GOULBURN BROKEN
CATCHMENT MANAGEMENT AUTHORITY

Goulburn River Environmental Flows Hydraulics Study

Executive Summary

Environmental flow scenarios

April 2010

WATER TECHNOLOGY
WATER, COASTAL & ENVIRONMENTAL CONSULTANTS

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Study background and scope

The Goulburn Broken Catchment Management Authority (Goulburn Broken CMA) commissioned the Goulburn River Environmental Flow Hydraulics Study with funding predominantly provided by the Murray Darling Basin Authority. This study was undertaken by Water Technology (lead consultant) and URS (sub-consultant).

The Living Murray Initiative recognised the Goulburn River as an important contributor of water to the River Murray and associated icon sites, and that it required management to provide maximum benefits to icon sites, including the River Murray Channel. In particular, flooding of Gunbower Forest could be highly dependent on flows from the Goulburn, given the limited ability to move water from the upper Murray through the Barmah Choke.

The Goulburn River itself also has significant economic and ecological value, and an Environmental Flow Determination Study (Cottingham et al 2003) has identified the flow regimes required to maintain or improve key ecological values in the Goulburn River. This includes recommendations for out-of-bank flows of between 15,000 and 60,000 ML/day to inundate floodplain wetlands and forests. As the Goulburn is ecologically and hydrologically linked to the River Murray, integrated management of both rivers is a highly desirable outcome.

In a scoping study (SKM 2006), the risk of flooding was identified as a constraint to the provision of environmental flows in the Goulburn River. Bankfull and out-of-bank flows were identified as potentially affecting public and private assets along the floodplain, and this potential impact needs to be understood and managed if possible.

This study aimed to understand what would be involved in generating improved environmental flow regimes on the Goulburn River floodplain downstream of Lake Eildon to the River Murray confluence. Further, the study explored the extent of compatibility of appropriate environmental flow regimes in the Goulburn River and to the River Murray with traditional floodplain management (eg, on public and private assets). It also estimated the flood levels associated with large floods for floodplain management purposes. The study area is displayed in Figure 1.

In particular, the study identified what land is inundated at different Goulburn River flows, and what benefits and dis-benefits were associated with that inundated land. The role of tributaries downstream of Lake Eildon was assessed, both in creating risk of increased flooding when an environmental flow is being released from Lake Eildon, and their importance in providing extra flows to enhance downstream environmental flooding.

The objectives of this study were to:

- Investigate the flood characteristics (e.g., extent, depth, velocity, capacity and duration) of the Goulburn River and floodplain to pass desirable environmental flows and the potential risks to private and community assets, and Goulburn River wetlands; and
- Estimate the socioeconomic effect of the recommended high flow scenario from the Goulburn Environmental Flow Study, the likely order of magnitude of the cost of those changes, and ways to manage the impacts.

This study is the first consideration at what may be involved in managing floodplain environmental flows. It is therefore a scoping study to build an understanding of the issues that could be involved, rather than providing clear proposals on how floodplain environmental flows should be provided. The information from this study will allow development of a work program for the next few years to resolve how floodplain environmental flows are to be provided and managed.

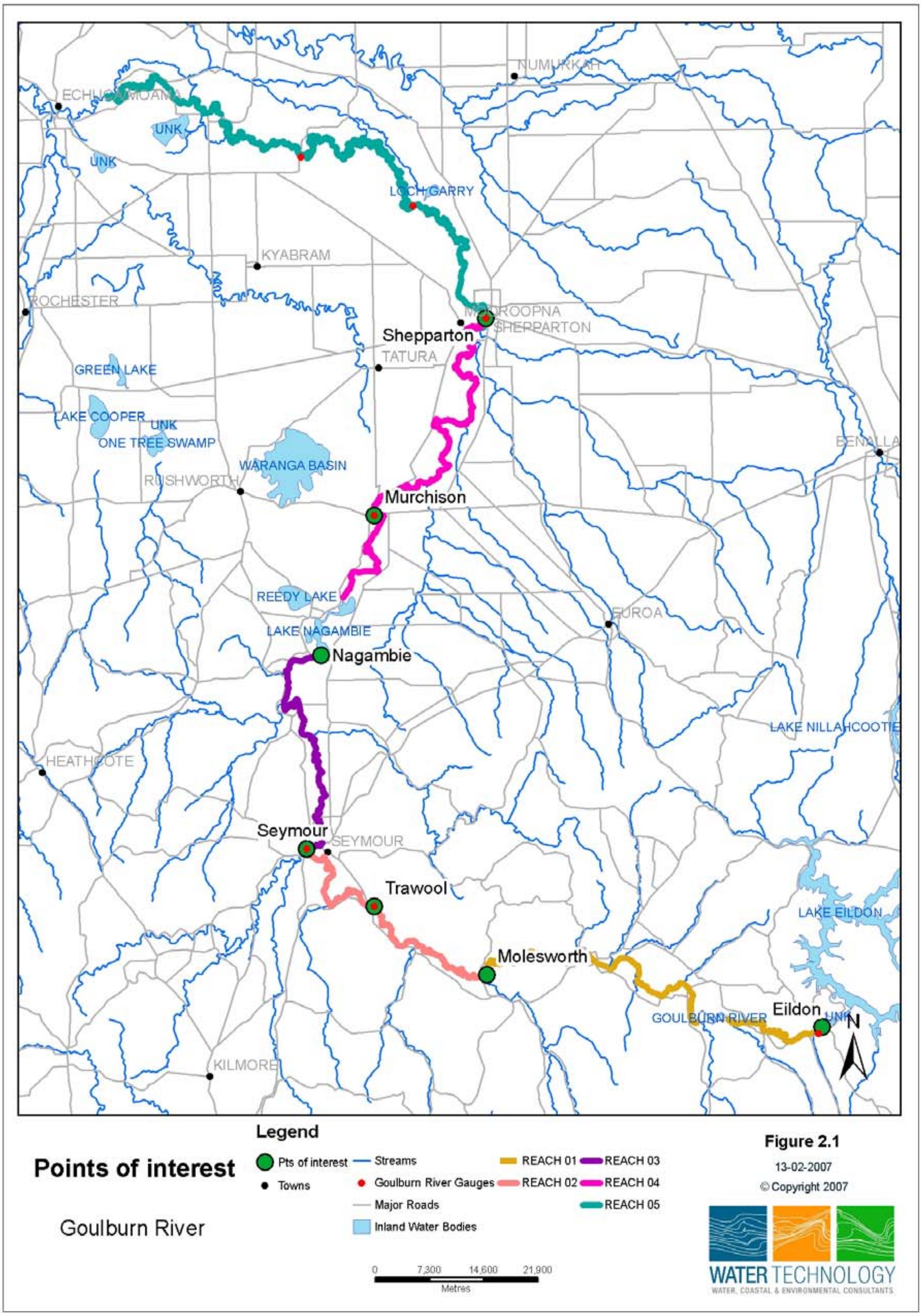

Figure 1 – Study area

The study consisted of the following tasks:

1. Data collation and review – Collate and review of the available topographic and streamflow data information.
2. Topographic data gap identification – Identify the gaps in the available topographic data, and suggest potential mediation options.
3. Asset mapping – Locate and map known public and private assets along the Goulburn River and adjacent surrounds.
4. Hydrologic analysis – Investigate relative contribution from downstream tributaries, and assess design flood hydrographs for the Goulburn River catchment.
5. Hydraulic analysis and flow behaviour – Assess flow behaviour of the Goulburn River over a range of potential environmental flows, and large flood events for floodplain management purposes (discussed in a separate report).
6. Socioeconomic assessment – Evaluate the social and economic costs of potential Goulburn River environmental flows.
7. Real time flow management – Review and scope real time flow management framework.
8. Management option assessment – Scope feasibility of management options for environmental flow releases.

To improve environmental flows on the Goulburn River floodplain, it is important to understand what areas of the floodplain are inundated at different levels of river flow in different reaches of the river. This requires the development, calibration and use of hydraulic models to determine these relationships. The models in turn need topographic data to describe the shape of the river channel and floodplain. The first two and the fifth tasks are directed to this outcome.

The location of environmental assets (wetlands and flood-dependent trees) on the floodplain then determines what environmental benefits can be achieved for different levels of river flow. However, there is also substantial human development on and use of the Goulburn River floodplain, where flooding could have negative impacts. The third task aims to identify the location of natural and human assets on the floodplain, so that the positive and negative effects of inundation for each level of flow can be determined.

In managing environmental flow releases, the uncontrolled tributaries downstream of Lake Eildon provide the opportunity to increase floodplain inundation for greater environmental benefit and a risk of increasing economic damage if flows are greater than planned. Task 4 aims to provide some understanding of the behaviour of the tributaries and their relationship to flows in the Goulburn River, and Task 7 aims to explore the ability to predict and manage around these tributary flows.

Task 6 aims to determine the economic impact of inundation on human uses of the floodplain. This allows exploration of the relative benefits of tradeoffs between environmental health and economic development.

The final task (Task 8) was intended to look at opportunities to improve environmental watering or limit economic damage by local works such as regulators and levees, rather than increase or decrease river flows. However, this task was not completed as part of the study, as increased progress on other tasks was deemed to be of more value to the study at this stage.

Releases of water from Eildon Dam to the River Murray to provide environmental benefits along the River Murray can be timed to coincide with Goulburn River floodplain environmental needs, or can be timed to be independent of those needs (in which case flows will be limited by keeping water off the floodplain). The tasks above inform this understanding.

This executive summary is built on the following project task reports

- Topographic Data Review July 2008 (prepared by Water Technology)
- Hydrologic analysis – Streamflow data assessment and tributary inflow analysis April 2010 (prepared by Water Technology)
- Hydraulic model construction and calibration (Environmental Flow – One dimensional & linked hydraulic models) April 2010 (prepared by Water Technology)
- Hydraulic model construction and calibration (Floodplain management – Two-dimensional hydraulic model) April 2010 (prepared by Water Technology)
- Asset Mapping – Data collation and review September 2009 (prepared by Water Technology)
- Hydraulic model application and affected asset assessment – Environmental flow scenarios April 2010 (prepared by Water Technology)
- Hydraulic model application – Floodplain management scenarios April 2010 (prepared by Water Technology)
- Potential flood damage assessment – April 2010 (prepared by URS)
- Real time flow management framework scoping – April 2010 (prepared by Water Technology)

The study was overseen by a technical steering committee consisting of:

- Geoff Earl, Guy Tierney and Simon Casanelia (Goulburn Broken CMA)
- Michael Jensz (DSE)
- Ian Burns (MDBA)
- Graeme Hannan/Bill Viney (G-MW)
- Robert Smalley (BoM)
- QJ Wang/David Robertson (CSIRO)

Further local input were obtained through the community reference group. This group consisted of landholders from along the study area.

Water Technology and URS wish to thank the steering committee and community reference group for invaluable guidance and input throughout the course of the study

The key recommendations for each study tasks are highlighted in bold italics throughout this executive summary.

Topographic data review (Tasks 1 & 2)

A review of the available topographic data was undertaken to assess its use in the hydraulic modelling of the Goulburn River below Lake Eildon.

Sources of topographic data collated included:

- Remote sensed topographic data
- Field surveyed topographic data

The base topographic data for the study area was sourced from Airborne Laser Scanning (ALS) undertaken by the Goulburn Broken CMA. This ALS data has a vertical accuracy of +/- 0.10 m at 1 standard deviation along the Goulburn River floodplain from Eildon to Bunbartha. The data was captured in March 2007. The ALS data is available as a 2 m and 10 m grid. The available ALS data set for the lower Goulburn River floodplain was captured in 2001, and extents the above coverage to the Murray River confluence. This Lower Goulburn ALS data has a vertical accuracy of +/- 0.15 m at 1 standard deviation

In addition to the ALS data, field surveyed waterway cross sections and bathymetry data are available from the following sources and at the following locations:

- State Rivers and Water Supply Commission : Seymour (15 Cross-sections), Shepparton (58 Cross-sections) and Lower Goulburn (54 Cross-sections)
- Goulburn River Environmental Flow Study (Cottingham et al 2003): Waterway cross sections were taken for 5 reaches. These sets consist of 16-18 cross sections at a separation of 200 m.
- Melbourne Water - North-South Pipeline Project investigations: Bathymetric survey of the Goulburn River at Killingworth
- Goulburn Murray Water – Lake Nagambie: Bathymetric survey of Lake Nagambie.
- Goulburn Broken CMA – Goulburn Weir to Murray confluence: Bathymetric survey of Goulburn River: Goulburn Weir to Murray confluence.

The review yielded the following conclusions:

- ALS data set provides a good representation of the waterway geometry above the water level at the time of the data capture, when compared to the available field surveyed cross sections.
- Field surveyed cross sections/ bathymetry is limited to several short reaches of the Goulburn River upstream of Lake Nagambie.
- Available field survey indicates significant variation in the bed level of the Goulburn River, over the available surveyed reaches.
- The use of ALS data set in the hydraulic modelling, without bed levels below the water, will overestimate water levels for a given flow. This overestimation ranges up to 2 m, with a median value of around 0.5 m for the available surveyed reaches. This is variable within short reaches and between reaches.
- The capture of additional bathymetric data, upstream of Lake Nagambie, removes an element of uncertainty regarding the waterway bed geometry and underpins a consistent bathymetric data source along the entire study area.
- The use of a uniform assumption for ALS data bed levels, upstream of Lake Nagambie, is likely to yield a good comparison of modelled and observed flow and water levels at gauges.
- The predictive capability of the 1D hydraulic model, in between the gauges, is unable to be formally evaluated, due to the absence of observed stages at immediate locations.

Further discussion regarding the impact of the available topographic/bathymetric data on the hydraulic model application, and the collection of additional bathymetric data is provided with the Hydraulic model construction and calibration (Task 5).

Asset Mapping – Data Collation and Review (Task 3)

For this study, spatial layers describing wetland features, native vegetation, land use classes, and built assets along the river were required. In all, the best and most appropriate datasets available have been acquired, or created to describe these features.

Wetlands

The existing DSE wetlands and native vegetation layer were found to be a poor locator for wetlands. An alternative approach was adopted for the identification of wetland location and extent.

The approach utilised the hydraulic modelling to locate depression on the floodplain that retained water following floodplain inundation. This was relatively accurate in locating significant wetlands, although did not locate other obvious wetland areas. ***This data set was considered adequate for initial scoping of the wetland inundation from different flooding scenarios. However, further investigation to the identification of wetlands is required.***

Native Vegetation

The existing DSE "highly likely native vegetation – woody" layer was adopted as the indictor for the location and extent of native vegetation.

Land use

The DPI and DNRE land use layers were considered reasonably accurate and provided sufficient detail to yield overall statistics on areas of different land use affected. Dryland and irrigated pastures, in particular, appear to be interchangeable, which may reflect the difficulty in identification, or in changing landuse patterns in response to recent drought conditions.

Built assets

The CFA building layer was found to be unsuitable for the location of buildings. Many buildings were found by comparison to aerial photography to be missing, and/or wrongly located.

The VICMAP layer IN_BUILDING_POINT layer was adopted for the study area. All buildings which fell within 100m of the 60,000 ML/day scenario were manually checked, and added if missing, using the aerial photography to determine their locations. Buildings were broken down into two classifications, 'house' and 'other'.

Roads and bridges

Roads and bridges were defined using the Vicmap layer, 'TR_ROADS'. This layer contained detailed attribute data which classified the roads into 11 different categories, and further distinguished sealed from unsealed roads, and also included bridges. No changes were made to this dataset as it's spatial accuracy was considered good.

Overall

Asset mapping data sets assembled were considered to be reasonable for the initial scoping work being undertaken in this study. The further investigations into improvements in spatial accuracy are strongly recommended. The identification of wetlands on the floodplain particularly needs substantial attention in the future, given it is one of the prime targets of environmental flooding.

Hydrologic analysis - Streamflow data assessment and Tributary inflow analysis (Task 2 & 4)

Streamflow data quantity and quality

The Goulburn River and major tributaries have good availability of streamflow data, with instantaneous streamflow data available for generally about 30 years. Mean daily flows records were generally available for a longer period. Several long term gauges on the Goulburn River have over 80 years of record. There were 18 streamflow gauges identified for use in this analysis.

Despite of this number of streamflow gauges, a large portion of the tributary catchment area is ungauged (over 50% of the tributary catchment between Eildon and Trawool and between the Seymour and Murchison). Data from existing stream gauging stations may not be sufficient to support all the requirements for operational management of environmental flow releases.

Except for the stations on the Home Creek and Major Creek rated as “fair to good”, and the station on Seven Creeks rated as “poor” in relation to high flows, the records of daily and continuous streamflow data have been judged to be “good”.

General statistics

The portion of the flow at Trawool added by the tributaries is considerably higher for the expected environmental flow release season (July – November) than for the rest of the year. On an annual basis Lake Eildon contributes 60% of the flow at Trawool but during the July to November period there is only a contribution of 44%. This observation confirms that the July to November period offers significant opportunities to enhance environmental releases from Eildon with flow contributions from the tributaries.

The seasonal pattern of flows varies considerably along the Goulburn River. At Eildon it is mainly determined by releases from the storage in response to irrigation demands and Eildon flood releases, and the gauge below Lake Eildon shows the highest mean daily flow (MDF) and mean maximum flow (MMF) in October. The seasonal flow pattern of the unregulated tributaries is determined by heavy rainfalls and runoffs that tend to occur predominantly in late winter and early spring. All the tributaries (except Major Creek and Broken River) thus have their highest MDF and MMF in August or September. The gauges on the middle and lower Goulburn River reflect a combination of these upstream influences, with the highest MDF and MMF occurring in September.

The results of the monthly analysis indicate that, in a typical environmental release season, the highest tributary inflows are likely to occur in the first half of the season, about two months earlier than the highest Eildon releases to irrigation demands. However, there is still a good chance of significant tributary flows in October when Eildon flood releases may occur.

Flow hydrographs

The flow hydrographs during the environmental release season show distinct differences between ‘dry’, ‘wet’ and ‘significant flood’ years. The controlled flood releases from Eildon in some seasons also have a distinct influence on the flow hydrographs at various sites along the Goulburn River. In dry seasons, releases from Eildon play a dominant role, while in wet and flood seasons the influences of tributary inflows and flood releases from Eildon predominate.

The analysis of the hydrographs for three flood events provided some information on typical flood travel times and flood hydrograph shapes. As the flood hydrograph moves from the upper tributaries down the river, its base broadens (typically from 2 to 3 days in the tributaries for moderate events to several weeks in the lower Goulburn for larger events), and the peak flattens out.

Examination of flow hydrographs suggests that a significant contribution to the flow at Trawool is sourced from the ungauged catchment between Eildon and Trawool. It appears that approximately 50 % of the flow at Trawool is from ungauged catchment areas during the early stages of the flood event.

The relatively large contribution of the tributaries to the reach above Trawool means that these tributaries have the greatest potential for making a positive contribution to environmental flood events. The relatively flashy flood response of the tributaries in the middle reach means that these tributaries may pose a significant threat to creating or aggravating unintentional flood consequences in the reaches further downstream. ***Detailed hydrologic modelling will be required to provide a more quantitative assessment of these potential benefits and impacts***.

Flood frequency analyses

As reliable flood frequency analysis results are available from recent studies for the Goulburn River at Seymour, Murchison and Shepparton, additional flood frequency analyses within this study were undertaken for 12 key sites on tributary streams.

The results of these analyses are mainly intended as a frame of reference for the high flow spells analysis; further data checking and possible revision is recommended, if these results are to be used for other purposes.

Spell analysis

The analysis of spells above a given threshold flow in one of the tributaries (Acheron River) indicated that the mean and longest periods between high flow spells increased with increasing threshold flow. However, the number of high flow spells, the mean duration of spells and the longest spell duration all decreased with increased threshold. This indicates that for larger tributary flow events there are significantly less opportunities for environmental releases being enhanced by tributary inflows.

Flow concurrence

The upper tributary catchments (Yea, Acheron and Rubicon) show some correlation for frequent flood events (up to 2-year ARI), with limited correlation for larger flood events. A similar pattern was found for the mid-catchment tributaries (Hughes, Sugarloaf, Sunday).

Further, mid catchment tributaries (Sunday and Sugarloaf Creeks) were generally affected by different storm rainfall patterns than those occurring over the upper tributary catchments (Yea, Acheron and Rubicon).

There is scope for more detailed flow concurrence investigations to assess the degree of correlation between flows in different parts of the system, to inform future planning for use of tributary flows.

Application of results

The analyses undertaken were of an exploratory nature, aimed at better understanding of the high flow behaviour of the Goulburn River tributaries and the interaction between flows in the tributaries and the Goulburn River itself. The relationships identified from the analyses are not considered sufficient to be directly applicable in operational decision making for environmental flow releases from Lake Eildon.

However, the findings will inform the development of a rainfall-runoff model to support operational decision making, in conjunction with real-time data and short-term forecasts of

rainfall data. Specifically, the results of the analyses have provided clear pointers to the desirable spatial resolution of the model and the associated rainfall inputs.

The results of the analyses reflect climate and system operating conditions experienced over the last 40 years. Modelling to support environmental flow release management will need to represent current operating rules for Eildon Dam under normal and flood release conditions, including specific modifications to these rules to enhance environmental flows.

Hydraulic model construction and calibration (Task 5)

Hydraulic model framework

A comparison of the environmental flow range and design peak flow estimates showed that the upper limit of the environmental flow range (60,000 ML/d) corresponded to approximately a 45 year ARI event downstream of Eildon reduces to about a 10 year ARI event at Trawool/Seymour, and a 8-9 year ARI event at Murchison. Further downstream at Shepparton, a 60,000 ML/d flows has ARI of 3-4 years. This variation in the ARI of a 60,000 ML/d flow highlighted the change in the hydraulic characteristics of the Goulburn River and floodplain throughout the study area. This change in hydraulic characteristics and the requirement to simulate the above flow regimes was reflected in the adopted hydraulic modelling framework.

The framework was required to simulate the flow behaviour over a full range of flows (in-channel to floodplain). Table 1 outlines the key elements of the hydraulic modelling framework.

Table 1 Model elements: purpose, calibration and application

Model elements	Purpose	Calibration	Application
One –dimensional (1D) model	In channel flows (up to 15,000 ML/d) Manning's n assessment Invert lowering evaluation	Stage-discharge (rating) curve	Building block for linked 1D-2D model
Two dimensional (2D) model	Floodplain flow for large floods (> 20 year ARI)	Observed flood levels and extents from major flood events	Flood behaviour (flood levels and extents) for large events Flood mapping outputs from Trawool to Murray River confluence
Linked 1D-2D model	In-channel and floodplain flows (15,000 - 60,000 ML/d)	Observed flood levels and extents from major flood events upstream of Trawool Stage-discharge (rating) curve downstream of Trawool	Flood behaviour (flood levels and extents) for environmental flow events Flood mapping outputs from Eildon to Trawool

To facilitate hydraulic model construction and use, the study area was divided into eight reaches (refer to Figure 2). A 25 m 2D model grid was employed for the seven model reaches from Eildon to Bunbartha (Reaches A to G), and a 60 m grid was employed for the lower Goulburn (Bunbartha to the Murray River confluence. Reach H). This grid resolution for the lower Goulburn River (Reach H) was consistent with the Lower Goulburn Rehabilitation investigations (Water Technology and Sinclair Knight Merz 2005)

Discussion of the 1D and linked 1D-2D models calibrations follows. The discussion of the 2D model calibration is provided in a separate report on the floodplain management scenarios.

Hydraulic model calibration - 1D model

The 1D model calibration considered appropriate Manning's n values for the in channel flows. Due to the absence of bathymetric survey upstream of the Lake Nagambie, the 1D model calibration also assessed a range of uniform invert lowerings. The calibration showed that a 1.5 m lowering provided a reasonable agreement between observed and modelled water levels at the streamflow gauges, Trawool and Seymour. Further refinements were made to the hydraulic roughness values (Manning's n) in the linked 1D-2D model.

The reliability of hydraulic model water levels and flows were unable to be established at locations away from the gauges. The reasonable preservation of the rise and fall, and travel time supported the model's ability in routing flows along the reach, and reflected reasonable accounting for storage along the reach.

Recommendation: To improve the assessment of the 1D models' performance at locations other then at the streamflow gauges, the following actions are recommended:

- ***GBCMA establish a series of water levels gauges along the Goulburn River and on key anabranches in the upper reaches. These water levels gauges could monitored manually during medium to high flow events.***
- ***GBCMA consult with other agencies with an interest in flow quantity and quality of the Goulburn River, to co-ordinate monitoring activities.***

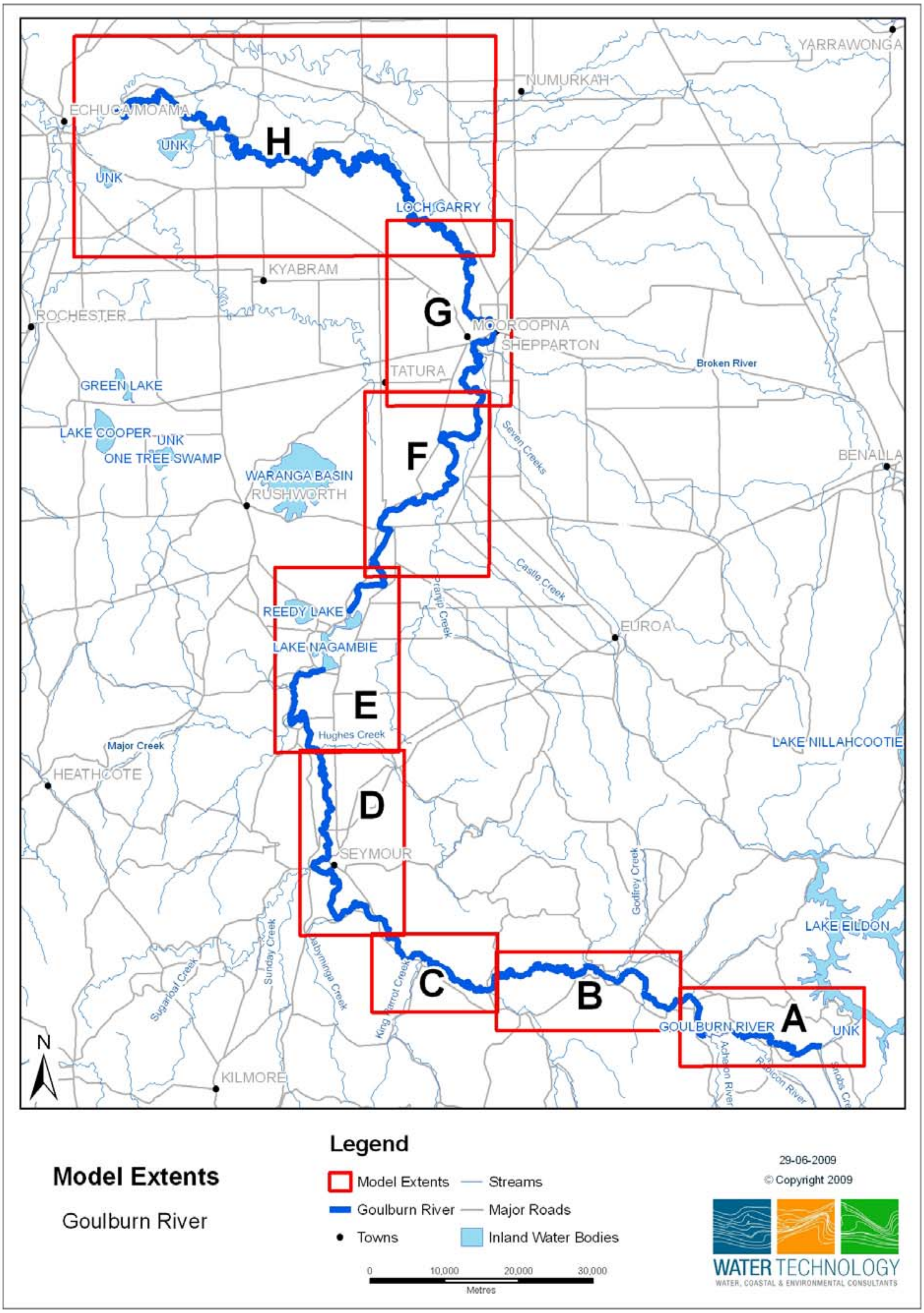

Figure 2 2D hydraulic model reaches

Hydraulic model calibration - Linked 1D-2D model

The linked 1D-2D models were calibrated to the October 1993 event, for the reach Eildon to Trawool (Reaches A, B & C), and to observed flow gaugings at Trawool, Seymour, Murchison, Shepparton and McCoy's Bridge.

Across the reach upstream of Trawool, 22 of 30 modelled flood levels lied within +/- 200 mm of the observed October 1993 flood levels. Given the uncertainty in model inflows from the tributaries, this calibration outcome was considered reasonable.

At the Trawool streamflow gauge, for flows from 15,000 to 28,000 ML/d, the modelled water levels were higher than the observed gaugings. Generally, the modelled water levels over this flow range were 200 – 400 mm above the gaugings. Over a flow range of 28,000 to 60,000 ML/d, the modelled and gauged water levels were found to be in good agreement (within 200 mm).

A similar pattern in modelled water levels was found at the Seymour streamflow gauge. For flows up to 32,000 ML/d, the modelled water levels were higher than gaugings by 200 – 400 mm. For higher flows, 32,000 ML/d to 60,000 ML/d, the modelled and gauged water levels were in good agreement (within 200 mm).

A Manning's n value of 0.042 was adopted for in-channel flows across the reach Eildon to Goulburn Weir.

The overestimation of water levels for flows up to ~30,000 ML/d may be in part due to the absence of bathymetric survey upstream of Lake Nagambie. As discussed, the waterway geometry below the water surface at the time of the ALS capture, was approximated by lowering the mid point of ALS data by a uniform 1.5 m. The comparison of the modelled and observed flow gaugings suggest that this approach has underestimated the waterway area, and lead to an overestimation of water levels for this range flow range.

The capture of bathymetric data for the reach upstream of Lake Nagambie may aid in the improvement of the linked models' performance for flows up to ~ 35,000 ML/d.

Recommendation: To assess the need whether bathymetric data is required for the reach the upstream of Lake Nagambie, the following actions are recommended:

- ***GBCMA to assess the importance of assets, both natural and built, affected for flows up to 35,000 ML/d.***
- ***GBCMA to scope the costs and deliverables from bathymetric survey the reach upstream of Lake Nagambie.***
- ***GBCMA to liaise with other relevant agencies to assess the potential uses of the bathymetric data in other project and activities.***

Similar to the 1D model calibration, the modelled rating curve showed a considerable discrepancy from the gaugings at Murchison. 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.

Recommendation: To improve the linked 1D-2D model's performance for the reach adjacent to Murchison, it is recommended that the GBCMA to consider further hydraulic analysis of the reach to assess, in detail, the influences of flow behaviour

At the Shepparton streamflow gauge, 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 the McCoy's Bridge streamflow gauge, 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.

A Manning's n value of 0.07 was adopted for in-channel flows across the reach Goulburn Weir to Murray river confluence. This adopted value differed from the 0.05 value assessed in the 1D model calibration.

The reliability of the linked 1D-2D hydraulic models' water levels and flows were unable to be established at locations where no or limited observed flood level data was available.

Recommendation: To verify the linked 1D-2D models' performance at locations with no ready available historical flood level data, it is recommended that the GBCMA undertake consultation with relevant local landholders or collect further water level data during flood events, if required.

Hydraulic model application – eflow scenarios (Task 5)

Overview

For the range of environmental flows, the purpose of the project was to provide preliminary understanding of the flood/flow characteristics of the Goulburn floodplain. Key questions were:

- How does water flow onto the Goulburn floodplain?
- What environmental and economic/social assets are inundated at different river flows (at different points along the river)?
- What is a 'safe' maximum flow rate for environmental flows being sent to the River Murray, and how does this vary along the river?
- What losses occur at different flow rates?
- What are the travel times for different flows along the Goulburn River?
- What attenuation occurs as water flows along the river?

This project provided an initial exploration of the above questions, and informed future directions of investigations.

Cottingham et al. (2003) discussed a floodplain wetland inundation regime between 15,000 – 60,000 ML/d. This regime has informed the range of environmental flow events considered by this study. For this initial exploration, a series of preliminary model application runs been have undertaken based on releases from Lake Eildon and no tributary flows. The peak flows considered included 20,000 ML/d, 30,000 ML/d, 40,000 ML/d, 50,000 ML/d and 60,000 ML/d. For each of these peak flows, the flow hydrograph was constructed to increase at the maximum rate of rise allowed, then held at the peak steady at the maximum 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.

The inundation characteristics assessed are discussed below.

Floodplain area and storage

The reach, Eildon to Alexandra (Reach A), Ghin Ghin to Kerrisdale (Reach C), Kerrisdale to Mitchellstown (Reach D), and Mitchellstown to Wahring (Reach E), displays a relative uniform increase in floodplain area inundated and storage with increasing flows. This reflects the absence of significant topographic thresholds on the floodplain.

The reach, Alexandra to Ghin Ghin (Reach B), displayed a step change in maximum floodplain area and storage inundated between 30,000 ML/d to 40,000 ML/d. A significant step change in floodplain area inundated and floodplain storage occurs for the lower reaches, Wahring to Kialla (F) and Kialla to Bunbartha (G), 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.

The reach Bunbartha to Murray River (H) has a significant 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.

The reaches, Ghin Ghin to Kerrisdale (C) and Mitchellstown to Wahring (E), have relatively smaller maximum floodplain area than other reaches. This in part reflects the confined nature of the floodplain and these reaches. Further, it should be noted that the Ghin Ghin to Kerrisdale reach (C) was the shortest model reach.

Affected buildings

The location and nature of buildings were identified using the VICMAP layer IN_BUILDING_POINT layer and reconciled against the aerial photography. The buildings were grouped into the following two categories:

- Residential
- Other (out buildings, hay shed, machinery shed etc)

Inundation of buildings is likely to cause significant inconvenience and possible economic loss (damage) to affected landholders. This preliminary identification of affected buildings provided a broad overview of the absolute and relative number of buildings affected for the range of environmental flow scenarios. Figure 3 displays the number of affected residential buildings.

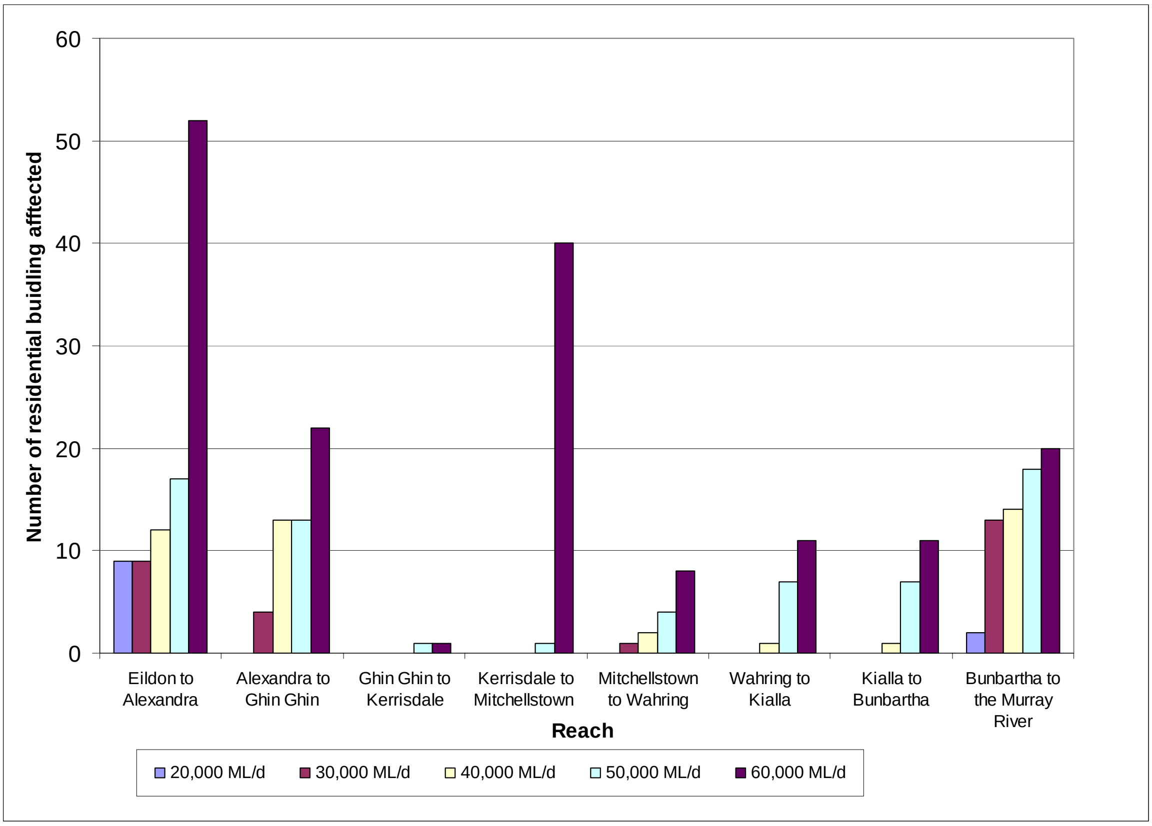

Figure 3 Environmental flow scenarios – Residential buildings affected

For upper reach, Eildon to Alexandra (A), nine residential buildings were affected for the 20,000 and 30,000 ML/d scenarios. The affected residential buildings increased to 17 for the 50,000 ML/d event. There was step increase to 52 affected residential buildings for the 60,000 ML/d scenario. This step increase reflected the flood affected residential buildings in Thornton.

No residential buildings are affected for the 20,000 ML/d scenario in the reach, Alexandra to Ghin Ghin (B). Four residential buildings affected for the 30,000 ML/d scenario, and increasing to 22 residential buildings in the 60,000 ML/d scenario. Affected residential buildings were isolated rural residential buildings outside Alexandra.

In reach Ghin Ghin to Kerrisdale (C), no residential buildings were affected for the 20,000 ML/d to 40,000 ML/d scenarios. A single residential building was affected for the 50,000 and 60,000 ML/d scenarios.

A step change in the affected residential buildings occurred in the reach Kerrisdale to Mitchellstown (D), for the 60,000 ML/d event. This reflected the inundation of residential buildings on fringe areas of Seymour.

The reaches, Mitchellstown to Wahring (E), Wahring to Kialla (F), Kialla to Bunbartha (G), have no residential buildings affected for the 20,000 ML/d event. A steady increase from one to eight affected residential buildings occurred for the reach Mitchellstown to Wahring (E). The reaches, Wahring to Kialla (F) and Kialla to Bunbartha (G), showed a step increase between the 40,000 ML/d and 50,000 ML/d flow events.

For the lower reach, Bunbartha to the Murray River confluence (H), there was a step increase from two residential buildings to 13 residential buildings between the 20,000 and 30,000 ML/d events. This was then followed by a steady increase to 20 affected residential buildings for the 60,000 ML/d.

This impact flagged the need for further local investigation of the flood impacts adjacent to the affected buildings, particularly in the Eildon to Alexandra, Alexandra to Ghin Ghin, and the Bubartha to Murray River reaches where residential buildings were affected under the lower river flow scenarios.

Affected roads and bridges

The location and nature of roads and bridges were identified using the VICMAP (TR_ROAD) layers. For the purposes of the damage assessment, the roads were grouped into the following two categories:

- Highway/Freeway (sealed)
- Arterial (sealed)
- Sub-arterial (sealed)
- Local (sealed and unsealed)

The length of sealed road affected for each flow scenario was considerably less than the unsealed road lengths. In case of the 20,000 ML/d event, the total affected sealed road length is 3.3 km compared to an unsealed road length of 106.5 km, and similarly for the 60,000ML/d event where the affected sealed road length was 35.3 km compared with an unsealed road length of 723.8 km.

The upper reach, Eildon to Alexandra (A), displayed a relatively higher affected length of sealed road in comparison to the upper - middle reaches (Alexandra to Kialla) (B,C,D,E &F) . The affected length of sealed roads for the upper reach, Eildon to Alexandra (A), was similar to the lower reaches, Kialla to the Murray River confluence (G & H).

The upper and middle reaches (Eildon to Wahring) (A to E) displayed lower length of affected road length (up to 30 km). However, there was a marked increase in the affected unsealed road length in the lower reaches (Wahring to the Murray River confluence) (F to H). In particular, there was a significant increase for the reaches Kialla to Bunbartha and Bunbartha to the Murray River confluence (G &H). For these two lower reaches, there was a step change in the affected unsealed road length between the 20,000 and 30,000 ML/d events.

A further investigation of the local and regional importance of these affected roads and bridges is required (e.g. access cut to medical facilities etc).

Affected land use categories

A variety of agricultural activities are undertaken on the floodplain of Goulburn River along the study reach. For the purposes of the damage assessment, the DPI land use classes were grouped into the following eight categories:

- Dryland Pasture
- Dryland Broadacre Crops
- Irrigated pasture
- Other Fruit
- Forestry
- Grapes
- Vegetables
- Intensive agriculture

Figure 4 displays the affected areas in the above land use groupings for the environmental scenarios across the entire study area.

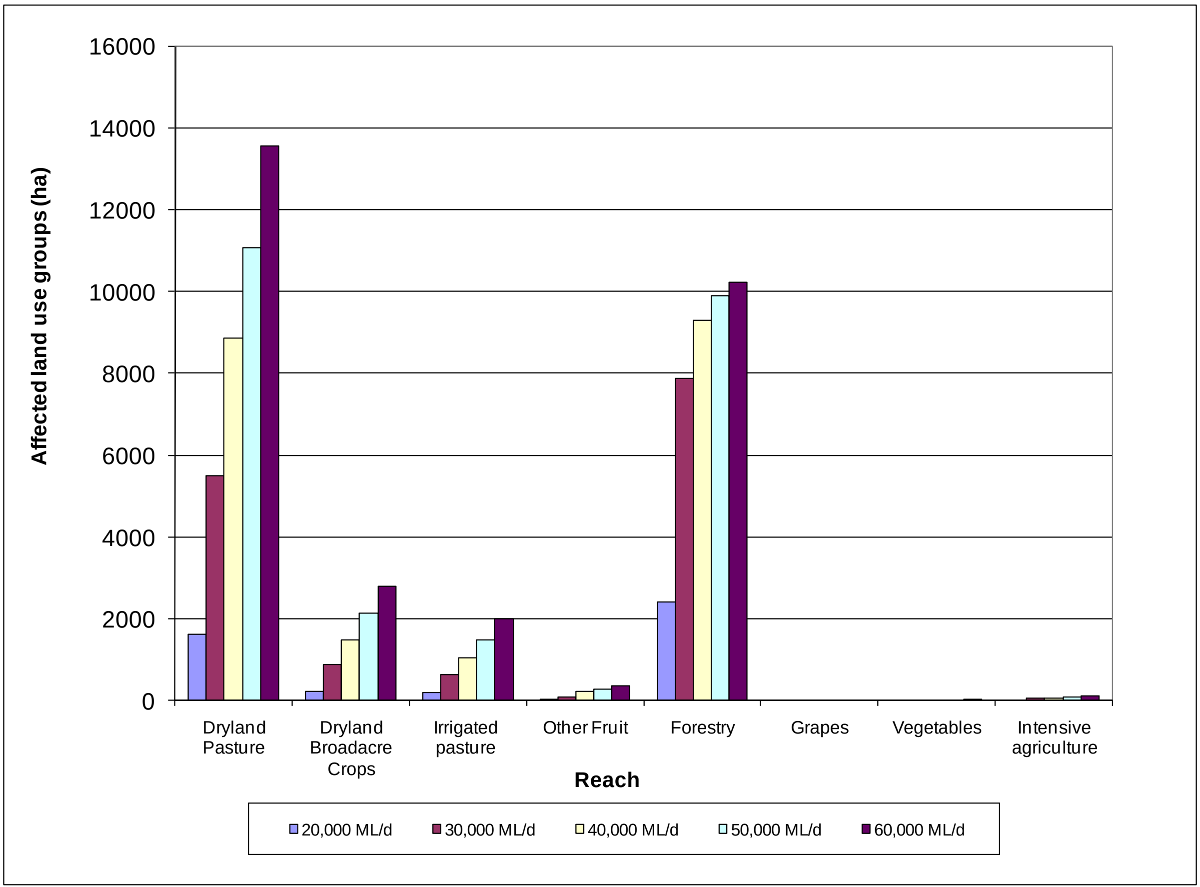

Figure 4 Environmental flow scenario – Affected land use – Entire study reach

As seen in Figure 4, the land use groupings, dryland pasture and forestry have the significant largest areas affected than the other groupings. Dryland broad acre cropping and irrigated pasture have similar total affected areas. The remaining land use groupings, other fruit, grapes, vegetables and intensive agriculture have relative small affected areas. However, these activities have a higher unit values.

The values of the potential damages for each land use grouping are detailed below in the Potential Flood Damages Assessment.

All land use groupings, except for forestry, displayed a relative uniform increase in affected area with flow magnitude. For forestry, there was a step change in affected areas between 20,000 ML/d and 30,000 ML/d. Flooding of forestry assets is likely to be beneficial to growth rates.

Inundated wetlands and terrestrial vegetation

Across the study reach, the 20,000 ML/d event affected about 26% of the identified wetland areas. There was a step increase to 70 % for the 30,000 ML/d flow event, then to 90 % and 96% for the event 40,000 and 50,000 ML/d flow events respectively.

The upper reaches, Eildon to Alexandra and Alexandra to Ghin Ghin (A&B), displayed a step change in the percentage of the inundated wetland areas between 30,000 and 40,000 ML/d. However, for the reach Ghin Ghin to Kerrisdale, the step change occured between 20,000 ML/d and 30,000 ML/d.

Over 50% of the wetland areas were inundated for the 20,000 ML/d flow in the reach Mitchellstown to Wahring (E). This contrasted with only 3% of the wetland areas inundated for the 20,000 ML/d flow in the reach Wahring to Kialla (F). There was a step increase to 62% for the 30,000 ML/d in the reach Wahring to Kialla (F).

For the lower reach, Kialla to Bunbartha (G), 28% of wetland area was inundated for a flow of 20,000 ML/d, with a marked step increase to 97 % for the 30,000 ML/d. This reflected the partial inundation of the adjacent riparian corridor under a flow of 30,000 ML/d, compared to limited inundation for the 20,000 ML/d flow.

Similar trends were observed for the inundated terrestrial native vegetation as for the wetland areas. Across the study reach, the 20,000 ML/d event affected about 24% of the identified terrestrial native vegetation. There was a step increase to 69 % for the 30,000 ML/d flow event, then to 87 % and 95% for the event 40,000 and 50,000 ML/d flow events respectively.

Across the entire study reach, the lower reaches, Wahring to the Murray River confluence (F, G &H) contained considerably larger areas of inundated terrestrial native vegetation than the other reaches. In part, this reflected the presence of sizable riparian vegetation corridors in these reaches.

Other assets: quarries, caravan park and aquaculture interests

Several other assets were identified as having a high potential damages due to inundation. These assets included:

- Caravan parks and holiday villages
- Quarries
- Aquaculture

In total, 7 caravan parks/ holiday villages were identified along the study reach. This preliminary assessment found six of the seven parks were significantly affected for flows 30,000 ML/d and greater. ***This impact flags the need for further local investigation of the flood impacts adjacent to the parks.***

Three working quarries were identified within the study reach. One of the three quarries was found to be affected significantly for a 30,000 ML/d flow and greater, while the other two quarries were affected significantly for 40,000 ML/d flows and greater. ***This impact flagged the need for further local investigation of the flood impacts adjacent to the quarries.***

Two aqua-cultural enterprises (fish farms) were identified within the study reach. One of the two was found to be affected significantly for a 40,000 ML/d flow and greater, while the other was unaffected for flows up to 60,000 ML/d flows. ***This impact flagged the need for further local investigation of the flood impacts adjacent to the fish farms***

Potential flood damage assessment (Task 6)

The assessment has shown that the environmental releases will potentially result in significant damages to a range of asset types. The total estimated value of these damages range from $1.2 million for a 20,000 ML release, to $17.1 million for a 60,000 ML release. Approximately half of these damages occur in Reach A (Eildon to Alexander) and Reach H (Bunbartha to the Murray River). Reaches A and H, and B (Alexandra to Ghin Ghin) and G (Kialla to Bunbartha) incur over 80% of the total damages in each flow scenario. Reach C (Ghin Ghin to Kerrsidale) suffers the least damage, comprising only about 1 percent of total damages.

Damages generally increase steadily with increased flow, although Reach A damages increase quickly at 40,000 and 50,000 ML/day, and Reach D and F increase significantly at 50,000 ML/day.

Table 2 summaries the flood damages estimates by reach across the environmental flow scenarios.

Table 2 Flood damages summary by reach

Reach	Environmental release scenario				
	20,000 ML/d	**30,000 ML/d**	**40,000 ML/d**	**50,000 ML/d**	**60,000 ML/d**
Reach A	$ 581,472	$ 734,217	$ 1,265,132	$ 2,591,087	$ 4,463,008
Reach B	$ 91,831	$ 460,051	$ 1,232,807	$ 1,652,161	$ 2,400,225
Reach C	$ 20,443	$ 48,680	$ 107,057	$ 229,579	$ 283,485
Reach D	$ 46,994	$ 183,716	$ 315,911	$ 742,133	$ 1,275,850
Reach E	$ 49,226	$ 219,006	$ 424,317	$ 742,096	$ 976,073
Reach F	$ 17,725	$ 114,950	$ 273,217	$ 675,876	$ 994,913
Reach G	$ 95,720	$ 406,048	$ 785,104	$ 1,626,148	$ 1,955,575
Reach H	$ 293,091	$ 1,607,744	$ 2,012,856	$ 3,669,523	$ 4,820,995
Total	**$ 1,196,503**	**$ 3,774,413**	**$ 6,416,401**	**$ 11,928,603**	**$ 17,170,125**

Buildings generally make up more than 50% of total damages, with roads and agriculture about 25%, and bridges only a few percent. The assumption of increased damages per km for roads at 50,000 and 60,000 ML/day makes them the largest source of damage under these scenarios.

The majority of building damage was from residential buildings for most environmental flow scenarios. The majority of the road damage was from major highway inundation in Reaches A, B, D, and G (and significant in H) under all flow scenarios. While pasture was the majority of the agricultural area inundated, high value fruits and vegetables provided the majority of damages in Reaches E (Mitchellstown to Wahring) and F (Wahring to Kialla), and significant damage in Reaches A (Eildon to Alexander), D (Kerrisdale to Mitchellstown) and G (Kialla to Bunbartha).

Table 3 summaries the flood damages estimates by asset type across the environmental flow scenarios.

Table 3 Flood damages summary by asset type

Asset type	Environmental release scenario				
	20,000 ML/d	**30,000 ML/d**	**40,000 ML/d**	**50,000 ML/d**	**60,000 ML/d**
Buildings	$ 558,187	$1,749,657	$ 2,784,127	$ 3,950,881	$ 6,476,433
Roads	$ 318,698	$ 939,915	$ 1,788,387	$ 4,979,544	$ 6,927,295
Bridges	$ 52,753	$ 111,495	$ 138,026	$ 669,422	$ 759,979
Agriculture	$ 266,866	$ 973,346	$ 1,705,861	$ 2,328,757	$ 3,006,418
Total	**$1,196,503**	**$3,774,413**	**$ 6,416,401**	**$11,928,603**	**$ 17,170,125**

The estimate of significant damage at the lower river flows was unexpected as this level of flooding already occurs relatively frequently, particularly in Reaches G (Kialla to Bunbartha) and H (Bunbartha to the Murray River).

Sensitivity analyses of reduced depth of flooding and reduced duration of flooding have shown reductions in total damages of 10 to 20 percent for all flows. Flooding in October would substantially increase agricultural damages, but increase overall damages by 6 to 14%, with December flooding resulting in only a further 1 to 3% of total damage. Less warning time of impending high flows can increase total damages by 12 to 18%.

It was not possible to attain adequate information about potential impacts of floods on quarries and aquaculture, which would require a more detailed study of individual businesses. Preliminary findings indicate that these impacts could be significant and would justify such a study.

Real time flow management framework scoping (Task 7)

The purpose of this work is to determine the predictability of flow to aid release planning and operations.

The current real time flow management frameworks can be grouped as follows:

- Short term (Event based): Flow forecasting for short duration events (up to 7 days). Typically applied to flood forecasting
- Medium term (Seasonal based): Flow forecasting over a season (up to 3-6 months). Typically applied to water resource allocation planning.

Current short term (Event based) real time flow management

The Bureau of Meteorology (BoM), through the Victorian Regional Office, undertakes flood forecasting for the Goulburn and Broken River catchments. This forecasting service provides peak height/flow and time of peak for locations along the Goulburn River (downstream of Eildon) and major tributaries.

The forecasts utilise a URBS runoff routing model as the principal forecasting tool. A data collection network provides real time streamflow, water level and rainfall data. At this stage, there is limited use of forecasted rainfall fields to provide flow forecasts.

This current event based forecasting service is targeted at flow events likely to approach and/or exceed the minor flood class levels along the Goulburn River and/or tributaries.

The flow range of primary interest to this study is 20,000 to 60,000 ML/d. Above Goulburn Weir, the environmental release flow range lies in the operational range of the current flood forecasting service. Below Goulburn Weir, the lower limit of the flow range (20,000 ML/d) lies below the operational range of the current flood forecasting service. However, flow above about 30,000 ML/d lie within the operational range.

Current medium term (Seasonal based) flow management

The Bureau of Meteorology currently provides a range of seasonal forecast services. Generally these current services are focused on seasonal rainfall and temperature. The current seasonal forecasts are predominantly based on statistical relationships to factors such as the Southern Oscillation Index and Indian Ocean Dipole. Current services provide exceedance probabilities for various climatic variables such as temperature and rainfall.

Future short term forecasting directions

CSIRO, in conjunction with the BoM, are developing a short term streamflow forecasting framework, as part of the BoM's Water Division program. The aim of the framework is to provide continuous flow forecasts for the coming 7 to 10 days for water managers for reservoir release planning.

These directions are potentially very useful for environmental flow management as they could predict tributary flows and allow reservoir releases to be timed to avoid or add to tributary flows. The use of numerical weather prediction will provide more lead-time to plan environmental flow management using tributary flows. The move to continuous forecasts will improve the understanding of the likely hydrograph of those flows over time, and improve prediction accuracy at the start of the event. A key issue will be to understand the likely accuracy of predictions from the start to the end of the forecast period, and as the flow events unfold.

At the meeting on 5/6/09, both Jim Elliot (BoM) and QJ Wang (CSIRO) expressed a desire to pursue the Goulburn River catchment as a potential pilot catchment. The ready application to the real time management of environmental flow releases was seen as a favourable aspect.

Recommendation: To progress the desire expressed at the meeting, it is recommended that the GBCMA liaise closely with G-MW, BoM and CSIRO to develop a proposal (business case) for the consideration of the Goulburn River catchment as pilot study catchment, and to help develop the forecasting services of relevance to environmental flow management.

Future medium term forecasting

BoM and CSIRO are currently developing a 3 month streamflow forecasting service using refined statistical techniques. They are also looking at using dynamic weather modelling to provide more dynamic forecasts.

Seasonal flow forecasts would allow environmental managers to understand likely water availability (particularly in winter/spring) and so plan for major environmental releases.

Preliminary discussions exploring the scope of expanded seasonal forecast products have been undertaken with Goulburn–Murray Water and GBCMA.

Recommendation: To further progress the scoping of the potential seasonal forecast services, it is recommended that the GBCMA to liaise closely with G-MW, BoM and CSIRO to develop the indicative scope of services of relevance to management of environmental flows in the Goulburn River.

Overview and Future Directions

The study has aimed to provide information on following two questions:

(1) What is involved in providing environmental flows onto the Goulburn River floodplain;

(2) What flow rates can be released to provide environmental flows to the Murray River: and

To provide environmental flows onto the floodplain requires an understanding of what areas of the floodplain are inundated at what river flows in different reaches of the river. The hydraulic modelling has provided an initial assessment of the areas inundated by 5 different flows. The model calibration showed better river level prediction (+/- 200 mm) at streamflow gauging sites at higher flows. However, at lower flows (below 30,000 to 40,000 ML/day), the model over-predicts river height at Trawool and Seymour, and under-predicts river height at Murchison (up to 1 metre), Shepparton and McCoys Bridge. Some of this may be due to the assumptions of river bed shape under the river water level and possibly variable flow resistance along the river bed and banks. Data is not available to calibrate the model between gauging sites.

To provide better predictability of river height and inundation, it is recommended that further work be undertaken to understand the potential causes of model accuracy behaviour, particularly below Goulburn Weir. This may require further topographic data collection, particularly in the river bed. It is also recommended that additional data be collected to calibrate the model between gauging stations, to improve predictability of water level and inundation along the river. This should include continuous water level monitoring and floodplain inundation mapping.

The areas inundated by different river flows showed the characteristics of the floodplain, with floodplain inundation area increasing proportionally with river flow for 4 reaches. Alexandra to Ghin Ghin, Wahring to Kialla, Kialla to Bunbartha, and Bunbartha to the Murray River show only small increases in inundation between 40,000 and 60,000 ML/day river flows.

Water retained on the floodplain after flooding (loss of water resource) from Eildon to Bunbartha increased from 26,500 ML for 20,000 ML/day flows to 113,500 ML for 40,000 ML/day flows, to 139,300 ML for 60,000 ML/day flows. ***Seepage and evaporative losses have not been computed, and water retained on the floodplain between Bunbartha and the Murray River was not computed. Further work on these issues is required.***

To understand the benefits of environmental flooding, treed areas and wetland areas on the floodplain were mapped against areas inundated by different river flows. The available data on treed areas is reasonable, but wetland mapping is poor. A technique was used to identify significant pools of water left after flooding in the model for this study, but this technique doesn't map flood runners where water drains away. ***Substantial future work is required to better define all wetland areas, and particularly important wetlands.*** Modelling in this study shows that 70% of wetland and treed areas are inundated at 30,000 ML/day river flow and 90% at 40,000 ML/day river flow.

A range of built and economic assets were also mapped against areas inundated by different river flows. This work showed that significant residential buildings and roads were inundated under lower flow scenarios in the Eildon to Alexandra and Alexandra to Ghin Ghin reaches where the river channel is smaller. However, a surprisingly significant amount of residences and roads were inundated in the Kialla to Bunbartha and Bunbartha to the Murray River Reaches. Locations of these assets was reasonable but not precise, and small errors in location could make a significant difference in how many are inundated. Local levee banks may also be important in reducing inundation risk.

Inundation of agricultural land uses showed extensive areas of pasture and cropping were progressively inundated at increasing flow rates. Small areas of higher value grapes, fruit trees and vegetables are also inundated, even at the lowest flows.

Residences, roads and high value agriculture generate the majority of the economic losses from inundation. ***It is recommended that more accurate mapping of high value assets is required and potentially inspection of key assets (particularly fish farms and quarries) to better understand the risk of inundation. This is particularly important in the upstream 2 reaches (Reaches A & B) and the downstream 2 reaches (Reaches G &H).***

Initial indications from this study are that environmental flows of up to 40,000 ML/day (rather than the 60,000 ML/day recommended in the environmental flow study) may provide the majority of the environmental benefits with the least economic cost. However, as the river varies in flow capacity along its length, a lower flow may be appropriate in the upstream reaches, and a higher flow in the downstream reaches.

For environmental releases to the River Murray, the primary constraint would appear to be the first reach below Lake Eildon (Eildon to Alexandra) where flooding occurs at flows of less than 20,000 ML/day. Unless part of a Goulburn floodplain inundation event, the limit on releases will be less than 20,000 ML/day. An additional 7,000 ML/day can be provided by not harvesting catchment flows at Goulburn Weir into Waranga Basin.

The hydrology analysis showed that the tributaries downstream of Lake Eildon can contribute significant flows to the Goulburn River at relatively short notice and for short durations. This can increase inundation in the Goulburn River downstream of the tributaries when environmental releases are being made. This could produce undesirable inundation, or could be used to add to environmental releases to increase desirable inundation downstream of the Eildon to Alexandra reach. For small floods, Yea, Acheron and Rubicon Rivers act somewhat in concert and provide significant flows. The tributaries further downstream can also flow together, but are not related to the upstream tributaries. ***Further work is needed to better understand tributary flows and their predictability including ungauged inflows. The proposed Bureau of Meteorology work to provide short term flow forecasts will be particularly important to allow Eildon releases and tributaries flows to be managed together.***

Engineering management options also have a potential role to play, both to limit damage to key assets, and to enhance flooding of environmental assets. A key area to assess is the Bunbartha to Murray River reach, where a number of effluents move water away from the main river channel. Regulators on these effluents may allow river flow to be concentrated in the main river channel, or moved into particular effluents. ***Further consideration of these engineering management options is required.***