Department of
Sustainability and
Environment

Overbank flow recommendations for the lower Goulburn River

Final report
February 2011

Victoria

EXECUTIVE SUMMARY

To be completed

TABLE OF CONTENTS

1. INTRODUCTION

The Department of Sustainability and Environment (DSE) in collaboration with the Goulburn Broken Catchment Management Authority (GBCMA) have undertaken an assessment of the environmental overbank flow requirements for the lower Goulburn River.

The environmental overbank flow assessment was based on a modified version of the FLOWS method, which is an established approach for the determination of environmental water requirements in Victoria (Figure 1; DNRE, 2002). The assessment only addressed the later stages of the FLOWS method (shown by the dashed green box in Figure 1). The assessment drew upon previous environmental flow assessments (see section 1.1) and hydraulic modelling which addressed the earlier stages of the FLOWS method.

This paper is the final (and only) report for the environmental overbank flow assessment of the lower Goulburn River. It documents the assessment approach and overbank recommendations.

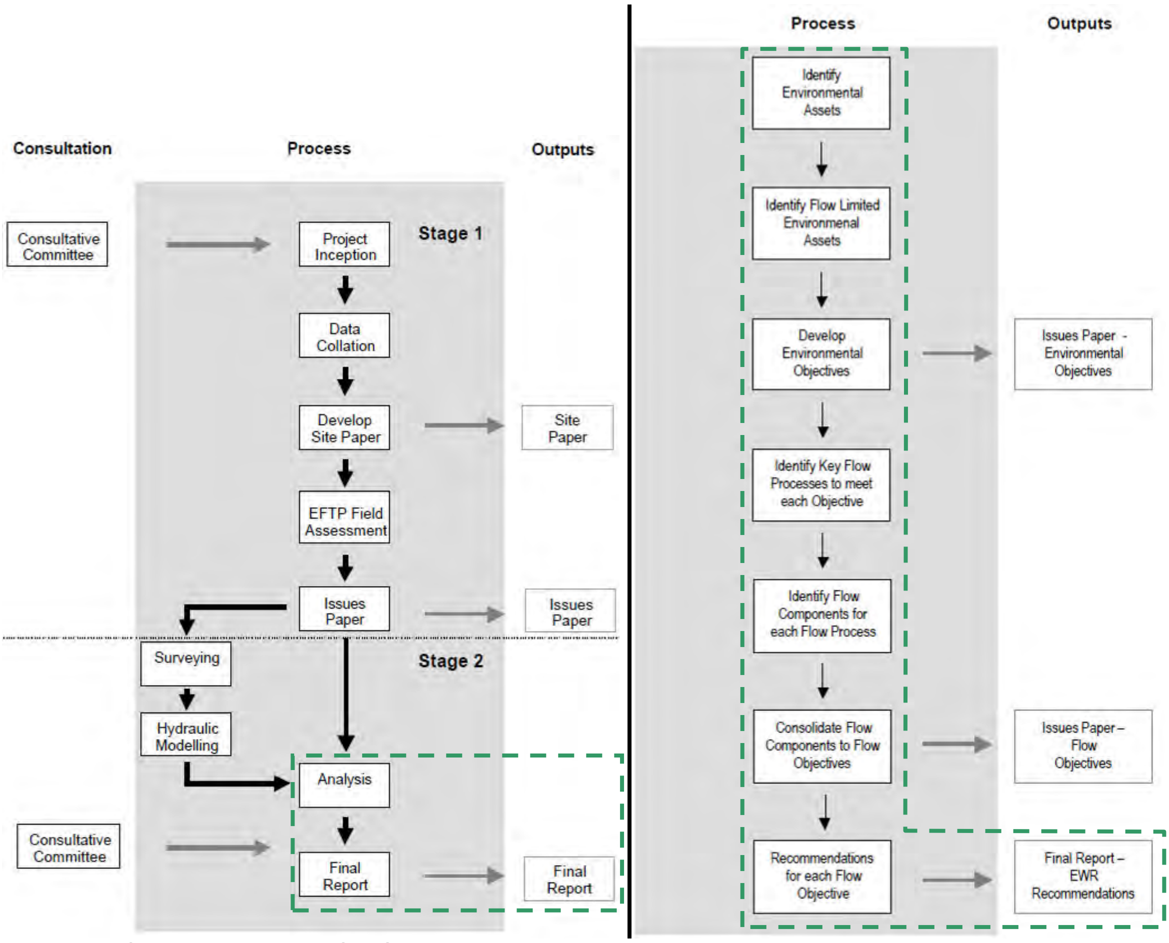


Figure 1. Outline of the FLOWS method (left) and process to determine environmental flow objectives and recommendations (right). The parts undertaken for this study are bounded by the dashed green box. Note EFTP is Environmental Flows Technical Panel.

1.1. Previous environmental flow assessments

The FLOWS method assists in the identification of critical flow components, as part of the total flow regime, to protect, sustain or restore specific flow dependent assets or values. The key elements of the FLOWS process include (DNRE, 2002):

- An objective setting process that links environmental objectives to flow objectives and recommendations,
- The use of an environmental flows Scientific Panel,
- The use of hydrologic and hydraulic analysis tools in the interpretation and development of recommendations.

The FLOWS method has previously been applied to assess the environmental flow requirements of the lower Goulburn River in 2003 (Cottingham et al., 2003) and 2007 (Cottingham et al., 2007). The two previous FLOWS studies recommend changes to the flow regime to achieve the desired flow related ecosystem objectives.

The FLOWS study in 2003 examined how water that might be released from Lake Eildon to the River Murray as part of The Living Murray Initiative could be used to protect or enhance the ecological condition of the Goulburn River. At that time, the study could only make limited assessments of future water delivery scenarios, as there was no information on the volume and timing of water that might be required for the River Murray.

From 2003 the expansion of water markets led to increasing use of inter-valley transfers (IVTs) and the possibility of significant use of IVTs in the lower Goulburn River, particularly between January and March (Cottingham et al., 2007). The Scientific Panel that developed environmental flow recommendations in 2003 was reconvened in 2007 to consider the implications of summer IVTs for the lower Goulburn River. The FLOWS study in 2007 was somewhat restricted in scope as it focused on in-channel IVTs and did not include specific flow-related ecosystem objectives for the floodplain and wetlands. However, some overbank flows were recommended based on in-channel and riparian process objectives.

The environmental flow recommendations from the 2003 and 2007 FLOWS studies are described further in Attachment A.

1.2. Purpose of this study

The 2003 and 2007 environmental flow recommendations have formed a basis for environmental water management in the Goulburn River. They have been used to identify water recovery targets through the Northern Region Sustainable Water Strategy (i.e. a target to recover a long-term average of 250GL per annum) and guide operational management of the Victorian and Commonwealth environmental water holdings.

However, when these recommendations were developed in 2003 and 2007 there was not a great need for detailed overbank flow recommendations and there was limited supporting information for this purpose. Consequently, the overbank recommendations in 2003 and 2007 were developed on a hydrological basis, rather than to specifically meet the floodplain objectives and the riverine objectives influenced by floodplain ecosystems and hydraulics.

With more than ten years of dry conditions, increasing Victorian and Commonwealth environmental water holdings, new water entitlement carryover provisions and other factors, the importance of overbank flow recommendations for the lower Goulburn River has greatly increased.

This 2010 study is intended to fill the gap in the 2003 and 2007 studies, by specifically examining the water requirements of the lower Goulburn River floodplain. The new overbank flow recommendations are intended to complement the existing 2003 and 2007 flow recommendations, by replacing all previous recommendations for flows greater than or equal to 24,000 ML/d in the lower Goulburn River.

Together the 2003, 2007 and 2010 flow recommendations are intended to provide valuable information for planning purposes (e.g. water recovery targets, floodplain management issues etc.), rather than detailed specifications for day-to-day management and operations.

1.3. Geographic scope

The geographic scope of this study is the floodplain of the lower Goulburn River between Goulburn Weir and the River Murray (Figure 2). This section has been divided into two reaches for the previous FLOWS studies: Goulburn Weir to Shepparton (reach 4) and Shepparton to the River Murray (reach 5).

The Goulburn River floodplain downstream of Shepparton is largely contained within a network of levees. These levees limit the inundation extent of overbank flows and increase the proportion of overbank flow which returns to the Goulburn River. There are four structures in the levee system where water can enter the section of the lower Goulburn floodplain that flows to the River Murray via the Deep Creek system (Figure 3):

- Loch Garry regulator,
- Deep Creek outlet,
- Wakiti Creek outlet,
- Hancocks Creek outlet.

The focus of this study is the entire floodplain of reach 4, plus the reach 5 floodplain within the levee system. The reach 5 floodplain within the levee system largely corresponds to the extent of the new Lower Goulburn National Park (Figure 3).

Under current arrangements the overbank flows being considered for this study may also cause some inundation of the Deep Creek, Wakiti Creek and Hancocks Creek floodplain systems. The DSE and GBCMA are planning other studies to assess the ecological requirements of Deep Creek, Wakiti Creek and Hancocks Creek floodplain systems to better understand their environmental flow requirements. These studies will guide options for structural works to allow for efficient watering of the floodplain environmental assets, inside and outside the levee network.

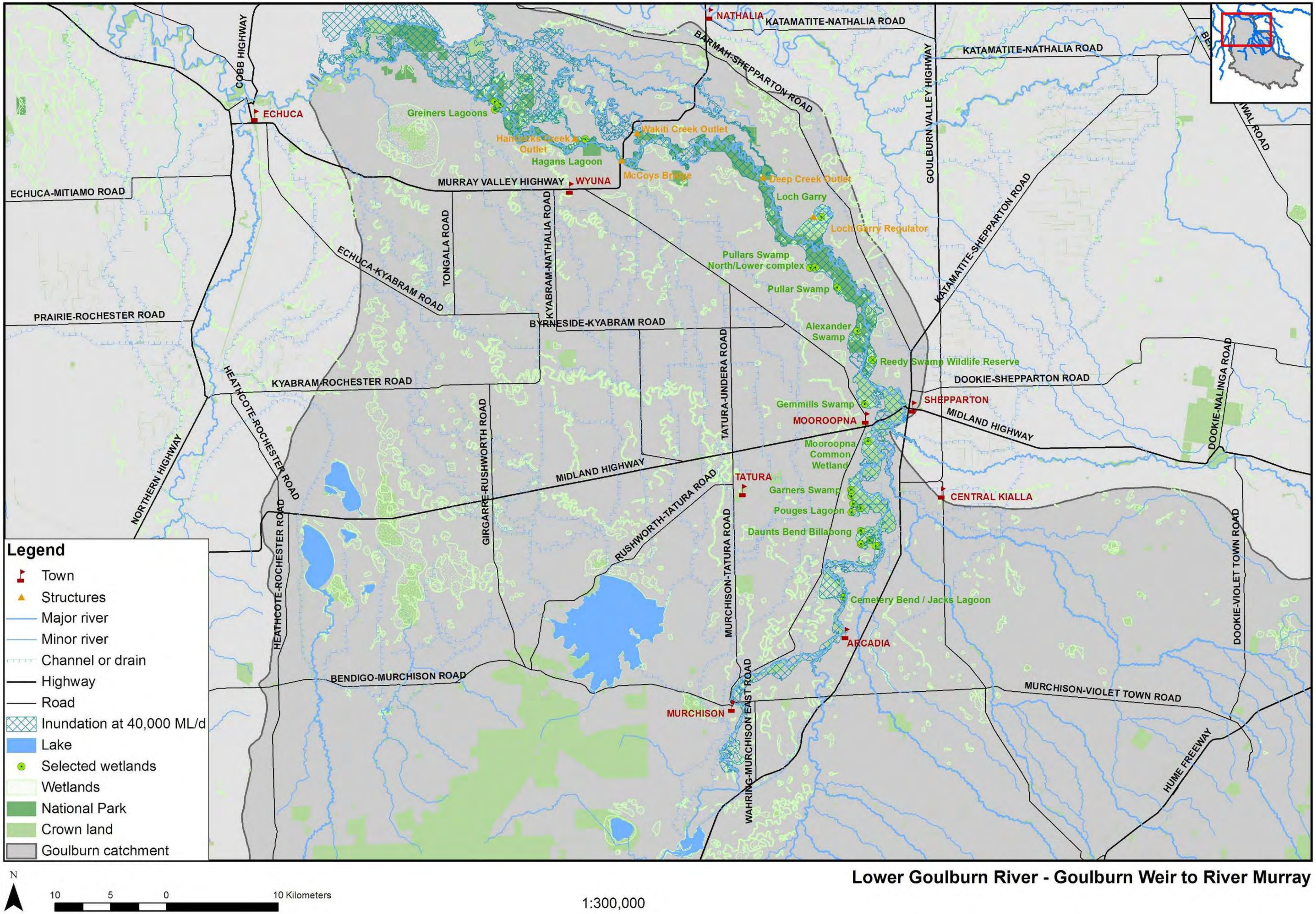


Figure 2. Map of the lower Goulburn River downstream of Goulburn Weir

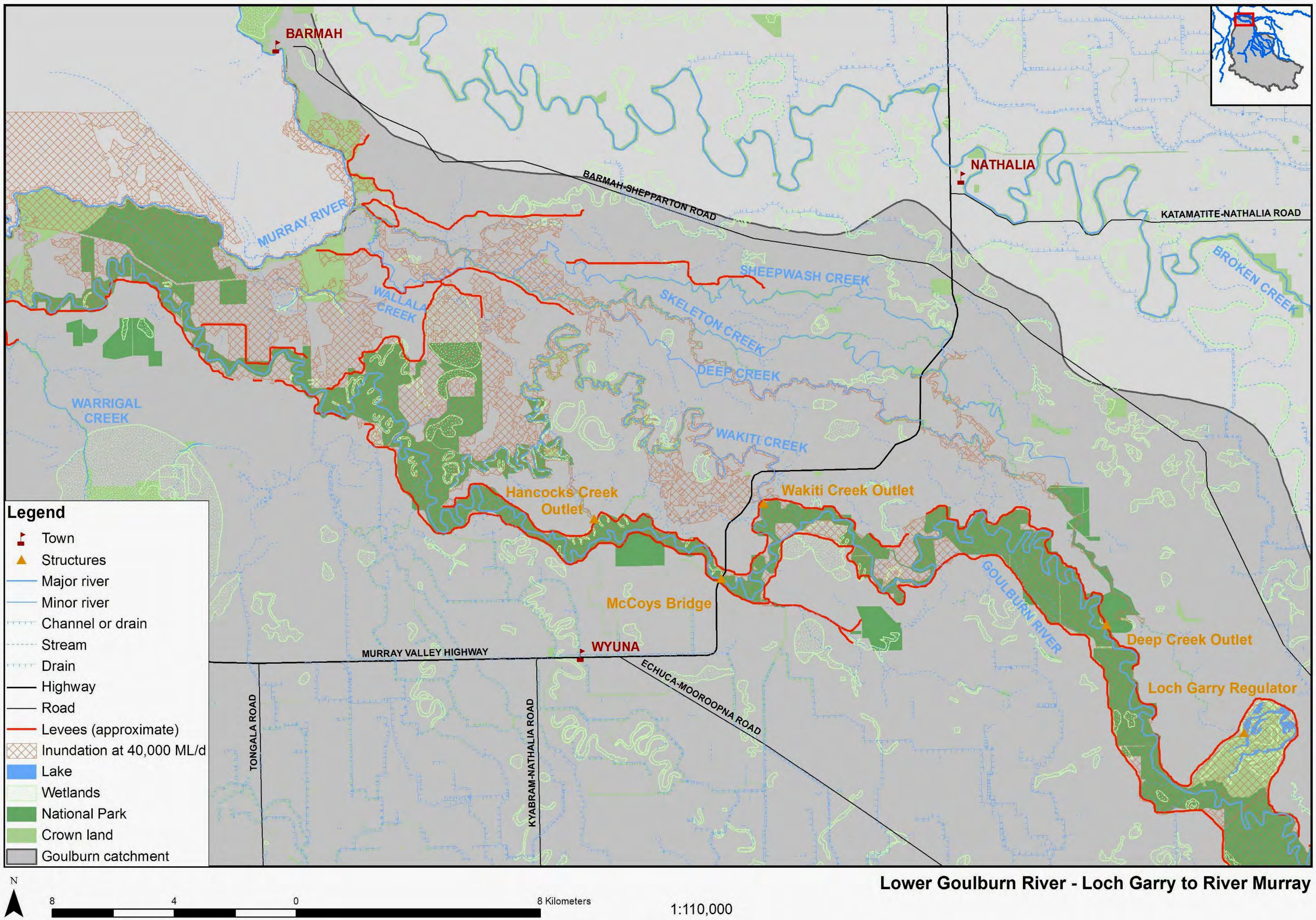


Figure 3. Map of the lower Goulburn River downstream of Shepparton, showing Deep Creek, Wakiti Creek and Hancocks Creek systems
Levees digitised from Levee Audit (June 1998) mapping in Water Technology, 2005 (Lower Goulburn Floodplain Rehabilitation Scheme Hydraulic Modelling Report)

2. ENVIRONMENTAL FLOW ANALYSIS

2.1. Overview of approach

2.1.1. Working Group and Scientific Panel

This study has developed environmental overbank flow recommendations through the use of a project Working Group and independent Scientific Panel (Table 1).

The Working Group was responsible for identifying the analytical approach and providing expert opinion on the ecological requirements of environmental assets in the study area.

The Scientific Panel was responsible for reviewing the approach undertaken by the Working Group and providing additional expert opinion on the ecological requirements of environmental assets. Their review identified improvements to the objectives and analytical approach, which have been incorporated into the final recommendations. The Scientific Panel provided an advisory role for this project, rather than the more 'hands-on' role of previous FLOWS studies.

Table 1. Members of the Working Group and Scientific Panel

Working Group		Scientific Panel	
Mark Stacey (lead author)	DSE	Peter Cottingham	Peter Cottingham & Associates
Paulo Lay	DSE	Dr David Crook	Arthur Rylah Institute
Keith Ward	GBCMA	Dr Terry Hillman	Latrobe University
Simon Casanelia	GBCMA	Dr Jane Roberts	Independent practitioner
Geoff Earl	GBCMA	Dr Mike Stewardson	University of Melbourne
Julia Reed	DSE		
Sharada Ramamurthy	DSE		

2.1.2. Approach

The general approach to this study followed five main steps. These steps are shown diagrammatically in Figure 4 and are summarised below.

Step 1 identifies the environmental assets, sets environmental objectives against these and then identifies the flow objectives required to meet the environmental objectives. This step and the modified environmental objectives are described in section 2.2.

Step 2 identifies a subset of the environmental assets for which flow requirements are best understood – these are termed the 'key environmental assets'. This step and the 'key environmental assets' are described in section 2.3.

Steps 3 and 4 use hydraulic and hydrologic analytical tools to examine the flood characteristics (i.e. frequency and duration of flooding) of the key environmental assets under pre-regulated and regulated conditions. The development of the analytical tools (i.e. step 3) is described in section 2.4; the application of the tools to the key environmental assets (i.e. step 4) is described in section 2.5.

Step 5 identifies flow recommendations which achieve the flow objectives identified in step 1. The recommended frequency, duration and magnitude of overbank flows were initially based on the key environmental assets. These recommendations were then assessed to ensure they were consistent with the full set of original flow objectives (which address all environmental assets). The development of the recommendations is described in section 3; the assessment of the recommendations is described in section 4.

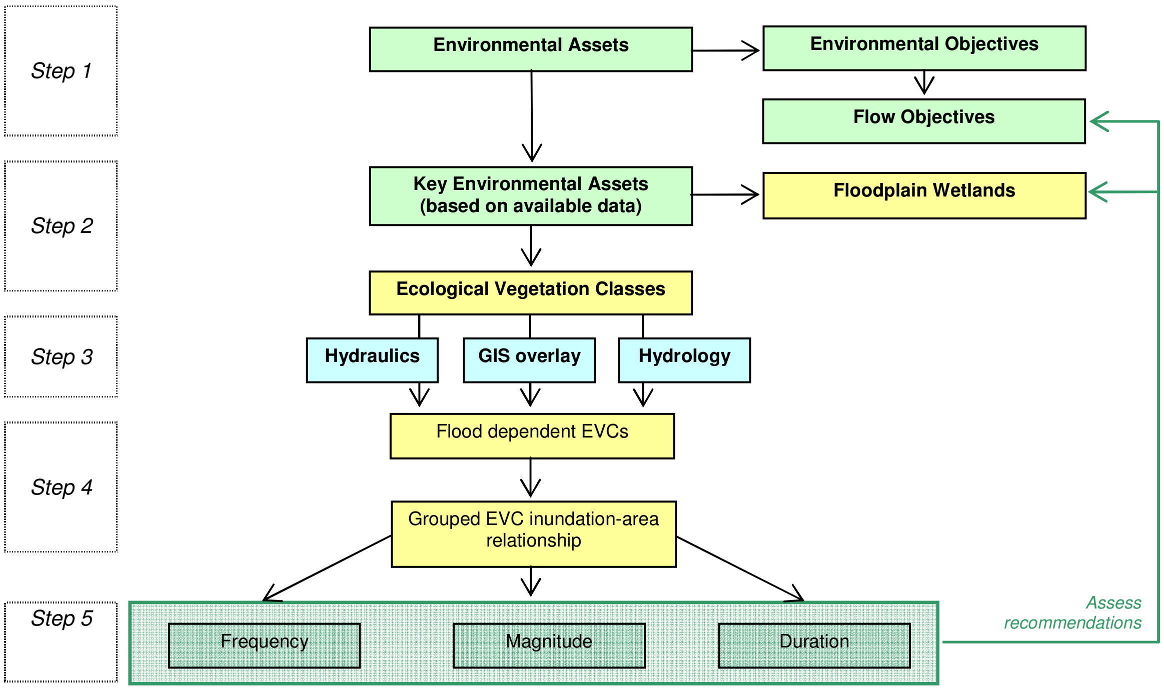
2.1.3. Terminology

The terminology used in this report is consistent with *The Flows Method* (DNRE, 2002). The key terms used in the report are defined in Table 2.

Table 2. Key terminology used in this report

Term	Definition	Example
Ecological feature	A hierarchical classification of environmental assets.	Wetland vegetation
Environmental asset	The environmental assets should identify the assets associated with an ecologically healthy river, which are strongly dependent of aspects of the flow regime.	Representative and natural plant communities
Key environmental asset	A subset of environmental assets, have the best understanding of their flow requirements.	Native plant communities
Environmental objective	The environmental objectives should identify the conditions required to sustain an ecologically healthy river. They should be measurable and describe the target ecological response. They should only relate to those environmental assets that have a clear dependence on some aspect of the flow regime.	Increase the extent and diversity of aquatic vegetation
Flow objective	The flow objectives should also be measurable. They should describe the required flow pattern (e.g. frequency, timing or duration of flow events) to produce the target ecological response.	Provide a range of flood peaks of suitable frequency and duration to maintain the health of river red gums

Figure 4. Approach to developing overbank flow recommendations



2.2. Environmental and flow objective setting

The objective setting process undertaken by the Working Group and Scientific Panel first identified environmental assets in the study area. The environmental assets were initially based on the issues paper for the 2003 study (Cottingham et al., 2003) which identified that an altered overbank flow regime is likely to have notable implications for the environmental assets of four ecological features (Table 3). The environmental assets of these four ecological features formed the starting point for this study. The environmental assets were then modified to include assets related specifically to the floodplain. The newly included environmental assets covered a range of floodplain related ecological features (e.g. wetland vegetation, wetland frogs and wetland fish).

Table 3. Summary of implications of Goulburn River overbank flows identified in Cottingham et al. 2003

Ecological feature	Implications from altered overbank flow regime
Geomorphology	No implications of note
Riparian vegetation	Reduced frequency, duration and altered timing of overbank flows may impact on: • vegetation pattern if flood intolerant species (including terrestrial and opportunistic species) establish more readily and persist for longer • species composition and dominance (i.e. the mix of winter- and summer-growing species)
Floodplain ecosystems	Reduced duration of connection and flow through wetlands may impact on: • carbon exchange and thereby vigour, biodiversity and robustness of the ecosystem Reduced frequency, duration and altered timing of wetland inundation may impact on: • long-term persistence of the wetland plant communities dependent on a wet phase to grow and set seed
Fish	Reduced frequency and duration of out of channel flows may impact on: • frequency of spawning opportunities for species that may require floods for successful spawning and/or recruitment (e.g. golden perch and silver perch) • drying out of habitat for species that utilise floodplain wetlands (e.g. Flat-headed galaxias, Freshwater catfish).
Macro-invertebrates	Reduced frequency and duration of out of channel flows may impact on: • the natural organic matter supply from floodplain-channel interactions, risking smothering the biofilm layers which may impact on the respiration of some macroinvertebrate taxa
Water quality	No implications of note

The 2003 environmental objectives were modified to address new environmental assets and more clearly reflect the intent of the original environmental objectives for existing environmental assets. The environmental objective setting approach recognised that there are other environmental assets that may be influenced by flooding, but are not directly related to overbank flow objectives. These include such species as the Broad-shelled turtle (*Macrochelodina expansa*), platypus (*Ornithorhynchus anatinus*) and water-rats (*Hydromys chrysogaster*). The Working Group considered that the requirements of these environmental assets is likely to be meet by the complete suite of flow objectives developed from the identified environmental assets and environmental objectives.

The environmental assets, environmental objectives and associated flow objectives are provided in Table 4. Table 4 also has two columns (right side) which identify which flow objectives are achieved by the final environmental overbank flow recommendations. A detailed discussion of the recommendations and what they achieve is provided in section 4.

Table 4. Adopted environmental assets, environmental objectives and flow objectives (modified from Cottingham et al., 2003)

Ecological feature(s)		Environmental asset(s)	Environmental objective(s)	Flow Objective(s)	Provided by the 25,000 ML/d recommendation [1]	Provided by the 40,000 ML/d recommendation [1]
Vegetation	Wetland	• Representative and natural plant communities • Habitat and refuge for small wetland and floodplain fauna • Contribute to river productivity	• Increase the extent and diversity of aquatic vegetation • Increase contribution of wetlands to processes such as river productivity	Provide a range of flood peaks: A. To provide suitable ponding duration for wetlands so that plant life cycles can be completed B. Of suitable frequency to provide a diversity of wetland wetting and drying patterns C. To maintain the natural connectivity to the channel from wetlands	✓ ✓ -	✓ ✓ ✓
	Floodplain matrix	• Spatial and structural diversity • Connects floodplain features • Native plant communities • Heterogeneous floodplain mosaic	• Increase the extent and diversity of aquatic vegetation • Increase contribution of floodplain to processes such as river productivity • Connection of floodplain ecosystem components, including grasslands, woodlands, permanent and temporary wetlands	Provide a range of flood peaks: D. Of suitable duration so that understorey diversity is maintained i.e. maintain a balance between terrestrial, flood tolerant and flood dependent understorey species E. Of suitable frequency and duration to maintain the health of river red gums	✓ -	✓ ✓
	Floodplain connectivity with channel	• Heterogeneous floodplain hydraulic characteristics	• Maintain an open exchange between the river and the floodplain for propagules, carbon, nutrients and biota • Flood regime has all the elements of a natural floodplain	Provide a range of flood peaks: • As specified for flow objectives A, B, C, D and E F. Of suitable frequency to maintain permanent habitat in low lying wetlands for fish that are wetland specialists G. To provide opportunity for fish to recolonise and use low lying floodplain habitats H. To provide sufficient floodplain inundation to facilitate exchange of propagules, carbon, nutrients and biota	refer to other objectives ✓ - -	refer to other objectives - ✓ ✓
Macro-invertebrate	Wetland	• Processing organic matter and nutrients • Diverse food for fish and terrestrial vertebrates (birds, bats)	• Dynamic food webs maintaining wetland diversity and productivity	Provide a range of flood peaks: • As specified for flow objective A	refer to other objectives	refer to other objectives
		• Provide resilience and trophic support sustainability	• Diverse, resilient communities through full range of physical conditions (i.e. a broad spatial representation of hydrological regimes)	Provide a range of flood peaks: • As specified for flow objective B I. To provide suitable ponding duration for wetlands so that invertebrate life cycles can be completed	refer to other objectives ✓	refer to other objectives -
		• Productivity - food for fish & terrestrials	• Biomass expressed in diverse organisms supporting diverse floodplain system	Provide a range of flood peaks: • As specified for flow objective A	refer to other objectives	refer to other objectives
Fish	Floodplain and wetland	• Diversity of native fish • Naturally reproducing and self-sustaining populations of native fish • Populations of threatened and icon species	• Suitable off-channel habitat for all life stages of fish • Access to floodplain and off-channel habitats for spawning and/or larval rearing • Floodplain inundation for exchange of food and organic material between floodplain and channel	Provide a range of flood peaks: • As specified for flow objectives A, B, C, D, E, F, G and H	refer to other objectives	refer to other objectives
Bird	Colonial nesting waterbirds	• Representative and natural avian community	• Increase abundance by improving recruitment conditions • Achieve successful recruitment in as many years as possible	Provide a range of flood peaks: J. Of suitable frequency within a season to provide suitable ponding duration under nests (3 to 4 months) to facilitate successful breeding of target species K. Of suitable frequency between seasons to provide sufficient recruitment opportunities to support regional objectives	✓ ✓	- ✓
	Waterfowl: longer flood durations (e.g. Musk Duck)	• Representative and natural avian community	• Increase abundance by improving recruitment conditions • Achieve successful recruitment in as many years as possible	Provide a range of flood peaks: • As specified for flow objective K L. Of suitable frequency within a season to provide suitable ponding duration around nests (3 to 4 months) to facilitate successful breeding of target species M. To provide areas of deep water for feeding	refer to other objectives ✓ -	refer to other objectives - ✓
	Waterfowl: shorter flood durations (e.g. Freckled Duck)	• Representative and natural avian community	• Increase abundance by improving recruitment conditions • Achieve successful recruitment in as many years as possible	Provide a range of flood peaks: • As specified for flow objective K N. Of suitable frequency within a season to provide suitable ponding duration in the vicinity of nests (2 to 3 months) to facilitate successful breeding of target species	refer to other objectives ✓	refer to other objectives ✓
	Woodland birds	• Representative and natural avian community	• Increase abundance by improving recruitment and feeding conditions	Provide a range of flood peaks: O. To facilitate productivity and flowering opportunities for canopy and fructiferous species P. To maintain aquatic insect production for insectivores	✓ ✓	✓ ✓
Frog	Wetland frogs	• Representative and natural amphibian community	• Increase the diversity and distribution of amphibian species	Provide a range of flood peaks: • As specified for flow objective L (for long breeders) Q. Of suitable frequency within a season to provide suitable ponding duration around nests (approximately 1 month) as often as possible (for short breeders) – local rainfall events will significantly contribute to this	refer to other objectives ✓	refer to other objectives ✓

[1] The final recommendations of 25,000 ML/d and 40,000 ML/d are presented in section 3. Their relation to the flow objectives is described in section 4.

2.3. Identifying key environmental assets

There is considerable variability in the available data and scientific knowledge on the specific interactions between overbank flows and individual environmental assets. The identification of key environmental assets sought to identify the environmental assets for which flow requirements are best understood.

Within the lower Goulburn River study area it was considered that the implications of an altered overbank flow regime were best known for floodplain and wetland vegetation. The floodplain and wetland vegetation related environmental assets (i.e. flood dependent flora) were therefore adopted as the 'key environmental assets'. These key environmental assets were used as basis of the flow recommendations in the first instance.

The watering requirements of the key environmental assets (i.e. flood dependent flora) were considered from two perspectives:

1. Vegetation communities of the floodplain as Ecological Vegetation Classes (EVCs),
2. Vegetation communities within selected individual floodplain wetlands.

The EVCs enabled a holistic, floodplain-wide analysis of vegetation water dependencies and was therefore used as the primary data source to develop the flow recommendations. The individual wetlands enabled a site-specific analysis and were therefore used to review and assess the recommendations developed through the consideration of EVC watering requirements.

2.4. Hydraulic and hydrologic analysis

The hydraulic and hydrologic analysis provided a way to assess the extent, distribution, duration and frequency of overbank flows. The hydraulic analysis provides information on the extent and distribution of flood waters between 20,000 ML/d and 60,000 ML/d, while the hydrologic analysis examines the duration and frequency of these flows under pre-regulated and regulated conditions. This information was used to evaluate the degree to which particular flows achieve the desired watering requirements of key environmental assets.

2.4.1. Hydraulic model

The hydraulic analysis was based on the modelling undertaken for the recent *Goulburn River Environmental Flows Hydraulics Study* (Water Technology, 2010). The hydraulic modelling approach is detailed in Attachment B and summarised below.

The Water Technology (2010) project involved linked 1D-2D hydraulic modelling from Lake Eildon to the River Murray to investigate the inundation characteristics of in-channel and overbank peak flows of:

- 20,000 ML/d,
- 30,000 ML/d,
- 40,000 ML/d,
- 50,000 ML/d,
- 60,000 ML/d.

For each of the 10,000 ML/d incremental peak flows, the flow hydrograph was constructed to increase at the maximum rate of rise allowed, held steady at the peak flow to allow equilibrium flow conditions to be established along the model reach, and then decreased at the maximum rate of fall allowed back to minimum flow. The hydraulic model continued to run to allow the floodplain to fully drain, except for the Bunbartha to Murray River reach (Water Technology, 2010).

The inundation extent under equilibrium flow conditions represents the maximum floodplain area inundated at that discharge. The areas which retain water once the floodplain is fully drained are called ‘storage’ areas and represent depressions in the landscape.

The hydrograph used in the hydraulic modelling is unlikely to represent a realistic managed environmental flow release. This is due to a variety of factors such as:

- The impact of flow attenuation between the upstream storages and the study reach,
- The impact of flow attenuation through the study reach,
- Unregulated tributary inflows between Goulburn Weir and Shepparton,
- Antecedent conditions of the floodplain are temporally and spatially variable,
- Structural works may change water management in the levee area downstream of Loch Garry.

Although a managed environmental flow release will not mimic the modelled flow hydrograph, the duration required to achieve peak flow at the downstream end of each model reach is within the range of the flow duration recommendations (compare Table 5 to Table 11). This suggests that the actual on-ground conditions from a peak flow at the recommended duration would be comparable to the modelled inundation extent under equilibrium conditions.

Table 5. Number of days to achieve peak flow at the downstream end of the model reaches. The duration required to achieve equilibrium conditions is a function of reach length and floodplain storage, which varies along the study reach. The attenuation along the entire study reach was not assessed in the study.

Reach	20,000 ML/d	30,000 ML/d	40,000 ML/d	50,000 ML/d	60,000 ML/d
E. Goulburn Weir to Wahring	1	1	2	3	4
F. Wahring to Kialla	5	5	5	5	3
G. Kialla to Bunbartha	5	6	5	4	3
H. Bunbartha to Murray River	not modelled	not modelled	10	not modelled	7

The model calibration process indicates the model is within acceptable bounds of accuracy, although the accuracy is variable with discharge and location within the reach (Water Technology, 2010). In particular the model:

- Is most accurate for flows up to 35,000 ML/d in the lower part of the study reach (i.e. model Reach H near McCoy's Bridge)
- More accurately models flows above 40,000 ML/d than instream flows in the middle part of the study reach (i.e. model Reach G near Shepparton)
- Produces water levels significantly lower than the observed gaugings for all flows up to 60,000 ML/d in the upper part of the study reach (i.e. model Reach F near Murchison). This is likely to have little influence on the environmental flow recommendations as the majority of inundated floodplain area occurs in the lower and middle part of the study reach.

2.4.2. Inundation overlay analysis

Morphology of the floodplain

The Goulburn River floodplain is quite confined through most of its length. The geomorphology of the river (see Attachment C for a more detailed description) results in a narrow floodplain from Goulburn Weir to south of Toolamba (Toolamba is near Daunts Bend Billabong – see Figure 2). From south of Toolamba to Loch Garry, the floodplain is wider with significant wetland/floodplain areas adjacent to the river.

From Loch Garry to Greiners Lagoons (Figure 2) artificial levees confine the connected river floodplain to a relatively narrow width (see Figure 3). The capacity of the levee network in this section decreases with distance downstream, from approximately 85,000 ML/d to 37,000 ML/d (Water Technology, 2005).

From Greiners Lagoons to the River Murray, the floodplain widens to the north to Deep Creek and Murray River, with artificial levees containing flows on the south side of the river. The major wetlands and floodplain forests of the lower Goulburn River are located within these confined areas.

Maximum extent of inundation

Hydraulic modeling (documented in Water Technology, 2010) shows the inundation at a flow of 60,000 ML/d covers the confined floodplain area of the study reach. Aerial photography taken during the September 2010 flood when the discharge was 52,000 ML/d at McCoys Bridge (Figure 5) shows that inundation covers effectively the same area as for the modeled extent at 60,000 ML/d.

The hydraulic modeling and aerial photography observations support the notion that flows of around 60,000 ML/d provide the maximum practical inundation extent of the lower Goulburn River. The results are consistent with previous estimates which suggested that flows in the order of 50,000 ML/d to 60,000 ML/d were required to inundate the contained floodplain to that extent (e.g. Cottingham et al., 2007).

The upper bound model flow of 60,000 ML/d effectively covers all of the tree and wetland areas within the study and therefore represents the maximum inundation required for the environmental assets on the confined floodplain.

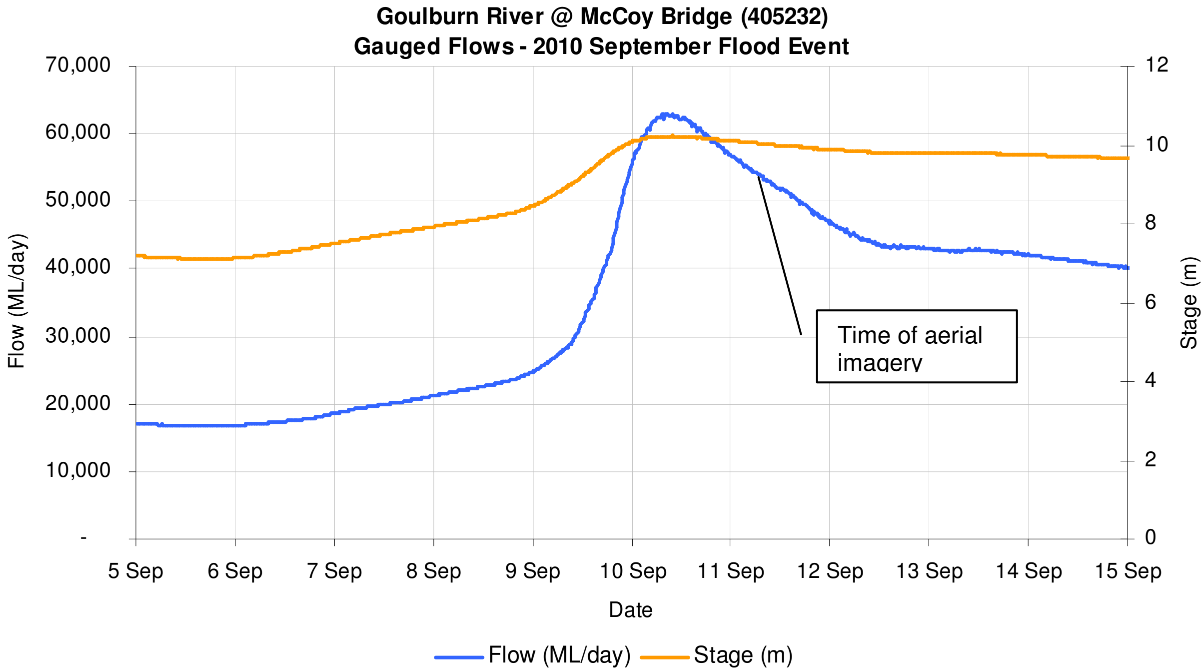


Figure 5. Hydrograph of the 2010 September flood at McCoys Bridge, showing the flood peak of 63,000 ML/d and flow of 52,000 ML/d during aerial photography capture.

Extent of inundation at varying discharges

A series of charts in Attachment D identify the total area of floodplain, 'storage' areas, wetlands and EVCs inundated at each discharge (within each model reach). This is expressed as a total area (in hectares) and also as a percentage of the area inundated at 60,000 ML/d. A summary chart of the detail in Attachment D is provided in Figure 6 and Figure 8 maps the inundation extent for each 10,000 ML/d interval discharge.

As described above, practically the entire confined floodplain (i.e. study area) is inundated at a discharge of 60,000 ML/d. In fact, a discharge of 60,000 ML/d also causes inundation outside of the levee network (i.e. outside the study area). Therefore, the percentage statistics (which express the extent of inundation for a given discharge relative to the total inundate at 60,000 ML/d) tend to underestimate the percentage of the study area inundated at each discharge.

Figure 8 demonstrates that practically all the study area (i.e. reach 4 floodplain plus reach 5 floodplain within the levees) is inundated at a flow of 40,000 ML/d. Flows of 50,000 ML/d and 60,000 ML/d generally cause inundation outside of the levee network, but produce very little extra inundation within the levees (i.e. these flows inundate outside of the study area).

Figure 6 shows that for all four model reaches in the lower Goulburn River, the maximum inundation area at 40,000 ML/d is approximately 70% or greater of the inundation at 60,000 ML/d (Figure 6). However, when the inundation outside the levees (i.e. outside the study area) is accounted for, the percentage of the study area inundated at flows up to 40,000 ML/d is even higher than the percentage statistics in Figure 6.

Figure 8 also indicates that a flow between 20,000 ML/d and 30,000 ML/d inundates a large proportion of the high value wetlands in the study area (refer to Figure 2). The selection of high value wetlands and their inundation characteristics is discussed later in section 4.2 and Attachment G. At a preliminary level, the hydraulic modelling of flows in this range is supported by observations from the August 2010 flood events, which indicated that the vast majority of these wetlands were inundated at a flow of approximately 25,000 ML/d (Figure 7).

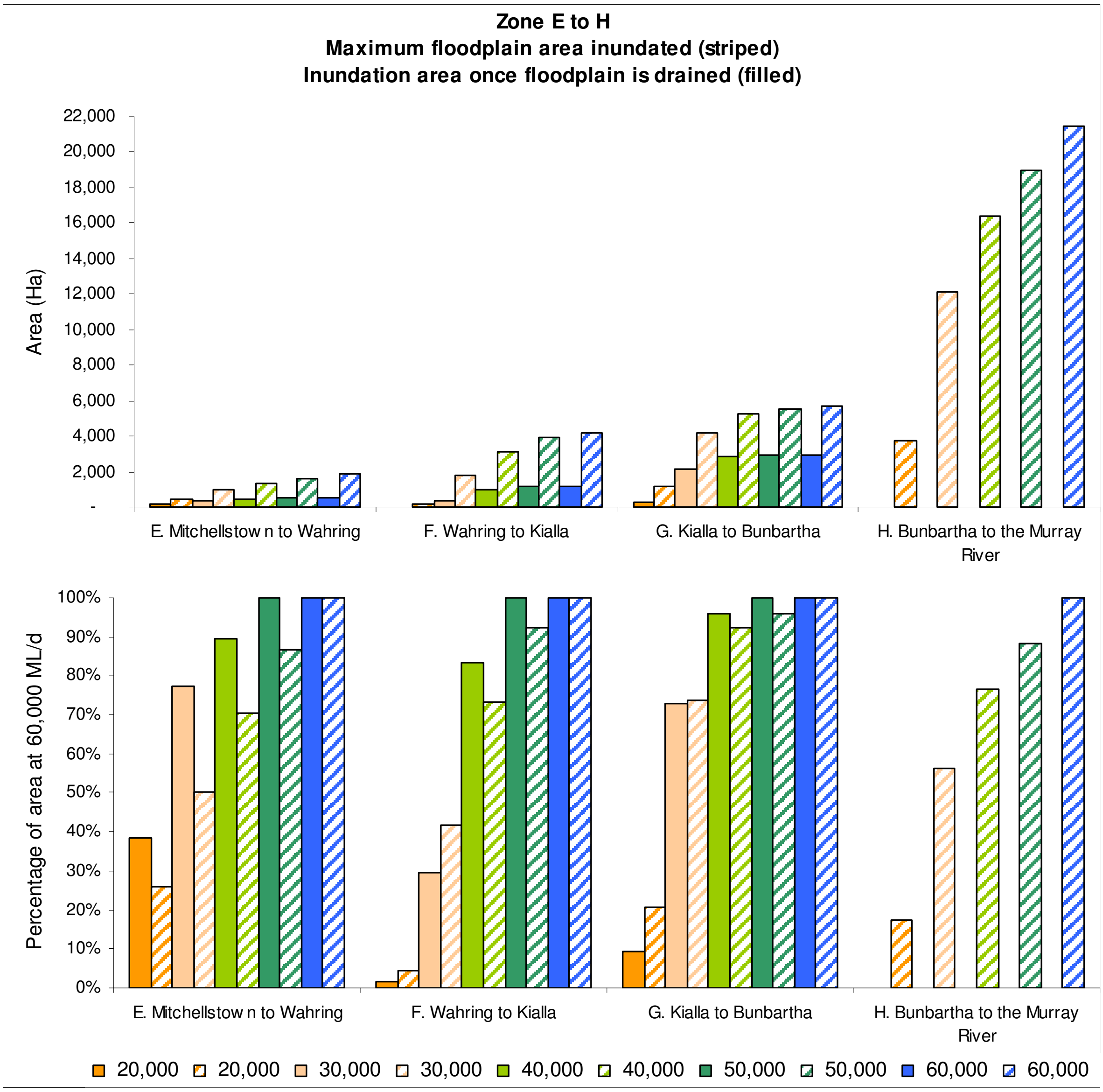


Figure 6. Area of maximum inundation and 'storage' area for each model reach of the lower Goulburn River, expressed as total area (top chart) and percentage of the area inundated at 60,000 ML/d (bottom chart). Practical limitations prevented the assessment of 'storage' areas in the reach Bunbartha to the River Murray confluence.

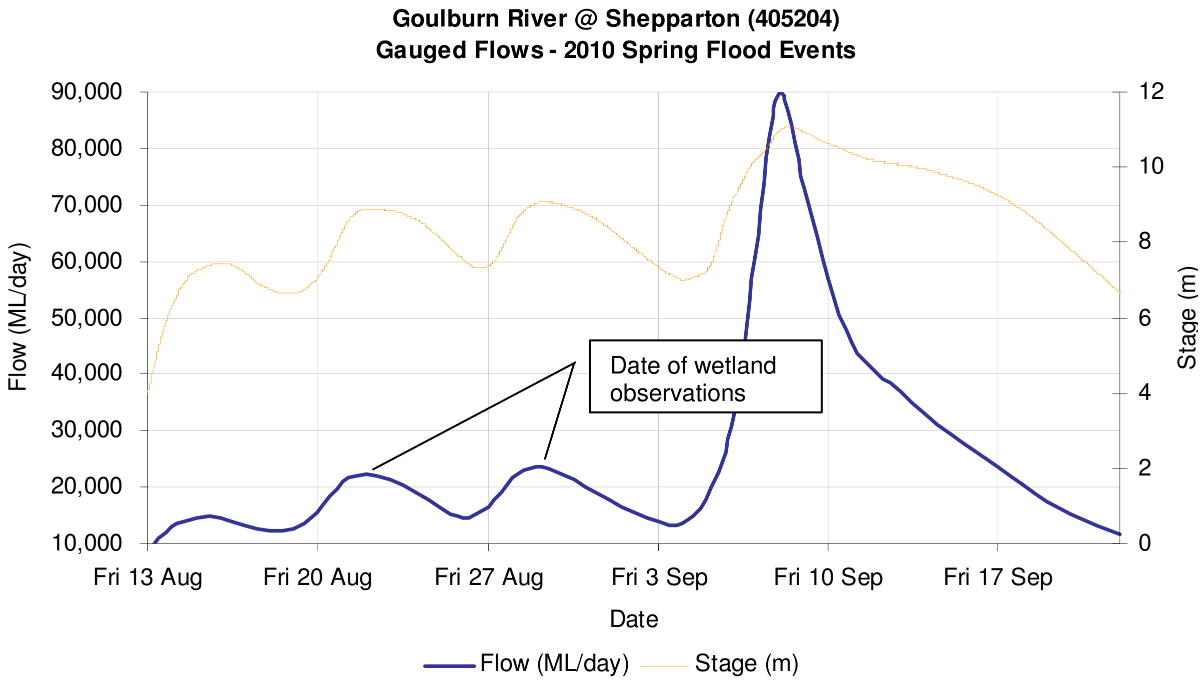


Figure 7. Hydrograph of the 2010 spring floods at Shepparton, showing the two flood peaks at approximately 25,000 ML/d and the highest flood peak at approximately 90,000 ML/d.

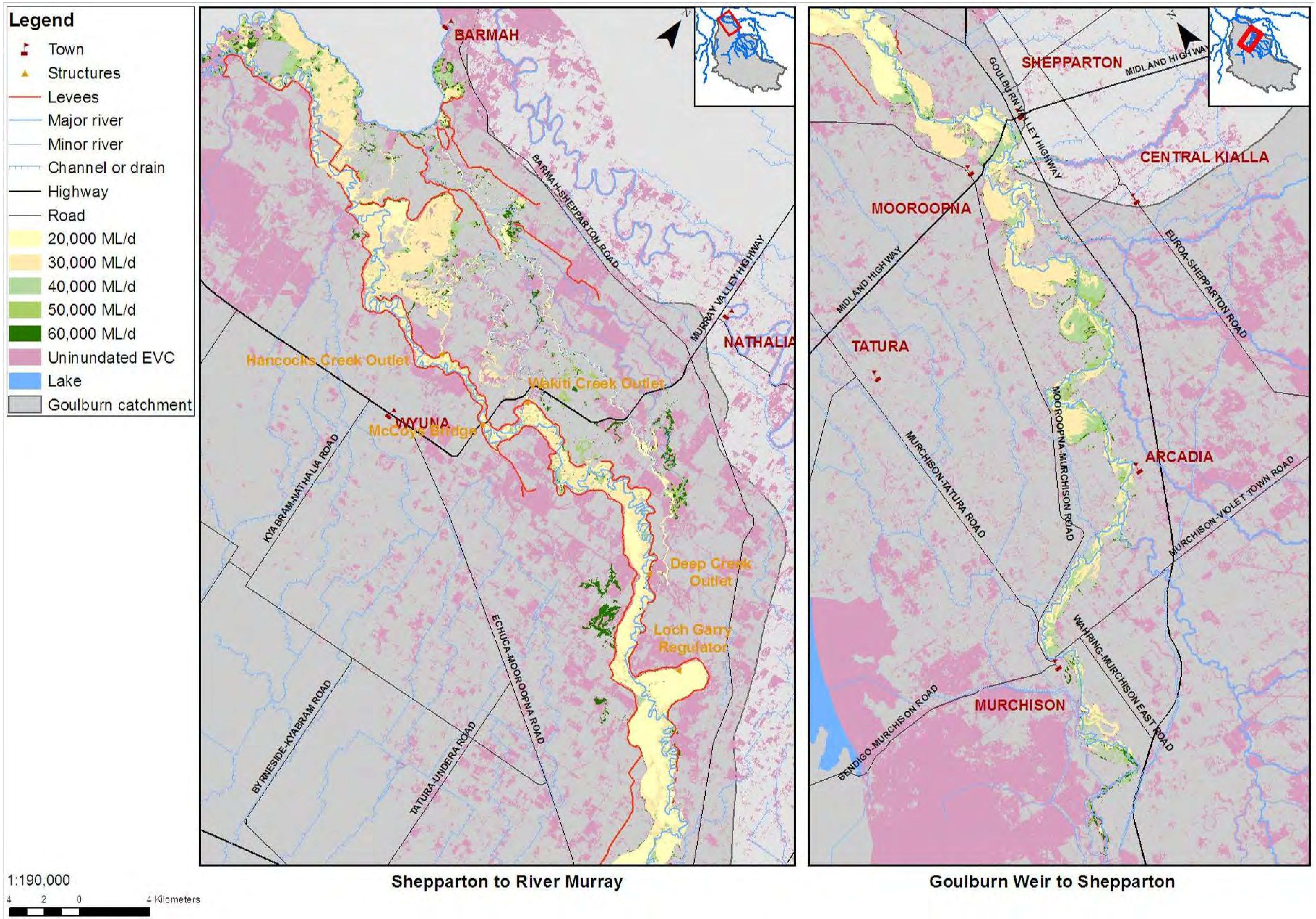


Figure 8. Extent of modelled EVC inundation in the lower Goulburn River

2.4.3. Hydrologic analyses

The hydrologic analyses aimed to establish the following hydrologic indicators under natural and current conditions, for each flow rate of interest:

- Flood frequency (average recurrence interval / average number events per 10 years),
- Flood frequency in event years,
- Individual duration of high spell events,
- Cumulative duration of high spells during winter/spring,
- Period between spells.

This involved a combination of compiling existing hydrologic analyses from the two previous FLOWS studies and undertaking new analysis. The methods used to derive each hydrologic statistic are outlined in Table 6. New analysis either involved custom spreadsheet analysis or the use of the River Analysis Package (v2.0.4) time series analysis module. All new analysis was based on modeled daily flow data at Shepparton from July 1896 to June 2006 and adopted a five-day independence period for high spells.

Table 6. Hydrologic analyses methods and location of results

Hydrologic indicator	Analyses
Flood frequency (average recurrence interval / average number events)	• Average recurrence interval determined from digitisation of 2003 FLOWS study chart • Average number of events per 10 years calculated from the digitised 2003 average recurrence interval
Flood frequency in event years	• Custom spreadsheet analyses used to calculate the number of events occurring between June and November each year, classified by different percentile years
Duration of high spell events during winter/spring	• Mean duration of high spells between September and November calculated with high spell analysis using River Analysis Package (v2.0.4) time series analysis module • Custom spreadsheet analyses used to calculate the event duration between June and November each year, classified by different percentile years
Cumulative duration of high spells during winter/spring	• Custom spreadsheet analyses used to calculate the cumulative event duration between June and November each year, classified by different percentile years
Period between spells	• Maximum period between spells under current and natural, from high spell analysis using River Analysis Package (v2.0.4) time series analysis module • Custom spreadsheet analyses used to calculate the period between spells (any timing), classified by different percentile gap lengths

Table 7 summarises the difference in the natural and current flow regime. Overall findings from this analysis are that under current regulated conditions, flow events between 25,000 and 55,000 ML/d:

- Occur at 20% to 30% of their natural frequency,
- Last for 50% to 70% of their natural duration,
- Have a maximum period between events that is 2.5 to 3.5 times longer than natural.

Further results and a description of the source data are provided in Attachment D.

Table 7. Summary of natural and current flow regime from Murchison to Shepparton

Flow (ML/d)	Natural flood freq (# per 10 years)	Current flood freq (# per 10 years)	Natural mean duration in spring (days)	Current mean duration in spring (days)	Natural max period b/w events (years)	Current max period b/w events (years)
25,000	25.0	7.5	9	6	2.8	7.0
27,000	23.5	5.9	8	5	2.8	7.1
28,000	21.5	5.6	7	5	2.8	7.1
29,000	21.5	5.3	7	4	2.8	7.1
30,000	20.2	4.9	7	4	2.8	8.8
32,000	18.9	4.1	7	4	2.8	8.9
35,000	18.4	3.5	6	3	2.9	8.9
36,000	17.9	3.5	6	3	2.9	8.9
40,000	14.6	3.2	5	3	2.9	9.9
55,000	6.9	1.3	5	3	2.9	9.9

Flood frequency: average number of flood events per ten years, calculated from the 2003 FLOWS average recurrence interval statistics at the Murchison flow gauge
Duration: mean duration of high spells during September to November, from modelled daily flow at Shepparton from July 1896 – June 2006
Maximum period between events: based on modelled daily flow at Shepparton from July 1896 – June 2006

2.5. Flow relationships for key environmental assets

Section 2.3 identified that the watering requirements of the key environmental assets (i.e. flood dependent flora) were considered from two perspectives:

1. Floodplain EVCs, which enable a holistic, floodplain-wide analysis of vegetation water dependencies,
2. Individual wetland vegetation communities, which enable a site-specific analysis that assesses the recommendations developed through the consideration of EVC watering requirements.

This section describes how the hydraulic and hydrologic tools were applied to examine the flow relationships of the floodplain EVCs. The process involved:

- Identifying all the EVCs in the study area inundated at flows of around 60,000 ML/d,
- Classifying each EVC as either flood dependent or terrestrial,
- Grouping flood dependent EVCs with similar watering requirements,
- Analysing the flow relationships of the flood dependent EVC groups.

The flow relationships of individual wetland vegetation communities are described later in section 4.2.

2.5.1. Grouping flood dependent EVCs

The outputs of the hydraulic model were used to identify the complete list of EVCs inundated at flows of up to 60,000 ML/d in the study area. An overlay of the EVC and the modelled inundation identified the area of each EVC inundated at flows ranging from 20,000 ML/d to 60,000 ML/d.

Approximately 20,000 ha of native vegetation within the lower Goulburn River floodplain is inundated at flows of around 60,000 ML/d, including 32 EVCs (Table 9). All 32 EVCs are inundated by large floods but not all of these are flood dependent. The following steps were used to define a list of flood dependent EVCs.

Firstly, EVCs with very small extents within the inundation area but large extents in the surrounding (non-inundated) landscape were removed from the analysis. Four EVCs are not reliant on lower Goulburn River flood flows as they typically occur outside the inundated area. Their distribution is shown in the supporting maps in Attachment E. One EVC was also removed (Water Body - Fresh) as it has an absence of native vegetation.

Secondly, Simplified Native Vegetation (SNV) groups and sub-groups[2] and EVC benchmarks (available on the DSE website) were used to classify EVCs as 'terrestrial', 'floodplain' or 'wetland'. Initial classification was made using the SNV groups and sub-groups. If there was still some ambiguity, descriptions provided in the EVC benchmarks were used to make a final decision (see Table 8). For example, EVCs in the *Plains Woodlands or Forests* SNV group and *Poorly draining* SNV sub-group were considered to be ‘terrestrial’ if they were described as 'flooded infrequently', 'flood tolerant rather than dependent' or 'flooded infrequently if at all’. Those EVCs classified as ‘terrestrial’ (8 in total) were removed from the list of flood dependent EVCs.

[2] In order to manage and illustrate statewide data, similar Ecological Vegetation Classes (EVCs) have been assigned to 20 Simplified Native Vegetation groups. Some of these groups have been further divided, giving a total of 35 sub-groups across Victoria.

Table 8. Process used to classify EVCs into terrestrial, floodplain or wetland EVCs

Simplified Native Vegetation Group	Sub-group	EVC benchmark required to classify	Final classification
Lower Slopes or Hills Woodlands	Grassy	No	Terrestrial
Plains Woodlands or Forests	Poorly draining	Yes	Terrestrial or Floodplain
	Freely draining	Yes	Terrestrial
	Lunettes, beach ridges or shallow sands	No	Terrestrial
Riverine Grassy Woodlands or Forests	Broader plain	Yes	Terrestrial or Floodplain
	Creekline and/or swampy	Yes	Floodplain or Wetland
Wetlands	Freshwater	No	Wetland

Of the remaining EVCs (19 in total), six were EVC complexes or mosaics, e.g. Riverine grassy woodland/Riverine swampy woodland mosaic. Complexes and mosaics are defined below (aggregates are defined in a footnote [3]):

- EVC complex - Mapping units with influences of two or more defined EVCs that cannot be differentiated at the site scale.
- EVC mosaic - Mapping units containing two or more defined EVCs that cannot be differentiated at the scale of mapping.

As complexes and mosaics cannot be differentiated without more detailed mapping and because the area of these was relatively small in comparison to the single component EVCs, such EVCs were grouped with the most extensive of their component EVCs and considered to have a similar water regime. For example, Riverine grassy woodland/Plains woodland/Gilgai wetland complex (15 ha inundated at 60,000 ML/d) was grouped with Riverine grassy woodland (6,063 ha inundated at 60,000 ML/d).

This process resulted in 10 individual EVC complexes and mosaics being incorporated into 6 EVC groups. The list of 32 EVCs inundated at 60,000 ML/d and the final grouped list of 13 flood dependent EVCs is provided in Table 9. A complete list of all the EVCs comprising each of the flood dependent and excluded EVC groups is provided in Attachment F.

[3] There are 3 different aggregate EVCs within the study area: Floodplain wetland aggregate (156 ha, comprised of 7 EVCs), Billabong wetland aggregate (417 ha, comprised of 6 EVCs) and
Drainage line aggregate (446 ha, comprised of 8 EVCs).

An EVC aggregate is a generalised label for wetlands occurring within a given ecological context (e.g. saline, brackish or freshwater lakes; billabongs; mineralised drainage-lines on grey-clay basalt derived soils). While the range of EVCs that can be variously expressed in these situations can be determined, the scale and intricacy can be prohibitive to resolution of the component EVCs, especially for the purpose of broader-scale mapping. On-ground assessment would be required to determine which individual EVCs are present; this is outside the scope of this project.

Table 9. Ecological Vegetation Classes inundated at modelled flow of 60,000 ML/d, showing the groupings and those targeted for watering

Group	EVC #	EVC name (32 in total)	Inundated EVC area (ha)			Bioregional conservation status		Targeted for watering	Flood dependent EVC group names (13 in total)	Note
			Murray Fans	Victorian Riverina	Total	Murray Fans	Victorian Riverina			
Wetland EVCs	992	Water Body – Fresh	734.9	384.6	1,119.5	N/A - no vegetation	N/A - no vegetation	No - No native vegetation recorded (also no EVC template)	-	1
	168	Drainage-line Aggregate	394.3	28.8	423.1	Vulnerable	Endangered	Yes	Drainage-line Aggregate	-
	1022	Drainage-line Aggregate / Riverine Swamp Forest Mosaic	21.4	2.0	23.5	Vulnerable	Endangered	Yes		-
	334	Billabong Wetland Aggregate	355.2	61.4	416.6	Depleted	Vulnerable	Yes	Billabong Wetland Aggregate	-
	172	Floodplain Wetland Aggregate	69.0	87.1	156.1	Depleted	Vulnerable	Yes	Floodplain Wetland Aggregate	-
	804	Rushy Riverine Swamp	51.6	88.0	139.6	Depleted	Depleted	Yes	Rushy Riverine Swamp	-
	1090	Tall Marsh / Open Water Mosaic	-	120.4	120.4	Least Concern	Depleted	Yes	Tall Marsh / Open Water Mosaic	-
	1081	Spike-sedge Wetland / Tall Marsh Mosaic	-	49.7	49.7	Vulnerable	Vulnerable	Yes	Spike-sedge Wetland / Tall Marsh Mosaic	-
	810	Floodway Pond Herbland	-	0.4	0.4	Depleted	Vulnerable	Yes	Floodway Pond Herbland	-
	74	Wetland Formation	-	4.3	4.3	Endangered	Endangered	No - Major extent is outside the maximum floodplain inundation area (i.e. 60,000 ML/d inundation)	-	-
	125	Plains Grassy Wetland	-	0.2	0.2	Endangered	Endangered	No - Major extent is outside the maximum floodplain inundation area (i.e. 60,000 ML/d inundation)	-	-
Floodplain EVCs	295	Riverine Grassy Woodland	3,898.8	2,163.9	6,062.7	Vulnerable	Vulnerable	Yes	Riverine Grassy Woodland	-
	871	Riverine Grassy Woodland / Plains Woodland / Gilgai Wetland Complex	15.0	-	15.0	Depleted	N/A – not present	Yes		-
	1040	Riverine Grassy Woodland / Riverine Swampy Woodland Mosaic	9.1	6.8	15.9	Vulnerable	Endangered	Yes		-
	56	Floodplain Riparian Woodland	2,011.9	1,143.1	3,156.2	Depleted	Vulnerable	Yes	Floodplain Riparian Woodland	1
	1035	Floodplain Riparian Woodland / Sedgy Riverine Forest Mosaic	-	48.8	48.8	Depleted	Vulnerable	Yes		-
	816	Sedgy Riverine Forest	1,471.4	2,073.9	3,545.4	Depleted	Vulnerable	Yes	Sedgy Riverine Forest	-
	815	Riverine Swampy Woodland	857.0	487.1	1,344.1	Vulnerable	Vulnerable	Yes	Riverine Swampy Woodland	-
	814	Riverine Swamp Forest	250.0	453.4	703.4	Depleted	Depleted	Yes	Riverine Swamp Forest	-
	1099	Riverine Swampy Woodland / Plains Grassy Wetland Mosaic	55.9	-	55.9	Endangered	N/A – not present	Yes		-
	1068	Riverine Swamp Forest / Sedgy Riverine Forest Mosaic	68.8	4.7	73.5	Depleted	Vulnerable	Yes		-
	68	Creekline Grassy Woodland	-	109.4	109.4	Endangered	Endangered	Yes	Creekline Grassy Woodland	-
	106	Grassy Riverine Forest	21.3	-	21.3	Depleted	Depleted	No - Major extent is outside the maximum floodplain inundation area (i.e. 60,000 ML/d inundation)	-	-
	823	Lignum Swampy Woodland	0.1	-	0.1	Vulnerable	Vulnerable	No - Major extent is outside the maximum floodplain inundation area (i.e. 60,000 ML/d inundation)	-	-
Terrestrial EVCs	803	Plains Woodland	2,059.1	194.6	2,253.7	Endangered	Endangered	No - EVC is not flood dependent	-	-
	103	Riverine Chenopod Woodland	276.2	-	276.2	Endangered	Endangered	No - EVC is not flood dependent	-	-
	264	Sand Ridge Woodland	91.6	71.4	163.0	Endangered	Endangered	No - EVC is not flood dependent	-	-
	55	Plains Grassy Woodland	-	57.6	57.6	Endangered	Endangered	No - EVC is not flood dependent	-	-
	66	Low Rises Woodland	4.0	9.6	13.6	Endangered	Vulnerable	No - EVC is not flood dependent	-	-
	985	Sandy Beach	-	4.9	4.9	Endangered	Endangered	No - EVC is not flood dependent	-	-
	267	Plains Grassland / Plains Grassy Woodland / Gilgai Wetland Mosaic	1.3	-	1.3	Endangered	Endangered	No - EVC is not flood dependent	-	-
	882	Shallow Sands Woodland	1.0	-	1.0	Vulnerable	Endangered	No - EVC is not flood dependent	-	-

1. Total area includes a small section (less than 2 ha) within the Goldfields bioregion

2.5.2. Flow relationships for flood dependent EVCs

At the start of this investigation, the expectation was that EVCs would be distributed in a across the floodplain in a way that is consistent with flooding patterns. EVCs that required a high frequency and/or duration of events were expected to be located at lower elevations, with EVCs that preferred less frequent and/or shorter floods located at high elevations.

The plan was to develop flow recommendations targeting the flooding requirements of the individual EVCs, based on their location on the floodplain and the inundation extent of each EVC at different river flows, and required frequencies and durations of inundation. Providing these flow recommendations would be expected to achieve the environmental objectives for floodplain vegetation (e.g. increase the extent and diversity of aquatic vegetation). The flow recommendations were expected to comprise of a suite of events at a number of different discharges with defined frequencies and durations.

Accordingly, the frequency, duration and critical interval between watering of the flood dependent EVCs mapped on the lower Goulburn River floodplain were determined from EVC mapping, expert opinion and literature (DSE, 2008; Roberts and Marston, 2000; EVC benchmarks). These watering requirements are provided in Table 10.

Table 10. Watering requirements of flood dependent EVCs

EVC #	EVC name	Working Group draft flooding requirements			Note
		Optimal flooding frequency (years in 10)	Optimal duration of ponded inundation (months)	Maximum tolerable interval between flooding (years)	
1090	Tall Marsh / Open Water Mosaic	8 - 10	8 - 12	2	1
804	Rushy Riverine Swamp	7 - 10	8 - 11	3	-
1081	Spike-sedge Wetland / Tall Marsh Mosaic	7 - 9	6 - 10	3	1
810	Floodway Pond Herbland	6 - 10	4 - 6	4	-
168, 1022	Drainage-line Aggregate	6 - 10	2 - 3	3	2
814, 1099, 1068	Riverine Swamp Forest	3 - 8	1 - 6	3	2
334	Billabong Wetland Aggregate	5 - 10	8 - 11	3	-
172	Floodplain Wetland Aggregate	3 - 7	< 1 - 4	4	-
816	Sedgy Riverine Forest	3 - 5	1 - 2	4	2
56, 1035	Floodplain Riparian Woodland	3 - 5	< 1 - 2	4	2
295, 871, 1040	Riverine Grassy Woodland	2 - 6	< 1 - 2	5	-
815	Riverine Swampy Woodland	2 - 6	< 1 - 2	5	2
68	Creekline Grassy Woodland	2 - 4	2 - 3	5	3

1. EVC information not listed in EVC guide books or published electronic data, therefore watering requirements are based on the individual EVCs that form the mosaic.
2. Watering requirements for these EVCs in the Murray region are identified in DSE, 2008. The watering requirements for the Goulburn River floodplain are in general agreement with the Murray River floodplain (as specified in DSE, 2008). However, the upper inundation duration of drainage-line aggregate has been reduced from 12 to 6 months based on the flashier overbank flow regime of the lower Goulburn River.
3. EVC information not listed in guide books and only a general description is available in published electronic data.

The inundated area of each flood dependent EVC group, relative to the inundation extent at 60,000 ML/d (i.e. the maximum practical inundation) is shown in Figure 9. Analysis of these flow relationships for flood dependent EVC shows that the shape of this relationship is very similar for all EVCs (Figure 9). The pattern is for a fairly rapid increase in area inundated between discharges of 20,000 ML/d (when out-of-channel flows commence) and 30,000

ML/d, then a more gradual increase in area inundated as flows increase from 30,000 to 60,000 ML/d. This pattern is generally consistent across all four of the separate hydraulic modelling reaches in the study area.

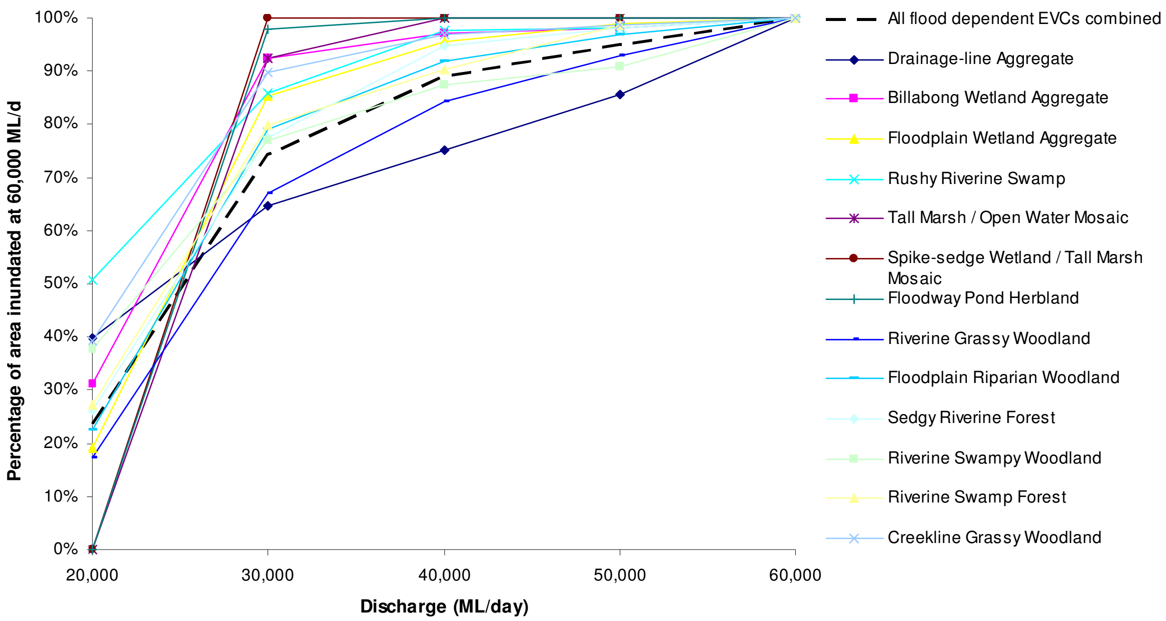


Figure 9. Relationship between flow and inundation of flood dependent EVCs

This suggests that each of the EVCs is distributed across the floodplain independently of flood inundation, as the expected zonation patterns are not evident. Instead, the whole floodplain seems to be a mosaic of all EVCs. The conclusion drawn from this is that the EVC distribution is not driven by magnitude, frequency and duration of flood events, but more by local micro-topographic effects. For example, EVCs that require longer duration inundation can be expected to occur in depressions where flood waters would pond, and any EVCs that are less water tolerant would be on raised areas or possibly on soil types that drained rapidly.

This is supported by examination of the types of floods which occur in the lower Goulburn River (refer to section 2.4.3). In the absence of river regulation, floods tended to be peaky, of short duration, and generally several events occurred per year. These floods would drain rapidly off the floodplain, except where depressions exist and the water would pond. These depressions would then be topped up by recurring flood events.

Given the relatively uniform distribution of EVCs across the floodplain, it is not necessary to develop flow recommendations for individual or groups of EVCs. The approach adopted instead is to develop a single relationship between discharge and the total inundated area of all 13 flood dependent grouped EVCs. A single relationship based on the total area of the 13 flood dependent grouped EVCs at each discharge is shown as a dotted black line in Figure 9. This single relationship is used to develop flow recommendations that suit the needs of all EVCs – between their optimal requirements and their estimated maximum tolerances (based on Table 10).

The combined flood dependent EVC relationship has the following inundation pattern (Figure 9):

- 25% is inundated at 20,000 ML/d,
- 74% is inundated at 30,000 ML /d,
- 89% is inundated at 40,000 ML /d,
- 95% is inundated at 50,000 ML /d,
- 100% is inundated at 60,000 ML /d.

3. RECOMMENDATIONS

3.1. Rationale and basis

3.1.1. Structure of recommendations

The recommendations made in 2007 were weather dependent, where the flow to be provided each year was a function of the weather conditions. This approach, which was a significant deviation from most other FLOWS studies, provided greater knowledge but presented significant challenges in planning future water management due to its high degree of complexity. Such complexity is considered to be too detailed and complex for the purposes of these overbank flow recommendations.

Accordingly, the recommendations developed in this investigation are expressed in the same way as most FLOWS studies. They are relatively simple and not variable with weather. The recommendations are not mutually exclusive i.e. meeting the highest magnitude event will also meet the lower magnitude events, provided the duration criteria can be achieved.

3.1.2. Magnitude recommendation

Cottingham et al. (2007) provided environmental flow recommendations for overbank flows of 24,000 ML/d, 32,700 ML/d and 55,000 ML/d. This 2010 analysis examined the hydrologic characteristics of multiple discharges between 20,000 ML/d and 60,000 ML/d.

A target overbank flow regime of the lower Goulburn River would involve a range of flood peaks, across a continuous spectrum between the onset of out-of-channel flow and the maximum practical inundation extent. As identified in past FLOWS studies (Cottingham et al., 2003; 2007) it is important that variability in peak magnitude of overbank flows is maintained, rather than providing repeat events at a consistent magnitude.

Unfortunately, overbank flow recommendations that attempt to incorporate this variability explicitly (by recommending a frequency and duration for many magnitudes) are impractical to operationalise and often overly confusing. This study has devised recommendations for two magnitudes (25,000 ML/d and 40,000 ML/d) to provide a guide to the intended overbank flow regime. It is recommended that environmental flow operations intentionally incorporate variability in the peak magnitude when delivering overbank environmental flows in this range. In many instances, such variability will be inevitable given the influence of flow attenuation, local rainfall and unregulated tributary inflows to the study reach. When combined with the variability of natural flood events, these two flow rates are assumed to encompass the key ecological requirements from all the overbank flows.

A flood event with a peak of 40,000 ML/d targets the maximum possible extent of inundation that is achievable with the existing physical constraints. The Working Group considered that a flow of 40,000 ML/d is an appropriate upper bound recommendation as it:

- Inundates almost the full extent of each flood dependent EVC within the study area (Figure 9),
- Avoids the major risks and liabilities that would be associated with managed environmental flow releases that exceeded this flow rate (e.g. flooding of private rural and urban land, damage to the existing levees, impacts on water resource reliability and the ability to deliver an event).

A flood event with a peak of 25,000 ML/d targets key environmental assets that require more frequent flooding than provided by the upper bound recommendation. The Working Group considered that a flow of 25,000 ML/d is the most appropriate lower bound recommendation as the vast majority of wetlands are inundated at this discharge (section

2.4.2 and Attachment G).

3.1.3. Seasonality / period of events

All overbank flow recommendations are to occur in winter to spring (i.e. June to November). This is based upon the seasonality of lower bound flood frequencies recommended by Cottingham et al. (2007).

3.1.4. Duration of events

In developing overbank flow recommendations for the lower Goulburn River, two important elements of flooding duration must be considered:

- Duration of high river flows (i.e. duration of river flows above a threshold discharge)
- Ponding duration (i.e. duration that water remains ponded on the floodplain).

For many lowland systems in south east Australia, flood events are likely to provide far longer ponding durations than the duration of high river flows. The Working Group discussions indicated that the lower Goulburn River floodplain is generally a ‘shedding’ floodplain with scattered ‘ponding’ wetlands (e.g. Gemmills Swamp and Reedy Swamp Wildlife Reserve) located throughout the floodplain.

Ponding wetlands only require a very short duration of high river flows (e.g. one day) to fill. However subsequent top-ups from additional floods will often be necessary to:

- Achieve the long duration of inundation necessary for the required ecological response,
- Provide intermittent connectivity between the wetlands and channel to maximise the return to the channel from the productivity bloom following wetland inundation.

The Working Group considered that the ponding duration in wetlands is of crucial importance to the environmental condition of wetlands along the lower Goulburn River. The required ponding duration is primarily driven by the needs of fauna (e.g. colonial water bird breeding), although it may also be influenced by the needs of flora (e.g. River Red Gum regeneration). In ponding wetlands, the flow frequency (rather than duration of high river flows) is considered to be the main determinant in achieving required ponding durations. Therefore, the ponding duration criteria are addressed via the flow frequency recommendations.

The duration of high river flow criteria should ideally be linked to the ecological requirements of the vegetation communities on the shedding floodplain. However, neither the Working Group nor Scientific Panel was aware of any scientific knowledge on the inundation duration required for the shedding floodplain. Given this knowledge gap, the natural flow regime was used as a basis to recommended high flow durations.

The duration of high river flow is specified at a single compliance point, but needs to be appropriate along the entire study reach. Section 2.4.1 identified that there can be considerable flow attenuation along the study reach and this is influenced by a variety of factors. Further work is required to understand these interactions and be able to accurately design flow releases that achieve the required duration (and peak flow) along the reach under particular conditions. In lieu of this further work, the high flow duration recommendation is to achieve at least the median of the natural flow duration for high spells during winter/spring.

The overall duration approach contrasts somewhat with previous environmental flow recommendations, which have not identified high river flow duration criteria to meet long ponding duration requirements. It also contrasts with the Murray-Darling Basin Authority’s environmental water requirements for the lower Goulburn River floodplain (MDBA, 2010), which suggested that a total of 30 days of high flow (i.e. around 30,000 ML/d) is required in spring/winter.

3.1.5. Frequency of events

The frequency criteria adopted for this study are comprised of three components:

- Number of 'event years' per 10 years (i.e. number of years in 10 with inundation),
- Number of events in an 'event year',
- Number of events per 10 years (i.e. linked to event average recurrence interval).

The frequency recommendations should be based on the best available scientific knowledge of the ecological requirements of the lower Goulburn River floodplain flora and fauna. Accordingly, the Working Group considered that the frequency recommendations should use whichever frequency component is supported by the greatest scientific knowledge.

The Working Group considered that the *number of event years per 10 years* was the frequency component with the best available scientific knowledge. The recommended *number of event years per 10 years* was primarily determined from the floodplain flora requirements i.e. required frequency of watering between seasons (e.g. Table 10).

The Working Group considered that the *number of events in an event year* was the frequency component with the second best available scientific knowledge. The recommended *number of events in an event year* was primarily determined from the floodplain fauna requirements i.e. required frequency within a season to provide the necessary ponding durations for fauna. The recommendation was informed by the natural within-season hydrology of the lower Goulburn River.

The Working Group considered that the *number of events per 10 years* (or the *average recurrence interval*) was the frequency component with the least available scientific knowledge. The 2003 scientific panel expressed a similar sentiment in their recommendations (which were based on this frequency component) by acknowledging that their approach was not based on specific scientific knowledge (Cottingham et al., 2003, p43):

> *In the absence of specific information on an optimal inundation frequency for events of various magnitudes, the Scientific Panel considered that a doubling of the natural recurrence interval for each flow magnitude represented an acceptable risk to floodplain ecosystems.*

These overbank flow recommendations are therefore based primarily on the *number of event years per 10 years* and *number of events in an event year*. The *number of events per 10 years* is a secondary recommendation which is generally calculated to achieve a balance with the two primary frequency criteria. The secondary recommendation was also cross-checked to ensure that the frequency was not significantly less than under a doubling of the natural recurrence interval from natural conditions (as per 2003 recommendations).

3.1.6. Maximum period between events

The maximum period between events was largely based on the maximum tolerable interval between flooding for the floodplain EVCs (Table 10). The most frequent flow needed to occur no longer than 3 years apart (i.e. critical interval of Rushy Riverine Swamp, Spike-sedge Wetland/Tall Marsh Mosaic, Drainage-line Aggregate and Riverine Swamp Forest) while the least frequent needed to occur no longer than 5 years apart (i.e. critical interval of Riverine Grassy Woodland, Riverine Swampy Woodland and Creekline Grassy Woodland).

The critical interval recommendation purposely does not try to account for the shorter 2 year critical interval of the Tall Marsh/Open Water mosaic EVC, as this is only located in Reedy Swamp Wildlife Reserve and Cemetery Bend State Forest. The higher frequency required by these sites will be addressed as needed by accessing other sources of water, including environmental water allocations targeted directly at these sites and, in the case of Reedy Swamp, potentially from irrigation drainage as has been the case to date.

The 3 and 5 year intervals were adopted as the recommended critical interval for the lower and upper magnitude flows respectively. A comparison with the natural flow hydrology indicates that these critical intervals generally exceed the longest period between events on record.

3.1.7. Compliance point

The compliance point for the recommendations is the Shepparton flow gauge i.e. the division between reach 4 and 5. This is downstream of all the major tributary inflows to the Goulburn River (Figure 2). The recommendations have been largely devised based on the hydrology of reach 4 between Murchison and Shepparton.

Tributary inflows between Murchison and Shepparton are expected to contribute to the environmental events measured at Shepparton. Consequently there is a risk that the upper part of reach 4 will not receive the recommended flow regime. The GBCMA are currently examining how flows could be augmented to achieve the recommended environmental flow regime. The outcome of that study will identify whether further work is required to address the possible shortfall in the upper part of reach 4.

3.2. Proposed recommendations

The consolidated list of refined overbank flow recommendations for the lower Goulburn River is provided in Table 11. For each flow magnitude, Table 11 recommends the optimal average *number of event years per 10 years* and also upper and lower bounds. These bounds represent the natural variability of floods during different climatic periods and also account for the scientific uncertainty.

Table 12 recommends lower and upper bounds for the number of overbank flow events in each event year. Table 12 also identifies how many events are recommended to occur over 10 years (based on multiplication of the two primary frequency components) and compares this to what would have occurred naturally. The comparison confirms that these recommendations meet the intent of the 2003 flow recommendations i.e. no more than a doubling of the natural recurrence interval.

Table 11. Primary overbank flow recommendations

Period	Component	Magnitude	Frequency (mean number of event years per 10 years)			Median duration	Maximum period between events
			Lower	Optimal	Upper		
Jun - Nov	Overbank	25,000 ML/d	7	8	10	5+ days	3 years
Jun - Nov	Overbank	40,000 ML/d	4	5	6	4+ days	5 years

Rates of rise and fall to follow both 2003 and 2007 recommendations. The 2003 recommendations are for the maximum rate of rise to be 135% and maximum rate of fall to be 85%, expressed as change in discharge (p50). The 2007 recommendations are for the maximum rate of rise to be limited to 2.70-3.60 metres in winter/spring, and maximum rate of fall to be limited to 1.75-2.70 metres in winter/spring (p88).

Spell independence of 5 days as per 2007 recommendations (p86).

The compliance point for the recommendations is the Shepparton gauge (number 405204).

Table 12. Secondary overbank flow temporal distribution recommendations

Magnitude	Mean number of event years per 10 years			Mean number of events in an event year		Mean number of events per 10 years	
	Lower	Optimal	Upper	Lower	Upper	Optimal	Natural
25,000 ML/d	7	8	10	2	3	16 - 24	24
40,000 ML/d	4	5	6	1	2	5 - 10	16

The recommendations in Table 11 and Table 12 are not mutually exclusive, i.e. meeting the highest magnitude event will also meet the lower magnitude events, provided the duration criteria can be achieved. For example, a peak which included at least 40,000 ML/d for 4 days and at least 25,000 ML/d for 1 day would count as supplying both events.

4. ASSESSING RECOMMENDATIONS

The recommendations in section 3 were developed from the watering requirements of wetland and floodplain EVCs (i.e. magnitude and frequency) and a review of natural flow hydrology (i.e. duration). This phase of the analysis involved assessing the recommendations to ensure consistency (i.e. recommendations are within tolerance bounds and meet the requirements) with:

- The watering requirements of wetland and floodplain (i.e. flood dependent) EVCs,
- The watering tolerance of terrestrial EVCs,
- The watering requirements of selected individual floodplain wetlands,
- Full set of original flow objectives (which address all environmental assets).

4.1. Ecological Vegetation Classes

4.1.1. Wetland and floodplain

The watering requirements independently derived by the Working Group for flood dependent EVCs are shown in Table 10. The optimal flow frequencies proposed in the flow recommendations in Table 11 fall within the range identified by the Working Group as being ideal for these EVCs.

Similarly, apart from one EVC, the maximum interval between floods in the flow recommendations is the same or shorter than identified by the Working Group for the EVCs. The one EVC (Tall Marsh / Open Water mosaic) which has a shorter maximum interval (2 years) than that which is recommended in this report (3 years) will be managed by targeted delivery of water as already outlined in section 3.1.6.

Additionally, the desirable range of optimal flood frequencies identified by the Working Group (Table 10) largely fit within the proposed range for the 25,000 ML/d events (7-10 years in 10, with 2-3 events per watering year) and 40,000 ML/d events (4–6 years in 10, with 1-2 events per watering year) (Table 11).

One exception is the Tall Marsh / Open Water mosaic EVC, which will be managed separately if necessary. The other exception is the Creekline Grassy Woodland EVC, of which approximately 100 ha is inundated on the floodplain. This EVC seems to tolerate or require a lower frequency of flooding than that proposed in the recommendations. However, rather than reduce the flood frequency to suit this EVC, which would then disadvantage the vast majority of the floodplain, and as the identification of the flow requirements does not have a high level of certainty (see Table 10), the decision was made to provide for the majority but maintain oversight of this community as the watering is undertaken to determine if changed management is required.

4.1.2. Terrestrial

There are eight terrestrial EVCs within the study area. None are likely to be adversely affected by the proposed water regime, particularly as the proposed water regime will not increase the flooding frequency beyond that experienced under natural (pre-regulation) conditions.

As previously discussed, the proposed water regime aims to provide the appropriate frequency of flooding; ponding duration will largely be governed by the local morphology of the floodplain. The EVC benchmarks descriptions indicate that most terrestrial EVCs occur on low rises and are rarely flooded except in major events. This suggests that these EVCs will either not be inundated through implementation of the proposed water regime (i.e. occur at a higher elevation) or may be periodically inundated but will not retain water as they do not occur in depressions.

The exceptions to this are EVCs 257 (Plains Grassland / Plains Grassy Woodland / Gilgai Wetland mosaic) and 803 (Plains Woodland). The benchmark descriptions for both indicate that they are seasonally waterlogged but considered flood tolerant rather than dependent, so occasional flooding is not considered to be a threat to the extent or quality. Again, local morphology will influence the duration of flooding within these EVCs.

4.2. Individual floodplain wetlands

4.2.1. Sample wetlands

The assessment of the flow recommendations against individual floodplain wetlands used high value wetlands that have the most known about their ecology and watering requirements.
The Northern Victorian Wetland Works Database (KBR, 2010) includes the best available information on the environmental assets, objectives, environmental water requirements and environmental water delivery structural works for wetlands in the Goulburn Murray Irrigation District.

Based on information within the database, other relevant reports and expert opinion the following high value wetlands[4] were identified to assess the flow recommendations:

1. Loch Garry,
2. Reedy Swamp Wildlife Reserve,
3. Greiners Lagoons,
4. Hagans Lagoon,
5. Alexander Swamp,
6. Garners Swamp,
7. Cemetery Bend / Jacks Lagoon complex,
8. Pullar Swamp / Pullars Swamp North/Lower complex,
9. Gemmills Swamp,
10. Daunts Bend Billabong,
11. Pouges Lagoon,
12. Mooroopna Common Wetland.

These wetlands are shown on Figure 2.

4.2.2. Wetland inundation characteristics

The output of the hydraulic model was used to identify the flow at which each of the 12 wetlands is inundated. These flows were provided in intervals of 10,000 ML/d, as per the hydraulic model. Maps showing the inundation characteristics of each wetland are provided in Attachment G. The number of wetlands inundated almost completely at flows of:

- 20,000 ML/d is 3 wetlands,
- 30,000 ML/d is 7 additional wetlands (i.e. 10 in total)
- 40,000 ML/d is 2 additional wetlands (i.e. 12 in total)

Therefore, flows in the range of 30,000 ML/d to 40,000 ML/d will achieve almost complete inundation at all wetlands. Flows beyond 40,000 ML/d appear to provide marginal benefit in the inundation extent of high value wetlands,

[4] High value wetlands can be identified from listings on the Ramsar convention, Directory of Important Wetlands of Australia, regional significance lists (Heron and Joyce, 2008) and sightings of species listed on the Environment Protection and Biodiversity Conservation Act (EPBC), Victorian Flora and Fauna Guarantee Act (FFG) or JAMBA and CAMBA conventions.

4.3. Ecological and flow objectives

In addition to the EVCs and individual wetlands, the flow regime must meet the needs of other biota identified in the environmental objectives. These include wetland macro-invertebrates, fish, water birds and frogs.

The water requirements to meet these objectives would be provided by the proposed recommendations. Table 4 indicates which of the flow recommendations would meet the flow requirements of each environmental objective.

The water requirements to maintain a diverse and productive macroinvertebrate community are expected to be met from the lower bound watering regime (25,000 ML/d events). These would provide adequate duration, extent and frequency of inundation to sustain a diverse and resilient community in the floodplain wetlands.

The fish objectives are expected to be met by both the upper (40,000 ML/d) and lower bound (25,000 ML/d) events. The inundation of the broader floodplain would provide a source of organic matter for the fish and allow short term access to the broader floodplain and to inundated creek lines and channels. The requirements of fish which prefer access to wetlands would be met by the lower bound watering recommendations, and the recommended series of events per year (2 to 3 in a year) would provide opportunities for fish to move between wetlands and the main channel in successive events as they matured.

The flow recommendations are expected to provide the appropriate conditions to meet the objectives for recruitment of waterbirds and woodland birds. The requirements for water under or near nest sites would be met by the recommendations to fill and top up wetlands (25,000 ML/d, 7 to 10 years in 10, and 2 to 3 times in a watering year). The need for provision of deep water for feeding by diving ducks could be met by both sets of flow recommendations, and the broader floodplain inundation (40,000 ML/d) will protect the condition and productivity of the vegetation and promote the flowering required by fruit or nectar eating species.

The objectives to increase the diversity and extent of frogs would be met by both sets of flow recommendations, which will provide areas of aquatic habitat across the floodplain and retention of water of suitable duration for breeding being provided by natural ponding of water, plus top ups during the year when watering was being undertaken (2 to 3 events during the year at 25,000 ML/d, or 1 to 2 events during the year at 40,000 ML/d).

4.4. Summary

The overbank flow recommendations for the lower Goulburn River were devised primarily from the watering requirements of flood dependent flora within the study area. The assessment has confirmed that these recommendations, based on best available science and information, are appropriate for the other environmental assets in the study area, including the full suite of environmental objectives identified in Table 4.

These overbank flow recommendations are designed to complement the existing in-stream flow recommendations (refer Cottingham et al. 2003 and Cottingham et al. 2007). The provision of a flow regime that integrates the recommendations from this study, Cottingham et al. 2003 and Cottingham et al. 2007 is expected to allow fulfilment of the stated environmental objectives, at a low level of risk of failure, provided the appropriate complementary river health works are implemented.

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ATTACHMENT A: PREVIOUS FLOW RECOMMENDATIONS

2003 Recommendations

The first environmental flow recommendations for the lower Goulburn River were provided in *Environmental flow recommendations for the Goulburn River below Lake Eildon* (Cottingham et al., 2003). The highest priority recommendation in this document (from a total of eight recommendations) was for the provision of an annual inundation event to address the issue of reduced floodplain/wetland wetting frequency. In particular the recommendation stated:

- The peak magnitude of the annual wetting event be varied between 15,000 ML/d and 60,000 ML/d (the discharge at which nearly all wetlands between Lake Eildon and Loch Garry are inundated).
- The annual wetting event is allowed to pass downstream of Loch Garry, with the position of levees and operation of the Loch Garry system reviewed so key areas of floodplain can be identified and the volume of water required for inundation can be optimised.
- Those environmental events should be provided so that peaks occur with no less than half their natural frequency, with their timing based on natural patterns.
- The annual floodplain inundation event is not required in drought years i.e. where wetland and floodplain inundation would not have occurred naturally. It was expected that drought years would only occur every 13 - 15 years.

2007 Recommendations

In 2007, the *Evaluation of Summery Inter-Valley Water Transfers from the Goulburn River* (Cottingham et al., 2007) provided an updated set of recommendations, which advanced the 2003 recommendations for the lower reaches.

The 2007 FLOWS study was concerned with evaluating the impacts of summer inter-valley transfers (IVT) on the Goulburn River. Its scope was somewhat restricted as it did not include specific environmental objectives for wetlands, because “the IVTs being considered fell well below commence to flow levels along the study reaches” (p21). Further the only flow-related ecosystem objectives from the 2003 FLOWS study that the 2007 considered were those with “a focus on in-channel and riparian processes” (p21).

While the flow-related ecosystem objectives were not chosen based on specific floodplain requirements, some of the objectives have implications for overbank flows. The relevant objectives and their corresponding flow stressors are provided in Table 13. Each flow stressor is characterised by one or more elements as shown in Table 14. However only some of these elements correspond to overbank flows and only a subset of these were used for the final recommendations.

The recommendations for overbank flows during summer and autumn are focused on limiting the number and duration of these events. Conversely the recommendations for overbank flows during winter and spring are focused on increasing the number and duration of these events. As this 2010 study is interested in setting minimum flow requirements for overbank flooding, only the winter and spring recommendations from 2007 are summarised in Table 15.

In summary, the 2007 recommendations for a median year require the following overbank flows to achieve the flow-related ecosystem objectives:

- 24,000 ML/d to be exceeded for 6 to 10 days during spring
- 32,700 ML/d to occur approximately 4 times during spring/winter
- 55,000 ML/d not required in a median year, but is required in wetter years.

The recommended duration and frequency of overbank events increases in wetter years and decreases in drier years. These weather dependent recommendations have been converted into a long-term annual average recommendation by DSE (Table 15), on the assumption that 90th percentile recommendations would apply for the 90th percentile year and wetter, 70the percentile recommendations would apply for the 70th-90th percentile years, and so on (Stewardson, 2008).

Table 13. Environmental objectives and flow stressors relevant to overbank flows (sourced from Table 4 and 5; Cottingham et al., 2007)

Environmental asset	Environmental objective (code)	Flow stressor (code)	Seasons
Natural gradient of native terrestrial vegetation up the river banks	Maintain native terrestrial cover at top of banks and reduce cover of terrestrial vegetation in areas of the bank influence by flow regulation (TerrBankVeg)	Maximum inundation duration for water level within given range (F006)	Dec - Apr
Diverse and resilient aquatic macroinvertebrate fauna	Entrainment of litter packs available as food/habitat source for macroinvertebrates (MI4)	Number of overbank events (F021)	All year
Natural channel form and dynamics	Maintain pool depth (Geo3)	Proportion of time water level is within given range (F026)	Summer
Diversity of native species, naturally self-reproducing populations of native fish, threatened and iconic species	Suitable off-channel habitat for all life stages (NatFish)	Proportion of time flow exceeds threshold (F027)	Spring

Table 14. Flow stressors elements relevant to overbank flows (sourced from Table 6; Cottingham et al., 2007). Note recommendations were only provided for the three in bold.

Flow stressor	Flow stressor element	Description
F006	F006a	Maximum spell duration (days) for water level higher than 8.64 m above bed level, corresponding to the 10% exceedence flow in the natural flow regime
F021	F021a	Number of floods exceeding 24,000 ML/d, corresponding to anecdotal onset of out of channel flow
	F021b	**Number of floods exceeding 32,700 ML/d, corresponding to minor flood warning in reach 4**
	F021c	Number of floods exceeding 58,700 ML/d, corresponding to moderate flood warning in reach 4
	F021d	**Number of floods exceeding 55,000 ML/d, corresponding to commence to flow at Loch Garry**
	F021e	Number of floods exceeding 26,000 ML/d, corresponding to commence to flow at Deep Creek
	F021f	Number of floods exceeding 21,000 ML/d, corresponding to commence to flow at Deep Creek
	F021g	Number of floods exceeding 23,000 ML/d, corresponding to commence to flow at Hancock's Creek
	F021h	Number of floods exceeding 19,500 ML/d, corresponding to commence to flow at Raftery Forest
F026	F026a	Proportion of time water level is higher than 8.64 m above bed level, corresponding to the 10% exceedence flow in the natural flow regime
F027	**F027a**	**Proportion of time flow exceeds 24,000 ML/d**
	F027b	Proportion of time flow exceeds 32,700 ML/d
	F027c	Proportion of time flow exceeds 58,700 ML/d
	F027d	Proportion of time flow exceeds 55,000 ML/d
	F027e	Proportion of time flow exceeds 26,000 ML/d
	F027f	Proportion of time flow exceeds 21,000 ML/d
	F027g	Proportion of time flow exceeds 23,000 ML/d
	F027h	Proportion of time flow exceeds 19,500 ML/d

Table 15. Summary of winter/spring overbank flow recommendations for reaches 4 and 5 (sourced from Cottingham et al. 2007 Decision Support Tool)

	F027: Flow to be exceeded for x days during spring		**F021: Flow to occur at least x times each year (during winter/spring period)**			
	24,000 ML/d		32,700 ML/d		55,000 ML/d	
Year wetness	Reach 4	Reach 5	Reach 4	Reach 5	Reach 4	Reach 5
Driest on record	-	-	-	-	-	-
10th percentile	0	0	-	-	-	-
30th percentile	0	4	-	-	-	-
50th percentile	6	10	4	3.5	-	-
70th percentile	15	20	7	5	-	-
90th percentile	35	40	8	7	4	3.6
Wettest on record	-	-	-	-	-	-
Long-term annual average (DSE)	8	11	3.0	2.4	0.4	0.4

A hyphen (-) indicates that no recommendation was made for that scenario
F006a and F026a do not apply to the winter-spring period

ATTACHMENT B: HYDRAULIC MODEL

Project scope

The Goulburn Broken CMA recently commissioned Water Technology to undertake the *Goulburn River Environmental Flows Hydraulics Study*, extending from Lake Eildon to the River Murray (Water Technology, 2010). The project involved the following tasks:

- Data collation and review – Collation and review of the available topographic and streamflow data information.
- Topographic data gap identification – Identify the gaps in the available topographic data, and suggest potential mediation options.
- Asset mapping – Locate and map known public and private assets along the Goulburn River and adjacent surrounds.
- Hydrologic analysis – Investigate relative contribution from downstream tributaries, and assess design flood hydrographs for the Goulburn River catchment.
- Hydraulic analysis and flow behaviour – Assess flow behaviour of the Goulburn River over a range of potential environmental flows.
- Socioeconomic assessment – Evaluate the social and economic costs of potential Goulburn River environmental flows.
- Real time flow management – Review and scope real time flow management framework.
- Management option assessment – Scope feasibility of management options for environmental flow releases.

The study area was divided into eight model reaches, with reaches F to H corresponding to reaches 4 and 5 in the FLOWS studies (Figure 10):

A. Eildon to Alexandra
B. Alexandra to Ghin Ghin
C. Ghin Ghin to Kerrisdale
D. Kerrisdale to Mitchellstown
E. Mitchellstown to Wahring
F. Wahring to Kialla
G. Kialla to Bunbartha
H. Bunbartha to the Murray River

This 2010 overbank flow study has used the maximum floodplain inundation extent (for each flow rate) derived from the hydraulic model to investigate the inundation characteristics of floodplain EVCs and high value wetlands.

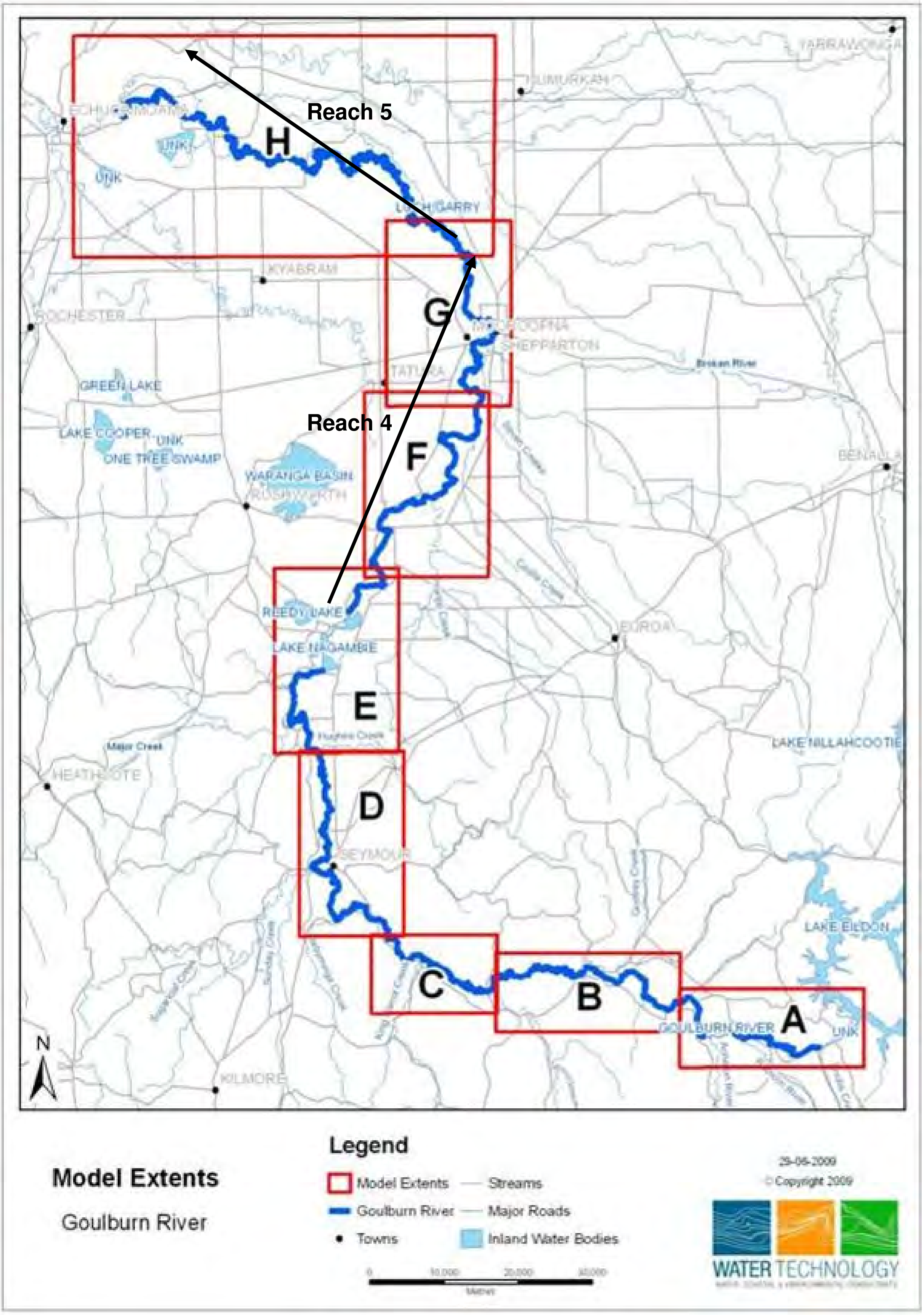


Figure 10. Model reaches A to H (red boxes) and FLOWS reaches 4 and 5 (black arrows)

Model hydrographs

The hydraulic modelling considered peak flows between 20,000 ML/d to 60,000 ML/d, in 10,000 ML/d intervals. These peak flow rates were based on the 2003 FLOWS recommendations for floodplain inundation flows between 15,000 and 60,000 ML/d (Cottingham et al., 2003).

For each of these peak flows, the flow hydrograph was constructed to increase at the maximum rate of rise allowed, then held steady at the peak flow to allow equilibrium flow conditions to be established (i.e. a steady state flow condition), and then decreased at the maximum rate of fall allowed back to minimum flow. The model continued to run to allow the floodplain to fully drain, except for the Bunbartha to Murray River reach (Water Technology, 2010).

The attenuation of flow hydrographs within each reach was assessed (see Appendix A of Water Technology, 2010). The duration required to achieve equilibrium conditions is a function of reach length and floodplain storage and varies along the study reach (Figure 16).

For all but the most downstream model (i.e. reaches E, F and G), the peak flow was held for approximately 4 days at the upstream end of the reach. In almost all cases the 4 day peak flow duration allowed equilibrium flow at the downstream end of the reach to be achieved. For the Kialla to Bunbartha model, it takes longer to achieve the downstream flow peak for flows between 20,000 and 40,000 ML/day than for flows between 50,000 and 60,000 ML/day. This reach shows the impact of the need to fill significant floodplain areas at slow rates between 20,000 and 40,000 ML/day.

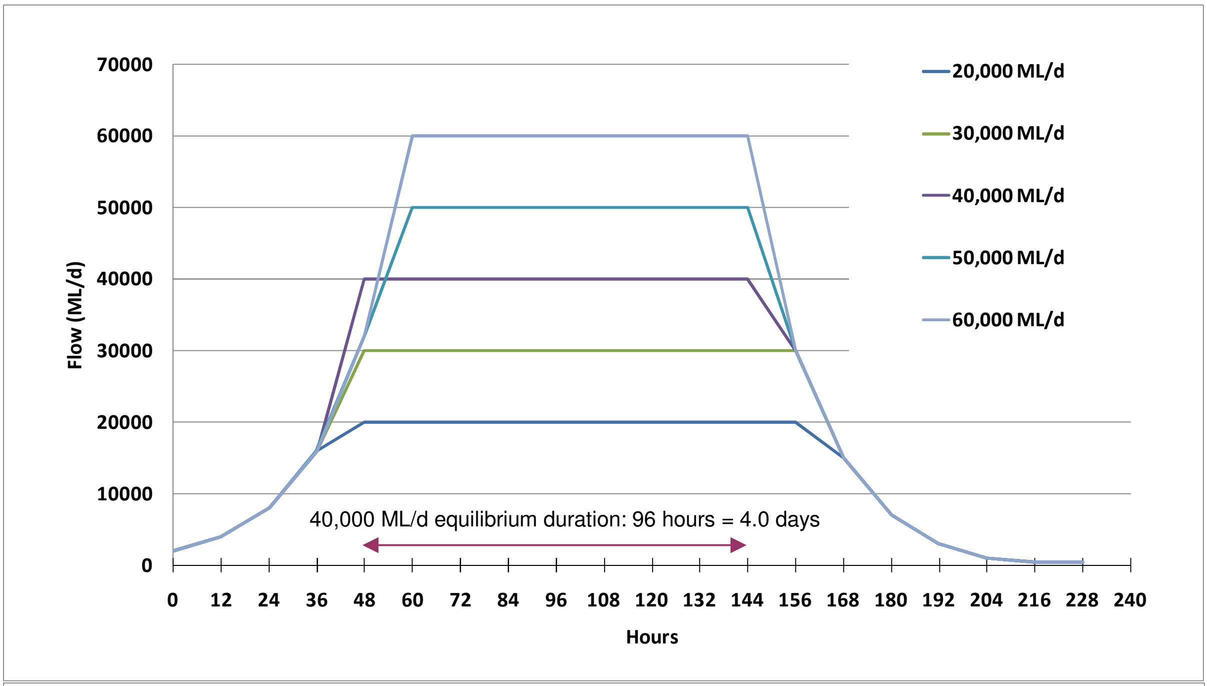
In the most downstream model (i.e. Bunbartha to Murray River) the peak flow was held for approximately13 days at the upstream end of the reach. The downstream end of the reach took 10 days to reach peak flow for the 40,000 ML/day flow after the upstream end, and 7 days for the 60,000 ML/day flow.

The attenuation along the entire study reach was not assessed in the study.

The resulting modelled hydrographs are shown in Figure 11.

Table 16. Number of days to achieve peak flow at the downstream end of the model reaches

Reach	20,000 ML/d	30,000 ML/d	40,000 ML/d	50,000 ML/d	60,000 ML/d
E. Goulburn Weir to Wahring	1	1	2	3	4
F. Wahring to Kialla	5	5	5	5	3
G. Kialla to Bunbartha	5	6	5	4	3
H. Bunbartha to Murray River	not modelled	not modelled	10	not modelled	7



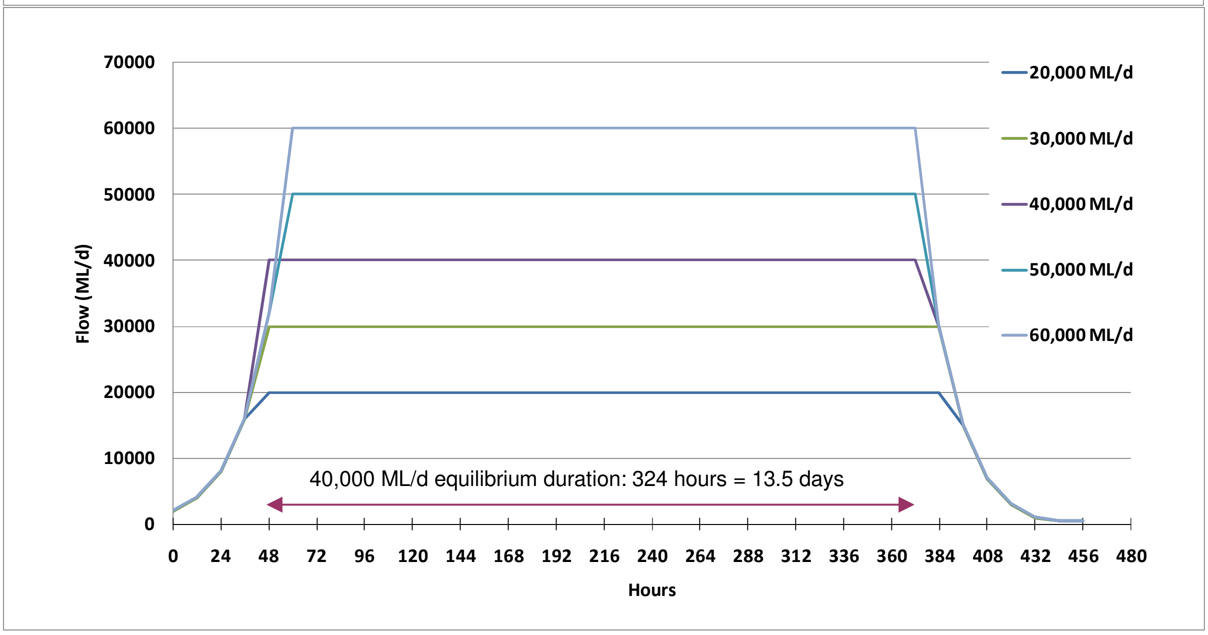


Figure 11. Model hydrographs for reaches between Eildon and Bunbartha (A to G - top chart) and Bunbartha to River Murray (H - bottom chart).

Relationship to managed actual hydrographs

Once the river exceeds the required height adjacent to a particular wetland/floodplain area, the wetland/floodplain area usually fills in less than 1 day. However, if the river height is only just above the height at which water flows into the wetland/floodplain area, the rate of flow into the area will be low and so filling can take much longer (especially if the wetland/floodplain area is large and requires a large volume to fill it). To achieve complete lateral inundation, increasing peak flow duration is much less effective than providing an adequate peak flow rate to significantly exceed wetland/floodplain sill levels.

In practise, the duration of the peak flow required to achieve the maximum inundation of the floodplain will be driven by the need to manage attenuation as water flows downstream along the entire river length. This will be reduced by any tributary inflows occurring along the reach between Goulburn Weir and Shepparton, by the wet or dry condition of the floodplain, and by any works to limit flows away from the river through the outlets in the levees from Loch Garry downstream. Further work is required to understand these interactions, to design flow releases for particular conditions.

Modeling accuracy

The hydraulic model calibration process (Water Technology, 2010) identified the following key points relating to the accuracy of modelling the lower Goulburn River:

- At Murchison, the modelled rating curve showed a considerable discrepancy from the gaugings. The observed gaugings at Murchison showed considerable scatter in the rating curve. The modelled water levels were found to be significantly lower than the observed gaugings for flows up to 60,000 ML/d.
- At Shepparton, the observed gaugings shows a considerable scatter for flows from 10,000 ML/d to 40,000 ML/d. This scatter can be up to 1 m for a given flow. The modelled rating curve lies at the lower limit of the scatter of the observed gaugings. Above 40,000 ML/d, the modelled rating curve and observed gaugings were in good agreement.
- At McCoy's Bridge, the modelled and observed rating curves were found to be in good agreement for flows up to 35,000 ML/d. For higher flows, significant flows occur in effluent streams such as Deep, Wakiti, Sheepwash and Skelton Creeks. Similar to observed gaugings at Shepparton, there was considerable scatter in the gaugings at McCoy's Bridge.

While there are clearly some uncertainties in the hydraulic modelling, this analysis represents the best available information at this stage. The observations from the recent spring 2010 flood events generally supported the hydraulic modelling results as described in the main body of this report. The Water Technology (2010) hydraulic model is therefore an appropriate tool to inform the overbank flow recommendations.

Results

The maximum inundated floodplain area and 'storage' areas were assessed for each model reach and environmental flow scenario. This 'storage' area shows depressions in the floodplain (anabranch, cut offs etc) where water is unable to flow back to the river, and is stored on the floodplain.

The maximum area inundated and 'storage' area within each reach of the lower Goulburn River is shown in Figure 12. The area of wetland inundation is shown in Figure 13 and the area of EVC inundation is shown in Figure 14.

A significant step change in floodplain area inundated occurs for the lower reaches, Wahring to Kialla and Kialla to Bunbartha, between flows 20,000 ML/d to 30,000 ML/d. Between 50,000 ML/d and 60,000 ML/d there was little change in floodplain area. A similar pattern was seen for the 'storage' areas.

The reach Bunbartha to Murray River has a significantly larger flood plain area than the other reaches. In part, this is due to the longer reach length. However, this does reflect the extensive floodplain area in this reach. A step change in floodplain area occurred between 20,000 ML/d and 30,000 ML/d.

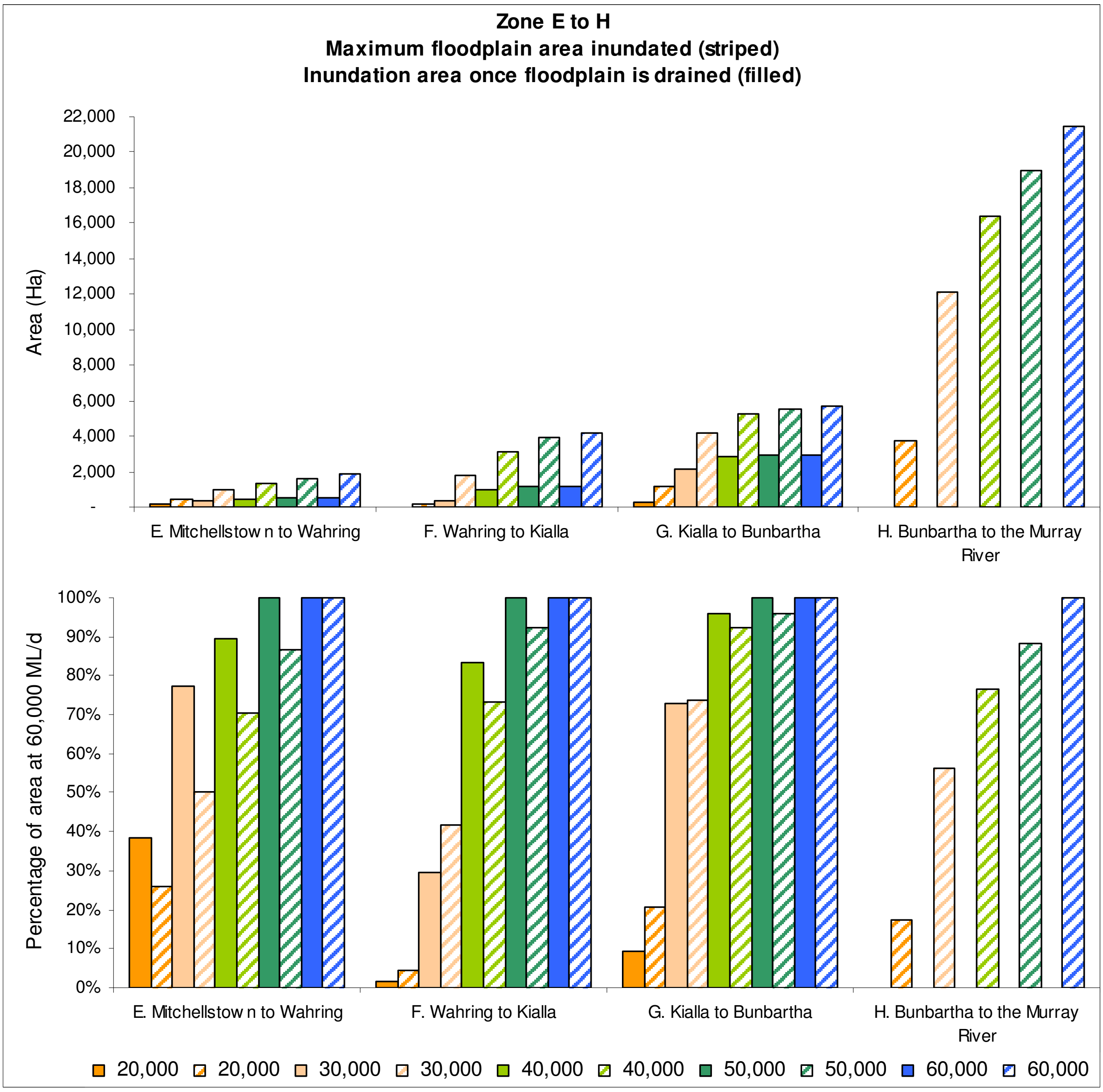


Figure 12. Area of maximum inundation and 'storage' area for each reach of the lower Goulburn River, expressed as total area (top chart) and percentage of the area inundated at 60,000 ML/d (bottom chart). Practical limitations prevented the assessment of 'storage' areas in the reach Bunbartha to the River Murray confluence.

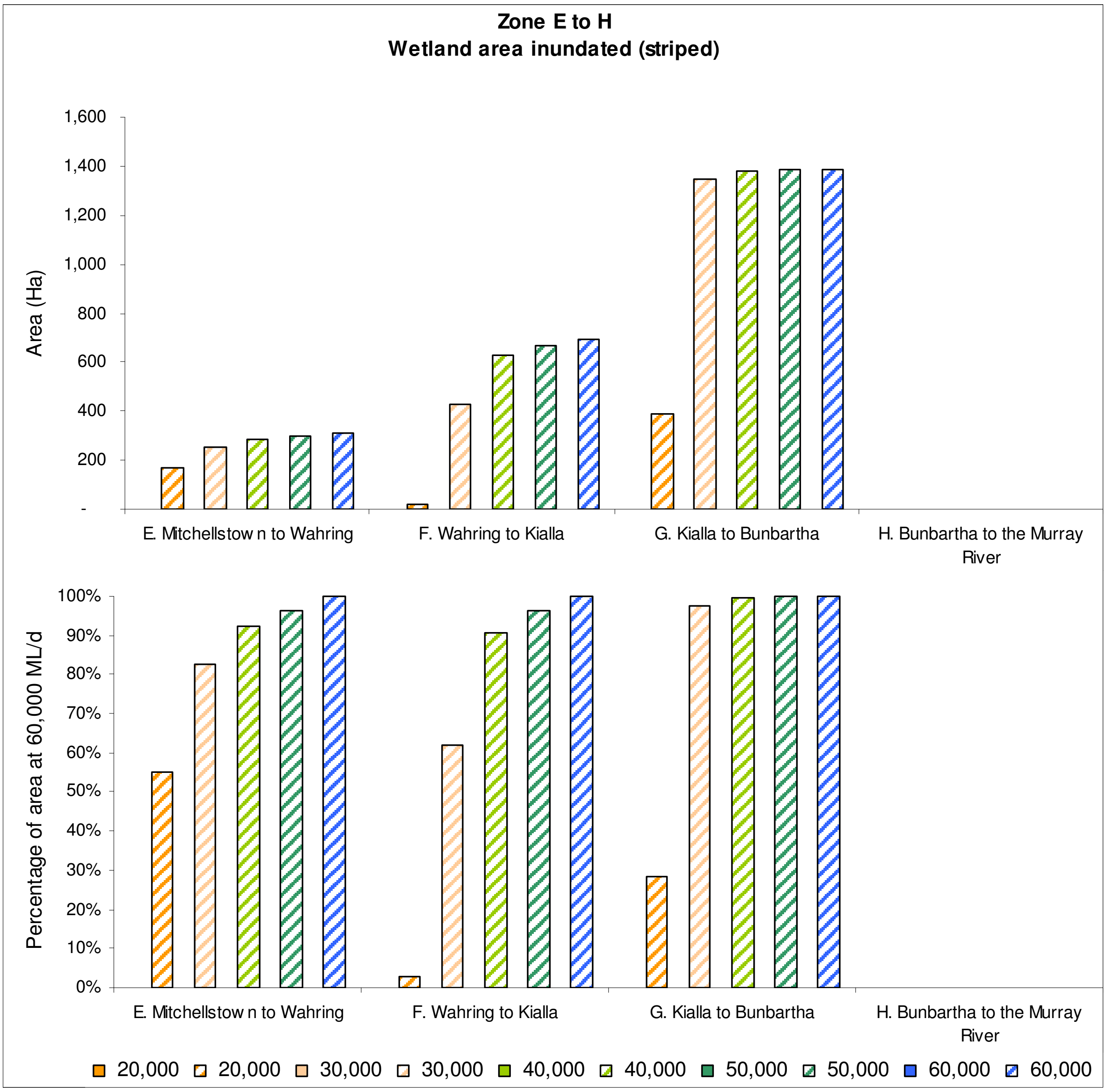


Figure 13. Area of wetland inundation for each reach of the lower Goulburn River, expressed as total area (top chart) and percentage of the area inundated at 60,000 ML/d (bottom chart). Practical limitations prevented the assessment of 'storage' areas in the reach Bunbartha to the River Murray confluence.

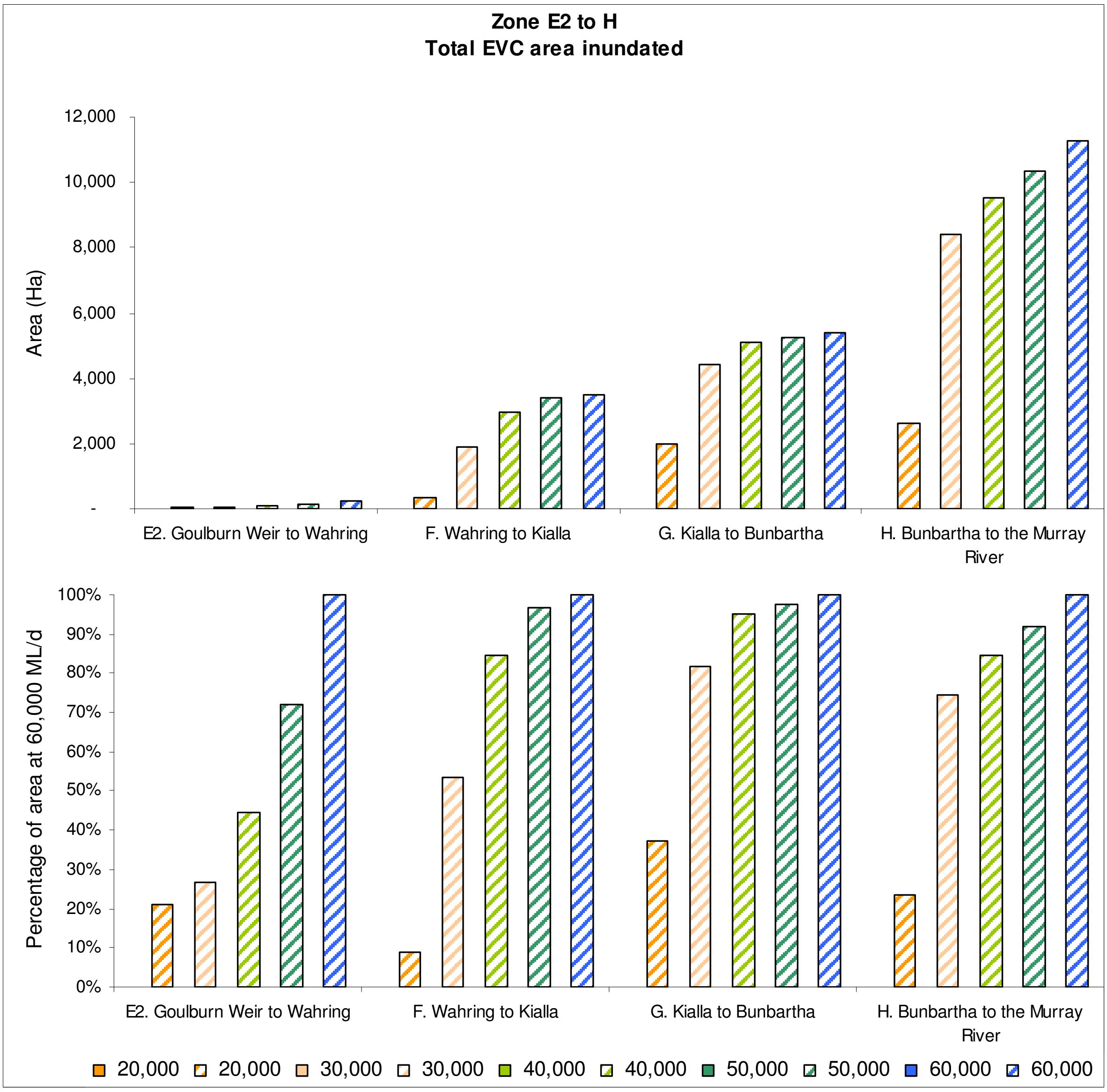


Figure 14. Area of EVC inundation for each reach of the lower Goulburn River, expressed as total area (top chart) and percentage of the area inundated at 60,000 ML/d (bottom chart). Note the Reach E statistics refer to only the part downstream of Goulburn Weir.

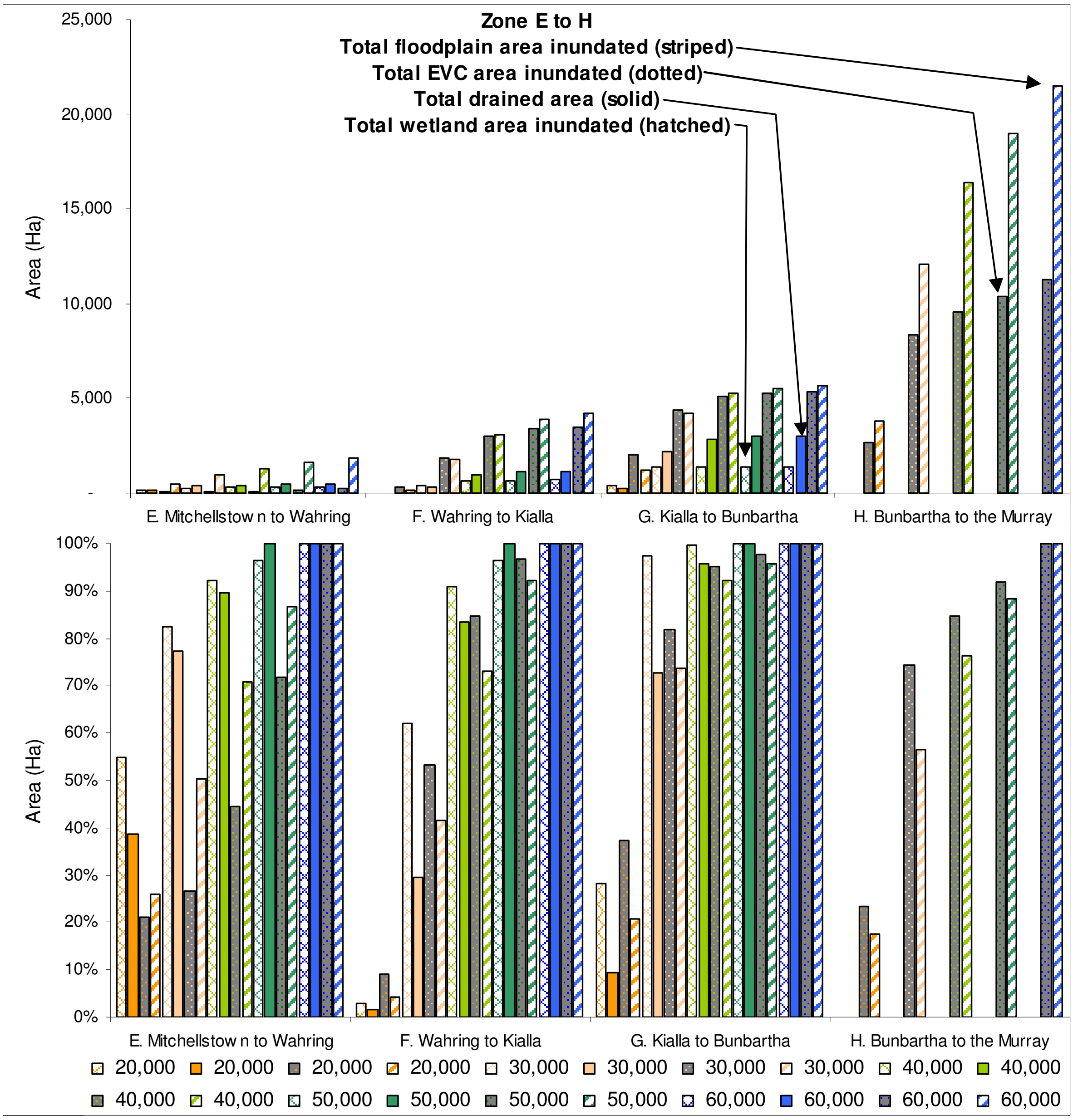


Figure 15. Area of floodplain, 'storage' area, wetland and EVC inundation for each reach of the lower Goulburn River, expressed as total area (top chart) and percentage of the area inundated at 60,000 ML/d (bottom chart). Note the Reach E for EVC statistics refer to only the part downstream of Goulburn Weir.

ATTACHMENT C: GEOMORPHIC SETTING

The geomorphology of the lower Goulburn River has been well described by Bowler (1976) and Erskine et al. (1993) and summarised in SKM (1998), Cottingham et al. (2003) and Cottingham et al. (2007). This review provides a brief summary from these sources as they relate to the floodplain of the lower Goulburn River.

The lower Goulburn River (i.e. downstream of Goulburn Weir) is a low gradient river cut into resistant clay and sand alluvial sediments of the Shepparton Formation. The lower Goulburn River region has a broad floodplain (approximately 2 km wide) which was formed by a larger, broader 'ancestral' river. The size and bedload of the river has changed over the last 40,000 years in response to climate change and changes to the course of the river due to channel avulsion. The contemporary river has flowed in its present course for the last 10,000 to 15,000 years (Cottingham et al., 2003).

Between Goulburn Weir and Loch Garry (i.e. reach 4), the contemporary Goulburn River has incised into the broad ancestral floodplain. The contemporary river has a sinuous flow path within this broad trench (i.e. broad ancestral floodplain).

Downstream of Loch Garry (i.e. reach 5), the Goulburn River changed course approximately 25,000 years ago (through channel avulsion) and left the broad ancestral floodplain. The contemporary Goulburn River floodplain in this reach is much narrower than the broad ancestral floodplain, presumably because this younger section has had less time to cut a larger trench (Cottingham et al., 2003). The floodplain between Wakiti Creek and the River Murray is even narrower than the floodplain between Loch Garry and Wakiti Creek, due to two phases of recent channel avulsion. The capacity (and width) of the floodplain therefore decreases downstream of Loch Garry, due to the progressively younger and narrower trenches. This is illustrated in Figure 16.

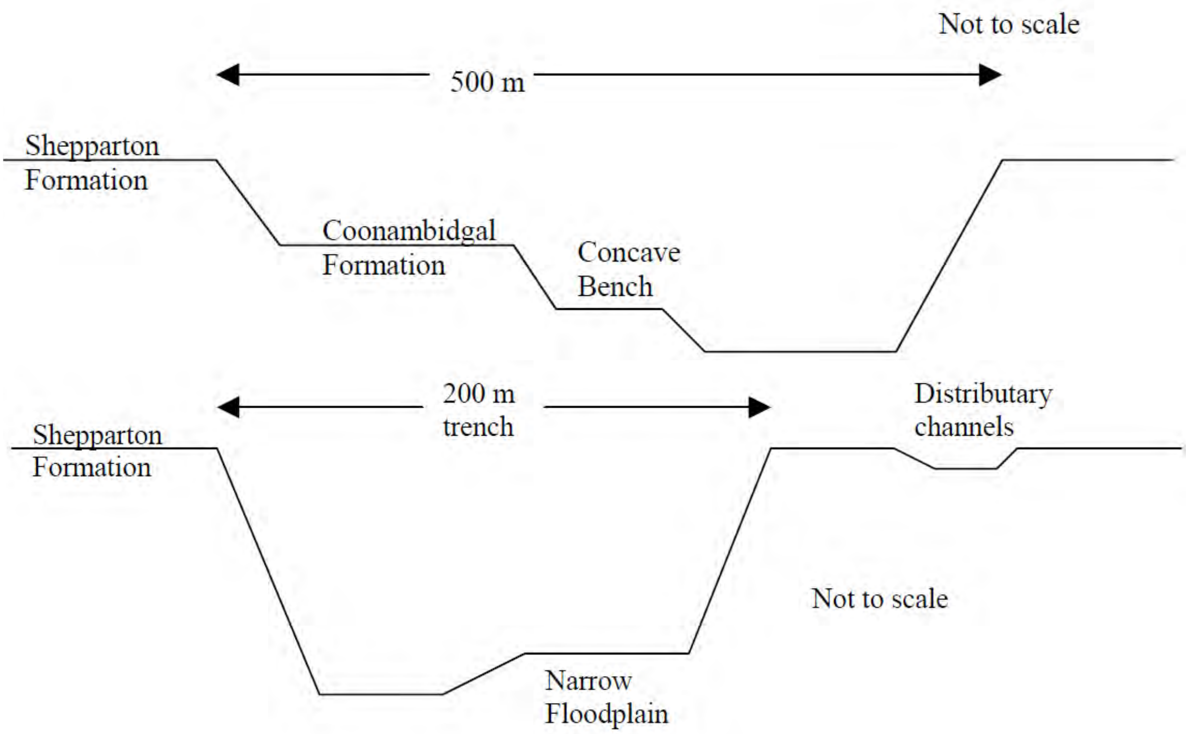


Figure 16. Schematic of a typical cross-section of the Goulburn River between Loch Garry and Wakiti Creek (above) and Wakiti Creek and River Murray (below).

Downstream of Shepparton the narrow contemporary floodplain is separated from the broader floodplain by natural levees. Natural levees are particularly well developed on the northern side of the Goulburn River below Loch Garry. Flood flows escaping from the river channel on the north bank drain to the north away from the river, following the slope of the broad floodplain to the River Murray.

An extensive network of artificial levees has been constructed on both sides of the river. This is now forcing larger volumes of flow much further downstream along the main Goulburn River channel than would have occurred naturally. The floodplain between the levees is only 700 m wide downstream of Loch Garry and 500 m wide near McCoys Bridge (SKM, 1998).

ATTACHMENT D: HYDROLOGIC ANALYSES OUTPUTS

The hydrologic analysis involved collating existing data and undertaking new analyses. All new analyses were based on modelled daily flow data at Shepparton from July 1896 – June 2006 as described in Table 17.

Three sources of existing data plus new analyses were used to examine the flood frequency in the study area as outlined in Table 17. The comparison identified considerable variation in the flood frequency results across the studies (Figure 17 and Figure 18). The exact reason for the variation is not known, but it is likely that it is due to different studies using different data sources and time periods (Table 17). With this uncertainty, the 2003 FLOWS analysis was considered to be the most robust, accurate and defensible. The 2003 FLOWS flow frequency analysis was adopted for the purposes of this 2010 refinement of overbank flow recommendations.

Table 17. Sources of hydrologic flow data

Study	Flow record	Flow location	Natural flow data source	Current flow data source	Reference
2003 FLOWS study	July 1975 – June 2000	At Murchison	REALM model (specific model not identified)	Recorded mean daily streamflow	Stewardson, 2003
2006 Goulburn, Broken, Campaspe, Loddon environmental flow delivery constraint study	25 year period (specific years not identified)	Nagambie to Loch Garry (r4) and Loch Garry to River Murray (r5)	REALM model (specific model not identified)	REALM model (specific model not identified)	SKM, 2006
2002 Shepparton-Mooroopna floodplain management study	Unknown	At Murchison and at Shepparton	Unknown	Unknown	SKM, 2002
New analyses (i.e. this study)	July 1896 – June 2006	At Shepparton[5] (r4)	REALM GBCL natural run ND09	Daily flows disaggregated from GSM current run 0885	-

[5] The modelled flow point in reach 4 is downstream of Pranjip Creek, Castle Creek, Seven Creeks and Broken River inflows i.e. ~ Shepparton gauge. It includes REALM arcs 38 and 152 in the Basin Plan November 2009 REALM model (based on GBCL_074_NAT.SYS with reservoirs/ demands off).

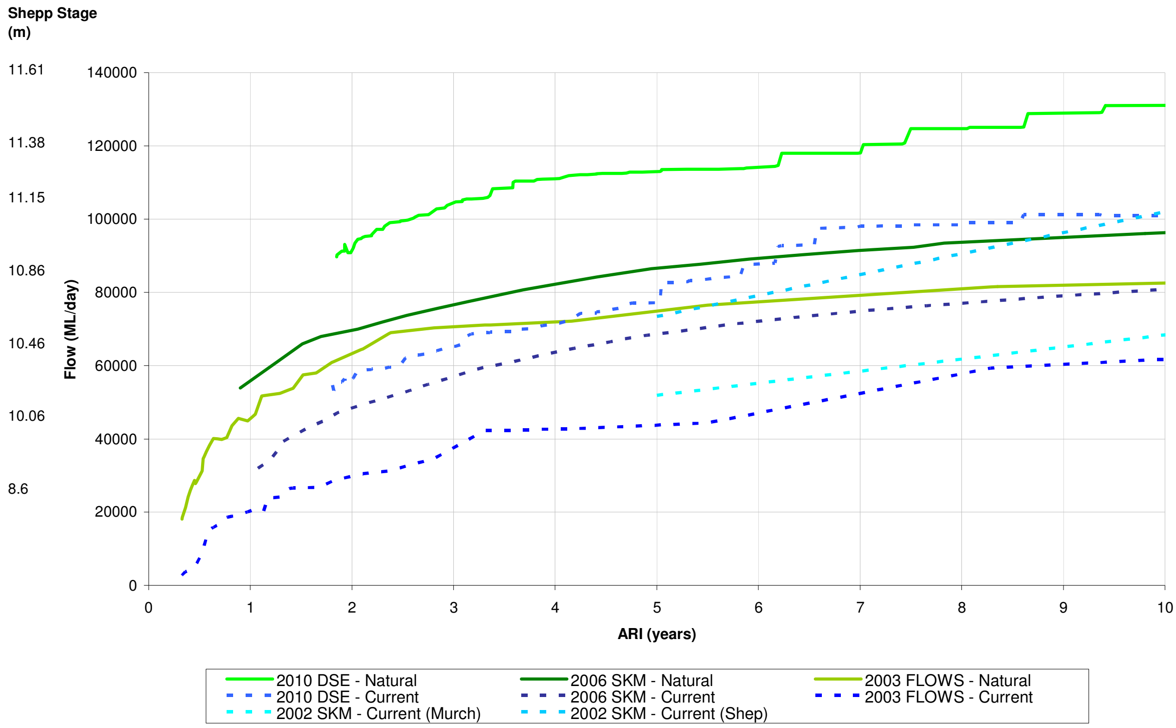


Figure 17. Comparison of reach 4 flood frequency from the four studies. Note the corresponding height on the Shepparton stage is provided (based on the gauge rating curve).

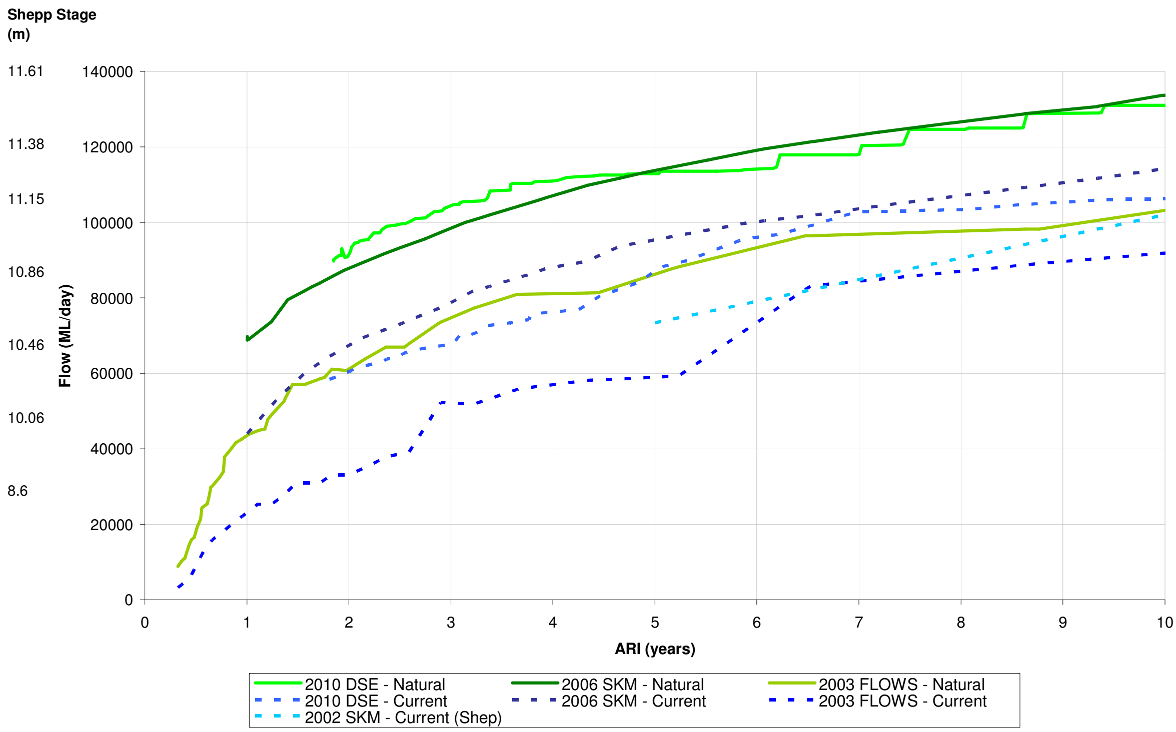
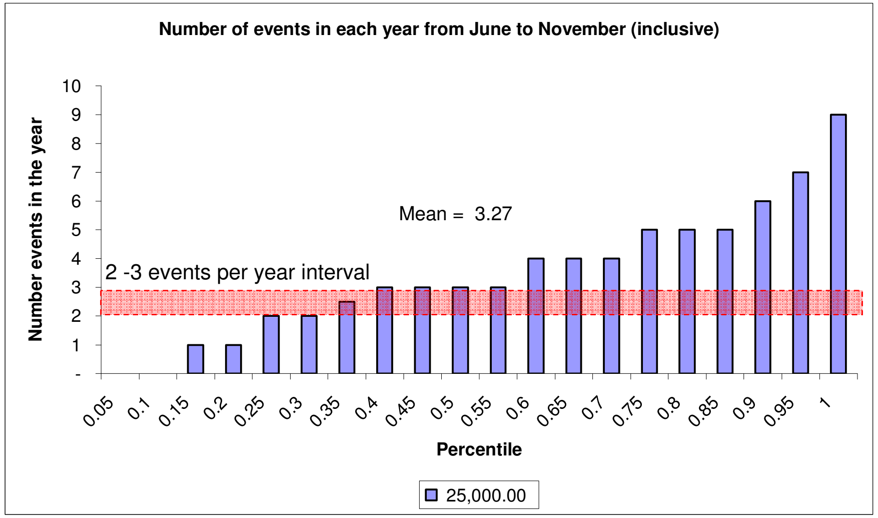
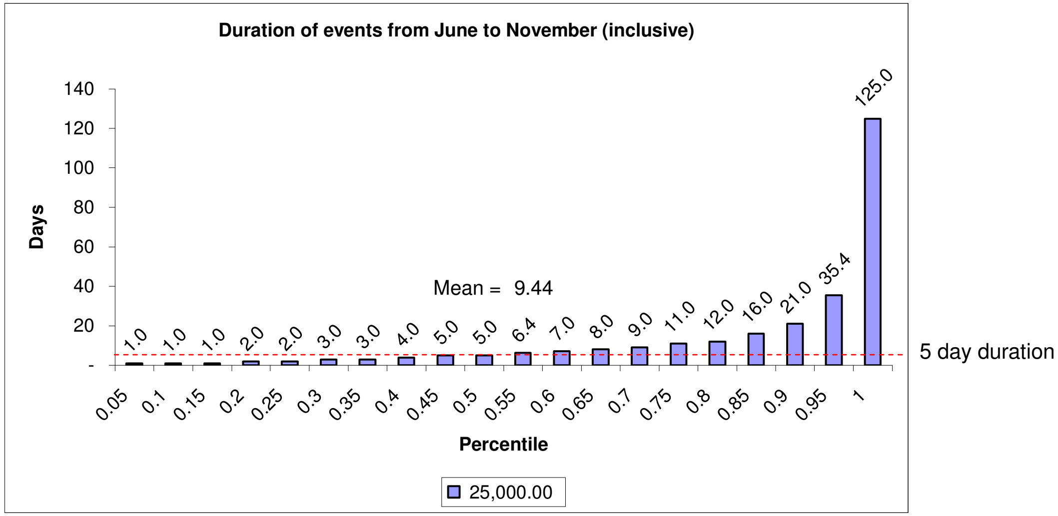
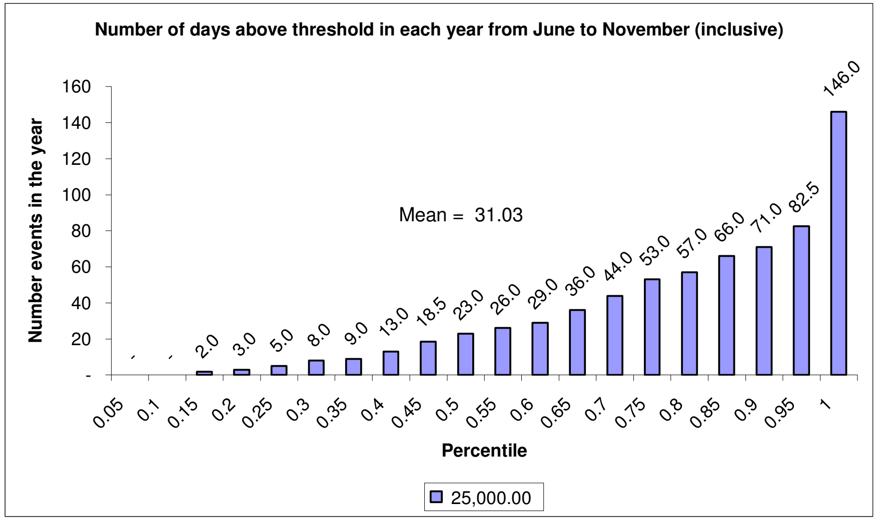


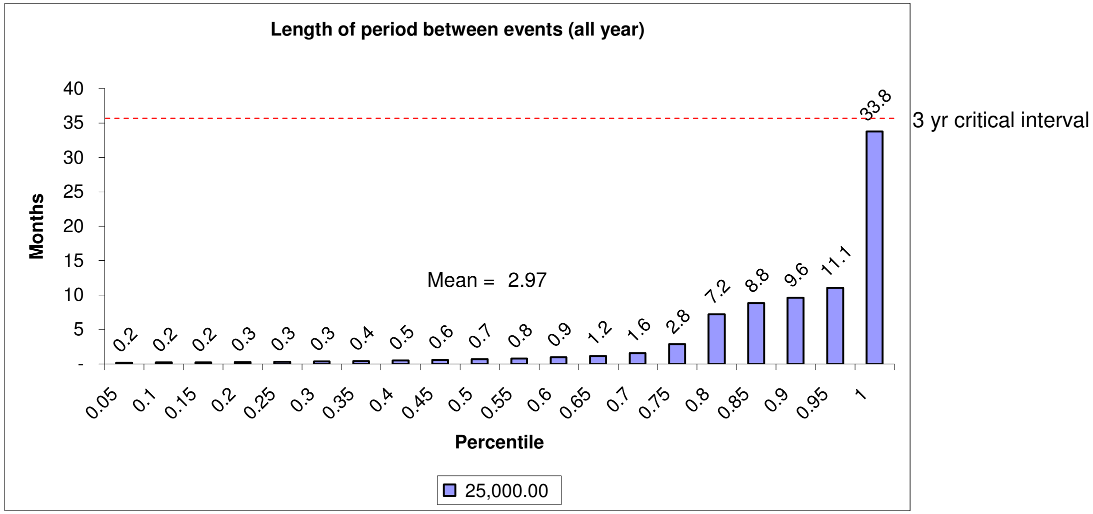
Figure 18. Comparison of reach 5 flood frequency from the four studies. Note the corresponding height on the Shepparton stage is provided (based on the gauge rating curve).

25,000 ML/d Natural daily 1896 to 2006 (red boxes/lines compare the flow recommendations to the natural flow series)

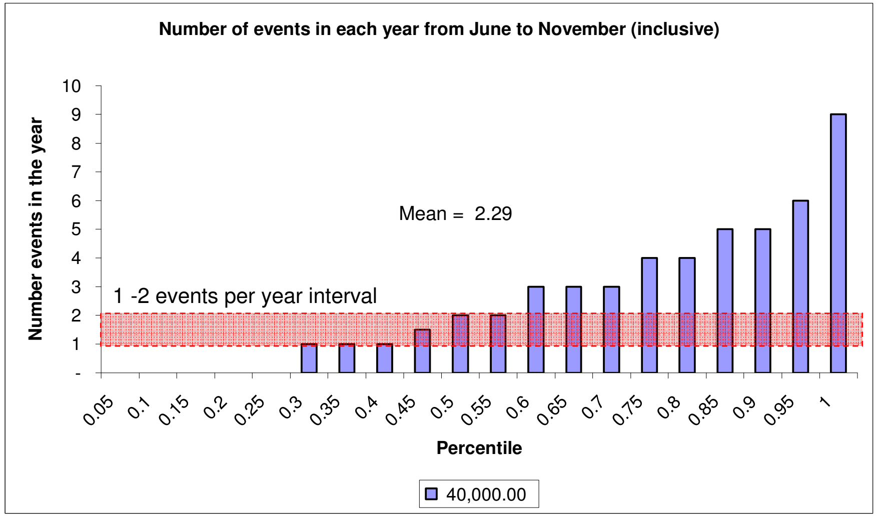


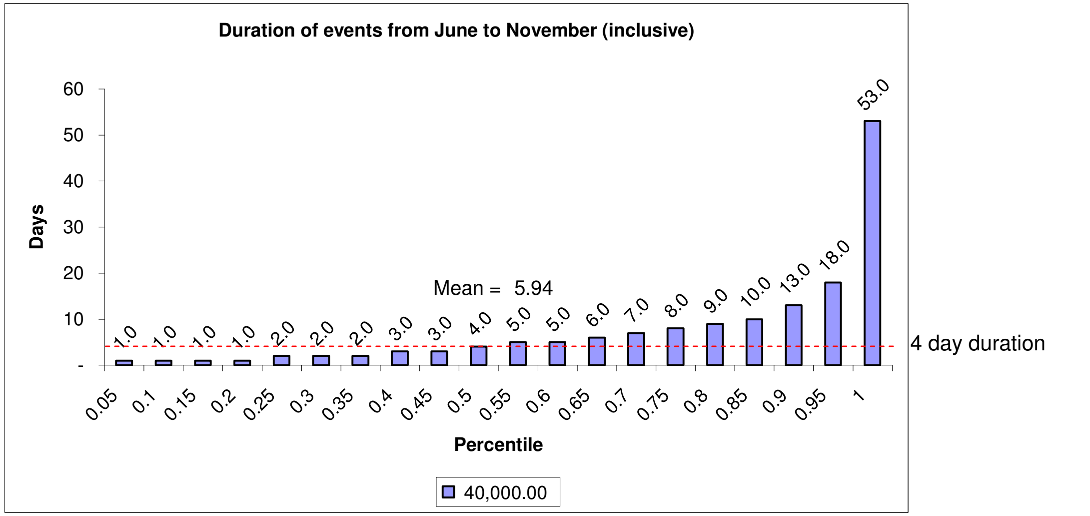


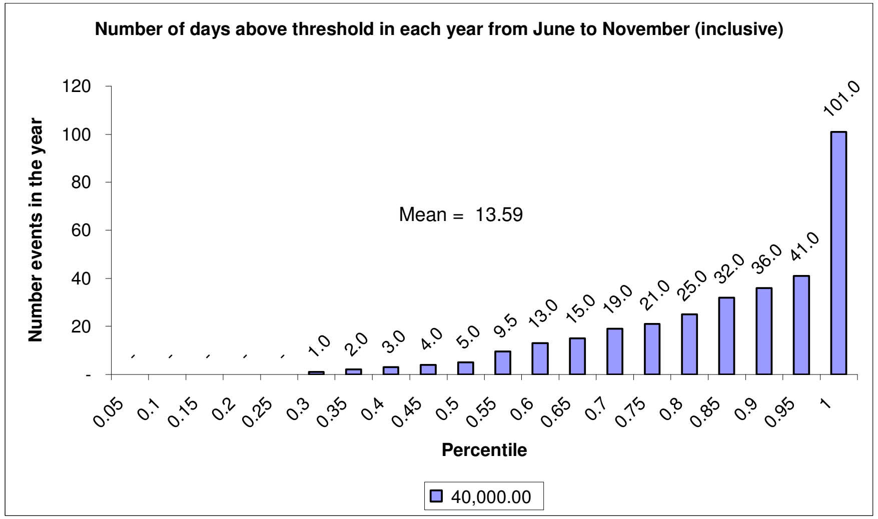


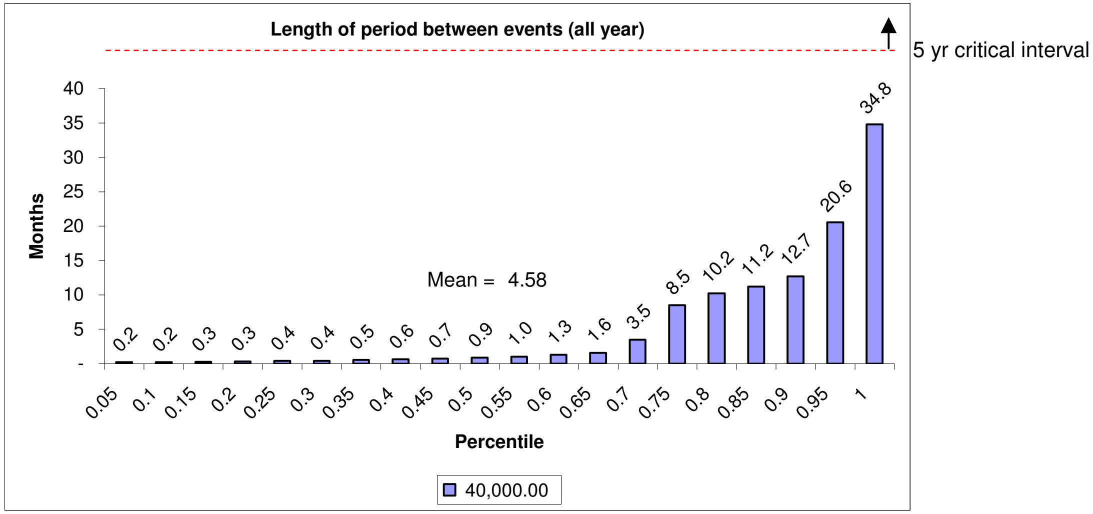


40,000 ML/d Natural daily 1896 to 2006 (red boxes/lines compare the flow recommendations to the natural flow series)



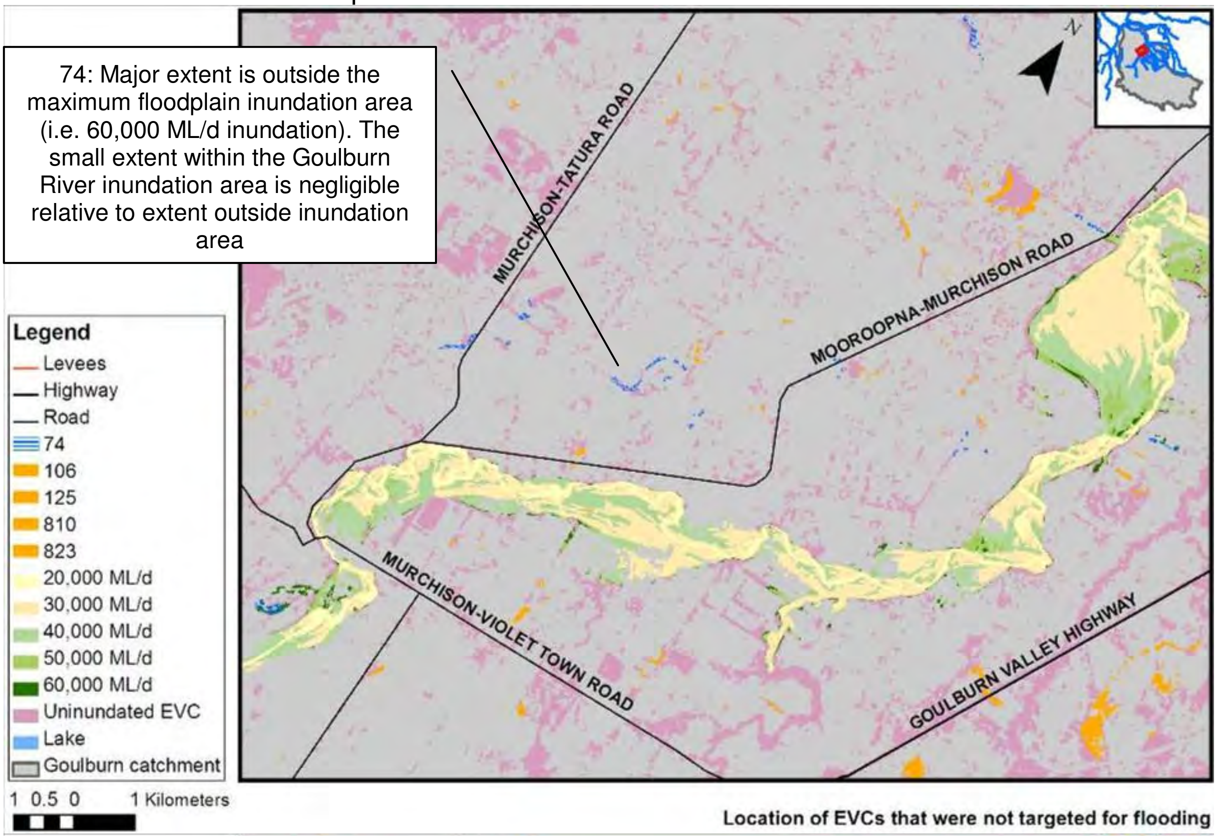


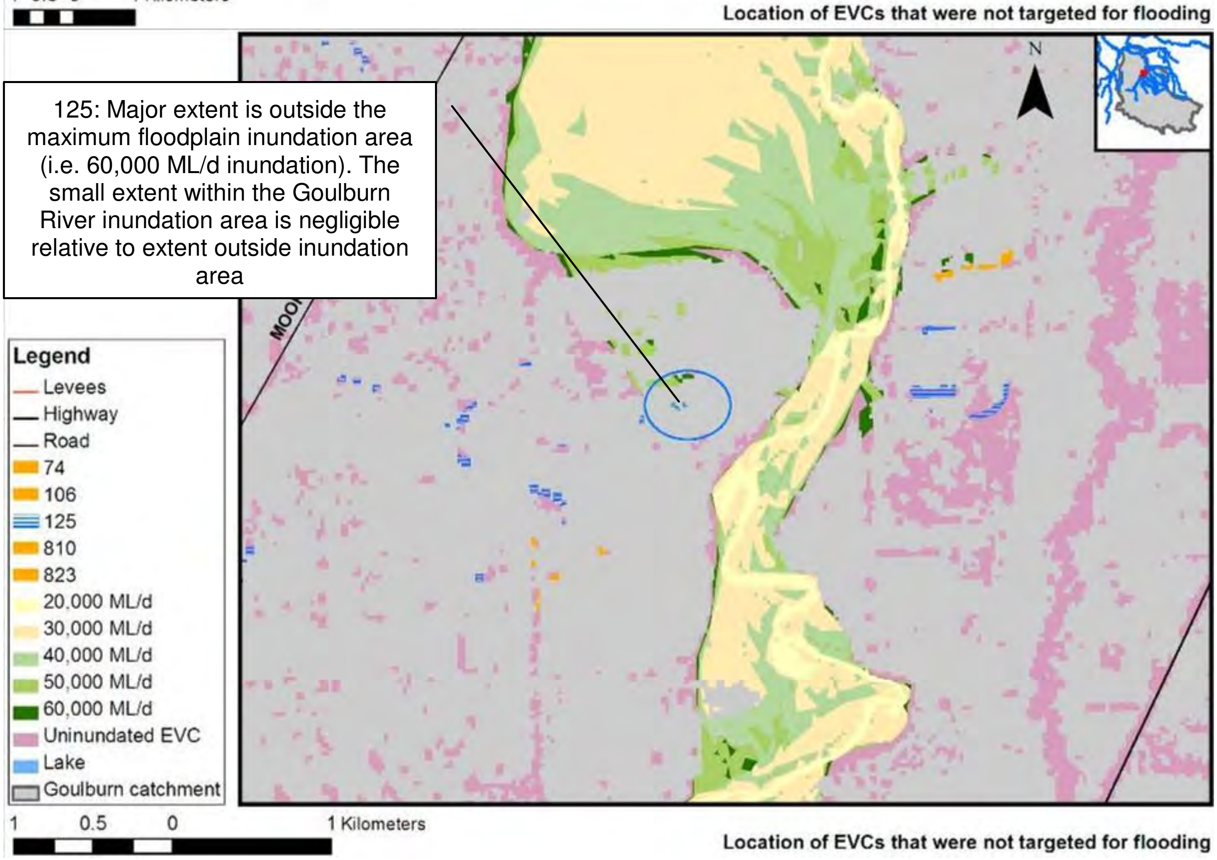


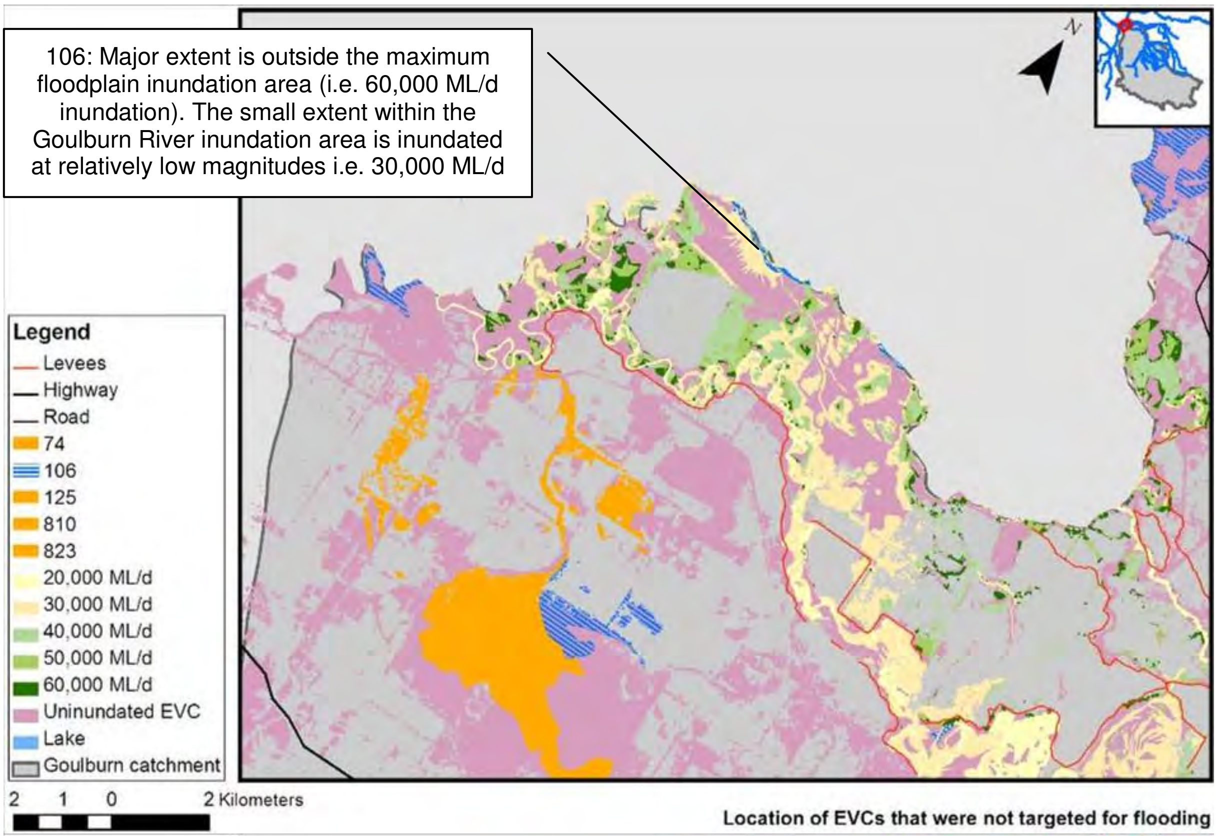


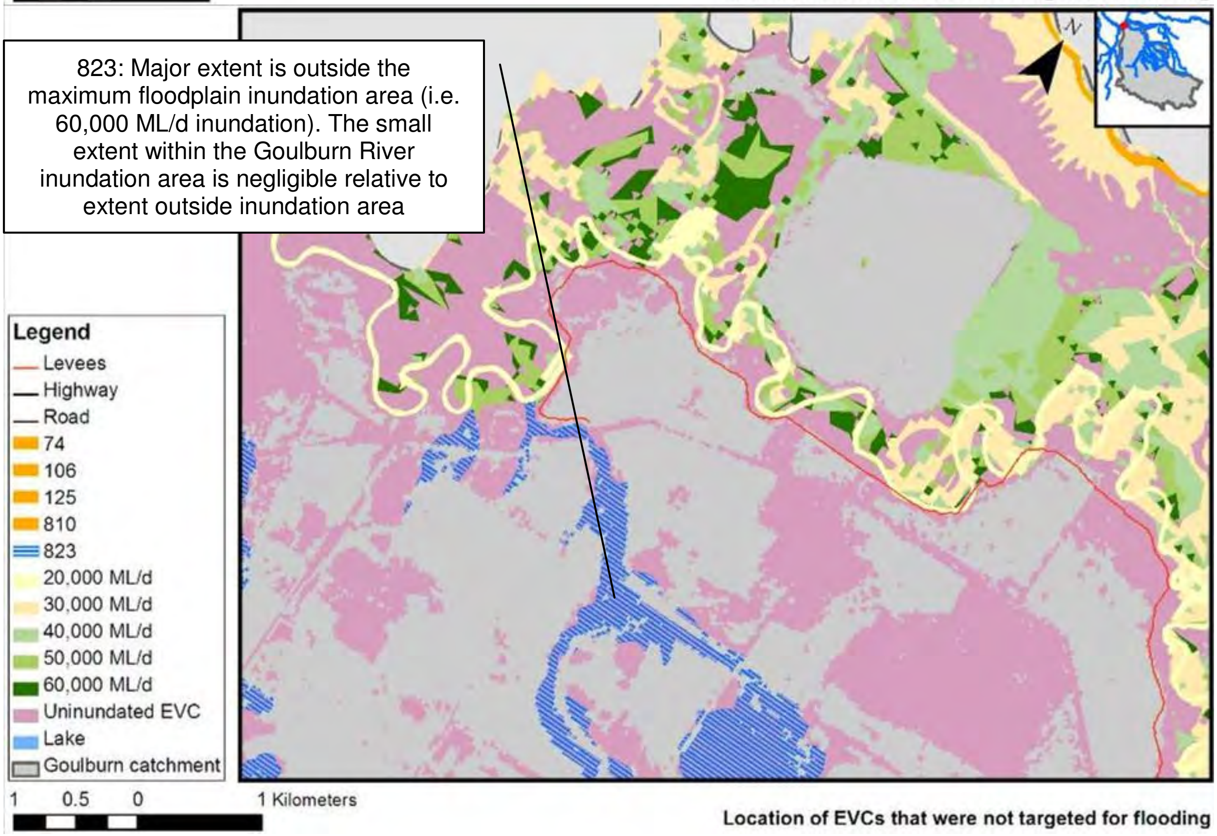
ATTACHMENT E: MAPS OF EXCLUDED EVCS

Five floodplain and wetland EVCs were excluded from the watering requirements investigation for the reasons described in Table 9 of the main report. The following maps show the location of each of these five EVCs (identified in blue on each map) within the lower Goulburn River floodplain.



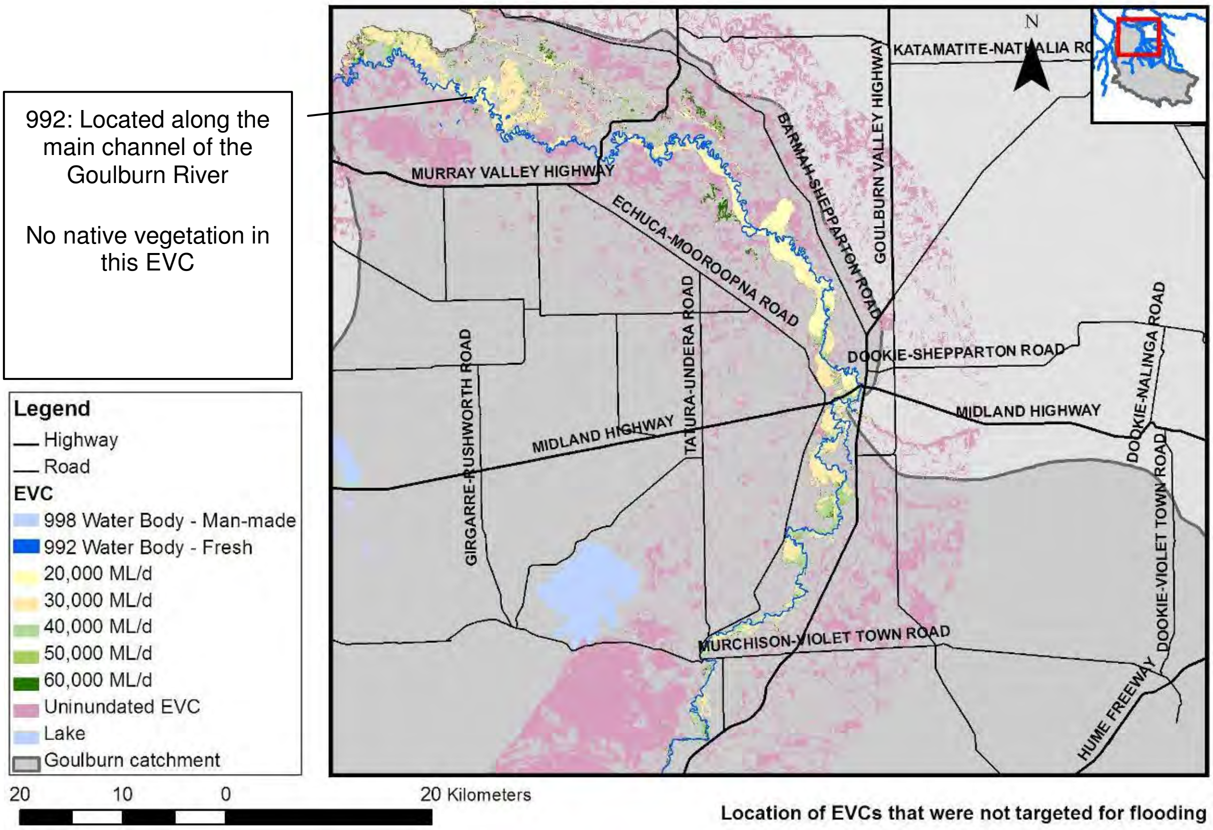



106: Major extent is outside the maximum floodplain inundation area (i.e. 60,000 ML/d inundation). The small extent within the Goulburn River inundation area is inundated at relatively low magnitudes i.e. 30,000 ML/d
Legend
Levees
Highway
Road
74
106
125
810
823
20,000 ML/d
30,000 ML/d
40,000 ML/d
50,000 ML/d
60,000 ML/d
Uninundated EVC
Lake
Goulburn catchment
2 1 0 2 Kilometers
N
Location of EVCs that were not targeted for flooding


823: Major extent is outside the maximum floodplain inundation area (i.e. 60,000 ML/d inundation). The small extent within the Goulburn River inundation area is negligible relative to extent outside inundation area
Legend
Levees
Highway
Road
74
106
125
810
823
20,000 ML/d
30,000 ML/d
40,000 ML/d
50,000 ML/d
60,000 ML/d
Uninundated EVC
Lake
Goulburn catchment
1 0.5 0 1 Kilometers
N
Location of EVCs that were not targeted for flooding

992: Located along the main channel of the Goulburn River

No native vegetation in this EVC



Location of EVCs that were not targeted for flooding

ATTACHMENT F: EVC GROUPINGS

This table shows the individual EVCs which comprise each of the EVC groups. The non flood dependent EVCs are shaded in grey. The table demonstrates that the requirements of all flood dependent EVCs are addressed by considering the requirements of a grouped subset of the flood dependent EVCs.

			53 Swamp Scrub	55 Plains Grassy Woodland	56 Floodplain Riparian Woodland	66 Low Rises Woodland	68 Creekline Grassy Woodland	74 Wetland Formation	103 Riverine Chenopod Woodland	106 Grassy Riverine Forest	125 Plains Grassy Wetland	132 Plains Grassland	168 Drainage-line Aggregate	172 Floodplain Wetland Aggregate	264 Sand Ridge Woodland	259 Plains Grassy Woodland / Gilgai Wetland Mosaic	267 Plains Grassland / Plains Grassy Woodland / Gilgai Wetland Mosaic	295 Riverine Grassy Woodland	308 Aquatic Sedgeland	334 Billabong Wetland Aggregate	537 Brackish Aquatic Herbland	653 Aquatic Herbland	803 Plains Woodland	804 Rushy Riverine Swamp	809 Floodplain Grassy Wetland	810 Floodway Pond Herbland	814 Riverine Swamp Forest	815 Riverine Swampy Woodland	816 Sedgy Riverine Forest	819 Spike-sedge Wetland	821 Tall Marsh	823 Lignum Swampy Woodland	871 Riverine Grassy Woodland / Plains Woodland / Gilgai Wetland Complex	882 Shallow Sands Woodland	932 Wet Verge Sedgeland	949 Dwarf Floating Aquatic Herbland	985 Sandy Beach	992 Water Body - Fresh	1022 Drainage-line Aggregate / Riverine Swamp Forest Mosaic	1035 Floodplain Riparian Woodland / Sedgy Riverine Forest Mosaic	1040 Riverine Grassy Woodland / Riverine Swampy Woodland Mosaic	1068 Riverine Swamp Forest / Sedgy Riverine Forest Mosaic	1081 Spike-sedge Wetland / Tall Marsh Mosaic	1090 Tall Marsh / Open Water Mosaic	1099 Riverine Swampy Woodland / Plains Grassy Wetland Mosaic	**Number of individual EVCs**
Targeted flood dependent EVCs	168, 1022	Drainage-line Aggregate								✓			✓									✓			✓	✓	✓		✓	✓	✓								✓							10
	334	Billabong Wetland Aggregate																	✓	✓	✓	✓				✓					✓					✓										7
	172	Floodplain Wetland Aggregate	✓											✓					✓			✓				✓					✓				✓	✓										8
	804	Rushy Riverine Swamp																						✓																						1
	1090	Tall Marsh / Open Water Mosaic																													✓													✓		2
	1081	Spike-sedge Wetland / Tall Marsh Mosaic																												✓	✓												✓			3
	810	Floodway Pond Herbland																								✓																				1
	295, 871, 1040	Riverine Grassy Woodland																✓					✓					✓					✓								✓					5
	56, 1035	Floodplain Riparian Woodland			✓																								✓											✓						3
	816	Sedgy Riverine Forest																											✓																	1
	815	Riverine Swampy Woodland																										✓																		1
	814, 1099, 1068	Riverine Swamp Forest									✓																✓	✓	✓													✓			✓	6
	68	Creekline Grassy Woodland					✓																																							1
ExcludedEVCs	992	Water Body – Fresh																																				✓								1
	74	Wetland Formation						✓																																						1
	125	Plains Grassy Wetland									✓																																			1
	106	Grassy Riverine Forest								✓																																				1
	823	Lignum Swampy Woodland																														✓														1
	803	Plains Woodland																					✓																							1
	103	Riverine Chenopod Woodland							✓																																					1
	264	Sand Ridge Woodland													✓																															1
	55	Plains Grassy Woodland		✓																																										1
	66	Low Rises Woodland				✓																																								1
	985	Sandy Beach																																			✓									1
	267	Plains Grassland / Plains Grassy Woodland / Gilgai Wetland Mosaic										✓				✓	✓																													3
	882	Shallow Sands Woodland																																✓												1
		Number of grouped EVCs	1	1	1	1	1	1	1	2	2	1	1	1	1	1	1	1	2	1	1	3	2	1	1	4	2	3	4	2	5	1	1	1	1	2	1	1	1	1	1	1	1	1	1	

ATTACHMENT G: HIGH VALUE WETLAND ANALYSES

The individual high value wetlands used to assess the flow recommendations are shown in Figure 2 of the main document. A series of maps have been created to show the inundation characteristics of each of the high value wetlands.

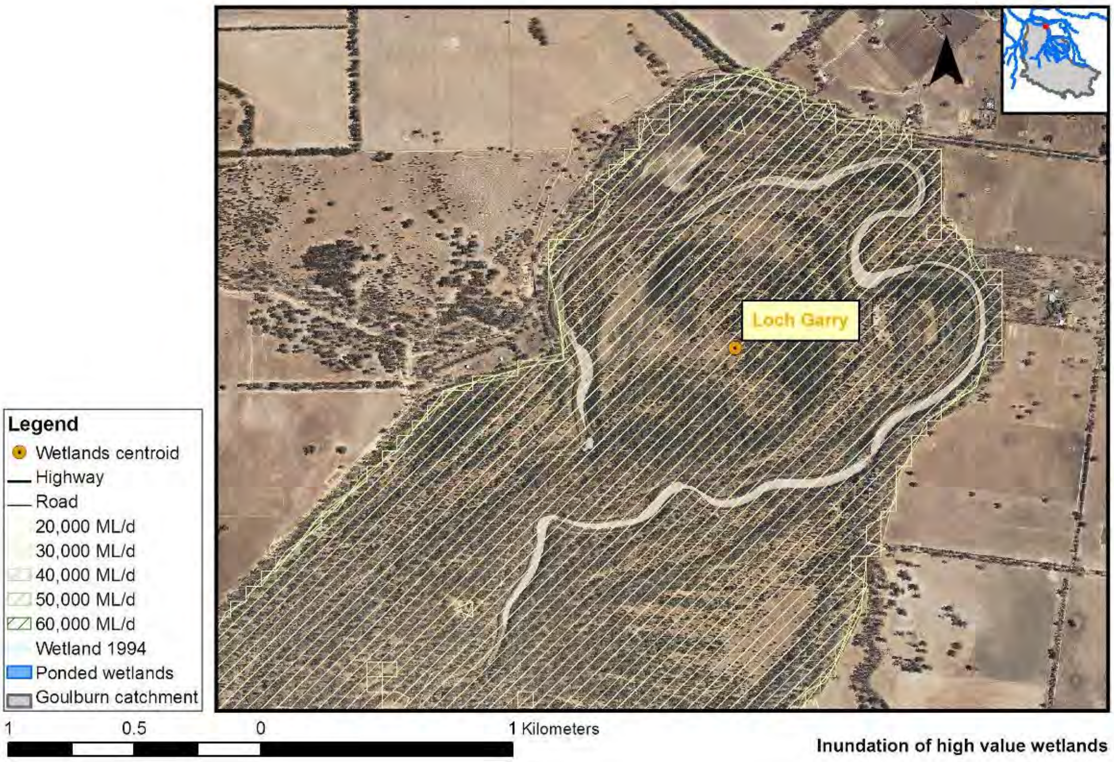
The planimetric accuracy of the wetland mapping has not been verified, but it is known to be questionable (Water Technology, 2009b). Aerial photography and the mapped ‘storage’ areas from the hydraulic modelling (called ponded wetlands in following maps) have been used to examine the location of each wetland, to account for the planimetric uncertainties in the wetland mapping.

At each wetland, the best available dataset (whether that be Wetland 1994, aerial photography or ‘storage’ areas) was used to make a subjective classification on the flow rate which inundates each wetland. Table 18 summarises the results.

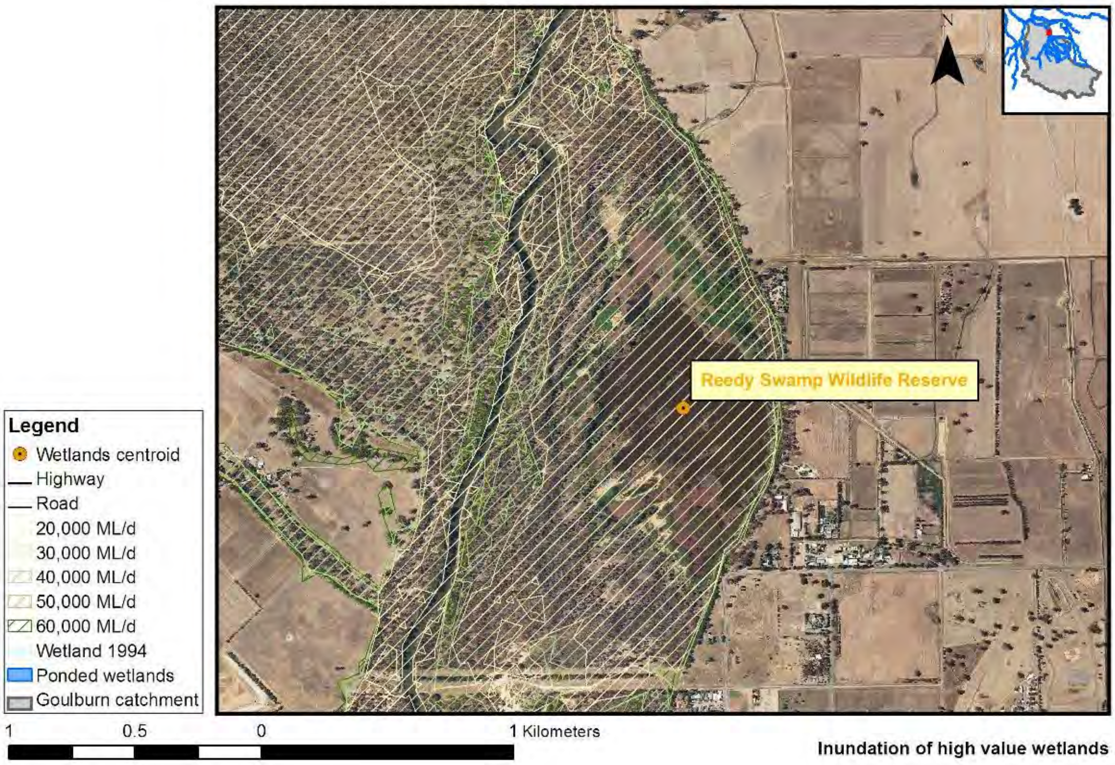
Table 18. Inundation characteristics of high value wetlands

Site	Complete inundation (ML/d)
Loch Garry	20,000
Reedy Swamp Wildlife Reserve	30,000
Greiners Lagoons	30,000
Hagans Lagoon	30,000
Alexander Swamp	20,000
Garners Swamp	30,000
Cemetery Bend / Jacks Lagoon	30,000 - 40,000
Pullar Swamp & Pullar Swamp North/Lower	20,000
Gemmills Swamp	30,000
Daunts Bend Billabong	30,000 – 40,000
Pouges Lagoon	30,000
Mooroopna Common Wetland	30,000

Loch Garry: Complete inundation at 20,000 ML/d

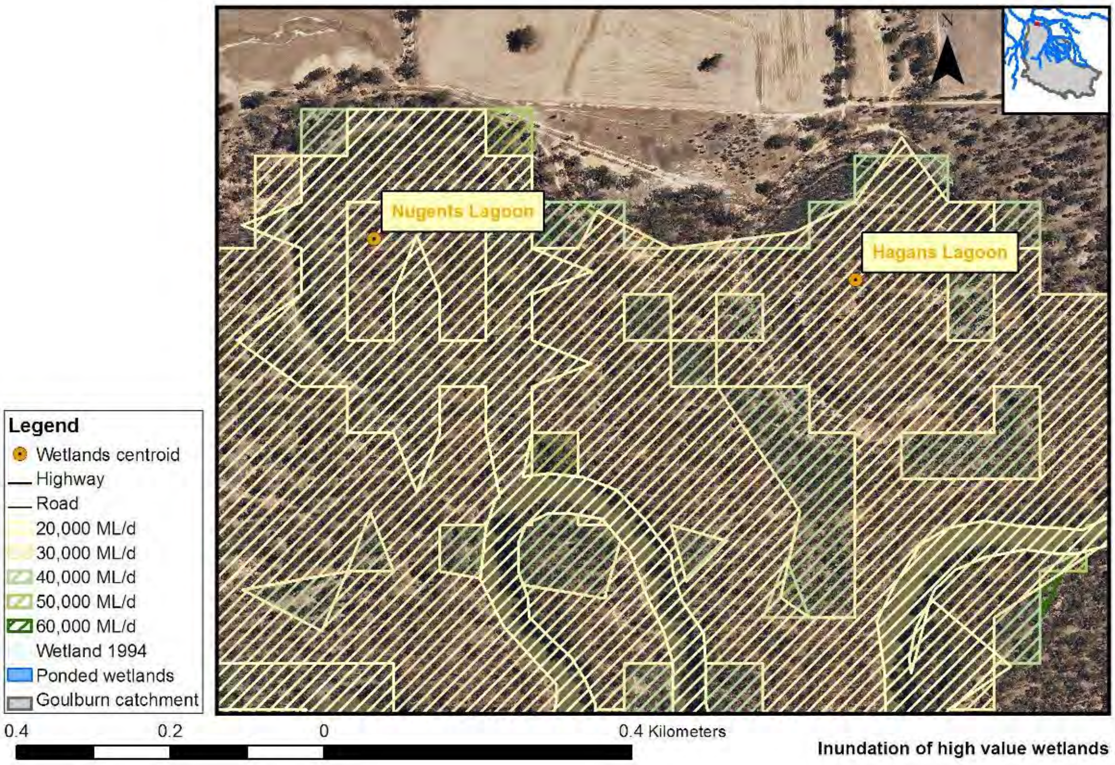


Reedy Swamp Wildlife Reserve: Complete inundation at 30,000 ML/d

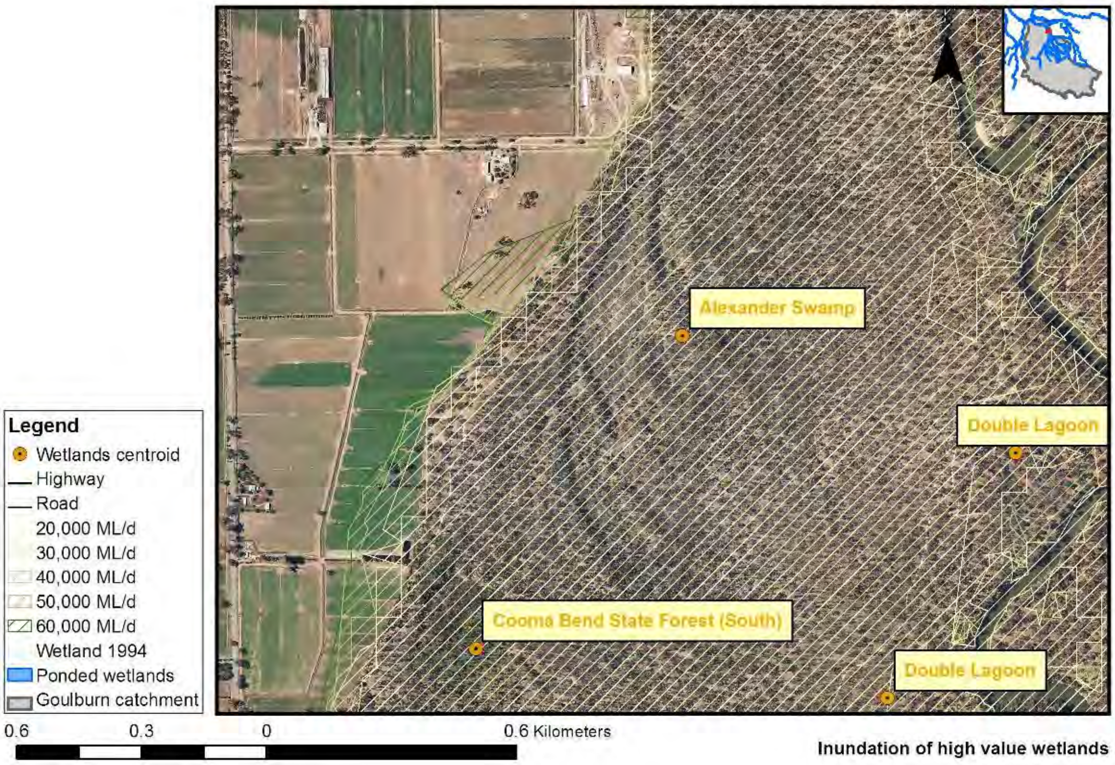


Greiners Lagoons: Complete inundation at 30,000 ML/d

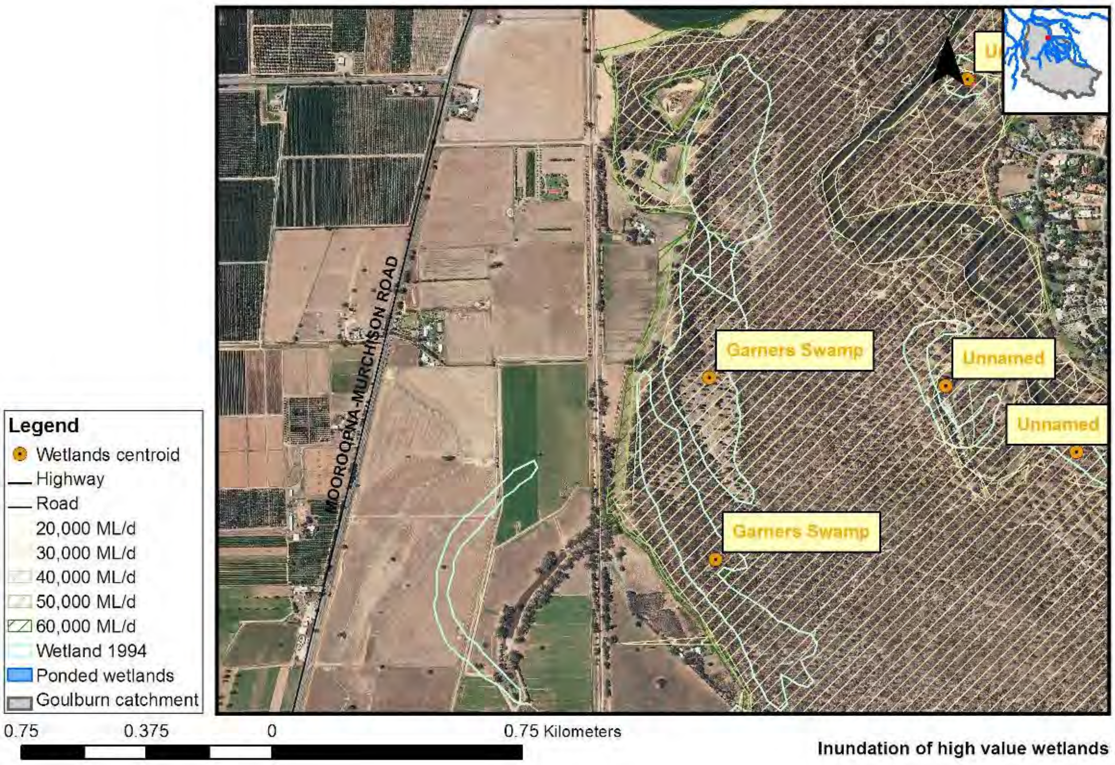
Hagans Lagoon: Complete inundation at 30,000 ML/d



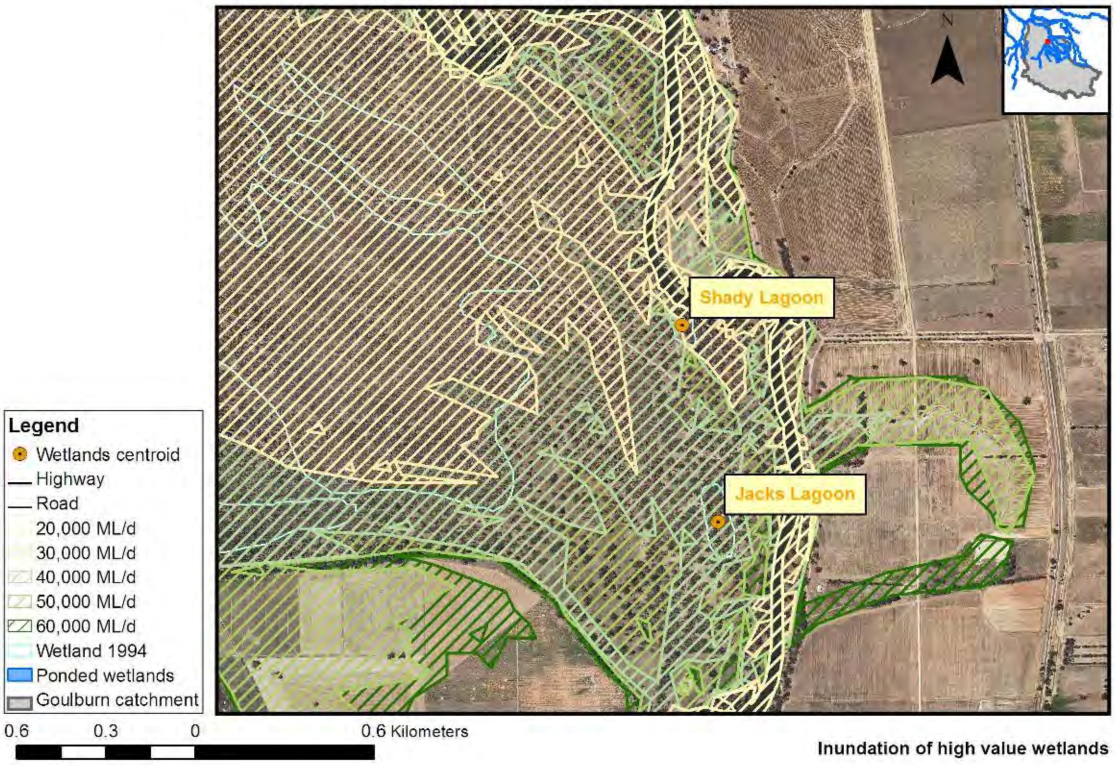
Alexander Swamp: Complete inundation at 20,000 ML/d



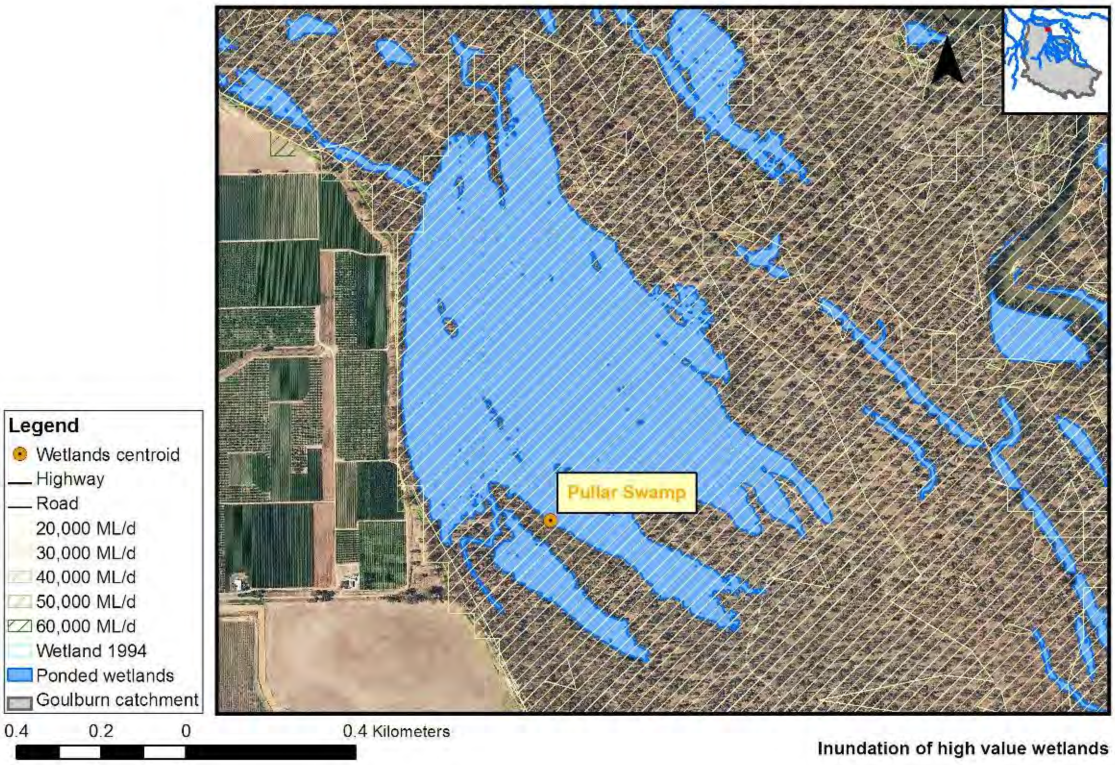
Garners Swamp: Complete inundation at 30,000 ML/d

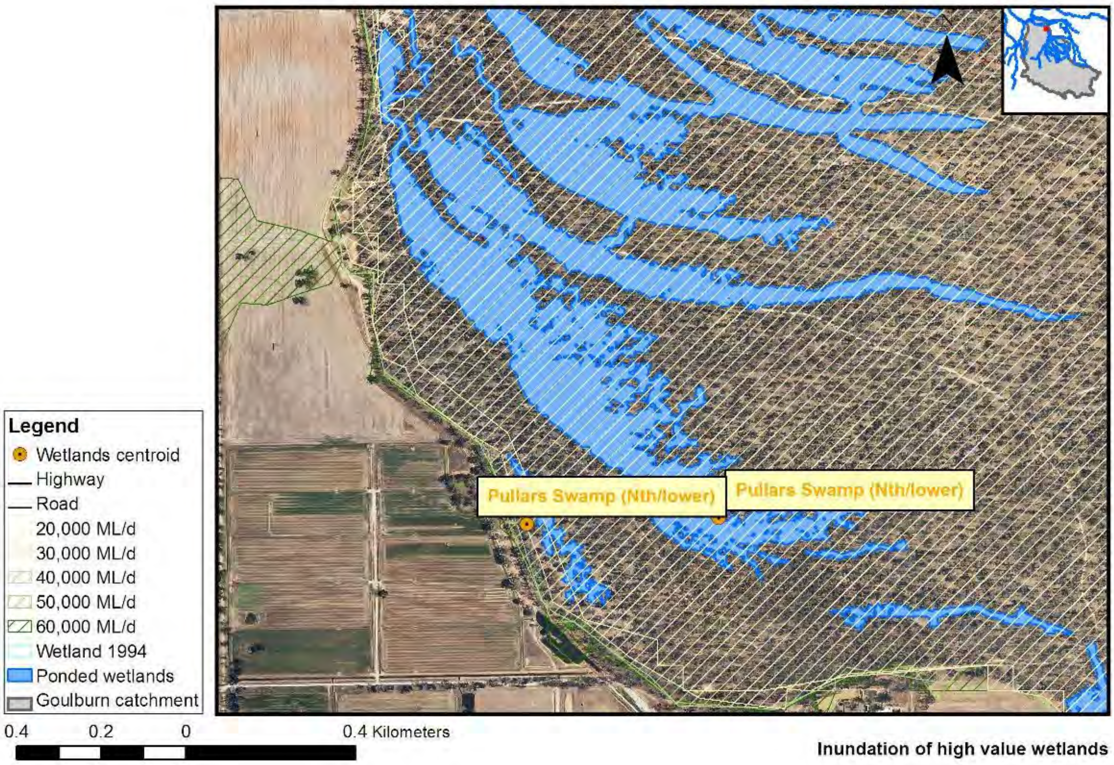


Cemetery Bend / Jacks Lagoon Complex: Inundation from 30,000 to 40,000 ML/d

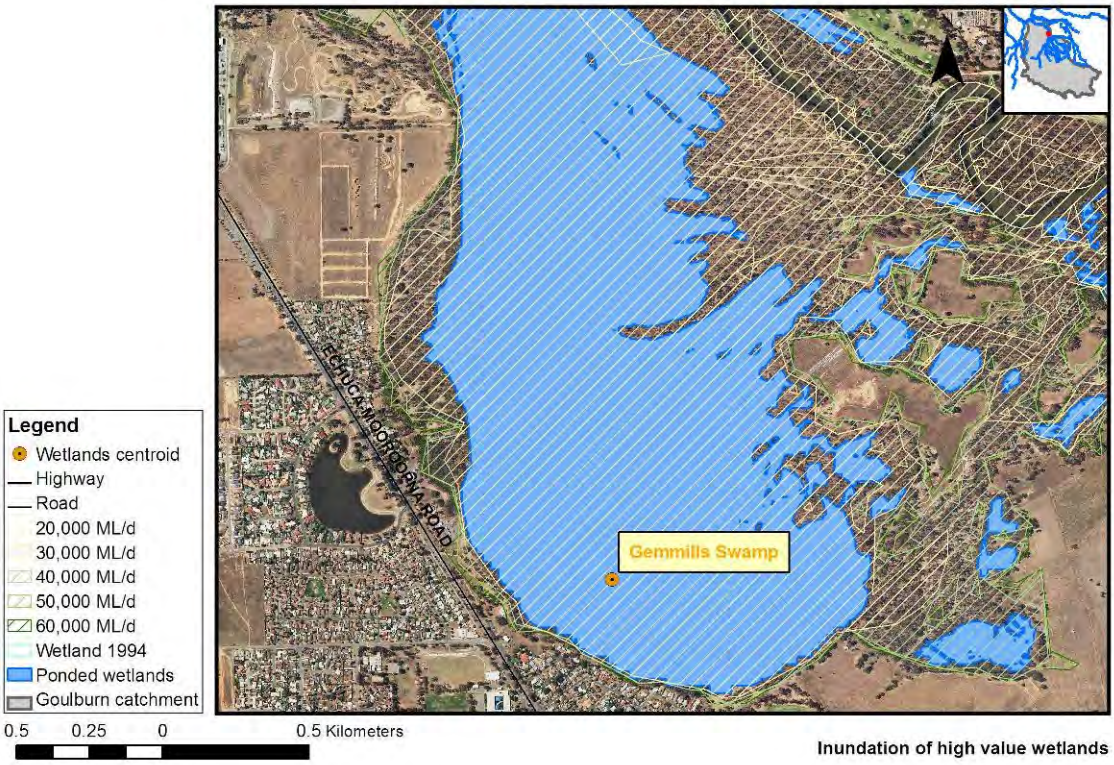


Pullar Swamp & Pullar Swamp (North/Lower): Complete inundation at 20,000 ML/d

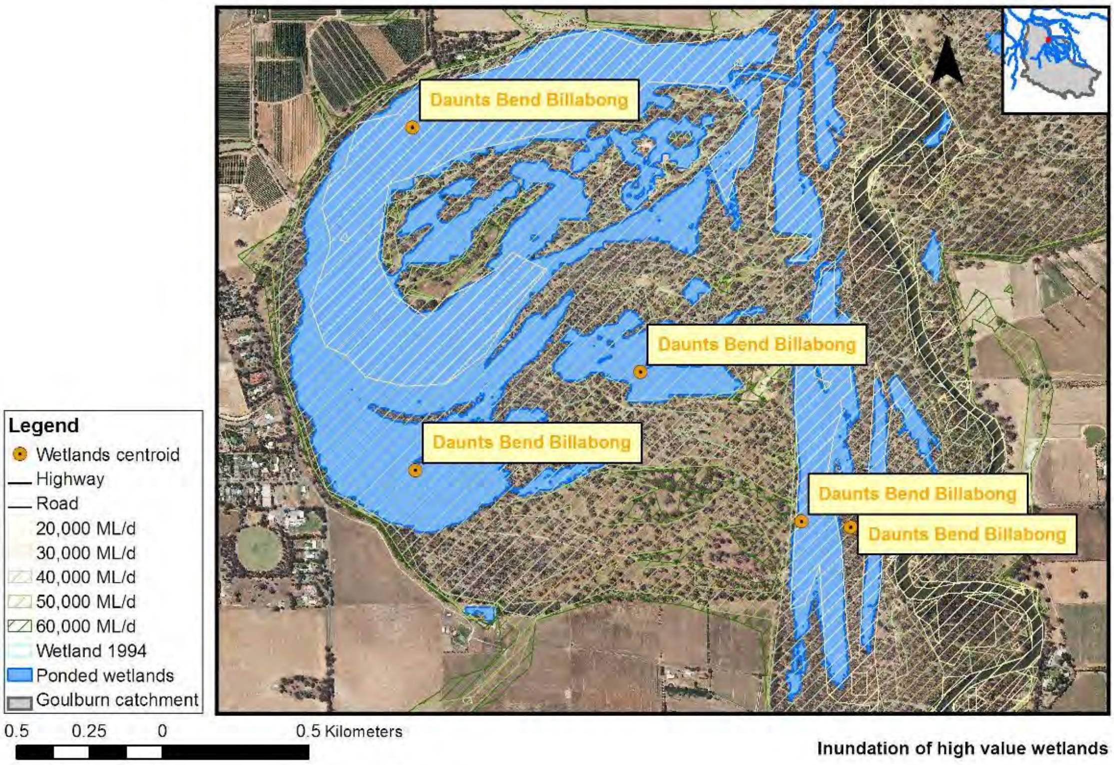




Gemmills Swamp: All inundated at 30,000 ML/d



Daunts Bend Billabong: Inundated from 30,000 to 40,000 ML/d



Pouges Lagoon: Complete inundation at 30,000

Mooroopna Common Wetland: Complete inundation at 30,000 ML/d