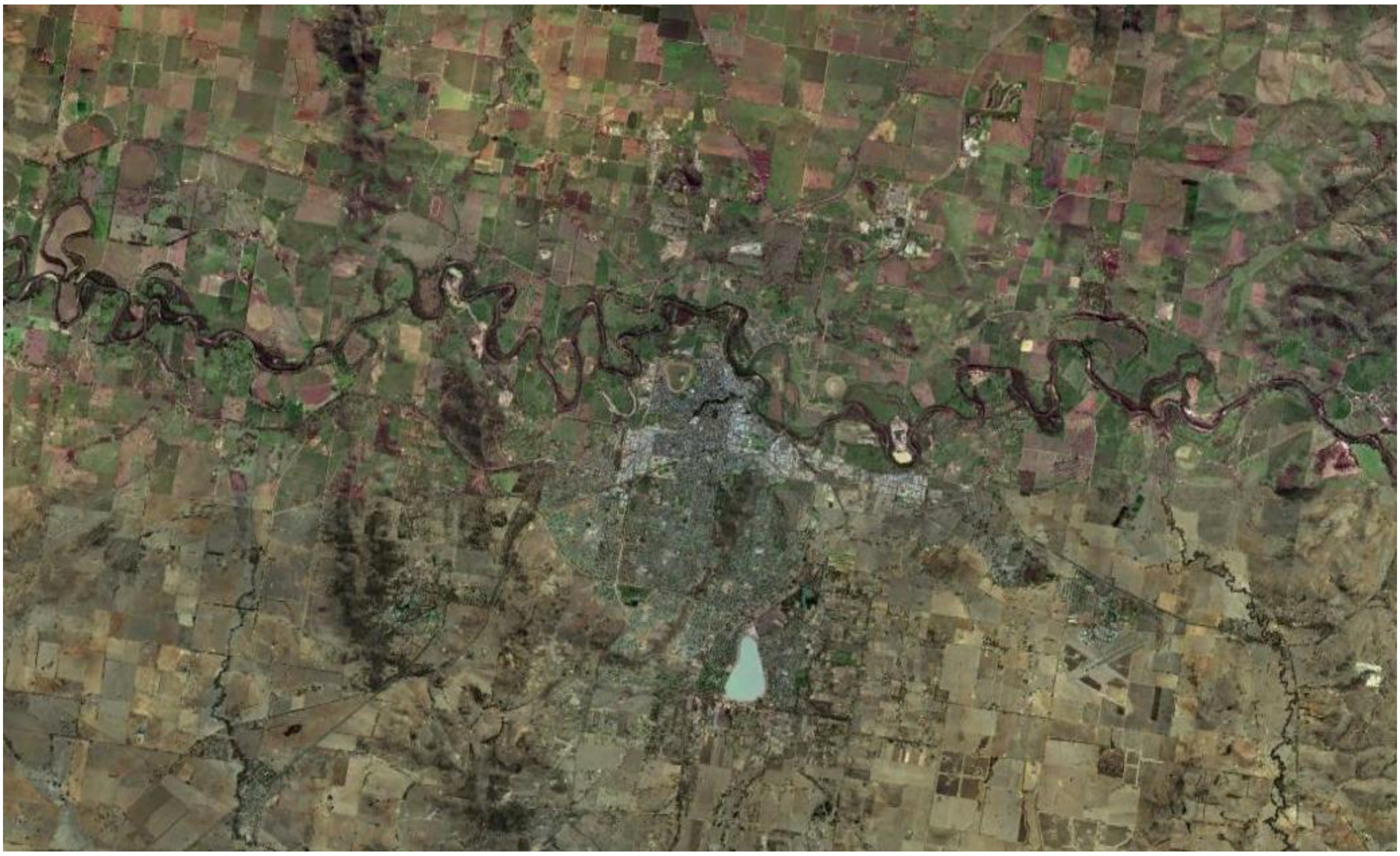
WAGGA WAGGA CITY COUNCIL

WAGGA WAGGA LOCAL GOVERNMENT AREA

MURRUMBIDGEE RIVER FLOOD MODELLING

FINAL REPORT



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Project Wagga Wagga LGA Modelling	**Project Number** 110075
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WAGGA WAGGA LGA MODELLING

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EXECUTIVE SUMMARY

Wagga Wagga City Council (Council) has appointed WMAwater to define design flood behaviour of the Murrumbidgee River in the entire Wagga Wagga Local Government Area (LGA). Whilst focussed on providing design flood information for the 1% AEP event specifically the study is not an official "flood study" undertaken under the NSW Floodplain Risk Management Program.

Previous Murrumbidgee River flood studies carried out by Council have focussed on specific areas. For example the 2010 study covering Braehour to upstream of Malebo Gap (WMAwater, 2010) and other work which has developed design flood levels between Oura and Braehour (WMAwater, 2011). Note that where such specific studies have previously been carried out Council will provide direction as to which study is to be consulted for design flood level information.

For this whole of LGA study, a 2D model of the Murrumbidgee River and surrounding floodplain has been built in the hydrodynamic modelling package TUFLOW. The model has a grid size of 40 m and has been calibrated to the 1974 event that had an Average Return Interval at Wagga of 70 years. The model has then been applied to modelling of the 1% AEP design event.

Calibration utilised a range of observed data from the 1974 flood event including gauged water levels, approximately 100 surveyed peak flood levels and peak flood extents. Model calibration has demonstrated a reasonable match with mean absolute error of 0.18 m and a standard deviation of 0.23 m. An indication of the models accuracy is that 95% of all points lie within the standard flood planning level freeboard of 500 mm (NSW, 2005).

The calibrated model was then used to generate the 1% AEP extent and flood levels. To further enhance confidence in the modelling undertaken 1% AEP results from the LGA extent model were compared to model results from the 2010 study (WMAwater, 2010) over the approximate modelled extent (i.e. Braehour to upstream of Malebo Gap). This comparison was favourable overall although, it did show that when flood planning levels are sought between Wagga Wagga and the Malebo Gap, that Council would be advised to use results from the current study in preference to results from the 2010 flood study as the current study more correctly models the significant flow control that is the Malebo Gap .

Overall the goal of the Study has been achieved with Council being provided with 1% AEP flood information for the entire Murrumbidgee River floodplain within the LGA. Whilst it is possible some areas of the model could be enhanced with further up-to-date data on in-bank conveyance characteristics the model does provide a large improvement in regards to the amount of information Council have to inform floodplain risk management within the LGA. For the future the following recommendations are made:

- Utilise the model to run the Probable Maximum Flood as its likely that the PMF work carried out as part of the 2010 study is underestimated due to Malebo Gap's constrictive impact on flows being underestimated;

- Merge current study 1% AEP flood extent and level information with that information developed as part of the 2010 study (WMAwater, 2010) for seamless inclusion in Councils flood planning software, or at the very least clearly demarcate locations at which various sources of design flood level information are applicable; and
- As and when possible Council could collect bathymetry data. For example previous work undertaken by the RTA on the Sturt Highway upgrade (west of Wagga) included River cross-section survey. Also, as part of an irrigation flow efficiency modelling project currently being undertaken for State Water survey of the entire River, presumably of the in-bank only, has been undertaken. Such information could aid refinement/improvement of modelling tools in the future and separately may aid Councils River management efforts.

1. INTRODUCTION

1.1. General

The Wagga Wagga Local Government Area (LGA) is located in the southern inland area of NSW. The study area (depicted in Figure 1) is surrounded by seven other LGAs, namely Coolamon and Junee to the north, Gundagai and Tumut to the east, Greater Hume and Lockhart to the south and Narrandera to the west. The Wagga Wagga LGA covers an area of approximately 4,886 km^2.

The Murrumbidgee River traverses the floodplain from east to west and is a major tributary to the Murray System draining some 100,000 km^2. The catchment area of the Murrumbidgee River at Wagga Wagga is approximately 26,400 km^2.

The majority of the floodplain is used for agricultural purposes. Most of the urban and industrial development is located in Central and North Wagga. Other industrial areas are located in the southern floodplain and east of Wagga Wagga along the Sturt Highway. Recent population growth has been mainly centred in the southern and elevated areas of Wagga Wagga. Other significant residential centres comprise Kooringal and Lake Albert.

The Wagga LGA is located at the converging point of two significantly different geographical types. Here the mountains of the Great Dividing Range flatten and form the Riverina Plain. A Digital Elevation Model (DEM) of the region shown in Figure 2 shows the contrast between the eastern end of the Wagga LGA and the flatter region to the west.

The model domain covers the Murrumbidgee River floodplain and this region is represented by the model extent shown in Figure 2. The modelled reach runs from slightly downstream of Wantabadgery which is located approximately 30 km east of Wagga Wagga (upstream) to downstream of Berembed Weir some 52 km to the west (downstream) of Wagga Wagga.

1.2. Background

The largest city within the Wagga LGA is the city of Wagga Wagga (situated on the south side of the Murrumbidgee River) although first settlement in the region was at what is now called North Wagga Wagga, situated in the northern floodplain. Numerous other towns are located in the LGA with a large number constructed on the floodplain including Oura, Yarragundry, Collingullie and Currawarna. In between these scattered towns lays predominately rural land with a mixture of both pastoral and cropping land uses. There are also pockets of natural vegetation and uncleared land throughout the LGA with many regions bordering the Murrumbidgee River and other smaller creeks dense with tree growth. Figure 3 shows the land use along the floodplain over the extent of the Wagga LGA.

Significant flood related structures that interact with floodplain flows include Wiradjuri, Gobbagombalin and Eunony bridges, with further structures up and downstream listed in later sections. Additionally, a number of levees have been constructed to protect the main city of Wagga Wagga, North Wagga and other small towns such as Gumly Gumly. The locations of bridges and levees within the Wagga LGA are shown in Figure 4.

1.3. Objectives

Council engaged WMAwater to develop a suitable 2D model, calibrated to the 1974 event, with the ultimate purpose of defining the 1% AEP flood extents and levels for Murrumbidgee River flooding over the entire LGA. Note that where design results overlap previous models results, particularly from the 2010 study (Reference 2), Council will need to be consulted as to which design flood information is to be used.

2. AVAILABLE DATA

This section details the data utilised in the model build process.

2.1. Previous Studies

For the purpose of this study large amounts of data have been acquired from two previous flood studies focusing on Murrumbidgee River floods at Wagga Wagga (Reference 1 & 2). The Murrumbidgee River Wagga Wagga Flood Study was completed in 2004 and used a 1D RUBICON model to determine design flood extents and levels (see section 2.1.1). In 2010 this study (Reference 2) was revised with the RUBICON model being converted into a 2D model and new design flood extents and levels were calculated (see section 2.1.2). Details of the data acquired from these studies is outlined in the following two sections.

2.1.1. Murrumbidgee River Wagga Wagga Flood Study, WMAwater, 2010 (Reference 1)

The main details provided by the 2004 study are exact details on how the floodplain, as surveyed by ALS in 2008, needs to be amended in order to satisfactorily recreate 1974 ground conditions. A concise summary of these are provided in Table 1 over the page. Also extracted from the report were flood marks around Wagga Wagga and Oura.

2.1.2. Wagga Wagga Murrumbidgee River Model Conversion Project, WMAwater, 2010 (Reference 2)

The following data was sourced from Reference 2:

- Wagga Wagga main city levee alignment and heights;
- North Wagga levee alignment and heights;
- Bridge locations and details;
- Calibrated roughness values with spatial distribution (albeit for the more limited model extent); and
- 1974 and 1% AEP inflow hydrographs.

Note that elements of the above listed information were also available from Reference 1.

2.2. Airborne Laser Survey

ALS data was recorded in 2008 by Fugro Spatial Systems Pty Ltd (Fugro) for the entire Murrumbidgee River floodplain from downstream of Burrinjuck Dam to the confluence of the River with the Murray. The data was collected on behalf of the then Department of Environment and Climate Change (now Office of Environment and Heritage) with the work managed by the Land and Property Management Authority (LPMA), who are also the custodians of the data.

The LPMA extracted data from the wider dataset for Council and this was then delivered to Council in May 2009. Details of this data are provided in Reference 2. Note that Fugro provided Council with a 1 m and 10 m raster for the study area. This was subsequently obtained by WMAwater in order to inform the topography of the 2D model. Figure 2 shows a map of the DEM.

Table 1: Historical changes to flood impacting structures in Wagga Wagga*

Date	Works on the Floodplain	Comment
Various	Narrung Street Sewage Treatment Ponds: • 1914 - The site was first developed as a sewage plant for the town of Wagga Wagga. • early 1950's - A formalised series of treatment ponds were constructed between the plant and the river. • 1967/1968 - The ponds were upgraded to a new configuration including construction of four ponds west of the Bomen rising main. • approx. 1977 - Three ponds west of the Bomen rising main were removed in order to reduce upstream flood levels. The bank around the emergency overflow pond (the remaining pond to the west) may have also been lowered at the same time. • mid 1990's - A floodway was partially constructed through the ponds. • 2007 to 2010 – Treatment Works reconstructured and use of ponds reduced substantially	Council is aware of the restriction caused by construction of the banks around the treatment ponds (Reference 4) and is currently addressing this issue including the associated environmental/public health issues.
1930s	Gobba weir and levee	(Upgrading to eastern end in late 1960's/early 70's)
1960	Main Town levee constructed on southern floodplain.	Limited the width of floodplain.
1975	Raising of East Street and Mill Street levee to 179.3 mAHD.	Up to 1 m high and 200 m long. This prevents floodwaters up to 9.3 m on the gauge (179.35 mAHD) from entering the northern floodway and cutting the Junee Road.
1975	Eunony Bridge was completed. In the August 1974 flood the bridge was only partially constructed with the approaches constructed by the time of the October 1975 flood.	
1975	The Gumly Gumly levee was temporarily raised to its present level following the August 1974 flood.	
1978-1983	The Main Town levee was upgraded to approximately 1 m above the 1974 flood level.	
1978	A private levee was constructed around the Allonville Motel and the access road to the Murray Cod Hatchery was raised.	
Late 1980's	The Sturt Highway was raised by up to 0.2 m.	
1990	Construction of the North Wagga Wagga levee to the 1 in 20 ARI +0.3m freeboard event	
1992	The Gumly Gumly levee was formalised to approximately the 1 in 10 ARI event.	
1995	Construction of Wiradjuri Bridge	Minor alterations to access road between Wiradjuri and Parken Pregan bridges
1997	Construction of Gobbagombalin Bridge	Changes to northern edge of floodplain from Gobba lagoon to Coolamon Road

* Table 1 initially appeared in Reference 1.

2.3. Calibration Data

Flood marks and other observations of the 1974 event were used in model calibration and these were obtained from a variety of sources. Available calibration data for the 1974 event are listed in the following sections.

2.3.1. Flood Extent

Council provided WMAwater with scans of a paper topographical map held in Council's offices that shows 1974 flood extent information (hand drawn). Office of Environment and Heritage (OEH) staff confirmed that the data is the same as that reported in the 1977 NSW Flood Atlas (NSW, 1977). This flood extent information was then digitised and geo-referenced so that it could most efficiently be utilised for calibration purposes. Note that copies of the scanned map (as *.pdf files) are included in the digital version of this report and with the CD that accompanies specific copies of this report.

2.3.2. Peak flood heights

The August 1974 flood event is well documented in terms of recorded flood levels. Flood marks were collected from a number of sources. Firstly some flood marks were available from work carried out in References 1 and 2, albeit limited to flood marks describing flooding within the previously modelled extents (Braehour to Malebo Gap and Oura to Braehour). Reference 1 indicates that this data was collected by both Council and the Department of Main Roads.

Further, the scans of paper copy maps referred to in the section above include handwritten notes of observed levels during this flood event. Note that accuracy estimates for these marks are not available and it's not known (but is presumed to be the case) that these flood level estimates are based on peak observations and are based on accurate survey methods. As will be demonstrated the accuracy of some of these points are suspect and its noted that inaccuracy could be attributed to one, or a combination of, several causes:

- Not an observation of peak behaviour (tend to apply to points overestimated by modelling only);
- Not an observation of Riverine flooding but instead tributary flooding instead (could be both under and over estimates); and
- Height accurate but marked location approximate only.

2.3.3. Stream gauging

Stream gauging data was utilised for calibration purposes in this study as well as being the base for the inflow hydrographs. The type of data and gauging stations sourced for this study are described below:

- **Hampden Bridge at Wagga Wagga (Gauge Station Number: 410001)**: Data from this gauge has been sourced from Reference 1. This data is comprised of the gauge rating curve prior to the 1974 flood event and stage levels (these curves can be seen in the calibration results, Figures 8 & 9). Note that the rating for this gauge is actually derived from observations taken approximately 2 km upstream at the Railway Line;

- **Murrumbidgee River at Eringoarrah (Gauge Station Number: 410143)**: The peak level during the 1974 flood was 10.38 m (196.19 mAHD) (personal communication with Council); and
- **Murrumbidgee River at Downstream Berembed Weir (Gauge Station Number: 410023)**: During the 1974 flood the gauge's recording range was exceeded failing to record the peak level (Reference 6).

3. MODEL BUILD

Given the objectives and requirements of the study and the availability of ALS data a 2D overland flow hydraulic model is the most suitable model to effectively assess flood behaviour. This is particularly the case for larger events which utilise the floodplain for a significant proportion of flow capacity.

3.1. Hydrology

Hydrology data utilised in the study has been sourced from Reference 2. This data includes hydrographs for the 1974 flood event and for the 1% AEP which are based on flood frequency analysis reported in Reference 1. These hydrographs were applied just upstream of Eringoarrah and can be seen in Figure 5. Note that the general approach utilised is the same as that employed and well documented in References 1 and 2.

Whilst the above detailed approach is an approximation of reality it does produce estimates of historical flood behaviour that match observed behaviour well. Potential issues associated with the method however include:

- Included in the upstream model input hydrograph at Eringoarrah are tributary contributions which are actually downstream of Eringoarrah (e.g. Kyeamba and Tarcutta Creek contributions); and
- The hydrograph shape as observed at Eringoarrah may be different (less routed) than that observed at Wagga Wagga.

Whilst both of the above issues are serious, neither of them is of critical importance. In the first instance tributary inputs to the peak of a large flood event are likely to be very small and so taking the model input hydrograph, which includes tributary inputs, upstream of tributary input locations is unlikely to result in significant error, particularly relative to freeboard of 0.5 m. Secondly whilst there is likely to be some attenuation of hydrograph shape between Eringoarrah and Wagga Wagga it's unlikely to be substantial. There would be more concern if for example, the hydrograph shape as gauged at Narrandera was applied to Eringoarrah, as downstream of Wagga Wagga the floodplain shape does change significantly and flow is significantly attenuated.

3.2. Hydraulics

In order to describe design flood behaviour in the Wagga Wagga LGA floodplain a 2D model (TUFLOW) was established for this purpose.

3.2.1. Introduction

TUFLOW is a 1D/2D hydraulic model used as the hydraulic model for the present study. The TUFLOW modelling package includes a finite difference numerical model for the solution of the depth averaged shallow water flow equations in two dimensions. The TUFLOW software is produced by BMT WBM (Reference 4) and has been widely used for a range of similar projects. The model is capable of dynamically simulating complex overland flow regimes. It is especially applicable to the hydraulic analysis of flooding in rural areas which is typically characterised by long duration events and a combination of supercritical and subcritical flow behaviour.

For the hydraulic analysis of overland flow paths, a two-dimensional (2D) model such as TUFLOW provides several key advantages when compared to a traditional one-dimensional (1D) model. For example, in comparison to a 1D approach, a 2D model can:

- provide localised detail of any topographic and/or structural features that may influence flood behaviour;
- better facilitate the identification of the potential overland flow paths and flood problem areas; and
- inherently represent the available floodplain storage within the 2D model geometry.

Importantly, a 2D hydraulic model can better define the spatial variations in flood behaviour across the study area. Information such as flow velocity, flood levels and hydraulic hazard can be readily mapped in detail across the model extent. This information can then be easily integrated into a GIS based environment enabling the outcomes to be incorporated into Council's planning activities.

3.2.2. Model Domain

The hydraulic model derived for the Wagga Wagga LGA (Figure 4) covers an area of approximately 780 km^2. The modelling area covers the Murrumbidgee River floodplain within the Wagga Wagga LGA.

3.2.3. Model Grid Size

The model grid size utilised in the model build process is a finite difference grid of 40 m by 40 m. The model grid size was adopted after considering the extent of the modelling area and the modelling run times involved. With some manipulation it was found that this resolution adequately represents the in-bank hydraulic properties of the Murrumbidgee River. This issue is further addressed in section 3.2.8.

3.2.4. Structures

Structures such as bridges, levee banks and road crossings can have a significant impact on flood behaviour.

A total of 7 bridges have been identified in the study area. The bridges are (from upstream to downstream) Eringoarrah private bridge, Eunony, Railway, Hampden, Wiradjuri, Gobbagombalin and Mundowey Road. The obstruction of bridge piers and deck have been modelled by a local increase in Manning's 'n' value in the section of the river where they are located. Ramp and abutment details are represented in the models topography. The Manning's 'n' value used for local bridge obstruction was 0.065 in contrast to the river in-bank Manning's 'n' value of 0.02. Bridge locations can be seen in Figure 4.

Berembed Weir, located at the downstream end of the model was assumed to be closed during the modelling runs.

In addition to these current structures there are a number of historical levees which fill low spots in the natural river bank in the vicinity of the urbanised regions of Wagga. These maximise the inbank flow, delaying breakouts. Primarily these levees run from near Kurrajong Lagoon upstream of Eunony Bridge down to Gobba weir.

3.2.5. Roughness Values

One of the more significant model parameters is roughness, represented by the Manning's 'n' co-efficient. As part of the calibration process roughness values were adjusted within reasonable limits in order to achieve observed peak flood levels at a variety of locations. Table 2 shows the adopted values in the model for the 1974 calibration event. For modelling of the 1% AEP changes to the Manning's coefficient were made as specified in Reference 2 in order to represent current day conditions/land use (see Section 5.1). A map of land use can also be seen in Figure 3.

Table 2: Land Type Classification and Manning's Coefficient

Land Type	Manning's 'n' coefficients
General, low level vegetation	0.040
River	0.020
Red Gum in Overbank	0.070
Yellow Box in Overbank	0.070
Urban	0.055
Properties with trees and houses	0.055
Cropping areas	0.060
Industrial areas	0.045
Parks	0.050
Golf courses	0.060

3.2.6. Levee embankments

For the calibration event of 1974[1] the North Wagga and Gumly Gumly levees were removed from the model (as they were formalised to current levels in 1990 and 1992 respectively, see Table 1) and the elevation of Hampden Avenue was reduced by 0.1 m in order to represent the 1974 floodplain conditions. For further details refer to Table 1.

[1] Note that the levees were partially present during this event but were overtopped and as such did not function as effective inundation controls.

For design runs, North Wagga and Gumly Gumly levees were included in the model and Hampden Avenue was represented with its present elevation.

Note that in all runs it is presumed that sand bags are used at the Sturt Highway near Marshall's Creek. It is assumed that the sand bags are placed at a crest elevation of 182.4 mAHD which corresponds to the levee elevation at that point.

Also it is noteworthy that for the 1% AEP run Wagga Wagga Main Levee was not failed as it was for design runs carried out as part of the 2010 study. The rationale behind this was that given 2010 results were to be given precedence over results from the current study for the Braehour to Malebo Gap extent, there was no need to incorporate levee failure. Also considered likely that the impact of levee failure on up and downstream modelling would be negligible.

3.2.7. Boundary Conditions

Upstream boundary conditions: Inflows were applied at the upstream end of the model (Wantabadgery) with hydrographs initially taken from Reference 1. The hydrographs for both the 1974 and the 1% AEP event are presented in Figure 5 and are further discussed in Section 3.1. Issues with the method used are also discussed at length in Section 3.1.

Downstream boundary conditions: The downstream end of the model is located in the vicinity of Berembed Weir (410023). A fixed water level boundary located 30 km downstream of the model extent downstream was established so that the resulting backwater profile did not impact upstream water levels and velocities. Similar boundary conditions were implemented on the irrigation channel downstream of the Berembed Weir as well as on Old Man Creek to the South, although parameters of slope and length were slightly adjusted to suit local conditions.

3.2.8. In Bank Conveyance

A review of surveyed cross sections used in Reference 2 revealed that in the region of Wagga Wagga City the average difference between the ALS surveyed surface of the Murrumbidgee River shown by the DEM[2] and the surveyed cross sections was approximately 3.1 metres. To approximate in-bank flow capacity, 3.1 metres was subtracted from the DEM over the width of the river (as identified through inspection of aerial photography and the DEM). This approach gave relatively good results near Wagga Wagga but less than ideal results both upstream and downstream of Wagga Wagga. To improve the match between modelled and observed data, bathymetry was iteratively adjusted based on the match between the modelled and observed 1974 flood levels and extent. Downstream of Malebo Gap as well as between the upstream boundary and Oura the channel invert was reduced by a further 2 m. At Oura cross sections sourced from Reference 3 were initially used in hope of generating a peak flood profile in the

[2] ALS does not penetrate the water surface and as such the DEM derived River "invert" is the water surface height at the time of survey. Overall the 40 m grid used in the modeling, and the lack of detailed bathymetric data, make the representation of in-bank conveyance an approximation only. In large flood events however the importance of in-bank conveyance to achieving good replication of flood behaviour is limited.

region that better matched observed reading. This attempt failed with flood mark correlation decreasing and thus an iterative process of defining river bathymetry was adopted. A similar approach was used at the Malebo Gap to reduce choking and decrease upstream water level so that observed flood levels better matched modelled levels. The same issue was later identified at the downstream end of the model. Again in-bank cell modelling was undertaken iteratively in order to optimise the match between modelled and observed data for the 1974 event.

Overall the process achieved the desired result (a reasonable representation of in-bank conveyance) however it's likely that an overall better model result could be achieved if survey of the in-bank was available for the entire River extent within the LGA. Such a data set could then facilitate the modelling of the in-bank in a 1D model with this model domain then dynamically linked to a 2D representation of anabranches and floodplain.

An alternative approach would be to have the in-bank bathymetry surveyed in a continuous manner (boat based hydro survey) and to then incorporate in-bank representation by way of a higher resolution 2D model. Based on the standard 2D model requirement that at least three cells lie within a watercourse to be modelled, and also given the sinuous nature of the River (and the need for orthogonal connectivity between cells in order to ensure choking doesn't occur), its likely the grid cell size for such a model would be at 20 m. Given a modelled extent of 780 km^2 this implies a model size of two million cells. The long duration of modelled events and the number of computational points mean such runs would currently take in the order of 14 days. Long model run times tend to lead to expensive and extended projects and as such a 20 m grid size is not currently practicable. In the future the relative duration of runs may be significantly reduced and so this option should likely be considered. Another model development consideration of relevance to Council is that mesh based models are improving with regard to stability and mass conservation and have been utilised in a variety of Riverine applications over the past five years. Mesh models allow for different size model elements facilitating for high resolution in-bank modelling in conjunction with coarse overbank representation. Such an approach could achieve detailed representation as well as reasonable run times.

4. MODEL CALIBRATION

Prior to utilising the model in design work it was calibrated. In this process modelled flood behaviour is compared with observed flood behaviour. As stated previously the 1974 flood event was used for this purpose.

4.1. Calibration

The 1974 flood event was an approximately 70 year ARI (1.4% AEP) event and it is the largest historical event for which a reasonable number of spatially distributed observations exist. As such it was an ideal event to use for model calibration.

The model calibration was assessed based on the match between the two data sets (modelled and observed) at different locations. The observed data set used in calibration is described in Section 2.3.

In order to model the 1974 floodplain conditions the model's topography, obtained from the 2008 ALS survey, had to be modified according to the floodplain change chronology observed in Table 1, Section 2.1.1.

For model calibration the 1974 inflow hydrograph was applied at the upstream end of the model. Roughness values were allocated based on those used in Reference 2. The model was run and observed peak flood levels were compared with modelled values. Additionally the stage/discharge rating curve (Figure 8) and hydrograph (Figure 9) at the Hampden Bridge Gauge were compared with modelled values.

Modification of in-bank conveyance (via changes to bathymetry as described in Section 3.2.8) as well as roughness values was carried out in order to obtain a satisfactory match between observed and modelled flood levels. This was most notable in the regions of Oura, the Malebo Gap and at the downstream end of the model as numerous iterations were required to optimise flood level correlation by way of in-bank bathymetry modification due to the unique nature of the local terrain. After this iterative process was complete[3] the hydraulic model was considered to be calibrated.

4.2. Verification

To further enhance confidence in model results the current study 1% AEP results were compared with those from the 2010 study for comparable locations. Calibration and verification results are discussed in Sections 6.2 and 6.3.

[3] Completion was indicated by an optimized match with the observed data set

5. DESIGN EVENT MODELLING

Design event modelling was carried out in order to define design flood behaviour in terms of flood depth, levels and provisional hazard across the Murrumbidgee River and the Wagga Wagga LGA floodplain for the 1% AEP event.

5.1. Changes to the floodplain

In order to account for floodplain changes dating from 1974 to the present the 2D model had to be altered. The following changes were made to the model:

- Three bridges were added to the model (relative to the calibration schematisation) namely; Eunony, Wiradjuri and Gobbagombalin (refer to Section 3.2.4); and
- Modifications were made to account for an increase in floodplain vegetation density since the 1970's in accordance with that specified in Reference 2 (refer to Section 3.2.5).

6. RESULTS

6.1. Introduction

Calibration and design modelling results are provided as tables (see Appendix B), peak profiles and maps of extents and peak flood level contours. All figures and maps are presented at the end of the report.

6.2. Calibration results

6.2.1. Introduction

Figure 6 shows the modelled peak flood profile for comparison with observed flood marks situated on the floodway. Observed flood marks within 200 m of the River only were utilised in the comparison.

Figures 7a – 7e show the modelled 1974 flood event depths (raster) and levels (contours) over the entire Wagga LGA. The location of each of the approximately 100 observed flood marks is presented and using the point ID number, the table in Appendix B can be used to compare modelled flood levels to observed. The same figures also show the observed extent information and this can be compared to the modelled extent.

Figures 8 and 9 show the observed and modelled stage/discharge rating and hydrograph comparison at Hampden Bridge Gauge.

6.2.2. Discussion

Generally the match is very good. The match for the flood marks is discussed at length below but the extent and stream gauge match, both indicate a very good correlation between modelled and observed. One area where discrepancy is observed with regard to the extent match is downstream of Wagga where extent upstream of the Malebo Gap tends to be overestimated whilst the extent downstream of the same appears underestimated. This is likely related to the in-bank efficiency for this section of the River being under represented in modelling.

6.2.2.1. Flood Marks

Average error for all flood marks (in which under and over estimates negate each other) is 0.01 m. More pertinently however the absolute average error is 0.18 m with a standard deviation of 0.23 m. Significantly, given the 500 mm freeboard typically used in determining floor levels for residential accommodation, approximately 95% of the marks show an error less than 0.5 m. Approximately 78% of the calibration points are within ± 0.25 m and approximately 50% within ± 0.15 m. For the full list of calibration points and match achieved see Appendix B.

The best results, relative to the flood marks, occurs around Wagga Wagga and North Wagga with the majority of modelled flood levels within 0.2 m of the observed marks.

The majority of observed flood marks were taken around Wagga Wagga itself. In this region the distribution of over and under estimated flood levels is in the main uniform although it appears that the northern bank has a tendency to be under estimated and the southern bank slightly over estimated. The majority of the flood marks in the region that have large error values are also found close to flood marks that have good correlation values. This tends to indicate that not all flood marks are accurate as generally Riverine flooding will exhibit relatively flat water surfaces although localised phenomena are always possible.

The maximum negative difference (-0.63 m) between observed and modelled levels was recorded at flood mark #48 which is situated immediately downstream of the Hampden bridge. Extent information and many flood marks proximate to flood mark 48 indicate a good match with both under and over estimated levels in the vicinity. This information tends to indicate that the point may not be an accurate observed flood mark.

The next worst point is #110 just upstream of the Malebo Gap. The observed flood mark has been modelled 0.59 m higher then the reported observed flood level. It's likely this overestimate is related to a relatively poor emulation of in-bank conveyance at the Malebo Gap and the over estimate is supported by an apparent overestimation of extent upstream of the Malebo Gap also. It's noteworthy that many iterations were required in order to achieve the result presented herein with initial runs showing an overestimate of approximately 2 m. This gives an indication of the importance of the in-bank conveyance at this location.

Another region in which observed flood marks have been overestimated is approximately 13 km downstream of the Malebo Gap where the two furthest downstream flood marks available are situated (see points #7 and #8 on Figure 7d). Both of these flood marks have been modelled approximately 0.5 m higher then the observed levels (0.58 and 0.45 m respectively), although the three next closest marks show good correlation (within ± 0.25 m).

Flood marks upstream of Wagga Wagga have mainly been over estimated and generally within reason it's perceived as being better to have the model overestimating flood levels rather than underestimating them.

6.3. Verification

Model results from the 1% AEP run were compared with those from the 2010 study for comparable areas. The match was good with most areas matching within +/- 0.2 m. Mean error was -0.03 m although this result includes high and low results cancelling each other out. The standard deviation was 0.15 m which is a good result and indicates that the two data sets are well matched.

It was noted that likely due to more complete inclusion of the Malebo Gap and its constrictive effect in the current modelling, design model results were high relative to those of the 2010 study for the area downstream of Wagga but upstream of the Malebo Gap.

An upshot of the result mentioned above is that it would be prudent to run the PMF through the whole of LGA model and to compare level estimates with those achieved during the 2010 study. It's likely that the constrictive impact of the Malebo Gap was slightly underestimated in the 2010 study and as such actual PMF levels, which might be applicable to the western end of Wagga, are likely higher than those presented in the 2010 report.

The mismatch at the Malebo Gap does highlight the importance of the in-bank at certain specific locations (Oura is another example) and as such it is recommended that Council endeavour to collect data describing the in-bank as and when possible. It's noted that State Water recently surveyed the Murrumbidgee River as part of another project currently underway and so perhaps Council might seek this data. Continuous in-bank survey of the River could give a tremendous insight into where more deeply incised sections of river provide a more capacious in-bank.

6.4. Design modelling results

Figures 10a -10e show the 1% AEP flood depths and levels over the entire LGA. Figures 11a – 11e show the provisional flood hazard for the 1% AEP event.

7. CONCLUSIONS

The major goal of the study has been achieved with Council being provided with 1% AEP flood information for the entire Murrumbidgee River within the LGA. Calibration work has established the general accuracy of the model.

The following recommendations are made:

- Utilise the model to run the Probable Maximum Flood as it's likely that the PMF work carried out as part of the 2010 study is underestimated due to the 2010 study underestimating the constrictive impact of the Malebo Gap on upstream flows;
- Merge current study 1% AEP flood extent and level information with information developed as part of the 2010 study (WMAwater, 2010) for seamless inclusion in Councils flood planning software, or at the very least clearly demarcate locations at which various sources of design flood level information are applicable;
- As and when possible Council could collect riverine bathymetry data. For example previous work undertaken by the RTA on the Sturt Highway upgrade (west of Wagga) included River cross-section survey. Also, as part of an irrigation flow efficiency modelling project currently being undertaken for State Water survey of the entire River, presumably of the in-bank only, has been undertaken. Such information could aid refinement/improvement of modelling tools in the future and separately may aid Councils River management efforts; and
- Care needs to be taken when utilising results from the studies and levels should be treated as interim only to be superseded once a more details flood study is undertaken.

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