Wunghu these wetlands are not able to be inundated by the regulation of in-channel flows (GBCMA 2008). For the purpose of this EWP it is therefore assumed that the other floodplain wetlands are unlikely to be impacted by the hydrologic modifications resulting from the works implemented under the GMW Connections Project and only the Black Swamp / Purdies Swamp system is described below.

Black and Purdies Swamps

Black Swamp and Purdies Swamp is a bioregionally significant wetland system lying to the north of Nine Mile Creek upstream of Wunghu (GBCMA 2008). Black Swamp and Purdies Swamp are both classified as Shallow Freshwater Marshes, with the channel joining the two swamps identified as Freshwater Meadow. Occupying an area of approximately 107 ha, the wetland complex supports aquatic, River Red Gum and Grey Box vegetation communities. Under natural conditions, Black Swamp received water from Nine Mile Creek to the east. Once Black Swamp filled, water overflowed to Purdies Swamp before returning to Nine Mile Creek (GBCMA 2008). Natural flooding would have occurred approximately annually during late winter and spring however with a shallow depth (approximately 50 cm), it would dry out most years during summer and autumn (GBCMA 2008).

More recently, Black Swamp has been subject to prolonged flooding under the regulated flow conditions prevailing in Nine Mile Creek. This has resulted in a change in species composition with the original Red Gum Swamp (EVC 292) now restricted to the perimeter of the wetland (Australian Ecosystems 2008), with the wetland floor dominated by species adapted to permanent inundation including Typha (GBCMA 2008). Purdies Swamp is currently hydraulically isolated from Black Swamp by a road through the middle of the site and has thus not been flooded for some years.

The recent (2008) refurbishment of a regulator on the inlet channel from Nine Mile Creek has facilitated the return to a more natural wetting and drying regime. A recommended flooding regime for Black Swamp was developed in 2007 (SKM 2007) with the objective of establishing a more diverse ecosystem and restoration of the original Red Gum Swamp community. The recommended flood regime for Black Swamp comprises:

- Timing: Winter/spring
- Frequency: Near annual
- Duration: 6 months
- Depth: Variable depths to 50 cm
- Rates of rise and fall: Driven by rate of rising flood and natural evaporation and seepage
- Variability: Based on variability in peak and natural flows

The regulator can be operated to prevent flows into the wetland system for events up to approximately bank full in Nine Mile Creek and thus unseasonal flooding can be prevented by regulator closure. Critically for the current EWP, the commence to flow level for flows into the wetland via the regulator is at a discharge of around 100 ML/d in Nine Mile Creek (SKM 2007). With a wetland volume of approximately 50 ML (excluding Purdies Swamp), and making allowance for seepage and losses from the system, a volume of approximately 100 ML is required to fill the wetland, requiring that the regulator remains open for approximately 10 days while flows in Nine Mile Creek exceed 100 ML/d (Simon Casanelia pers. comm. 2010). There may be some benefits in leaving the regulator open for a longer period than this minimum fill time (to facilitate access to the wetland for smaller bodied fish) however this may exacerbate issues with carp breeding in the wetland and then returning to the Nine Mile Creek system (Jarod Lyon pers. comm. 2010).

Recent drying and watering events have resulted in an improvement in health and species diversity of the wetland vegetation communities and provided improved habitat for wetland dependent birds (Australian Ecosystems 2009). The wetland is being flooded approximately annually (2008, 2009) at the present time but the frequency of inundation is likely to slightly reduced and be randomised in the future to enhance the role of the wetland as a drought refuge for waterbirds (Simon Casanelia pers. comm. 2010).

Figure 6-1 Black Swamp and Purdies Swamp north of Nine Mile Creek in Reach 2

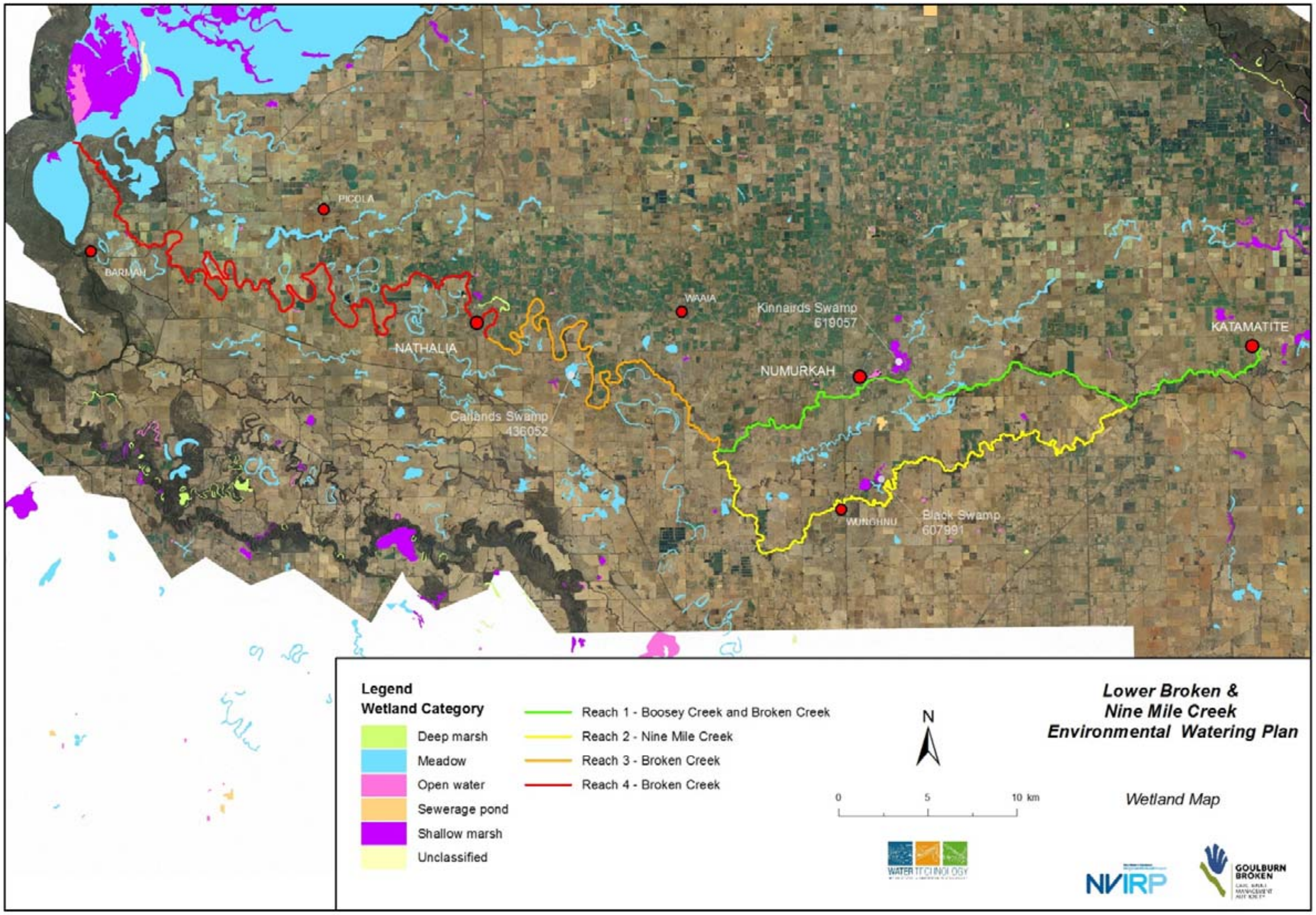

Figure 6-2 **Wetland extents within the EWP project area (DSE 1994)**

6.5 Fish

6.5.1 Introduction

While there is incomplete knowledge of the current status of the native and exotic fish populations in the Broken Creek system, available monitoring data indicates that the Broken system (including Broken River and Broken Creek) supports a diverse native fish community (O'Connor and Amtstaetter 2008). As noted in Section 4.3.1, Broken Creek below Nine Mile Creek is known as an important Murray Cod (*Maccullochella peelii peelii)* habitat and is identified as a high priority reach in the Regional River Health Strategy (GBCMA 2005) on this basis.

Native and exotic fish populations in the Broken Creek system have been investigated and documented in a number of studies in the last 10 years (O'Connor and O'Mahony 2008; O'Connor and Amtstaetter 2008; O'Connor and Koster 2005; O'Connor 2006; and O'Connor *et al*. 2003). Recent investigations have focussed on the planning and outcomes of the Broken Creek fishway installation program in which vertical slot fishways were constructed on all weirs between Nathalia and the Murray River between approximately 1998 and 2005. The majority of the monitoring effort has thus been in the lower reaches of Broken Creek (EWP Reaches 3 and 4) however there is a reasonable state of knowledge on conditions and fish populations in the upstream reach of Broken Creek (EWP Reach 1). By contrast, there has been no formal monitoring of fish populations in Nine Mile Creek (EWP Reach 2).

Current monitoring (i.e. O'Connor and Amtstaetter 2008, O'Connor 2006) indicates that the fishway installation program has facilitated the upstream movement of fish in the lower reaches of Broken Creek and that the diversity and abundance of native fish species around Nathalia has increased relative to the situation prior to construction of the fishways. However the native fish diversity and abundance between Nathalia and Numurkah is depressed relative to downstream populations but the cause is not clear.

O'Connor and Amtstaetter (2008) investigated possible factors limiting the population diversity and abundance upstream of Nathalia including habitat quality (depth and width variation) and in-stream structure. While habitat was found to be progressively poorer upstream, the presence of high quality habitat in the sites immediately upstream of Nathalia suggested that the low native fish population in this reach may be an indication of limited movement of fish from the downstream reach, either due to restrictions in fish passage at the Nathalia weir (due to low flow or inappropriate operation) or limited population pressures to drive upstream population processes. GBCMA (2008) recommends a minimum flow of 40 ML/d in the system to provide for passage of native fish species through the vertical slot fishways however O'Connor and Amtstaetter (2008) also highlight other factors (i.e. variation in flow level, full opening of fishway gates, removal of debris from within the fishway) which can enhance the effectiveness of the fishways.

In the reach between Nathalia and Numurkah (EWP Reach 3 and downstream end of EWP Reach 1), O'Connor and Amtstaetter (2008) identified that some areas of Broken Creek do not contain sufficient habitat to support permanent or temporary (migrating) fish populations. This habitat limitation reflects the impact of past de-snagging and channel modification works (refer Section 6.2.3). Despite the degraded state of EWP Reaches 1 and 3 (and by inference, EWP Reach 2 – Nine Mile Creek) native fish populations are still found in some locations within these reaches (refer Section 6.5.2)

6.5.2 Species distribution

The distribution of native and exotic fish species amongst the EWP reaches is summarised in Table 6-6, compiled based on information contained in Douglas (2000), O'Connor and Amtstaetter (2008) and GBCMA (2008) and the knowledge of historic and recent monitoring activities contributed by members of the Scientific Reference Group (refer Section 13.2). Table 6-6 also notes which species are migratory (from Douglas 2000) and characterises flow dependence of each species based on the distribution of species relative to the partially restored hydrology in upstream reaches of the Broken and Boosey system (after Reich *et al.* 2009). A number of other species have been captured in low numbers in EWP Reach 4 including Silver perch, Freshwater catfish, Short finned eel, Atlantic salmon and Brown trout (O'Connor and O'Mahony (2008); O'Connor (2006); O'Connor and Koster (2005) O'Connor *et al*. (2003)).

Table 6-6 Presence of native and exotic fish species within EWP waterways

Species	**Migratory (Douglas 2000)**	**Flow dependence (Reich *et al.* 2009)**	**EWP Reach 1**	**EWP Reach 2**	**EWP Reach 3**	**EWP Reach 4**	**Vic. status**	**Nat. status**
Australian smelt (*Retropinna semoni*)	Yes	FG	Y	Y	Y	Y		
Carp gudgeon (*Hypseleotris* sp)	No?	FG	Y	Y	Y	Y		
Crimson-spotted rainbowfish (*Melanotaenia fluviatilis*)	No	FD				Y	Vul, L	
Golden perch (*Maquaria ambigua*)	Yes	FD	Y	Y	Y	Y	NT	
Murray cod (*Maccullochella peelii peelii*)	Yes	FD	Y	Y	Y	Y	Vul, L	V
Unspecked hardyhead *(Craterocephalus stercusmuscarum fulvus)*	No?	-				Y	DD, L	
Common carp (incl Goldfish X)* (*Cyprinus carpio*)	Yes	FG	Y	Y	Y	Y		
Gambusia* (*Gambusia holbrooki*)	No	FG	Y	Y	Y	Y		
Goldfish* (*Carassius auratus)*	No	FG	Y	Y	Y	Y		
Oriental weatherloach* (*Misgurnus anguillicaudatus*)	No?	FG	Y	Y	Y	Y		
Redfin* (*Perca fluviatilis*)	No	FD	Y	Y	Y	Y		

Notes: * introduced species
Flow association (after Reich *et al.* 2009)
FD Flow dependent – Present at highly regulated sites with perennial flow and low monthly flow variation
FG Flow generalist – Present across the hydrological gradient
Victorian and National Status
DD data deficient within Victoria and suspected of being threatened
NT near threatened within Victoria
Vul considered vulnerable within Victoria
End considered endangered in Victoria
L listed as threatened under the Victorian Flora and Fauna Guarantee Act 1988
V vulnerable in Australia (listed under the EPBC Act)

Of the threatened native fish species present within the EWP waterway reaches, the large bodied species (Murray cod and Golden perch) are likely to be the most significantly exposed to potential changes in the flow regime as this may impact on:

- habitat quantity – depth and extent if pool or stream levels are significantly reduced;
- habitat suitability – if geomorphic change (i.e. sedimentation) reduces in-stream habitat; and
- habitat availability – if movement through fishways is compromised by modified flow.

Both large and small bodied species may potentially be impacted by:

- reduced water quality – if dissolved oxygen, temperature or turbidity levels cross biological thresholds; and
- modified food webs – if macroinvertebrate communities are significantly impacted.

Introduced species, particularly Common carp and Oriental Weatherloach may be favoured by reductions in the future flow regime if water temperatures increase.

6.6 Threatened species – Flora and fauna

Broken Creek and Nine Mile Creek retain remnants of the original vegetation cover within an otherwise broadly cleared landscape. The remaining vegetation is highly fragmented and occurs as small isolated remnants (DSE 2008). These remnants support threatened flora and fauna populations, including some potentially impacted by changes in the hydrology or character of the Broken Creek system.

Threatened flora and fauna species lists for flora and fauna found along or adjacent to the EWP waterways have been compiled from various existing reports (DSE 2008, Heard 2007, Parks Victoria 2006) and the DSE Threatened Flora and Fauna spatial layer (provided by Goulburn Broken CMA). These lists are provided in Appendix C.

The most comprehensive lists are those contained in the Biodiversity Action Plans (BAPs) covering the project area, namely:

- the Central Creek Landscape Zone (DSE 2008) covering EWP Reaches 1, 2 and part of Reach 3, and
- the Barmah Landscape Zone (Heard 2007) covering part of EWP Reach 3 and EWP Reach 4

Biodiversity Action Planning (BAP) identifies priorities for the conservation of native biodiversity at a landscape scale. These BAPs document the significant flora and fauna within the respective landscape zones. While the landscape zones extend beyond the immediate riparian environment, the threatened species lists contained in the BAPs are of relevance to the EWP as the major creeklines provide habitat for most of the threatened species found in the zone (DSE 2008), and are considered to be of “Very High” conservation value as they provide essential conduits of contiguous vegetation, which will facilitate species movement and provide habitat, food and shelter for a range of species, particularly fauna (Ahern *et al.* 2003 cited in Heard 2007).

In recognition of the scope of the EWP, namely that it is focussed on the impact of the GMW Connections Project on high value assets dependent on the current regulated flow regime, the threatened species lists from the BAPs have been reviewed to identify those species with a strong riparian zone or in-stream association. A considerable area of the Broken Creek system is contained within the Broken-Boosey State Park, with the most of the threatened species and communities associated with the floodplain and adjacent woodlands to the Creek (i.e. Plains Grassy Woodland or Plains Grassy Woodland/Gilgai Wetland Mosaic EVCs, based on Buloke or Grey Box overstorey (Parks Victoria 2006). It is highly likely that predominantly ‘terrestrial’ flora and fauna will not be impacted by changes in regulated flow, and it is only those taxa that are aquatic or typically found on the terrestrial/aquatic ecotone that will experience any change.

With this in mind, the total species list has been filtered to identify those species likely to be impacted by a change in the regulated flow hydrology, i.e. particularly the aquatic plants (Section 6.6.1) and fish and frogs (Section 6.6.2), and these more likely impacted groups have had potential impacts considered more fully. Some of the species of vascular flora found within the boundary zone, such as the *Cardamine* species, Pale Spike-sedge (*Eleocharis pallens*) and Small-flowered Mud-mat (*Glossostigma cleistanthum*), could be negatively impacted by changes in regulated flow, based on their habitat preferences, and position within the ecosystem. The full consideration of the potential impacts of changed regulated flow regime on these species is beyond the scope of this study, but should be undertaken prior to any changes in flow regime. Notwithstanding the need to more fully consider these species, the evaluation of the effect of change in regulated flow in this instance must be considered in the context that the existing regime is likely to result in the long term loss of existing threatened vegetation, and replacement with more tolerant River Red Gum communities (ECC 2001 from Parks Victoria 2006). The change in regime proposed is probably a significantly lesser disturbance than the imposition of the original altered flow and flooding regime.

While numerous other more terrestrial fauna (i.e. birds, lizards, mammals) are found in proximity to the waterway due to reliance on the habitat or food sources found in the riparian zone, the suitability of this zone for their role in the fauna lifecycle is more likely to be controlled by the riparian zone and adjacent community condition and management (i.e. vegetation composition and structure, and critical species abundance), than a minor alteration to the regulated hydrologic regime.

6.6.1 Threatened flora with waterway association

Parks Victoria (2006) states that no threatened aquatic plant species are known to occur within the Broken-Boosey State Park and associated reserves however large populations of the nationally vulnerable Ridged Water Milfoil (*Myriophyllum porcatum*) and endangered (in Victoria) Slender Water Milfoil (*Myriophyllum gracile* var. *lineare*) have been found in Kinnairds Swamp (adjacent Broken Creek) following flooding (Australian Ecosystems 2009) (refer Section 6.3.3).

A threatened species list, focussing on aquatic and flood dependent species has been developed from the full listings discussed above. This listing is provided in Table 6-7 and has been developed using plant habitat descriptions from NSW Flora Online (http://plantnet.rbgsyd.nsw.gov.au/)

Table 6-7 Threatened flora – Likely to be associated with waterways (after Heard 2007 and DSE 2008)

Common name	Scientific name	Australian status	Victorian status	FFG code	Waterway setting	Habitat description (from NSW flora online : http://plantnet.rbgsyd.nsw.gov.au/)
Slender Water-milfoil	*Myriophyllum gracile* var. *lineare*		e	L	a	Perennial herb, aquatic or fully emergent; stems mostly 1 mm diameter
Ridged Water-milfoil	*Myriophyllum porcatum*	V	v	L	a	??
Slender Water-ribbons	*Triglochin dubia*		r		a	Grows in still ephemeral freshwater to 50 cm deep, in swamps creeklets and floodplains
Pale Spike-sedge	*Eleocharis pallens*		k		e	Grows in seasonally wet situations such as floodways, usually on clayey soils
Slender Club-sedge	*Isolepis congrua*		v	L	e	Grows in seasonally damp situations
River Swamp Wallaby-grass	*Amphibromus fluitans*	V			m	Grows mostly in permanent swamps; uncommon
Western Water-starwort	*Callitriche cyclocarpa*	V			m	
Winged Water-starwort	*Callitriche umbonata*		r		m	In damp often swampy places
Riverina Bitter-cress	*Cardamine moirensis*		r		m	Grows in low-lying areas adjacent to streams and swamps
Long Eryngium	*Eryngium paludosum*		v		m	Grows in swampy, irrigated or flooded areas, depressions on sand, loam, clay and cracking clays
Small-flower Mud-mat	*Glossostigma cleistanthum*		r		M	Grows in silt in rock-pools, in clay on creek beds, on swamp margins or river flats or in dams, submerged or exposed
Bluish Raspwort	*Haloragis glauca f. glauca*		k		M	Often along seasonal watercourses
Swamp Star	*Hypoxis exilis*		v		M	Restricted to swampy areas on the floodplains of the Murray, Edward and Murrumbidgee Rivers
Button Rush	*Lipocarpha microcephala*		v		M	Grows in open damp places such as sandy stream banks; widespread but scattered
Leafless	*Maireana*		k		m	Widespread in low-lying

Common name	Scientific name	Australian status	Victorian status	FFG code	Waterway setting	Habitat description (from NSW flora online : http://plantnet.rbgsyd.nsw.gov.au/)
Bluebush	*aphylla*					seasonally inundated areas with heavy soils
Smooth Minuria	*Minuria integerrima*		r		m	Grows in a variety of habitats and soils near places of permanent or ephemeral water
Striped Water-milfoil	*Myriophyllum striatum*		v	L	m	In damp situations on the banks of creeks and around waterholes, Creeping, matted herb, fully emergent
Large River Buttercup	*Ranunculus papulentus*		k		m	Grows in wet sites, on mud or in pools
Annual Buttercup	*Ranunculus sessiliflorus* var. *pilulifer*		k		m	Grows in intermittently moist sites, often in grassland or woodland on nutrient-rich soils

Definitions: Australian status
V: vulnerable in Australia
Victorian status
k: poorly known in Victoria
e: endangered in Victoria
v: vulnerable in Victoria
r: rare in Victoria
FFG codes
L: listed under FFG
N: nominated under FFG
Waterway setting (assigned based on description from NSW flora online)
a: aquatic
e: seasonally flooded
m: waterway margin

Note: Threatened status and FFG listing updated in accordance with DEPI 2014.

6.6.2 Threatened fauna dependent on the aquatic environment

As discussed in Section 6.6, the threatened species likely to be found within the EWP project waterways are documented in Appendix C. While the list includes a significant number of birds, including waterbirds, reptiles and mammals it is considered that the only species likely to be impacted by a change in the regulated flow regime are fish and frogs. The retention of sustainable populations of the other species dependent on the broader riparian environment is more dependent on the management of the broader riparian zone and the regime of floods above that impacted by the GMW Connections Project. Threatened fish and frogs within the EWP waterways are thus summarised in Table 6-8. The status and flow dependence of the identified fish species are discussed in Section 6.5. Information from the Scientific Reference Group suggests that the Trout cod (*Maccullochella macquariensis)*, Freshwater catfish (*Tandanus tandanus)* (a single Freshwater catfish was captured moving upstream through the Kennedys Weir fishway in 2000 (O'Connor *et al.* 2003)) and Macquarie perch (*Macquaria australasica*) are unlikely to be currently present within the EWP waterway reaches despite their inclusion on the threatened species lists.

Table 6-8 Threatened fish and frogs along EWP waterways (after DSE 2008 and Heard 2007)

Scientific name	Common name	Australian status	Victorian status	FFG listed
Maccullochella macquariensis	Bluenose (Trout) Cod #	E	cr	L
Tandanus tandanus	Freshwater Catfish #		e	L
Macquaria ambigua	Golden Perch		nt	
Macquaria australasica	Macquarie Perch #	E	e	L
Maccullochella peelii peelii	Murray Cod	V	v	L
Bidyanus bidyanus	Silver Perch		v	L
Limnodynastes interioris	Giant Bullfrog		cr	L
Litoria raniformis	Growling Grass Frog	V	e	L

Definitions: Victorian (denoted by lower case) Status of Species:
cr = critically endangered e = endangered, v = vulnerable, nt = near threatened, r = rare , dd = data deficient, k = poorly known
FFG (Flora Fauna Guarantee Act 1988) taxon:
L = listed
# - considered unlikely to be present within EWP reaches

Note: Threatened status and FFG listing updated in accordance with DSE 2013.

6.7 Macroinvertebrates

Anthropogenic alteration of water regimes within lowland rivers such as the Broken Creek may affect the abundance of many taxa without eliminating them (Chessman *et al.* 2006). Historically, the macroinvertebrate communities within the Broken Creek would have been dominated by mobile taxa adapted to intermittent flows and capable of tolerating environmental extremes (e.g. floods and drying) (Cottingham *et al.* 2001, Chessman *et al.* 2006). The Broken Creek is now a permanently flowing creek and the macroinvertebrate community is likely to have changed to less mobile and more persistent taxa (Cottingham *et al.* 2001).

Within the Broken Creek there are three distinct habitat types:

- benthic substrate composed of sand or mud;
- stands of macrophytes (*Typha* and *Phragmites* spp.); and
- large woody debris (LWD).

In general, the communities within each habitat will have a similar number of taxonomic groups (i.e. similar diversity) but the composition of the communities will differ (i.e. a different suite of macroinvertebrates will be found in association with each habitat), and the LWD habitat type may support the highest macroinvertebrate densities (Humphries *et al.* 1998).

There is likely to be a change in macroinvertebrate communities longitudinally, with more diverse communities likely to be found in the upper reaches where there is potentially greater habitat diversity and better water quality compared to EWP Reach 4, which appears to have reduced habitat diversity and deteriorating water quality.

6.8 Threats to asset condition

The environmental assets documented in previous sections are exposed to various threatening processes. GHD / URS (2005) discusses threats in the context of the RiVERS database. Within the context of the EWP those threats which are potentially exacerbated by a modified flow regime and which pose the greatest threat to environmental condition include degraded water quality, the increasing dominance of aquatic weeds and potential geomorphic change impacting on in-stream habitat values. These threats are discussed in the following sections.

6.8.1 Water quality

The availability of water quality data within the EWP project waterway reaches is limited, with long term monitoring undertaken at only one site (Rices Weir) where data has been gathered since 1978 (GHD / URS 2005). SKM (2004) (cited in GHD / URS 2005) contains additional data for Broken Creek at Rices Weir and Shepparton irrigation district Drains 11 and 12, while water quality was also monitored on Boosey Creek at Katamatite (Waterwatch Site Code BOO010) between 1995 and 2002. There has been no long term monitoring of water quality in Nine Mile Creek (GBCMA 2008).

GHD / URS (2005) reviews the available water quality monitoring data (based principally on the Rices Weir site) and notes that while Broken Creek would have had naturally high turbidity levels for much of the year, land use changes have resulted in elevated turbidity and nutrient levels which, along with low flows and increased water temperatures, have resulted in an increased frequency of algal blooms and nuisance aquatic plant growth. Dissolved oxygen, turbidity and nutrient levels fail to meet State Environment Protection Policy (SEPP) – Waters of Victoria water quality objectives.

Drain and channel outfalls from the GMID, along with historic and current land management practices and urban drainage, contribute significant nutrient and turbidity loads to the Broken Creek system. There is potential that the rationalisation of the outfall and drainage network and ongoing changes in land and irrigation management may bring about a long-term reduction in sediment and nutrient supply. The most immediate ecological impact of the degraded water quality in the Broken Creek system is an increase in the occurrence of low dissolved oxygen conditions which compromises the survival of aquatic fauna (fish, macroinvertebrates, and zooplankton).

A major fish kill event in the Rices Weir pool in November 2002 has been attributed (Rees 2006) to low dissolved oxygen levels resulting from excessive growth of the floating fern *Azolla* sp. This occurred during a drought period when low creek flows, elevated air and water temperatures provided near optimal conditions for *Azolla* growth. While the fish kill event has focussed attention on Rices Weir the nutrient, sediment and water column conditions in Rices Weir essentially represent a worst-case scenario for the other weirs in the lower Broken Creek system (Rees 2006). No water quality data is available for upstream weir pools but similar issues are conceivable throughout EWP Reach 4.

Rees (2006) discusses the factors contributing to the 2002 fish kill event and the ecological implications of *Azolla* proliferation in the lower Broken Creek. The highly modified nature of the Broken Creek system is highlighted, with the lower reaches now comprised of a series of shallow weir pools with high nutrient levels in both incoming water and bed sediments. This contributes to very high in-stream primary production resulting in strong diurnal and seasonal variations in dissolved oxygen. It is identified that nutrient management is unlikely to resolve the *Azolla* issues in the short term due to high nutrient levels in the bed sediment.

A response plan has been implemented since the 2002 fish kill event based on the provision of flushing flows to prevent the build up of *Azolla* and to supply oxygenated water from upstream so as to prevent future fish deaths (GBCMA 2008). Typically this has required the provision of flushing flows (total flows over Rices Weir) of 100-200 ML/d from July to November (peak growth period), with flows adjusted based on real-time monitoring of dissolved oxygen and temperature in Rices Weir (GBCMA 2008). Goulburn Broken CMA has trialled the use of pulsed flushing flows rather than sustained flows over the growth period but this was not found to be effective. Mechanical removal or harvesting of *Azolla* from the Rices Weir pool has been trialled but issues relating to on-site impacts of machinery, limited disposal options for removed *Azolla* and the inability to remove all *Azolla* (leading to rapid re-infestation) mean that this approach is not currently recommended.

Rees (2006) supports management through provision of flushing flows, based on the current state of knowledge, as an effective means to minimise the effects of *Azolla* on water quality.

6.8.2 Aquatic weeds

Aquatic plants tolerant of or favoured by permanent water and low flow velocity conditions are an increasing issue within the Broken Creek system. Under natural conditions, flows in the system were ephemeral and would have provided habitat for a range of perennial and annual macrophytes adapted to wetting and drying cycles (GBCMA 2008). The modified flow regime favours robust perennial species adapted to permanent or near-permanent inundation and low flow velocity (GBCMA 2008).

Arrowhead (*Sagittaria graminea*) is the most significant aquatic weed species known to be present in the Broken Creek system (GHD / URS 2005, Parks Victoria 2006, GBCMA 2008). Large stands are known on Nine Mile Creek near Wunghu and as control is difficult further spread in shallow reaches (EWP Reaches 1 and 2) is likely (GHD / URS 2005). Although isolated infestations were observed within Reach 4 in July 2015, this weed appears to be relatively well controlled in that reach (Jamie Kaye, pers. comm. 2015).

Cabomba (*Cabomba caroliniana*), a Weed of National Significance (WoNS), occurs in the Broken River between Benalla and Caseys Weir. Cabomba has also been recorded within the Broken Creek cut section immediately downstream (within 400m) of the Caseys Weir offtake (Jamie Kaye, pers. comm. 2010). Rices Weir pool (downstream end of the EWP area) was assessed for the presence of Cabomba in January 2013 and March 2014, however no infestations were observed (Water Technology 2014). While it is not known to occur within the EWP project area, future spread down Broken Creek is possible.

Lippia (*Phyla canescens*) occurs in the riparian zone of Broken Creek, and while not flow dependent, it is difficult to control and has the potential to spread widely throughout the riparian zone (GHD / URS 2005).

Two native species, Cumbungi (*Typha* sp.) and to a lesser degree, Common Reed (*Phragmites australis*) are now dominant in some locations. While they provide important in-stream habitat, particularly in the absence of LWD, their dense growth form and ability to colonise a range of water depths has seen an increase in their extent in the system. Cumbungi is noted as being a problem upstream of Numurkah around Kinnairds Swamp and upstream of Wunghu on Nine Mile Creek (GHD / URS 2005) and is said to impact on provision of water to Black Swamp. Control by spraying and mechanical removal or cutting below water level has been undertaken in some areas to facilitate passage of irrigation water.

Another native species, *Azolla*, has become prolific particularly in the weir pools in EWP Reach 4, and has been linked with a fish kill event in 2002 (GHD / URS 2005), refer Section 6.8.1,

6.8.3 Altered geomorphic processes

In a highly modified and regulated system such as Broken Creek, altered geomorphic processes can threaten other in-stream values. Unnaturally high levels of bed and bank instability can result in a change in geomorphic form and contribute elevated sediment loads, impacting on water quality, bed form and substrate composition. Weir pools can change stream flow and sediment transport processes, causing increased sediment deposition and loss of bed variability.

The history of bank and bed instability, along with historic channel modifications within the EWP waterway reaches are discussed in GHD / URS (2005).

Fluvial bank scour has generally not been a significant issue within the EWP project area, reflecting the low energy environment of the streams. Some bank erosion has been noted around weir pools due to constant water levels and the formation of an erosion notch in the bank and bank waterlogging. Significant bank erosion was reported in Nine Mile Creek following dredging and bed deepening in the 1960s (SKM 1998 cited in GHD / URS 2005) and SKM (1998) indicates that there is still minor bank erosion in Nine Mile Creek due to the relatively confined channel capacity relative to drainage outfall volumes.

Bed instability is not considered to pose a major threat to future waterway condition. Localised incision has occurred, particularly in response to dredging and weir construction but GHD / URS (2005) found little evidence of sediment build-up in weir pools. Recognising that the existing weirs in the lower Broken Creek are to be retained, the modification to channel form and flow dynamics and the historic removal of large woody debris from the channel are likely to be the most significant ongoing threats to habitat availability in the Broken Creek system.

7. HYDROLOGY

The hydrologic analysis and reporting components of the current EWP were undertaken by Sinclair Knight Merz (SKM) for the Goulburn Broken CMA. The complete report by SKM is provided in Appendix D. Relevant sections have been copied, with some abbreviation, to Section 7.2 onward. The reader is referred to Appendix D for full details of the hydrologic assessment.

7.1 Current operational regime

7.1.1 Operational guidelines

The "Lower Broken Creek Operational Guidelines" (GMW 2003) were developed following the completion of the fishway installation program (refer Section 6.5.1). The operational guidelines document GMW's role in operating the system to meet supply obligations and minimise environmental impact. The operational guidelines were developed by GMW in consultation with the Department of Primary Industries (DPI) (now Department of Economic Development, Jobs, Transport and Resources, DEDJTR), the Department of Sustainability and Environment (DSE) (now the Department of Land, Water and Planning (DELWP)), the Goulburn Broken CMA and the local community and were intended to allow flexibility in operation to meet broader strategic requirements (GMW 2003). Given that the operational guidelines precede the most recent Waterway Management Strategy (GHD / URS 2005) they do not provide a full coverage of the operational requirements to satisfy environmental objectives but suggest that operational flexibility is provided to meet future environmental requirements.

The operational guidelines (GMW 2003) establish the general principles of operation for three operational modes: "In season" (August to May), "Out of season" (May to August) and "Flood operation". Amongst other things, these principles include:

- Target operating levels for each weir.
- Management for environmental objectives – namely passage of fish (Murray Cod identified as the critical species) and management of nuisance flooding of Goose Swamp between Rices Weir and the Barmah Forest (by operation of regulators).
- Weed management – providing for passing flows over Rices Weir to flush *Azolla* mats downstream. No target flow volumes (ML/d) are established in the guidelines however this is not inconsistent with the current management practice where flows are varied dependent on monitored dissolved oxygen levels.

The operational guidelines (GMW 2003) contain a large amount of useful information in relation to system operation however sections of the document may require updating to reflect current practice (i.e. modified provisions for flows at Rices Weir, where the timing and magnitude of flushing flows have changed in recent years).

7.1.2 Monitoring and incident response

A "Monitoring and Incident Response Management Manual" (GMW 2004) was prepared in response to the fish kill event in November 2002. The manual documents monitoring activities, trigger levels (based on monitored DO levels in Rices Weir, *Azolla* coverage, reported fish death and low flow conditions) and management responses including passage of additional flows to remove *Azolla* and / or increase dissolved oxygen. The manual notes an agreement between GMW and the River Murray Commission to provide a 40 ML/d allocation from the River Murray (passed to Broken Creek and returned to the River Murray) to manage the Azolla build up. The agreement was modified to 80 ML/d for the 2003/04 irrigation season but the current status of this agreement is unknown.

7.1.3 Delivery of irrigation water to manage environmental assets

The Operational Guidelines (GMW 2003) and Monitoring and Incident Response Management Manual (GMW 2004) jointly document the operational regime however there is no formal agreement concerning the delivery of water to manage environmental assets in the Broken Creek system. GMW and Goulburn Broken CMA have a mutual interest in dealing with the low dissolved oxygen and *Azolla* issues and management of environmental assets in lower Broken Creek and to date have managed flow delivery cooperatively. As outlined in GMW (2003), irrigation water has been delivered in such a manner as to achieve identified environmental outcomes (specifically for passage of Murray Cod during the irrigation season) where feasible.

Where sufficient or timely flows cannot be delivered as a component of irrigation water delivery, specifically in relation to low dissolved oxygen and *Azolla* issues, Goulburn Broken CMA has made recommendations concerning the flows that may be required and GMW has agreed to these. As the resource manager GMW has called upon the Goulburn Water Quality Reserve (a provision within the GMW Goulburn Bulk Entitlement (Victorian Government 1995) which can be used for management of the Broken Creek) or arranged for Inter Valley Transfers (IVTs) to meet the recommended flows. Environmental water sources (including IVTs) are discussed in Section 7.1.4.

7.1.4 Other environmental water sources

Environmental water to protect or enhance environmental values in the Broken Creek system can be sourced from outside of the Broken Creek system as outlined below.

Inter-Valley Transfers (IVT)

As a result of water entitlements trading from the Goulburn Supply System to the Murray Supply System, water needs to be physically transferred from the Goulburn System to the Murray River to supply these traded entitlements. These transfers are requested by the Murray Darling Basin Authority when the Murray Supply System can best use them. This is usually between December and April. Instead of the water flowing along the Goulburn River downstream of Goulburn Weir, it can be diverted at Goulburn Weir through the Shepparton Irrigation Area channel system (and particularly the EGMC) to Broken Creek, and then along Broken Creek and back to the Murray River. It requires the planned volume to be returned to the River Murray. Further discussion of the potential application of Inter Valley Transfers in relation to the Broken Creek system is provided in the Northern Region Sustainable Water Strategy (DSE 2009).

Goulburn Water Quality Reserve

The Goulburn Water Quality Reserve is a provision in the Eildon-Goulburn Weir Bulk Entitlement (Victorian Government 1995). Up to 30,000 ML is available in every financial year to maintain water quality in the Goulburn River and Broken Creek. For Broken Creek, the water is diverted at Goulburn Weir through the Shepparton Irrigation Area channels to Broken Creek. This water can be consumed or passed to the River Murray.

Murray Flora and Fauna Bulk Entitlement

The River Murray Flora and Fauna Bulk Entitlement (Victorian Government 1999) is 27,600 ML of high reliability water shares. Water availability in any year is subject to seasonal allocations for the Victorian Murray Supply System. Water can be diverted from the River Murray at Lake Mulwala and through the Murray Valley Irrigation Area channel system to Broken Creek, or it can be traded into the Goulburn Supply System and delivered through the Shepparton Irrigation Area channel system. This water can be consumed or passed back to the River Murray.

7.2 Natural water regime

The Lower Broken Creek[3] and Nine Mile Creek have been regulated for more than 100 years. Under natural conditions the creeks would have ceased to flow during summer and autumn. There is no long-term gauge record available to describe the natural flow regime in the system prior to regulation (refer Section 7.3.2).

7.3 Current water regime before the GMW Connections Project

7.3.1 Introduction

Under regulated flow conditions, the Lower Broken Creek and Nine Mile Creek are perennial streams with significant flows maintained through summer and autumn to supply water for irrigation, stock and domestic use. There are a number of weirs downstream of Katamatite which maintain water levels for private pumps (refer Section 4.2). Water quality in the weir pools during summer and autumn is often poor, and in recent years environmental managers have passed increasing volumes of water down the creek to manage the threats posed by low dissolved oxygen levels and *Azolla* blooms (refer Section 6.8.1).

Of the regulated inflows to the Lower Broken Creek, the major sources are the EGMC outfall and the Murray Valley 7/3 channel outfall (Figure 7-2). The major sources of unregulated inflows are the upstream catchments (i.e. the Upper Broken Creek and Boosey Creek), Shepparton Drain 11, Shepparton Drain 12 and Murray Valley Drain 13. In recent years, unregulated inflows have become a very small proportion of total inflows. All together, there are currently eleven outfall structures and six drains that connect directly to the Lower Broken Creek from the Murray Valley irrigation district, while five outfall structures and six drains connect directly to the Lower Broken Creek and Nine Mile Creek from the Shepparton irrigation district. As part of the GMW Connections Project works, seven of the eleven Murray Valley outfall structures connected to the creek will be decommissioned. The outfall structures that will be retained are denoted by an asterisk in Figure 7-2. Some outfall structures discharging to drains will also be removed.

7.3.2 Gauged flow records

Three stream flow gauges are located within the study area:

- Boosey Creek at Tungamah (404204)
- Broken Creek at Katamatite (404214)
- Broken Creek at Rices Weir (404210)

The flow records for each of the three gauges begin in the mid 1960s (Figure 7-1). The gauge records thus represent the hydrology of the system during the period of flow regulation (refer Section 4.1.3), rather than indicating flows under natural conditions. The records for the Boosey Creek at Tungamah and the Broken Creek at Katamatite are generally of good quality. In contrast, there is much data missing from the Broken Creek at Rices Weir record. Some of these missing periods coincide with floods along the Murray River, when water would have backed up Broken Creek and drowned out the gauging station.

Missing data for the Boosey Creek at Tungamah and Broken Creek at Katamatite records were short enough to infill using linear interpolation. Linear interpolation was not appropriate for infilling the Broken Creek at Rices Weir record. Instead, the Murray Darling Basin Authority (MDBA) supplied a daily time-series of modelled flows past Rices Weir (1891 – 2009), assuming current conditions. While not exactly comparable to historically gauged streamflows (which captures the range of

[3] Downstream of the confluence of Broken Creek and Boosey Creek at Katamatite

development and management conditions the creek has been subjected to), the current modelled time-series does provide a good indication of flows expected at Rices Weir under the system's current regulation, were the past 120 years of climate repeated.

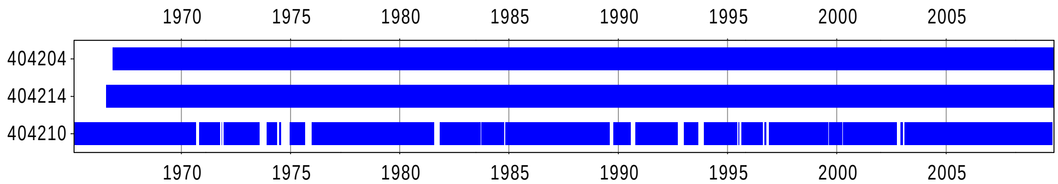

Figure 7-1 Extent of streamflow data available

Based on the flows observed at gauges 404204, 404214 and 404210, and the modelled flows for Rices Weir (404210) assuming current conditions, the following observations can be made:

- Flow in the Boosey Creek at Tungamah and the Broken Creek at Katamatite ceases for approximately 20% of the time. In contrast, there is flow past Rices Weir for all but a small portion of time (Figure 7-3).
- Flows past Rices Weir are elevated in summer and autumn by regulated releases through outfall structures located along the Lower Broken Creek (Figure 7-5). In winter and spring, the average recorded flow is of similar magnitude to the average flow recorded in summer and spring, but this is because there are significant periods of data missing during winter and spring for 16 of the 45 years of record. In contrast, the MDBA modelled time-series for Rices Weir, while showing elevated flows in summer and autumn, has the highest average flows occurring in spring. In recent years however, drought conditions have seen recorded flow past Rices Weir fall below 10 ML/d for extended periods during winter and spring. The flow regime for the Boosey Creek at Tungamah and the Broken Creek at Katamatite follows a more natural pattern, with low flows in summer and higher flows in winter and spring, including occasional flood events.
- On average, flows to the study area from the upstream catchments for the period of record available are 33 ML/d for December to May and 157 ML/d in for June to November (Table 7-1). The bulk of these inflows come from the Boosey Creek catchment. Average daily flows past Rices Weir for December to May and June to November are 300 ML/d – 500 ML/d, depending on whether the recorded or modelled streamflows are analysed.
- Although average flows at Rices Weir are greater than for the Boosey Creek at Tungamah and the Broken Creek at Katamatite, the peaks of high flow events recorded at the upstream end of the study area are often attenuated by the time they reach Rices Weir (Figure 7-7).

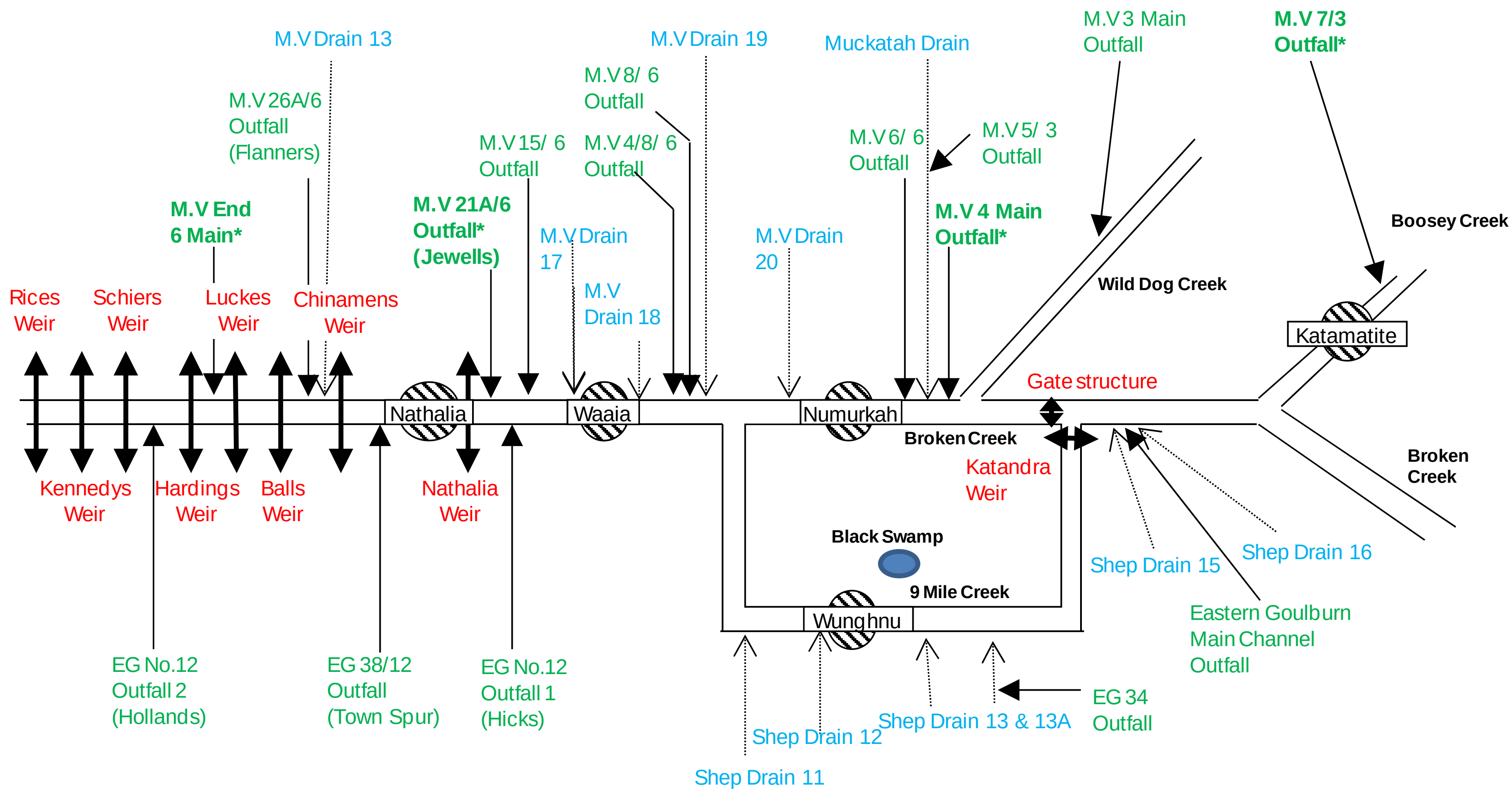

Figure 7-2 A schematic of the lower Broken Creek and Nine Mile Creek system

Names of regulating structures are in red, names of drains are in blue and outfall numbers are in green. Murray Valley outfall structures that will not be removed as part of the the GMW Connections Project works are shown by an asterisk. All outfall structures on the Shepparton side of the creeks are being retained.

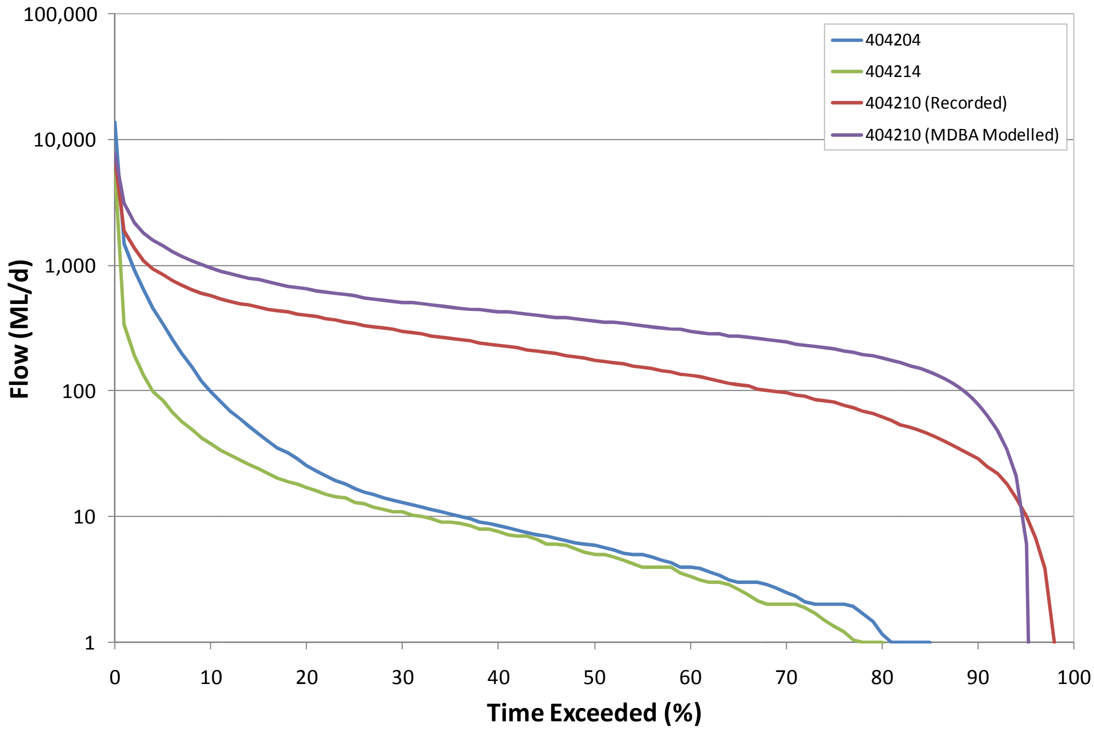

Figure 7-3 **Daily flow duration curve for streamflow gauges 404204, 404214 and 404210 (1997 to 2009 data with MDBA modelled data available at Rices Weir)**

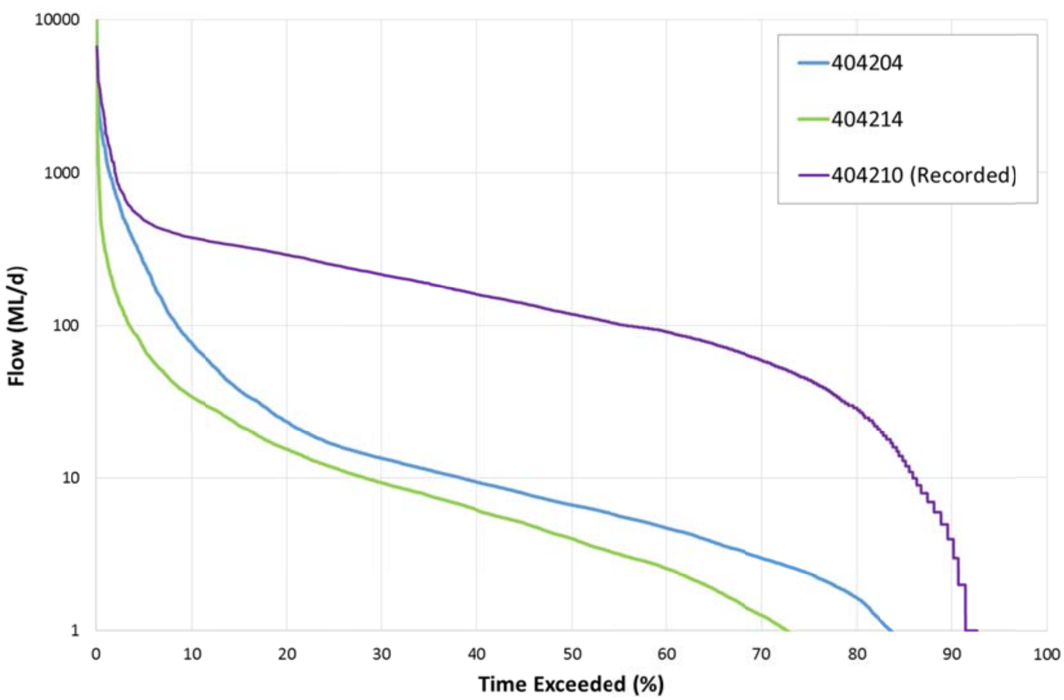

Figure 7-4 **Daily flow duration curve for streamflow gauges 404204, 404214 and 404210 (1997 to 2015 data with MDBA modelled data unavailable at Rices Weir)**

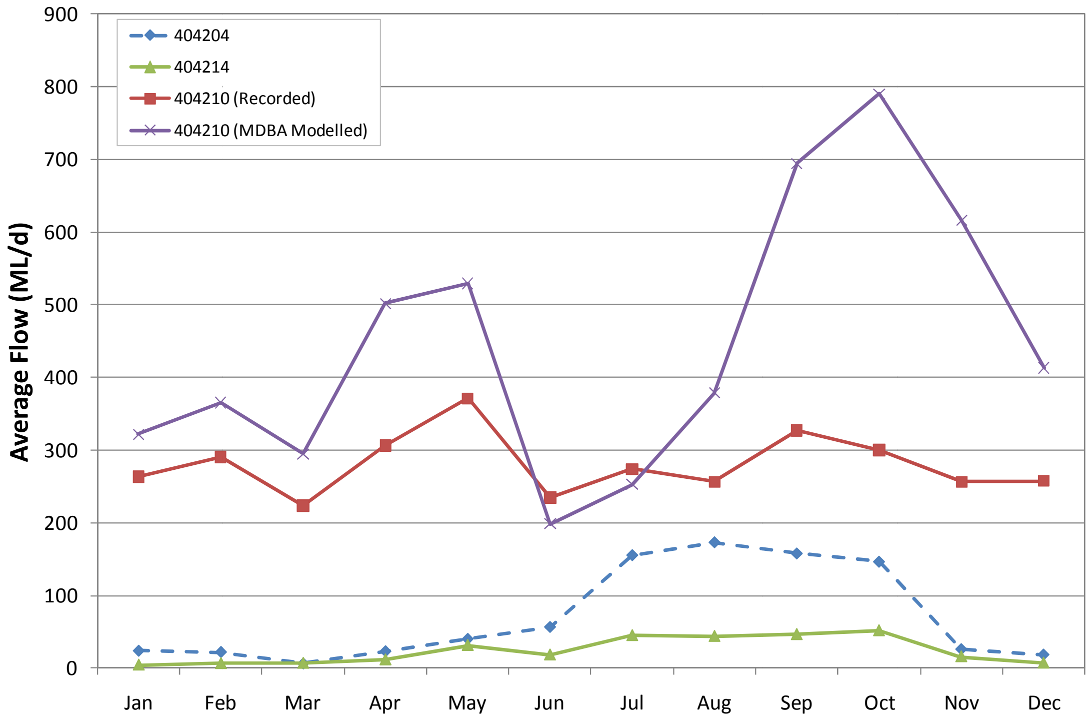

Figure 7-5 **Average daily flow for streamflow gauges 404204, 404214 and 404210 (1997 to 2009 data with MDBA modelled data available at Rices Weir)**

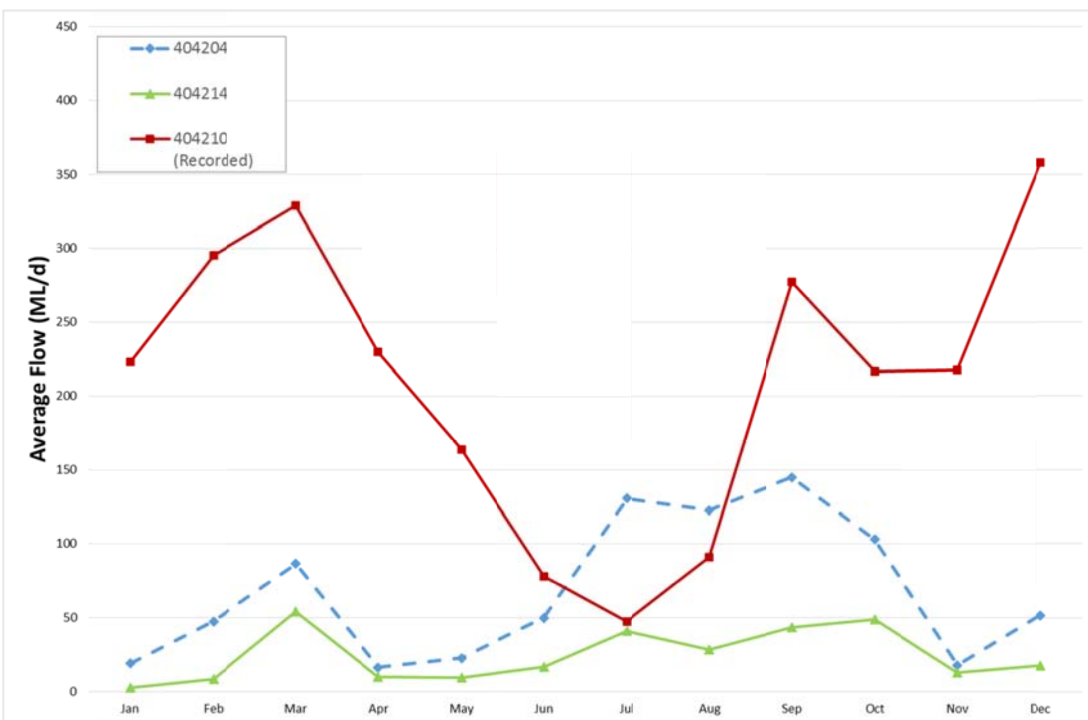

Figure 7-6 **Average daily flow for streamflow gauges 404204, 404214 and 404210 (1997 to 2015 data with MDBA modelled data unavailable at Rices Weir)**

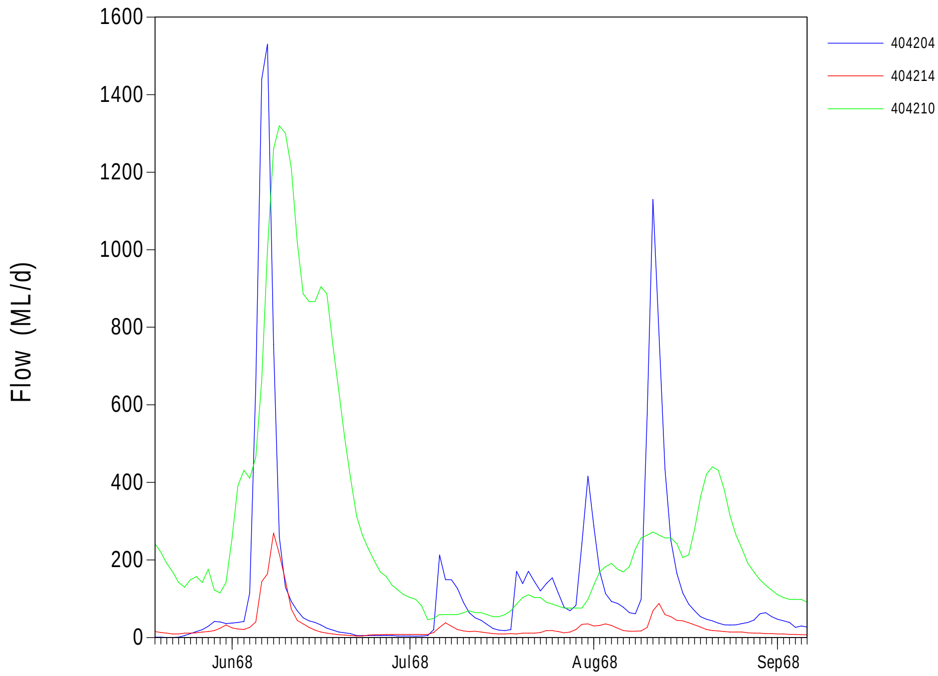

Figure 7-7 **Attenuation of high flow events as they move from the upstream end of the study area (404204 and 404214) to the downstream end (404210)**

Table 7-1 **Flow statistics for gauges 404204 and 404214, and downstream gauge 404210**

Statistic (ML/d)	*Flow Gauge*				
	404204	*404214*	*404204 + 404214*	*404210 (Recorded)^*	*404210 (Modelled)**
Minimum daily flow	0	0	0	0	0
Average daily flow	68	25	92	204	492
Maximum daily flow	21,200	11,600	15,800	7,800	7,670
Summer minimum daily flow	0	0	0	0	0
Summer average daily flow	41	17	57	261	468
Summer maximum daily flow	21,200	11,600	23,400	6,705	4,390
Winter minimum daily flow	0	0	0	0	0
Winter average daily flow	96	32	127	146	549
Winter maximum daily flow	13,700	5,910	14,600	7,800	7,670

Note: Summer refers to the months December to May, while winter refers to the months June to November.
Note:^ Without infilling missing periods in the gauge record.
Note: *Modelled time-series was provided by the MDBA from BigMod for the period 1891-2009.

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7.3.3 Current outfall contributions

Inflows to the Lower Broken Creek and Nine Mile Creek come from three sources:

- The upstream catchments;
- Irrigation channels that outfall directly to the creeks; and
- Drains that discharge to the creeks.

The flow contribution from the upstream catchments is described in Section 7.3.2.

Flow through outfall structures to the creeks is comprised of two parts:

- Inflows ordered by local diverters or environmental managers; and
- Inflows in excess of orders.

In addition to the outfall structures that connect directly to the creeks, a number discharge to drains. Flows through the outfall structures into drains combine with drainage flows. Often a portion of drainage flows will be diverted by irrigators before reaching the creek. Isolating the contribution of outfalls to drainage flows that enter the creeks is difficult.

Data on inflows to the Lower Broken Creek and Nine Mile Creek through outfall structures and drains was sourced from GMW and Thiess for the period of available record from 1998 to 2015. Missing data was infilled as outlined in Appendix D.

Total inflows

Of the total inflows to the Lower Broken Creek and Nine Mile Creek system, a large portion flows downstream and passes to the Murray River (Figure 7-8). Over the past 10 water years, the annual flow past Rices Weir has only been 25% to 45% lower than total estimated inflows. In this report, water year 1997/98 is defined as 1st July 1997 to 30th June 1998.

Figure 7-8 A comparison of annual total inflows (including from the upstream catchments, outfalls and drains) and annual flow past Rices Weir (some data infilled as outlined in Appendix D) up to 2009

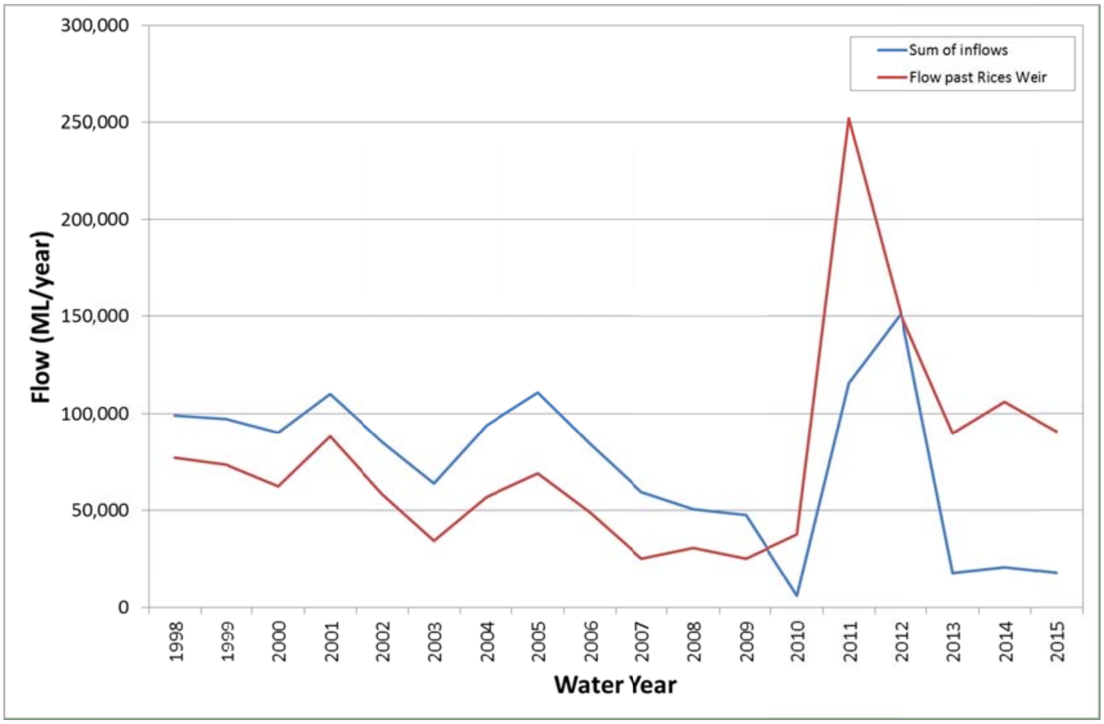

Figure 7-9 A comparison of annual total inflows (including from the upstream catchments, outfalls and drains) and annual flow past Rices Weir (some data infilled as outlined in Appendix D) up to 2015 (limited data post-2009)

Total inflows through outfall structures

Of total inflows to the Lower Broken Creek and Nine Mile Creek systems, the majority comes through the channel outfall structures (Figure 7-10). Over the past 10 years, as drought conditions have reduced the percentage contributions from unregulated sources of water (i.e. the upstream catchments and drains), the percentage contribution from outfall structures has increased. In 2008-09, inflows from outfall structures contributed approximately 95% of total inflows.

At the same time as the percentage contribution to inflows from outfall structures has increased, the inflows through outfall structures in excess of orders has decreased. In short, the distribution of water through outfall structures to the Lower Broken Creek and Nine Mile Creek has been managed more tightly in recent years.

Interestingly, over the past five years, the volume of water ordered through outfall structures by environmental managers (using environmental allocations or inter valley transfers (IVTs)) has rapidly increased, while the volumes ordered by diverters has decreased (Figure 7-14). In 2008-09, the volume of water ordered for the environment and IVTs exceeded local diverter orders for the first time. The decrease in diverter orders can be linked with Murray and Goulburn irrigation allocations (Table 7-2). As allocations have decreased, the volume of water ordered by diverters has also decreased. Environmental managers have therefore needed to order more water for the Lower Broken Creek and Nine Mile Creek systems for the purpose of maintaining sufficient water quality in the weir pools.

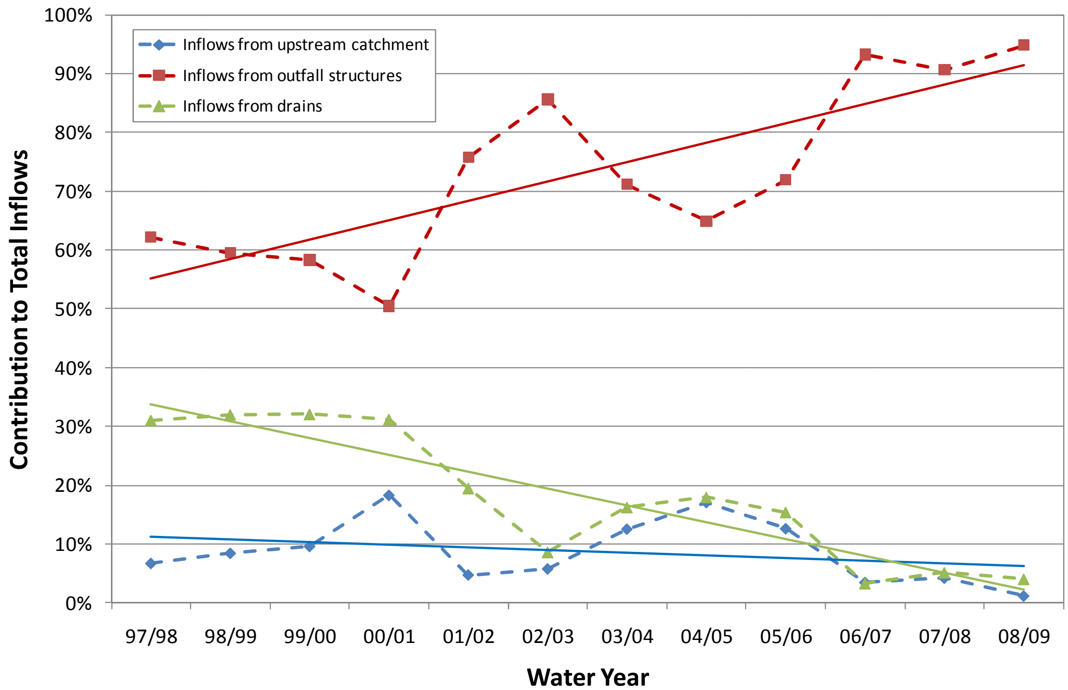

Figure 7-10 **The contribution of inflows from the upstream catchment, outfall structures and drains up to 2009**

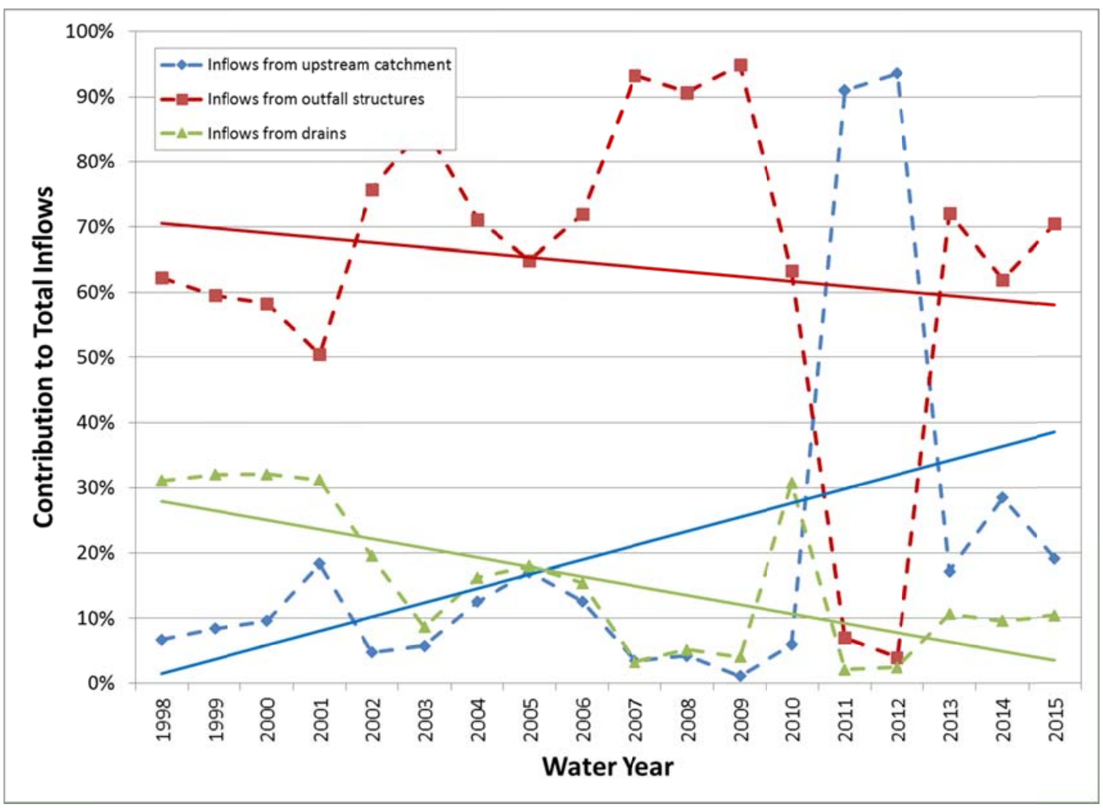

Figure 7-11 **The contribution of inflows from the upstream catchment, outfall structures and drains up to 2015 (limited data post-2009)**

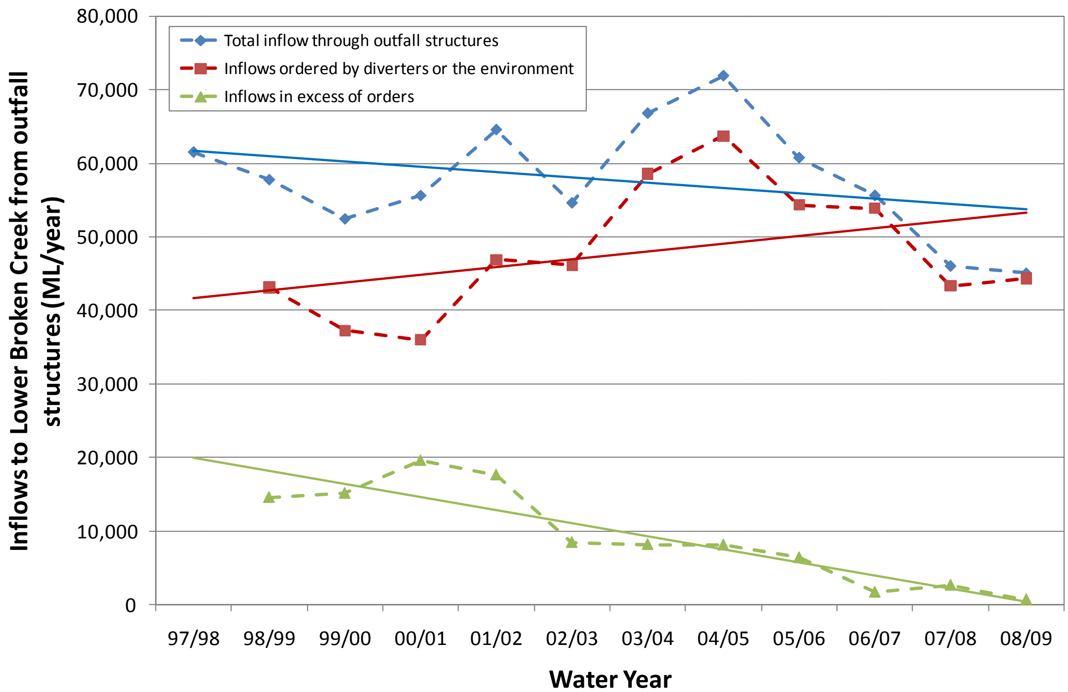

Figure 7-12 **The total inflow through outfall structures, divided into ordered inflows and inflows in excess of orders up to 2009**

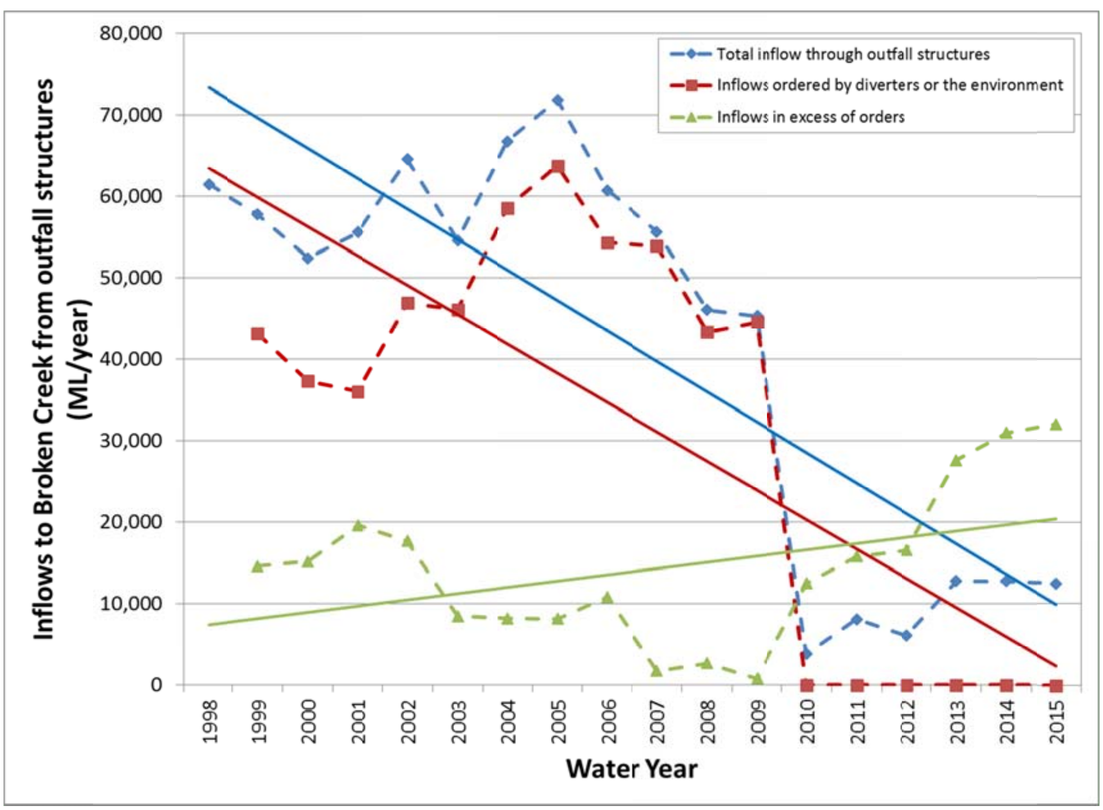

Figure 7-13 **The total inflow through outfall structures, divided into ordered inflows and inflows in excess of orders up to 2015 (limited data post-2009)**

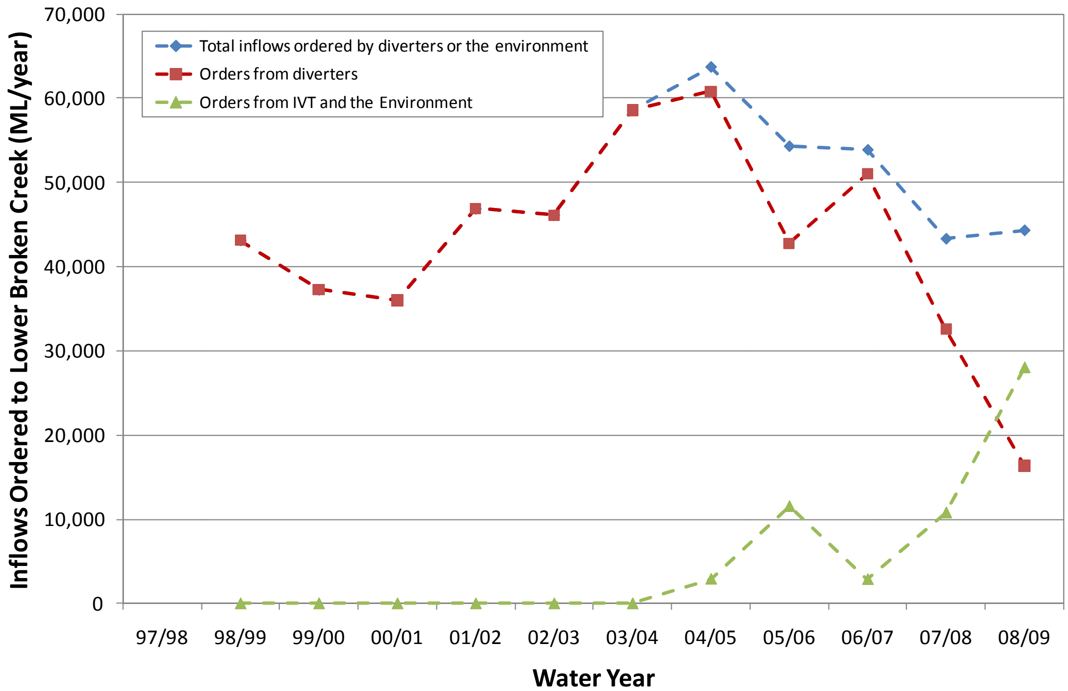

Figure 7-14 The volume of ordered water for diverters, the environment and IVTs to 2009

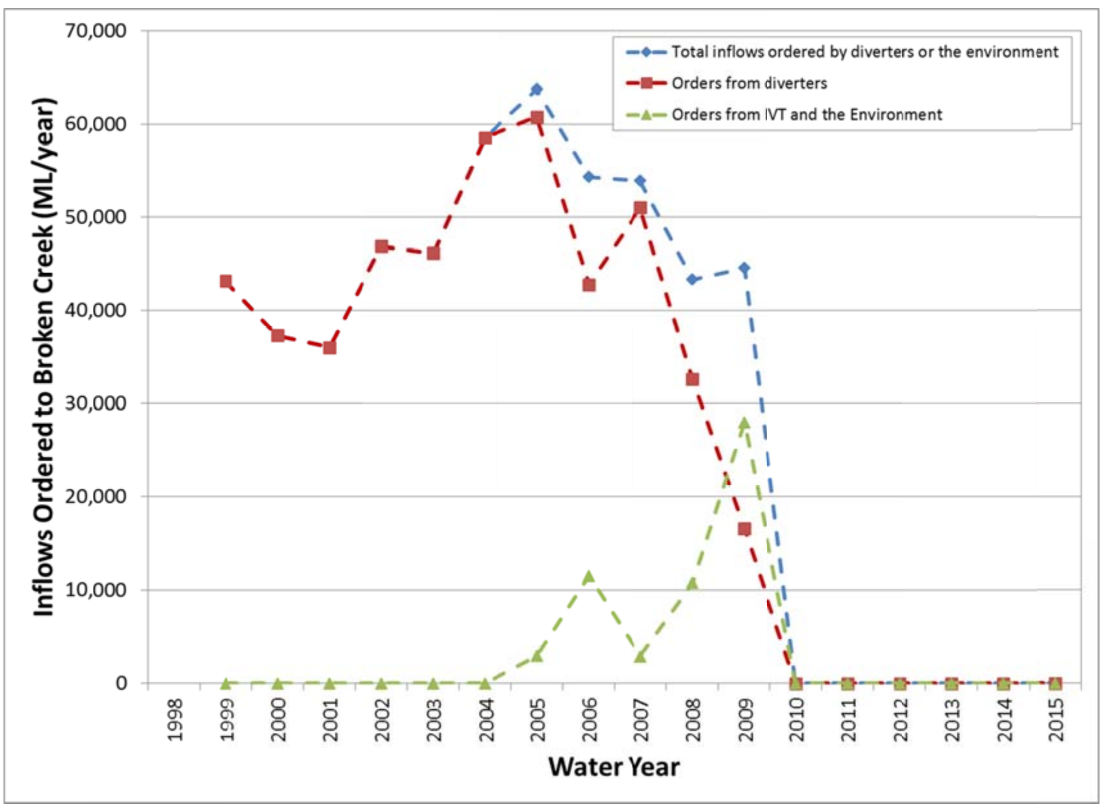

Figure 7-15 The volume of ordered water for diverters, the environment and IVTs to 2015 (limited data available post-2009)

Table 7-2 Murray and Goulburn February irrigation allocations

Water Year	Murray Allocation	Goulburn Allocation
1997/98	130%	120%
1998/99	200%	100%
1999/00	130%	100%
2000/01	200%	100%
2001/02	200%	100%
2002/03	129%	53%
2003/04	100%	100%
2004/05	100%	100%
2005/06	141%	100%
2006/07	95%	25%
2007/08	42%	53%
2008/09	35%	33%
2009/10	100%	100%
2010/11	100%	100%
2011/12	100%	100%
2012/13	100%	100%
2013/14	100%	100%
2014/15	100%	100%

Inflows through outfall structures in excess of orders

Inflows to the Lower Broken Creek and Nine Mile Creek system in excess of orders have declined significantly over the past 10 years. In 2004/05 (which is often used as a base case for assessing the impacts of the GMW Connections Project works), inflows through outfall structures in excess of orders were approximately 8,100 ML. Of this, 6,000 ML was contributed from the Shepparton irrigation district and 2,100 ML was from the Murray Valley irrigation district. In 2009, inflows in excess of orders were only 730 ML, half of which came from both irrigation districts (Figure 7-16). Inflows in excess of orders through Shepparton outfall structures are likely to have been impacted by the Shepparton Modernisation Project, which was in place for the 2008/09 irrigation season.

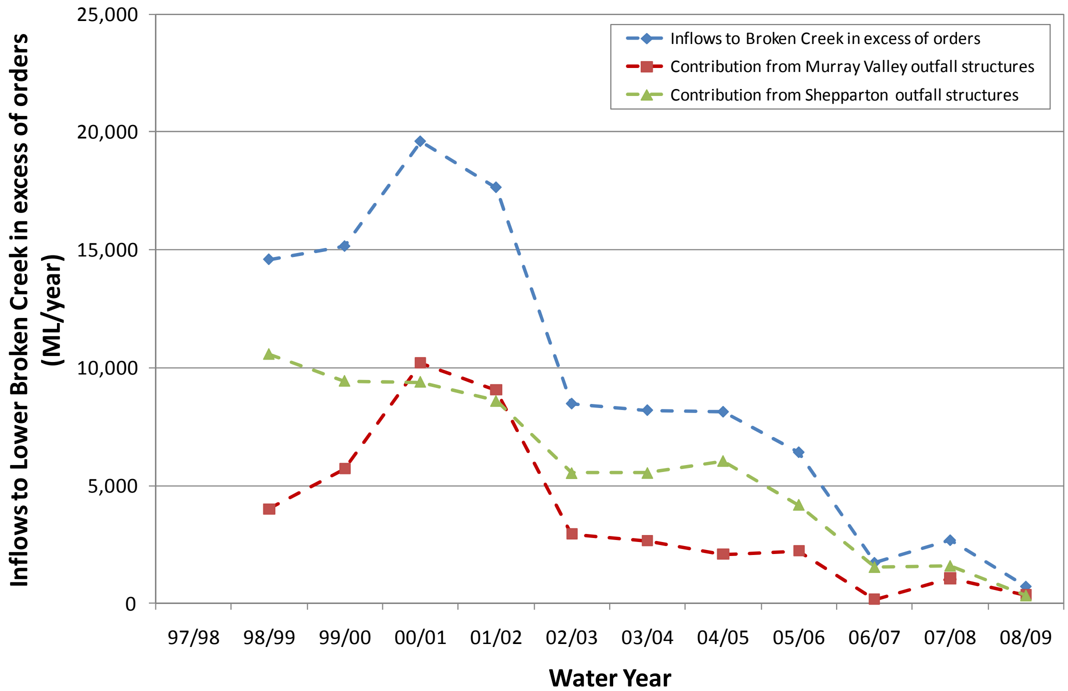

Figure 7-16 The inflows in excess of orders contributed by the Murray Valley outfall structures and the Shepparton outfall structures

Inflows through drains

Inflows to the Lower Broken Creek and Nine Mile Creek system through drains have also declined significantly over the past 10 years. In the late 1990s and early 2000s, drainage inflows to the system were 30,000 ML/year – 35,000 ML/year. In the past few years however, inflows from drains have been a minor component of total inflows. This reduction in drainage inflows is probably attributable to a combination of less rainfall runoff, less runoff from irrigation application, less channel outfalls into drainage systems and increased drainage diversions.

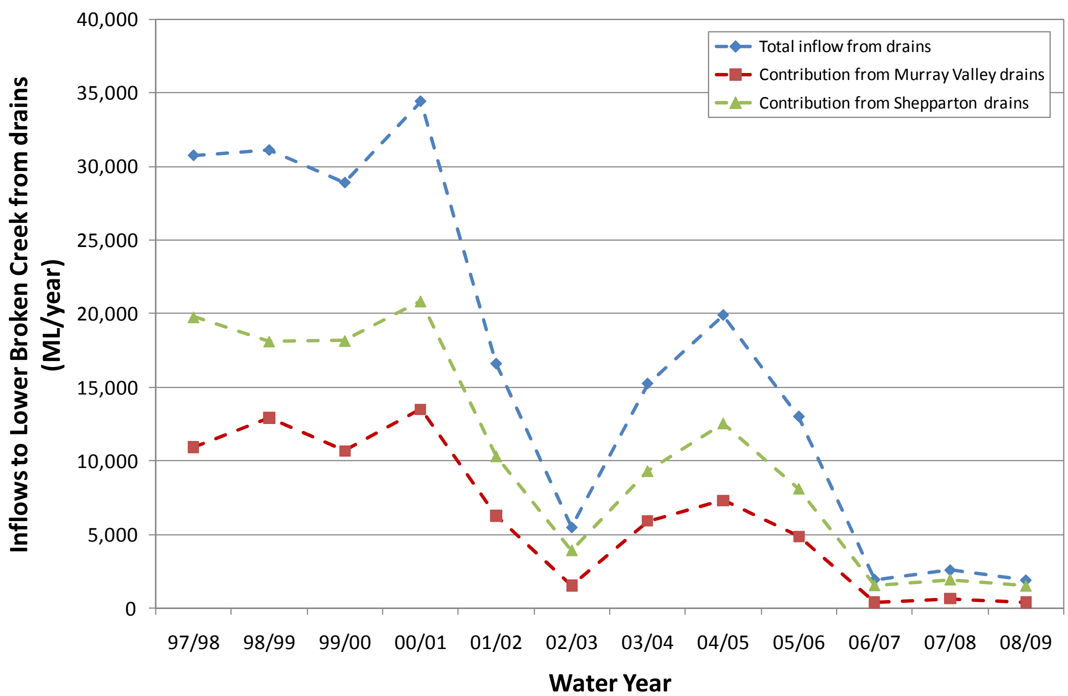

Figure 7-17 The inflow volume from drains contributed by the Murray Valley drains and the Shepparton drains

Murray Valley contributions to total inflows

GMW Connections Project works are being implemented in the Murray Valley irrigation district. Therefore, changes to the Lower Broken Creek and Nine Mile Creek flow regimes attributable to the GMW Connections Project, will be reflected in changes to flow contributions from the Murray Valley side of the creeks. Figure 7-18 shows the inflows through Murray Valley outfall structures (ordered and in excess of orders) and the inflows through Murray Valley drains in comparison with total inflows to the system. This figure shows that inflows in excess of orders through Murray Valley outfall structures are a small component of total inflows.

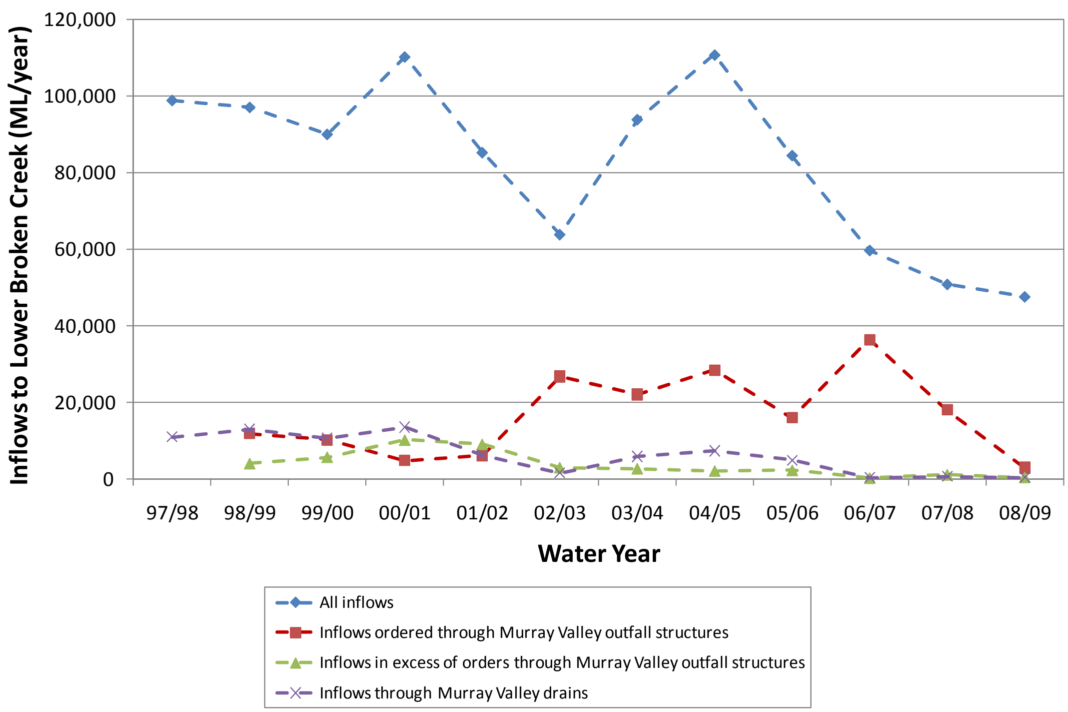

Figure 7-18 Total inflow, inflow through outfalls that will be decommissioned (both ordered and in excess of orders) and inflows through Murray Valley drains

Reach inflows

On a reach by reach basis, the contribution of total inflows is weighted to the upstream end of the study area. This is particularly the case in recent years (i.e. 2008/09), when minimal inflows to the system were recorded downstream of where the Lower Broken Creek and Nine Mile Creek split (Figure 7-19). If it is assumed that flows are split 30%:70% down the Lower Broken Creek and Nine Mile Creek at Katandra weir, inflows to each of the four environmental reaches can be calculated (Figure 7-20).

Given this analysis focuses on inflows, and the contribution of inflows in excess of orders, it needs to be recognised that inflows may not be a reliable indication of flows within the creeks because of diversions and losses. However, for the Lower Broken Creek at least, an understanding of total inflows generally provides a reasonable understanding of flow passing Rices Weir (Figure 7-21). That is, the pattern of inflows generally matches the pattern of flow at Rices Weir, with the differences in magnitude attributable to diversions and losses.

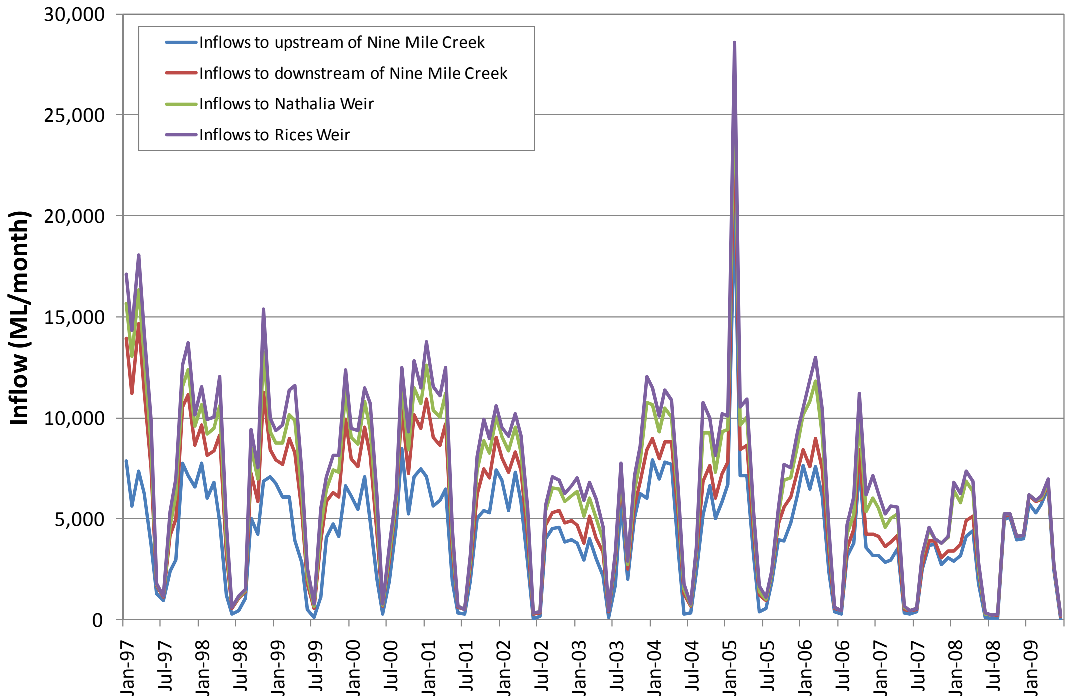

Figure 7-19 Inflows to different locations along the Lower Broken Creek

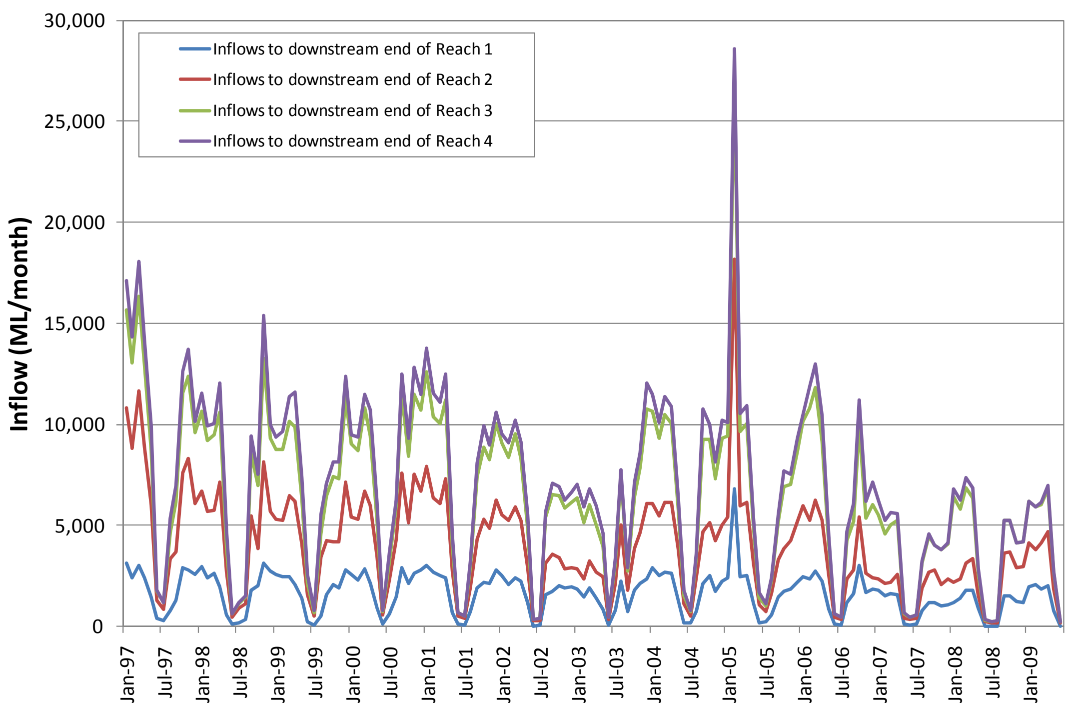

Figure 7-20 Inflows to the four environmental reaches, assuming a 30%:70% division of flows where the Lower Broken Creek and Nine Mile Creek split

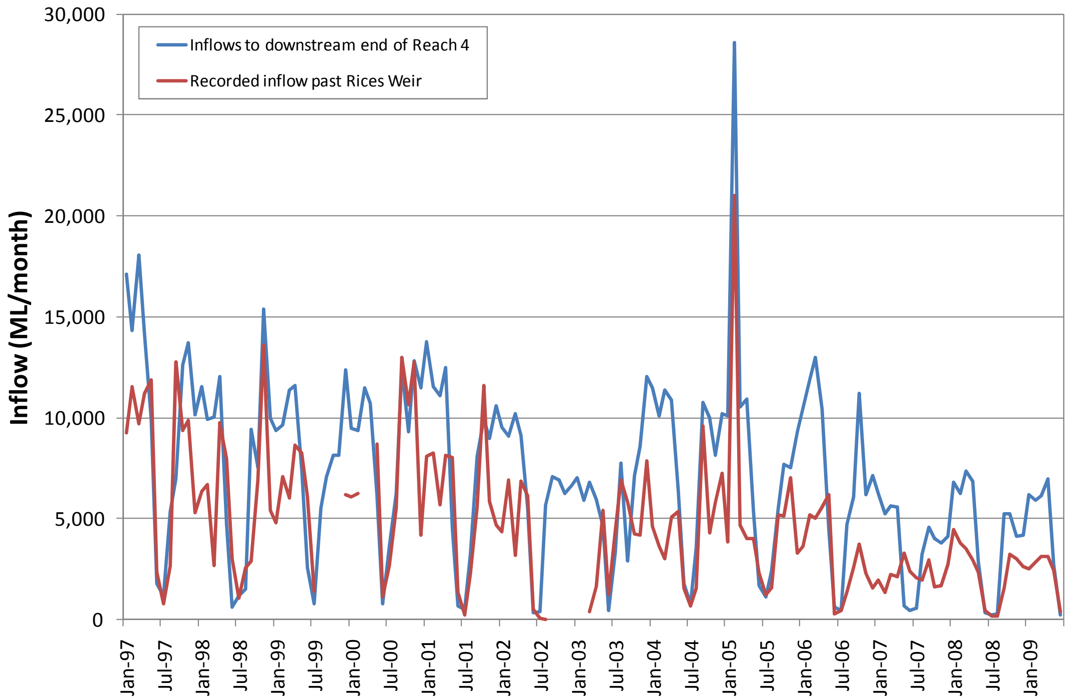

Figure 7-21 Inflows to Rices Weir (the downstream end of Reach 4), compared to recorded flow past Rices Weir

7.4 GMW Connections Project impact assessment

7.4.1 Modelling and data sources

There is currently no long term computer model of the Lower Broken Creek (an existing daily FORTRAN model only covers the period 1st January 1997 to 30th June 2002) and building such a model was well outside the scope and time available for this project.

The analysis of the existing flow regime (Section 7.3) is therefore undertaken using historical records sourced from GMW and Thiess (refer Section 7.3.3). The analysis of GMW Connections Project impacts (Section 7.4.2 onward) is based on modification of the outfall volumes recorded for the period 1998-2009 to reflect the expected impact of the implementation of the GMW Connections Project on the Murray Valley outfalls (i.e. inflows in excess of orders reduced by 85%). The impact of this outfall reduction is then assessed based on the resultant total percentage change in inflows.

The use of recorded outfall volumes, manually modified to reflect the expected outfall reductions, is in contrast to the approach adopted in other EWPs, i.e. the Loddon River EWP (NCCMA 2010) which utilises modelled current and post GMW Connections Project flow sequences from existing REALM modelling.

Given the non-availability of a long-term REALM model for the Broken Creek system (as was available for the development of other EWPs), the adopted approach using recorded outfall volumes is considered a reasonable analysis method for Broken Creek. Had this study shown that GMW Connections Project works are likely to have a significant impact on inflows, the time and money required to develop a long term model of the Lower Broken Creek may have been justified, but this is not the case. A limitation of the adopted approach is that it is not possible to translate the predicted inflow reductions into changes in streamflow for the long term average, base case year (2004/05) or the year with the lowest Murray allocations (2008/09). However, it is logical to surmise that if GMW Connections Project works cause a minimal reduction in inflows, there will be a minimal reduction in streamflows through each of the environmental flow reaches.

7.4.2 Water regime after GMW Connections Project – analysis

The stated aim of the GMW Connections Project is to reduce the inflows though Murray Valley outfall structures in excess of orders (i.e. the outfalls) by 85%. This situation is different to some other irrigation systems, where all the water flowing through an outfall structure is considered an outfall, 85% of which will be saved by GMW Connections Project works. The Shepparton irrigation district was modernised in a separate project (the Shepparton Modernisation Project), but the impact of this project on inflows to the Lower Broken Creek and Nine Mile Creek is not assessed as part of this study.

To reduce the inflows in excess of orders, GMW Connections Project will implement Total Channel Control (TCC). Implementing TCC involves replacing the manually operated drop boards currently used to regulate channel flows, with a system of remotely controlled flume gates. The GMW Connections Project is planning to decommission seven of the eleven Murray Valley outfall structures. Those to be kept are denoted by an asterisk in Figure 7-2. However, for this study, it was assumed the 85% reduction of inflows in excess of orders is distributed along the Lower Broken Creek and Nine Mile Creek reaches in accordance with current inflows in excess of orders. This is considered appropriate, because all reaches will still have inflows from Murray Valley outfall structures (reach two receives a contribution from the Murray Valley 7/3 outfall structure), and the remaining structures will need to pass the flows previously carried by the decommissioned outfalls to meet local diverter orders.

Figure 7-22 to Figure 7-25 show the estimated total inflows to each reach for January 1997 to June 2009, and the total inflows assuming inflows through Murray Valley outfall structures in excess of orders are reduced by 85%. Information for categorising monthly inflows through Murray Valley outfall structures as ‘ordered’ or ‘excess’ are not available for 2000/01, or the years prior to 1998/99. Regardless, these figures show that reducing inflows through Murray Valley outfall structures in excess of orders by 85% would not have a material impact on inflows to the Lower Broken Creek or Nine Mile Creek, especially for 2002/03 onwards.

The expected reduction in inflows in percentage terms is shown in Figure 7-26. If the years 1997/98 to 2001/02 were repeated with GMW Connections Project works in place, the reduction in inflows to Reach 1 would be as high as 18%. Inflows to Reach 3 and Reach 4 would be reduced by as much as 10% and 12% respectively however this was prior to GMW undertaking a loss management program and this level of input is unlikely to occur again. However if the years 2004/05 onwards were to be repeated with GMW Connections Project works in place, the reduction in inflows would be less than 5% for all reaches. Reach 2 (Nine Mile Creek) is particularly unaffected, given no Murray Valley outfall structures discharge to Nine Mile Creek, and only one discharges upstream of where Lower Broken Creek and Nine Mile Creek split.

On a yearly time-step, the expected reduction in inflows would range from 9% in 2001/02 to 0.3% in 2006/07 (Table 7-3). However, it should also be recognised that GMW implemented a loss management program in 2002/03, and losses observed in 2001/02 and prior are unlikely to be repeated while this loss management program continues.

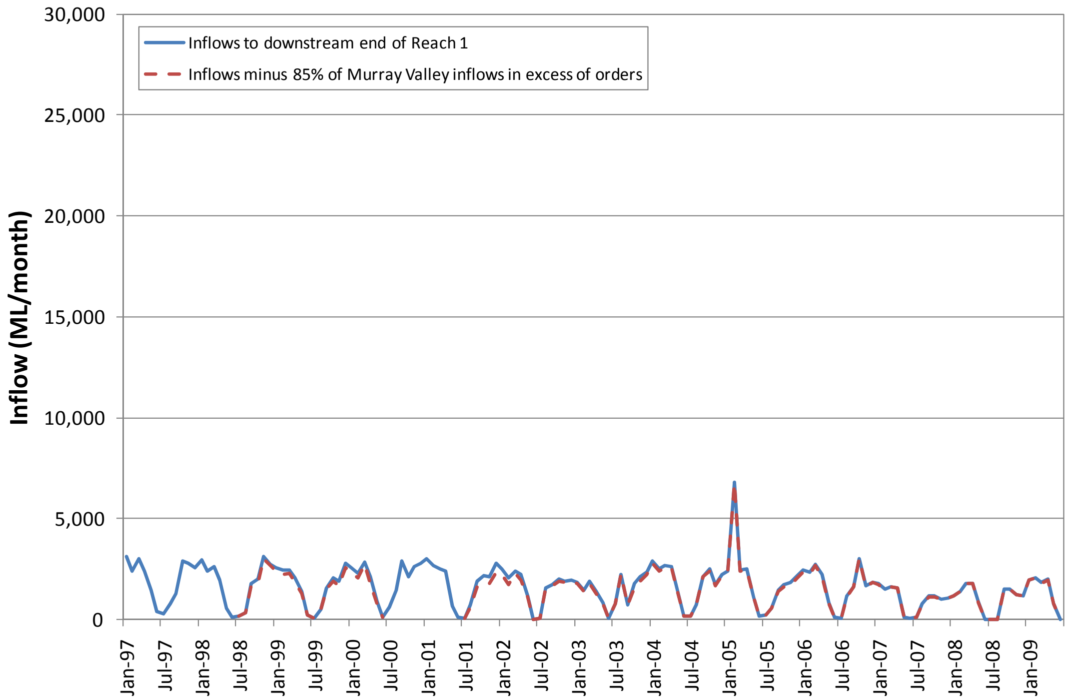

Figure 7-22 The impact of GMW Connections Project works on monthly flows in Reach 1

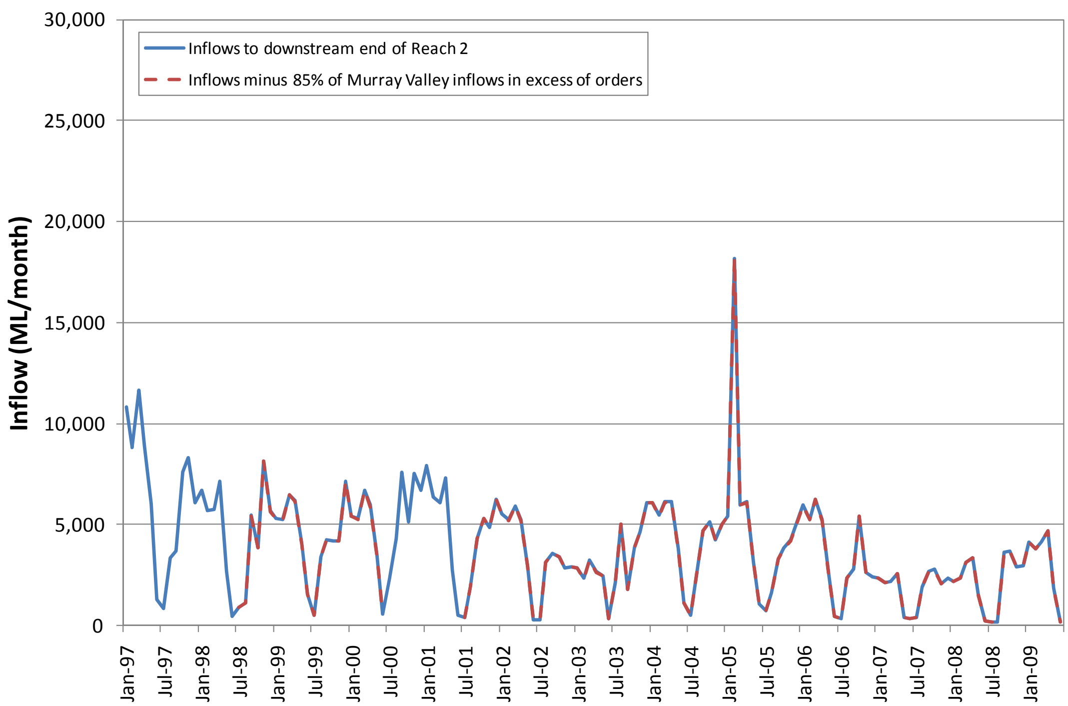

Figure 7-23 The impact of GMW Connections Project works on monthly flows in Reach 2

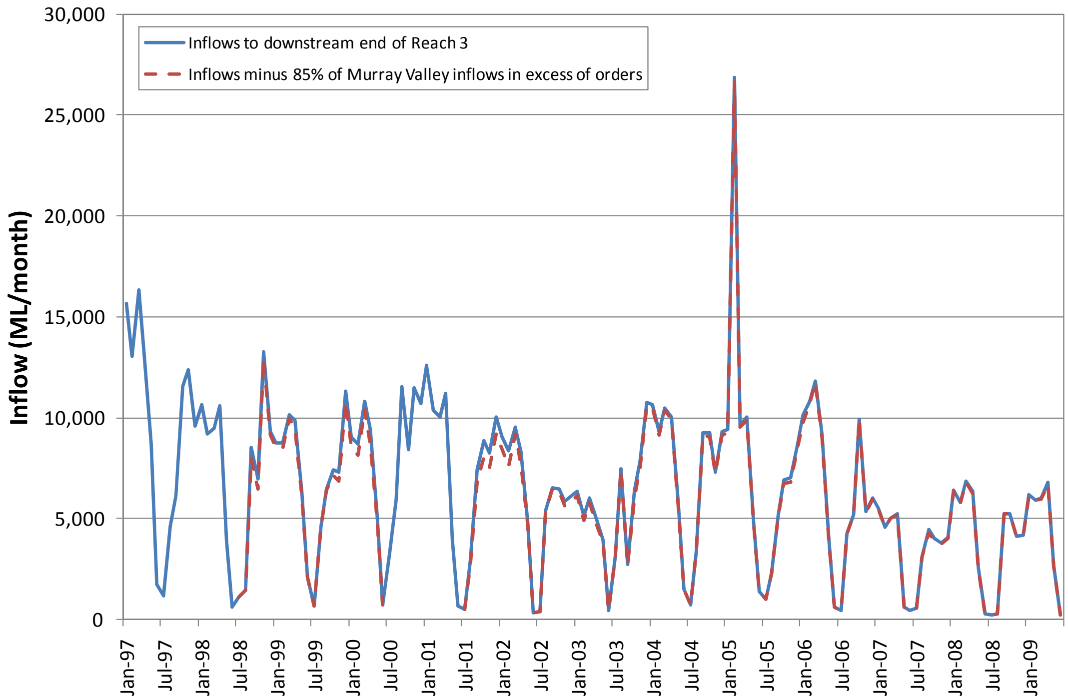

Figure 7-24 The impact of GMW Connections Project works on monthly flows in Reach 3

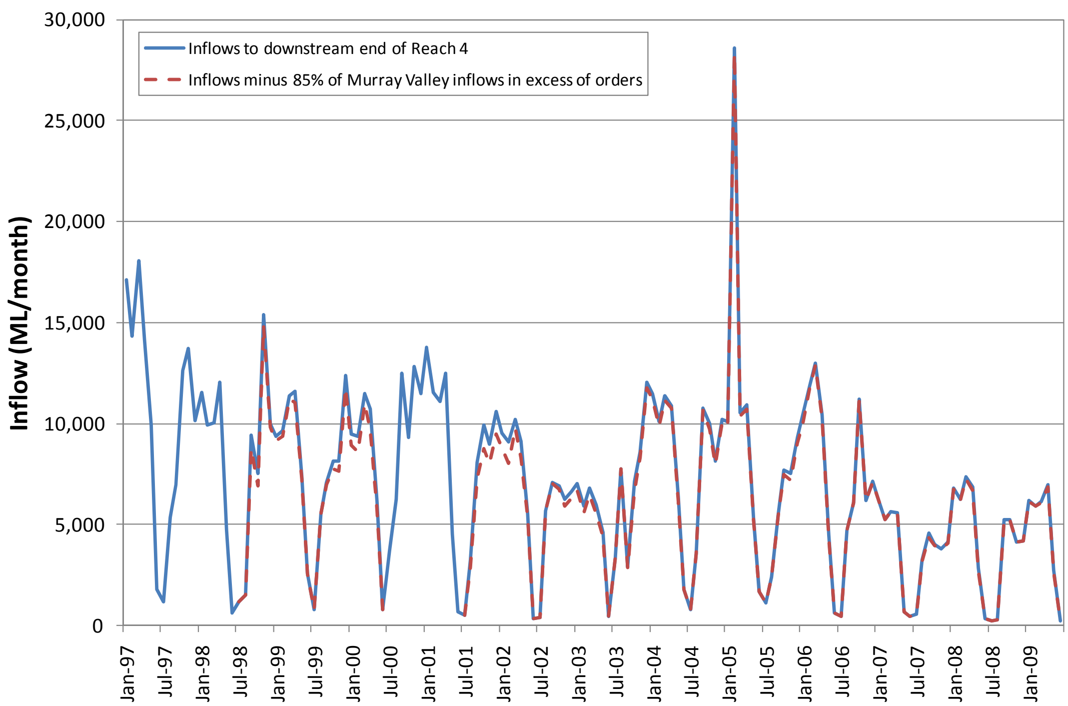

Figure 7-25 The impact of GMW Connections Project works on monthly flows in Reach 4

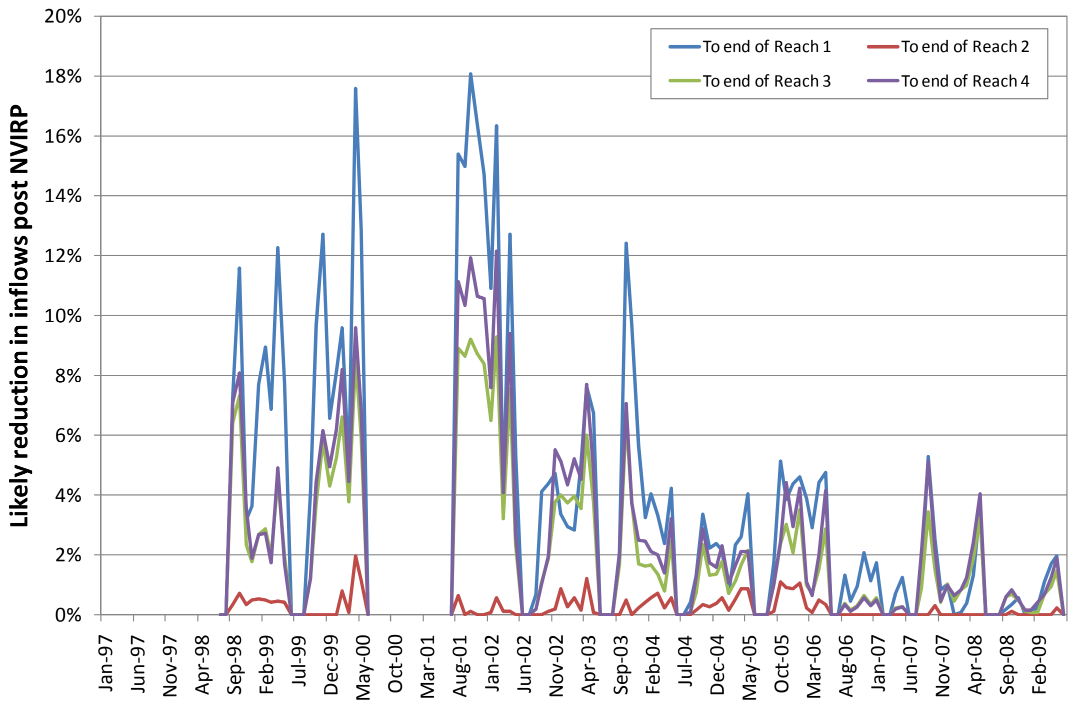

Figure 7-26 **Reduction in inflows because of GMW Connections Project works, assuming inflows through Murray Valley outfall structures in excess of orders are reduced by 85%**

Table 7-3 The annual impact of GMW Connections Project works on total inflows to the Lower Broken Creek and Nine Mile Creek, assuming inflows through Murray Valley outfall structures in excess of orders are reduced by 85%

Year	Total Inflow	85% of Murray Valley Inflows in Excess of Orders (1)	Total Inflow minus (1)	Percent Reduction
1997/98	98,800			
1998/99	97,000	3,400	93,600	3.5%
1999/00	90,000	4,900	85,100	5.4%
2000/01	110,200	8,700	101,500	7.9%
2001/02	85,200	7,700	77,500	9.0%
2002/03	63,800	2,500	61,300	3.9%
2003/04	93,800	2,300	91,500	2.4%
2004/05	110,700	1,800	108,900	1.6%
2005/06	84,400	1,900	82,500	2.2%
2006/07	59,650	100	59,500	0.3%
2007/08	50,800	900	49,900	1.8%
2008/09	47,500	300	47,200	0.7%

7.4.3 Water regime after GMW Connections Project – discussion

Agreed practice under the WCMF is to analyse the impact of GMW Connections Project works assuming a 2004/05 base case (Figure 7-27, which isolates 2004/05 from Figure 7-26). Were the year 2004/05 repeated, the monthly reduction in inflows attributable to GMW Connections Project works would be less than 1% for Reach 2, between 1% and 3% for Reaches 1 and 3, and up to 4% for Reach 4. The impact of GMW Connections Project works during 2008/09 is also of interest, given irrigation allocations in the Murray system that year were the lowest on record. Were the year 2008/09 repeated, the monthly reduction in inflows because of GMW Connections Project works would be less than 2% for each reach (Figure 7-28). It is noted, however, that the 2008/09 was towards the end of the Millennium Drought and followed over a decade of dry years.

Figure 7-27 and Figure 7-28 present the reduction in inflows assuming the only impact of GMW Connections Project works is to reduce inflows through Murray Valley outfall structures in excess of orders. However, this is probably a conservative estimate of the impact of GMW Connections Project works, because there are a number of Murray Valley outfall structures that connect to drains, which in turn discharge to the Lower Broken Creek.

Isolating the contribution of outfalls to drainage flows that enter the creek is difficult. Flows through the outfall structures into drains combine with flows from other sources. Often a portion of drainage flows will be diverted by irrigators before reaching the creek. To test the sensitivity of total inflows to changes in drainage inflows that may result from GMW Connections Project works, it was assumed that drainage flows are evenly comprised of the three major contributors (i.e. 33% rainfall runoff, 33% irrigation runoff and 33% channel outfalls).

Assuming 85% of channel outfalls are saved by GMW Connections Project works, drainage inflows to the Lower Broken Creek and Nine Mile Creek through Murray Valley drains would reduce by approximately 30%.

Figure 7-29 and Figure 7-30 show the impact of GMW Connections Project works on total inflows assuming that inflows in excess of orders through Murray Valley outfall structures that connect directly to the creek are reduced by 85% **and** inflows through Murray Valley drains are reduced by 30%. It should be kept in mind that this 30% reduction in drainage inflows is subjective and most Murray Valley drains are not metered. However, Figure 7-29 and Figure 7-30 show that assuming drain inflows will also reduce does not invalidate the conclusion that GMW Connections Project works will have a minimal impact on total inflows.

Given a long term computer model of the Lower Broken Creek is yet to be developed (an existing daily FORTRAN model only covers the period 1st January 1997 to 30th June 2002), and building such a model was well outside the scope and time available for this project, it is not possible to translate the predicted inflow reductions into changes in streamflow for the long term average, base case year (2004/05) or the year with the lowest Murray allocations (2008/09). However, it is logical to surmise that if GMW Connections Project works cause a minimal reduction in inflows, there will be a minimal reduction in streamflows through each of the environmental flow reaches. Had this study shown that GMW Connections Project works are likely to have a significant impact on inflows, the time and money required to develop a long term model of the Lower Broken Creek may have been justified, but this is not the case.

The changes in water levels throughout the Lower Broken Creek and Nine Mile Creek system attributable to GMW Connections Project works is also predicted to be negligible, given the minimal changes in inflow. This is especially true for the lower reaches of the Lower Broken Creek, where water levels are held artificially high, and variations are dampened, by the many weirs between Nathalia and Rices Weir.

In summary, the flows that pass through the Lower Broken Creek and Nine Mile Creek are much more sensitive to irrigation allocations, the volumes of water ordered by local diverters or environmental managers, and the extent to which the waterway is used for inter-valley transfers, than the contribution of inflows in excess of orders through Murray Valley outfall structures.

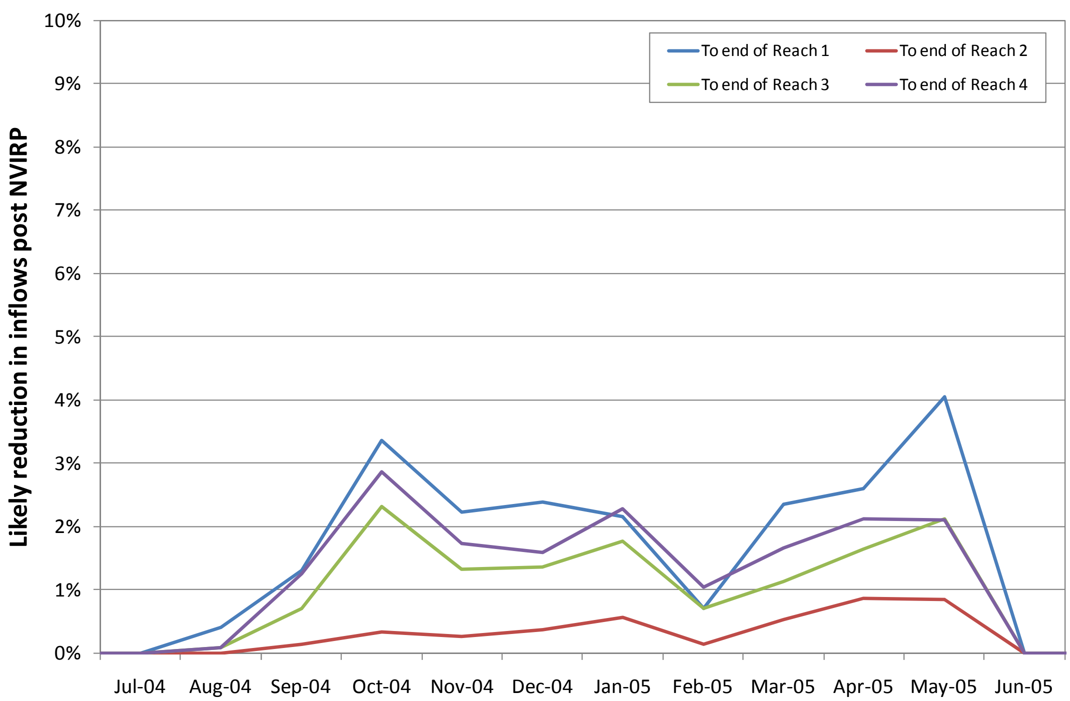

Figure 7-27 Reduction in inflows because of GMW Connections Project works for 2004/05, assuming inflows through Murray Valley outfall structures in excess of orders are reduced by 85%

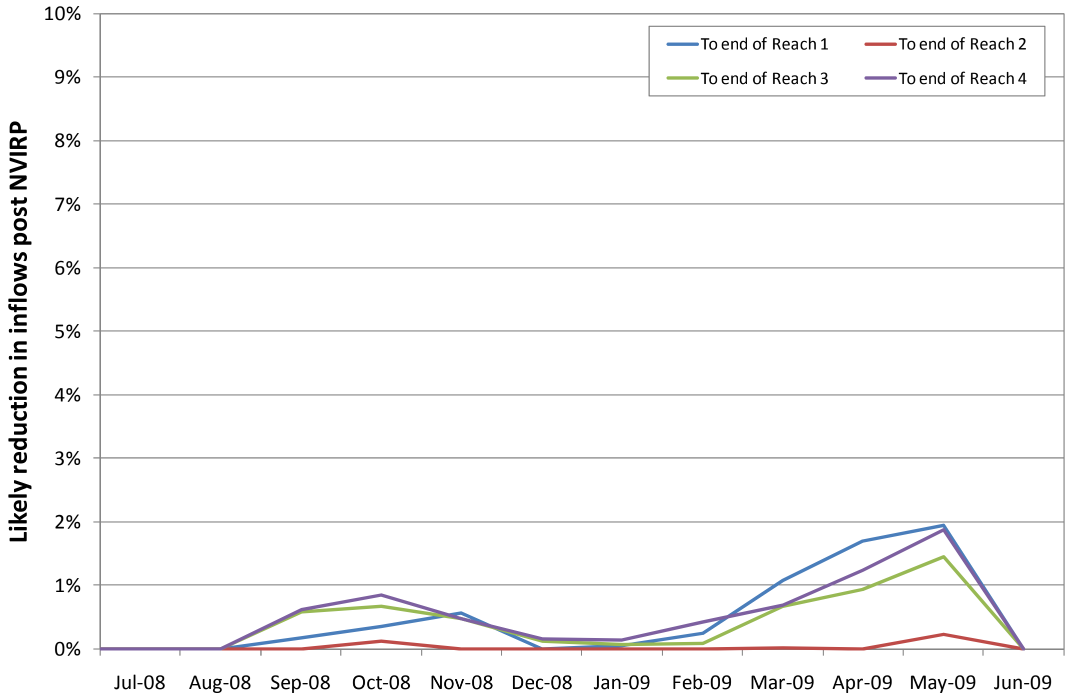

Figure 7-28 Reduction in inflows because of GMW Connections Project works for 2008/09, assuming inflows through Murray Valley outfall structures in excess of orders are reduced by 85%

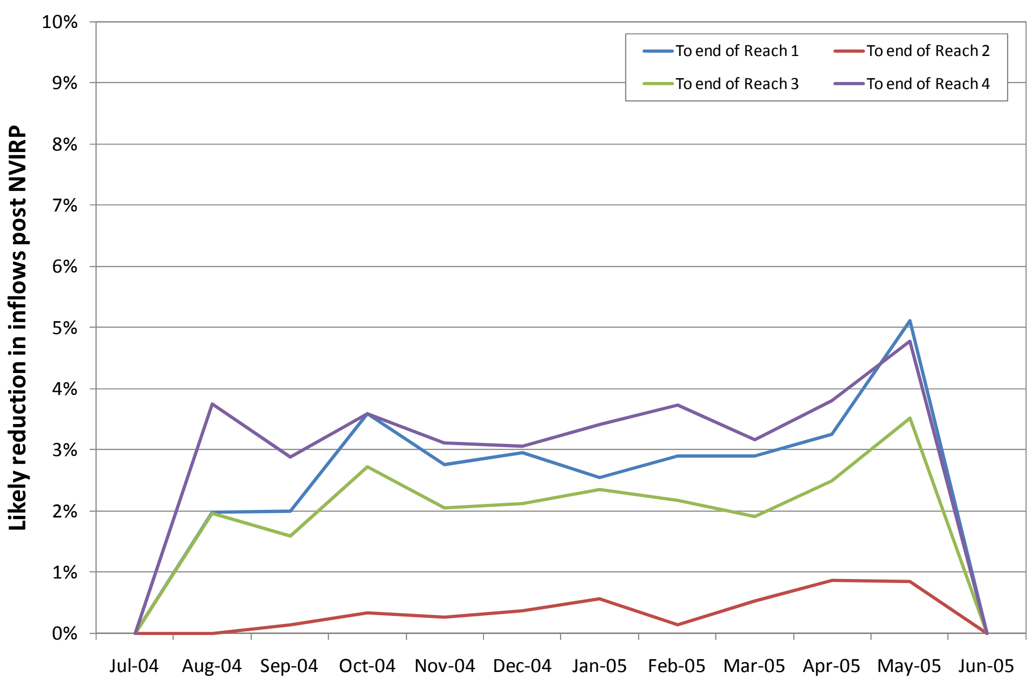

Figure 7-29 Reduction in inflows because of GMW Connections Project works for 2004/05, assuming inflows through Murray Valley outfall structures in excess of orders are reduced by 85% and inflows through Murray Valley drains are reduced by 30%

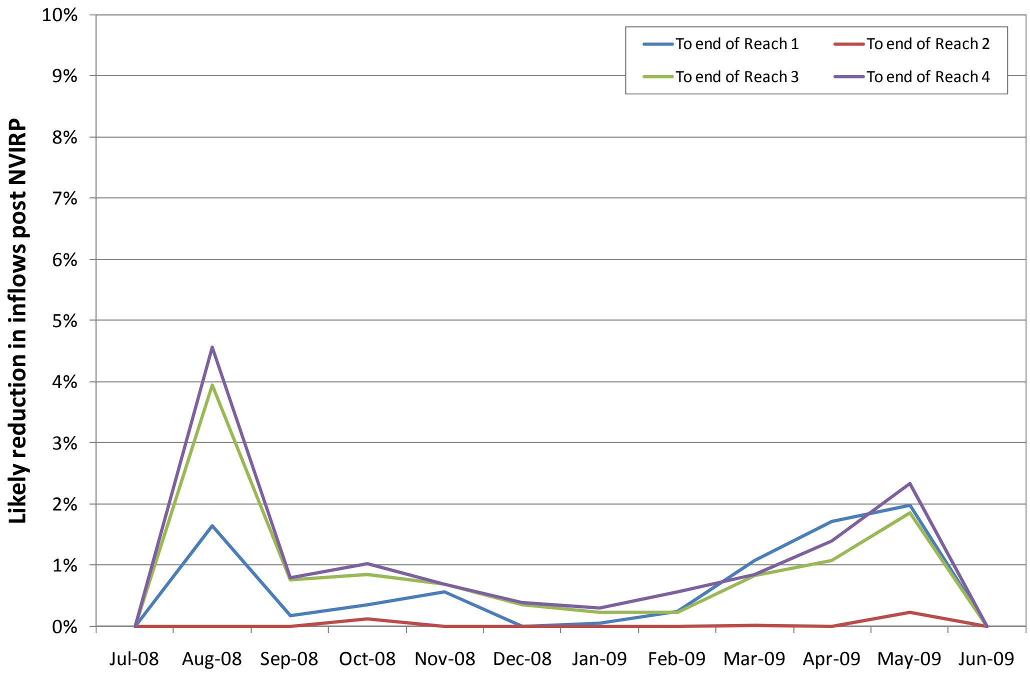

Figure 7-30 Reduction in inflows because of GMW Connections Project works for 2008/09, assuming inflows through Murray Valley outfall structures in excess of orders are reduced by 85% and inflows through Murray Valley drains are reduced by 30%

7.4.4 Water regime after GMW Connections Project – summary

The Lower Broken Creek and Nine Mile Creek is a highly regulated system. The vast majority of inflows to the system come through channel outfall structures that connect directly to the creeks from both the Murray Valley and Shepparton irrigation districts. Inflows through outfall structures are comprised of two parts – inflows ordered by local diverters or environmental managers, and inflows in excess of orders.

GMW Connections Project plans to reduce the inflows through Murray Valley outfall structures in excess of orders by 85%. This is likely to reduce the volume of water flowing down the creeks. However, the contribution of this 'excess' to total inflows is minor, especially post 2002/03. Therefore, reducing Murray Valley inflows in excess of orders by 85% is expected to reduce monthly inflows by less than 4% for all environmental flow reaches, assuming 2004/05 is the base case for this assessment. Even when assuming Murray Valley drainage inflows reduce by 30% because of GMW Connections Project works, the reduction in monthly inflows in 2004/05 remains below 5% for all environmental flow reaches.

8. MITIGATION WATER ASSESSMENT

8.1 Introduction

The implementation of the GMW Connections Project's works within the EWP project area is expected to result in a small reduction in the volume of outfalls to the Broken Creek system, as discussed in Section 7. This will be achieved by rationalisation and re-configuration of the existing water supply system and through improvements in system operation and management. Of the 11 existing drain outfalls discharging to the Broken Creek system waterways, seven will be retained and four removed as part of the system rationalisation. The distribution of outfall volumes may be altered as a result of the changed system operation however the total volume of excess outfall is expected to reduce by 85%.

GMW Connections Project has developed a set of principles and environmental commitments in relation to managing the ecological consequences of hydrological changes arising from implementation of the GMW Connections Project, including avoiding any contribution to diminishing ecological values in waterways and wetlands (NVIRP 2010). Under these principles, "Mitigation water will be provided where water to be saved is shown to have a material and beneficial effect on high environmental values" (NVIRP 2010).

In this context "mitigation water" is defined as the water that is required to ensure no net impacts due to the project on high environmental values. Water savings resulting from the implementation of works under the GMW Connections Project are calculated after supply of mitigation water with water savings defined as the total (gross) volumes saved less the volume of water required to ensure no net impacts due to the project on high environmental values. (NVIRP 2010)

The process for calculation of mitigation water is set out in Attachment G of the GMW Connections Project Water Change Management Framework (NVIRP 2010). Six steps are identified:

- Step 1 Obtain the desired filling frequency or flow regime
- Step 2 Determine the baseline year loss contributions
- Step 3 Assess dependency on mitigation water
- Step 4 Calculate the baseline mitigation water volume
- Step 5 Calculate the mitigation water commitment
- Step 6 Calculate the LTCE[4] mitigation water volume (this is a requirement of the GMW Connections Project water saving reporting and is not included in the EWP)

The calculation of mitigation water in accordance with Steps 1 to 5 is outlined in Sections 8.2 to 8.6.

8.2 Step 1 – Obtain the desired filling frequency or flow regime

Establishment of the desired flow regime for the EWP waterway reaches is informed by the preceding sections of the EWP. For most of the other waterway systems within the GMID impacted by works under the GMW Connections Project, a full environmental flow assessment (using the FLOWS method (NRE 2002)) has been previously undertaken. For the Broken Creek system, a FLOWS study has not previously been completed and thus some additional work is required in the documentation of the required flow regime.

A brief summary of the relevant information from earlier sections of the EWP (principally Section 6 – Environmental Values and) is therefore provided in Table 8-1 to highlight known or likely flow

[4] LTCE = Long-term cap equivalent as defined by NVIRP (2010)

dependencies of the existing environmental assets and assist in identification of the requirements for mitigation water.

Table 8-1 forms the basis for the mitigation water assessment and includes:

- A summary of **high value assets** within each asset group.
- A management **objective** for each high value asset. The objectives currently established in existing plans and strategies (Section 5) for the management and condition of these assets are typically generic and do not directly identify the association between flow or hydrologic regime and the expected environmental outcomes. Asset specific objectives have therefore been developed during the preparation of this EWP based on the broad objectives discussed in Section 5 and inputs from the Scientific Reference Group, community consultation and goal development (further discussed in Section 13.2).
- Known or assumed **flow associations** (linkages between environmental asset condition and flow).
- **Associated threats or processes** which have the potential to impact on the flow association.
- **Flow recommendations (magnitudes)** where identifiable and comment on **the potential for implementation of the GMW Connections Project to impact on the identified assets**, based on the flow magnitude reductions indicated in Section 7

The approach documented in Table 8-1 is consistent with the general process followed in the FLOWS method (NRE 2002) for determination of environmental flow objectives and recommendations, specifically identification of ecological assets, development of environmental objectives for each asset or asset class and identification of key flow processes and flow magnitudes to meet each objective. The main omission relative to the FLOWS method is the cross-section survey and hydraulic modelling which normally informs the process (excluded from the scope of this EWP).

In this regard, the main risk is that the flow magnitudes required to sustain environmental processes (where identified in Table 8-1) are based on the opinion and experience of members of the flow rather than outcomes from hydraulic modelling. This is in contrast to the full application of the FLOWS method where expert opinion is supported by the use of metrics such as flow depth, velocity, wetted area obtained by hydraulic modelling. As the regulated flow regime under consideration in this EWP is comprised of in-channel flows (i.e. overbank flooding is not influenced by flow regulation), the GMW Connections Project impacts in terms of wetted area and habitat availability will be relatively small and thus the absence of hydraulic modelling is less likely to be a critical shortcoming.

Table 8-1 Summary of environmental values and flow association

Asset group	High value assets	Objective	Flow association	Threat or process with potential to impact on high value asset	Flow recommendation and potential for GMW Connections Project impact on identified assets
Geomorphology	The inherited form of the Tallygaroopna channel is likely to be of state or regional significance (based on Rosengren 1987).	Avoid or mitigate impact of hydrologic change on reach scale morphology.	Geomorphic change at the reach scale (planform, channel capacity, anabranch development) is most dominantly influenced by bankfull and larger flows. The hydrologic changes discussed in Section 7 are unlikely to contribute to changes in reach scale geomorphic processes.	Significant change in hydrology influencing large scale morphology.	None – No flow association at regulated flow levels.
	Channel form is not of itself a high value asset but can have critical impact on other high value assets (i.e. Fish habitat, wetland form etc) and therefore should be protected from impact.	Avoid or mitigate impact of hydrologic change on in-channel morphology, specifically avoid further loss of geomorphic diversity.	Process will be dominant in weir pools (principally Reach 4) but could occur locally in upstream reaches. Reduction in flow generally has potential to increase this but velocity reduction in weir pools will be negligible so unlikely to see a significant change.	Ongoing deposition and limited potential for remobilisation of sediment will result in continued aggradation, loss of habitat and contribute to ongoing DO/nutrient issues.	Minor – Requires assessment of deposition conditions / threshold in each reach under current and proposed conditions. Unlikely to see significant change in occurrence of threshold levels as a result of GMW Connections Project.
Floodplain vegetation	Dominant near channel EVCs are endangered: • EVC68 – Creekline grassy woodland • EVC259 – Plains Grassy Woodland / Gilgai Wetland Mosaic • EVC803 – Plains Woodland • EVC168 – Drainage Line Aggregate (Vulnerable)	Avoid or mitigate impact of hydrologic change on high value floodplain EVCs.	Dominant near channel EVCs are Endangered but not identified as flow dependent.	Major change of hydrology above regulated flow level would cause redistribution of communities to suit habitat niche. Increase in permanent water in channel could cause loss of non waterlogging tolerant species (box) found in the existing community.	None – Minor reduction in flow magnitudes within the regulated flow regime will not have any impact on floodplain vegetation communities.
In channel vegetation	Much of the Broken Creek system is covered under the Directory of Important Wetlands in Australia listing. The riparian wetland asset is therefore considered of high value.	Maintain and enhance extent and diversity of native in-channel vegetation associated with the riparian wetland asset (covered under the Directory of Important Wetlands in Australia listing).	In channel vegetation is now dominated by the historically prevailing regulated flow regime (rather than natural regime) and comprises species adapted to permanent and near permanent water with low flow velocities. Species diversity is much reduced compared to natural conditions. Hydrologic modification from GMW Connections Project works will not restore ephemeral system and is unlikely to change species composition although may provide some additional zones for colonisation if there is an increase in short term water level variations.	Vegetation community composition will be influenced by flooding regime and habitat niches. Modification to regime has potential to change composition.	Minor – No quantifiable impact of flow reduction on potential for diverse aquatic vegetation provided wetted channel area is not significantly changed. Improvements in diversity could result from increase in flow variability.
			Aquatic weeds, particularly Sagittaria are an increasing problem. Reduction in flows may increase weed threat in some reaches if conditions for establishment or spread are enhanced.	Suitable areas for colonisation or spread of existing infestations may be increased by modified hydrology.	Minor – Further spread of aquatic weeds is likely under current flow regime and potential for spread is not significantly impacted by the small change in hydrologic regime as a result of GMW Connections Project.

Floodplain wetlands	The Black Swamp / Purdies Swamp system is bioregionally significant as a drought refuge and waterbird habitat and is the only large floodplain wetland with connectivity to the Broken Creek system under regulated flows. Kinnairds Swamp contains significant populations of threatened, flood dependent species but is not flooded by Broken Creek, except in large events (outside EWP scope) – can be connected by system manipulation but is more commonly flooded by Muckatah system.	Avoid detrimental impact on hydrologic regime of floodplain wetland assets.	The Black Swamp / Purdies Swamp system is the only major floodplain wetland with the potential to be connected under regulated flow conditions. Flow greater than 100 ML/d in Nine Mile Creek required to facilitate filling.	Flows in Nine Mile Creek do not exceed CTF of 100 ML/d during period when filling is required.	None – For Black Swamp, a flow of 100 ML/d in Nine Mile Creek during Winter/Spring (Jun-Nov) is required to facilitate filling over a minimum period of 10 days. The target frequency is approximately annual. The potential to fill is unlikely to be impacted by GMW Connections Project.
Fish	Murray Cod (Nationally Listed - Endangered) are found in all reaches but more significant populations in Reaches 3 and 4.	Maintain or enhance self-sustaining native fish populations at current levels with diversity of size classes (all reaches).	Suitable water quality (DO) and temperature. DO<5mg/L increases mortality. Temperatures greater than 30 deg C are undesirable - lowered growth and productivity of individuals and metabolic damage to fish.	DO in Reach 4 likely to drop below limits in Oct-Apr. Require DO > 5mg/L year round. Temperature limits are less frequently exceeded than DO.	None – Dissolved oxygen / nutrient / Azolla interactions in Reach 4 are not fully understood to the point where they can be managed with certainty. Adaptive management approach requires provision of passing flows over Rices Weir to prevent build up of Azolla or flush it through when rapid growth occurs. Recommendation is for flows 150-250 ML/d Oct-Apr to flush Azolla and boost DO levels. The required flow magnitudes are not likely to be impacted by GMW Connections Project hydrologic modifications.
			Spring spawning – Inundate habitat during spawning season (Sep-Nov). Water temperature will trigger spawning and flow will trigger movement.	No ability to move during spawning period.	Minor – Spring spawning (Sep-Nov) requires a flow trigger to commence movement and inundate habitat – GBCMA (2008) recommends 250 ML/d. No indication that GMW Connections Project will impact on flows at this level (dominated by IVTs and irrigation demands).
			Ability to move through system.	Loss of connectivity through fishways and natural / other constructed barriers in all reaches for spawning and location of suitable habitat.	Minor – Year round requirement is minimum flow of 35-40 ML/d for fish to pass upstream through the fishways on weirs in all reaches to access appropriate habitat. Not likely to be satisfied outside of irrigation season.
			Available and suitable habitat is dominated by weir pools – levels unlikely to be impacted by reduced flow in Reach 4.		
	Murray Darling rainbowfish and Unspecked hardyhead (FFG – Threatened) in all reaches.		Availability of wetted habitat with in-channel / fringing vegetation is the critical control on population (+ competition from small bodied introduced species). Subject to the same biological limits (temperature and DO) as large bodied species.	Drying of channel or loss of connectivity for longitudinal movement.	Minor – Cease to flow periods not tolerable for small bodied fish but minimum flows required for passage of large bodied fish will satisfy habitat requirements for small bodied fish. Incidence of cease to flow not significantly impacted by the GMW Connections Project.

Threatened species – Flora	19 Threatened Flora species with a likely waterway association/habitat have been identified within the EWP reaches. Of these, three are aquatic, 14 grow on or around waterway margins and two require seasonal flooding.	Maintain or enhance self-sustaining populations of identified flood/water dependent threatened species.	Aquatic species will require wet habitat (shallow-deep), other species will be found around the margin of pools, particularly where water level variation occurs. Ephemerally flooded species may be on higher ground.	Significant modification in the extent of wetted, marginal or ephemerally flooded habitat may impact on species distribution or viability.	Medium – Little is known of the spatial and seasonal distribution of many of the threatened species and thus the impact of GMW Connections Project flow modifications cannot be readily quantified. Relatively short term variations in regulated water levels (as may be impacted by GMW Connections Project) have potential to impact on germination and survival of some species.
Threatened species – Fauna	Large number of threatened fauna species but only fish and to a lesser degree frogs are fully dependent on the aquatic habitat influenced by regulated flows. Birds, mammals and reptiles are dependent on the health of the riparian zone but within the context of the EWP this is more significantly influenced by land management practice than modified hydrology. The listed fish species (as discussed above) therefore remain as the aquatic / water dependent threatened fauna species.	Maintain or enhance self-sustaining populations of identified threatened fauna species dependent on the aquatic environment.	Impact on threatened fauna species is dominated by the impact on fish, discussed above. Birds may utilise the waterway zone for breeding but this will be dominated by flooding events in the broader floodplain wetlands (outside the scope of the EWP). Provision of food is dependent on aquatic and riparian ecosystems covered under the other asset groups and / or not influenced by the regulated flow regime. The threatened frogs (Giant Bullfrog *Limnodynastes interioris* and Growling Grass Frog *Litoria raniformis*) are dominantly associated with wetland habitats not influenced by the GMW Connections Project hydrologic modifications.	Related to fish only – see above	None (excluding fish above)
Macro-invertebrate community	No specific high value species or communities.	Manage to increase diversity of macroinvertebrates by complementary actions.	Macroinvertebrate population in Reaches 1-3 is probably typical of other lowland river systems. Degraded community composition in Reach 4 reflects constant weir pool levels and limited habitat variability. Macroinvertebrate population and composition is dominated by habitat availability, not flow regime. Modifications to hydrology are unlikely to impact macroinvertebrate diversity.	Absence of refuge in cease to flow periods would cause community deterioration.	None – No flow dependence at the scale of hydrologic change discussed in Section 7 – cease to flow is not likely under GMW Connections Project modification.
				Loss of habitat variability due to changed geomorphic process or in-stream vegetation	None – No flow dependence at the scale of hydrologic change discussed in Section 7. Introduction of habitat (LWD) in Reach 4 could increase macroinvertebrate diversity. Additional variation in weir pool level has potential to inundate fringing habitat (where present) and improve diversity.

8.3 Step 2 – Determine the baseline year loss contributions

Not undertaken as mitigation water is assessed as not required – refer Section 8.4.

8.4 Step 3 – Assess dependency on mitigation water

Section 9 of the Water Change Management Framework (NVIRP 2010) sets out criteria under which the volume of mitigation water may be assessed as zero. In general terms, this applies where the environmental asset do not currently receive an identifiable benefit from the provision of water via the irrigation system i.e. if any of the following conditions apply:

- When there is no hydraulic connection between the irrigation system and the environmental asset.
- When the water supplied by the irrigation system is surplus to that required to support the asset, occurs at a time that is detrimental to the environmental value or is of poor quality.
- When the irrigation water forms a very small proportion of the water required to support the environmental value.

The specific criteria area for each of these conditions are assessed in a mitigation water dependency assessment, as outlined in Table 8-2.

Table 8-2 Mitigation water dependency assessment (after NVIRP 2010 and NCCMA 2009)

<table>
<tr><th>Criteria by which mitigation water may be assessed as zero</th><th>Link between outfall water (losses) and environmental values</th></tr>
<tr><td colspan="2">Mitigation water may be assessed as zero where:</td></tr>
<tr><td>There is no hydraulic connection (direct or indirect) between the irrigation system and the wetland or waterway</td><td rowspan="2">The irrigation system is directly linked to the Broken Creek system with 11 Murray Valley outfall structures currently discharging directly to the Broken Creek system. 12 outfalls discharge to drains with subsequent discharge to the creek system. As discussed in Section 7.4, the impact of the GMW Connections Project on total outfall volumes is small even using conservative assumptions regarding the percentage of outfalls discharged via drains which subsequently enter the creek system. This degree of connectivity does not satisfy the criteria by which mitigation water may be assessed as zero.</td></tr>
<tr><td>The water does not reach the wetland or waterway with environmental values (e.g. the outfall is distant from the site and water is lost through seepage and evaporation before reaching the area with environmental values)</td></tr>
<tr><td>The margin of error in the estimate of mitigation water is greater than the savings available from the relevant system operating component (e.g. the specific outfall)</td><td>The percentage reductions in total inflows to the Broken Creek system as a result of the GMW Connections Project are discussed in Section 7.4 and Appendix D. The flow reductions on both a monthly and annual basis are small, particularly in recent years (2002 onward). Reductions in total annual inflow would be less than 10% in all years (1997/98 to 2008/09) or less than 4% since 2002/03 (Table 7-3). In the 2004/05 baseline year flow reductions are less than 4% in all reaches with the smallest impact in Reach 2 (<1%) and the greatest impact in Reach 1 (<4%) (Figure 7-27). These flow reductions are less than the feasible accuracy of flow recommendations documented in Table 8-1 and thus mitigation water may be assessed as zero.</td></tr>
</table>

Criteria by which mitigation water may be assessed as zero	Link between outfall water (losses) and environmental values
Mitigation water may be assessed as zero where the wetland or waterway receives water from the irrigation system:	
That is surplus to the water required to support the environmental values (e.g. changing from a permanently wet to an intermittently wet or ephemeral regime is beneficial or has no impact)	While the seasonality of flows in the Broken Creek system is essentially reversed compared to natural conditions, the regulated hydrology over the last 50-years has effectively determined the occurrence and distribution of the current environmental assets. The environmental values are thus reliant on major elements of the current regime and thus mitigation water may not be assessed as zero according to this criterion.
During a season that is detrimental to the environmental values	
That is of poor quality (or results in water of poor quality entering a site e.g. seepage resulting in saline groundwater intrusions to wetlands) and the removal of which would lead to an improvement in the environmental values	The current water quality is a factor in the DO / Azolla interactions in Reach 4 however removal of irrigation water would not rectify this issue, given the high nutrient loads in bed sediment and thus mitigation water may not be assessed as zero according to this criterion.
Mitigation water may be assessed as zero where the environmental values:	
Do not directly benefit from the contribution from the irrigation system (e.g. river red gums around a lake may not directly benefit from an outfall and may be more dependent on rainfall or flooding)	The identified environmental values are dependent largely on the regulated flow regime and thus mitigation water may not be assessed as zero according to this criterion.

Mitigation water may be assessed as zero if any of the above criteria apply. As the magnitude of the reduction in flow is less than the degree of uncertainty associated with assessment of flow requirements to sustain the identified environmental assets, mitigation water may be assessed as zero in all EWP reaches.

8.5 Step 4 – Calculate the baseline mitigation water volume

Not required given that mitigation water may be assessed as zero in accordance with Section 8.4.

8.6 Step 5 – Calculate the mitigation water commitment

Not required given that mitigation water may be assessed as zero in accordance with Section 8.4.

8.7 Other water sources

The annualised baseline mitigation water volume only represents 13% of the mean long-term annual volume of water required to deliver the desired water regime to (447 ML). GMW Connections Project are only accountable for mitigating any potential impact from the project i.e. for provision of mitigation water as a proportion of the total outfall, seepage and leakage volumes received by the wetland if they are supporting high environmental values. As such, it is important that the environmental water holder secures additional sources of water in years when water is proposed to be filled. The most likely additional sources of water will be existing and future environmental entitlements.

Potential sources of environmental water to provide the desired water regime to Lower Broken and Nine Mile Creeks are discussed below.

8.7.1 75 GL environmental entitlement

Water savings generated by GMW Connections Project will provide up to 75 GL to be vested in the Minister for Environment and Climate Change as an Environmental Water Entitlement. This environmental water is in addition to Government's commitments to provide water for the Living Murray process and will be used to help improve the health of stressed wetlands and waterways in Northern Victoria and the River Murray (NVIRP 2010).

In addition, the Australian Government may co-invest in Stage 2 of GMW Connections Project which will generate up to 100 GL of water savings, some of which will be allocated to the environment. This water will be available for use across the Murray Darling Basin.

8.7.2 Commonwealth environmental water

Under Water for the Future the Australian Government has committed to purchase water in the Murray-Darling Basin over 10 years. The program will complement a range of other measures to address sustainable water management in the Basin. The Commonwealth Environmental Water Holder, in DoE, will manage the Commonwealth's environmental water.

The Water Act 2007 provides that "the Commonwealth Environmental Water Holder must perform its functions for the purpose of protecting or restoring environmental assets so as to give effect to relevant international agreements". Wetlands of International Importance (Ramsar wetlands) are considered priority environmental assets for use of the Commonwealth environmental water (DEWHA 2008). It is the current practice of the MDBA to pass a base flow around Barmah via the Murray Channels to meet Environmental watering requirements downstream and this is expected to continue into the foreseeable future.

9. USING MITIGATION WATER TO MANAGE IMPACTS

No requirements for mitigation water have been identified in the development of this EWP.

10. RISKS

While no requirement for mitigation water has been identified in development of this EWP, risks to the future condition of the high value environmental assets may still arise in association with implementation of works under the GMW Connections Project. Critical risks are summarised in Table 10-1. Recommendations to manage these risks are included in Section 11 (Adaptive Management) and Section 15 (Management Actions).

Table 10-1 Risks associated with GMW Connections Project implementation

<table>
<tr><th>Risk</th><th>Impact</th><th>Management response</th></tr>
<tr><td>Flow dependency of environmental assets not fully represented by EWP process.</td><td>Flow regime assessed as providing acceptable conditions for environmental asset may not allow objective to be satisfied.</td><td rowspan="3">Address key knowledge gaps as identified in Section 14.

Monitor condition of environmental assets and provide for review of EWP and water delivery in the future (refer Section 11).</td></tr>
<tr><td>GMW Connections Project works provide greater water savings than targeted, resulting in greater impact on stream flows.</td><td>Additional hydrologic impact (i.e. reduction in stream flow) could stress environmental assets beyond thresholds.</td></tr>
<tr><td>Reduction in outfalls due to the GMW Connections Project has local effects not identified by reach scale analysis.</td><td>Assets or values in immediate proximity to outfalls may be more exposed to changed hydrologic regime than indicated by analysis undertaken at reach scale.</td></tr>
<tr><td>Timing, spatial distribution or magnitude of irrigation deliveries (and hence stream flows) change significantly due to factors external to the GMW Connections Project (i.e. climate change, industry change).</td><td>Potentially greater impact than the water savings proposed under the GMW Connections Project as environmental assets dependent on relatively large water volumes (passage for fish, flushing flows for water quality and Azolla) are largely supported by irrigation deliveries currently.</td><td rowspan="2">Monitor condition of environmental assets and provide for review of EWP and water delivery in the future (refer Section 11).

Review and formalise means by which irrigation deliveries including IVTs are managed to achieve water supply obligations and protection of environmental assets (refer Section 15).</td></tr>
<tr><td>Flows currently available through IVTs or the Goulburn Water Quality Reserve become unavailable to the Broken Creek due to changed operation of waterway systems external to Broken Creek.</td><td>As Broken Creek within the EWP project area has no current environmental flow entitlement (excluding some undefined portion of the Goulburn Water Quality Reserve), reduction in IVT usage or availability of the Goulburn Water Quality Reserve has potential large impact on those objectives not satisfied by flows associated with irrigation deliveries.</td></tr>
</table>

11. ADAPTIVE MANAGEMENT FRAMEWORK

A key GMW Connections Project principle is that an adaptive management approach is adopted to ensure an appropriate response application of the scientific method to management (Section 9.4, GMW 2013).

Adaptive management is a continuous management cycle of assessment and design, implementation, monitoring, review and adjustment. Table 11-1 shows how the adaptive management approach will be applied in the context of this EWP.

Table 11-1 Adaptive management framework

Adaptive management phase	Application to this EWP (Responsible agency)	When (Sections 15 and 19, GMW 2013)
Assessment and design	Assessment identifies environmental values, their water dependencies, and the potential role of incidental water. Design determines the desired water regime to support environmental values and determines any mitigation water commitment. Details of both these phases are documented in this EWP. (GMW Connections Project)	2015
Implementation	Implementation is the active management of environmental water, of which mitigation water may form a portion, consistent with this EWP. (Goulburn Broken CMA)	Continuous
Monitoring (and reporting)	Monitoring is gathering relevant information to facilitate review and enable any reporting obligations to be met. Two types of monitoring are required. Compliance monitoring is checking that the intended water regime is applied. Performance monitoring is used to inform the review of the effectiveness of the mitigation water contribution to achieving the water management goal by monitoring individual ecological objectives. (Goulburn Broken CMA).	Annual
Review	Review is evaluating actual results against objectives and identifying any improvement opportunities which may be needed. (GMW Connections Project, until responsibilities transferred to other agencies)	2015, 2020, 2025, etc
Adjustment	Adjustment is determining whether changes are required following review or after considering any new information or scientific knowledge and making any design changes in an updated version of the EWP. (GMW Connections Project, until responsibilities transferred to other agencies, adjustment is limited to the extent that the new information relates to the impact of the GMW Connections Project at the time of the impact occurred, and only insofar as the new information could change the mitigation outcomes)	2015, 2020, 2025, etc

11.1 Monitoring and reporting

Mitigation water is not required assuming the current environmental and consumptive water regime is maintained. It is expected the Goulburn Broken CMA will monitor environmental water delivery (i.e. quantity, timing, duration and frequency) and implement a monitoring program to enable assessment of the maintenance of hydrological and ecological objectives. GMW Connections Project will not implement a detailed monitoring program. It is beyond the scope of this EWP to provide a detailed monitoring program to determine the effectiveness of the desired water regime in achieving ecological objectives and the water management goal.

11.2 Review

Periodic reviews provide the opportunity to evaluate monitoring results in terms of compliance, ecological objectives and to learn from implementation.

It is expected this EWP will be reviewed in 2015, 2020 and every five years thereafter, or at any time, if requested by the Victorian Minister for Water or Commonwealth Minister for the Environment (Sections 15 and 19, GMW 2013). The GMW Connections Project is responsible for reviews until such time as responsibility is transferred.

12. MANAGEMENT AND GOVERNANCE ARRANGEMENTS

A summary of the roles and responsibilities of the various bodies relating to the delivery and review of management and mitigation measures is provided in (GMW 2013). Table 12-1 outlines the roles and responsibilities before and during the implementation of GMW Connections Project in the modified GMID.

Table 12-1 Roles and Responsibilities

Agency	Assess and develop management and mitigation measures	Deliver and review management and mitigation measures during GMW Connections Project implementation
GMW Connections Project (until such time as responsibility is transferred)	• identify and account for water savings, subject to audit by DELWP accredited auditor • Lead the assessment and development processes for management and mitigation measures including developing and gaining approval to the WCMF (which guides the development of EWPs and the assessment of mitigation water). • Maintain short-list of all wetlands, waterways and groundwater dependent ecosystems for mitigation. • Identify and source mitigation water required to implement management and mitigation measures including the adaptive development of EWPs. • Retain or provide infrastructure to deliver water to wetlands and waterways. • Convene and chair the Environmental Technical Advisory Committee. • Convene the Expert Review Panel	• Apply, review and, as necessary, develop amendments and gain approval to updated versions of the WCMF. • Provides resources to enable monitoring and review of management and mitigation measures • Establish protocols for transfer of responsibility to relevant agencies. • Coordinate with other agencies to deliver management and mitigation measures. • Arrange for the provision of delivery and measurement infrastructure including capacity and operational flexibility for mitigation water
Catchment Management Authority	• Identify and inform GMW Connections Project of opportunities for best practice. • Inform GMW Connections Project of its infrastructure requirements to deliver environmental water. • Participate in the Environmental Technical Advisory Committee. • Agree to implement relevant components of Environmental Watering Plans. • Agree to implement other relevant regional management and mitigation measures required due to the implementation of GMW Connections Project.	• Advise Environmental Water Holder and system operator on priorities for use of environmental entitlements (including mitigation water) in line with recommendations outlined in the EWPs • Implement the relevant components of Environmental Watering Plans. • Operate, maintain and replace, as agreed, the infrastructure required for delivery of mitigation water, where the infrastructure is not part of the GMW irrigation delivery system. • Report on environmental outcomes (e.g. wetland or waterway condition) from the delivery of the water, in the course of normal reporting on catchment condition. • Where agreed conduct the periodic review of EWPs and report results to GMW Connections Project. • Manage and report on other relevant catchment management and mitigation measures required due to the implementation of GMW Connections Project.
Land Manager (Public and private as relevant)	• Identify and inform GMW Connections Project of opportunities for best practice. • Participate in the Environmental Technical Advisory Committee. • Agree to implement relevant components of Environmental Watering Plans. • Agree to implement other relevant regional management and mitigation	• Implement the relevant components of Environmental Watering Plans. • Operate, maintain and replace, as agreed, the infrastructure required for delivery of mitigation water, where the infrastructure is not part of the GMW irrigation delivery system.

Agency	Assess and develop management and mitigation measures	Deliver and review management and mitigation measures during GMW Connections Project implementation
	measures required due to the implementation of GMW Connections Project.	• Where agreed, participate in the periodic review of relevant EWPs. • Manage and report on other relevant catchment management and mitigation measures required due to the implementation of GMW Connections Project.
System Operator	• Identify and inform GMW Connections Project of opportunities for best practice. • Participate in the Environmental Technical Advisory Committee. • Agree to implement relevant components of Environmental Watering Plans.	• Implement the relevant components of Environmental Watering Plans, namely delivery of mitigation water. • Operate, maintain and replace, as needed, the infrastructure required for delivery of mitigation, or other, water, where the infrastructure is part of the GMW irrigation delivery system. • May negotiate transfer of ownership of infrastructure to the environmental water/land manager for provision of mitigation water if it is no longer required for the public distribution system, in accordance with the principles set out in the WCMF. • Where the infrastructure assets are due for renewal or refurbishment, the water corporation will undertake the upgrade to the best environmental practice, including any requirements to better provide Environmental Water Reserve, and to remain consistent with the current WCMF. • Report annually on the availability and delivery of water for mitigating environmental impacts as part of reporting upon meeting obligations under its bulk entitlement. In some instances, it will be appropriate to measure mitigation flows to ensure mitigation volumes of water are delivered.
DELWP	• Identify and inform GMW Connections Project of opportunities for best practice. • Participate in the Environmental Technical Advisory Committee. • Arrange funding to enable environmental water manager, catchment manager and land manager to deliver agreed measures.	• Participate in the periodic review of the Water Change Management Framework and relevant EWPs.
Environmental Water Holder		• Hold and manage environmental entitlements, including mitigation water that becomes a defined entitlement. • Consult with CMAs in identifying priority wetlands, waterways and groundwater systems for environmental watering. Plan and report on the use of environmental entitlements. • Negotiate with Commonwealth Environmental Water Holder to arrange delivery of Commonwealth environmental water.

13. CONSULTATION

13.1 Community consultation

No specific community consultation activities have been undertaken to date in the development of this EWP.

13.2 Scientific and technical review

A Scientific Reference Group was established by Goulburn Broken CMA at the commencement of the EWP development process. The use of a Scientific Reference Group, comprising specialists with relevant knowledge of current and historic conditions in the Broken Creek system assisted in providing an appropriate level of scientific rigour to the process.

This Scientific Reference Group (refer Table 13-1) provided inputs in the collation and review of relevant information, site inspection, identification of environmental assets and condition, establishment of management objectives for assets and review of flow dependencies for the identified assets. This input was provided during a field trip on 11 February 2010, an initial project workshop on 19 February 2010 and a second workshop on 31 March 2010. Members of the Scientific Reference Group also reviewed the draft EWP and provided comment to ensure that their respective areas of expertise are appropriately addressed by the EWP and that the likely impacts of any hydrologic modification resulting from the implementation of works under the GMW Connections Project are understood within the context of current knowledge.

Table 13-1 Scientific Reference Group for development of the EWP

Name	Expertise	Role	Field trip 11 Feb	Workshop 1 19 Feb	Workshop 2 31 March
Darren Baldwin	Biogeochemistry / water quality / aquatic ecology	Scientific Reference Group	✓	✓	X
Daryl Nielsen	Invertebrates / aquatic ecology	Scientific Reference Group	✓	✓	✓
Gavin Rees	Microbial ecology / water quality / azolla	Scientific Reference Group	✓	✓	X
Jarod Lyon	Fish biology	Scientific Reference Group	✓	✓	X
Rick Stoffels	Fish / aquatic ecology	Scientific Reference Group	X	✓	✓

Peter Cottingham and Nick Bond provided peer reviews of the Draft EWP.

Additional inputs and strategic direction were provided by personnel outlined in Table 13-2.

Table 13-2 Personnel involved in project management, support and reporting during development of the EWP

Name	Expertise	Role	Field trip 11 Feb	Workshop 1 19 Feb	Workshop 2 31 March
Simon Casanelia	GBCMA river health and environmental water reserve	Project manager	✓	✓	✓
Wayne Tennant	GBCMA Manager strategic river health	Strategic direction	X	✓	✓
Simon Lang	Hydrology	Hydrology consultant	✓	✓	✓
Chris Solum	GMW Connections Project	System knowledge	X	✓	X
Mark Poole	GMW Connections Project	System knowledge	X	✓	X
Anne Graesser	Goulburn-Murray Water	System knowledge	X	X	✓
Jim Castles	Site knowledge / ecology	Project support	✓	X	X
Tim Barlow	Ecology	Project support	✓	X	X
Toby Alker-Jones	Project support	Project support and mapping	✓	✓	X
Tim Loffler	Project management	Project co-ordinator and author	✓	✓	✓

14. KNOWLEDGE GAPS

Key knowledge gaps or risks which must be acknowledged and addressed through ongoing management and monitoring are outlined below.

- As a full environmental flow study utilising the FLOWS method (NRE 2002) has not been undertaken for Broken Creek (refer Section 8.2), the flow requirements documented in this EWP have been developed based on available information (including inputs from the Scientific Reference Group) and desktop review of flow dependencies. While the approach used is consistent with that of the FLOWS method it has not included any survey or hydraulic modelling to assess the sensitivity of variables such as depth, velocity and wetted area to changes in flow magnitude. Some modelling or monitoring of conditions in the field at a range of flows could be useful to validate the flow magnitudes required to achieve certain in-stream conditions (i.e. passage of fish through fishways, mobilisation of *Azolla* mats).
- There is an incomplete understanding of sediment, water quality and flow interactions in the development of low DO conditions in the lower reaches of Broken Creek (Rees 2006).
- There is a lack of water quality data in weir pools, excluding Rices Weir, to understand the extent of the waterway reach with potential exposure to low DO conditions (predominantly within EWP Reach 4). Additional data in upstream weir pools may provide additional information to enable management intervention to respond more rapidly to site conditions (e.g. low DO levels) before they are ultimately recorded at Rices Weir Pool (i.e. at the downstream end of the system).
- Current and future hydrology (under the implementation of the GMW Connections Project) have been assessed based on historic flow records (refer Section 7). Flow records are generally weekly or monthly and it is currently not possible to interpret the implementation of the GMW Connections Project on daily flows. When considered at a finer time scale the GMW Connections Project may have an impact greater than that revealed by the monthly data. Of the assets and threats considered in the EWP assessment, water quality is most likely to be impacted by short term flow variations possibly influenced by the GMW Connections Project, as *Azolla* and DO interactions in EWP Reach 4 respond rapidly to changes in flow, temperature and nutrients.
- The EWP has identified flow dependencies for specific threatened or high value flora and fauna based on existing literature and / or expert knowledge. Flow dependencies are not well documented or understood for some assets so some uncertainty remains in the mitigation water assessment.
- Identification of waterway assets has been based on existing knowledge and mapping. This information may be incomplete or inaccurate. The possible existence of high value assets, with exposure to modified hydrology under implementation of GMW Connections Project activities cannot be ruled out but is not addressed through this EWP.

15. CONSOLIDATED LIST OF MANAGEMENT ACTIONS

This EWP is only a component of the overall management framework for the Broken Creek system. For example, the Lower Broken Creek Waterway Management Strategy (GHD / URS 2005) and the Goulburn Broken Regional River Health Strategy (GBCMA 2005) recommend management actions based on broad reviews of threats to waterway condition. This EWP is more focussed in its scope relating to threats to waterway environmental assets resulting from the implementation of the GMW Connections Project. Key management actions recommended to protect or enhance these waterway environmental assets, as identified during development of the EWP are outlined below. However reference should be made to the afore-mentioned strategies (amongst others) for a more complete listing of management actions of relevance to Broken Creek.

Table 15-1 Recommended management actions for Broken Creek, as identified in development of the EWP

Type	Detail
Flow dependencies	Flow dependencies of the environmental assets / threats which have the greatest impact on flow magnitudes currently delivered under the regulated flow regime (critically passage and habitat for Murray Cod and *Azolla* / DO management) should be further investigated through survey and hydraulic modelling (as is the case for other systems where the FLOWS method has been applied).
Flow variation	Investigate the potential to increase the short-term (typically < 1 week) variation in water levels through all EWP reaches to increase cover and diversity of native aquatic and fringing vegetation. An identified factor possibly limiting the effectiveness of fish passage at the installed fishways (vertical slots) is lack of flow variation. Flow should be manipulated to improve fish migration and create a more natural healthy stream. Flow variation of as little as 0.15 m can be a strong stimulus for fish migration (O'Connor and Amtstaetter 2008). It is recognised that this variability is likely to be negatively impacted by the GMW Connections Project (in seeking more consistent and efficient system operations) but consideration should be given to short term variation at ecologically critical times.
Water quality	Install water quality monitoring equipment in weir pools upstream of Rices Weir (already monitored) to improve the understanding of water quality, Azolla and DO interactions in the lower reaches of Broken Creek. There is an opportunity to link this to existing telemetry at four existing ARI sites (used for remote monitoring of fish movements within the fish ladders) at Rices, Kennedys, Schiers and Nathalia Town weirs.
	Provide for further research and development of the adaptive management approach for the low DO / Azolla issues in the Lower Broken Creek (beyond that contained in GMW (2004)) to extend the system understanding and response model beyond the current Rices Weir focus. Modelling of weir pool hydraulic and water quality processes may provide an opportunity to tailor the delivery of flows to mitigate the water quality concerns while using less water.
Management	Review of the Lower Broken Creek Operational Guidelines (GMW 2003) to encompass more up to date and detailed information (including information contained in this EWP) would provide a more explicit basis for operation of the system to protect key environmental assets. The revised Guidelines (possibly

	formalised in a MOU) would provide more formal protection for those assets dependent on the current operational practices.
	Secure a minimum passing flow for the creek during the irrigation season of about 100 ML/d (over Rices Weir) to maintain DO and control the build up of Azolla. The water could be diverted from the Murray River through the Murray Valley Irrigation network into the Broken Creek and back to the Murray River. This would be a reliable source of water and would require agreement from GMW and the MDBA. The capacity of the Murray Valley Irrigation network may need to be increased to deliver this passing flow, which could be undertaken as part of the GMW Connections Project's planned water saving initiatives. Flows up to 150 ML/d may be required in addition to the 100 ML/d minimum passing flow to managed Azolla and DO, and provide native fish habitat. This water may be sourced from the Murray River, IVT or the Goulburn water quality reserve.

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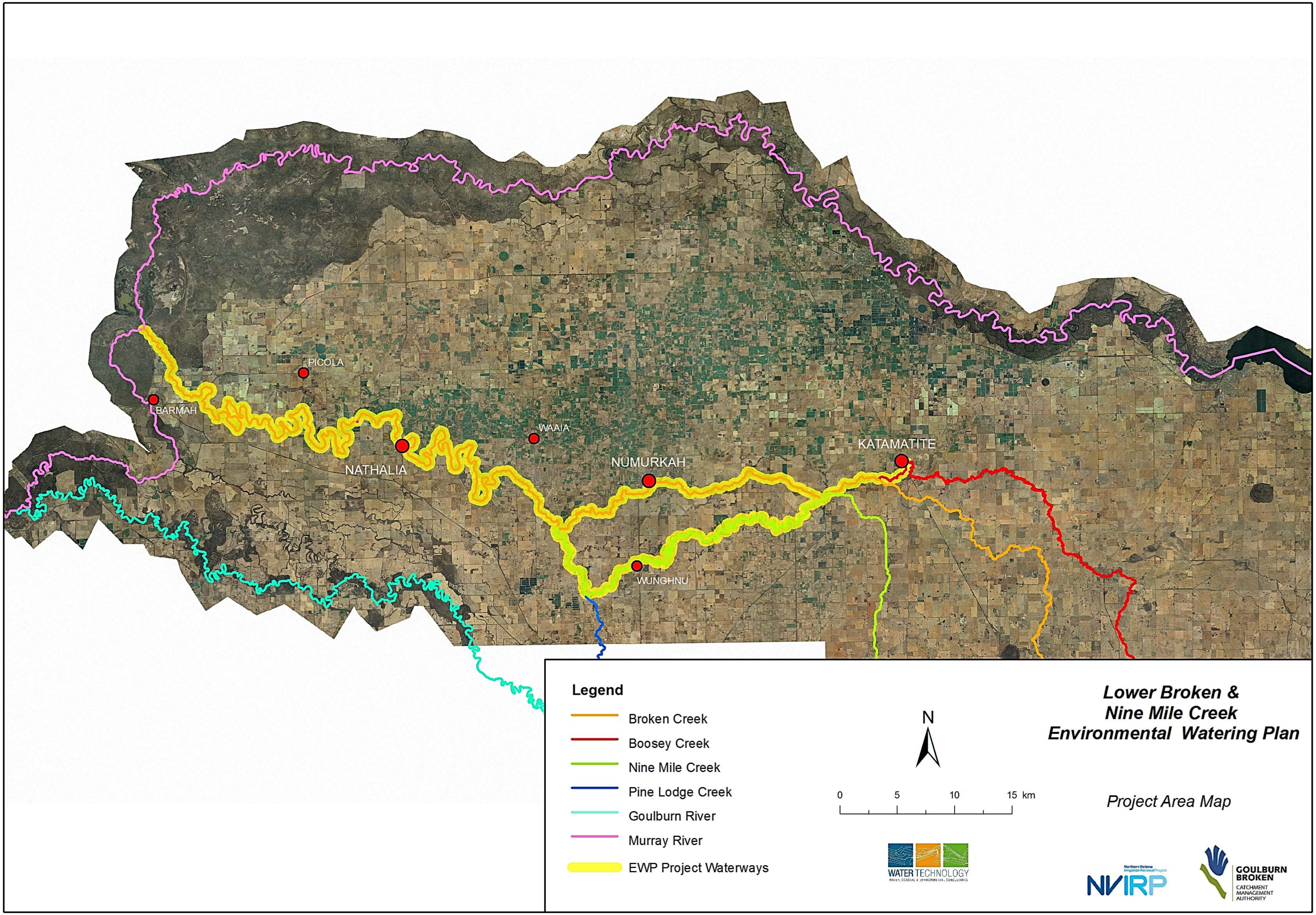
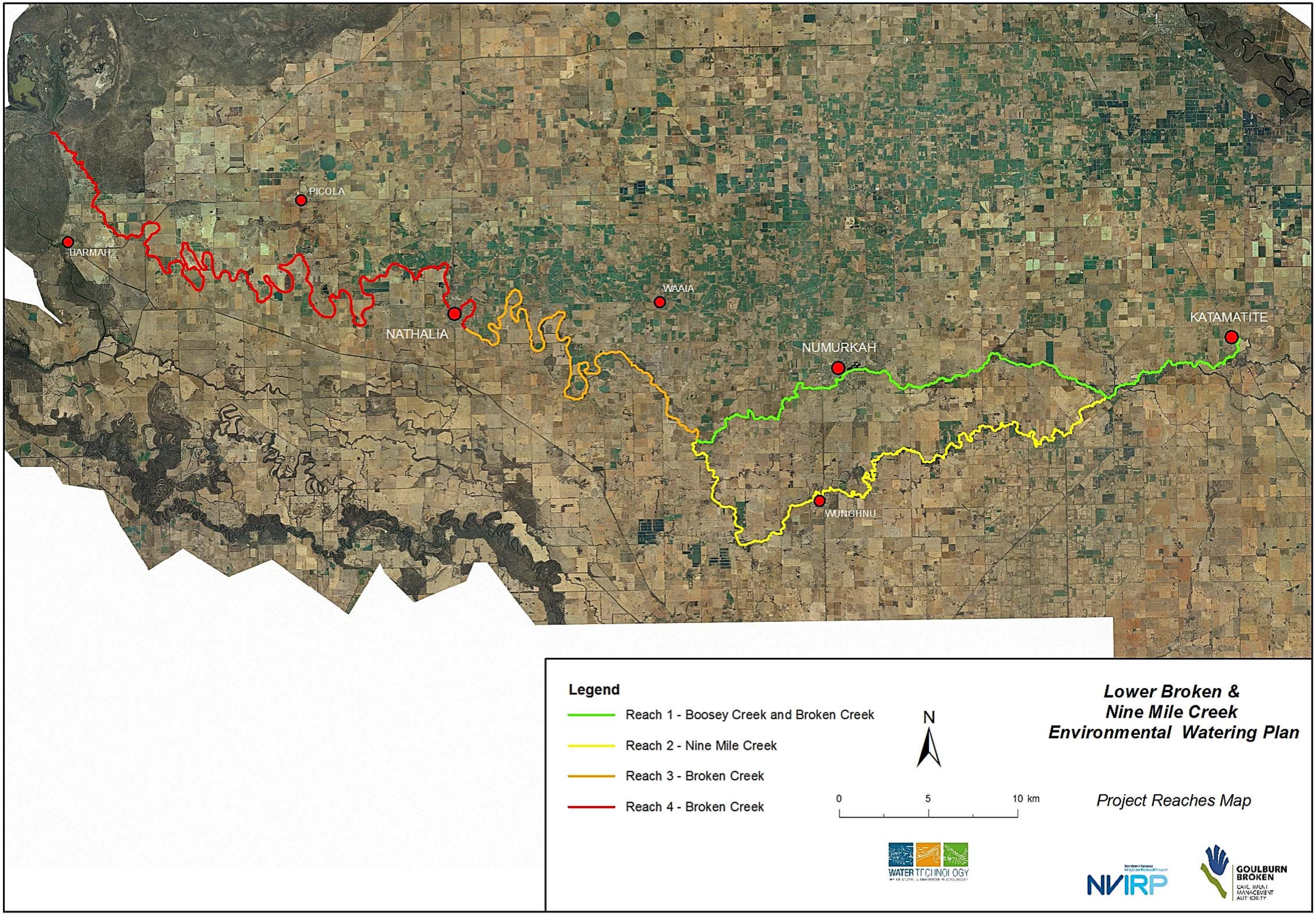
APPENDIX A PROJECT AREA AND REACH MAPS


PICOLA
BARMAH
WAAIA
NATHALIA
NUMURKAH
KATAMATITE
WUNGHNU
Legend
Broken Creek
Boosey Creek
Nine Mile Creek
Pine Lodge Creek
Goulburn River
Murray River
EWP Project Waterways
N
0 5 10 15 km
Lower Broken & Nine Mile Creek Environmental Watering Plan
Project Area Map
WATER TECHNOLOGY
NVIRP
GOULBURN BROKEN CATCHMENT MANAGEMENT AUTHORITY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NUMURKAH
KATAMATITE
WUNGHNU
Legend
Reach 1 - Boosey Creek and Broken Creek
Reach 2 - Nine Mile Creek
Reach 3 - Broken Creek
Reach 4 - Broken Creek
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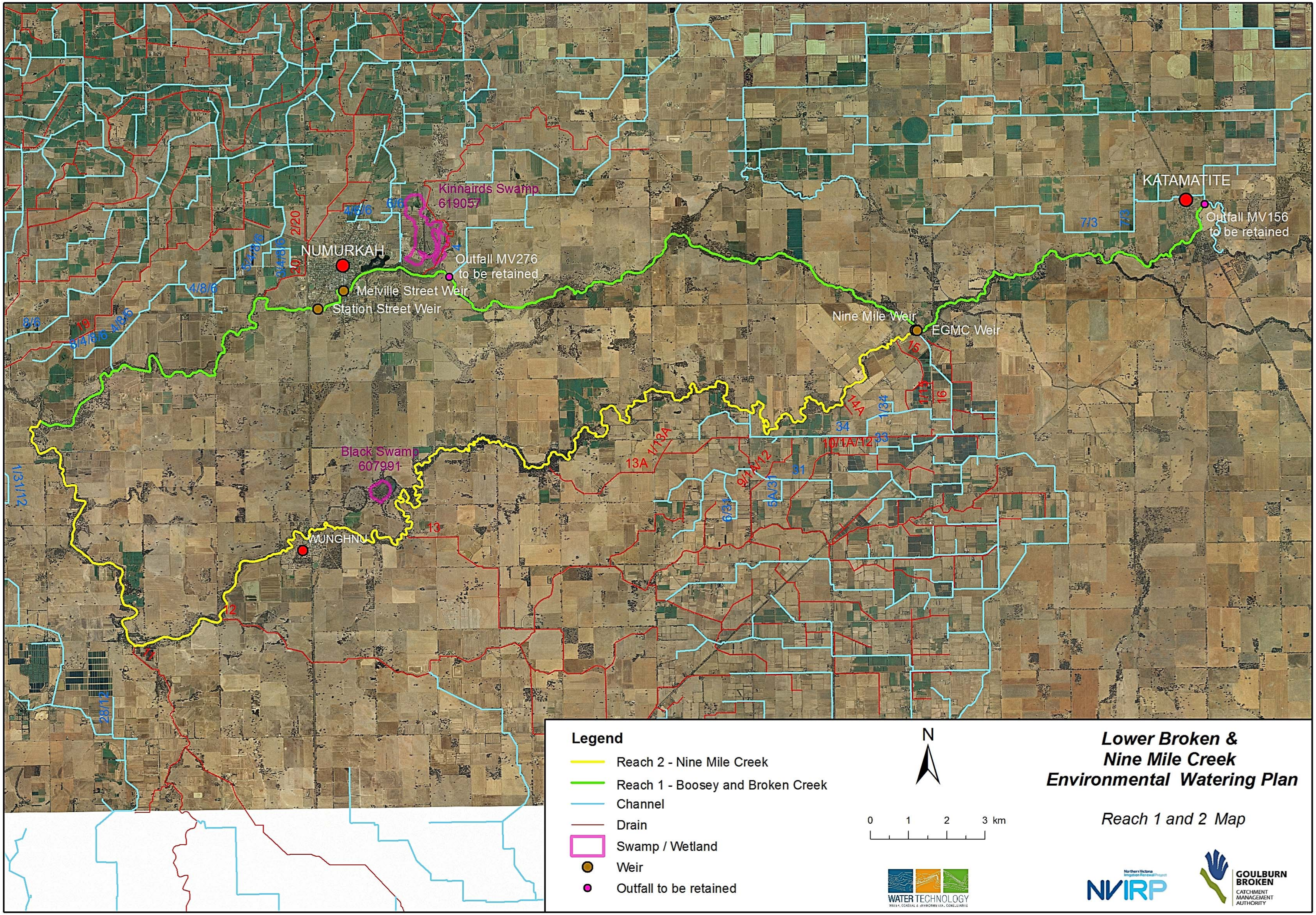
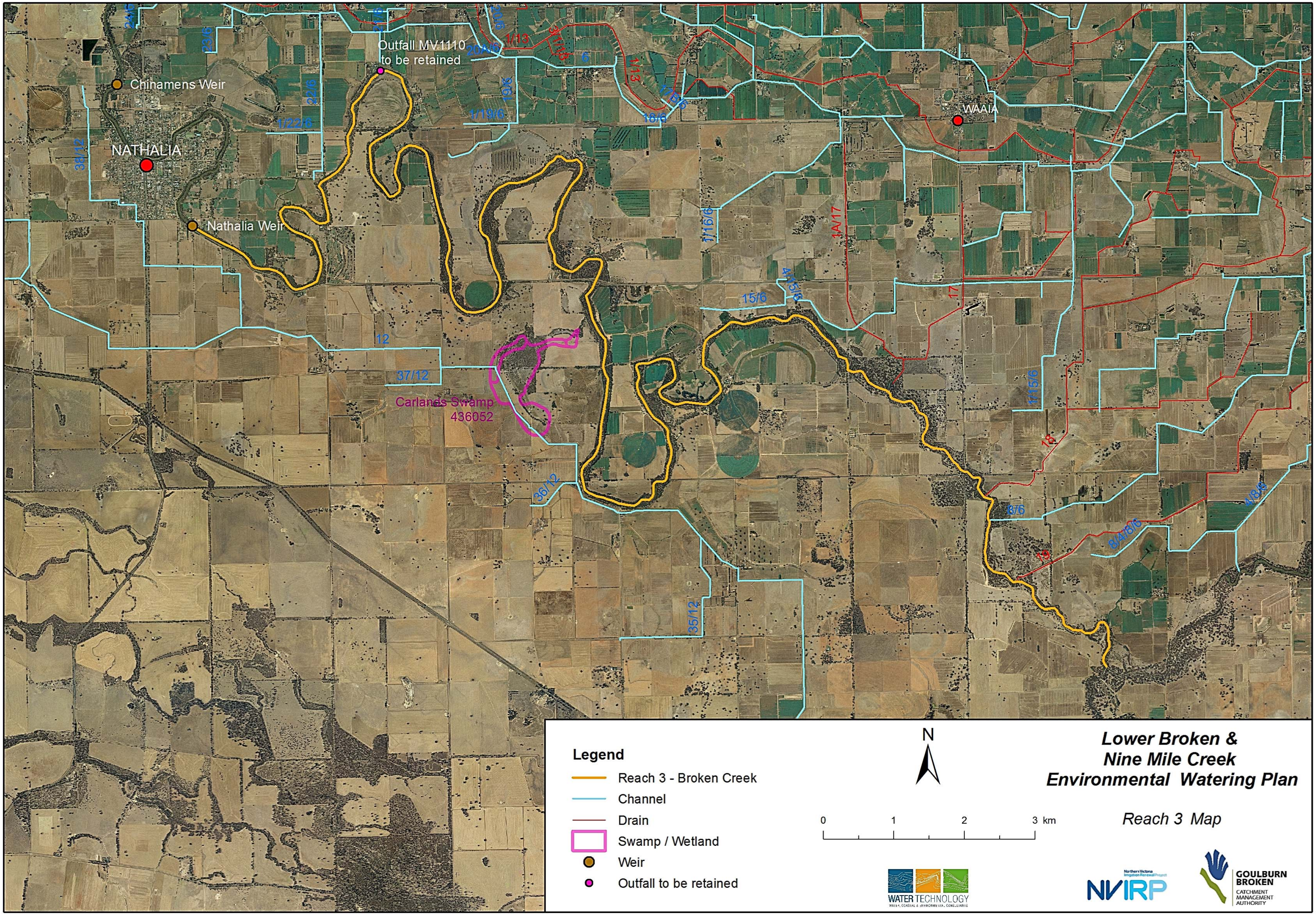
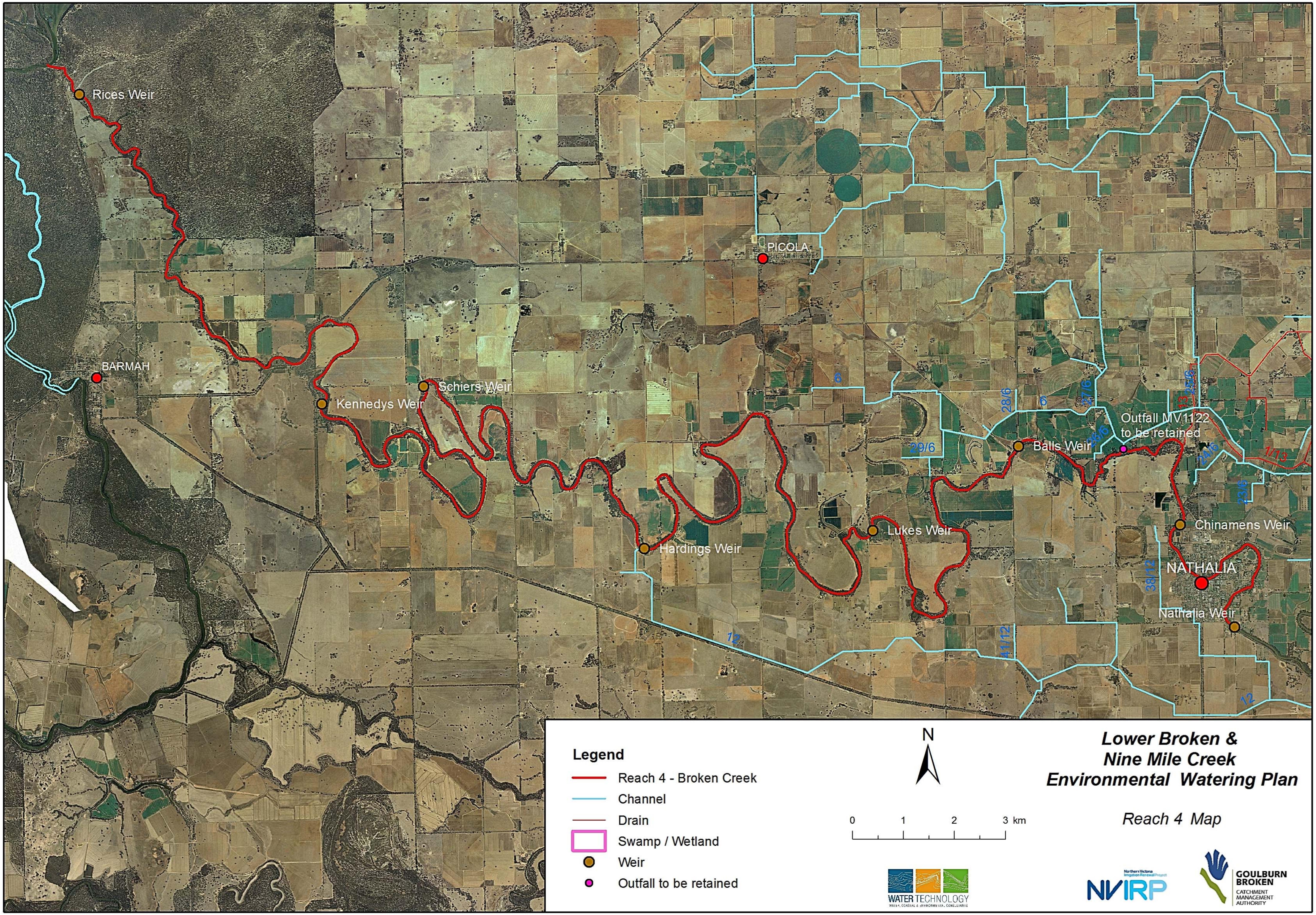
5
10 km
Lower Broken &
Nine Mile Creek
Environmental Watering Plan
Project Reaches Map
NVIRP
GOULBURN
BROKEN



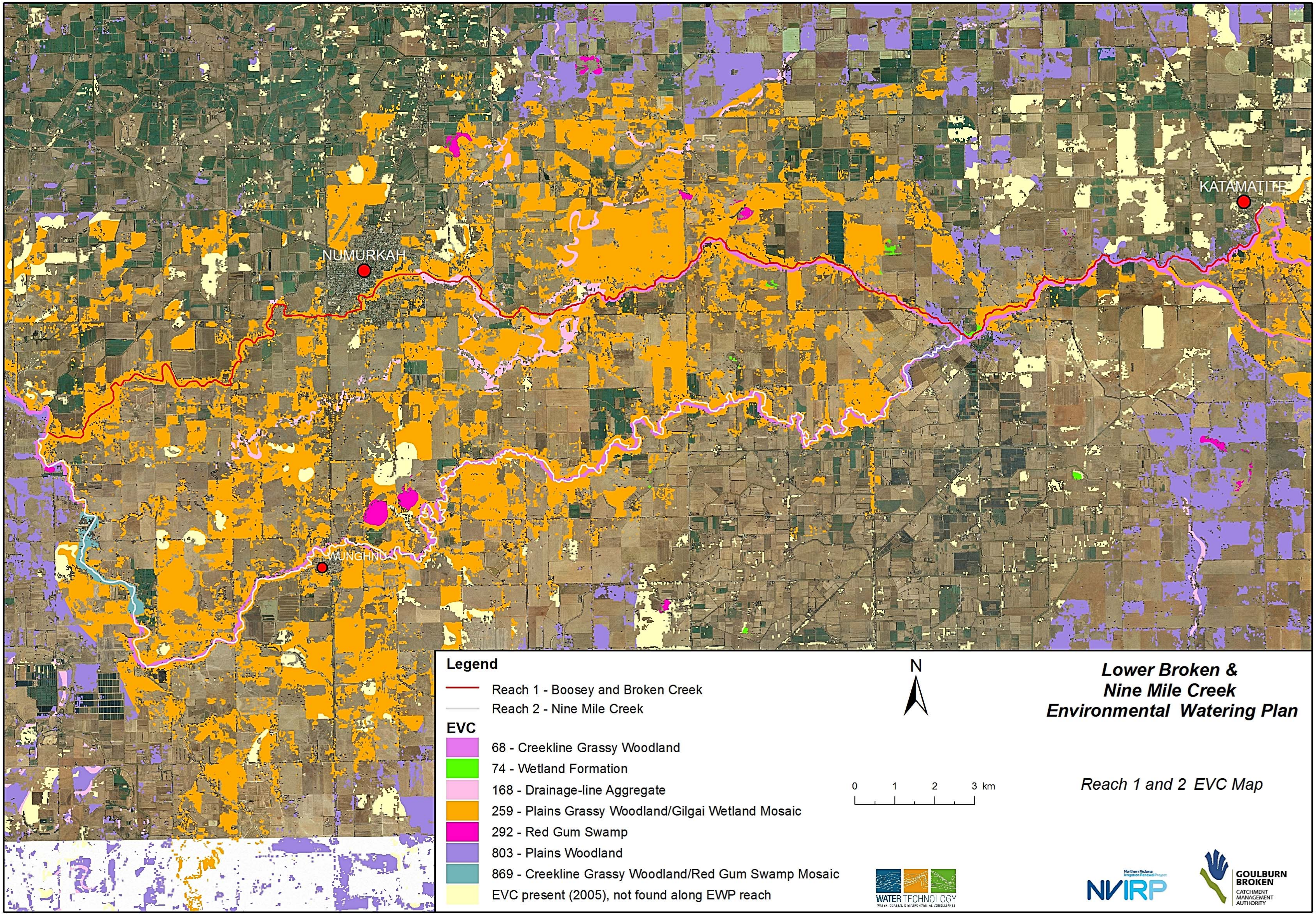
Lower Broken & Nine Mile Creek Environmental Watering Plan
Reach 1 and 2 Map
Legend
Reach 2 - Nine Mile Creek
Reach 1 - Boosey and Broken Creek
Channel
Drain
Swamp / Wetland
Weir
Outfall to be retained
N
0 1 2 3 km
NUMURKAH
KATAMATITE
WUNGHNU
Kinnairds Swamp 619057
Black Swamp 607991
Outfall MV276 to be retained
Outfall MV156 to be retained
Melville Street Weir
Station Street Weir
Nine Mile Weir
EGMC Weir
WATER TECHNOLOGY
NVIRP
GOULBURN BROKEN CATCHMENT MANAGEMENT AUTHORITY



Outfall MV1110 to be retained
Chinamens Weir
NATHALIA
Nathalia Weir
WAAIA
Carlands Swamp 436052
1/22/6
1/19/6
1/16/6
15/6
12
37/12
36/12
35/12
1A/17
17
1/15/6
8/6
N
Lower Broken & Nine Mile Creek Environmental Watering Plan
Reach 3 Map
Legend
Reach 3 - Broken Creek
Channel
Drain
Swamp / Wetland
Weir
Outfall to be retained
0 1 2 3 km
WATER TECHNOLOGY
NVIRP
GOULBURN BROKEN CATCHMENT MANAGEMENT AUTHORITY

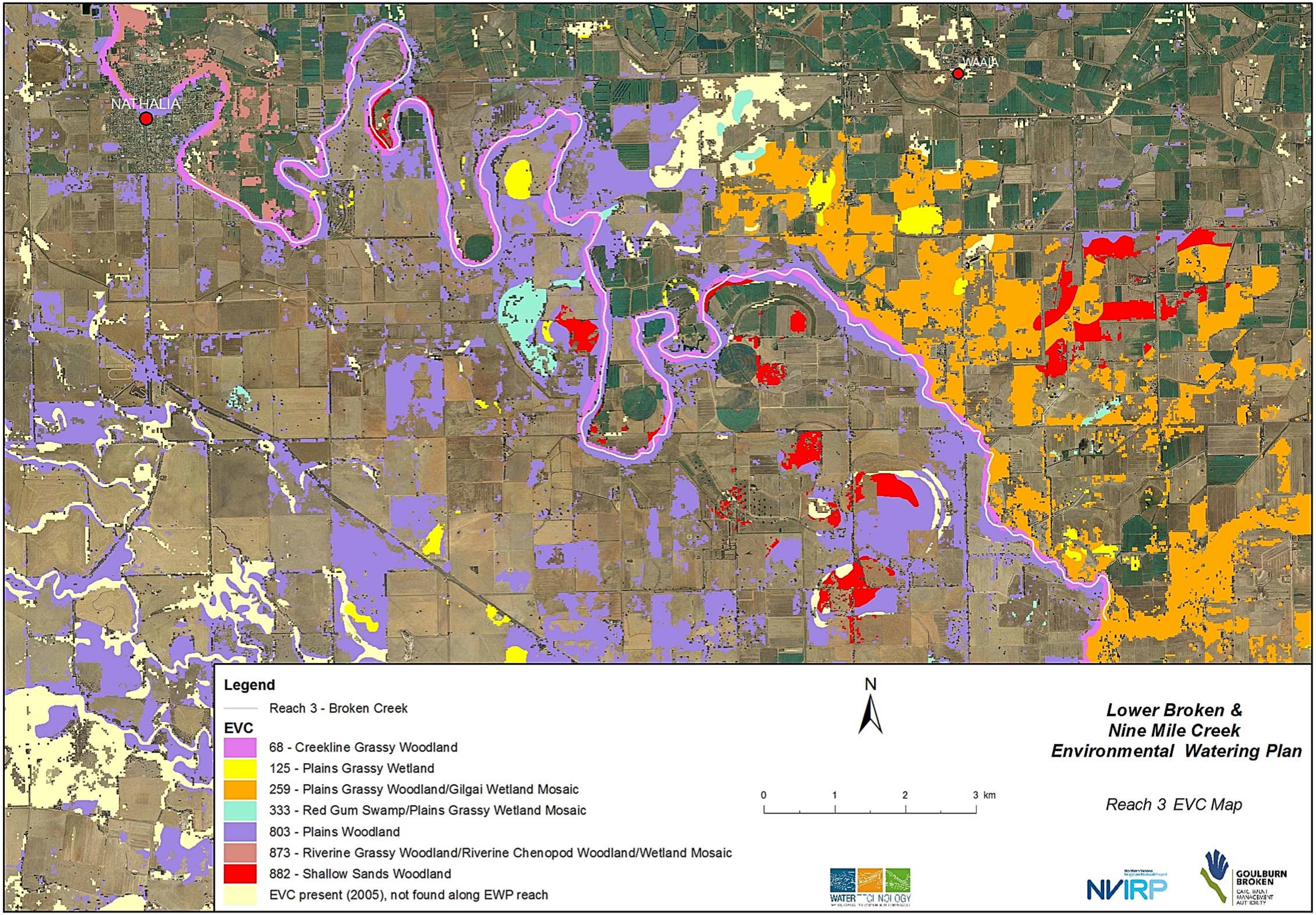

Rices Weir
BARMAH
Kennedys Weir
Schiers Weir
PICOLA
Hardings Weir
Lukes Weir
Balls Weir
Outfall MV1122
to be retained
Chinamens Weir
NATHALIA
Nathalia Weir
Legend
Reach 4 - Broken Creek
Channel
Drain
Swamp / Wetland
Weir
Outfall to be retained
N
0 1 2 3 km
Lower Broken &
Nine Mile Creek
Environmental Watering Plan
Reach 4 Map
WATER TECHNOLOGY
NVIRP
GOULBURN BROKEN
CATCHMENT MANAGEMENT AUTHORITY

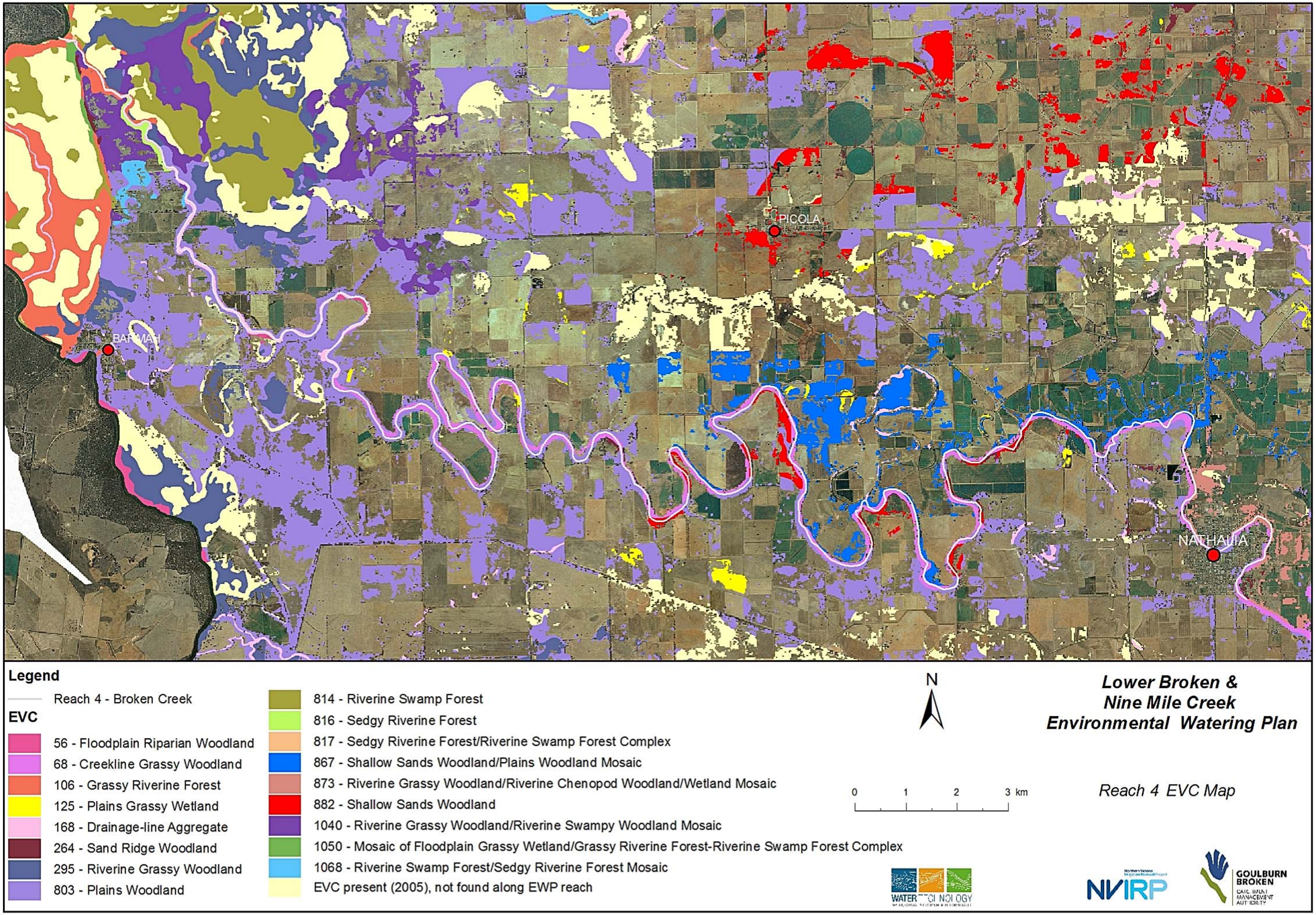
APPENDIX B REACH EVC MAPS (2005 EXTENTS)



Lower Broken & Nine Mile Creek Environmental Watering Plan

Reach 1 and 2 EVC Map


NATHALIA
WAAIA
Legend
Reach 3 - Broken Creek
EVC
68 - Creekline Grassy Woodland
125 - Plains Grassy Wetland
259 - Plains Grassy Woodland/Gilgai Wetland Mosaic
333 - Red Gum Swamp/Plains Grassy Wetland Mosaic
803 - Plains Woodland
873 - Riverine Grassy Woodland/Riverine Chenopod Woodland/Wetland Mosaic
882 - Shallow Sands Woodland
EVC present (2005), not found along EWP reach
N
0 1 2 3 km
Lower Broken &
Nine Mile Creek
Environmental Watering Plan
Reach 3 EVC Map
NVIRP
GOULBURN BROKEN


PICOLA
BARMAH
NATHALIA
Legend
Reach 4 - Broken Creek
EVC
56 - Floodplain Riparian Woodland
68 - Creekline Grassy Woodland
106 - Grassy Riverine Forest
125 - Plains Grassy Wetland
168 - Drainage-line Aggregate
264 - Sand Ridge Woodland
295 - Riverine Grassy Woodland
803 - Plains Woodland
814 - Riverine Swamp Forest
816 - Sedgy Riverine Forest
817 - Sedgy Riverine Forest/Riverine Swamp Forest Complex
867 - Shallow Sands Woodland/Plains Woodland Mosaic
873 - Riverine Grassy Woodland/Riverine Chenopod Woodland/Wetland Mosaic
882 - Shallow Sands Woodland
1040 - Riverine Grassy Woodland/Riverine Swampy Woodland Mosaic
1050 - Mosaic of Floodplain Grassy Wetland/Grassy Riverine Forest-Riverine Swamp Forest Complex
1068 - Riverine Swamp Forest/Sedgy Riverine Forest Mosaic
EVC present (2005), not found along EWP reach
N
0 1 2 3 km
Lower Broken &
Nine Mile Creek
Environmental Watering Plan
Reach 4 EVC Map
NVIRP
GOULBURN BROKEN

APPENDIX C THREATENED FLORA AND FAUNA LISTS

Table C-1 Threatened flora – Central Creek landscape zone (DSE 2008)

Scientific name	English name	Australian status	Victorian status	FFG code
Allocasuarina luehmannii	Buloke		e	L
Alternanthera nodiflora	Common Joyweed		k	
Atriplex spinibractea	Spiny-fruit Saltbush		e	
Brachyscome chrysoglossa	Yellow-tongue Daisy		v	L
Brachyscome muelleroides	Mueller Daisy	V	e	L
Callitriche umbonata	Winged Water-starwort		r	
Calotis cuneifolia	Blue Burr-daisy		r	
Calotis lappulacea	Yellow Burr-daisy		r	
Cardamine moirensis	Riverina Bitter-cress		r	
Cardamine paucijuga s.s.	Annual Bitter-cress		v	
Eleocharis pallens	Pale Spike-sedge		k	
Eryngium paludosum	Long Eryngium		v	
Glossostigma cleistanthum	Small-flower Mud-mat		r	
Haloragis glauca f. glauca	Bluish Raspwort		k	
Hypoxis exilis	Swamp Star		v	
Leiocarpa leptolepis	Pale Plover-daisy		e	L
Lepidium pseudohyssopifolium	Native Peppercress		k	
Maireana aphylla	Leafless Bluebush		k	
Minuria integerrima	Smooth Minuria		r	
Myoporum montanum	Waterbush		r	
Myriophyllum gracile var. lineare	Slender Water-milfoil		e	L
Myriophyllum porcatum	Ridged Water-milfoil	V	v	L
Myriophyllum striatum	Striped Water-milfoil		v	L
Panicum laevinode	Pepper Grass		v	
Panicum queenslandicum var. queenslandicum	Coolibah Grass		e	
Ranunculus sessiliflorus var. pilulifer	Annual Buttercup		k	
Sclerolaena muricata var. muricata	Black Roly-poly		k	
Swainsona behriana	Southern Swainson-pea		r	
Swainsona sericea	Silky Swainson-pea		v	L
Triglochin dubia	Slender Water-ribbons		r	
Tripogon loliiformis	Rye Beetle-grass		r	

Definitions: V: vulnerable in Australia
k: poorly known in Victoria
e: endangered in Victoria
v: vulnerable in Victoria
r: rare in Victoria
L: listed under FFG
N: nominated under FFG

Note: Threatened status and FFG listing updated in accordance with DEPI 2014.

Table C-2 Threatened fauna – Central Creek landscape zone (DSE 2008)

Scientific name	English name	International Status	Australian status	Victorian status	FFG code
Botaurus poiciloptilus	Australasian Bittern			e	L
Anas rhynchotis	Australasian Shoveler			v	
Falco subniger	Black Falcon			v	
Melithreptus gularis	Black-chinned Honeyeater			n	
Coturnix ypsilophora	Brown Quail				
Climacteris picumnus	Brown Treecreeper			n	
Burhinus grallarius	Bush Stone-curlew			e	L
Stagonopleura guttata	Diamond Firetail			n	L
Stictonetta naevosa	Freckled Duck			e	L
Ardea alba	Great Egret	J		v	L
Litoria raniformis	Growling Grass Frog		V	e	L
Aythya australis	Hardhead			v	
Gallinago hardwickii	Latham's Snipe	J, R		n	N
Biziura lobata	Musk Duck			v	
Nycticorax caledonicus	Nankeen Night Heron			n	
Todiramphus pyrrhopygia	Red-backed Kingfisher			n	
Platalea regia	Royal Spoonbill			v	
Circus assimilis	Spotted Harrier			n	
Petaurus norfolcensis	Squirrel Glider			e	L
Polytelis swainsonii	Superb Parrot		V	e	L
Lathamus discolor	Swift Parrot		E	e	L
Varanus varius	Tree Goanna			e	
Chlidonias hybridus	Whiskered Tern			n	

Definitions: C: CAMBA listed (China-Australia Migratory Bird Agreement)
J: JAMBA listed(Japan-Australia Migratory Bird Agreement)
R: ROKAMBA listed (Republic of Korea-Australia Migratory Bird Agreement)
V: vulnerable in Australia
E: Endangered in Australia
e:endangered in Victoria
v: vulnerable in Victoria
n: near threatened in Victoria
L: listed under FFG
N: nominated for FFG listing

Note: Threatened status and FFG listing updated in accordance with DSE 2013. International Status updated from DoE 2015.

Table C-3 Threatened flora – Barmah landscape zone (Heard 2007)

Scientific name	English name	Australian status	Victorian status	FFG listed
Amyema linophylla ssp. Orientale	Buloke Mistletoe		v	
Lipocarpha microcephala	Button Rush		v	
Cyperus bifax	Downs Nutgrass		v	
Menkea crassa	Fat Spectacles		e	L
Hakea tephrosperma	Hooked Needlewood			
Ranunculus papulentus	Large River Buttercup		k	
Maireana aphylla	Leafless Bluebush		k	
Eryngium paludosum	Long Eryngium		v	
Acacia notabilis	Mallee Golden Wattle		v	
Swainsona recta	Mountain Swainsona-pea	E	e	L
Brachyscome muelleroides	Mueller Daisy	V	e	L
Acacia loderi	Nealie		v	N
Myriophyllum porcatum	Ridged Water-milfoil	V	v	L
Amphibromus fluitans	River Swamp Wallaby-grass	V		
Swainsona sericea	Silky Swainson-pea		v	L
Digitaria ammophila	Silky Umbrella-grass		v	
Isolepis congrua	Slender Club-sedge		v	L
Swainsona murrayana	Slender Darling-pea	V	e	L
Rhodanthe stricta	Slender Sunray		e	L
Myriophyllum gracile var. lineare	Slender Water-milfoil		e	L
Cullen parvum	Small Scurf-pea		e	L
Cullen tenax	Tough Scurf-pea		e	L
Sida intricata	Twiggy Sida		v	
Acacia oswaldii	Umbrella Wattle		v	N
Swainsona adenophylla	Violet Swainson-pea		e	L
Acacia pendula	Weeping Myall		e	L
Callitriche cyclocarpa	Western Water-starwort	V		
Acacia omalophylla	Yarran Wattle		e	L
Brachyscome chrysoglossa	Yellow-tongue Daisy		v	L

Definitions: * Victorian (denoted by lower case) Status of Species:
e = endangered, v = vulnerable, r = rare, k = poorly known,
cr = critically endangered.
* FFG (Flora Fauna Guarantee Act 1988) taxon:
L = listed, N = Nominated to be Listed (individual species only - not if part of listed communities) and the accompanying identification number.

Note: Threatened status and FFG listing updated in accordance with DEPI 2014.

Table C-4 Threatened fauna – Barmah landscape zone (Heard 2007)

Scientific name	English name	Australian status	Victorian status	FFG listed
Botaurus poiciloptilus	Australasian Bittern		e	L
Anas rhynchotis	Australasian Shoveler		v	
Porzana pusilla	Baillon's Crake		v	L
Ninox connivens	Barking Owl		e	L
Falco subniger	Black Falcon		v	
Oxyura australis	Blue-billed Duck		e	L
Maccullochella macquariensis	Bluenose (Trout) Cod	E	cr	L
Grus rubicunda	Brolga		v	L
Climacteris picumnus	Brown Treecreeper		n	
Phascogale tapoatafa	Brush-tailed Phascogale		v	L
Burhinus grallarius	Bush Stone-curlew		e	L
Morelia spilota metcalfei	Carpet Python		e	L
Stagonopleura guttata	Diamond Firetail		n	L
Stictonetta naevosa	Freckled Duck		e	L
Tandanus tandanus	Freshwater Catfish		e	L
Limnodynastes interioris	Giant Bullfrog		cr	L
Macquaria ambigua	Golden Perch		n	
Ardea alba	Great Egret		v	L
Accipiter novaehollandiae	Grey Goshawk		v	L
Pomatostomus temporalis	Grey-crowned Babbler		e	L
Coracina maxima	Ground Cuckoo-shrike		v	L
Aythya australis	Hardhead		v	
Ardea intermedia	Intermediate Egret		e	L
Rallus pectoralis	Lewin’s Rail		v	L
Ixobrychus minutus	Little Bittern		e	L
Egretta garzetta	Little Egret		e	L
Macquaria australasica	Macquarie Perch	E	e	L
Cacatua leadbeateri	Major Mitchell’s Cockatoo		v	L
Tyto novaehollandiae	Masked Owl		e	L
Maccullochella peelii peelii	Murray Cod	V	v	L
Biziura lobata	Musk Duck		v	
Grantiella picta	Painted Honeyeater		v	L
Rostratula benghalensis	Painted Snipe	V	c	L
Ninox strenua	Powerful Owl		v	L
Xanthomyza phrygia	Regent Honeyeater	E	cr	L
Gadopsis marmoratus	River Blackfish			
Platalea regia	Royal Spoonbill		n	
Bidyanus bidyanus	Silver Perch		v	L
Chthonicola sagittata	Speckled Warbler		v	L
Petaurus norfolcensis	Squirrel Glider		e	L
Polytelis swainsonii	Superb Parrot	V	e	L
Lathamus discolor	Swift Parrot	E	e	L

Scientific name	English name	Australian status	Victorian status	FFG listed
Varanus varius	Tree Goanna		e	
Litoria raniformis	Growling Grass Frog	V	e	L
Haliaeetus leucogaster	White-bellied Sea-Eagle		v	L

Definitions: * Victorian (denoted by lower case) Status of Species:
e = endangered, v = vulnerable, r = rare, k = poorly known,
cr = critically endangered, n = near threatened.
* FFG (Flora Fauna Guarantee Act 1988) taxon:
L = listed, N = Nominated to be Listed (individual species only - not if part of listed communities) and the accompanying identification number.

Note: Threatened status and FFG listing updated in accordance with DSE 2013.

Table C-5 Rare or threatened flora – Broken Boosey State Park and reserves (Parks Victoria 2006)

Scientific name	Common name	Conservation status
Acacia notabilis	Mallee Golden Wattle	v
Allocasuarina luehmannii	Buloke	L,e
Alternanthera nodiflora	Common Joyweed	k
Atriplex spinibractea	Spiny-fruit Saltbush	e
Brachyscome chrysoglossa	Yellow-tongue Daisy	L, v
Cullen parvum	Small Scurf-pea	L, e
Cullen tenax	Tough Scurf-pea	L, e
Desmodium varians	Slender Tick-trefoil	k
Eleocharis pallens	Pale Spike-sedge	k
Eremophila debilis	Winter Apple (Amulla)	e
Eryngium paludosum	Long Eryngium	v
Glossostigma cleistanthum	Small-flower Mud-mat	r
Haloragis glauca f. glauca	Bluish Raspwort	k
Hypoxis exilis	Swamp Star	v
Maireana aphylla	Leafless Bluebush	k
Minuria integerrima	Smooth Minuria	r
Myoporum montanum	Waterbush	r
Myriophyllum gracile var. lineare	Slender Water-milfoil	L, e
Myriophyllum striatum	Striped Water-milfoil	L, v
Panicum laevinode	Pepper Grass	v
Panicum queenslandicum var. queenslandicum	Coolibah Grass	e
Swainsona behriana	Southern Swainson-pea	r

Victorian status	e	endangered in Victoria
	v	vulnerable in Victoria
	d	depleted in Victoria
	r	rare in Victoria
	k	species poorly known in Victoria
	L	listed under the Flora and Fauna Guarantee Act
National status:	E	endangered

Note: Threatened status and FFG listing updated in accordance with DSE 2013

Table C-6 Rare or threatened fauna – Broken Boosey State Park and reserves (Parks Victoria 2006)

Scientific name	Common name	Conservation status
Birds		
Ardea alba	Great Egret	Vul, L, J
Burhinus grallarius	Bush Stone-curlew	End, L, A, LC
Climacteris picumnus	Brown Treecreeper	NT
Gallinago hardwickii	Latham's Snipe	NT, J, R
Grus rubicunda	Brolga	Vul, L, A
Melithripterus gularis	Black-chinned Honeyeater	NT, LC
Numenius madagascariensis	Eastern Curlew	NT, C, J, R
Nycticorax caledonicus	Nankeen Night Heron	NT
Platalea regia	Royal Spoonbill	NT
Polytelis swainsonii	Superb Parrot	V, End, L
Pomatostomus temporalis	Grey-crowned Babbler	End, L, A, LC
Stagonopleura guttata	Diamond Firetail	NT, L, LC
Todiramphus pyrropygia	Red-backed Kingfisher	NT
Members of the FFG-listed Victorian-temperate woodland bird community		
Glossopsitta pusilla	Little Lorikeet	LC
Lichenostomus fuscus	Fuscous Honeyeater	LC
Melithreptus brevirostris pallidiceps	Brown-headed Honeyeater	LC
Microeca fascinans	Jacky Winter	LC
Petroica goodenovii	Red-capped Robin	LC
Turnix varia	Painted Button-quail	LC
Mammal		
Petaurus norfolcensis	Squirrel Glider	End, L, A
Reptile		
Varanus varius	Lace Monitor	End
Amphibian		
Litoria raniformis	Growling Grass Frog	V, End, L
Fish		
Maccullochella peelii peelii	Murray Cod	Vul, L, A
Macquarie australasica	Macquarie Perch	End, L, E
Maquaria ambigua	Golden Perch	NT
Melanotaenia fluviatilis	Crimson-spotted Rainbowfish	dd, L
Maccullochella macquariensis	Trout Cod	Cen,L, E
Tandanus tandanus	Freshwater Catfish	End, L

Victorian status	Cen	critically endangered in Victoria
	End	endangered in Victoria
	Vul	vulnerable in Victoria
	NT	near threatened in Victoria
	dd	data deficient in Victoria
	L	listed under the Flora and Fauna Guarantee Act

	LC	member species of the FFG-listed Victorian temperate-woodland bird community
	A	an Action Statement has been prepared for its management
National status:	E	endangered
	V	Vulnerable in Australia
Migratory species:	J	listed under the Japan-Australia Migratory Bird Agreement (JAMBA)
	C	listed under the China-Australia Migratory Bird Agreement (CAMBA)
	R	listed under the Republic of Korea-Australia Migratory Bird Agreement (ROKAMBA)

Note: Threatened status and FFG listing updated in accordance with DSE 2013. International Status updated from DoE 2015.

APPENDIX D HYDROLOGY ASSESSMENT REPORT – SKM

SINCLAIR KNIGHT MERZ

SKM

GOULBURN BROKEN
CATCHMENT MANAGEMENT AUTHORITY

Lower Broken Creek and Nine Mile Creek Hydrology

FINAL REPORT

- April 2010

Lower Broken Creek and Nine Mile Creek Hydrology

FINAL REPORT

- April 2010

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1. Introduction

The Northern Victoria Irrigation Renewal Project (NVIRP) is a $2 billion works program to upgrade ageing irrigation infrastructure across the Goulburn-Murray Irrigation District (GMID) and save a proportion of the water currently lost through seepage, leakage, evaporation, metering error and system inefficiencies. Works will include automating channel regulation, lining channels, building pipelines and installing new outlet meters. These works will increase the efficiency with which irrigation water is delivered, and reduce losses by an average of 425 GL of per year.

The GMID uses a number of natural waterways and wetlands with significant environmental values to both store and convey water. NVIRP has identified four waterways that may be impacted by proposed water savings initiatives, including the lower Broken Creek and Nine Mile Creek. NVIRP plans to reduce the current number of outfall structures that discharge directly from the Murray Valley irrigation district to the lower Broken Creek from eleven to four, and reduce the volumes supplied above customer requirements by 85%. This is likely to reduce the volume of water flowing down the creeks.

NVIRP has committed to ensuring there is no net environmental loss caused by the works program. To achieve this commitment, NVIRP requires that environmental watering plans (EWP) be developed for the lower Broken Creek and Nine Mile Creek that:

- assess the ecological impacts of the planned water savings initiatives; and
- identify mitigation measures.

To assess the ecological impacts of the planned water savings, the likely changes in hydrology resulting from the NVIRP works need to be understood. Therefore, this report includes the following:

- Chapter 2 describes the characteristics of the study area (including schematics showing the location of regulating structures, and natural tributaries, drains and outfalls that contribute flows).
- Chapter 3 analyses the flow regimes of the upstream and downstream ends of the study area, using the gauge records for the Boosey Creek at Tungamah (404204), the Broken Creek at Katamatite (404214) and the Broken Creek at Rices Weir (404210). The records for these gauges begin in the mid-1960s.
- Chapter 4 examines the current contribution of outfalls to flows in the lower Broken Creek and Nine Mile Creek, using data provided by Goulburn-Murray Water (G-MW) and NVIRP.
- Chapter 5 predicts the likely impact on flows of reducing the volume of outfalls.
- Chapter 6 provides a summary of key findings and conclusions.

2. Study Area

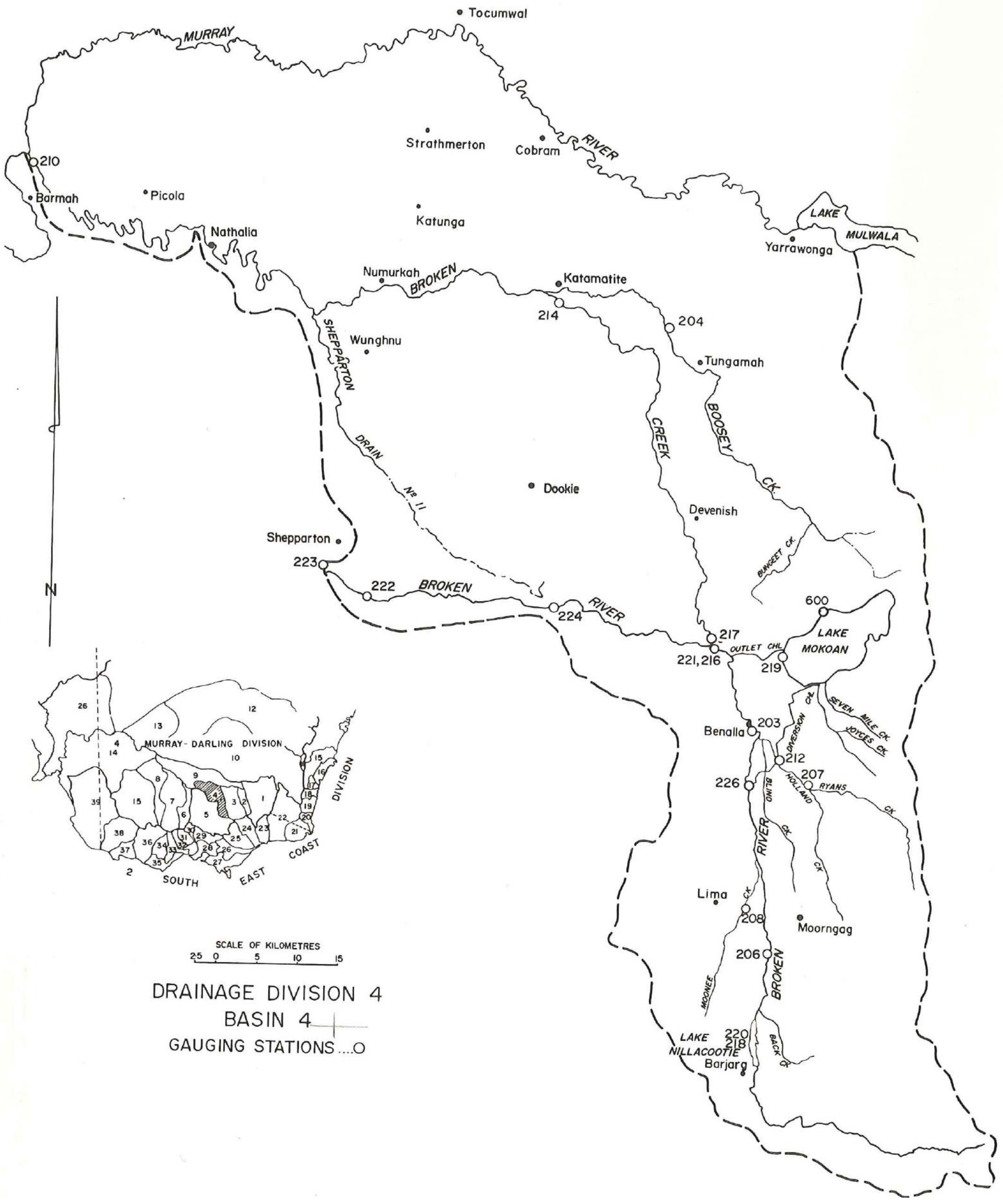
The Broken Creek is formed by a breakaway on the Broken River at Caseys Weir (Figure 1). The terms Upper Broken Creek and Lower Broken Creek are often used to refer to reaches of the creek upstream and downstream of the Boosey Creek confluence. The study area for this project includes a small section of the Boosey Creek downstream of the Murray Valley 7/3 channel outfall, the Lower Broken Creek, Nine Mile Creek, and connected wetlands (Figure 2). The Murray Valley irrigation district is north of the creeks, while the Shepparton irrigation district is to the south.

For this project, the study area has been divided into four environmental flow reaches by the Scientific Reference Group, based on the group's understanding of the creek's hydrology, geomorphology and environmental values. The four reaches are:

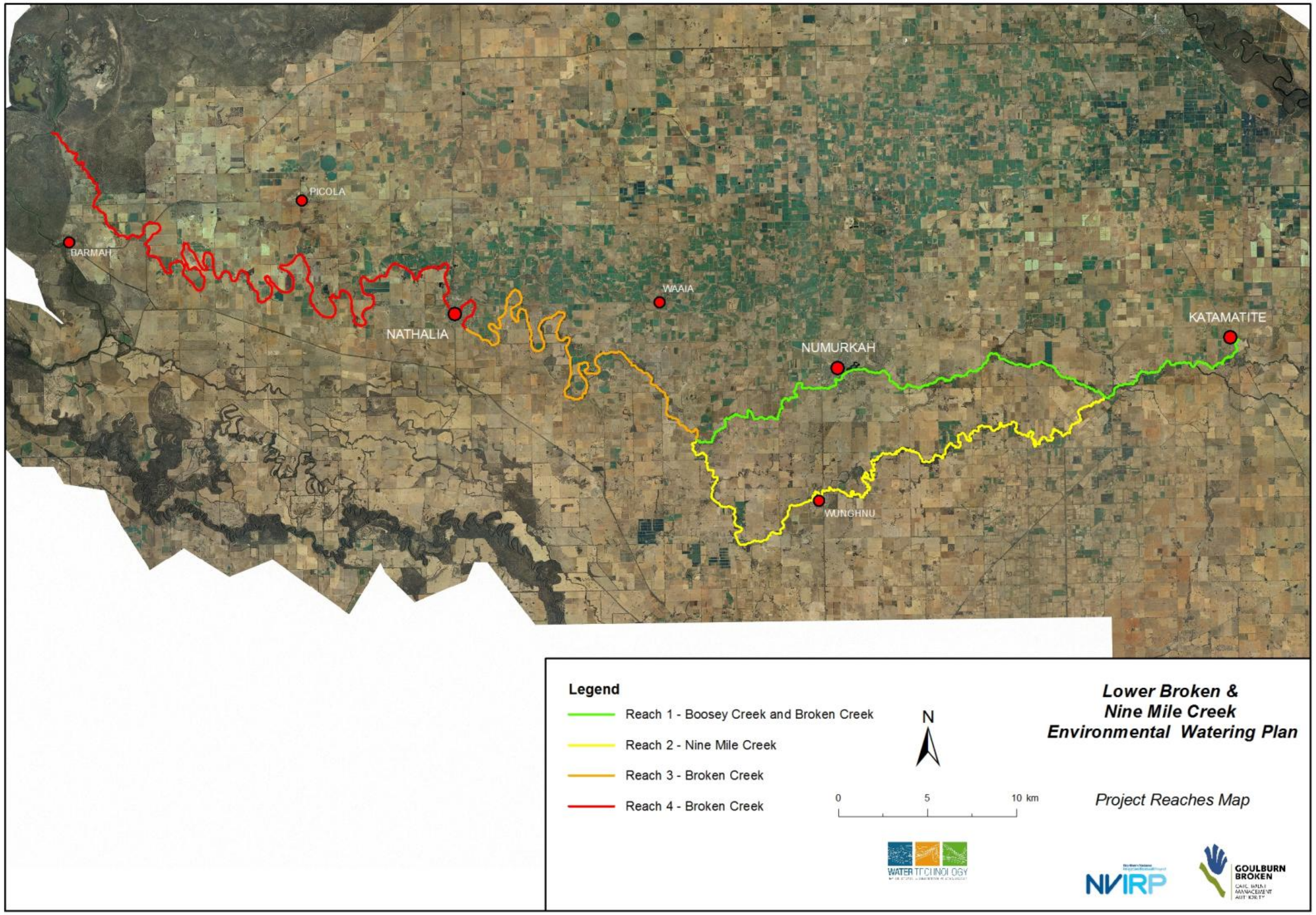
- Reach 1 – The Boosey Creek downstream of the Murray Valley 7/3 channel outfall, and the Broken Creek downstream of the Boosey Creek confluence to the Nine Mile Creek confluence
- Reach 2 – The Nine Mile Creek
- Reach 3 – The Broken Creek downstream of the Nine Mile Creek confluence to the upstream end of the Nathalia weir pool.
- Reach 4 – From the Nathalia weir pool to the Murray River.

The Lower Broken Creek and Nine Mile Creek have been regulated for more than 100 years. Under natural conditions the creeks would have ceased to flow during summer and autumn. Today the creeks are perennial streams with significant flows maintained through summer and autumn to supply water for irrigation, stock and domestic use. There are a number of weirs downstream of Katamatite which maintain water levels for private pumps. Water quality in the weir pools during summer and autumn is often poor, and in recent years environmental managers have passed increasing volumes of water down the creek to manage the threats posed by low dissolved oxygen levels and Azolla blooms.

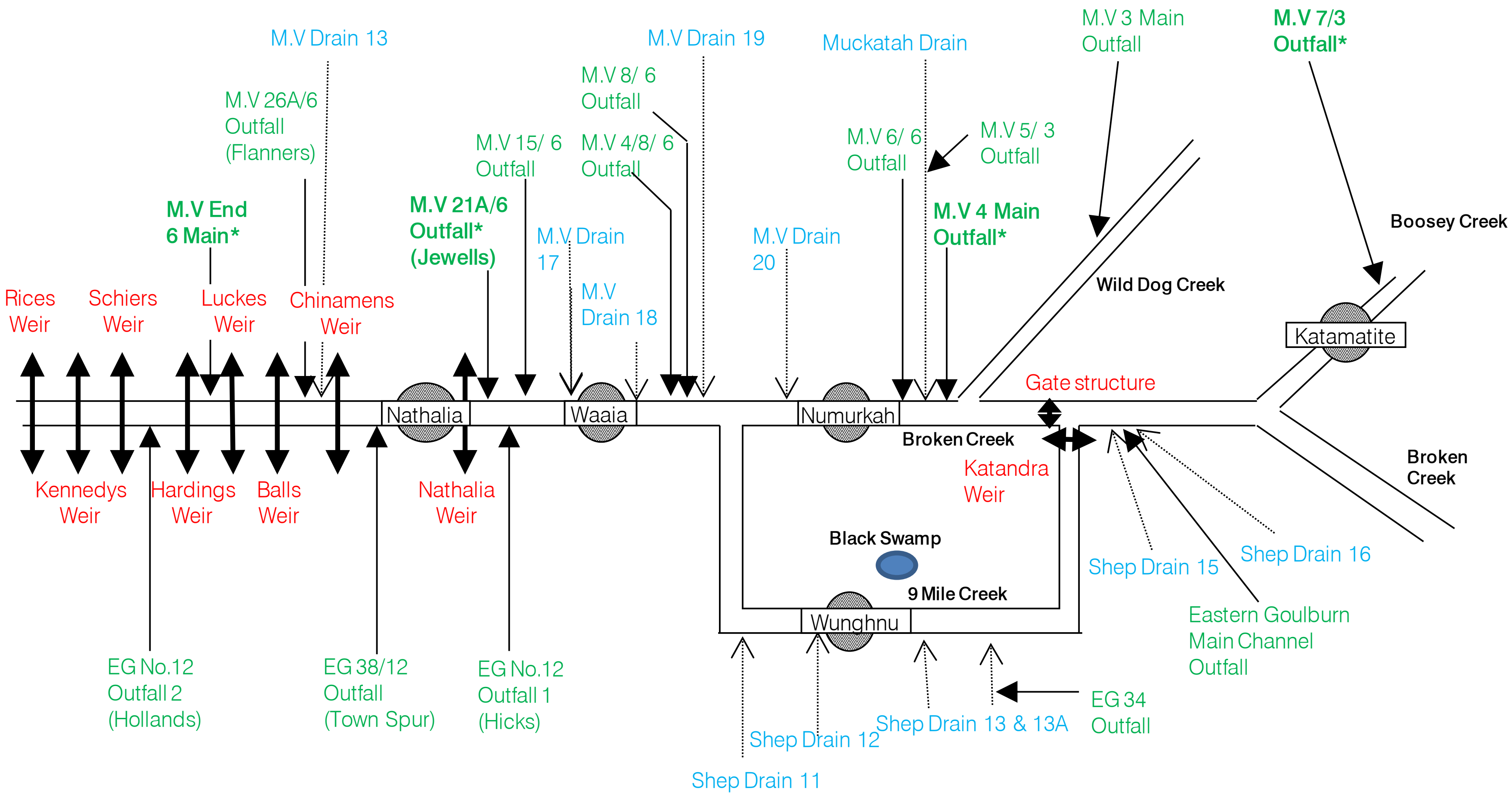
Of the regulated inflows to the Lower Broken Creek, the major sources are the East Goulburn Main channel outfall and the Murray Valley 7/3 channel outfall (Figure 3). The major sources of unregulated inflows are the upstream catchments (i.e. the Upper Broken Creek and Boosey Creek), Shepparton Drain 11, Shepparton Drain 12 and Murray Valley Drain 13. In recent years, unregulated inflows have become a very small proportion of total inflows (Section 4). All together, there are currently eleven outfall structures and six drains that connect directly to the Lower Broken Creek from the Murray Valley irrigation district, while five outfall structures and six drains connect directly to the Lower Broken Creek and Nine Mile Creek from the Shepparton irrigation district. As part of the NVIRP works, seven of the eleven Murray Valley outfall structures connected to the creek will be decommissioned. The outfall structures that will be retained are denoted by an asterisk in Figure 3. Some outfall structures discharging to drains will also be removed.



- **Figure 1 – Broken Creek, within the context of the Broken River basin. The term Lower Broken Creek refers to the reach from the confluence with Boosey Creek through to the Murray River (RWC, 1987).**



- **Figure 2 – The project study area. The Murray Valley irrigation district is to the north of Reach 1, 2 and 3, while the Shepparton irrigation district is to the south.**



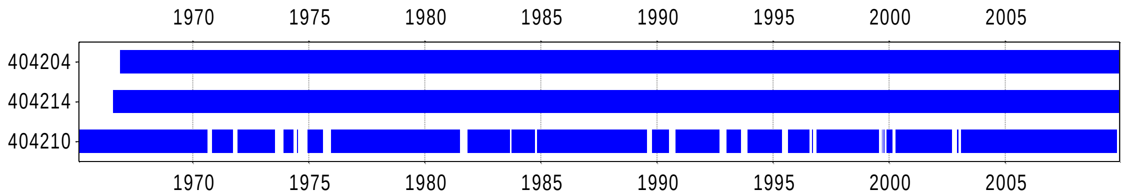
- **Figure 3 – A schematic of the lower Broken Creek and Nine Mile Creek system (SKM, 2003). The names of regulating structures are in red, the names of drains are in blue and the numbers of outfalls are in green. Murray Valley outfall structures that will not be removed as part of the NVIRP works are shown by an asterisk. All outfall structures on the Shepparton side of the creeks are being retained.**

3. Gauged Flow Records

Three stream flow gauges are located within the study area. The Boosey Creek at Tungamah (404204) and Broken Creek at Katamatite (404214) gauges are located at the upstream end of the study area, while the Broken Creek at Rices Weir (404210) gauge is located at the downstream end of the catchment.

The flow records for each of the three gauges begin in the mid 1960s (Figure 4). The records for the Boosey Creek at Tungamah and the Broken Creek at Katamatite are generally of good quality. In contrast, there is much data missing from the Broken Creek at Rices Weir record (Appendix A). Some of these missing periods coincide with floods along the Murray River, when water would have backed up Broken Creek and drowned out the gauging station.

Missing data for the Boosey Creek at Tungamah and Broken Creek at Katamatite records were short enough to infill using linear interpolation. Linear interpolation was not appropriate for infilling the Broken Creek at Rices Weir record. Instead, the Murray Darling Basin Authority (MDBA) supplied a daily time-series of modelled flows past Rices Weir (1891 – 2009), assuming current conditions. While not exactly comparable to historically gauged streamflows (which captures the range of development and management conditions the creek has been subjected to), the current modelled time-series does provide a good indication of flows expected at Rices Weir under the system's current regulation, were the past 120 years of climate repeated.



- **Figure 4 – Extent of streamflow data available.**

Based on the flows observed at gauges 404204, 404214 and 404210, and the modelled flows for Rices Weir (404210) assuming current conditions, the following observations can be made:

Flow in the Boosey Creek at Tungamah and the Broken Creek at Katamatite ceases for approximately 20% of the time. In contrast, there is flow past Rices Weir for all but a small portion of time (Figure 5).

Flows past Rices Weir are elevated in summer and autumn by regulated releases through outfall structures located along the Lower Broken Creek (Figure 6). In winter and spring, the average *recorded* flow is of similar magnitude to the average flow *recorded* in summer and spring, but this is because there are significant periods of data missing during winter and spring for 16 of the 45 years of record. In contrast, the MDBA modelled time-series for Rices Weir, while showing elevated flows in summer and autumn, has the highest average flows occurring in spring. In recent years however, drought conditions have seen recorded flow past Rices Weir fall below 10 ML/d for extended periods during winter and spring (Appendix A). The flow regime for the Boosey Creek at Tungamah and the Broken Creek at Katamatite follows a more natural pattern, with low flows in summer and higher flows in winter and spring, including occasional flood events (Appendix A).

On average, flows to the study area from the upstream catchments for the period of record available are 33 ML/d for December to May and 157 ML/d in for June to November (Table 1). The bulk of these inflows come from the Boosey Creek catchment. Average daily flows past Rices Weir for December to May and June to November are 300 ML/d – 500 ML/d, depending on whether the recorded or modelled streamflows are analysed.

Although average flows at Rices Weir are greater than for the Boosey Creek at Tungamah and the Broken Creek at Katamatite, the peaks of high flow events recorded at the upstream end of the study area are often attenuated by the time they reach Rices Weir (Figure 7).

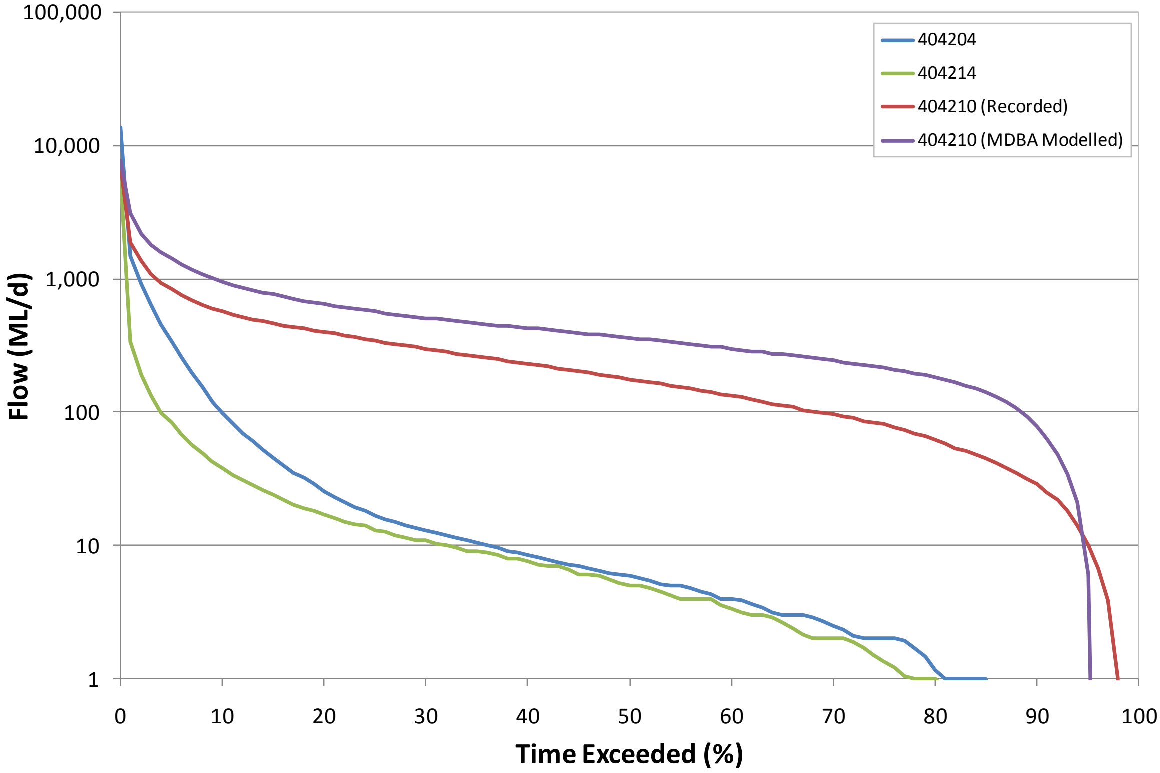


Figure 5 – Daily flow duration curve for streamflow gauges 404204, 404214 and 404210.

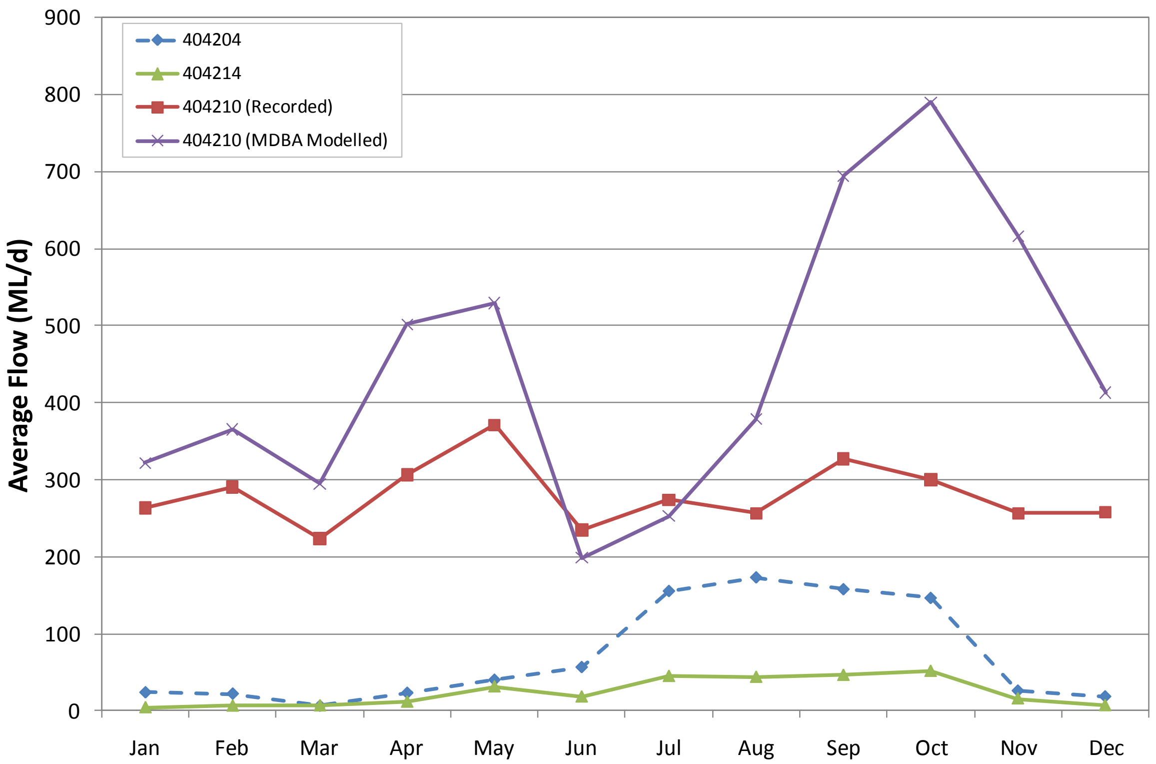
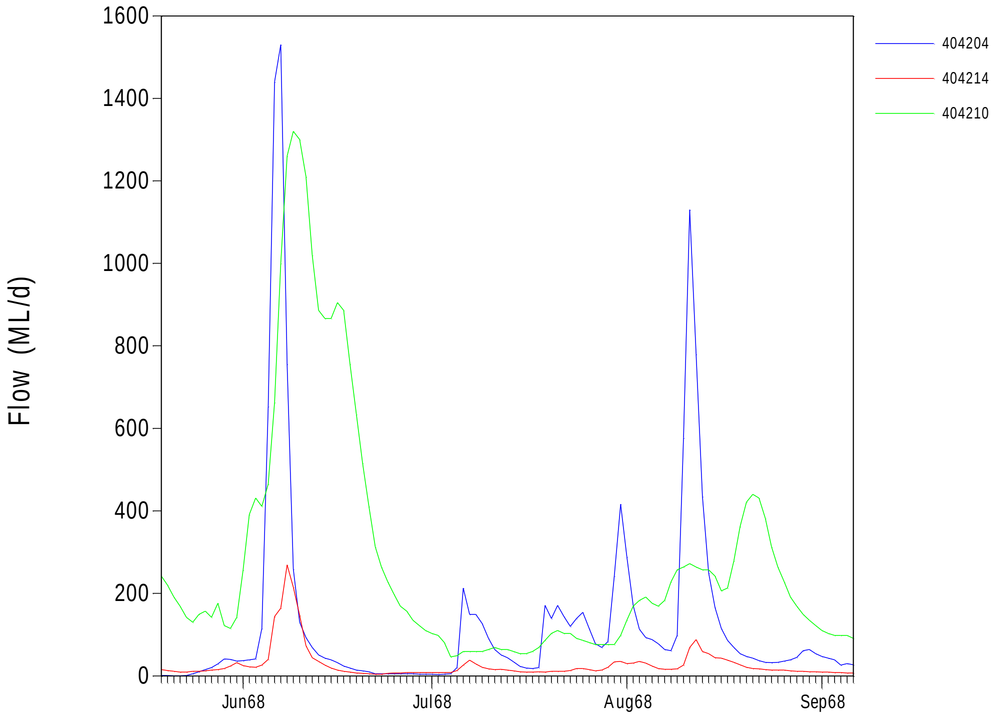


Figure 6 – Average daily flow for streamflow gauges 404204, 404214 and 404210.



- **Figure 7 – Attenuation of high flow events as they move from the upstream end of the study area (404204 and 404214) to the downstream end (404210).**

- **Table 1 – Flow statistics for gauges 404204 and 404214, and downstream gauge 404210.**

Statistic (ML/d)	Flow Gauge				
	404204	404214	404204 + 404214	404210 (Recorded)^	404210 (Modelled)*
Minimum daily flow	0	0	0	0	0
Average daily flow	71	24	95	280	492
Maximum daily flow	13,700	5,910	15,800	7,050	7,670
Summer minimum daily flow	0	0	0	0	0
Summer average daily flow	22	11	33	286	468
Summer maximum daily flow	3,390	4,800	6,920	7,020	4,390
Winter minimum daily flow	0	0	0	0	0
Winter average daily flow	120	37	157	273	549
Winter maximum daily flow	13,700	5,910	15,800	7,050	7,670

Note: Summer refers to the months December to May, while Winter refers to the months June to November.
Note:^ Without infilling missing periods in the gauge record.
Note: *Modelled time-series was provided by the MDBA from BigMod for the period 1891-2009.

4. Current Outfall Contributions

4.1. Introduction

Inflows to the Lower Broken Creek and Nine Mile Creek come from three sources:

- The upstream catchments;
- Irrigation channels that outfall directly to the creeks; and
- Drains that discharge to the creeks.

The flow contribution from the upstream catchments is described in Section 3.

Flow through outfall structures to the creeks is comprised of two parts:

- Inflows ordered by local diverters or environmental managers; and
- Inflows in excess of orders.

In addition to the outfall structures that connect directly to the creeks, a number discharge to drains (Appendix C). Flows through the outfall structures into drains combine with drainage flows. Often a portion of drainage flows will be diverted by irrigators before reaching the creek. Isolating the contribution of outfalls to drainage flows that enter the creeks is difficult.

4.2. Data Availability and Infilling – Outfall Structures and Drains

Data on inflows to the Lower Broken Creek and Nine Mile Creek through outfall structures and drains was sourced from Goulburn-Murray Water and Thiess (Table 2; Table 3).

For the outfalls, the 2000/2001 data was missing for the Murray Valley irrigation district, and the 1998/99 data was missing for the Shepparton irrigation district. For the drains, gauged data was available for the Muckatah drain, Shepparton Drain 12 and Shepparton Drain 11. No data was available for the remaining drains.

Missing records were infilled using the relationships developed by SKM in 2003 when a daily model of the Broken Creek was built (the model covers the period 1st January 1997 to 30th June 2002). These infilling methods are summarised in Appendix D. For more information refer to Section 2.2 SKM (2003).

- **Table 2 – Outfall structures discharging directly to the Lower Broken Creek and Nine Mile Creek.**

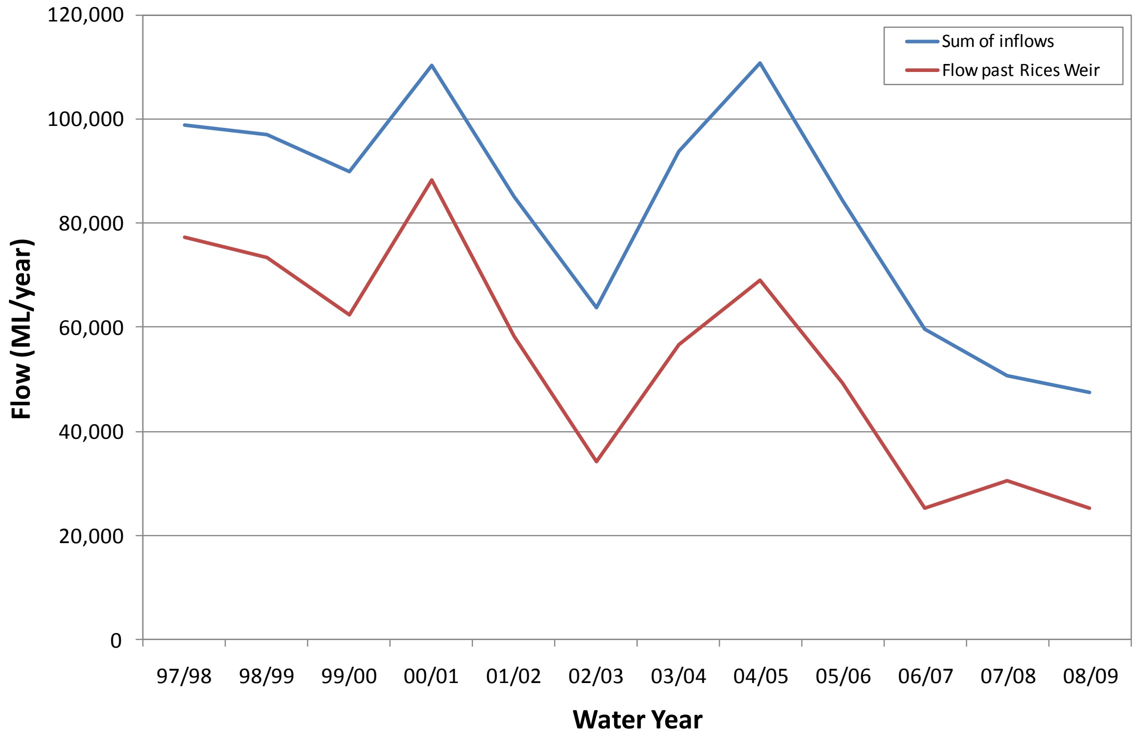
Asset Code	Asset Name	Data Source
ST066229	7/3	G-MW (Murray Valley)
ST072180	3 Main	G-MW (Murray Valley)
ST041815	4 Main	G-MW (Murray Valley)
ST057773	5/3	G-MW (Murray Valley)
ST056529	6/6	G-MW (Murray Valley)
ST056668	8/6	G-MW (Murray Valley)
ST056597	4/8/6	G-MW (Murray Valley)
ST066584	15/6	G-MW (Murray Valley)
ST058403	Jewells (21A/6)	G-MW (Murray Valley)
ST056428	Flanners (26A/6)	G-MW (Murray Valley)
ST056447	End 6 Main	G-MW (Murray Valley)
ST043762	EGM Outfall	G-MW (Shepparton)
ST018998	EG.34 Union Rd	G-MW (Shepparton)
ST019005	EG.34 End	G-MW (Shepparton)
ST045754	EG.12 No 1 (Hicks)	G-MW (Shepparton)
ST046200	EG.38/12 Town Spur	G-MW (Shepparton)
ST045802	EG.12 No 2 (Hollands)	G-MW (Shepparton)

- **Table 3 – Drains discharging to the Lower Broken Creek and Nine Mile Creek.**

Asset Name	Data Source
Muckatah Drain	Thiess (404712)
Murray Valley Drain 20	Not available
Murray Valley Drain 19	Not available
Murray Valley Drain 18	Not available
Murray Valley Drain 17	Not available
Murray Valley Drain 13	Not available
Shepparton Drain 16	Not available
Shepparton Drain 15	Not available
Shepparton Drain 13	Not available
Shepparton Drain 13A	Not available
Shepparton Drain 12	Thiess (405758)
Shepparton Drain 11	Thiess (405757)

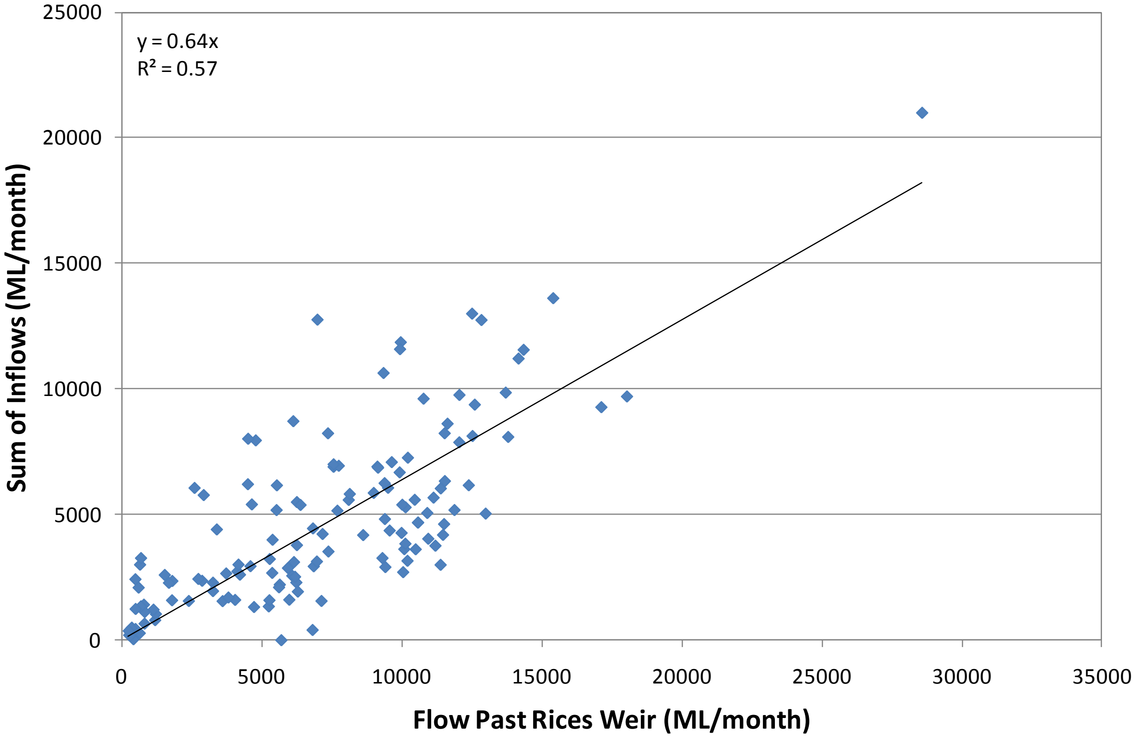
4.3. Total Inflows

Of the total inflows to the Lower Broken Creek and Nine Mile Creek system, a large portion flows downstream and passes to the Murray River (Figure 8). Over the past 10 water years, the annual flow past Rices Weir has only been 25% to 45% lower than total estimated inflows. In this report, water year 1997/98 is defined as 1st July 1997 to 30th June 1998.



- **Figure 8 – A comparison of annual total inflows (including from the upstream catchments, outfalls and drains) and annual flow past Rices Weir.**

Two aspects of the data plotted in Figure 8 are noted as follows. Firstly, missing data in the flow record for Rices Weir (Aug-99 to Nov 99; Mar-00 to Apr-00 and Sep-02 to Feb-03) was infilled using the relationship shown in Figure 9. Secondly, to check that the sum of inflows was a reasonable estimate, the difference between the sum of inflows and flow past Rices Weir was compared to the water use along the Lower Broken Creek and Nine Mile Creek as reported by SKM (2003) (Table 4). The difference between the sum of inflows and flow past Rices Weir would be attributable to diversions and losses, and therefore you would expect this number to be similar to but slightly higher than the estimated water use. In general, the difference calculated is not too dissimilar to the estimated water use, indicating that the sums of inflows estimated are within the order of magnitude expected.



- **Figure 9 – The regression relationship used to infill missing periods in the Rices Weir flow record.**

- **Table 4 – Comparing the sum of inflows with flow past Rices Weir, and the total water along the Lower Broken Creek and Nine Mile Creek (as estimated by SKM (2003)).**

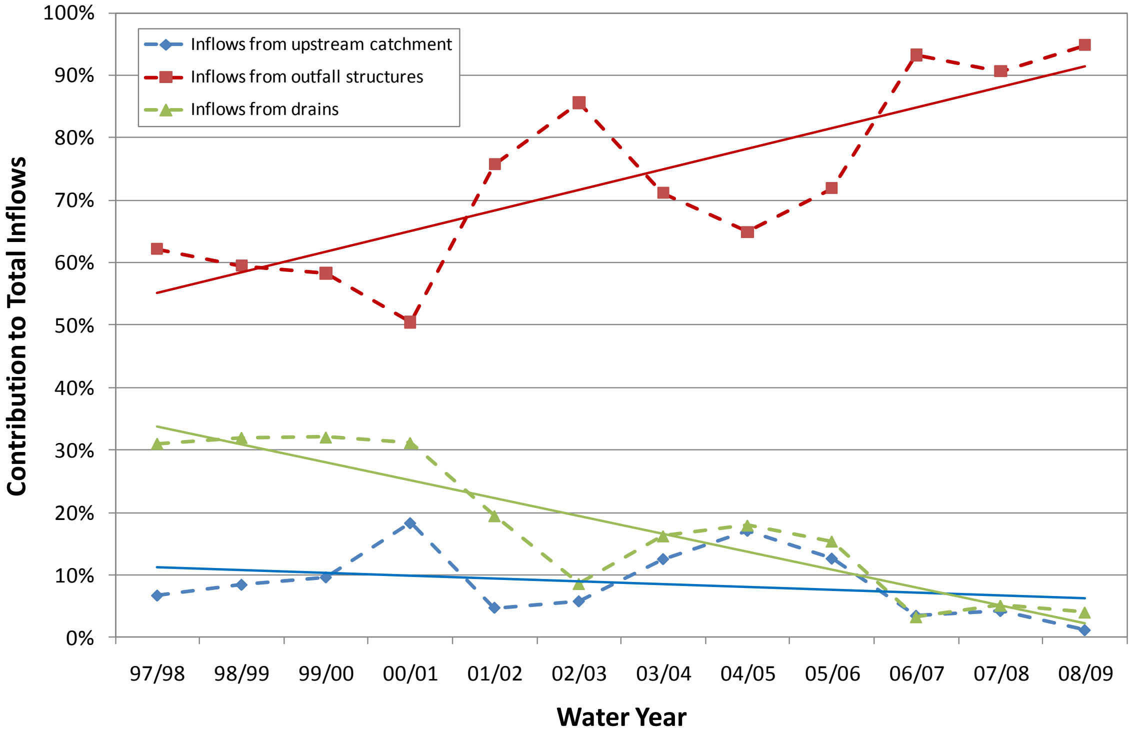
Water Year	Sum of Inflows (ML)	Flow Past Rices Weir (ML)	Difference (ML)	Water Use (ML) (SKM, 2003)
1997/98	98,800	77,200	21,600	26,900
1998/99	97,000	73,300	23,700	28,600
1999/00	90,000	62,400	27,600	18,400
2000/01	110,200	88,200	22,000	22,900
2001/02	85,200	58,200	27,000	25,600
2002/03	63,800	34,200	29,600	
2003/04	93,800	56,700	37,100	
2004/05	110,700	69,000	41,700	
2005/06	84,400	49,300	35,100	
2006/07	59,650	25,300	34,400	
2007/08	50,800	30,600	20,200	
2008/09	47,500	25,300	22,200	

4.4. Total Inflows through Outfall Structures

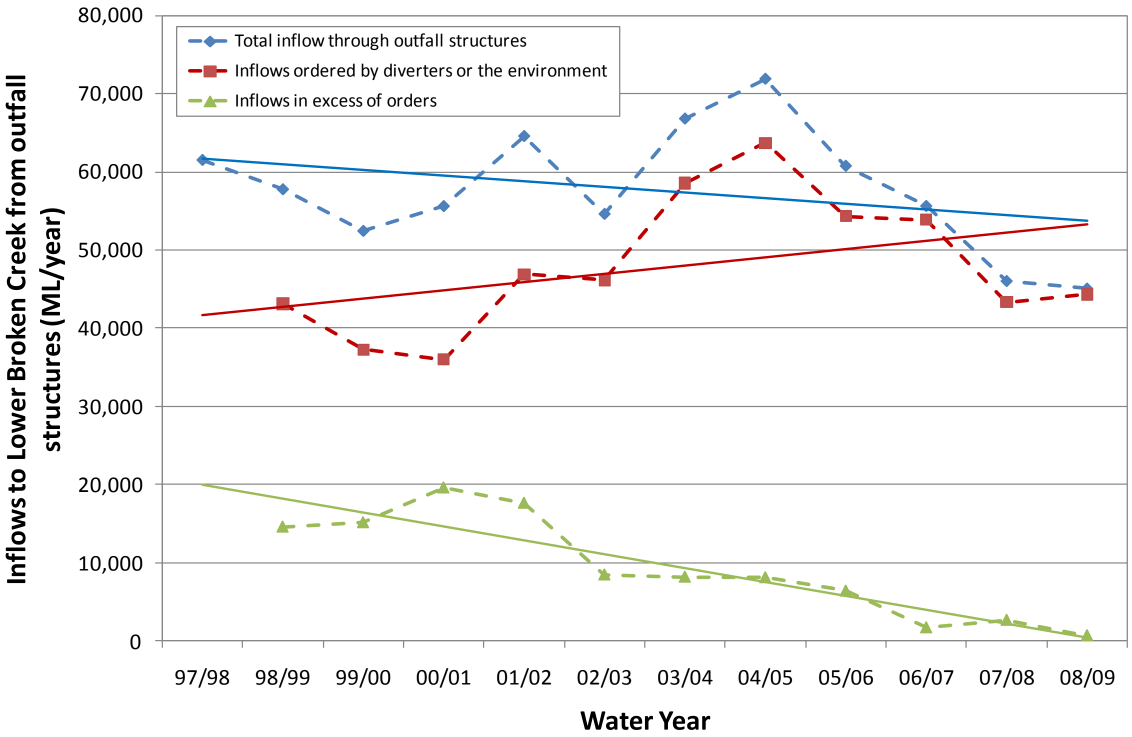
Of total inflows to the Lower Broken Creek and Nine Mile Creek systems, the majority comes through the channel outfall structures (Figure 10). Over the past 10 years, as drought conditions have reduced the percentage contributions from unregulated sources of water (i.e. the upstream catchments and drains), the percentage contribution from outfall structures has increased. In 2008-09, inflows from outfall structures contributed approximately 95% of total inflows.

At the same time as the percentage contribution to inflows from outfall structures has increased, the inflows through outfall structures in excess of orders has decreased. In short, the distribution of water through outfall structures to the Lower Broken Creek and Nine Mile Creek has been managed more tightly in recent years.

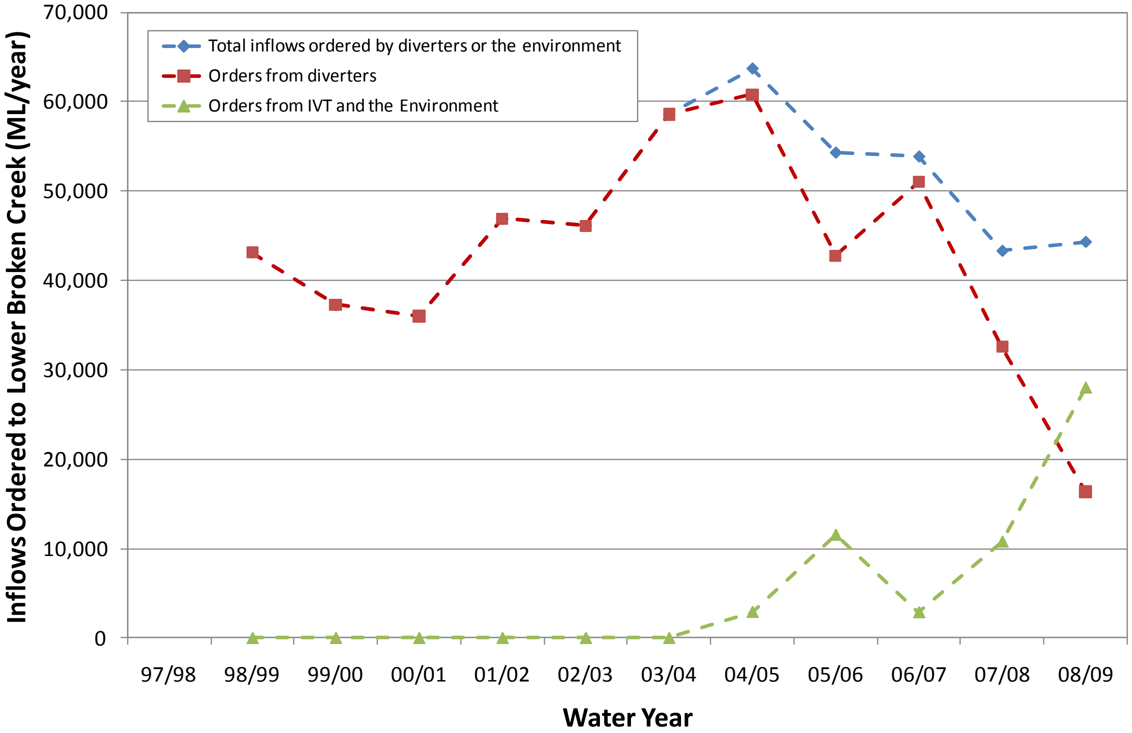
Interestingly, over the past five years, the volume of water ordered through outfall structures by environmental managers (using environmental allocations or inter valley transfers (IVTs)) has rapidly increased, while the volumes ordered by diverters has decreased (Figure 12). In 2008-09, the volume of water ordered for the environment and IVTs exceeded local diverter orders for the first time. The decrease in diverter orders can be linked with Murray and Goulburn irrigation allocations (Table 5). As allocations have decreased, and the volume of water ordered by diverters has also decreased. Environmental managers have therefore needed to order more water for the Lower Broken Creek and Nine Mile Creek systems for the purpose of maintaining sufficient water quality in the weir pools.



▪ **Figure 10 – The contribution of inflows from the upstream catchment, outfall structures and drains.**



▪ **Figure 11 – The total inflow through outfall structures, divided into ordered inflows and inflows in excess of orders.**



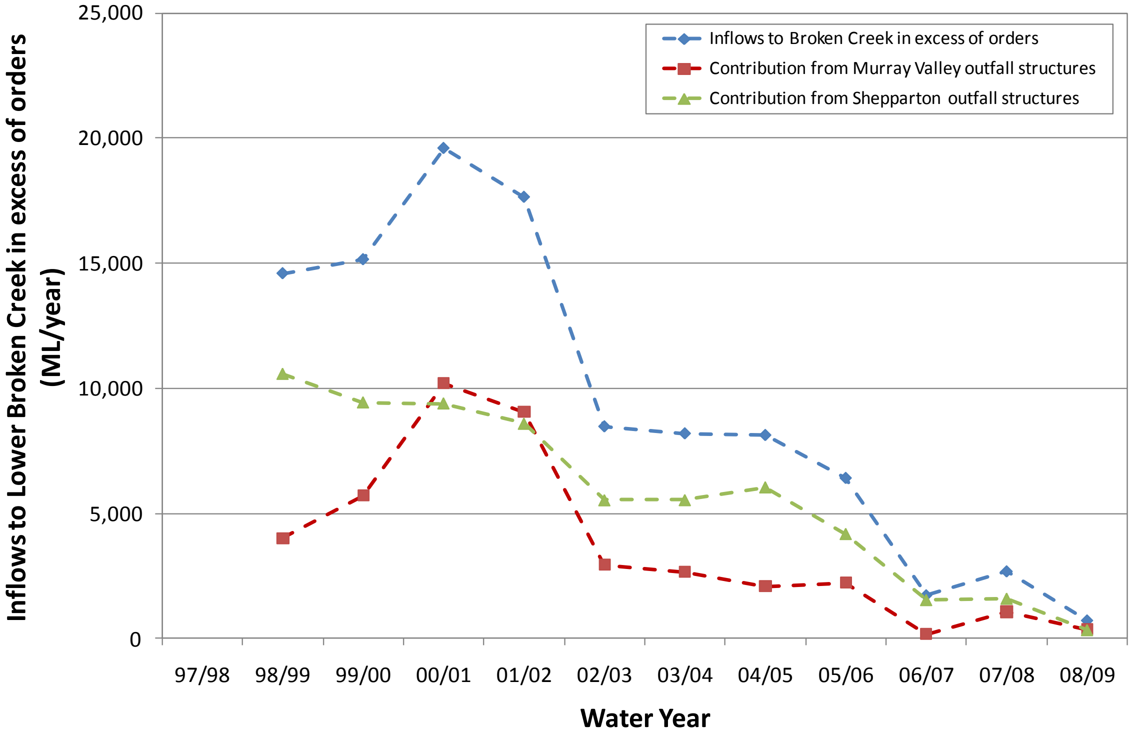
- **Figure 12 – The volume of ordered water for diverters, the environment and IVTs.**

- **Table 5 – Murray and Goulburn February irrigation allocations.**

Water Year	Murray Allocation	Goulburn Allocation
1997/97	200%	200%
1997/98	130%	120%
1998/99	200%	100%
1999/00	130%	100%
2000/01	200%	100%
2001/02	200%	100%
2002/03	129%	53%
2003/04	100%	100%
2004/05	100%	100%
2005/06	141%	100%
2006/07	95%	25%
2007/08	42%	53%
2008/09	35%	33%

4.5. Inflows through Outfall Structures in Excess of Orders

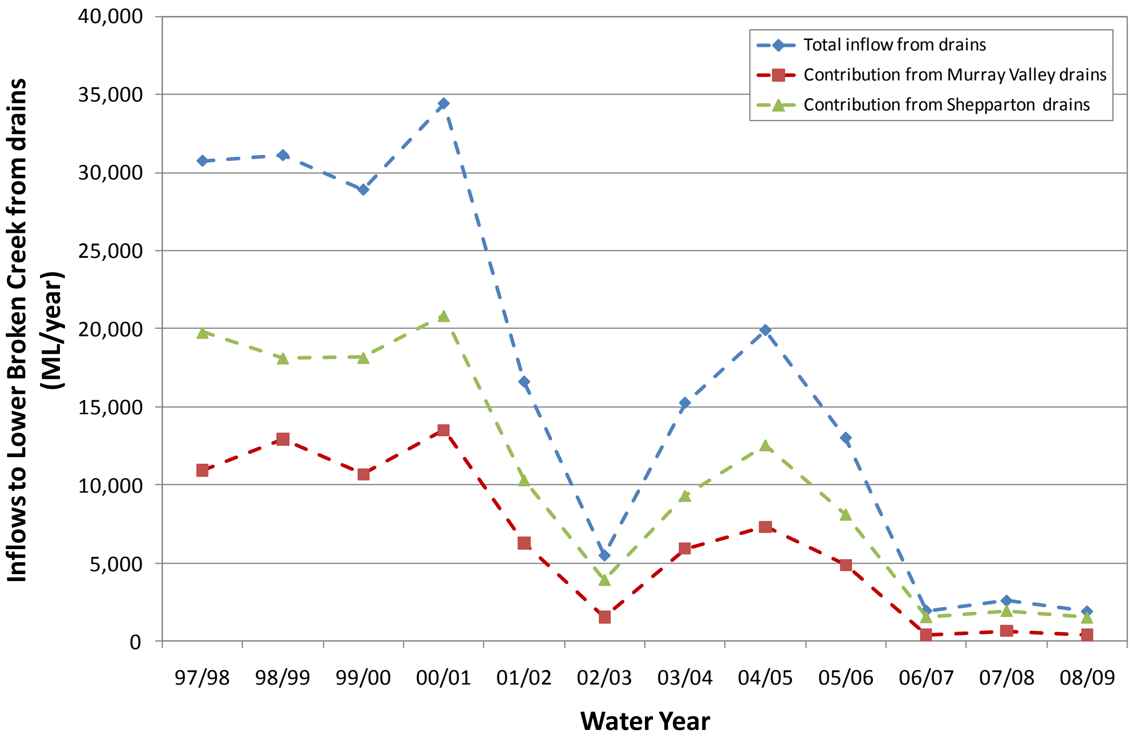
Inflows to the Lower Broken Creek and Nine Mile Creek system in excess of orders have declined significantly over the past 10 years. In 2004/05 (which is often used as a base case for assessing the impacts of NVIRP works), inflows through outfall structures in excess of orders were approximately 8,100 ML. Of this, 6,000 ML was contributed from the Shepparton irrigation district and 2,100 ML was from the Murray Valley irrigation district. In 2009, inflows in excess of orders were only 730 ML, half of which came from both irrigation districts (Figure 13). Inflows in excess of orders through Shepparton outfall structures are likely to have been impacted by the Shepparton Modernisation Project, which was in place for the 2008/09 irrigation season.



- **Figure 13 – The inflows in excess of orders contributed by the Murray Valley outfall structures and the Shepparton outfall structures.**

4.6. Inflows through Drains

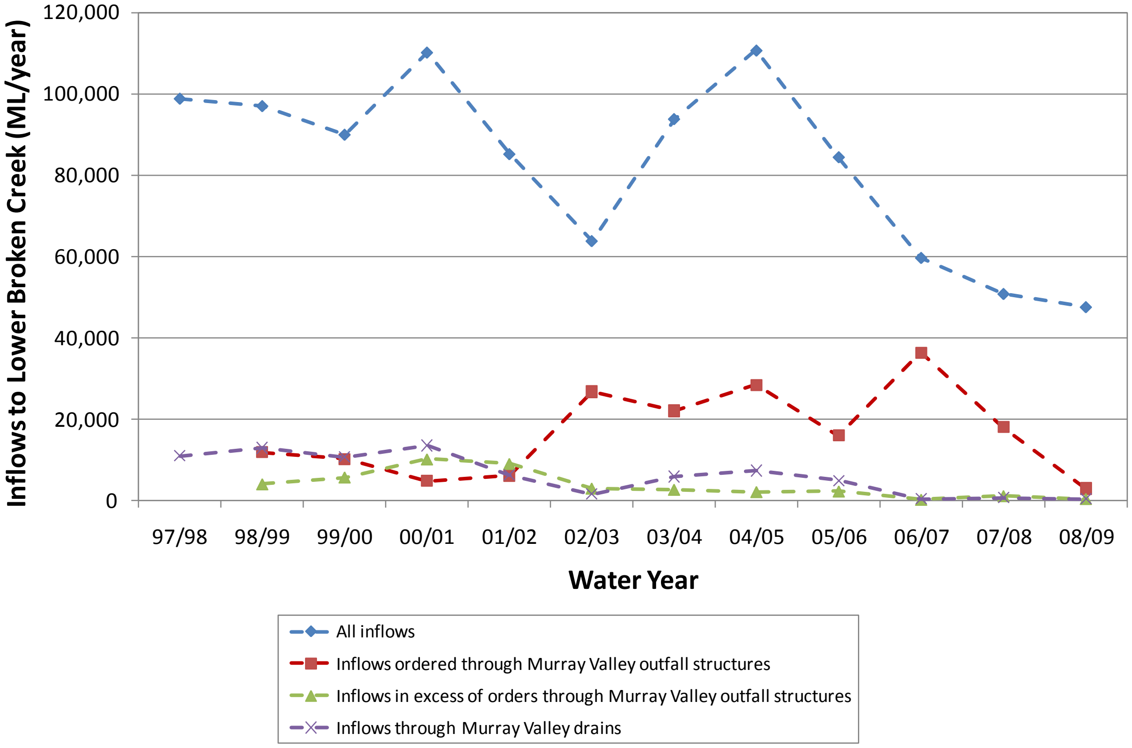
Inflows to the Lower Broken Creek and Nine Mile Creek system through drains have also declined significantly over the past 10 years. In the late 1990s and early 2000s, drainage inflows to the sytem were 30,000 ML/year – 35,000 ML/year. In the past few years however, inflows from drains have been a minor component of total inflows. This reduction in drainage inflows is probably attributable to a combination of less rainfall runoff, less runoff from irrigation application, less channel outfalls into drainage sytems and increased drainage diversions.



- **Figure 14 – The inflow volume from drains contributed by the Murray Valley drains and the Shepparton drains.**

4.7. Murray Valley Contribution to Total Inflows

NVIRP works are being implemented in the Murray Valley irrigation district. Therefore, changes to the Lower Broken Creek and Nine Mile Creek flow regimes attributable to NVIRP, will be reflected in changes to flow contributions from the Murray Valley side of the creeks. Figure 15 shows the inflows through Murray Valley outfall structures (ordered and in excess of orders) and the inflows through Murray Valley drains in comparison with total inflows to the system. This figure shows that inflows in excess of orders through Murray Valley outfall structures are a small component of total inflows.

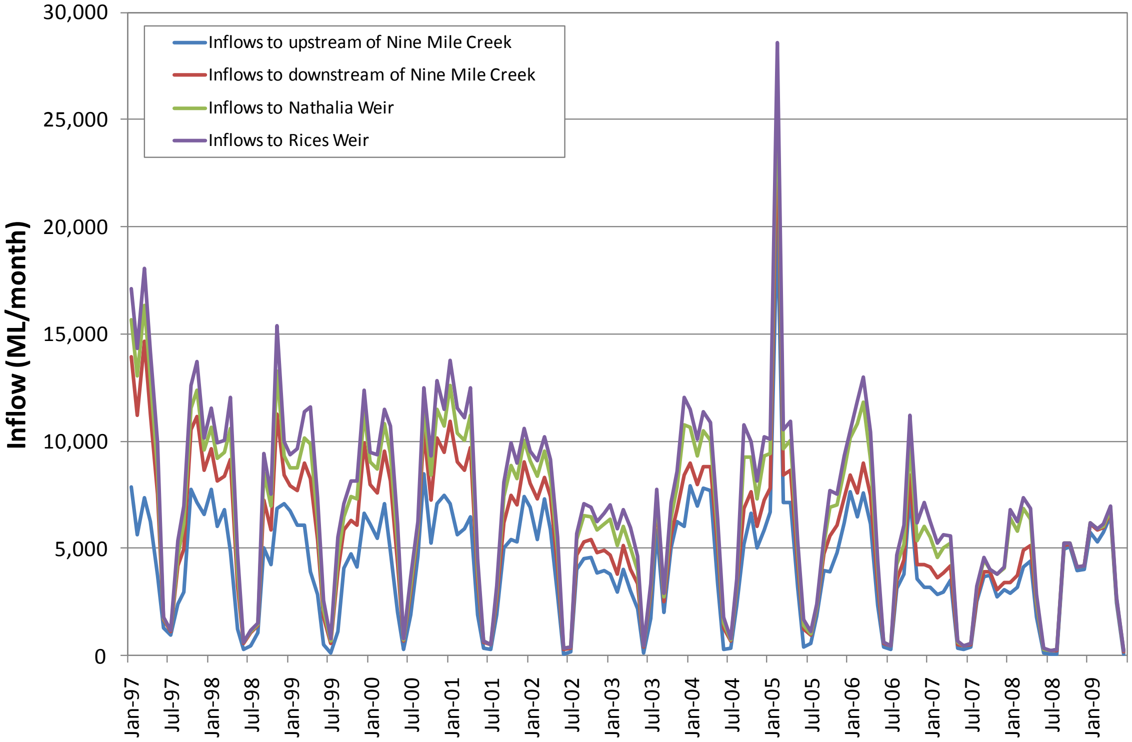


- **Figure 15 – Total inflow, inflow through outfalls that will be decommissioned (both ordered and in excess of orders) and inflows through Murray Valley drains.**

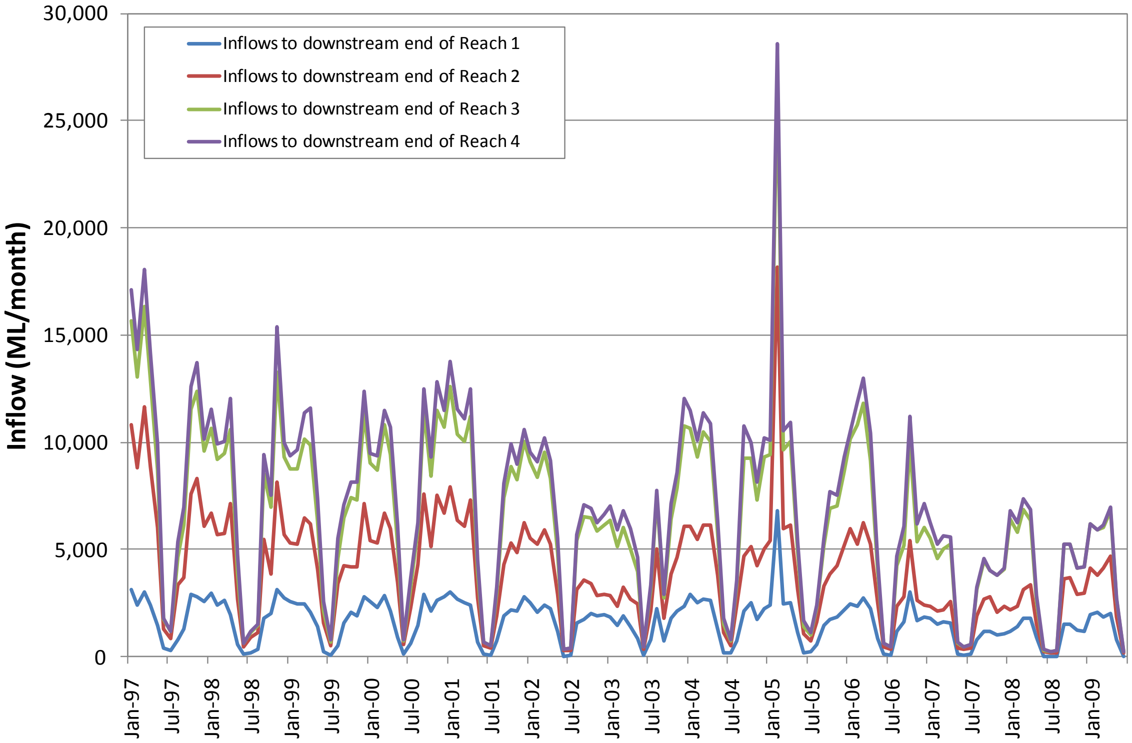
4.8. Reach Inflows

On a reach by reach basis, the contribution of total inflows is weighted to the upstream end of the study area. This is particularly the case in recent years (i.e. 2008/09), when minimal inflows to the system were recorded downstream of where the Lower Broken Creek and Nine Mile Creek split (Figure 16). If it is assumed that flows are split 30%:70% down the Lower Broken Creek and Nine Mile Creek at Katandra weir, inflows to each of the four environmental reaches can be calculated (Figure 17). Inflows for each of the reaches compared to inflows through outfalls structures, drains and from the upstream catchments are shown in Appendix E.

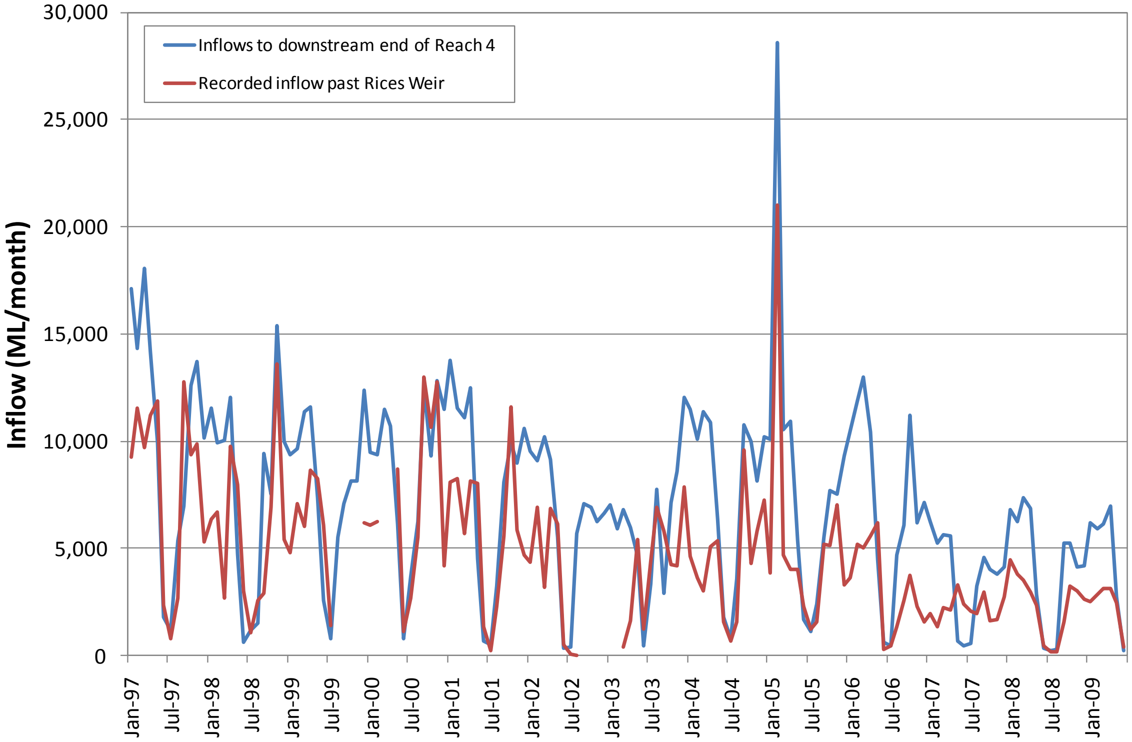
Given this analysis focuses on inflows, and the contribution of inflows in excess of orders, it needs to be recognised that inflows may not be a reliable indication of flows within the creeks because of diversions and losses. However, for the Lower Broken Creek at least, an understanding of total inflows generally provides a reasonable understanding of flow passing Rices Weir (Figure 18). That is, the pattern of inflows generally matches the pattern of flow at Rices Weir, with the differences in magnitude attributable to diversions and losses.



- **Figure 16 – Inflows to different locations along the Lower Broken Creek.**



- **Figure 17 – Inflows to the four environmental reaches, assuming a 30%:70% division of flows where the Lower Broken Creek and Nine Mile Creek split.**



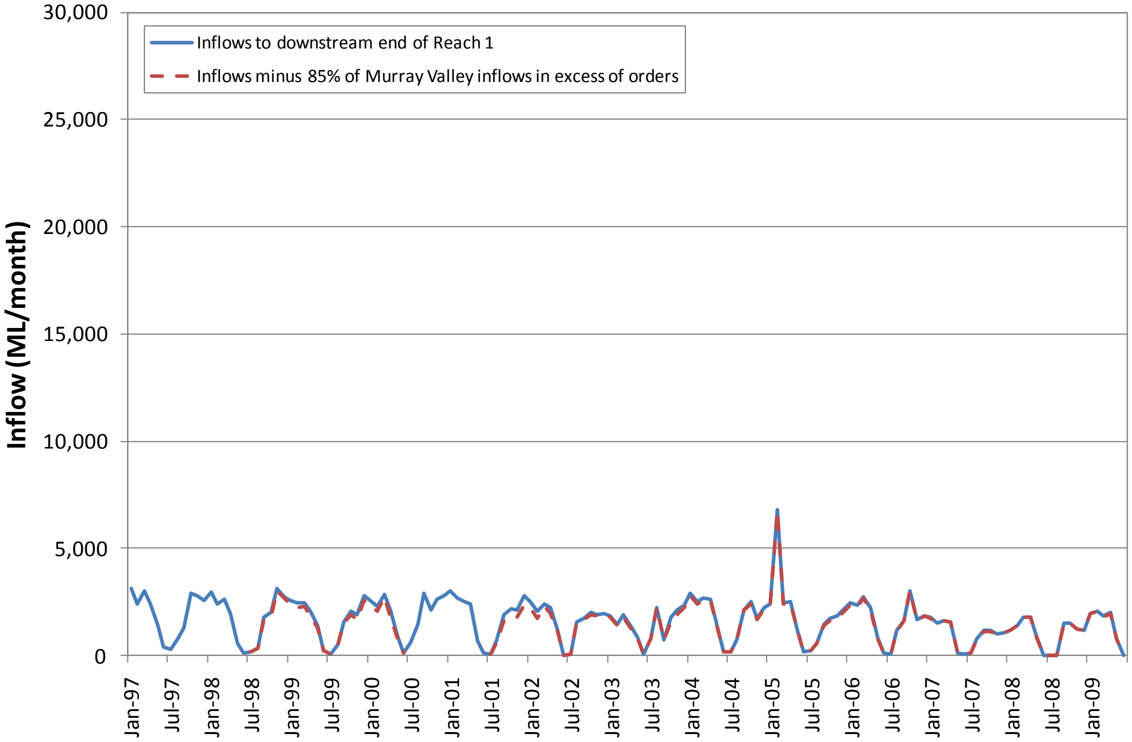
- **Figure 18 – Inflows to Rices Weir (the downstream end of Reach 4), compared to recorded flow past Rices Weir.**

5. Likely Impacts of NVIRP Works

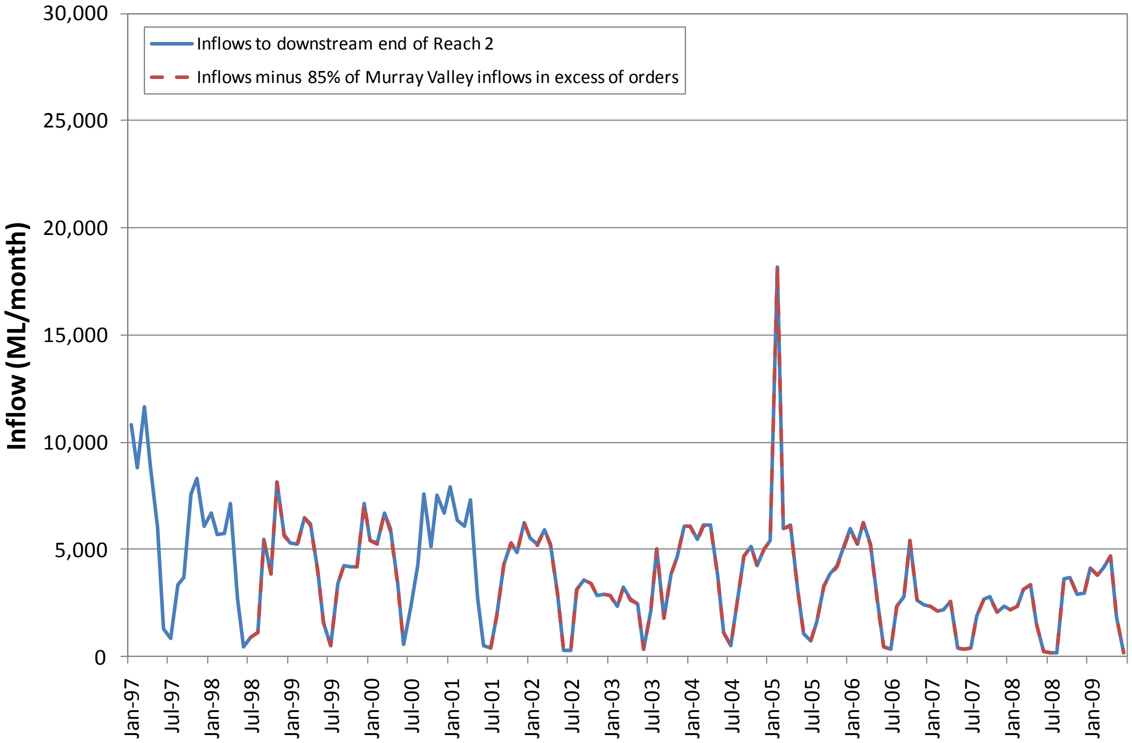
The stated aim of NVIRP is to reduce the inflows though Murray Valley outfall structures in excess of orders (i.e. the outfalls) by 85%. This situation is different to some other irrigation systems, where all the water flowing through an outfall structure is considered an outfall, 85% of which will be saved by NVIRP works. The Shepparton irrigation district was modernised in a separate project (the Shepparton Modernisation Project), but the impact of this project on inflows to the Lower Broken Creek and Nine Mile Creek is not assessed as part of this study.

To reduce the inflows in excess of orders, NVIRP will either decommission existing outfall structures, or implement Total Channel Control (TCC). Implementing TCC involves replacing the manually operated drop boards currently used to regulate channel flows, with a system of remotely controlled flume gates. At the time of writing, NVIRP were planning to decommission seven of the eleven Murray Valley outfall structures. Those to be kept are denoted by an asterisk in Figure 3. However, for this study, it was assumed the 85% reduction of inflows in excess of orders is distributed along the Lower Broken Creek and Nine Mile Creek reaches in accordance with current inflows in excess of orders. This is considered appropriate, because all reaches will still have inflows from Murray Valley outfall structures (reach two receives a contribution from the Murray Valley 7/3 outfall structure), and the remaining structures will need to pass the flows previously carried by the decommissioned outfalls to meet local diverter orders.

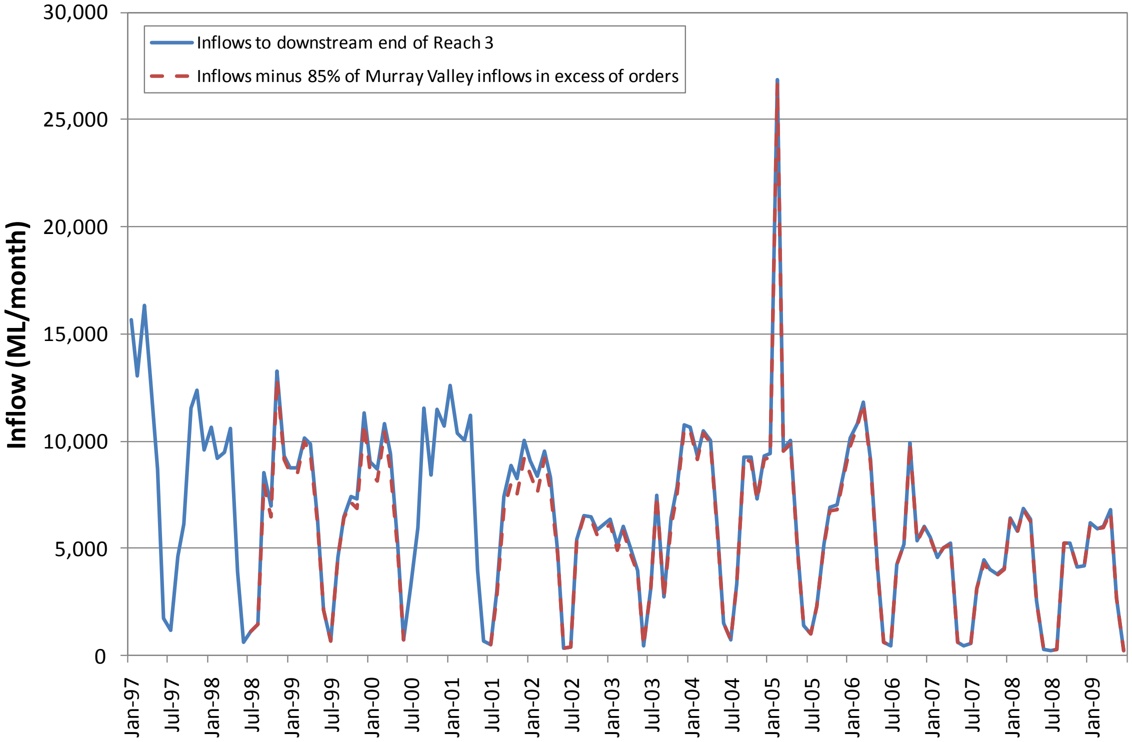
Figure 19 to Figure 22 shows the estimated total inflows to each reach for January 1997 to June 2009, and the total inflows assuming inflows through Murray Valley outfall structures in excess of orders are reduced by 85%. Information for categorising monthly inflows through Murray Valley outfall structures as ‘ordered’ or ‘excess’ are not available for 2000/01, or the years prior to 1998/99. Regardless, these figures show that reducing inflows through Murray Valley outfall structures in excess of orders by 85% would not have a material impact on inflows to the Lower Broken Creek or Nine Mile Creek, especially for 2002/03 onwards.



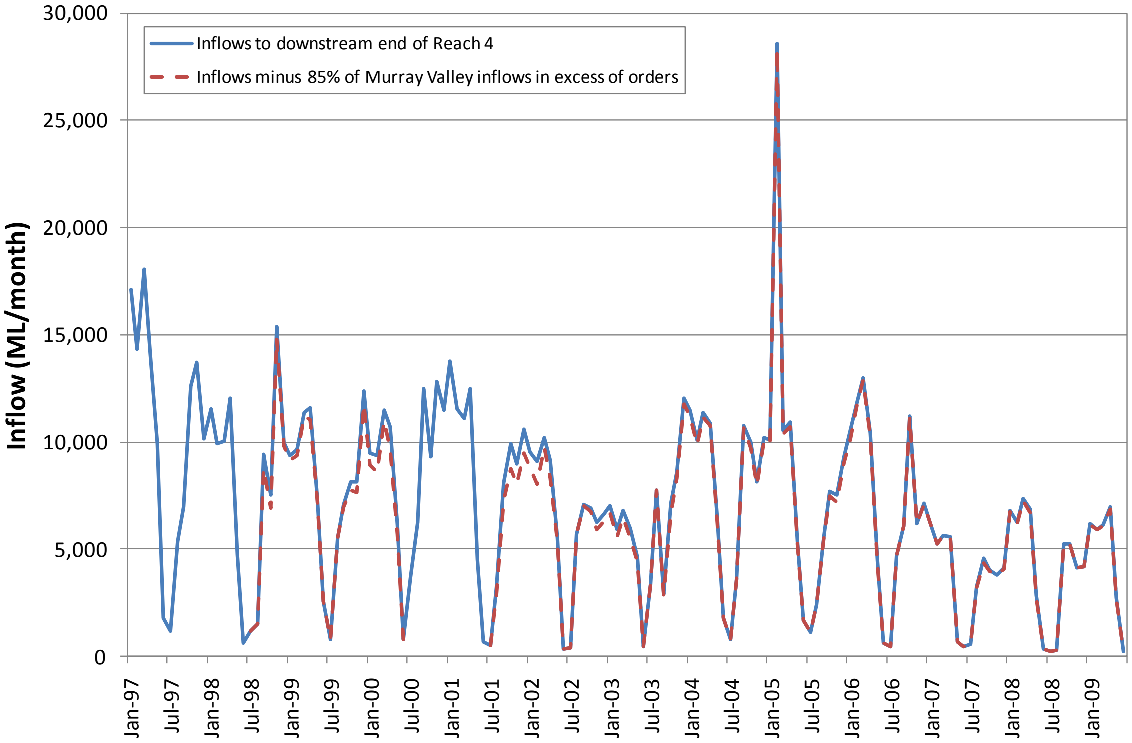
- **Figure 19 – The impact of NVIRP works on Reach 1.**



- **Figure 20 – The impact of NVIRP works on Reach 2.**



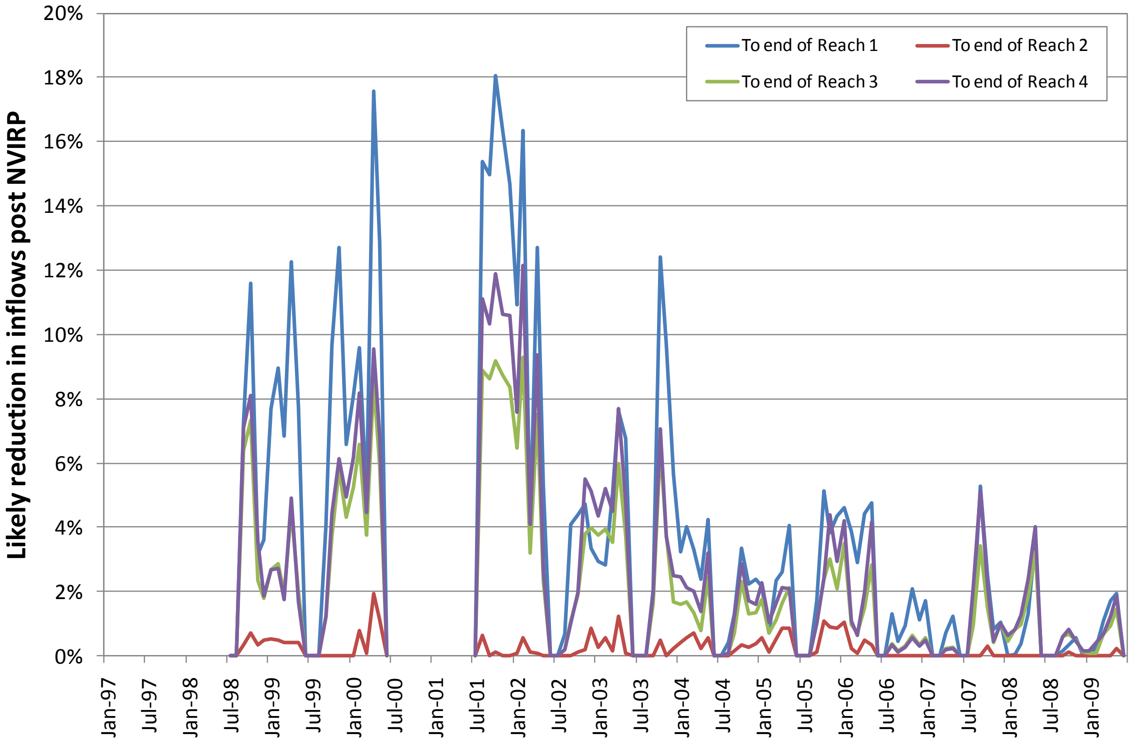
- **Figure 21 – The impact of NVIRP works on Reach 3.**



- **Figure 22 – The impact of NVIRP works on Reach 4.**

The expected reduction in inflows to each environmental flow reach in percentage terms is shown in Figure 23. If the years 1997/98 to 2001/02 were repeated with NVIRP works in place, the reduction in inflows to Reach 1 would be as high as 18%. Inflows to Reach 3 and Reach 4 would be reduced by as much as 10% and 12% respectively. However if the years 2004/05 onwards were to be repeated with NVIRP works in place, the reduction in inflows would be less than 5% for all reaches. Reach 2 (Nine Mile Creek) is particularly unaffected, given no Murray Valley outfall structures discharge to Nine Mile Creek, and only one discharges upstream of where Lower Broken Creek and Nine Mile Creek split.

On a yearly time-step, the expected reduction in total inflows would range from 9% in 2001/02 to 0.3% in 2006/07 (Table 6). However, it should also be recognised that G-MW implemented a loss management program in 2002/03, and losses observed in 2001/02 and prior are unlikely to be repeated while this loss management program continues.



- **Figure 23 – Reduction in inflows because of NVIRP works, assuming inflows through Murray Valley outfall structures in excess of orders are reduced by 85%.**

- **Table 6 – The annual impact of NVIRP works on total inflows to the Lower Broken Creek and Nine Mile Creek, assuming inflows through Murray Valley outfall structures in excess of orders are reduced by 85%.**

Year	Total Inflow	85% of Murray Valley Inflows in Excess of Orders (1)	Total Inflow minus (1)	Percent Reduction
1997/98	98,800			
1998/99	97,000	3,400	93,600	3.5%
1999/00	90,000	4,900	85,100	5.4%
2000/01	110,200	8,700	101,500	7.9%
2001/02	85,200	7,700	77,500	9.0%
2002/03	63,800	2,500	61,300	3.9%
2003/04	93,800	2,300	91,500	2.4%
2004/05	110,700	1,800	108,900	1.6%
2005/06	84,400	1,900	82,500	2.2%
2006/07	59,650	100	59,500	0.3%
2007/08	50,800	900	49,900	1.8%
2008/09	47,500	300	47,200	0.7%

Current practice is to analyse the impact of NVIRP works assuming a 2004/05 base case (Figure 24, which isolates 2004/05 from Figure 23). Were the year 2004/05 repeated, the monthly reduction in inflows attributable to NVIRP works would be less than 1% for Reach 2, between 1% and 3% for Reaches 1 and 3, and up to 4% for Reach 4. The impact of NVIRP works during 2008/09 is also of interest, given irrigation allocations in the Murray system that year were the lowest on record. Were the year 2008/09 repeated, the monthly reduction in inflows because of NVIRP works would be less than 2% for each reach (Figure 25). Appendix F shows how total monthly inflows would change in 2004/05 and 2008/09 given these percentage reductions.

Figure 24 and Figure 25 present the reduction in inflows assuming the only impact of NVIRP works is to reduce inflows through Murray Valley outfall structures in excess of orders. However, this is probably a conservative estimate of the impact of NVIRP works, because a there are a number of Murray Valley outfall structures that connect to drains, which in turn discharge to the Lower Broken Creek (Appendix C).

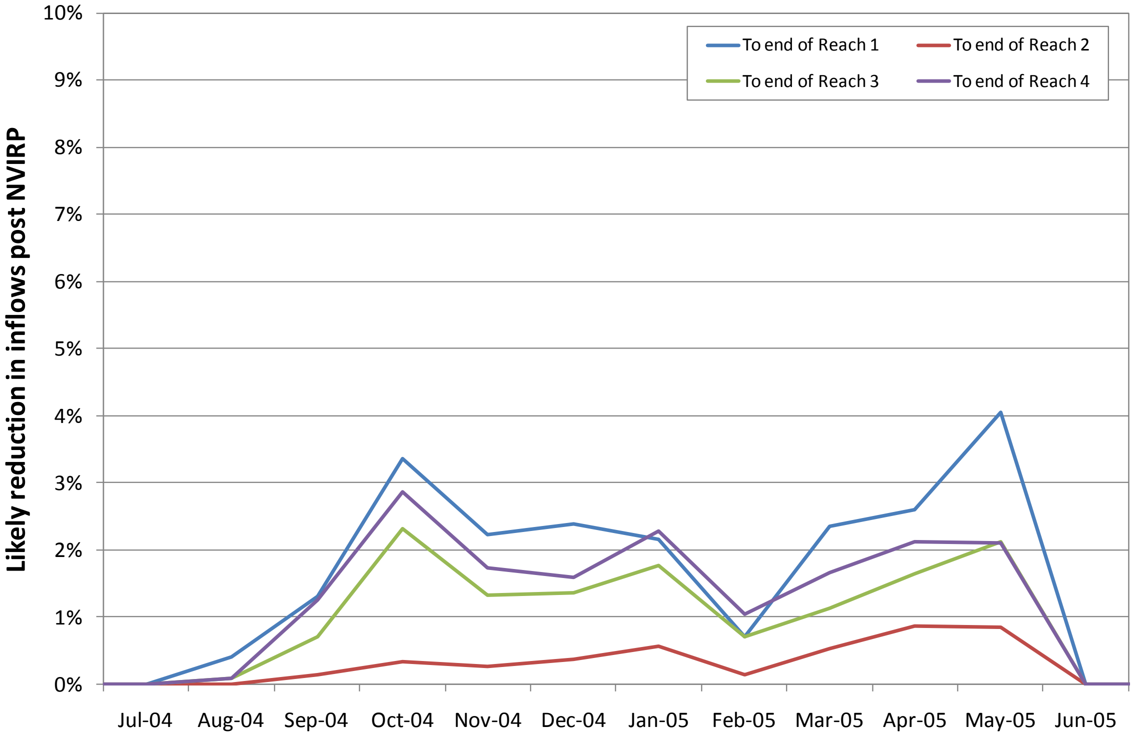
Isolating the contribution of outfalls to drainage flows that enter the creek is difficult. Flows through the outfall structures into drains combine with flows from other sources. Often a portion of drainage flows will be diverted by irrigators before reaching the creek. To test the sensitivity of total inflows to changes in drainage inflows that may result from NVIRP works, it was assumed that drainage flows are evenly comprised of the three major contributors (i.e. 33% rainfall runoff, 33% irrigation runoff and 33% channel outfalls).

Assuming 85% of channel outfalls are saved by NVIRP works, drainage inflows to the Lower Broken Creek and Nine Mile Creek through Murray Valley drains would reduce by approximately 30%. Figure 26 and Figure 27 show the impact of NVIRP works on total inflows assuming that inflows in excess of orders through Murray Valley outfall structures that connect directly to the creek are reduced by 85% **and** inflows through Murray Valley drains are reduced by 30%. It should be kept in mind that this 30% reduction in drainage inflows is subjective and most Murray Valley drains are not metered. However, Figure 26 and Figure 27 show that assuming drain inflows will also reduce does not invalidate the conclusion that NVIRP works will have a minimal impact on total inflows.

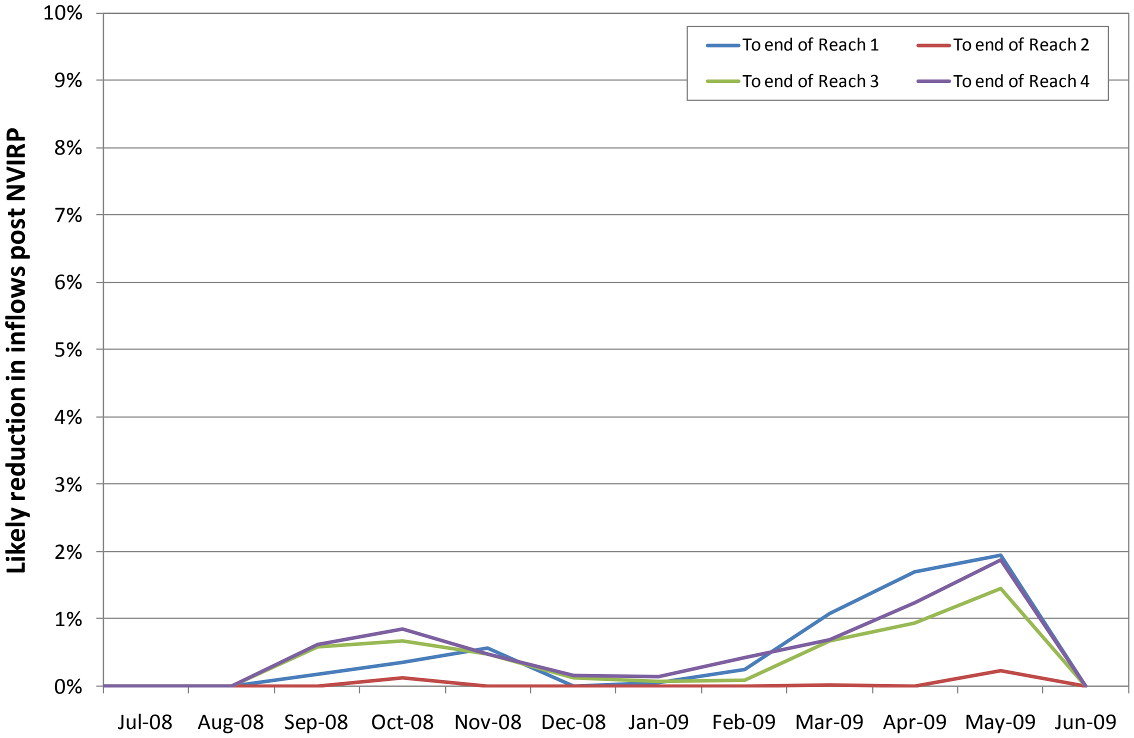
Given a long term computer model of the Lower Broken Creek is yet to be developed (an existing daily FORTRAN model only covers the period 1st January 1997 to 30th June 2002), and building such a model was well outside the scope and time available for this project, it is not possible to translate the predicted inflow reductions into changes in streamflow for the long term average, base case year (2004/05) or the year with the lowest Murray allocations (2008/09). However, it is logical to surmise that if NVIRP works cause a minimal reduction in inflows, there will be a minimal reduction in streamflows through each of the environmental flow reaches. Had this study shown that NVIRP works are likely to have a significant impact on inflows, the time and money required to develop a long term model of the Lower Broken Creek may have been justified, but this is not the case.

The changes in water levels throughout the Lower Broken Creek and Nine Mile Creek system attributable to NVIRP works is also predicted to be negligible, given the minimal changes in inflow. This is especially true for the lower reaches of the Lower Broken Creek, where water levels are held artificially high, and variations are dampened, by the many weirs between Nathalia and Rices Weir.

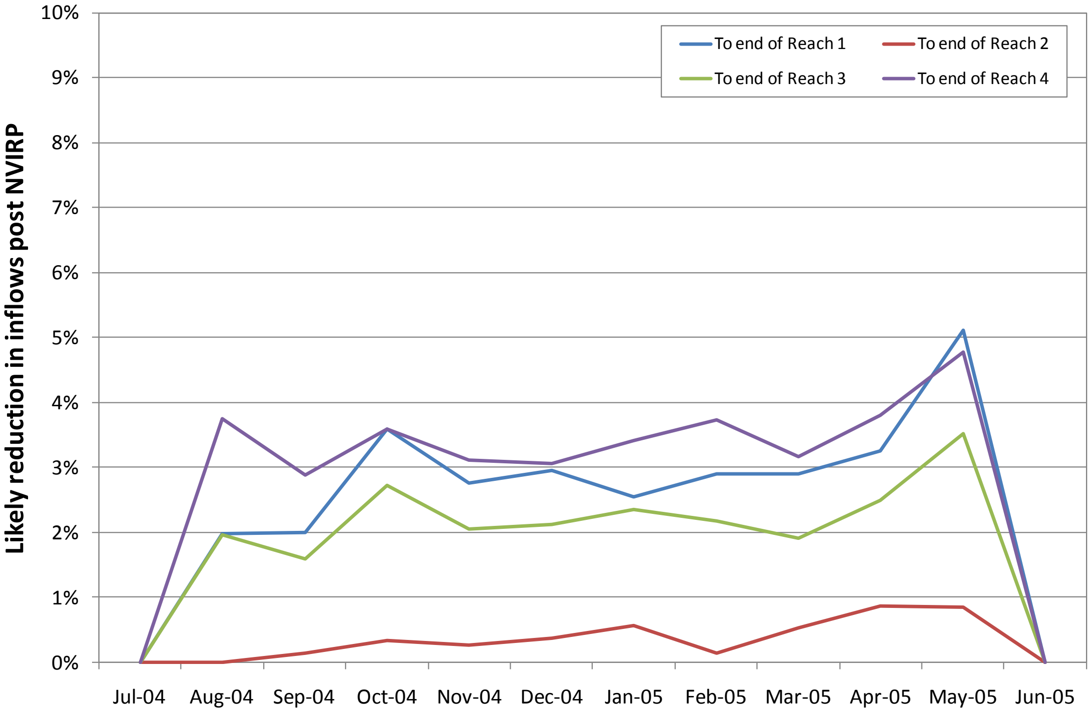
In summary, the flows that pass through the Lower Broken Creek and Nine Mile Creek are much more sensitive to irrigation allocations, the volumes of water ordered by local diverters or environmental managers, and the extent to which the waterway is used for inter-valley transfers, than the contribution of inflows in excess of orders through Murray Valley outfall structures.



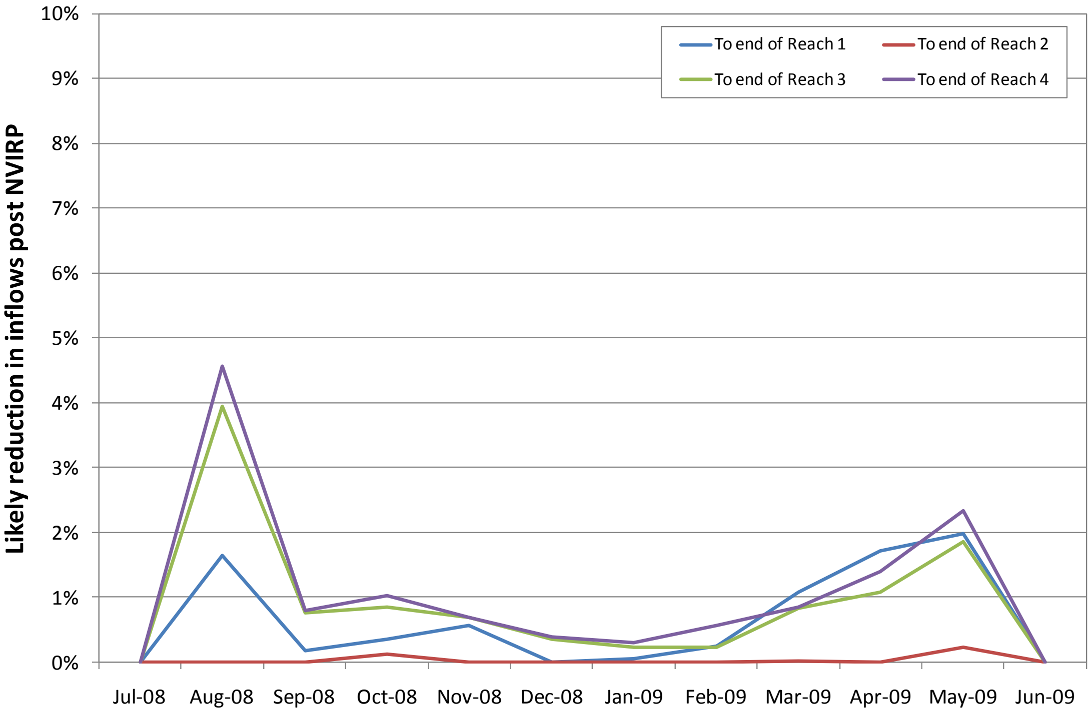
- **Figure 24 – Reduction in inflows because of NVIRP works for 2004/05, assuming inflows through Murray Valley outfall structures in excess of orders are reduced by 85%.**



- **Figure 25 – Reduction in inflows because of NVIRP works for 2008/09, assuming inflows through Murray Valley outfall structures in excess of orders are reduced by 85%.**



- **Figure 26 – Reduction in inflows because of NVIRP works for 2004/05, assuming inflows through Murray Valley outfall structures in excess of orders are reduced by 85% and inflows through Murray Valley drains are reduced by 30%.**



- **Figure 27 – Reduction in inflows because of NVIRP works for 2008/09, assuming inflows through Murray Valley outfall structures in excess of orders are reduced by 85%, and inflows through Murray Valley drains are reduced by 30%.**

6. Summary and Conclusions

The Lower Broken Creek and Nine Mile Creek is a highly regulated system. The vast majority of inflows to the system come through channel outfall structures that connect directly to the creeks from both the Murray Valley and Shepparton irrigation districts. Inflows through outfall structures are comprised of two parts – inflows ordered by local diverters or environmental managers, and inflows in excess of orders.

NVIRP plans to reduce the inflows through Murray Valley outfall structures in excess of orders by 85%. This is likely to reduce the volume of water flowing down the creeks. However, the contribution of this ‘excess’ to total inflows is minor, especially post 2002/03. Therefore, reducing Murray Valley inflows in excess of orders by 85% is expected to reduce monthly inflows by less than 4% for all environmental flow reaches, assuming 2004/05 is the base case for this assessment. Even when assuming Murray Valley drainage inflows reduce by 30% because of NVIRP works, the reduction in monthly inflows in 2004/05 remains below 5% for all environmental flow reaches.

7. References

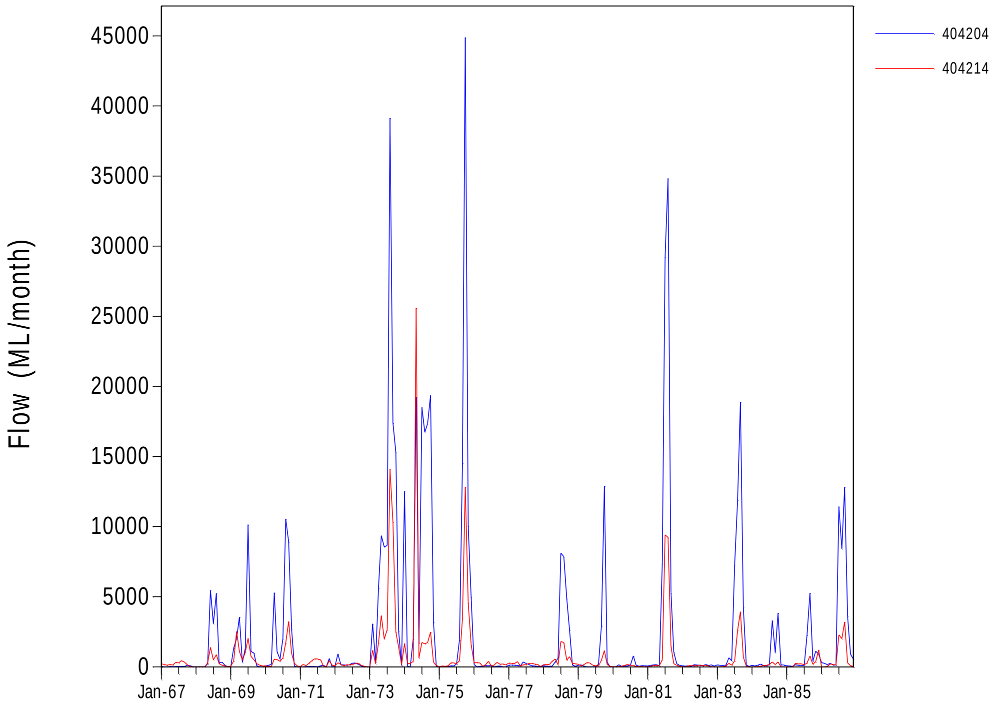
RWC (1987). Victorian Surface Water Information to 1987. Volume 3.

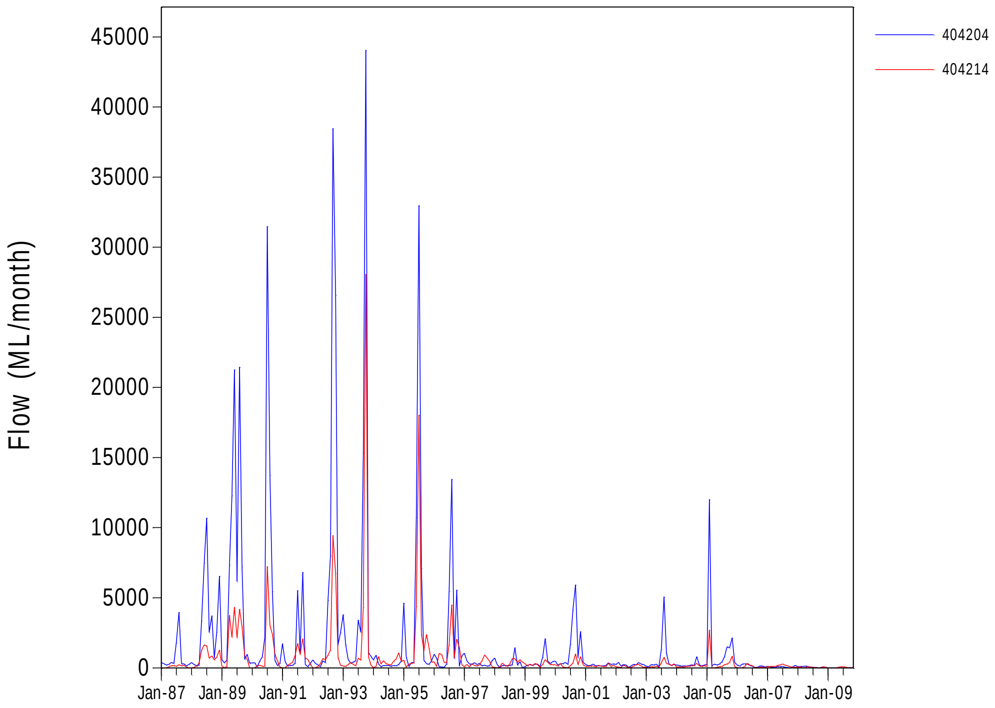
SKM (2003). Broken Creek Model – Stage 2, Final Report, Prepared for Goulburn Murray Water, January 2003.

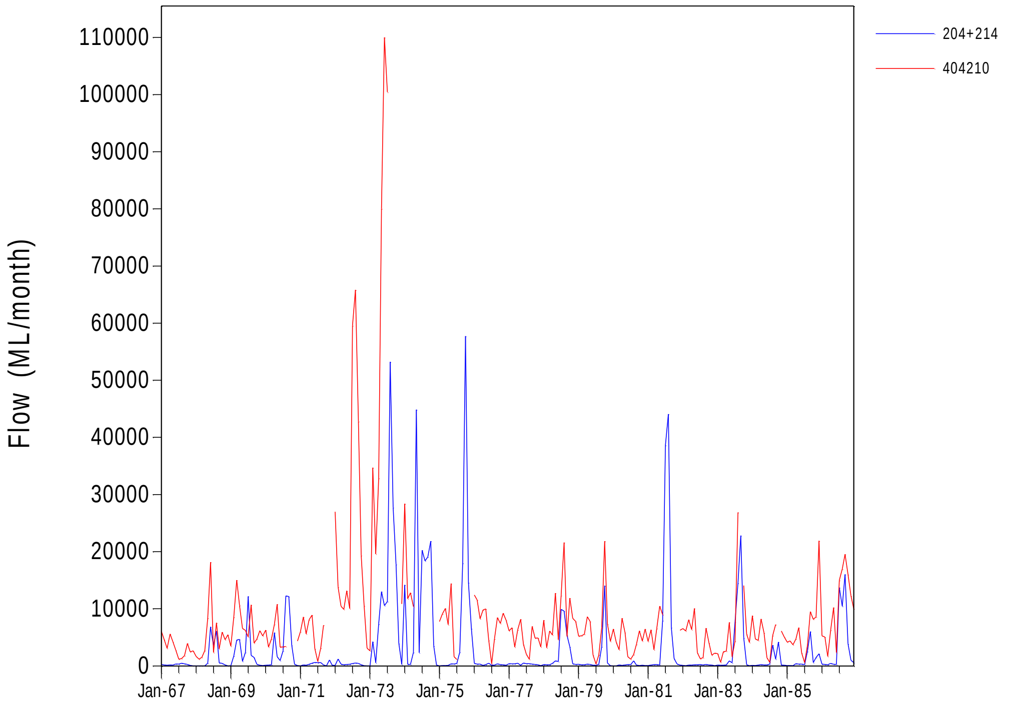
Appendix A Quality of Gauge Records

Gauge	Quality Code	Thiess Quality Statement	Percentage of Record
404204 Boosey Creek at Tungamah	1	Good continuous records	73.72
	2	Good quality edited data	22.29
	3	Linear infill to first value in block (no data lost)	0.29
	8	Pool reading only	0.53
	9	Pool dry - no data collected	2.01
	10	Data transposed from recorder chart	0.29
	82	Linear interpolation across gap in records	0.51
	104	Records estimated	0.33
	255	No data exists	0.04
404214 Broken Creek at Katamatite	1	Good continuous records	36.95
	2	Good quality edited data	58.14
	3	Linear infill to first value in block (no data lost)	0.32
	8	Pool reading only	1.36
	9	Pool dry - no data collected	0.23
	10	Data transposed from recorder chart	0.63
	15	Minor editing	0.07
	82	Linear interpolation across gap in records	0.47
	104	Records estimated	0.18
	150	Rating extrapolated due to insufficient gaugings	1.33
	254	Rating table exceeded	0.29
	255	No data exists	0.04
404210 Broken Creek at Rices Weir	1	Good continuous records	63.19
	2	Good quality edited data	21.61
	3	Linear infill to first value in block (no data lost)	0.18
	10	Data transposed from recorder chart	0.15
	15	Minor editing	0.67
	20	Edited to measurements	0.45
	26	Daily read records	1.79
	50	Medium editing	0.21
	65	Other authorities data	0.74
	75	Height correction applied	0.06
	76	Reliable interpolation	0.31
	77	Correlation with other station, same variable	0.58
	82	Linear interpolation across gap in records	0.50
	100	Irregular data use with caution	0.07
	104	Records estimated	1.38
	150	Rating extrapolated due to insufficient gaugings	0.04
	153	Water below instrument threshold	0.30
	160	Backed-up by d/s influence	2.13
	170	Raw unedited data stored in archive	0.26
	180	Equipment malfunction	0.18
	255	No data exists	5.21

Appendix B Recorded Flows






110000
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
Flow (ML/month)
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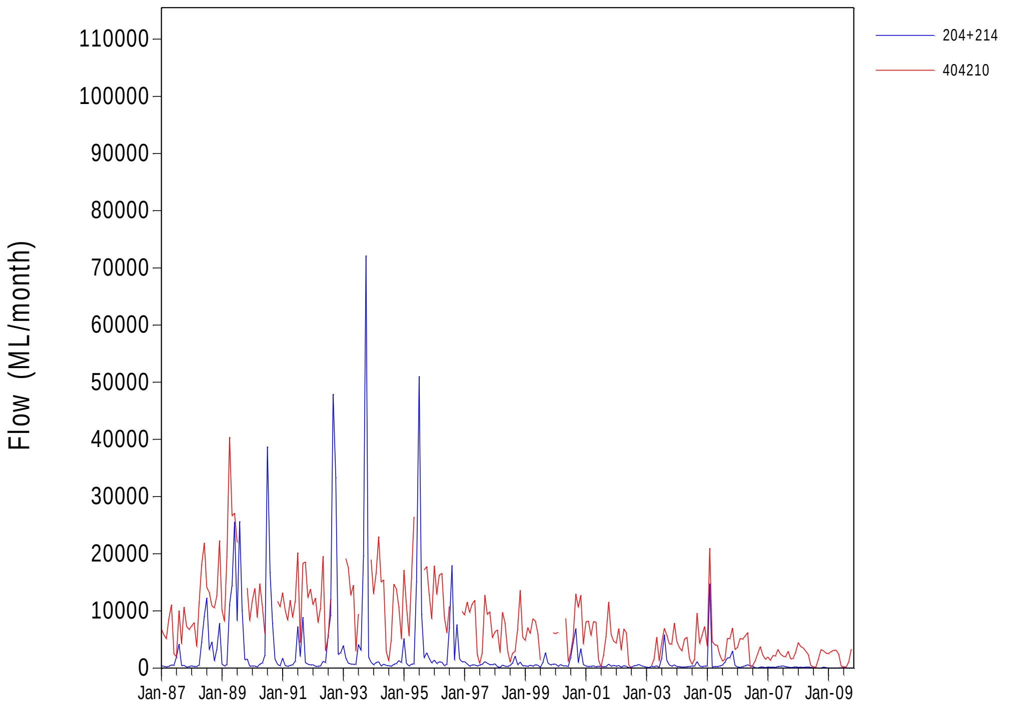
Jan-69
Jan-71
Jan-73
Jan-75
Jan-77
Jan-79
Jan-81
Jan-83
Jan-85
204+214
404210


110000
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
Flow (ML/month)
Jan-87
Jan-89
Jan-91
Jan-93
Jan-95
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09
204+214
404210

Appendix C Outfall Structures

C.1 Murray Valley Outfall Structures

Asset Code	Asset Name	Outfalls To…	Enters Broken Creek via…
ST066229	7/3	Boosey Creek	direct outfall
ST072180	3 Main	Wild Dog Creek	direct outfall
ST041815	4 Main	Broken Creek	direct outfall
ST057773	5/3	Drain 2	Muckatah Drain
ST056529	6/6	Broken Creek	direct outfall
ST056668	8/6	Broken Creek	direct outfall
ST056597	4/8/6	Broken Creek	direct outfall
ST056669	10/8/6	Drain 1/18	MV Drain 18
ST056373	6 Main Dr 18	Drain 18	MV Drain 18
ST064176	End 13/6	Drain 13	MV Drain 18
ST058386	14/6	Drain 2/18	MV Drain 18
ST066584	15/6	Broken Creek	direct outfall
ST069070	15B/6	Drain 1/17	MV Drain 17
ST058403	Jewells (21A/6)	Broken Creek	direct outfall
ST066583	12/6	Drain 9/13	MV Drain 13
ST066577	Middle 13/6	Drain 13	MV Drain 13
ST071907	Middle 9/6	Drain 10	MV Drain 13
ST058439	Bourkes	Drain 1/13	MV Drain 13
ST058499	20/6	Drain 13	MV Drain 13
ST058488	Vallender (19A/6)	Drain 1/13	MV Drain 13
ST056428	Flanners (26A/6)	Broken Creek	direct outfall
ST056447	End 6 Main	Broken Creek	direct outfall

C.2 Shepparton Outfall Structures

Asset Code	Asset Name	Outfalls To…	Enters Broken Creek via…
ST043762	EGM.Outfall InverWeir	Drain 16	direct outfall
ST018998	EG.34 Union Rd	Drain 2/13A	Shep Drain 13A
ST019005	EG.34 End	Drain 1/13A	Shep Drain 13A
ST015505	EG.5/25	Drain 1/1B/1/12	Shep Drain 13
ST015903	EG.30	Drain 5/1A/12	Shep Drain 13A
ST015731	EG.18	Drain 12	Shep Drain 12
ST015618	EG.22	Drain 1/5/12	Shep Drain 12
ST015415	EG.4/24	Drain 1B/12	Shep Drain 12
ST015432	EG.24	Drain 1/1B/12	Shep Drain 12
ST015462	EG.2/25	Drain 1/12	Shep Drain 12
ST015467	EG.1/2/25	Drain 4/1/12	Shep Drain 12
ST015536	EG.2/3/25	Drain 12	Shep Drain 12
ST015546	EG.3/25	Drain 1B/12	Shep Drain 12
ST015488	EG.1/4/25	Drain 1/1/12	Shep Drain 12
ST015495	EG.25	Drain 1/1/12	Shep Drain 12
ST015566	EG.2/28	Drain 6/8/1A/12	Shep Drain 12
ST015324	EG.28	Drain 1B/1/12	Shep Drain 12
ST015883	EG.29	Drain 5/1A/12	Shep Drain 12
ST015846	EG.1/1/30	Drain 11/1A/12	Shep Drain 12
ST015920	EG.1/30	Drain 1/A/12	Shep Drain 12
ST018959	EG.31	Drain 4/1A/12	Shep Drain 12
ST018977	EG.33	Drain 10/1A/12	Shep Drain 12
ST017240	EG.1/1/15	Drain 5/11	Shep Drain 11
	EG.2/15		
ST066259	EG.15 Andersen's	Drain 5/11	Shep Drain 11
ST017227	EG.15 End Blake's	Drain 4/11	Shep Drain 11
ST049324	EG.3/17	Drain 11	Shep Drain 11
ST015400	EG.17	Drain 11	Shep Drain 11
ST052367	EG.1/18	Congupna Creek	
ST045754	EG.12 No 1 (Hicks)	Broken Creek	direct outfall
ST046200	EG.38/12 Town Spur	Broken Creek	direct outfall
ST045802	EG.12 No 2 (Hollands)	Broken Creek	direct outfall

Appendix D Outfall and Drainage Data Infilling

Inflows through channel outfall structures

Where flows through outfall structures were recorded on a weekly time-step, the following pattern was used to disaggregate the data to a daily time-step.

- **Table 7 – Daily pattern of irrigation outfalls (SKM, 2003).**

Day	*Proportion of weekly outfall flow*
Monday	0.16
Tuesday	0.12
Wednesday	0.12
Thursday	0.14
Friday	0.12
Saturday	0.15
Sunday	0.19

Data for one irrigation season was missing for both irrigation districts. Murray Valley data was missing for 2000/2001, and Shepparton data was missing for 1998/1999 irrigation season. The absence of any other data was interpreted as meaning that no flow was recorded on that day[1]. The 1998/99 and 2000/2001 periods had been previously infilled by SKM (2003), and these time-series were adopted for this study. The infilling was based on relationships between total flows through outfall structures, and therefore in 2000/01 it was not possible to separate the time-series into Murray Valley inflows that were 'ordered' or 'in excess'. However, in one of the datasets provided for this study, a yearly estimate of inflows ordered through Murray Valley outfall structures was available for 2000/01, and this was used to back calculate inflows 'in excess', given the SKM (2003) estimate of total inflows through outfall structures.

Inflows through drains

Only limited records were available for flows in the drains discharging to Broken Creek. Thiess has daily gauged flow data for three sites from 1998 onwards (Muckatah Drain, Shepparton Drain 12 and Shepparton Drain 11), and spot gauge readings for some Murray Valley drains. Regressions were used to infill periods missing in the Thiess records, and estimate discharge from drains that are not continuously monitored. These regressions were developed in 2003 (SKM, 2003).

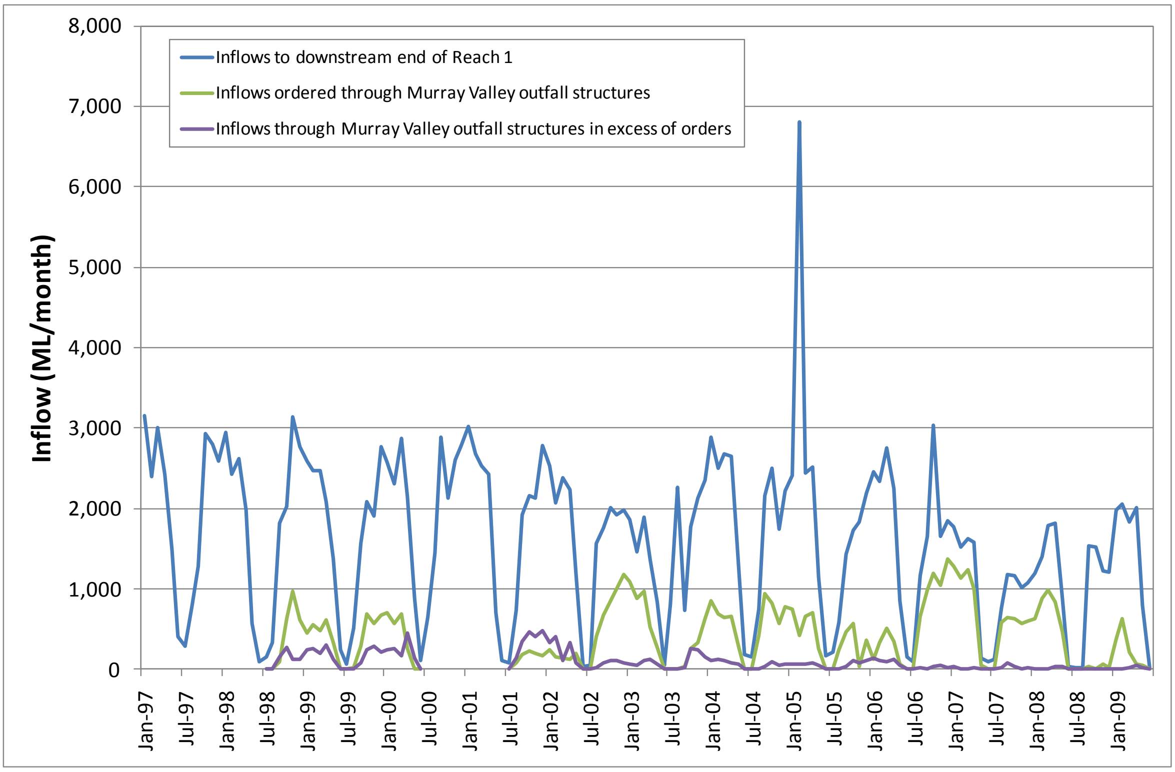
[1] This is the approach adopted during development of the Broken Creek Model in 2003.

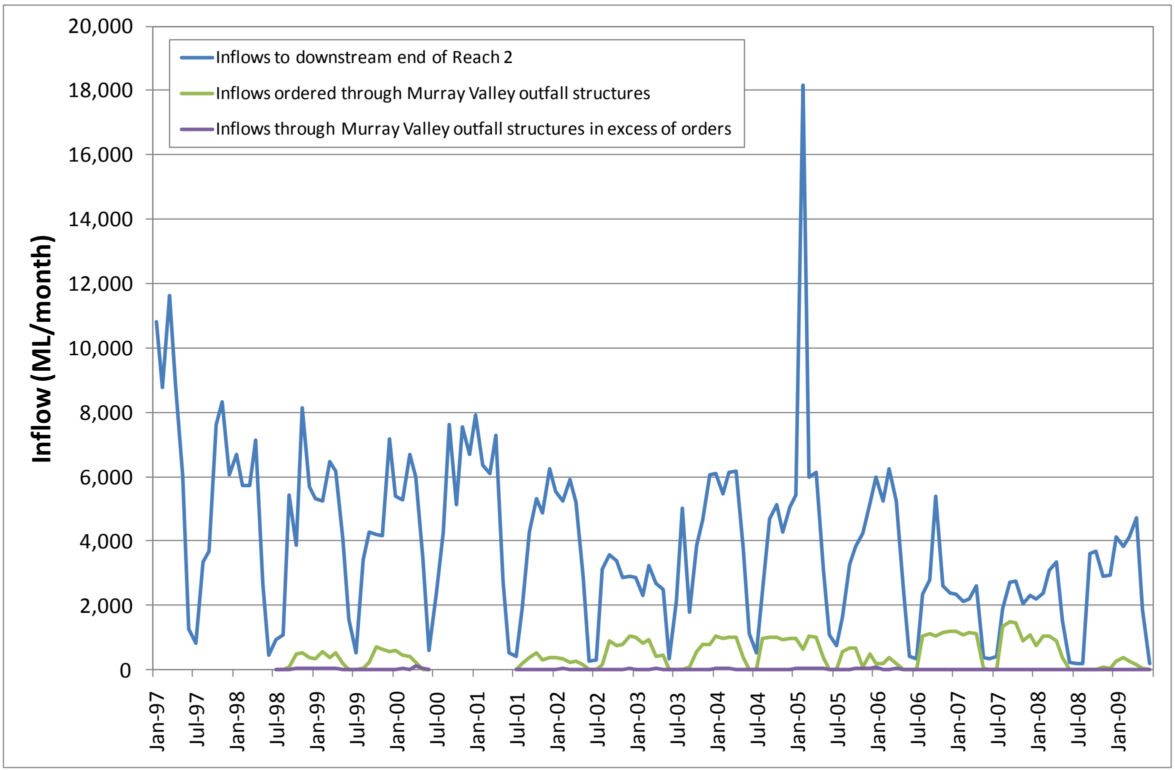
▪ **Table 8 – Regression relationships for estimating drainage inflows (SKM, 2003).**

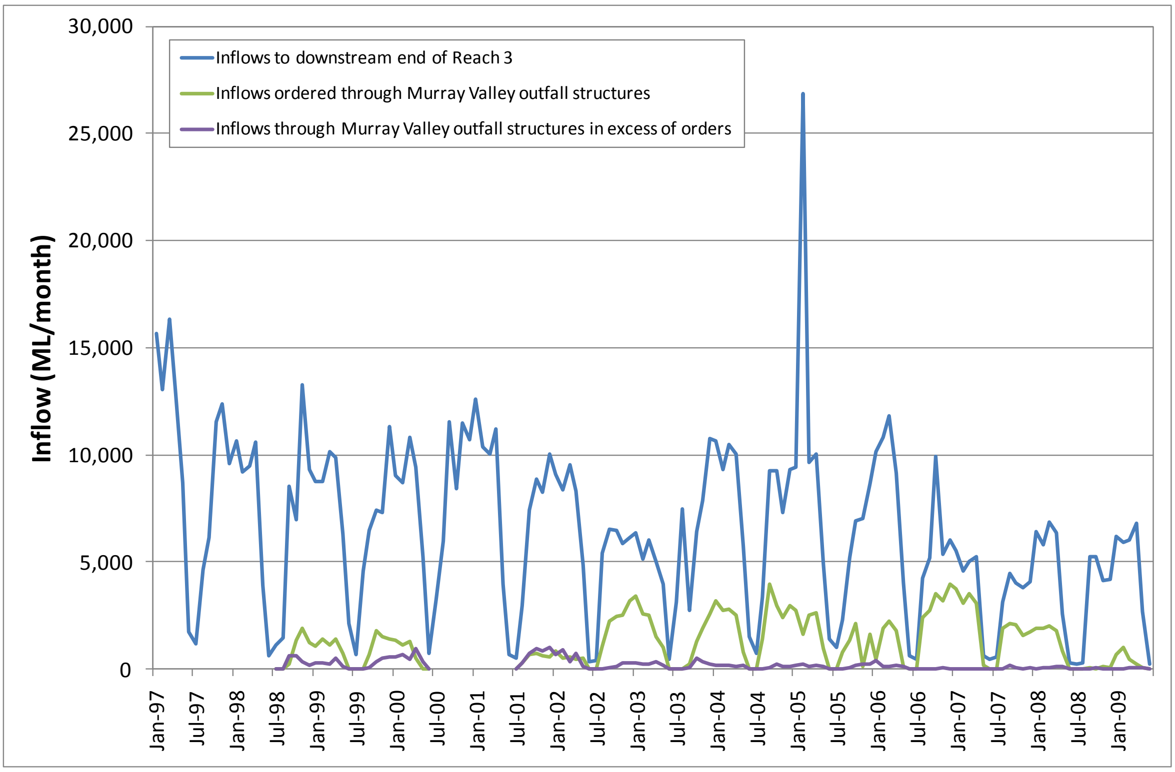
Drain Name	*Relationship for infilling missing data*
Muckatah Drain	Average monthly flow
Murray Valley Drain 20	0.1654 x Shepparton Drain 11, R^2 = 0.1
Murray Valley Drain 19	0.1048 x Shepparton Drain 11, R^2 = 0.13
Murray Valley Drain 18	0.531 x Shepparton Drain 11, R^2 = 0.3
Murray Valley Drain 17	Assume 1 ML/d throughout year
Murray Valley Drain 13	1.041 x Shepparton Drain 11
Shepparton Drain 16	Transposed from Shepparton Drain 11 on the basis of catchment area
Shepparton Drain 15	Transposed from Shepparton Drain 11 on the basis of catchment area
Shepparton Drain 13	Assume 1 ML/d throughout year
Shepparton Drain 13A	Assume 3 ML/d throughout year
Shepparton Drain 11	0.4865 x Shepparton Drain 12

Appendix E Reach Inflow Plots

E.1 Inflows through Murray Valley outfall structures






30,000
25,000
20,000
15,000
10,000
5,000
0
Inflow (ML/month)
Inflows to downstream end of Reach 3
Inflows ordered through Murray Valley outfall structures
Inflows through Murray Valley outfall structures in excess of orders
Jan-97
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
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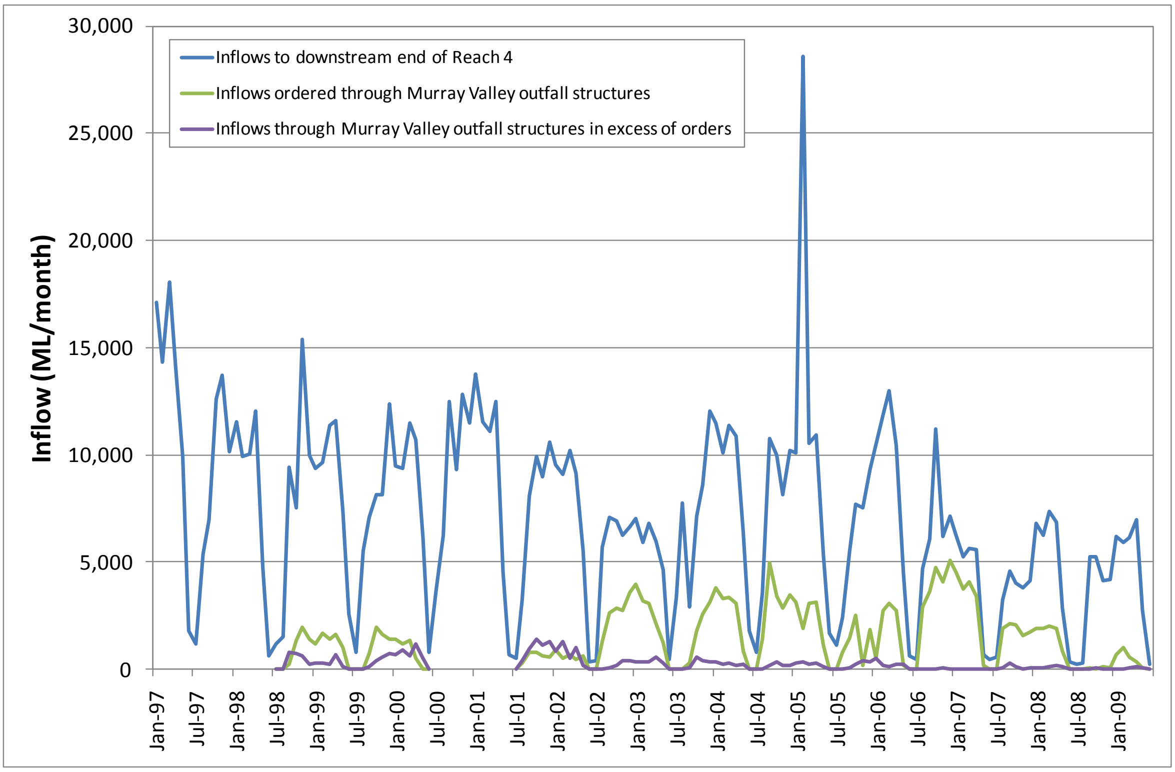
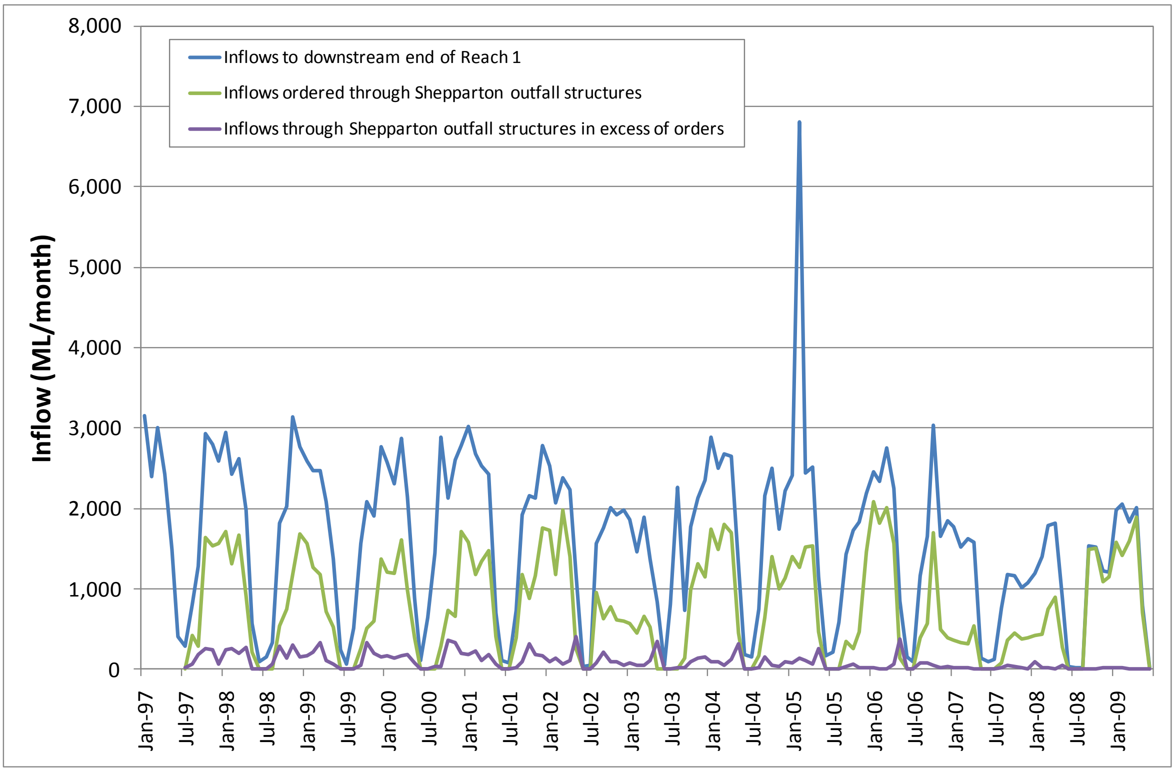
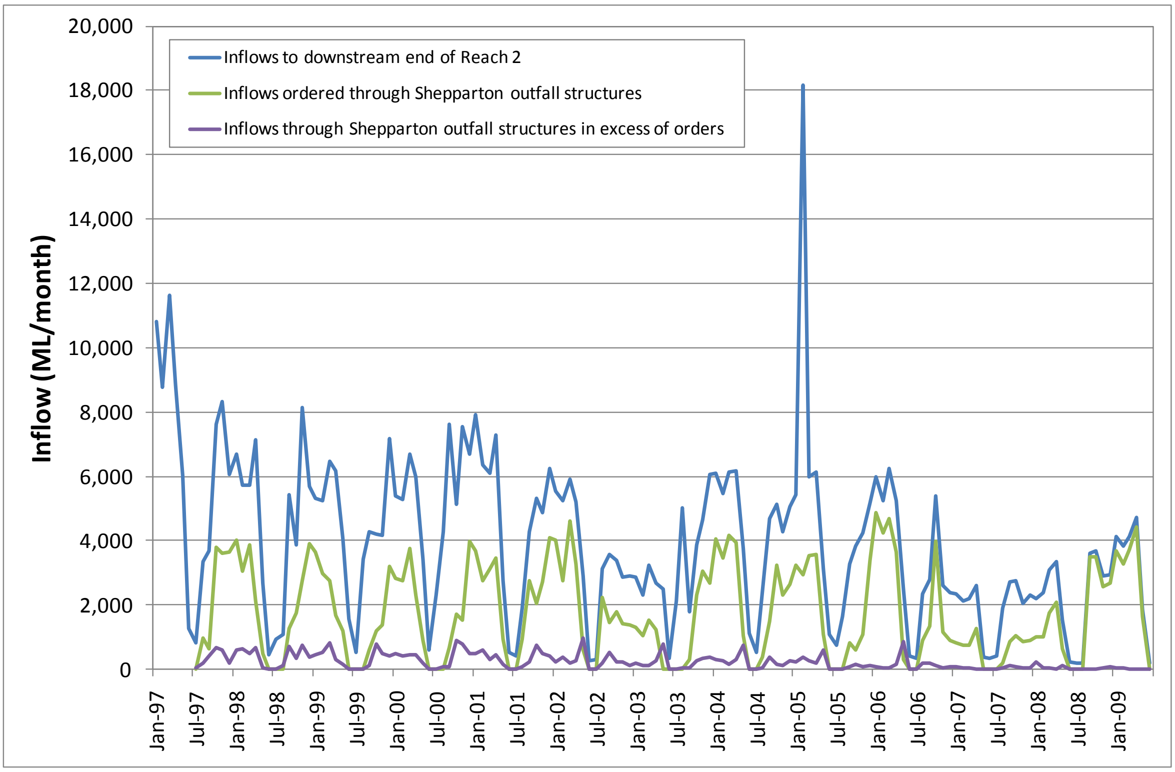
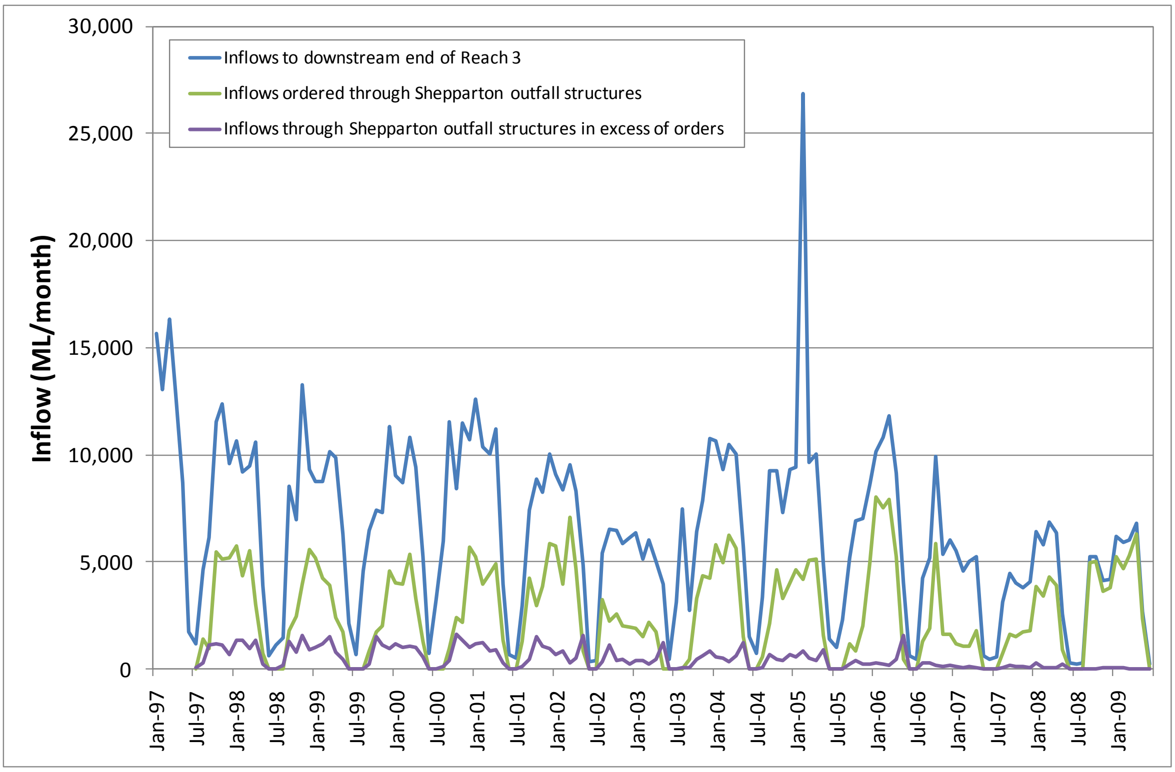
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09


30,000
25,000
20,000
15,000
10,000
5,000
0
Inflow (ML/month)
Inflows to downstream end of Reach 4
Inflows ordered through Murray Valley outfall structures
Inflows through Murray Valley outfall structures in excess of orders
Jan-97
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09

E.2 Inflows through Shepparton outfall structures






Inflows to downstream end of Reach 3
Inflows ordered through Shepparton outfall structures
Inflows through Shepparton outfall structures in excess of orders
Inflow (ML/month)
30,000
25,000
20,000
15,000
10,000
5,000
0
Jan-97
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
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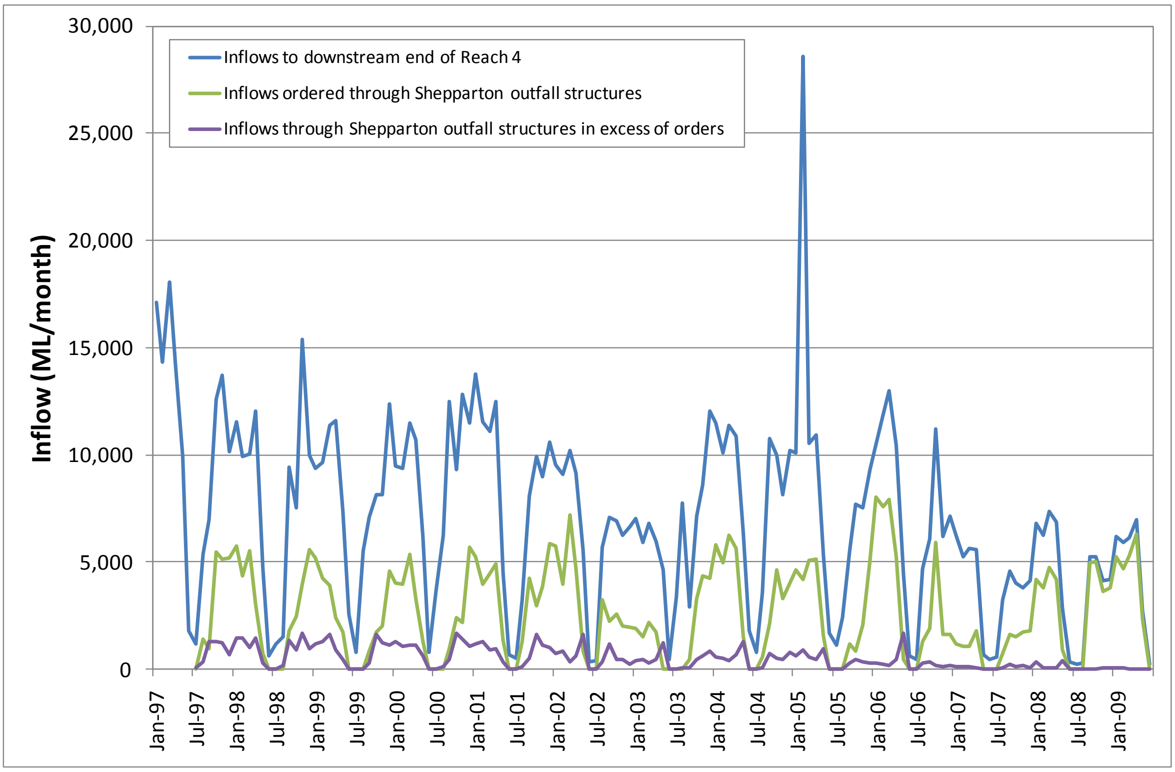
Jan-08
Jul-08
Jan-09


Inflows to downstream end of Reach 4
Inflows ordered through Shepparton outfall structures
Inflows through Shepparton outfall structures in excess of orders
Inflow (ML/month)
30,000
25,000
20,000
15,000
10,000
5,000
0
Jan-97
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
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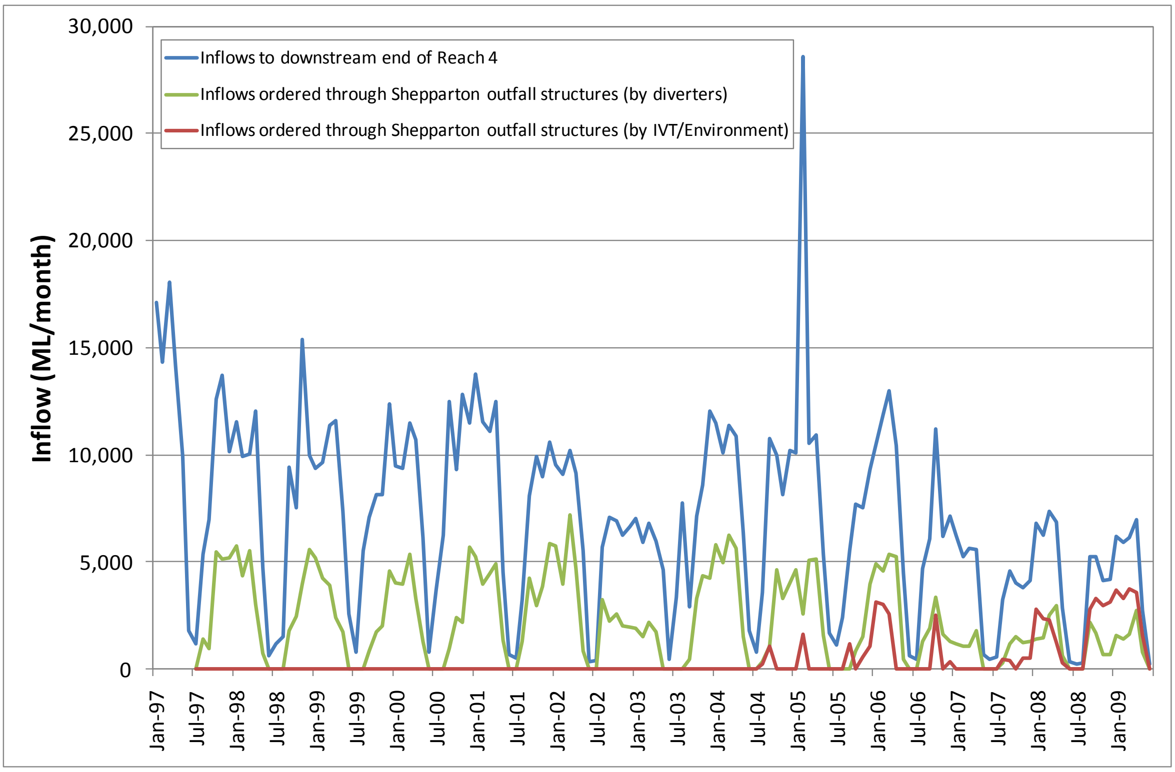
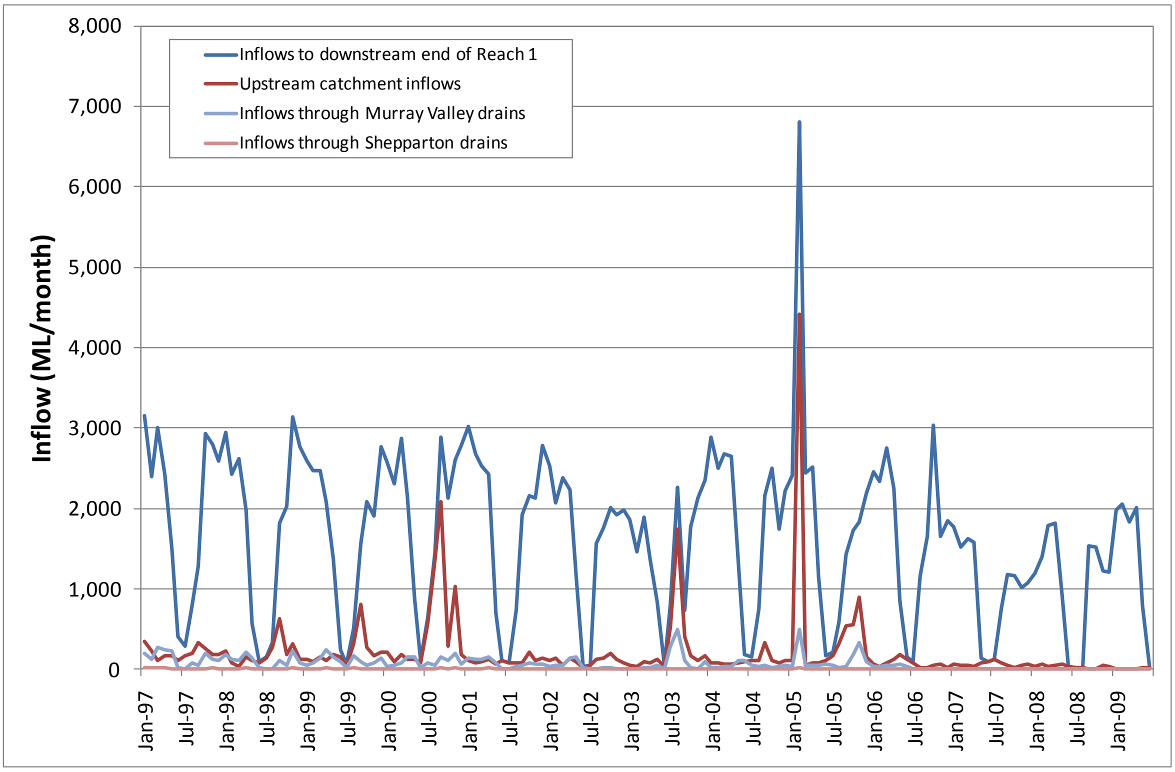
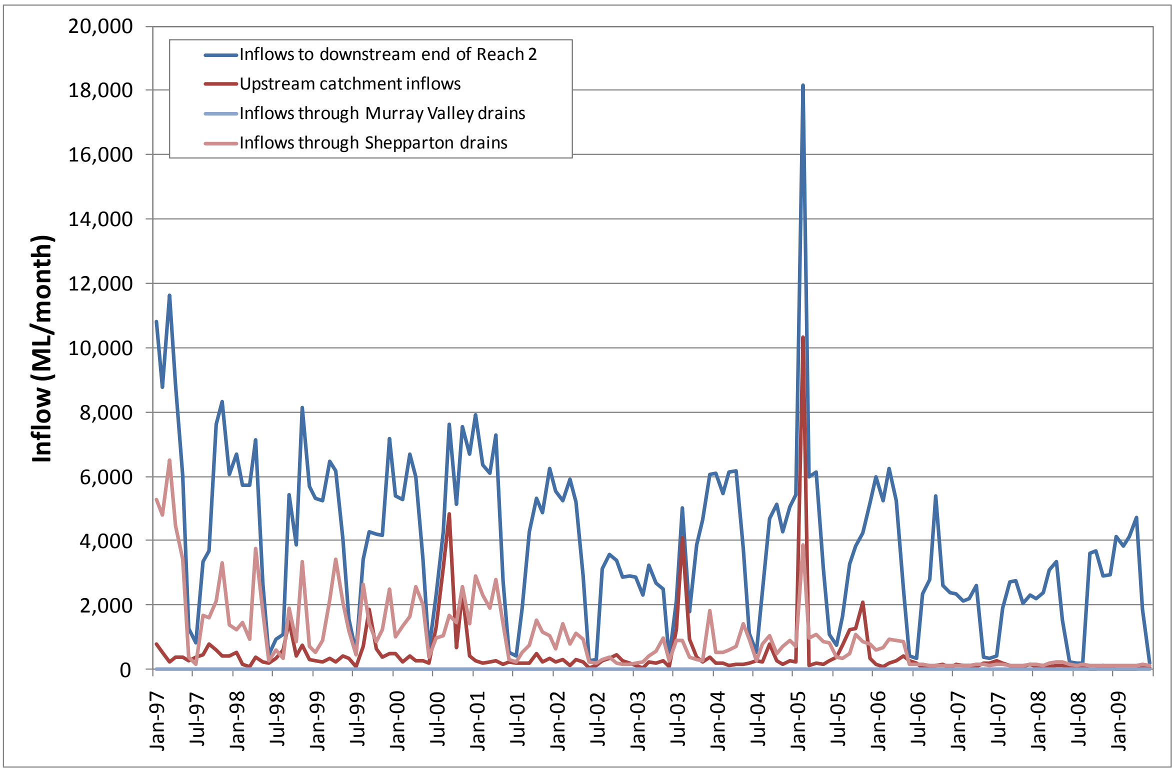
Jan-08
Jul-08
Jan-09

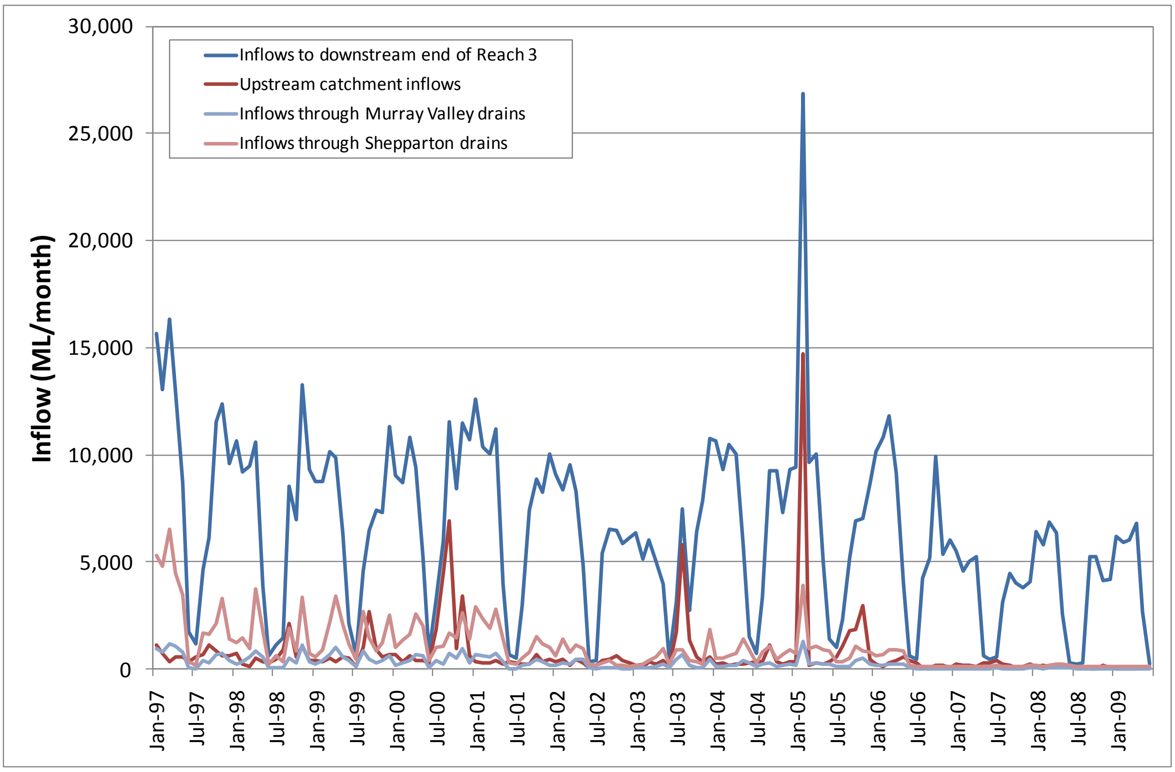


Inflow (ML/month)
30,000
25,000
20,000
15,000
10,000
5,000
0
Inflows to downstream end of Reach 4
Inflows ordered through Shepparton outfall structures (by diverters)
Inflows ordered through Shepparton outfall structures (by IVT/Environment)
Jan-97
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09

E.3 Inflows through Murray Valley and Shepparton drains







30,000
25,000
20,000
15,000
10,000
5,000
0
Inflow (ML/month)
Inflows to downstream end of Reach 3
Upstream catchment inflows
Inflows through Murray Valley drains
Inflows through Shepparton drains
Jan-97
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
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Jul-04
Jan-05
Jul-05
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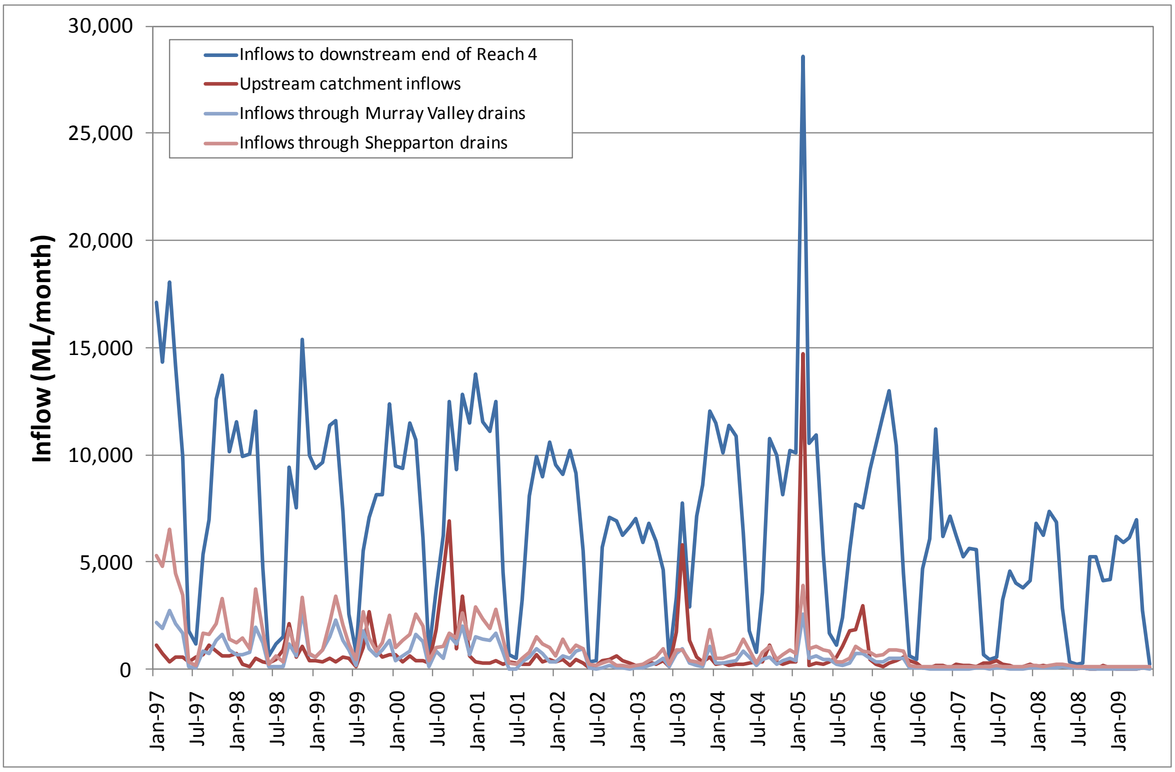
Jan-08
Jul-08
Jan-09



30,000
25,000
20,000
15,000
10,000
5,000
0
Inflow (ML/month)
Inflows to downstream end of Reach 4
Upstream catchment inflows
Inflows through Murray Valley drains
Inflows through Shepparton drains
Jan-97
Jul-97
Jan-98
Jul-98
Jan-99
Jul-99
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Jul-08
Jan-09

Appendix F NVIRP Impacts – 2004/05 and 2008/09