GOULBURN BROKEN
CATCHMENT MANAGEMENT AUTHORITY

Barmah-Millewa Hydrodynamic Modelling
Model Re-calibration

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PROJECT DETAILS

Project Name	Barmah-Millewa Hydrodynamic Modelling
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1. INTRODUCTION

Water Technology was commissioned by the Goulburn Broken Catchment Management Authority (GBCMA) to develop an updated hydrodynamic model of the Barmah-Millewa wetland/forest system. This work has been undertaken as part of the Living Murray initiative of the Murray Darling Basin Authority.

Previous investigations and modelling of the Barmah Millewa forest and wetlands (Water Technology (2005, 2006) highlighted that the original LIDAR data set for the Barmah Forest contained systematic errors in the processing of data, affecting the model results. The LIDAR issues were outlined in two Memo's by Water Technology to the GBCMA in November and December 2006 (WT, 2006a and 2006b, see Appendix C).

This report documents the level of re-calibration achieved with the hydraulic model incorporating new air borne laser scanning survey (ALS or LIDAR) and cross-section information.

These investigations and this report draw on previous work undertaken for the GBCMA and documented in the reports:

Barmah-Millewa Forest Hydrodynamic Model, Report J129/R01FA Rev 1, Water Technology (2005)

Barmah-Millewa Hydrodynamic Model - Additional Investigations, Report J419/R01DA Water Technology (2006)

2. AVAILABLE DATA

2.1 Survey Information

The following is a compilation of all the main sources of topographic and structural survey information gathered over the course of this and previous hydraulic modelling exercises that has been incorporated into the hydraulic model.

2.1.1 ALS - Topography

The main source of topographic information utilised in the development of the hydraulic model was the topographic survey data collected using the Light Detection and Ranging (LiDAR) (also referred to as airborne laser scanning (ALS) survey) airborne remote sensing technique. This technique allows for the rapid collection of topographic data over large areas. The raw ALS data has an average spacing of 2.4 m and a reported vertical accuracy of 0.15 m Root Mean Square Error (RMSE) and horizontal accuracy of 1.0 m RMSE. The raw ALS data was processed and interpolated onto 1 m and 10 m cell grids. A comparison of the latest ALS dataset with the original ALS dataset is presented and discussed in Section 3. The latest survey data set has a reported accuracy of ± 0.1 m to 1 standard deviation.

2.1.2 Feature Survey Data

Feature survey including information on hydraulic structures, cross-sections and levees was sourced from a number of different organisations. The data source and origin for each data-set are listed below in Table 2-1. A significant amount of effort was allocated to searching for and gathering historic plan data. Many useful records were recovered from Goulburn-Murray Water and the GBCMA.

Table 2-1 Available Feature Survey Data

Data	Source
River Murray Cross Section Survey	SR&WSC (1977)
Regulator Structural Drawing Plans	Goulburn-Murray Water (various dates) DIPNR (various dates)
Victorian Levee Survey	LICS, GBCMA (various dates)
New South Wales Levee Survey	Berrigan Shire, DIPNR (various dates)
Tuppal and Bullatale Creek cross-section survey	EarthTech (2002)
Black Engine Creek Cross Section Survey	EarthTech (2002)
Edward River Cross Section Survey	Fluvial Systems (2001)
Forest Regulator Survey	SKM (2006)
Edward River and Gulpa Creek Cross Section Survey	Coomes Consulting (2007)

3. COMPARISON OF ALS DATASETS

A comparison of the original (1999) and more recent (2007) ALS datasets has been undertaken in a GIS. The comparison has been performed by subtracting the surface elevations from a 10 m grid of the latest ALS dataset from the surface elevations from the 10 m grid of the original ALS dataset. The residual difference grid developed from this technique provides a very effective method for assessing the relative magnitude and spatial variability of the systematic errors observed in the original ALS dataset. The residual difference grid is displayed in Figure 3-1.

From Figure 3-1 the banded discontinuities in elevations aligned approximately northwest-southeast are clearly evident. This banding is associated with the original ALS dataset. Two cross-sections of residual differences have been extracted from the residual grid across the floodplain. These sections clearly show the abrupt discontinuities in both positive and negative residuals. It is important to note that the relative magnitude of these discontinuities in elevations, of approximately -0.3 to +0.3 m, are of the same order of magnitude as the flooding depths experienced over much of the floodplain which are of interest and that are being modelled. It is these abrupt and systematic discontinuities in floodplain elevations associated with the original ALS dataset that caused difficulties when modelling the fine details of flood flow distributions and flooding extents on the Barmah-Millewa floodplain with the original ALS dataset. An example of the effect of this banding on the original hydraulic modelling results is displayed in Figure 3-2 compared with the results developed with the latest ALS dataset.

It should be noted that residual comparison displayed in Figure 3-1 also suggests there is minor banding in the elevations from the latest ALS dataset. This banding is aligned approximately northeast to southwest, the direction in which the ALS was flown. However the magnitude and extent of this banding is significantly less extensive than the original ALS dataset. It does, however, highlight that no ALS dataset can be considered totally free from errors and this should be considered when assessing the level of calibration that can be achieved with the hydraulic model and when interpreting model results.

The analysis undertaken indicates that the latest ALS dataset is superior to the original ALS data for the Barmah-Millewa Forest area and provides a much improved base from which to develop the hydraulic model.

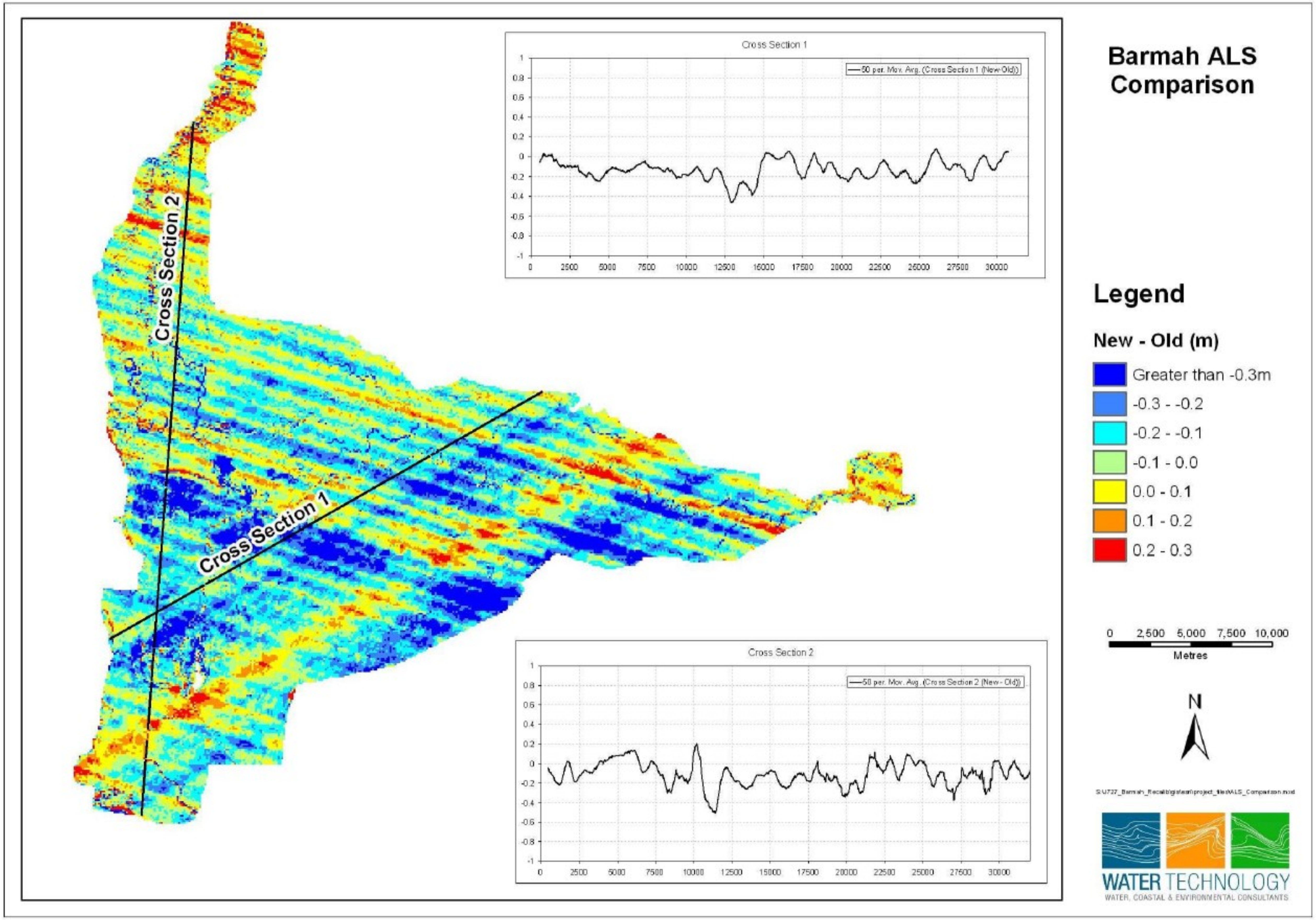


Figure 3-1 ALS Comparison – Residual Difference Grid

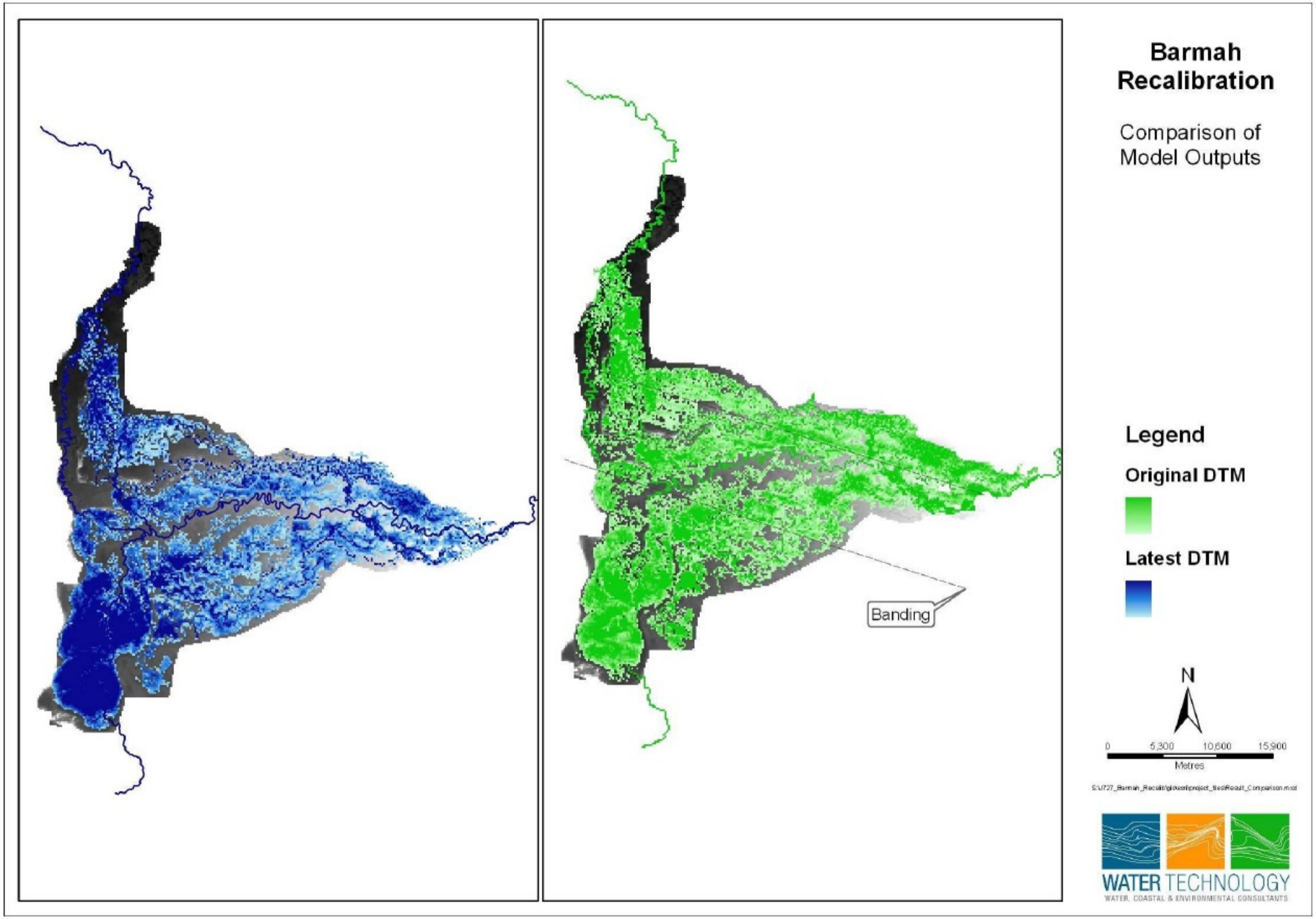


Figure 3-2 Comparison of Model Outputs from Original and Latest ALS Datasets

4. MODEL RE-ESTABLISHMENT

The underlying modelling approach in terms of the floodplain schematisation is essentially the same in the present model as was applied in the original hydraulic model. This involved representing major rivers and anabranches as one-dimensional elements including the forest regulators. These one-dimensional branches are dynamically linked to a two-dimensional model of the broader floodplain. Sections of the original hydraulic model, in particular the River Murray and forest regulators have therefore been directly incorporated into the latest model. The main difference between the present and previous hydraulic model is the floodplain topography, based on more recent ALS data.

Continued improvements in computational power and in the modelling software since the original model establishment provided the opportunity to reduce the model grid size to improve the floodplain schematisation. The model grid size was reduced from the original size of 80 m to 50 m. This change in resolution has resulted in approximately 2.5 times the number of floodplain cells in the new model compared to the original model. This increase in computational points in the model domain and associated reduction in the model time-step (to maintain numerical stability) has resulted in an increase of the total number of computations by a factor of 8 above that required for an equivalent simulation in the original model. This provides some measure of the improvement in the models detail compared to the original model.

A visual indication of the change in resolution of the floodplain is provided in Figure 4-1. This shows a comparison of a sub-section of the study area and highlights the significantly improved resolution of the floodplain geometry with the reduced grid size.

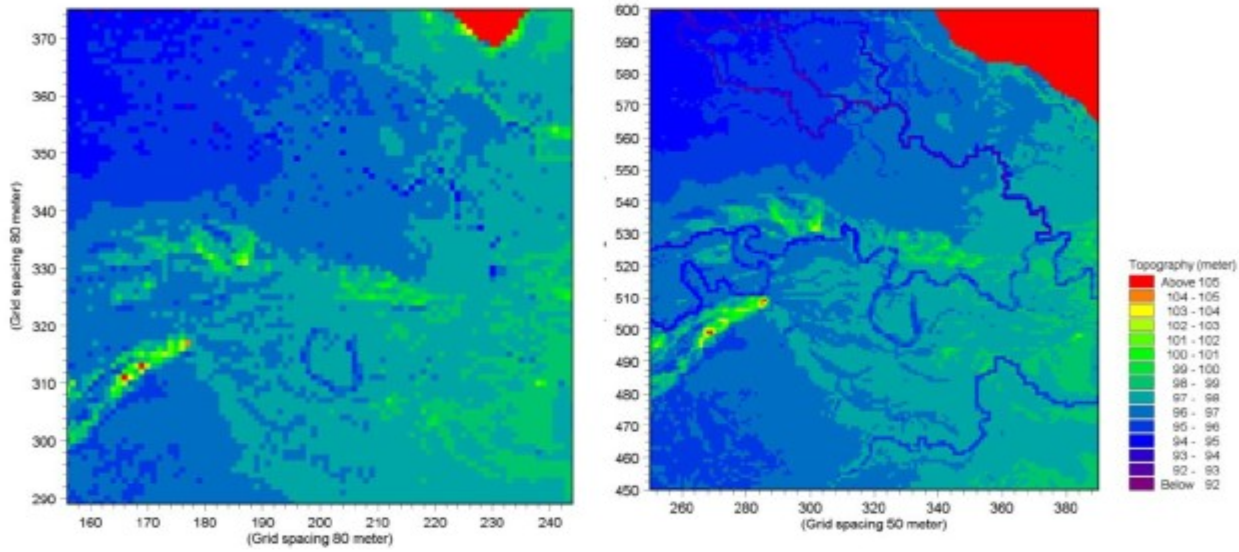


Figure 4-1 Typical Comparison of 80 m and 50 m Topography Grids

5. MODEL CALIBRATION

5.1 Overview

The revised hydraulic model, consisting of a finer floodplain grid, based on new ALS topographic data, was re-calibrated against historic flood events.

The calibration process consists of systematically comparing observed flooding behaviour within the study area against the hydraulic model's reproduction of that behaviour. This process incorporated comparisons between gauged stream flow data, observed flood levels and maximum area of inundation as shown by aerial photography or extents derived from analysis of satellite imagery. Where the model does not adequately represent observed conditions, the reason for the discrepancy is identified and inputs into the model are adjusted as required.

The historical floods used to calibrate the model were chosen from the previous hydraulic modelling projects on the following basis:

- A reasonable calibration data set of coincident flood information was available to make meaningful comparisons with the model; and
- The flood was of a significantly different magnitude to the other calibration floods to ensure the model was capable of accurately reproducing the flooding behaviour of the forest over a large range of flood magnitudes.
- The flood was relatively recent (<10years).

The three historical floods selected for calibration of the model are as follows:

1. October – November 2000
2. October – December 2002
3. October – November 2005

Figure 5-1 displays the inflow hydrographs at Tocumwal for the three calibration events to provide an indication as to the relative magnitude of the different flood events employed for the calibration. Table 5-1 displays some basic hydrologic characteristics of the three calibration events with approximate flood frequencies derived from a recent hydrologic review of design flows for the River Murray at Tocumwal (Water Technology, 2008).

A summary of the various forest regulators included in the model is provided in Appendix D. The reader is referred to the previous report Water Technology (2005) for further details on the different regulators. Information on each of the regulators for each flood event varies and therefore regulator performance has only been compared to the modelled results where sufficient records exist.

Table 5-1 Calibration Flood Hydrologic Characteristics

Tocumwal (409202)	Calibration Event		
	2000	2002	2005
Volume (GL)	3,695	1,596	2,047
Peak Flow (m^3/s)	1,035	178	331
Peak Flow (ML/day)	89,424	15,379	28,598
Average Recurrence Interval (years)	5	<1	<2

It should be noted that although this is termed a “calibration” process, in reality it is more a “verification” process due to the large number of uncertainties and data gaps in the historic flood data. In particular, information on the operating regime of the various regulators is limited and in many cases significant assumptions had to be made regarding how the regulator was operated over the flood period. As the operating regime of the regulators has significant impact on flows throughout the forest if their operation during an event is not adequately described then calibrating the model to the observed water levels or flows becomes difficult. The modeller is in effect “second guessing” the operating regime.

This does not mean however that where there are differences between the modelled and observed results that the results are incorrect. The regulators are represented explicitly in the model, which means that given a particular flow/water level upstream or downstream the regulator will adjust itself according to its operating rules, i.e. for a weir this is the weir height and width. So for scenario type simulations the regulators will operate as designed and uncertainties in how a particular regulator was operated need not be considered.

During the calibration process for each flood event the known or assumed operating procedure for each regulator was applied to the regulator settings in the model. These setting were not adjusted during the calibration procedure due to the following reasons:

Due to the complexity of the interaction of different flows throughout the forest, the operation of more than one regulator may affect water levels in a particular area. Therefore adjusting a single regulator would not capture these effects.

Given that assumed operating procedures where applied to the majority of the regulators, to systematically adjust each regulator, or groups of regulators, creates potentially an infinite number of operational permutations.

The Barmah-Millewa hydrodynamic model is complex and computationally intensive. Multiple simulations are not possible within the time frame of the project and therefore in terms of a time-cost-benefit approach it was considered inefficient to focus resources on completely replicating regulator operation for historic events. Especially as for future scenario modelling the operation of the regulator can be explicitly described.

The calibration process therefore focussed on ensuring that flow distribution throughout the forest is well represented. In a 2D model such as this, slight changes in topography can alter flow paths and distributions. As the chosen grid size is 50m in the model sometimes small scale features are not well represented. For example, the ground level is averaged over the 50m grid cell which means that in some areas smaller channel features are not adequately captured. Of there may be a locally higher grid cell due to an inaccuracy in the original surface which prevents flow getting into a particular location. During the calibration process these types of issues were addressed to improve flow distribution and therefore the overall performance of the model.

Also, as is mentioned in more detail in Section 6.2 roughness parameterisation throughout the model was investigated during the calibration. In some areas under low flow conditions the roughness values adopted may not provide the best calibration for particular locations; however the choice of roughness values is a compromise between accuracy for individual calibration events and producing a model that can well represent a wide range of flow conditions.

Into the future, as further flow events occur that are well monitored and recorded throughout the forest, particularly in relation to operation of the regulators, then further model calibration can be undertaken. The model will continue to improve as data deficiencies are addressed (i.e. improved survey data along watercourses, flow and regulator monitoring as discussed in Section 6) and new or improved information can be incorporated into the model on a regular basis.

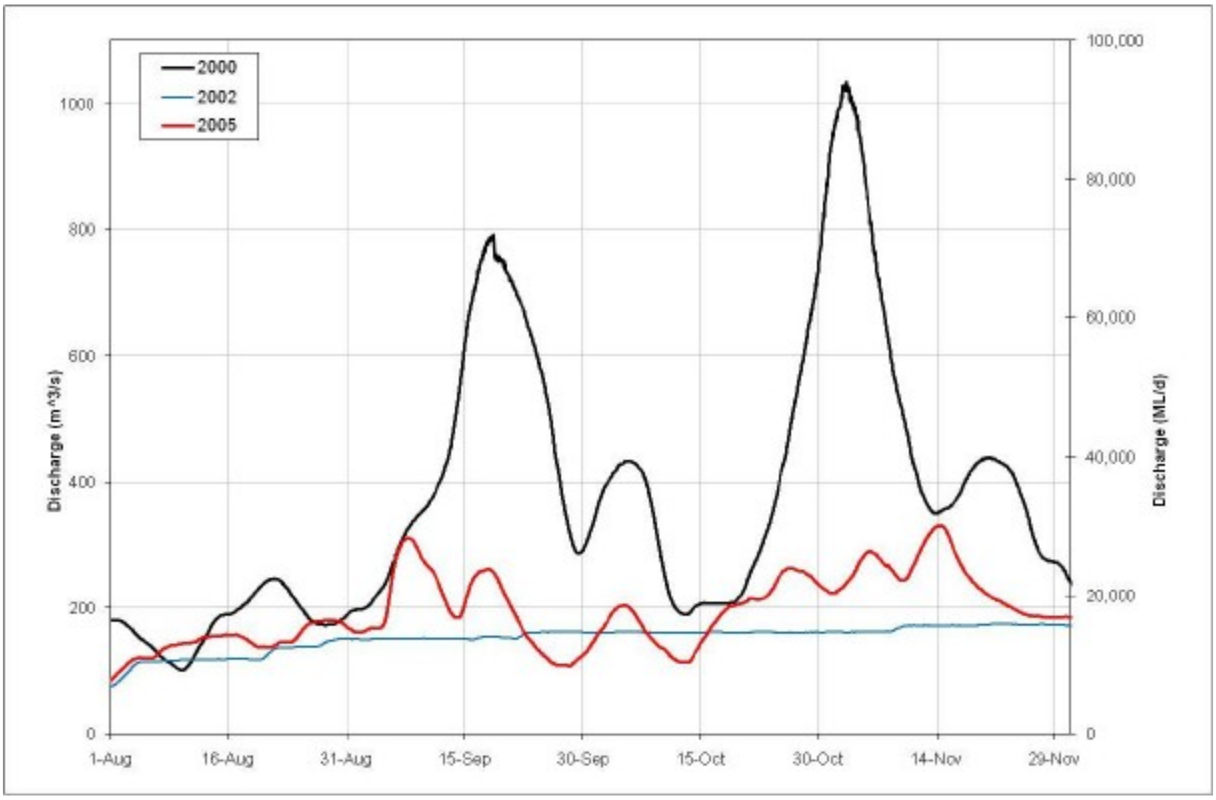


Figure 5-1 Tocumwal Inflow Hydrographs for Calibration Events

5.2 October – December 2002

The recorded discharge hydrograph at Tocumwal was applied to the models upstream boundary from the 20th September until the 1st December. The inflow hydrograph at Tocumwal is presented in Figure 5-2. Broken Creek flows at Rices Weir (404210) during the period were also applied to the model. It is understood the Stevens Weir boards on the Edward River were in place during this flood and therefore the recorded level at Deniliquin (409003) has been applied to the downstream model boundary on the Edward River. The rating curve at Lower Moira (409221) was applied to the downstream model boundary on the River Murray at Lower Moira. Average monthly evapotranspiration values for the Barmah-Millewa forest were also applied to the model.

5.2.1 Calibration Results

The model results have been compared against available gauge records in Figure 5-3 through to Figure 5-11. The model flood extent results have been compared to satellite derived flooding extents in Figure 5-13 and Figure 5-14.

It should be noted that the satellite derived flood extents are not necessarily definitive as they also rely on ground truthing.

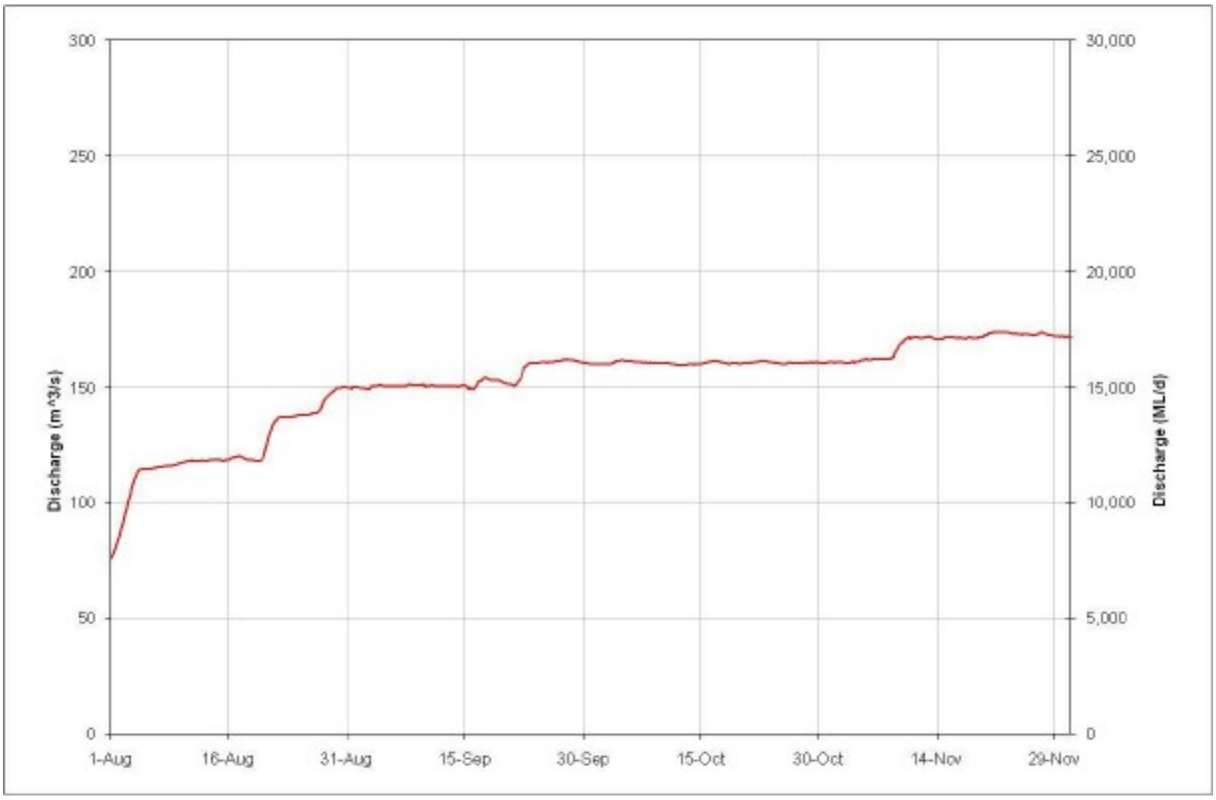


Figure 5-2 River Murray Hydrograph at Tocumwal, October – December 2002

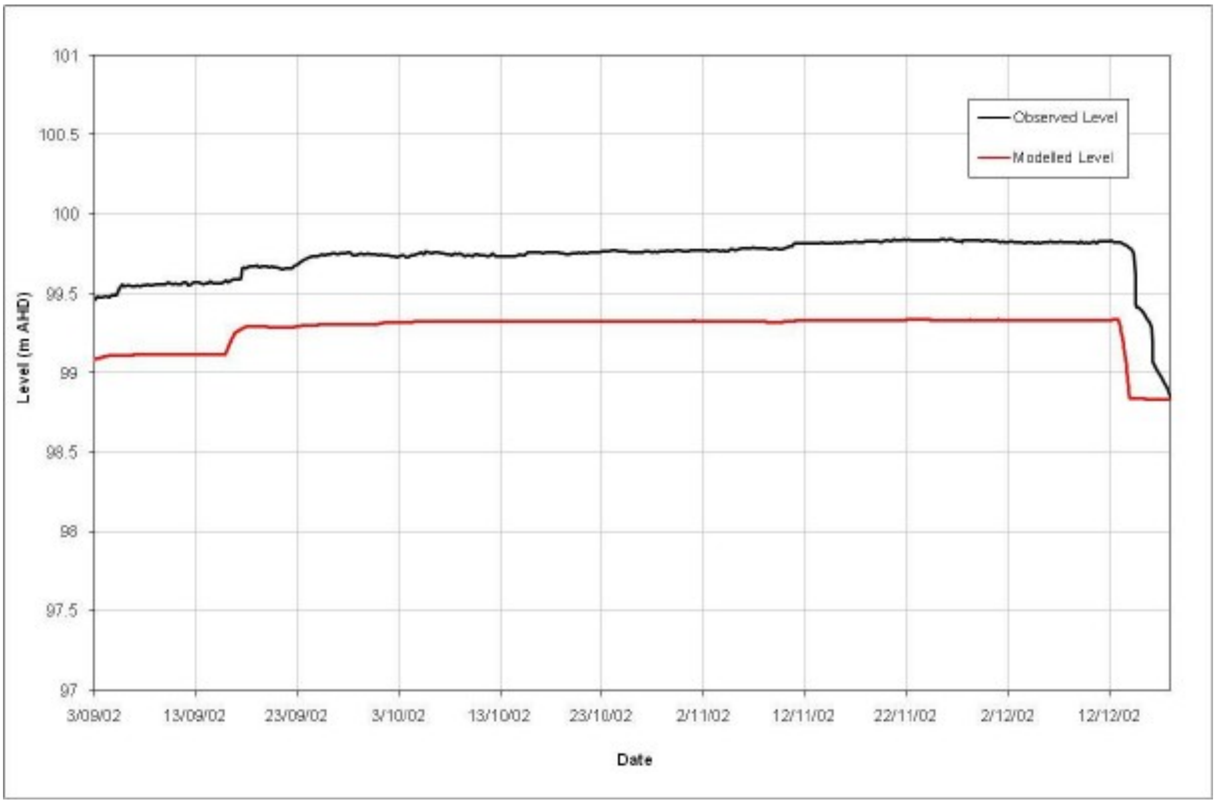


Figure 5-3 4090391 Gulf Creek at Gulf Track Regulator

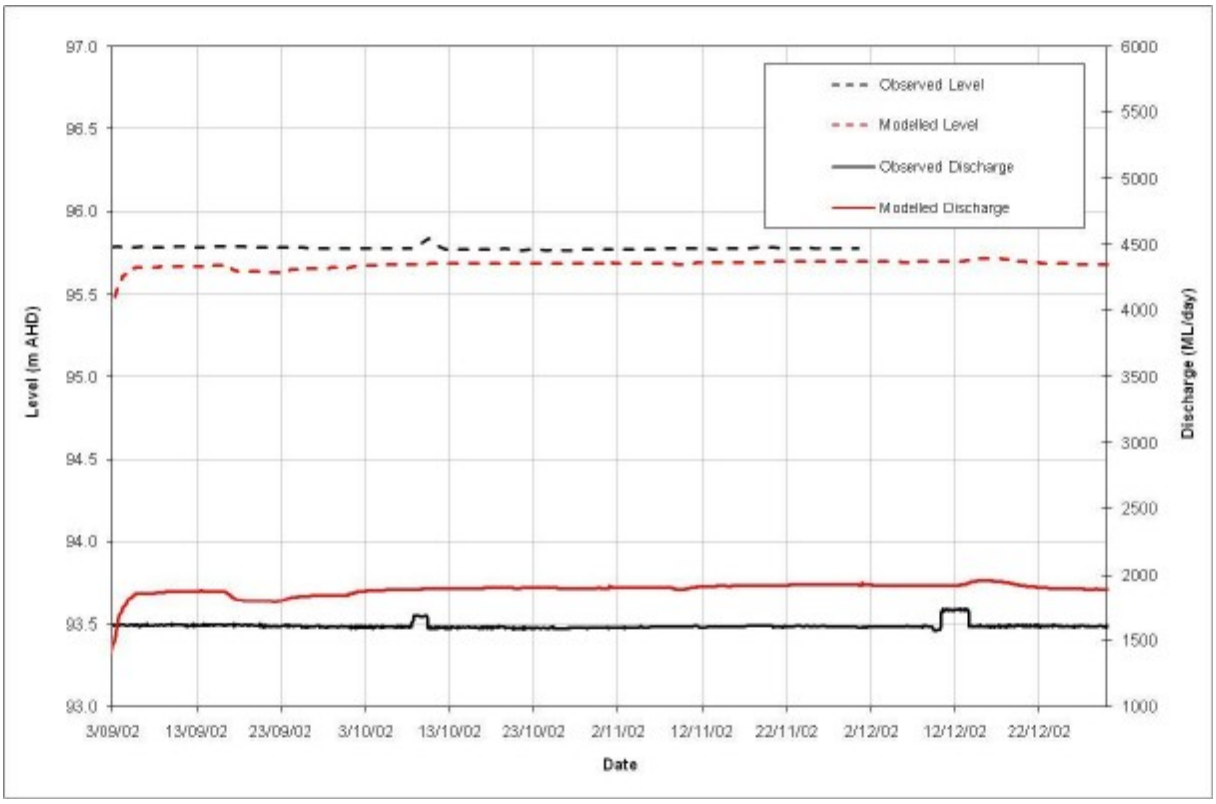


Figure 5-4 409008 Edward River D/S Offtake Regulator

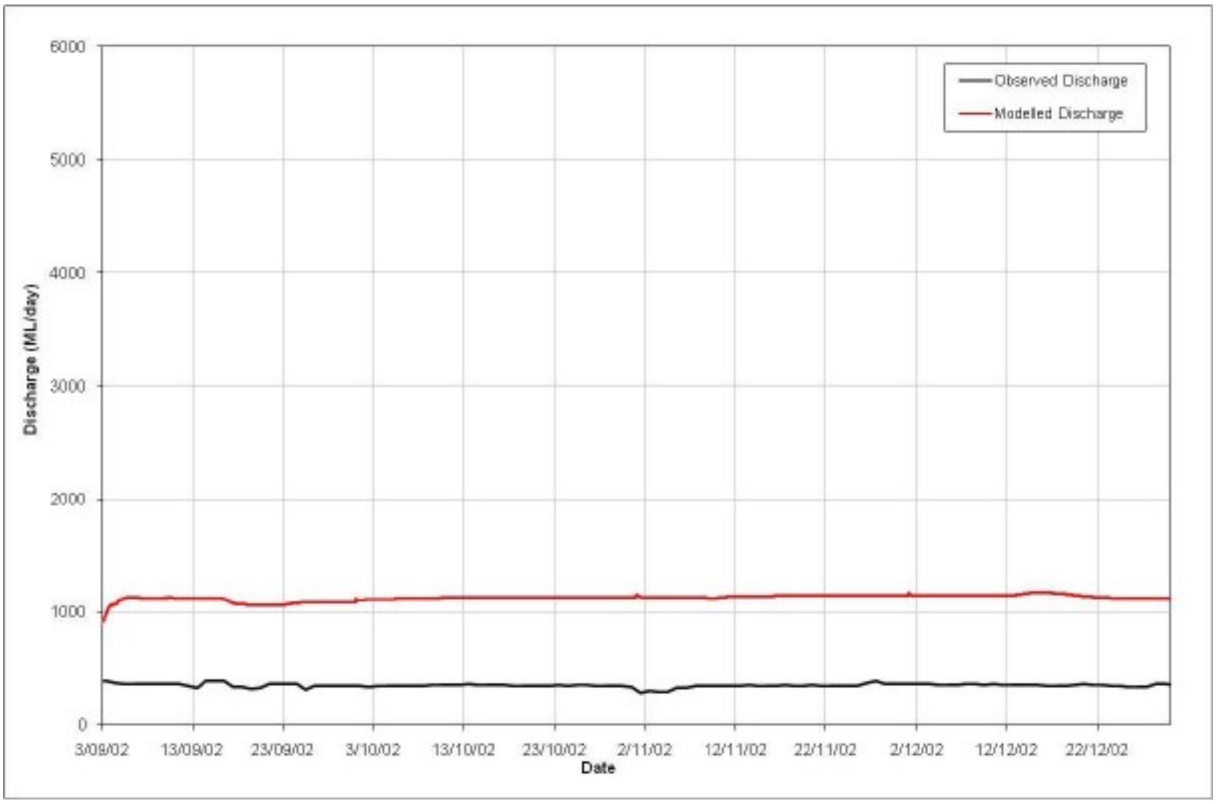


Figure 5-5 409030 Gulpa Creek D/S Offtake Regulator

Note that the discrepancy at Gulpa Creek is influenced by poor regulator operation records and limited cross-section information in the creek channel.

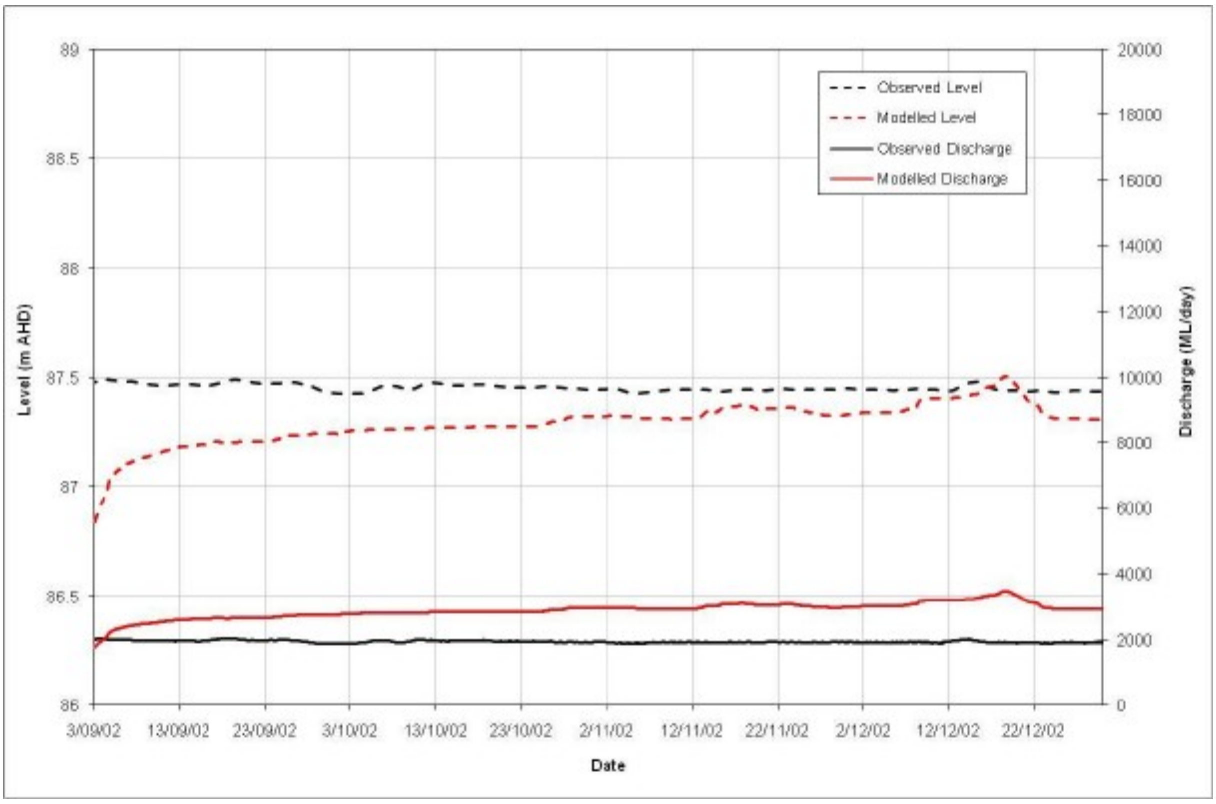


Figure 5-6 409047 Edward River at Toonalook

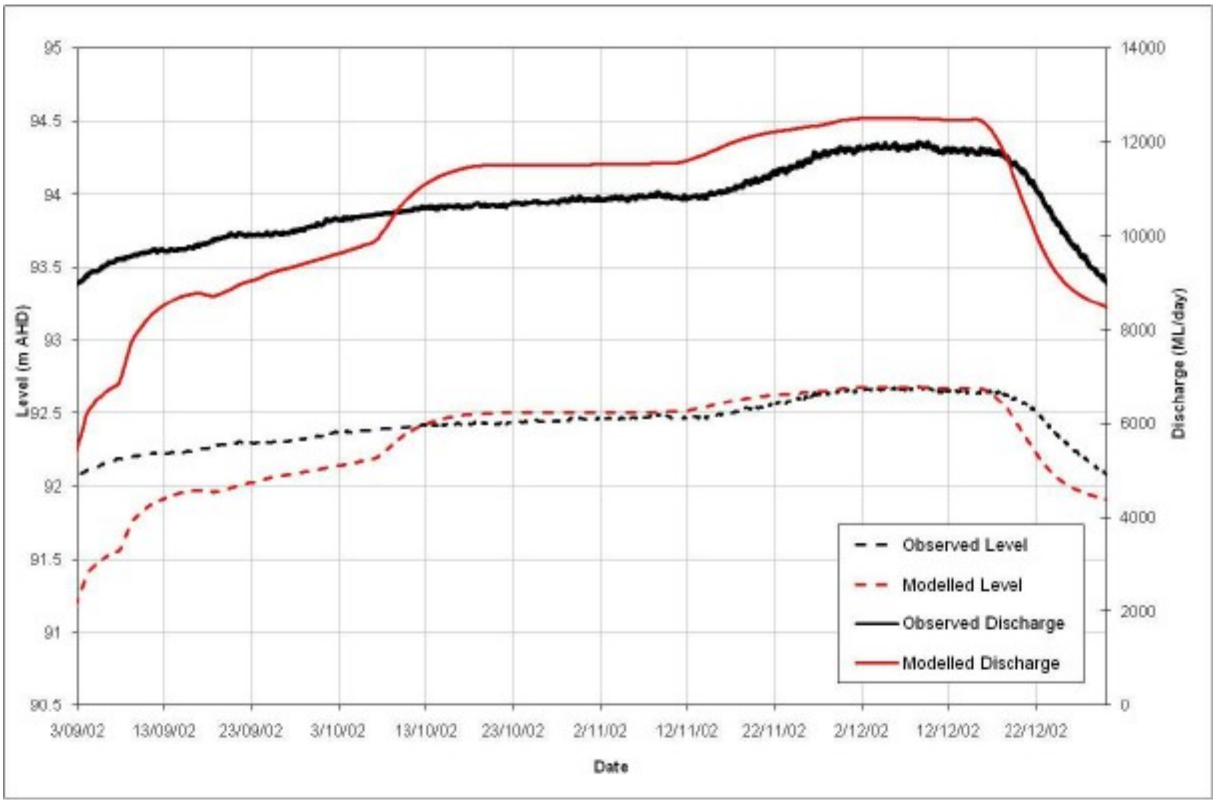


Figure 5-7 409215 River Murray at Barmah

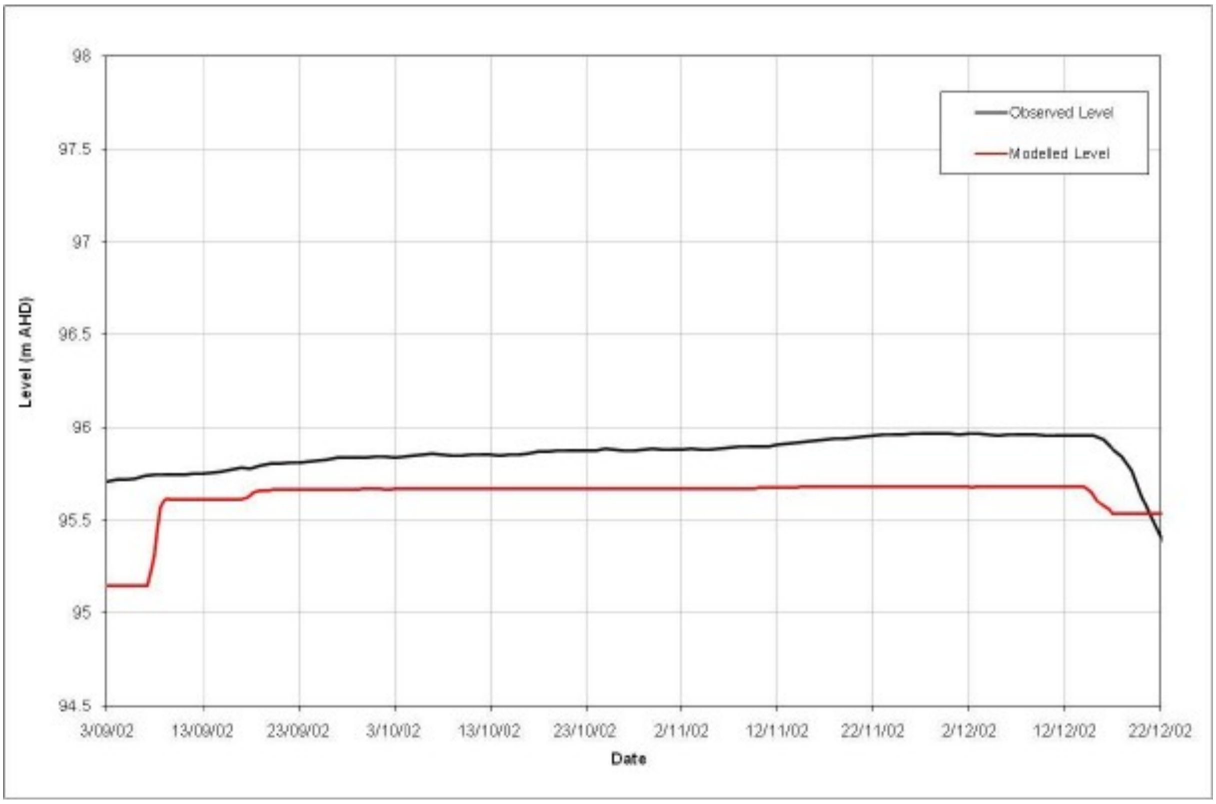


Figure 5-8 409394A Snag Creek at Gowers Track

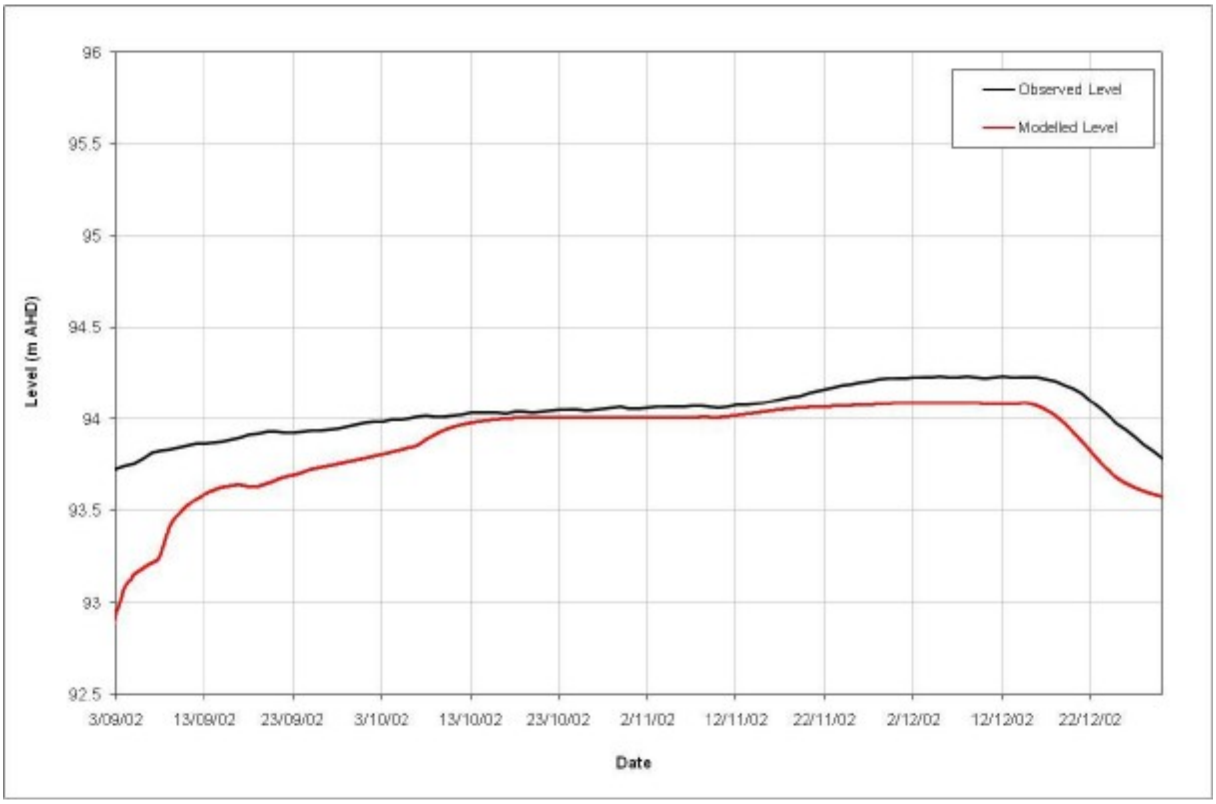


Figure 5-9 409232A Moira Creek at Moira Lake

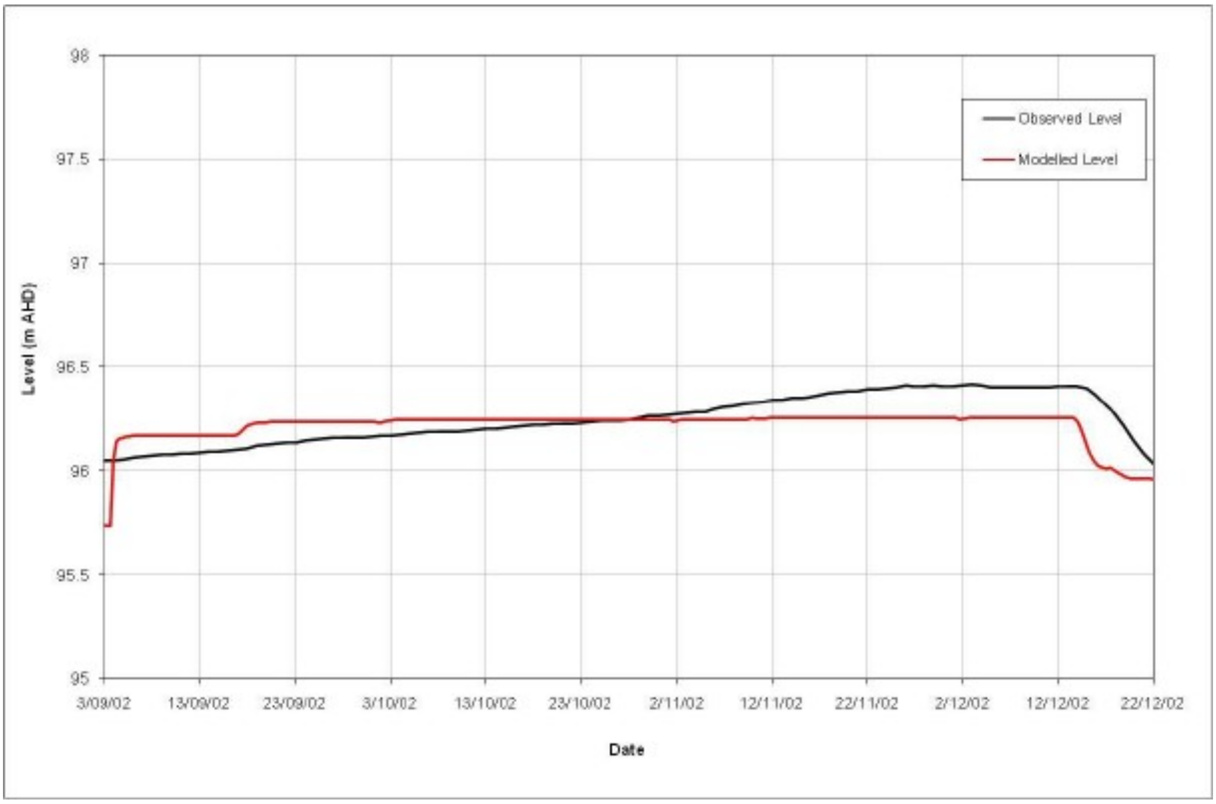


Figure 5-10 409393A Gulf Creek at Long Plain Track – Keys Point

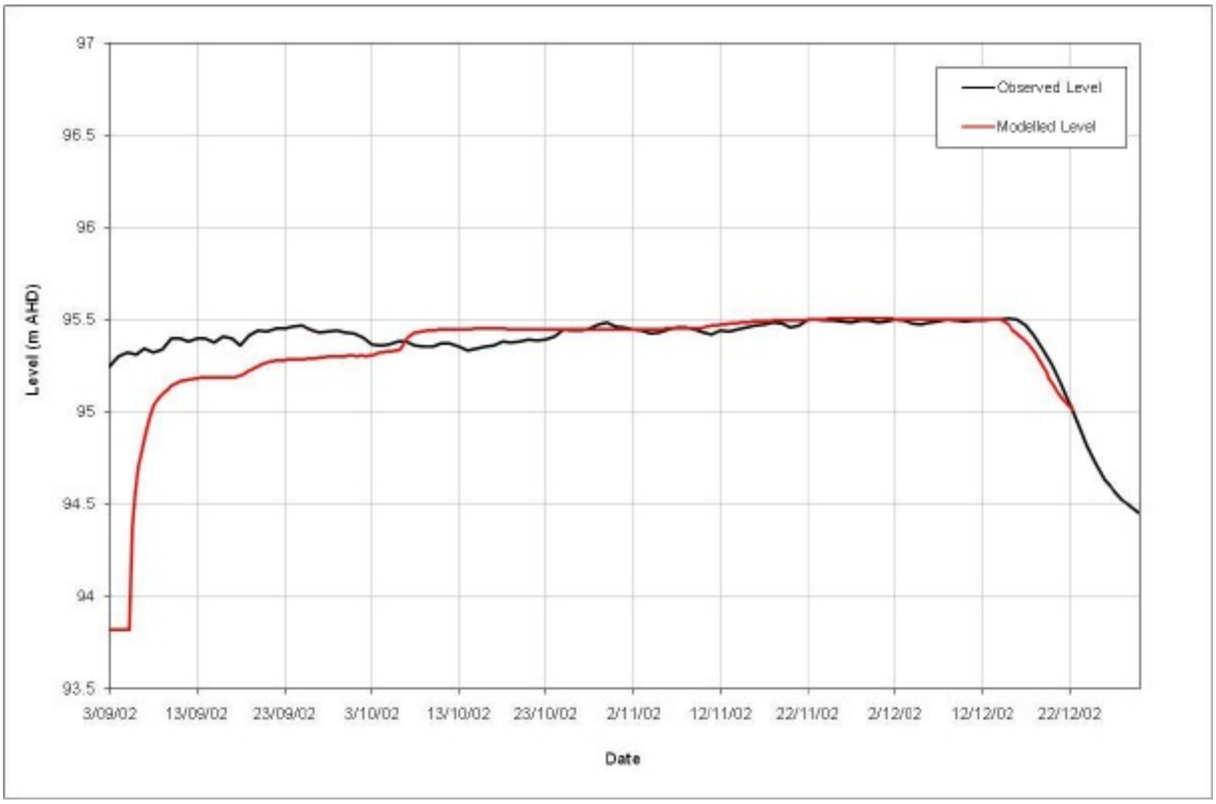


Figure 5-11 409396A Budgee Creek at Sand Ridge Track

Cumulative modelled and observed mass curves have been compared on the River Murray at the Barmah gauge in Figure 5-12.

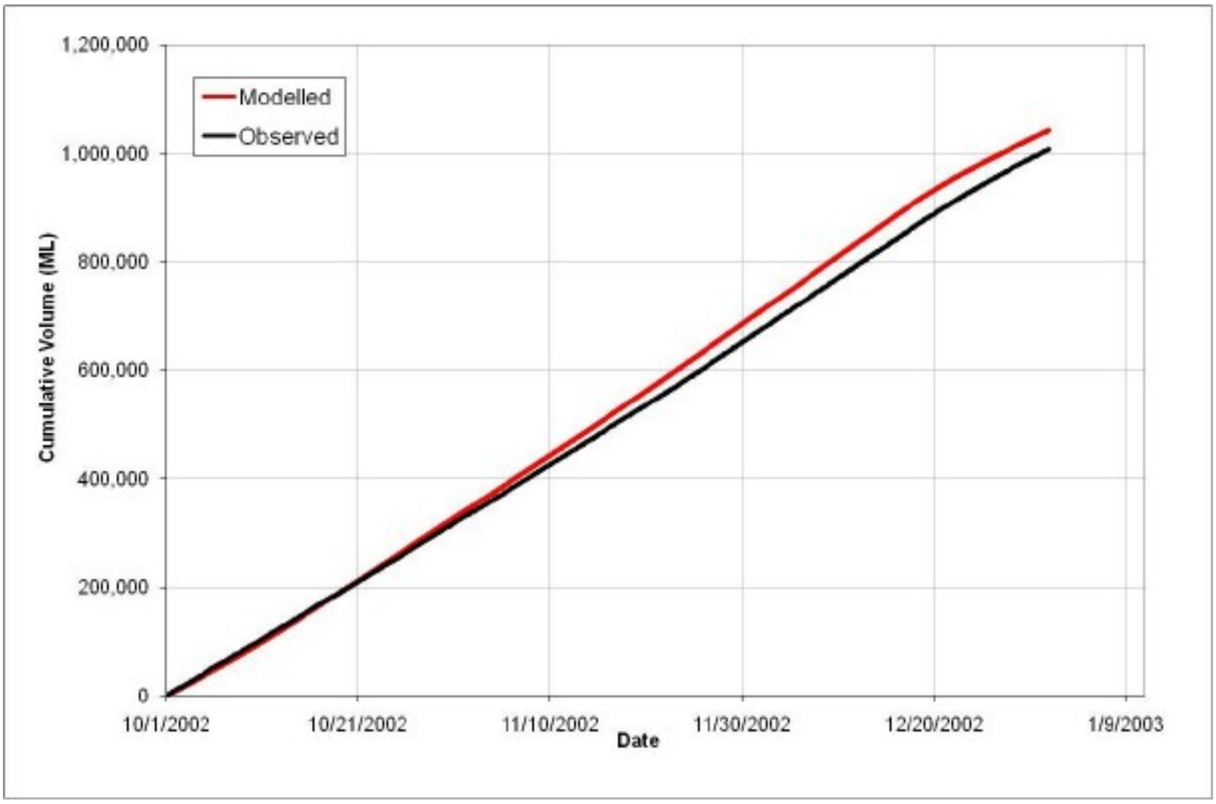


Figure 5-12 Comparison of Cumulative Mass Curve River Murray at Barmah (409215)

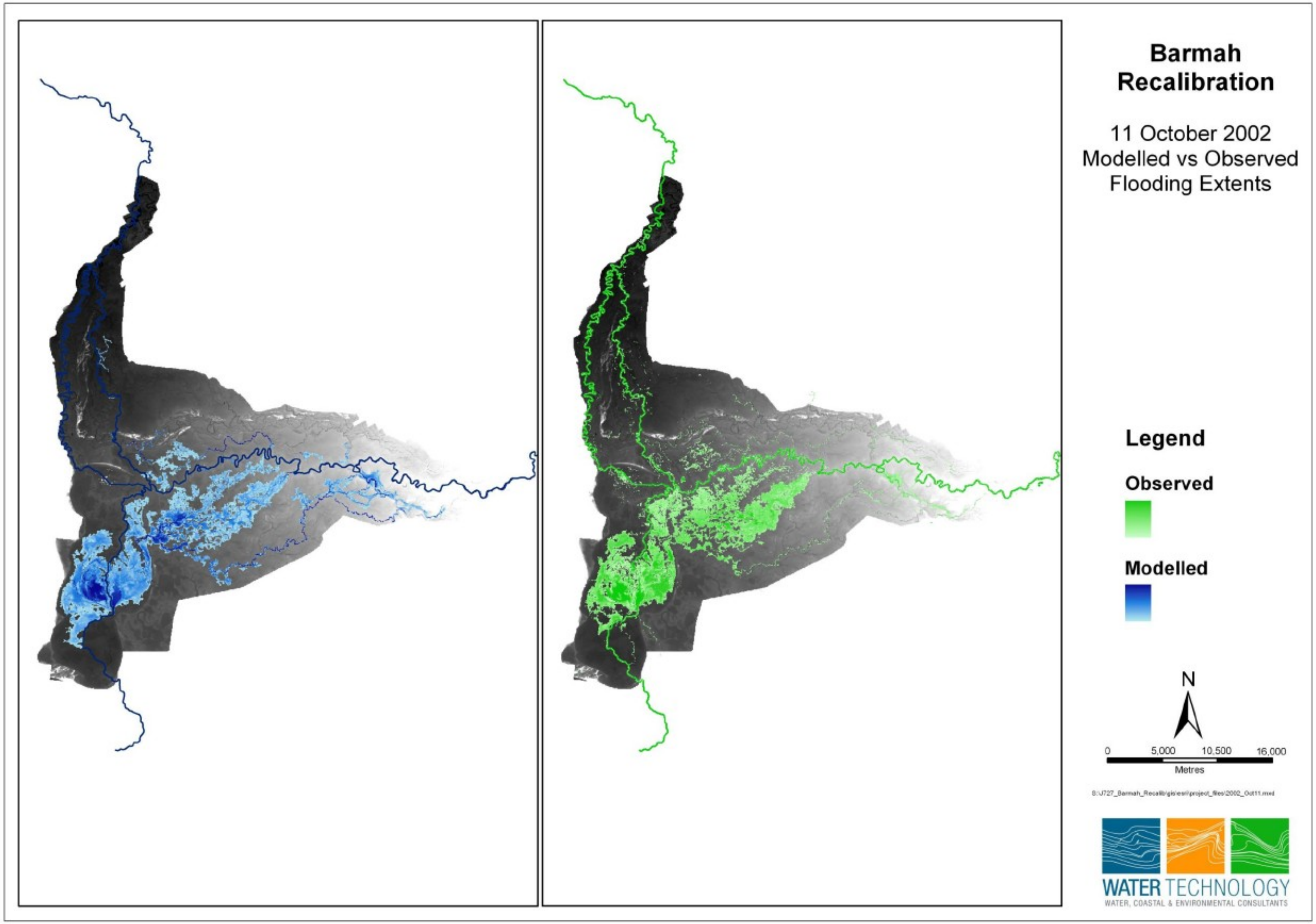


Figure 5-13 11th October 2002 Modelled vs Observed Flooding Extents

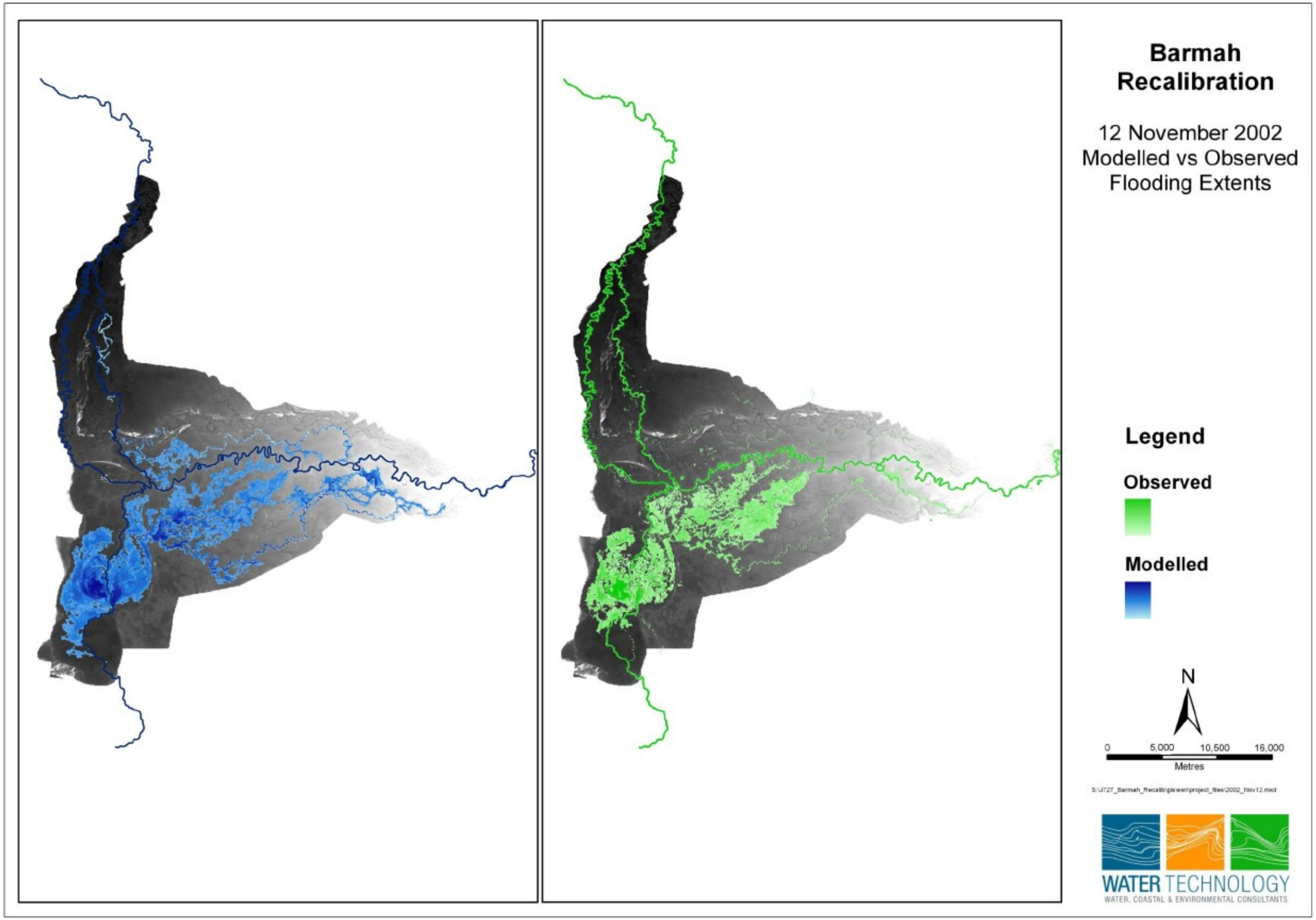


Figure 5-14 12th November 2002 Modelled vs Observed Flooding Extents

5.3 October – December 2005

During spring 2005 moderate flows in the River Murray, originating predominately from the Ovens catchment, initiated overbank flooding into the Barmah-Millewa Forest. This catchment flooding was supplemented in late October and November with increased discharges from the Hume Reservoir drawn from the Environmental Water Allocation (EWA) for the Barmah–Millewa Forest. The spring 2005 hydrograph at Tocumwal is presented in Figure 5-15.

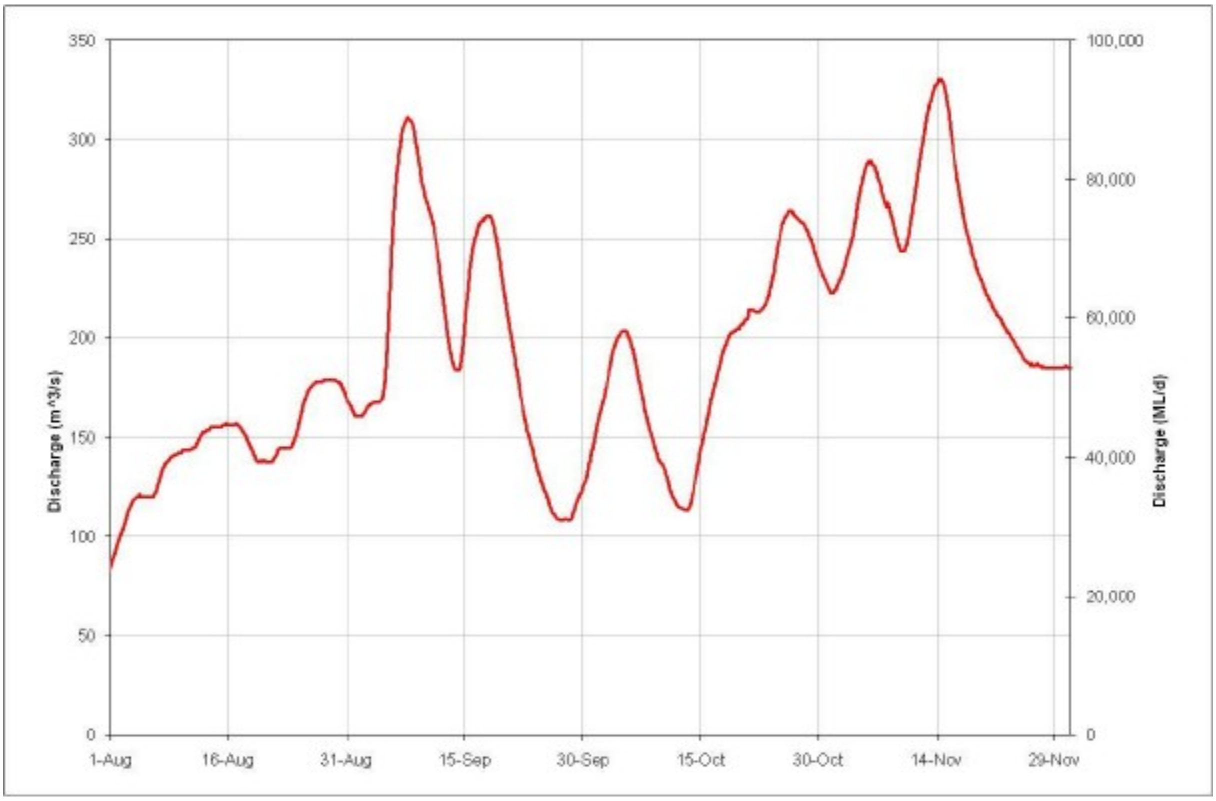


Figure 5-15 Spring 2005 Hydrograph at Tocumwal

The spring 2005 hydrograph at Tocumwal was applied to the upstream model flow boundary. The recorded water level at Stevens Weir on the Edward River at Deniliquin (gauge 409003) was applied to the downstream model boundary on the Edward River. The rating curve at Lower Moira (gauge 409221) was applied to the downstream model boundary on the River Murray at Lower Moira

The regulator operation records during 2005 for both the NSW and Victorian regulators were sourced from the MDBC. These operation records were implemented in the hydraulic model as time controllers to reproduce the regulator operations during the spring 2005 period.

5.3.1 Calibration Results

The model results have been compared against available gauge records in Figure 5-16 through to Figure 5-26. The model flood extent results have been compared to satellite derived flooding extents in Figure 5-28 and Figure 5-29.

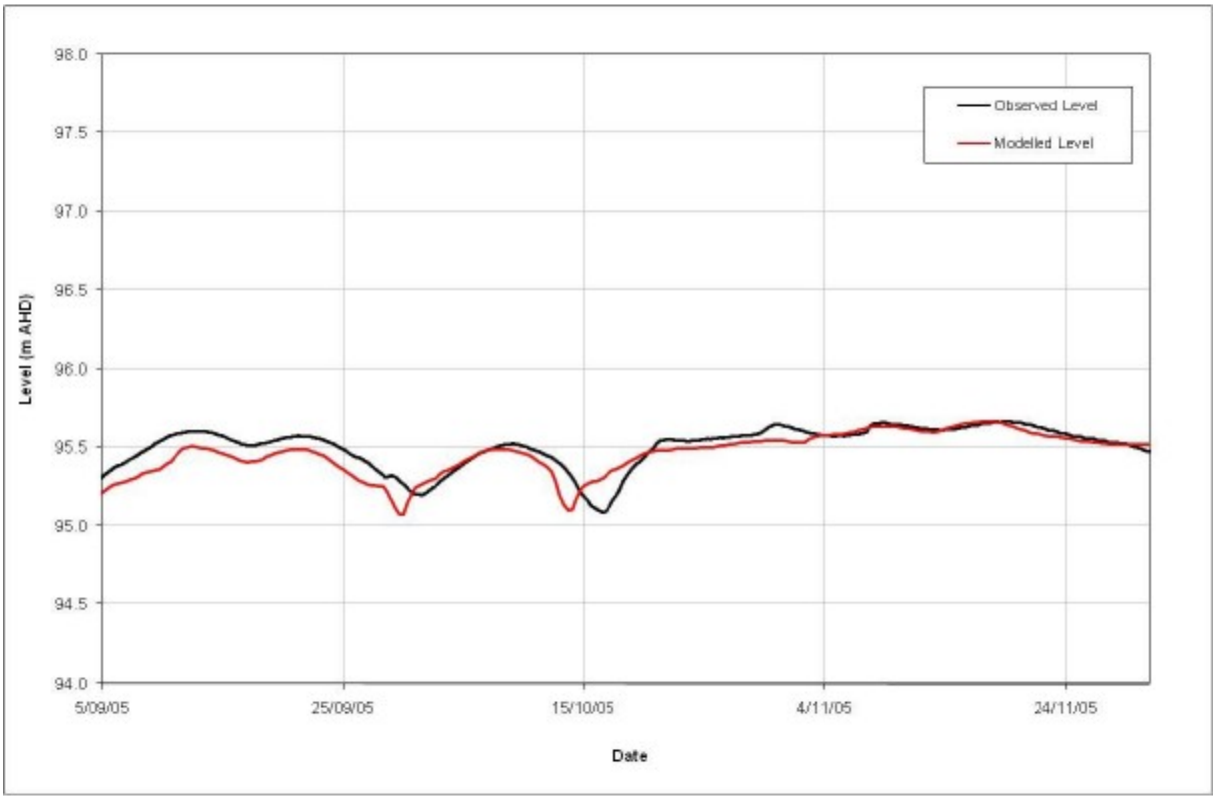


Figure 5-16 409229A Wild Dog Creek at Douglas Swamp

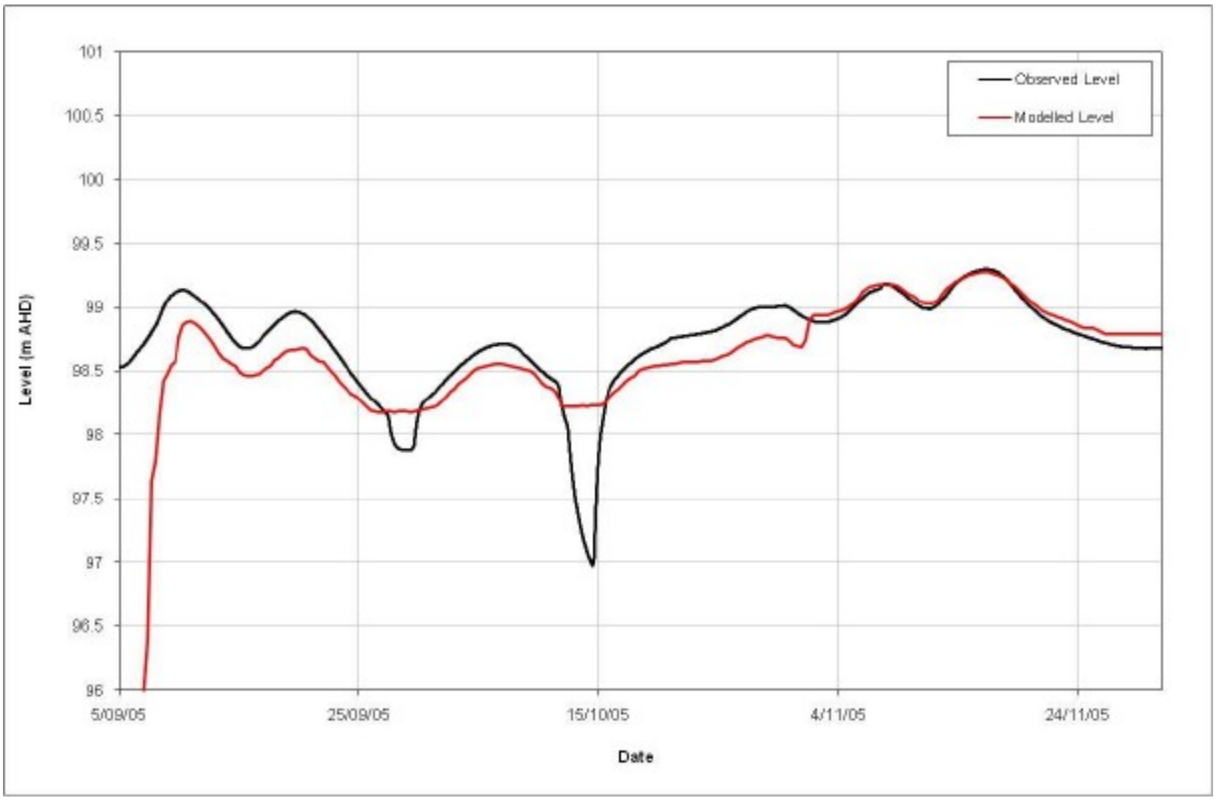


Figure 5-17 409226 Toupna Creek at Murhpy's Crossing

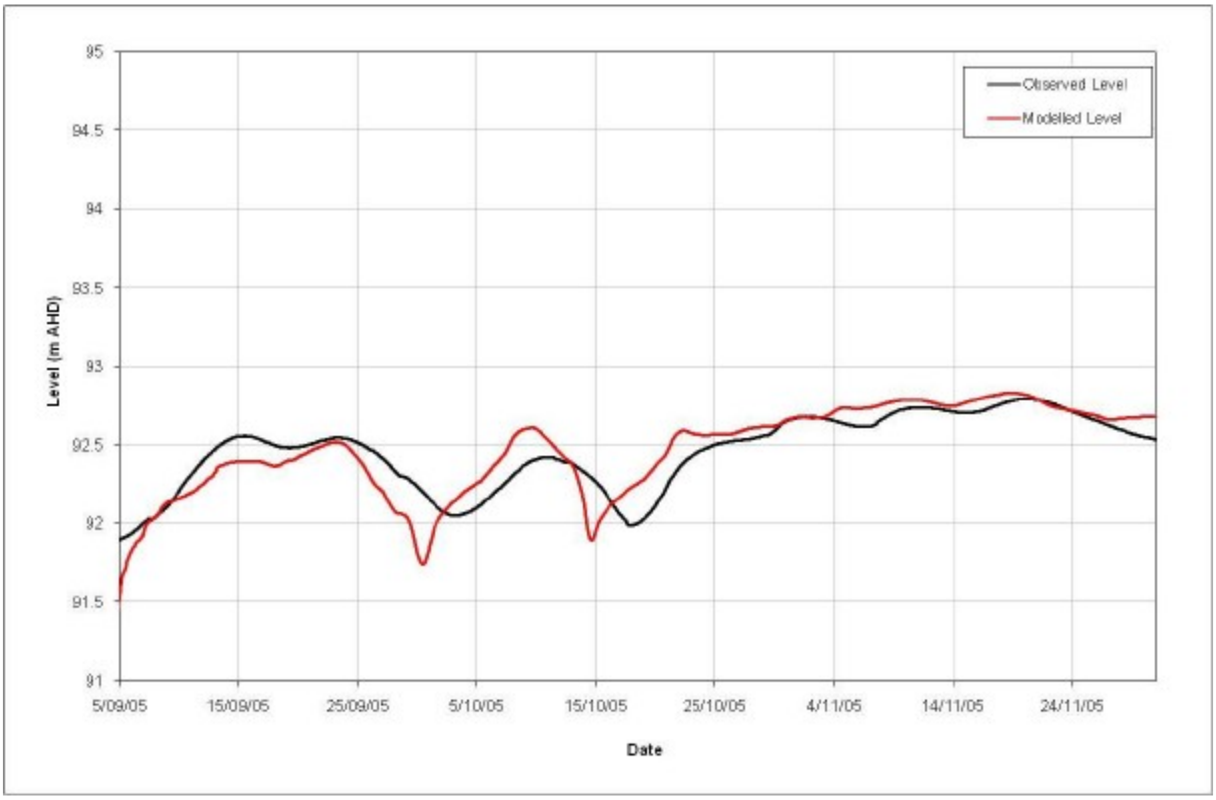


Figure 5-18 409224 Edward River at Taylor's Bridge

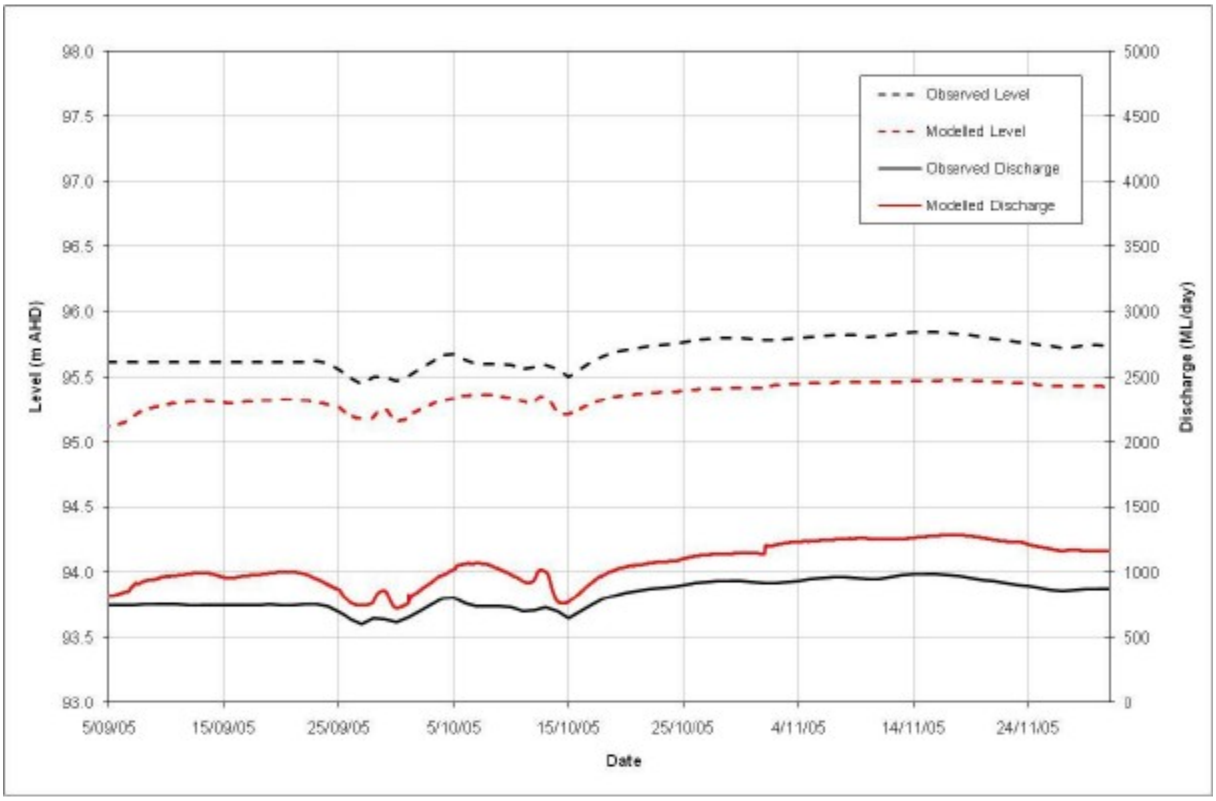


Figure 5-19 409030 Gulpa Creek at Offtake

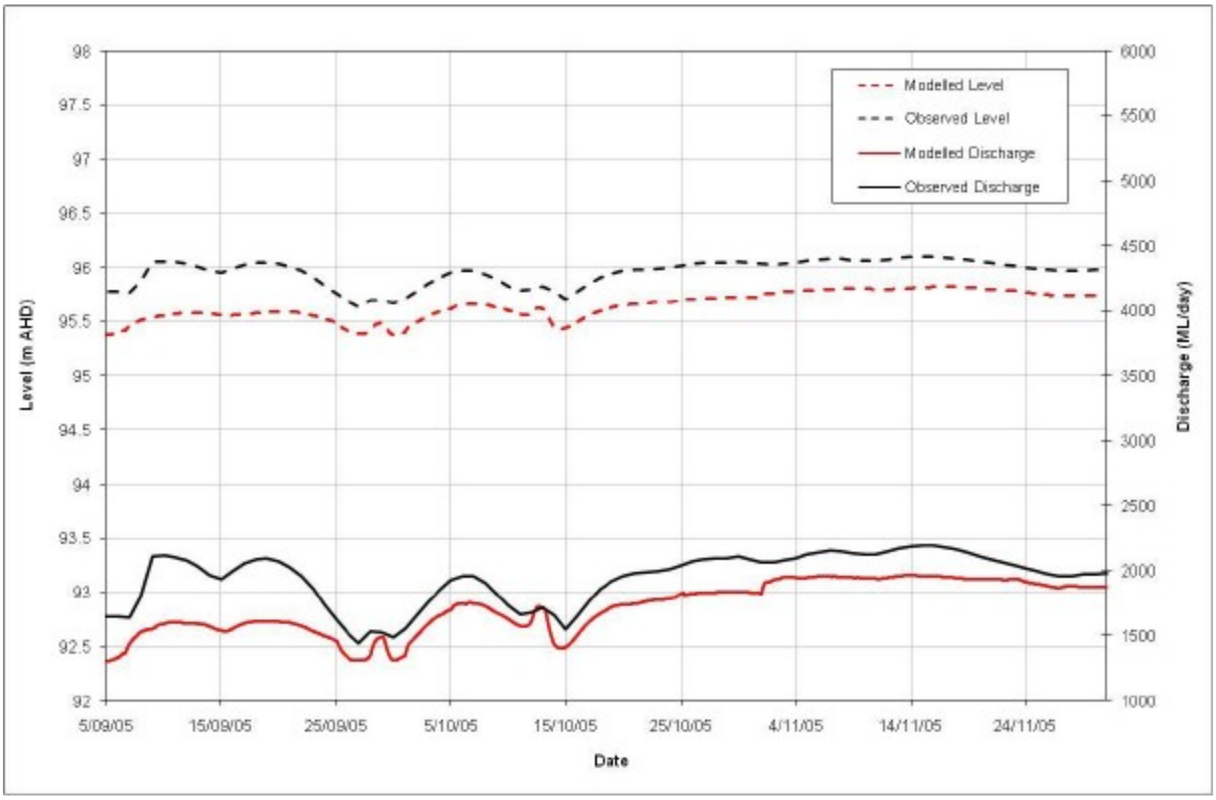


Figure 5-20 409008 Edward River at Offtake

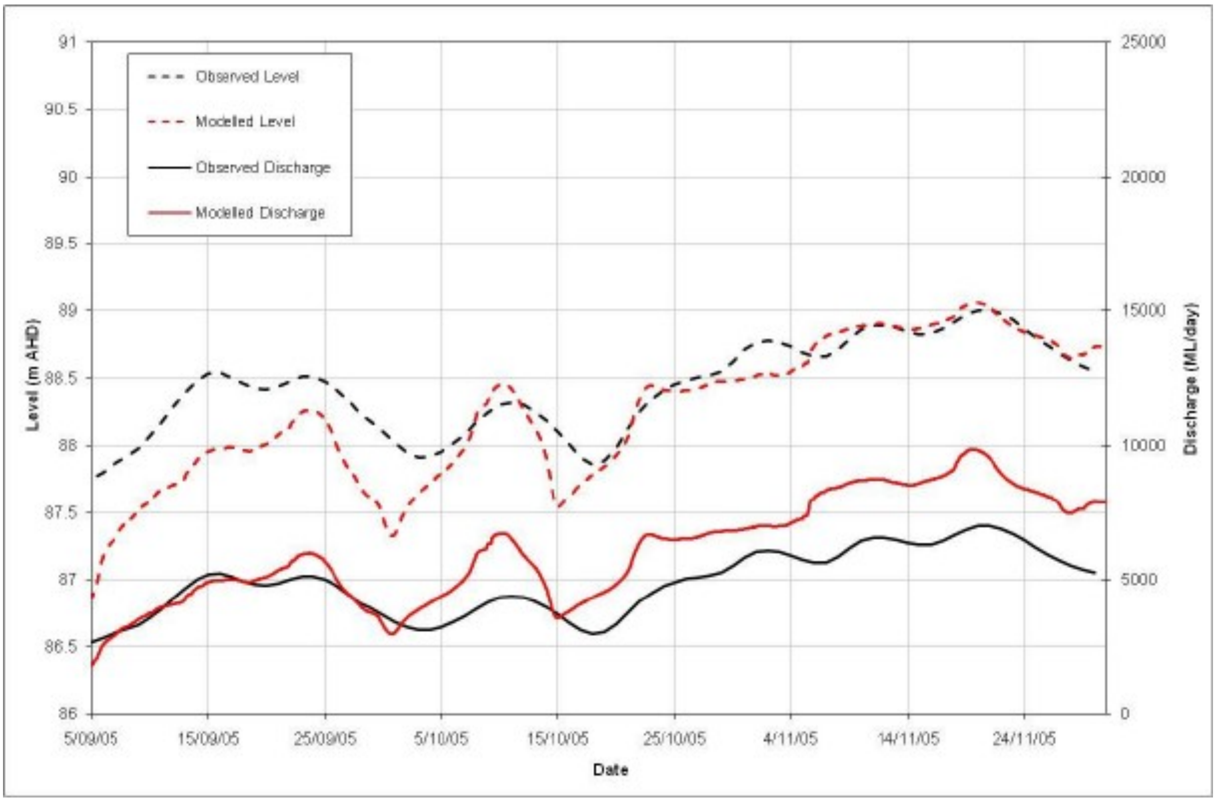


Figure 5-21 409047 Edward River at Toonalook

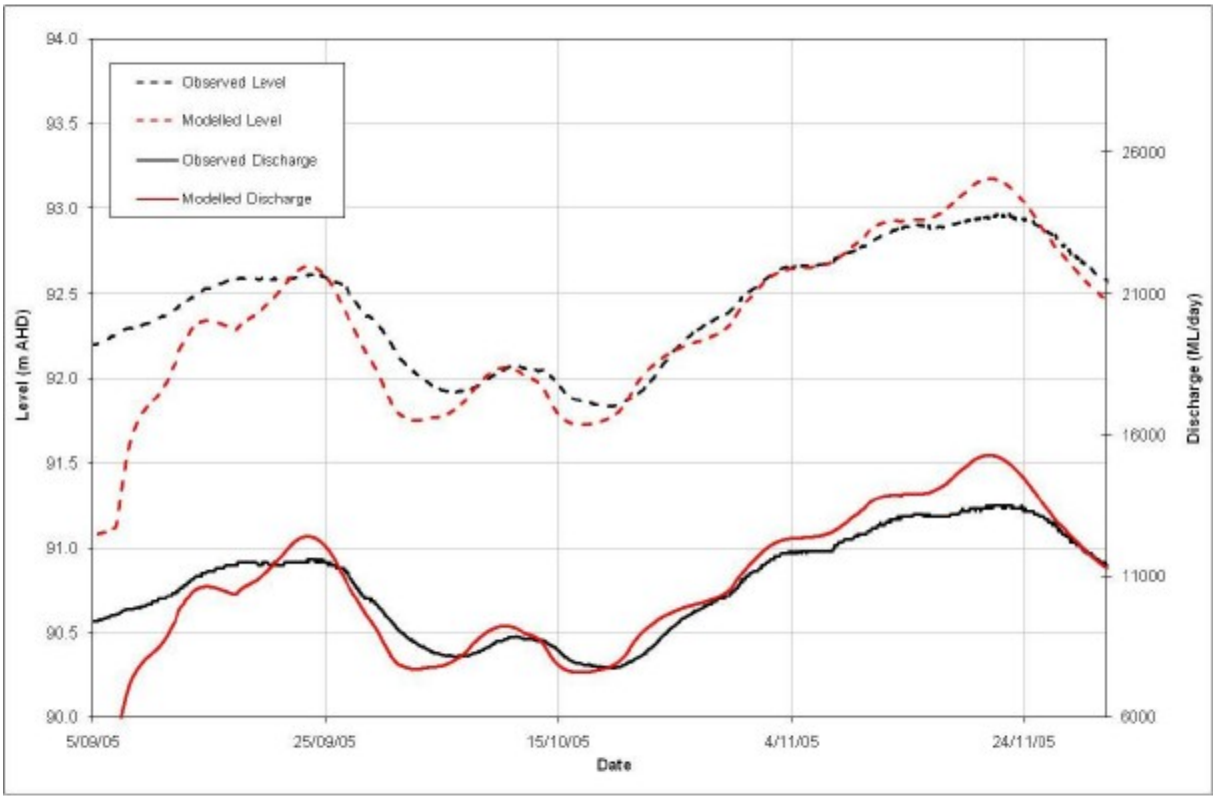


Figure 5-22 409215 River Murray at Barmah

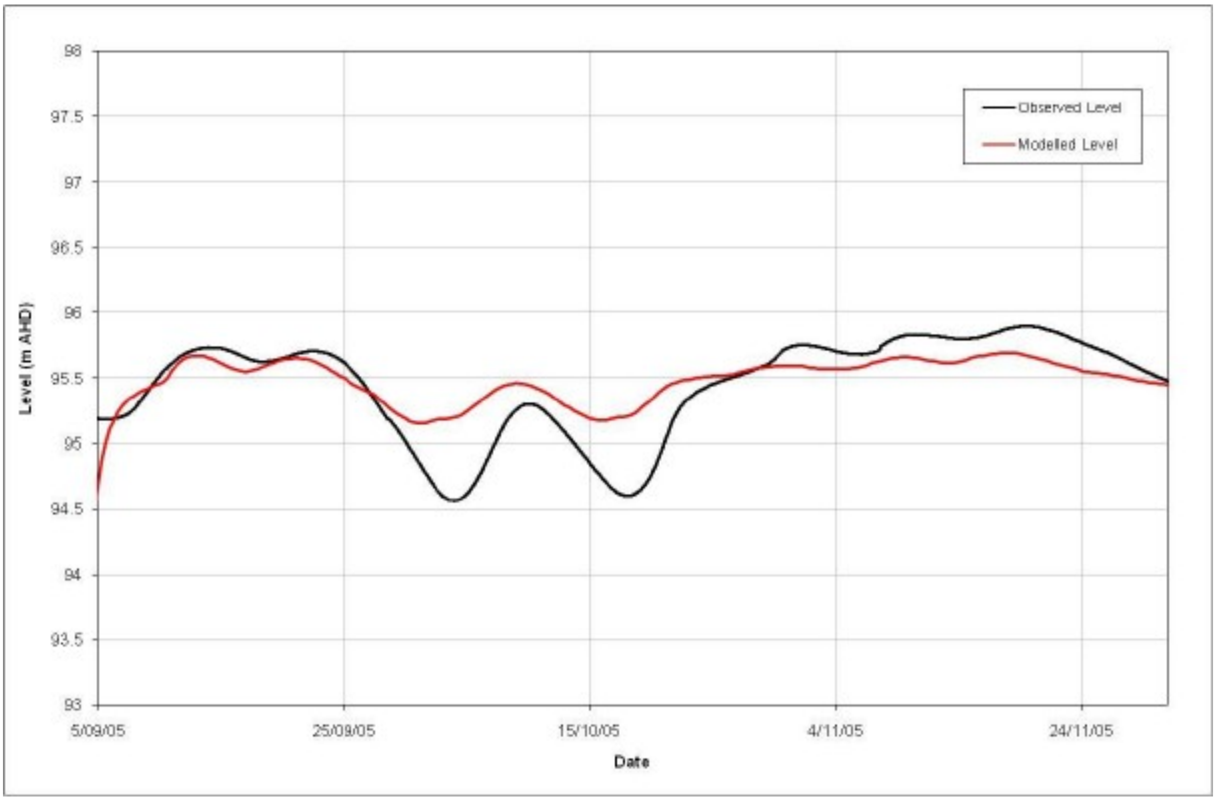


Figure 5-23 409396 Budgee Creek at Sand Ridge Track

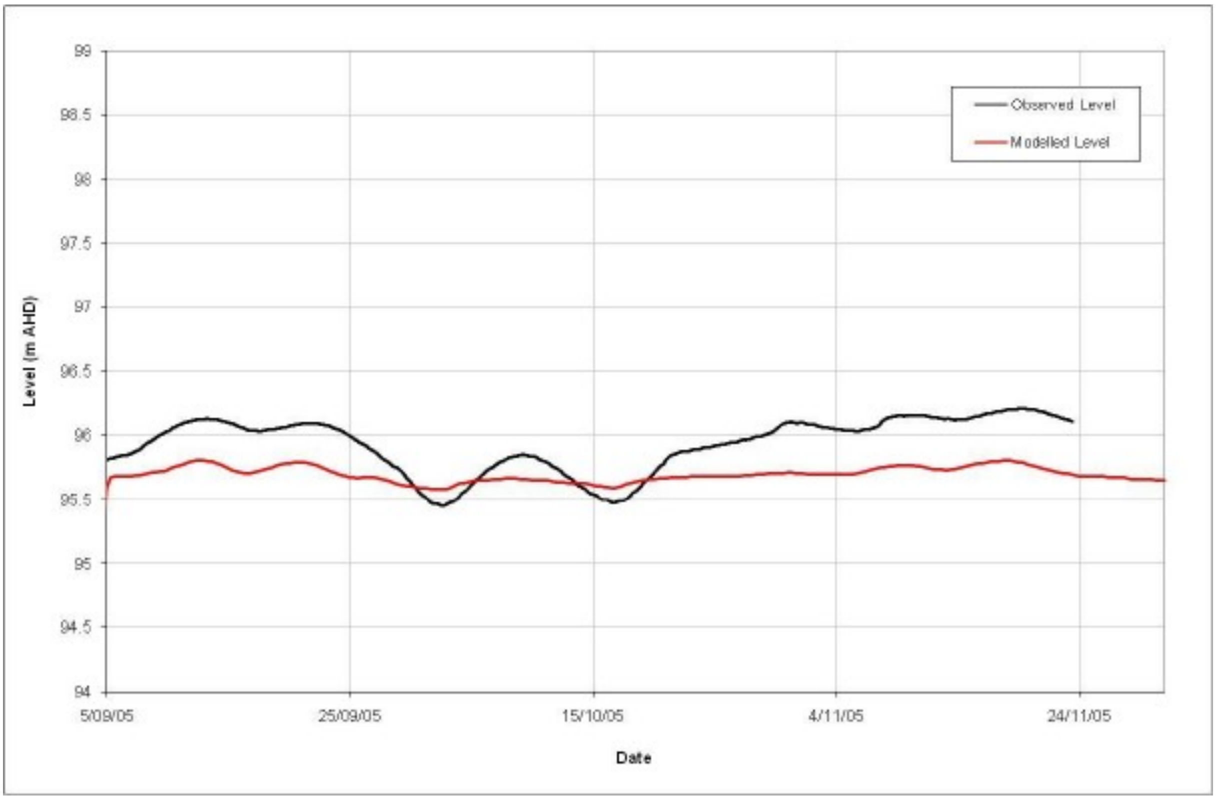


Figure 5-24 409394 Snag Creek at Gowers Track

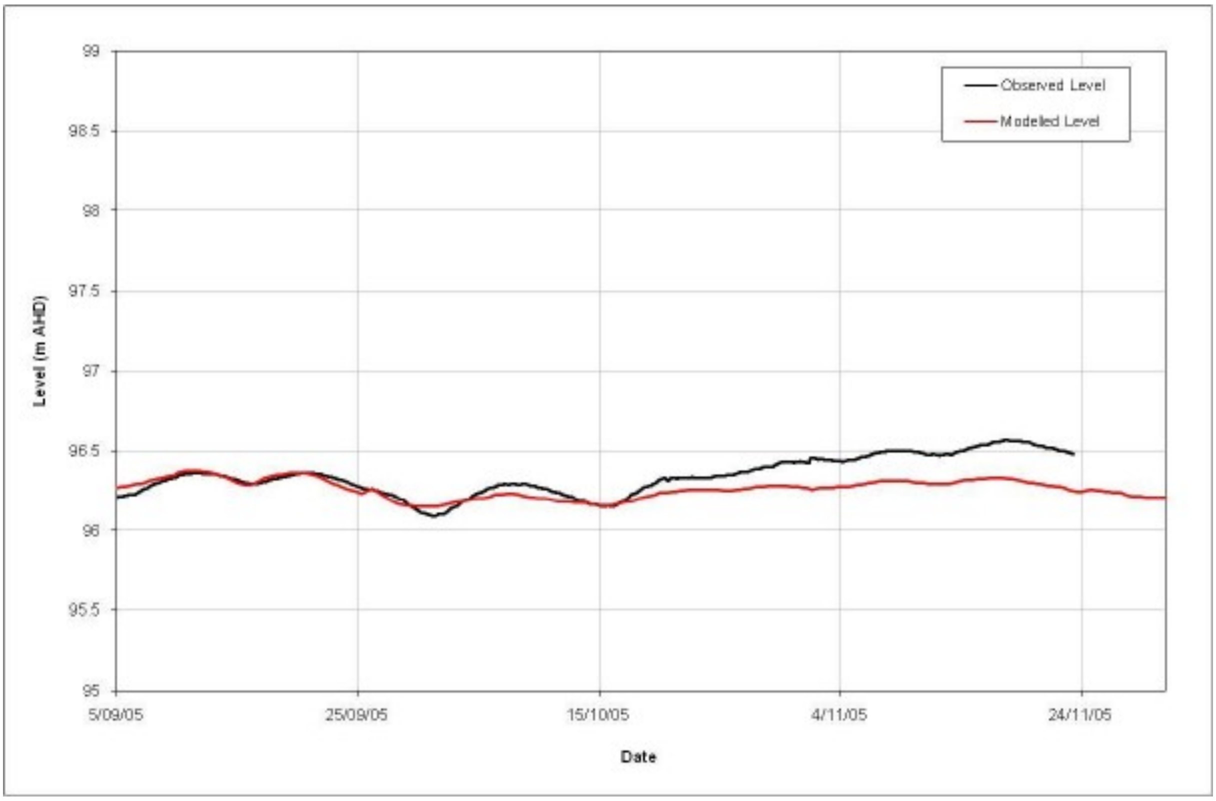


Figure 5-25 409393 Gulf Creek at Lone Pine Track

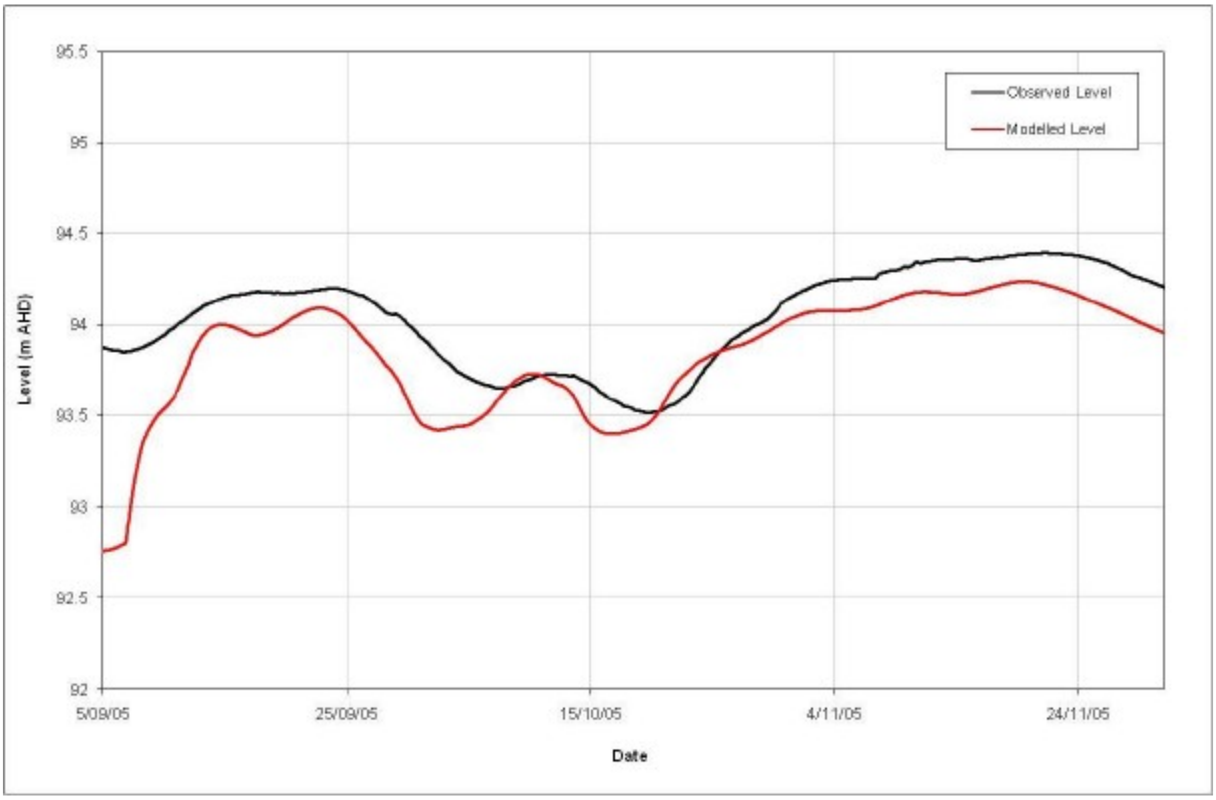


Figure 5-26 409232 Moira Creek at Moira Lake

Cumulative modelled and observed mass curves have been compared on the River Murray at the Barmah gauge in Figure 5-27.

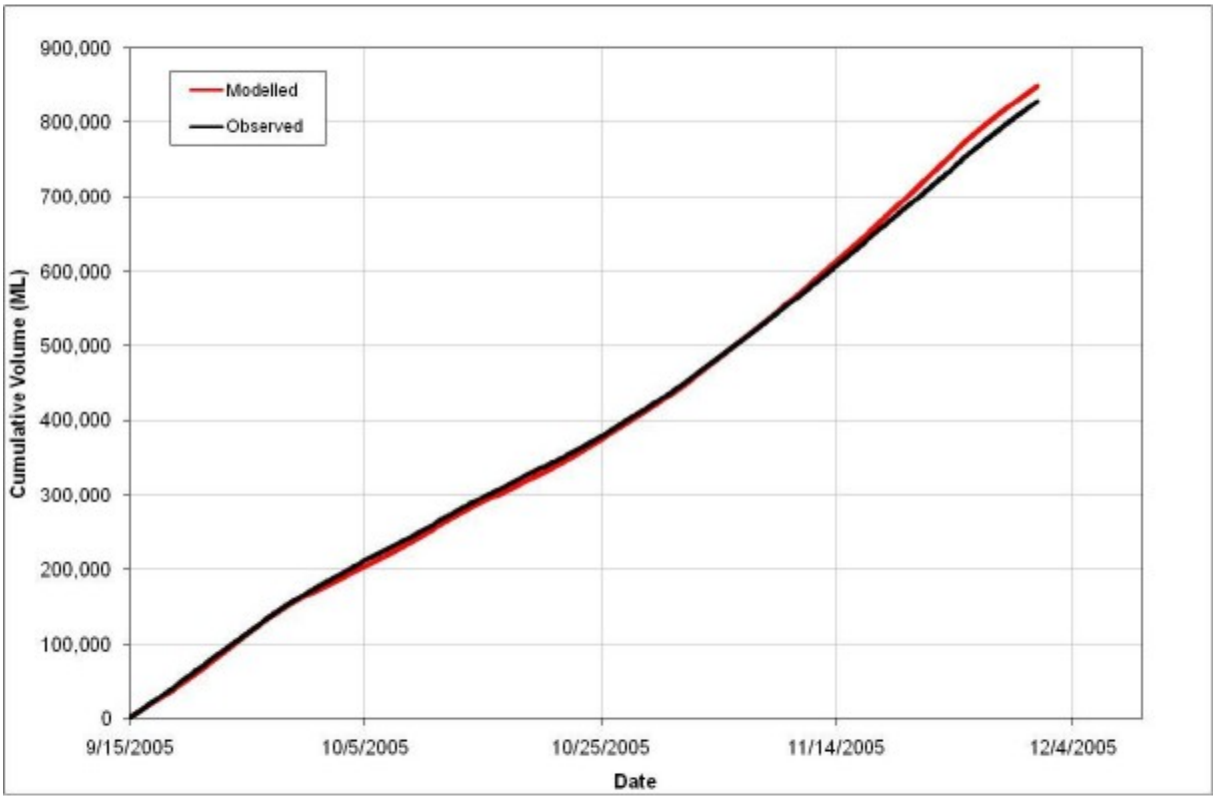


Figure 5-27 Comparison of Cumulative Mass Curve River Murray at Barmah (409215)

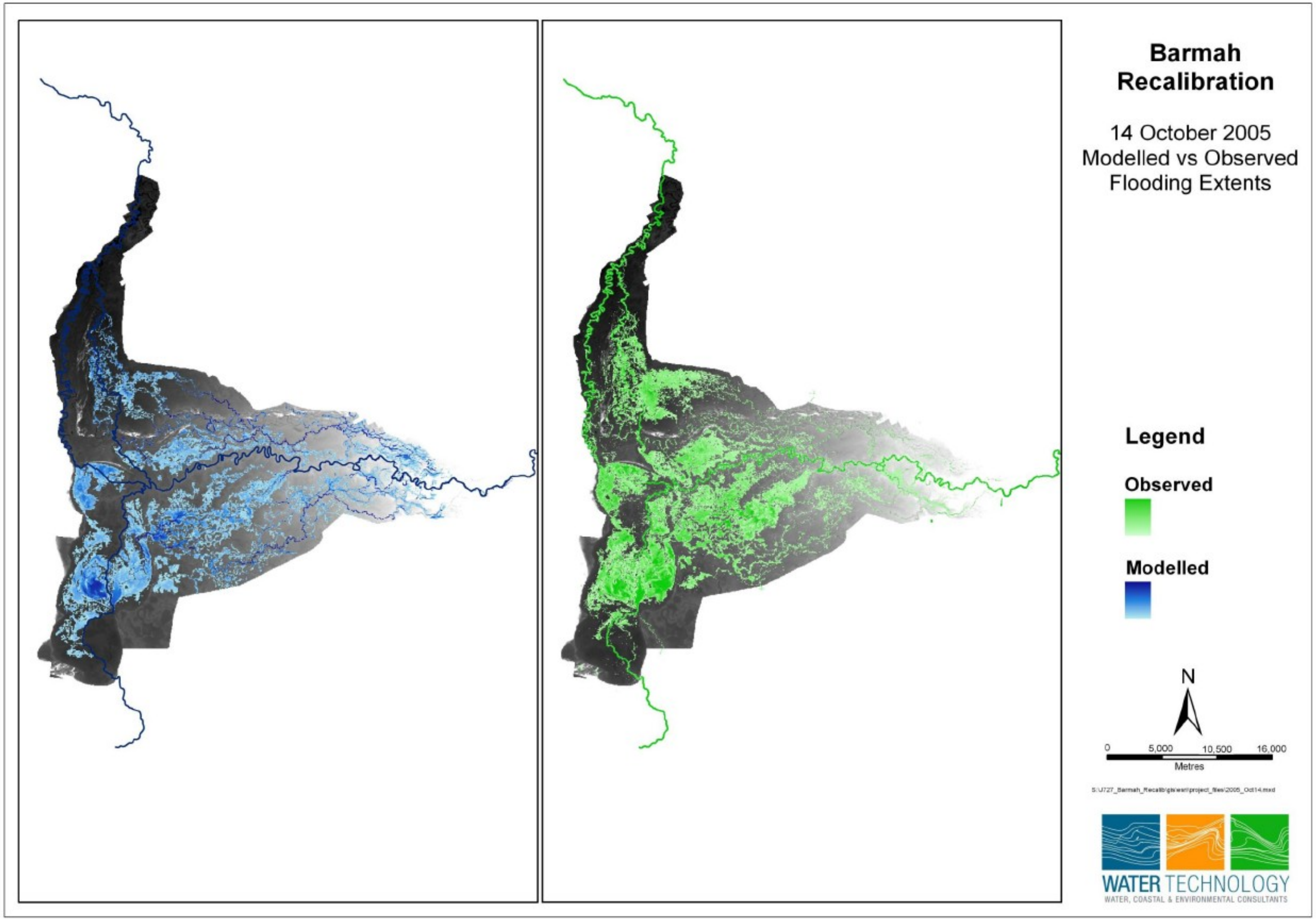


Figure 5-28 14th October 2005 Modelled vs Observed Flooding Extents

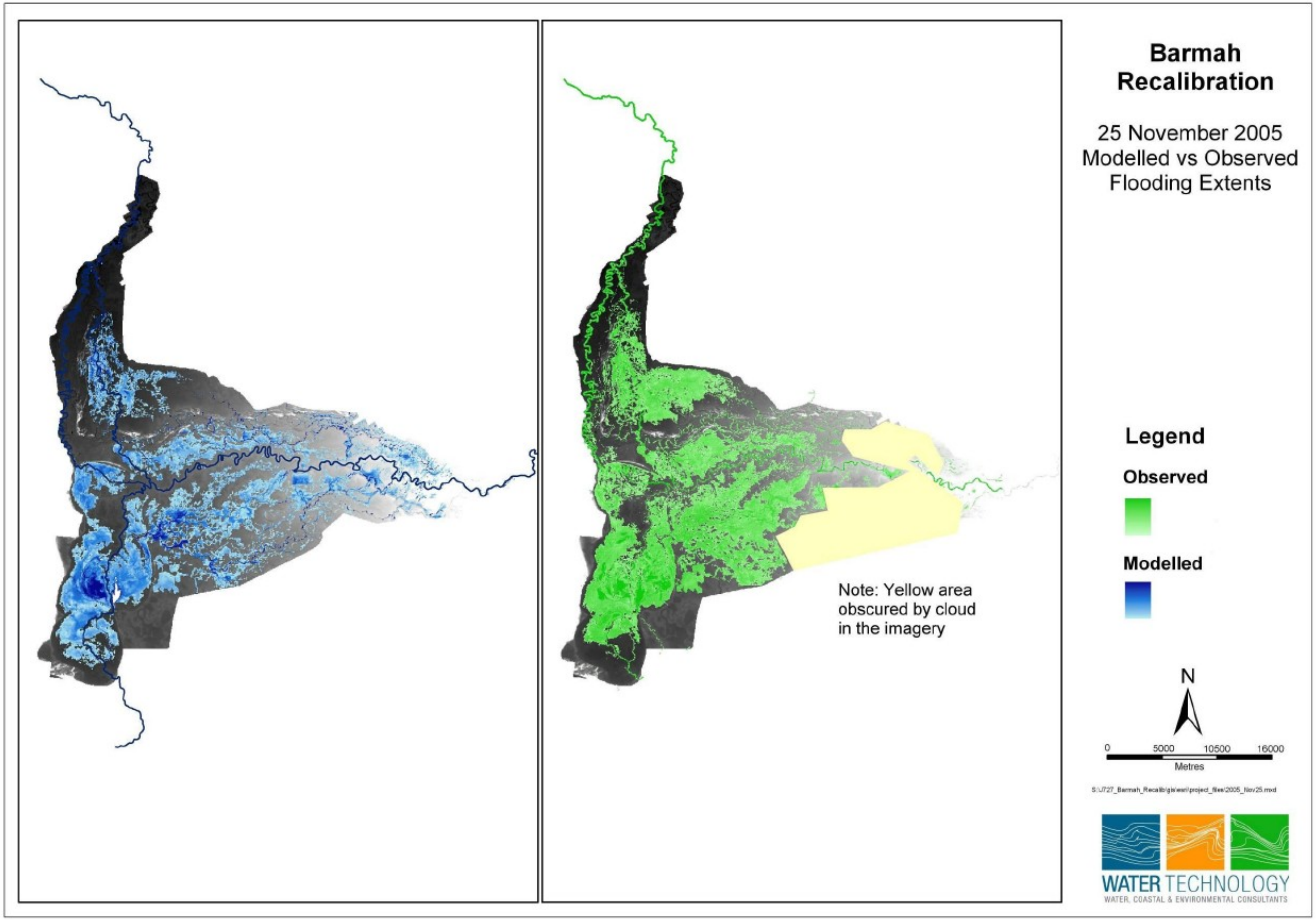
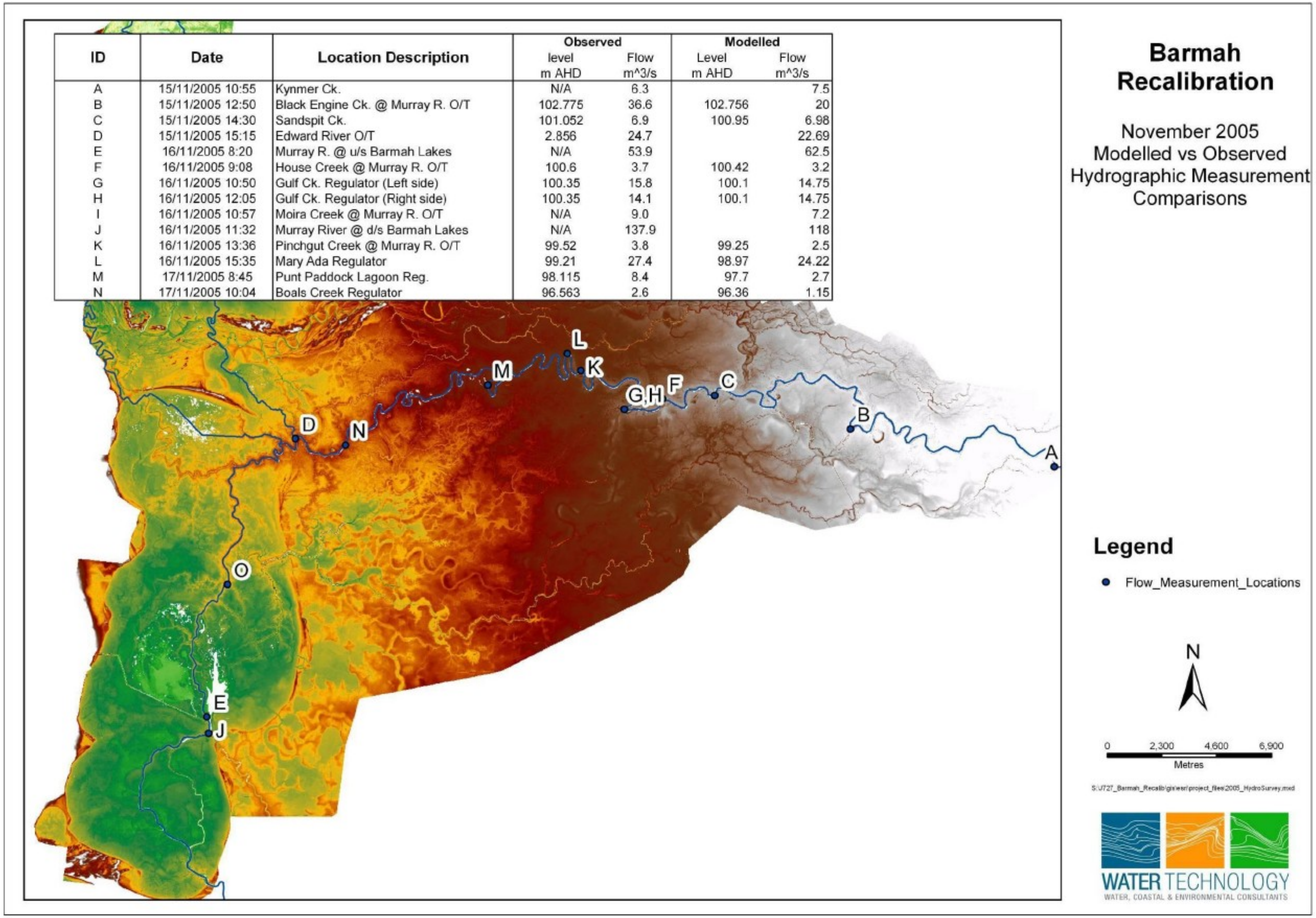


Figure 5-29 25th November 2005 Modelled vs Observed Flooding Extents



ID	Date	Location Description	Observed level m AHD	Observed Flow m^3/s	Modelled Level m AHD	Modelled Flow m^3/s
A	15/11/2005 10:55	Kynmer Ck.	N/A	6.3		7.5
B	15/11/2005 12:50	Black Engine Ck. @ Murray R. O/T	102.775	36.6	102.756	20
C	15/11/2005 14:30	Sandspit Ck.	101.052	6.9	100.95	6.98
D	15/11/2005 15:15	Edward River O/T	2.856	24.7		22.69
E	16/11/2005 8:20	Murray R. @ u/s Barmah Lakes	N/A	53.9		62.5
F	16/11/2005 9:08	House Creek @ Murray R. O/T	100.6	3.7	100.42	3.2
G	16/11/2005 10:50	Gulf Ck. Regulator (Left side)	100.35	15.8	100.1	14.75
H	16/11/2005 12:05	Gulf Ck. Regulator (Right side)	100.35	14.1	100.1	14.75
I	16/11/2005 10:57	Moira Creek @ Murray R. O/T	N/A	9.0		7.2
J	16/11/2005 11:32	Murray River @ d/s Barmah Lakes	N/A	137.9		118
K	16/11/2005 13:36	Pinchgut Creek @ Murray R. O/T	99.52	3.8	99.25	2.5
L	16/11/2005 15:35	Mary Ada Regulator	99.21	27.4	98.97	24.22
M	17/11/2005 8:45	Punt Paddock Lagoon Reg.	98.115	8.4	97.7	2.7
N	17/11/2005 10:04	Boals Creek Regulator	96.563	2.6	96.36	1.15

Figure 5-30 Comparison of Model Results with 2005 Hydrographic Measurements

5.4 October – November 2000

The recorded discharge hydrograph at Tocumwal was applied to the upstream model boundary from the 20th September until the 1st December. The inflow hydrograph at Tocumwal is presented in Figure 5-1. Broken Creek flows at Rices Weir (404210) during the period were also applied to the model. It is understood the Stevens Weir boards on the Edward River were in place during this flood and therefore the recorded level at Deniliquin (409003) has been applied to the downstream model boundary on the Edward River. The rating curve at Lower Moira (409221) was applied to the downstream model boundary on the River Murray at Lower Moira. Average monthly evapotranspiration values for the Barmah-Millewa forest were also applied to the model.

It is noted that inflows from Deep Creek into the River Murray occurred during late November and some back up of the River Murray is evident in the gauge records at Barmah. The extent of these inflows from Deep Creek has not been determined however and these flows have therefore not been able to be modelled as part of the calibration event. It is considered that the magnitude and relative influence of the flows from Deep Creek during the spring 2000 flood was small. This absence of Deep Creek inputs is only expected to have a minor impact on the ability of the model to reproduce the flooding behaviour experienced at Barmah during this flood.

5.4.1 Calibration Results

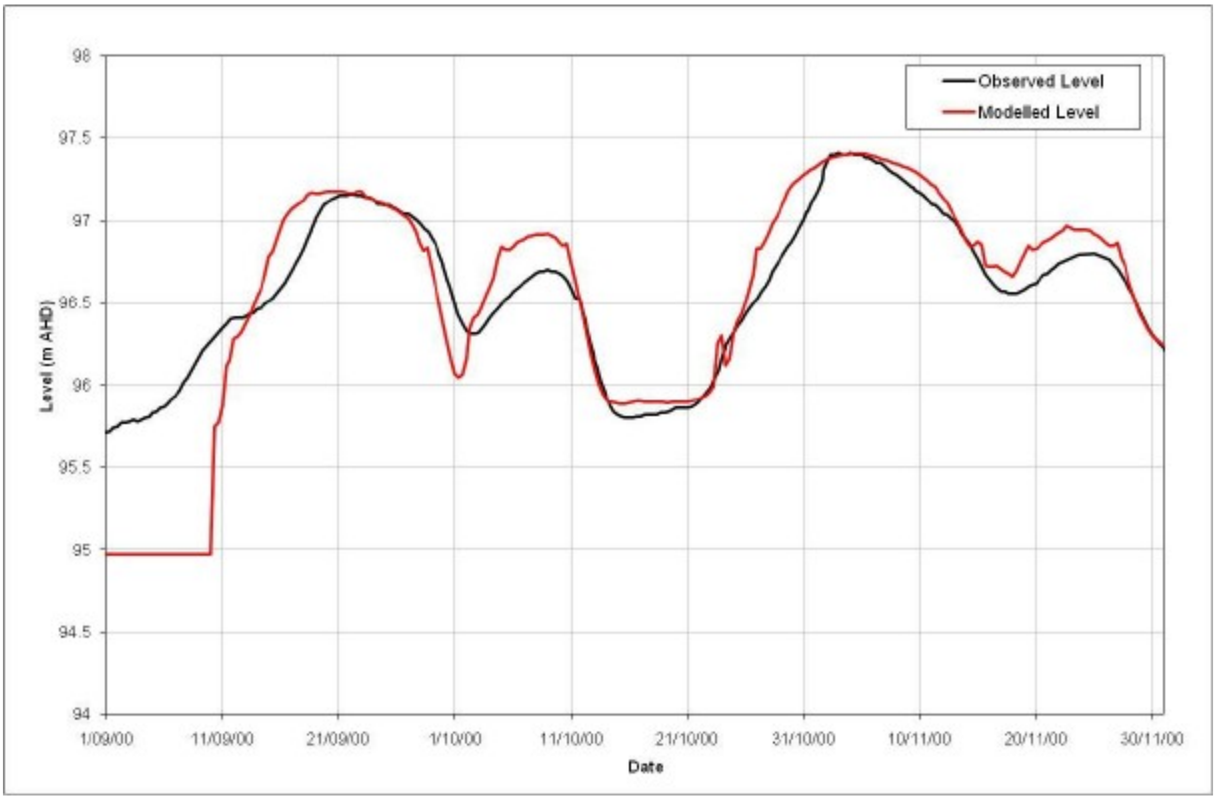


Figure 5-31 409225A Towrong Creek at Tocumwal Road

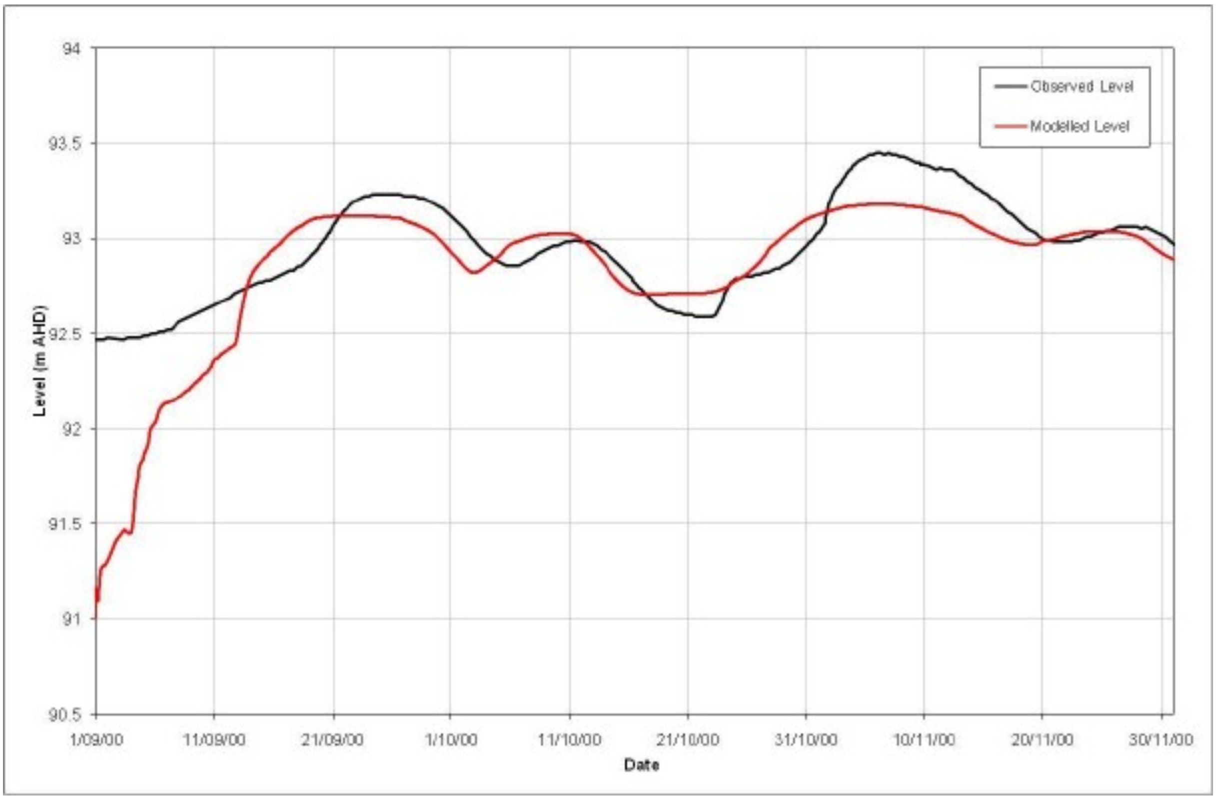


Figure 5-32 409224 Edward River at Taylors Bridge

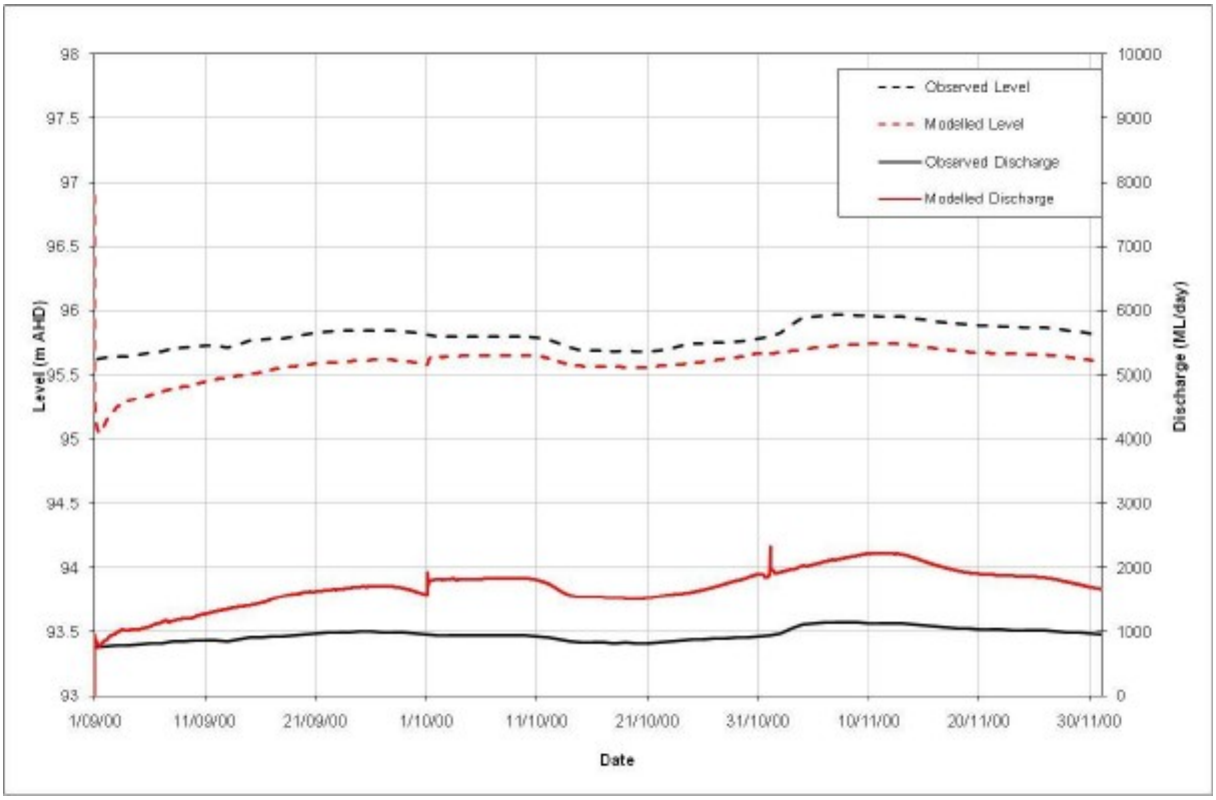


Figure 5-33 409030 Gulpa Creek at Offtake

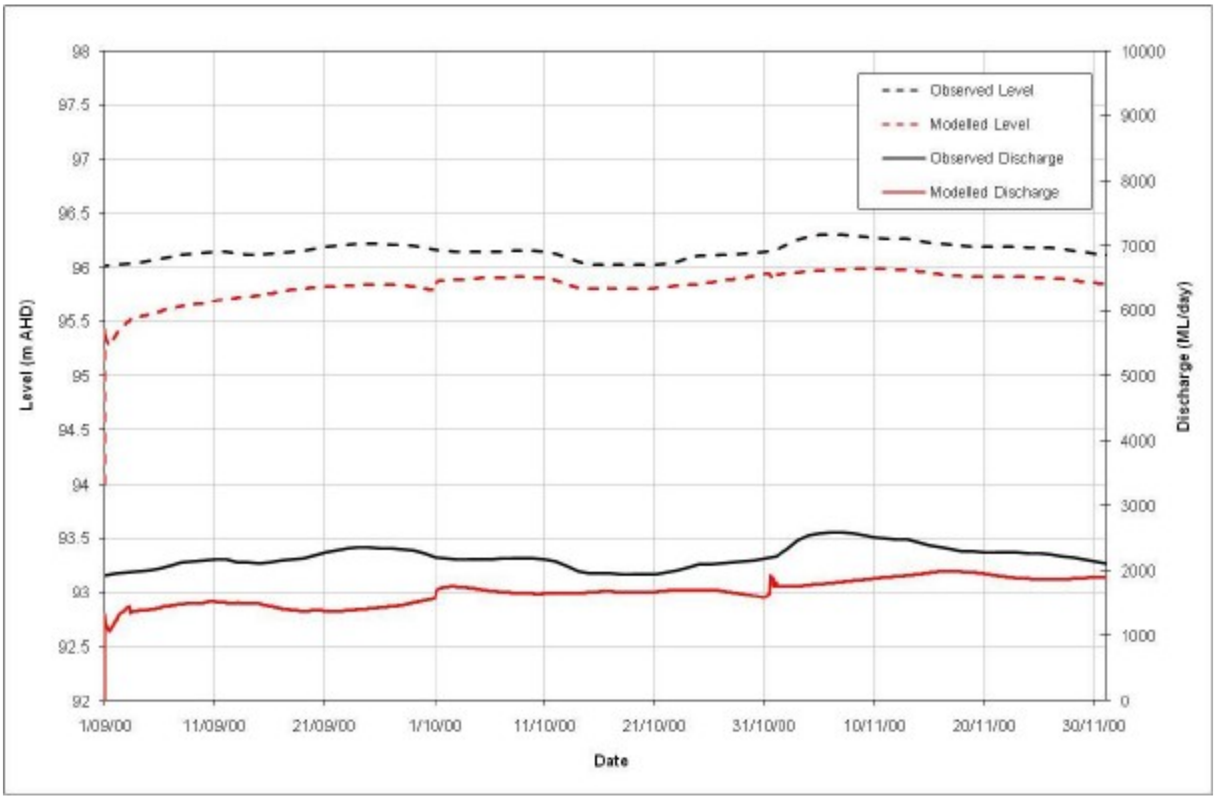


Figure 5-34 409008 Edward River at Offtake

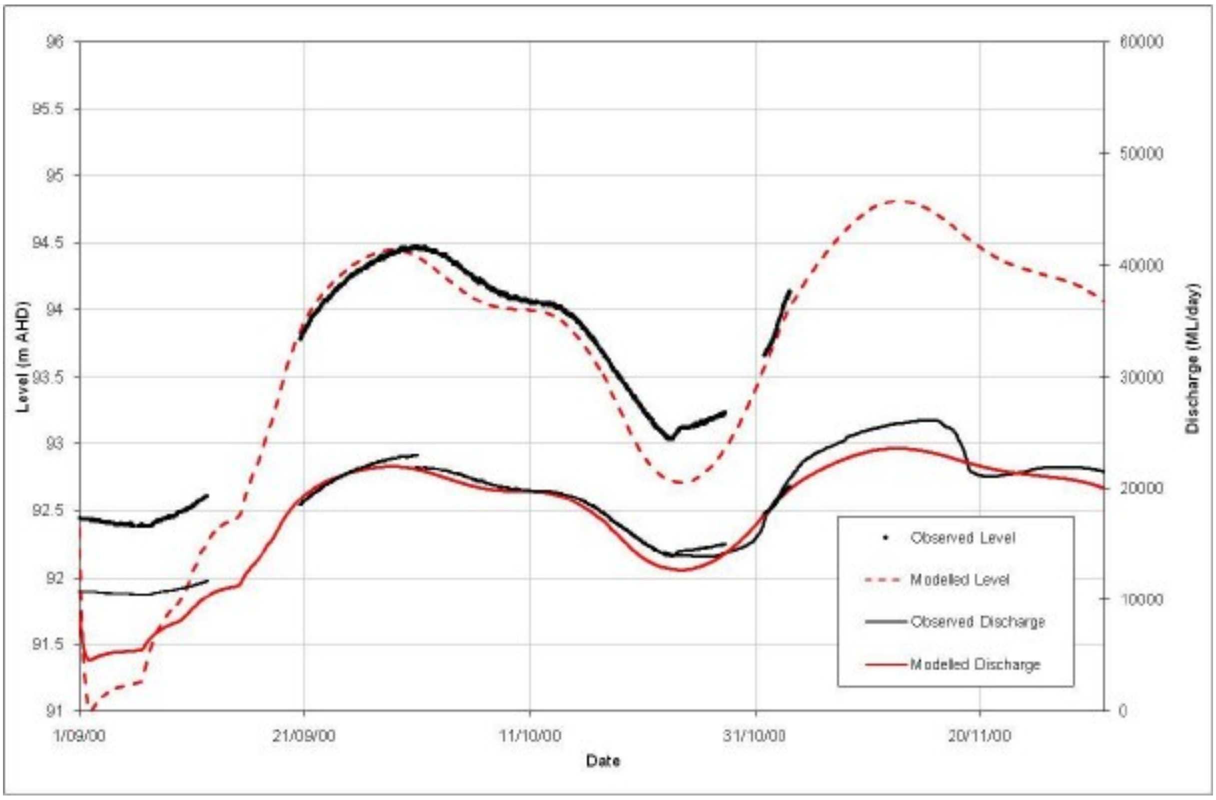


Figure 5-35 409215 River Murray at Barmah

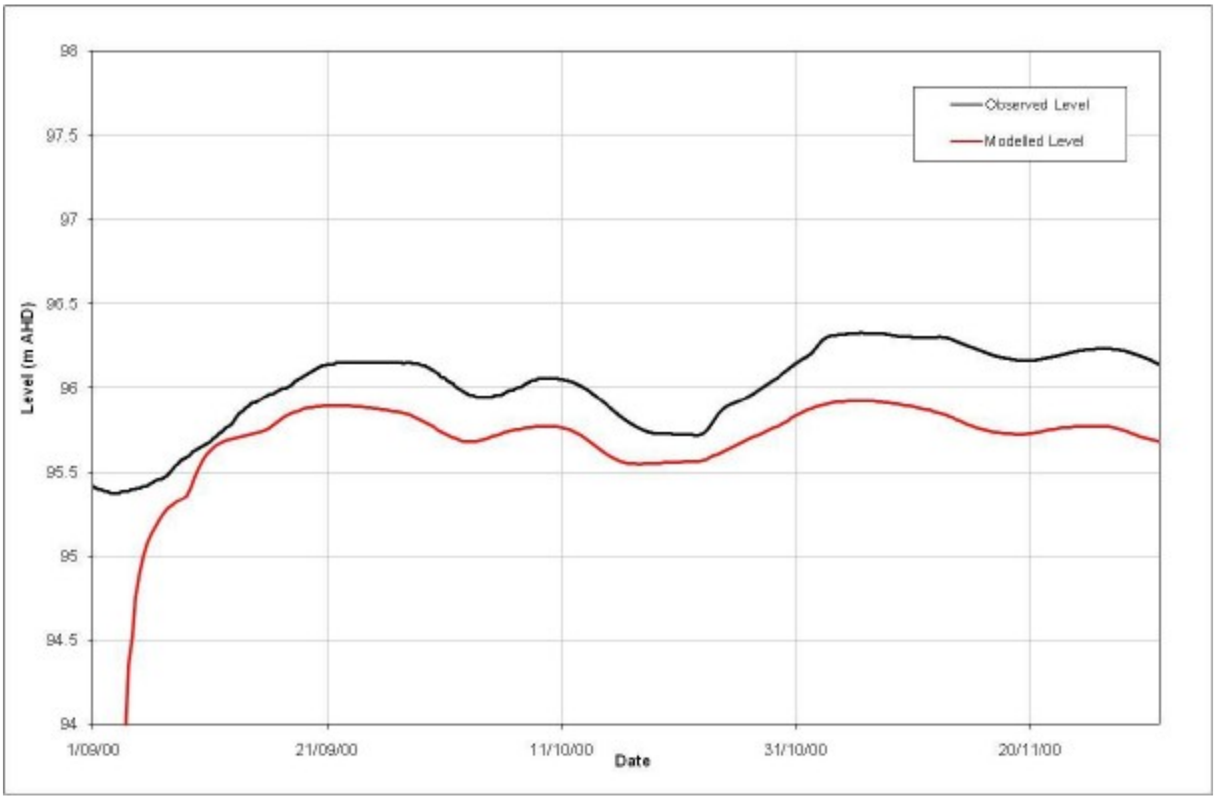


Figure 5-36 409396 Budgee Creek at Sand Ridge Track

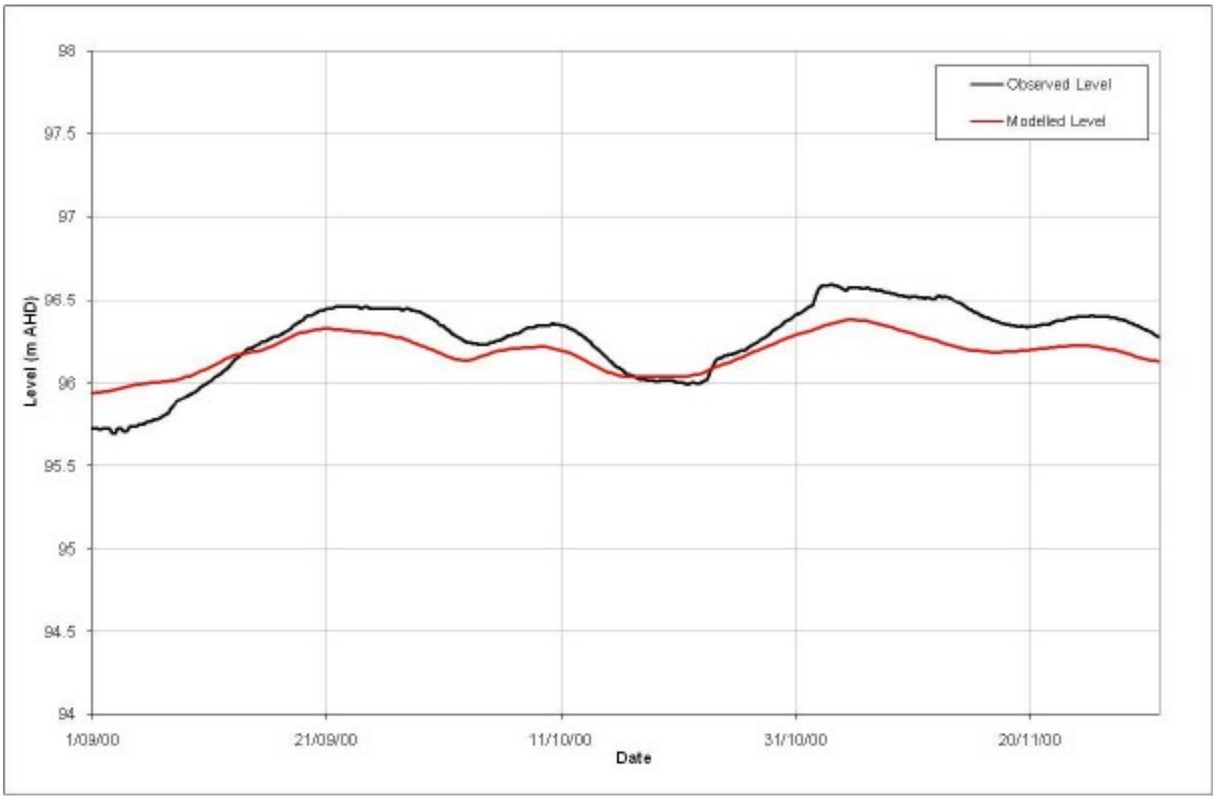


Figure 5-37 409394A Snag Creek at Gowers Track

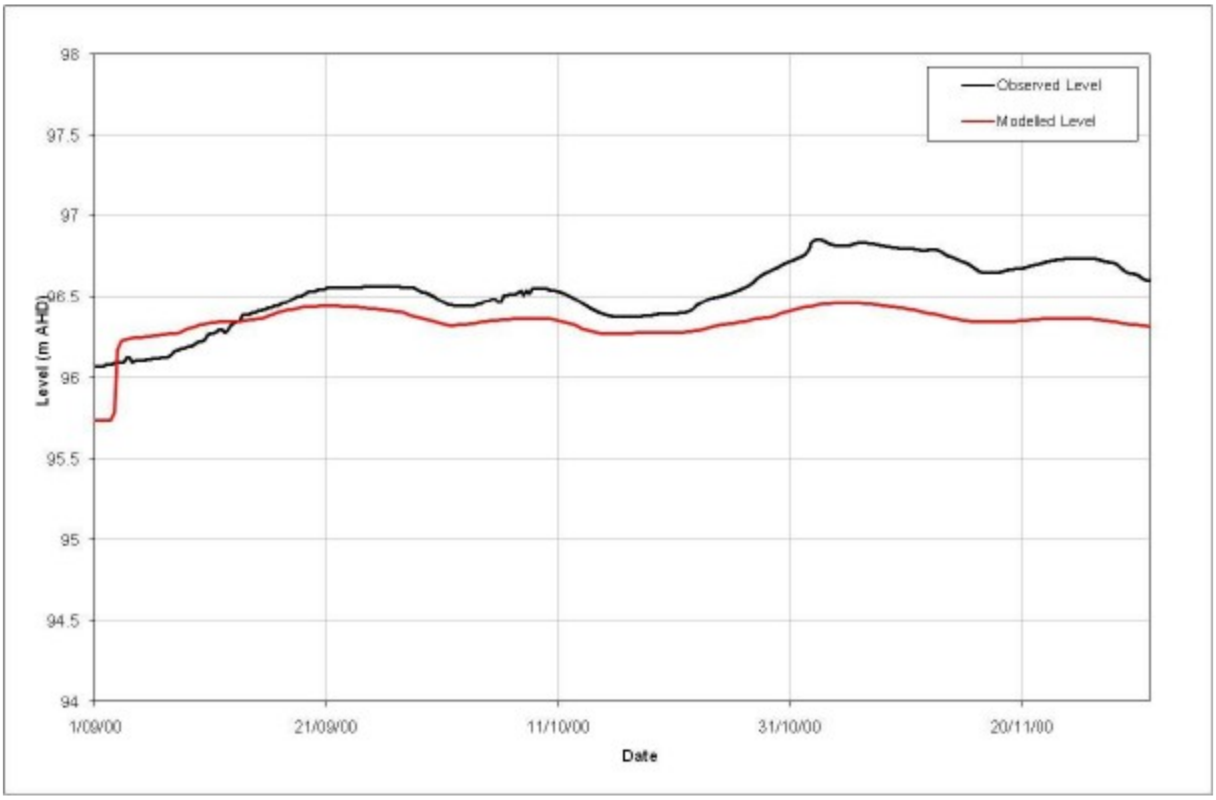


Figure 5-38 409393 Gulf Creek at Lone Pine Track

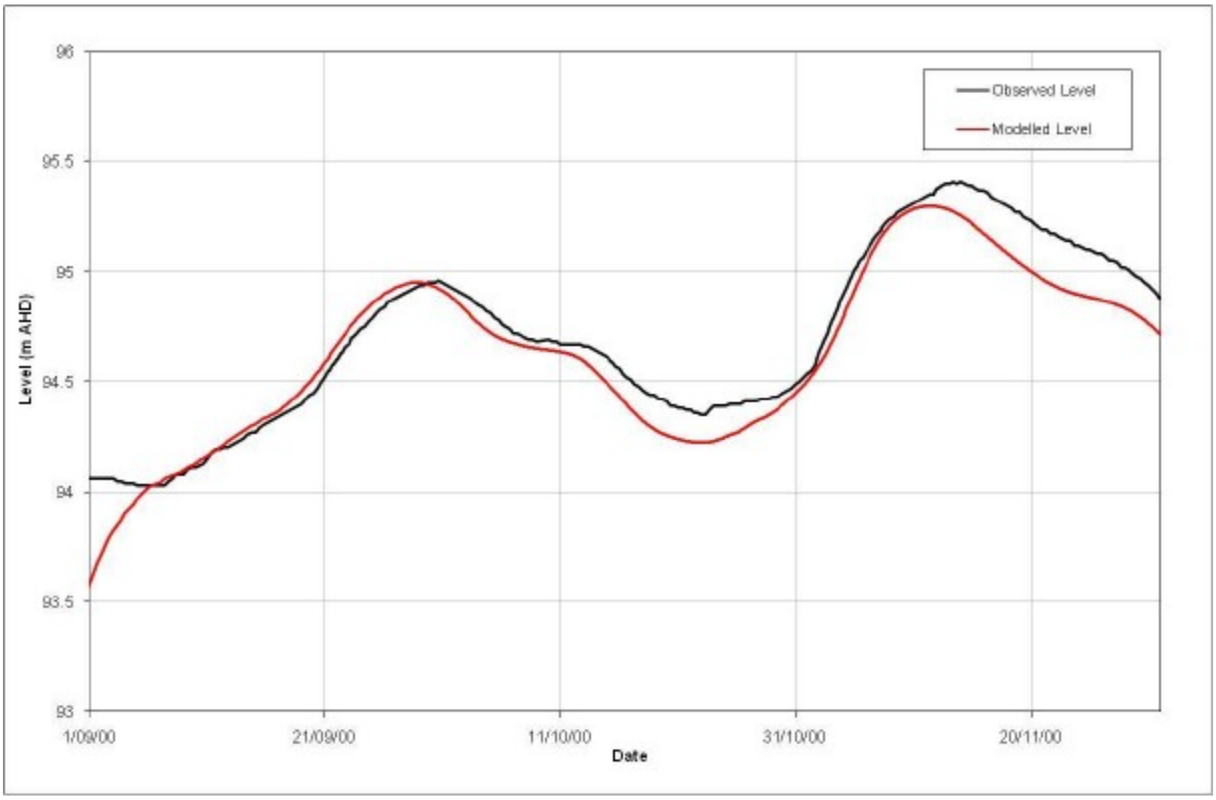


Figure 5-39 409232A Moira Creek at Moira Lake

6. DISCUSSION

Calibration of the model has been undertaken for three different flood flows of significantly different magnitudes, initial conditions and with different regulator operations. It is considered the level of agreement for all three floods between the observed and modelled flooding behaviour in terms of flood levels, discharges and flood extents is good considering the size and complexity of the study area being modelled. The degree of accuracy achieved by the model during the calibration process is considered more than adequate to enable very useful information on predicted flooding behaviour for various River Murray flow scenarios to be computed.

As with any modelling exercise of this nature the quality of the model outputs can only be expected to be as good as the quality of the inputs and the numerical scheme and inbuilt assumptions inherent in the hydraulic modelling process. Sources of uncertainty in the model process and other issues impacting the model results are discussed in the following sections.

6.1 Sources of Uncertainty

There are numerous contributing factors to the ultimate output uncertainty in a complex hydraulic modelling exercise such as that undertaken for the Barmah-Millewa floodplain. Some of the uncertainties relate to the data inputs, whilst others are dependent on the numerical modelling processes itself. Sources of output uncertainty related to the input data for the hydraulic modelling include:

- ALS data
- Bathymetry and cross section survey
- Definition of hydraulic controls/structures
- Observed/modelled flood flows

Sources of uncertainty related to the hydraulic modelling process include:

- Model numerical and computational schemes – these relate to the ability of the model to replicate the physics of free-surface flow in channels and over land.
- Floating point accuracy of computing resources (truncation error)
- Model schematisation and set-up (location and spacing of cross-sections, grid resolution)
- Model parameters such as computational time-steps, surface-friction and other energy-loss parameters (expansion/contraction coefficients and eddy viscosity for example).
- Level/accuracy of model calibration

Due to the complexity of the relationships between the input data and modelling outputs, there is no direct correlation between input and output data accuracy. Further, the error bounds on the data inputs are generally not cumulative. For example, inaccuracies in survey data inputs may be compensated for through adjustment of calibration parameters to achieve output hydraulic results that are nominally more accurate than the sum of the errors in the input data.

6.2 Surface Roughness Parameterisation

Some difficulty has been encountered in determining appropriate Manning's hydraulic roughness coefficients to adopt for the floodplain to reflect the hydrodynamic conditions over the relatively large range of flood depths (less than 0.1m to greater than 1.0m) encountered on the floodplain as part of the calibration. For shallow depths (0.1 – 0.2 m) the surface roughness (representing vegetative resistance) is likely to project through the full profile resulting in a relatively high resistance to flow. The numerical scheme employed by the model assumes a logarithmic velocity profile and is likely to overestimate the depth averaged velocity at these small depths.

Additionally, minor undulations in the surface topography result in flow at shallow depths having to flow laterally in places (compared to the overall direction of flow) imparting another degree of resistance to the overall floodplain flow. This 'mesoscale' roughness is not resolved within the hydrodynamic model topographic grid.

The sum impact of these two different processes is that the hydrodynamic model is somewhat over estimating the rate at which flows at shallow depths are routed across the floodplain. This has an impact on results in the Barmah Millewa forest due to the very large distances over which flooding at water depths of only 100-200 mm is routed (10's of kilometres). The impact of these processes on the results can be partially compensated for by adopting greater overall roughness values however this will have the impact of affecting the flood routing for larger flood events where greater depths are encountered.

The hydraulic roughness values adopted for the modelling represent a compromise between improving the flood routing behaviour of shallow depth flows whilst not unduly impacting results for flooding at greater depths. The quality of the calibration results suggest that the adopted roughness parameters provide a good representation of the hydrodynamic behaviour of the forest system under a range of flow conditions.

6.3 Data Gaps

While very large inroads have been made in filling data gaps within the forest to enable the hydrodynamic model to be developed, the number and resolution of cross-sections available for the Edward River and Gulpa Creek are still only considered the minimum required to enable a reasonable description of the water surface profile to be developed by the hydraulic model.

6.4 Conclusion

It is considered that overall, reasonable reproduction of the hydrodynamic behaviour of the flooding process on the floodplain has been achieved considering the complexity of the system and the degree of uncertainty associated with a number of the model inputs and parameters. In summary the model has demonstrated the capability to reproduce the following important hydrodynamic processes associated with flooding of the Barmah-Millewa floodplain:

- The influence of the forest regulators on the pattern of flooding observed and the impact of the manipulation of the regulators on flooding during flood events in the forest.
- Adequate representations of the observed water level response at a number of geographically disperse locations on the floodplain under a variety of different flood magnitudes.
- Adequate reproduction of the observed discharges through the majority of the major forest regulators during the 2005 flood.
- Good reproduction of the pattern and temporal variation in flooding extents compared to satellite-derived flood extent observations under a variety of different flood magnitudes.
- Reasonable reproduction of the overall floodplain mass balance as observed at the Barmah and Tocumwal gauges.

For the reasons above, the calibration achieved to date is considered appropriate to allow informed analysis of the relative response of flood behaviour in the forest to be made under varying flow rates and regulator scenarios.

7. SCENARIO MODELLING

7.1 Steady Flow Scenarios

A number of various steady flow rates and regulator operation scenarios have been simulated in the model to provide a basis from which comparisons can be made to assist in the management of future flow scenarios in the forest.

The steady flow scenarios were simulated with the regulator operations outlined in Table 7-1 for a period of 30 days.

Table 7-1 Summary of Steady Flow Scenarios

Scenario No.	Design Flow (ML/d) at Tocumwal	Regulator Status
0	10,400	All closed
1	13,000 (VIC)	Victorian Regulators Open – (Sandspit, Bull Paddock, Stewarts Kitchen, 70% Gulf Creek)
2	15,000 (VIC)	All NSW Regulators Open – (except Mary Ada)
3	13,000 (NSW)	All Victorian Regulators Open
4	15,000 (NSW)	All NSW Regulators Open
5	25,000	All Open
6	35,000	All Open
7	45,000	All Open
8	60,000	All Open

Figure 7-1 and Figure 7-2 show the flood extents for the recalibrated Barmah-Millewa model for each steady flow scenario.

The flood extents after 1 month for the 10,400 ML/d through to 60,000 ML/d flow scenarios have been processed to determine the area of inundation for each different vegetation classification, divided between the NSW and VIC forests. This analysis is considered to provide a useful method for quantifying the relationship between the River Murray flow rate and resulting flood extents within various sections of the forest.

Figure 7-3 and Figure 7-4 summarise the percentage of each different vegetation classification inundated on the active floodplain, for NSW and VIC forests respectively.

Summary tables (Appendix A) and detailed vegetation maps (Appendix B) have been produced for each scenario.

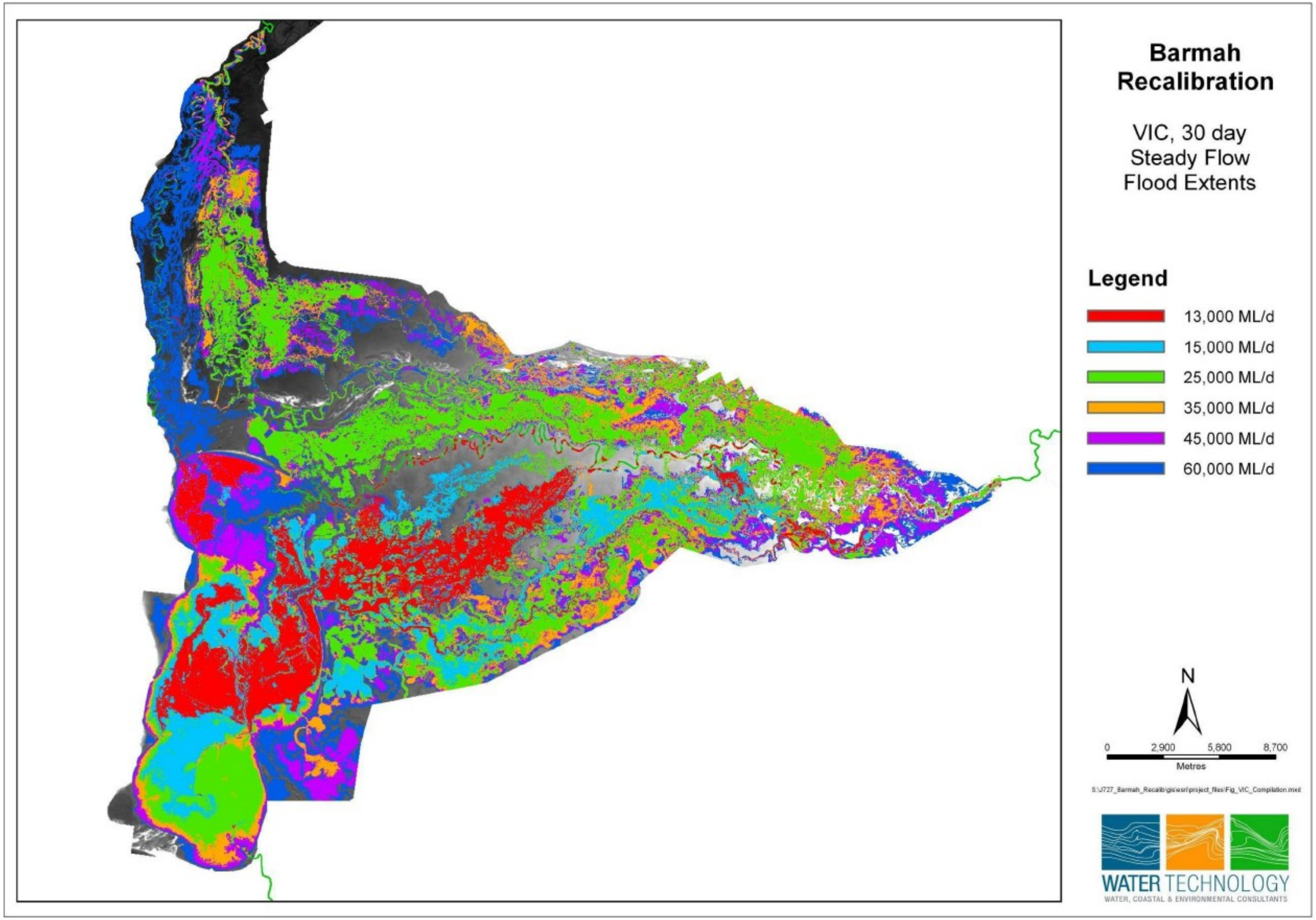


Figure 7-1 Recalibrated model results for different steady flow scenarios, VIC

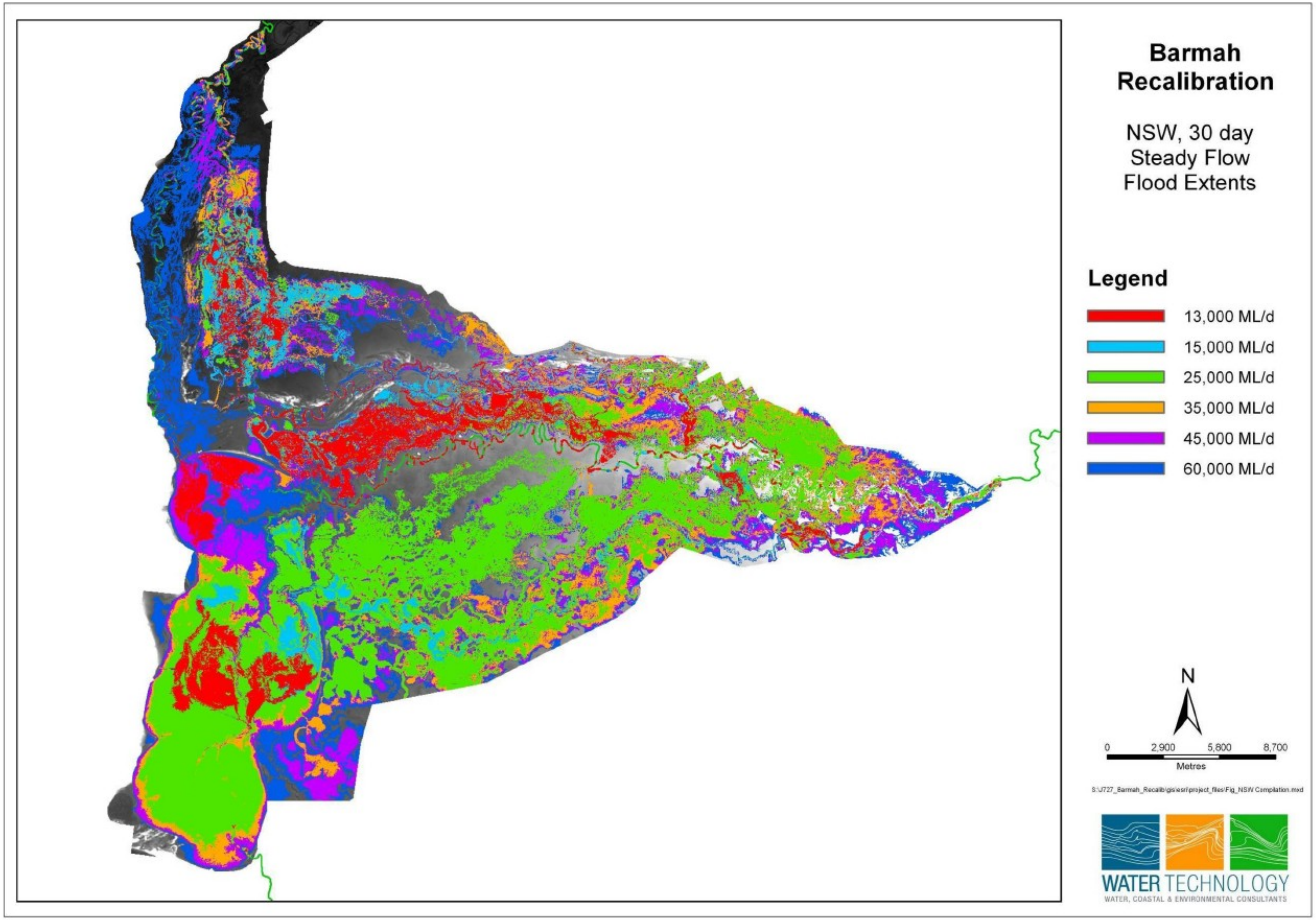


Figure 7-2 Recalibrated model results for different steady flow scenarios, NSW

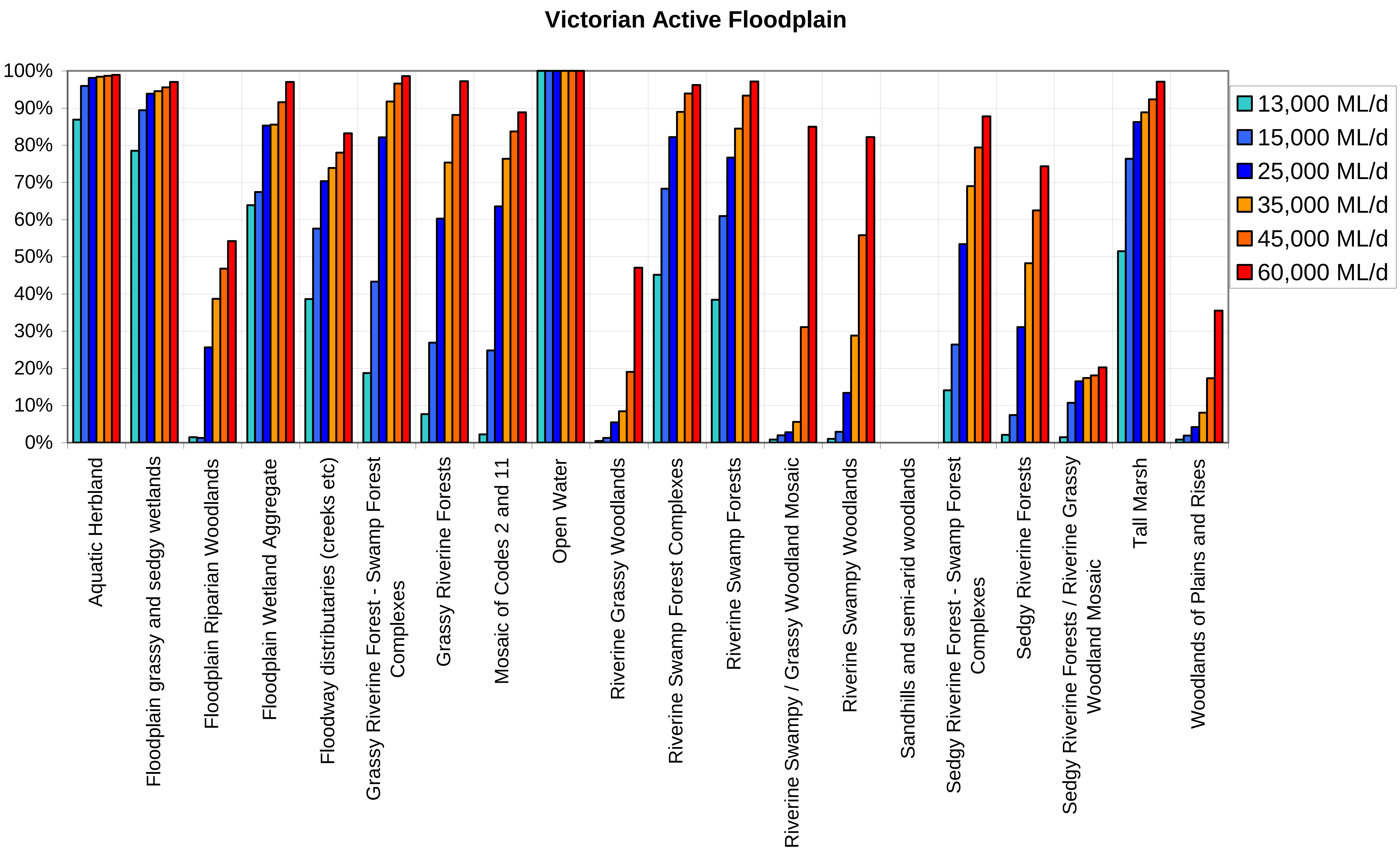


Figure 7-3 Percentage of each vegetation class inundated over the VIC active floodplain

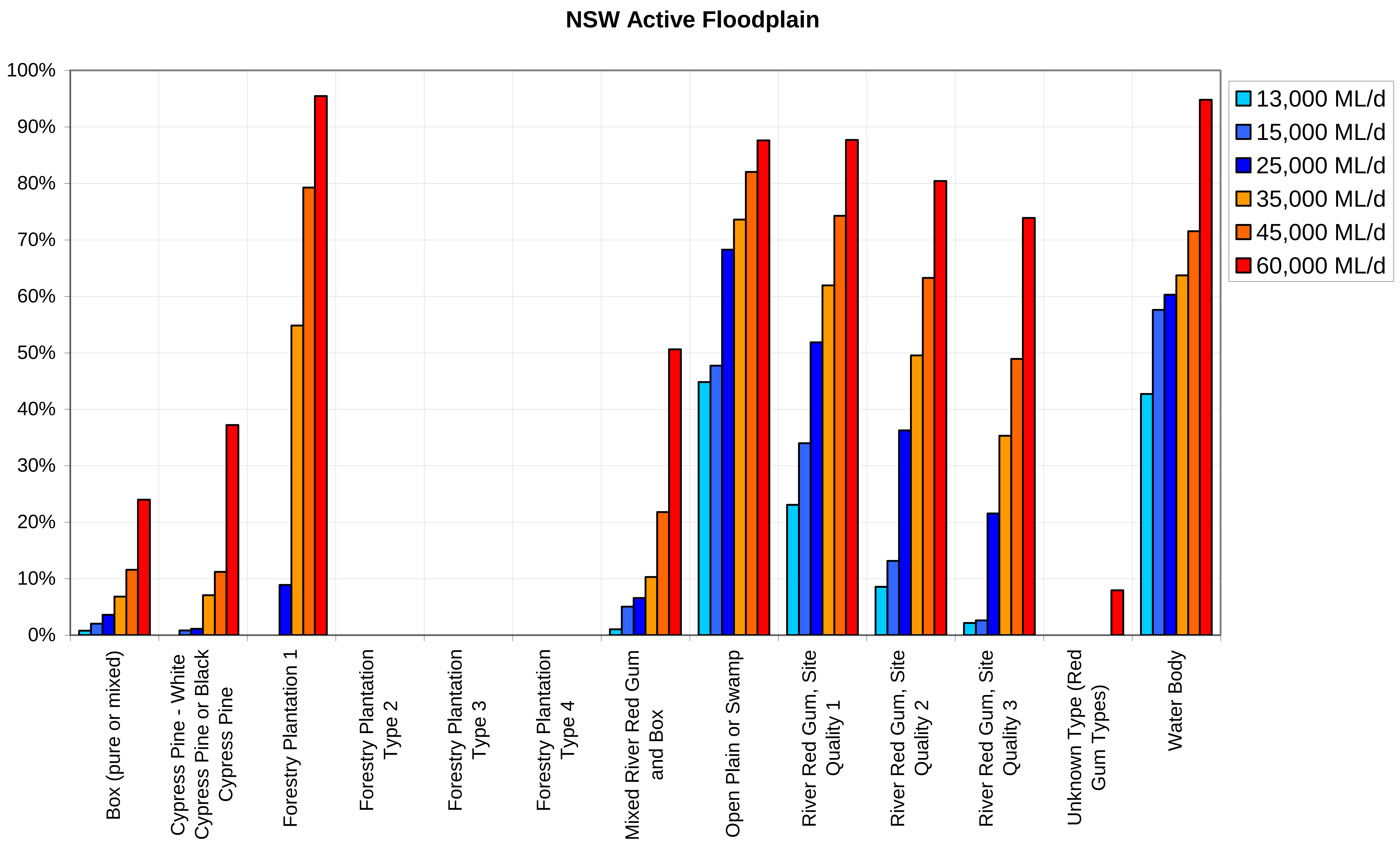


Figure 7-4 Percentage of each vegetation class inundated over the NSW active floodplain

8. CONCLUSIONS

8.1 Overview

The focus of the present study has been to develop an updated hydrodynamic model of the Barmah-Millewa wetland/forest system. This work has been undertaken as part of the Living Murray initiative of the Murray Darling Basin Authority.

This report documents the level of re-calibration achieved with the hydraulic model incorporating new air borne laser scanning survey (ALS) and cross-section information.

In addition to the model recalibration, steady state flow scenario modelling has been carried out to assess the active floodplain inundation area. Detailed analysis of the inundation area of each vegetative class on the floodplain has been performed and detailed mapping produced. This analysis is considered to provide a useful method for quantifying the relationship between the River Murray flow rate and resulting flood extents within various sections of the forest under essentially unregulated conditions.

8.2 Model Applicability

Based on the results of this study it is considered that the model is well suited to the assessment of options to enhance watering within the overall forest/wetland system. It is important to recognise the limitations of the model in terms of the data used to develop it, the available calibration information and the technical ability of the model reproduce real flow behaviour on the ground. Whilst there is significant confidence in the models overall predictive ability, the following points should be considered with respect to the application of the model in its current form.

- The model is appropriate to be used at a "whole of forest" scale
- The model is suitable to assess the impact of individual regulation structures
- Model scenario options and results can considered down to a scale of approximately 1 km^2 (100 Ha), however it should be recognised that over smaller areas, the model results become more prone to uncertainty due to local topographic features that are not captured in the 50 m model grid resolution. Over larger areas, these errors tend to average out.
- In general, the model will be more reliable in the assessment of variations or differences between scenarios than in absolute terms for any particular scenario.
- In general, the reliability of results increases with flows, i.e. at high flows the modelled extents could be expected to be more accurate than at low flows.
- Flow splits in major creeks and channels will be more reliable than for minor waterways. Where specific local flow details are important, nested models incorporating local topography details may be more appropriate in the future.

8.3 Recommendations

With regard to future model develop the following recommendations are made:

- It is recommended that for further flood events or environmental water releases in the forest that continuous monitoring be undertaken to enable sufficient data for future model calibration/verification.

- Consideration should be given to incorporating Yarrawonga (in addition to or instead of Tocumwal) in the model.
- Key flow stations could be identified and included in the model to assist environmental managers for targeted environmental water applications to specific areas.
- For higher flows (> 45,000 ML/day) it is recommended that real hydrographs be applied to ensure the correct representation of flood levels and volumes within the model for such flows. This may also allow the inclusion of dynamic representation of losses throughout the model when this feature is available within the software.
- With future increases in computing capacity further refinement of the model grid size can be undertake.

9. REFERENCES

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Barmah-Millewa Hydrodynamic Model - Additional Investigations, Report J419/R01DA Water Technology (2006)

Barmah Millewa ALS Banding Issue – Memo to GBCMA, Water Technology, November 2006 (2006a)

Barmah Millewa ALS Banding Issue – Memo to GBCMA, Water Technology, December 2006 (2006b)

Murray River Regional Flood Study Dicks/Seppelts levees to downstream of the Ulupna Creek confluence Study Report - Report J150/R02 Draft B, Water Technology (2008)

Survey Data

River Murray Cross Section Survey – SR&WSC (1977)

Regulator Structural Drawing Plans – Goulburn-Murray Water (various dates), DIPNR (various dates)

Victorian Levee Survey – LICS, GBCMA (various dates)

New South Wales Levee Survey – Berrigan Shire, DIPNR (various dates)

Tuppal and Bulltale Creek cross-section survey – EarthTech (2002)

Black Engine Creek cross section survey – EarthTech (2002)

Edward River cross section survey – Fluvial Systems (2001)

Forest Regulator Survey – SKM (2006)

Edward River and Gulpa Creek cross section survey – Coomes Consulting (2007)

APPENDIX A STEADY FLOW SCENARIOS, VEGETATION-INUNDATION INTERSECTION

Table A Summary of Overall Total Results for Each Scenario tested

Scenario No.	Veg Class	Inundated Area (Ha)	Forest Reserve (Ha)	% Forest Reserve	Active Floodplain (Ha)	% Active Floodplain
1	VIC	5212	29253	17.8	27884	18.7
	NSW	2070	36131	6.3	33014	5.7
2	VIC	798	29253	2.7	27884	2.9
	NSW	4934	36131	13.7	33014	14.9
3	VIC	9075	29253	31.0	27884	32.5
	NSW	4795	36131	13.3	33014	14.5
4	VIC	1825	29253	6.2	27884	6.5
	NSW	6739	36131	18.7	33014	20.4
5	VIC	14955	29253	51.1	27884	53.6
	NSW	13291	36131	52.7	33014	57.7
6	VIC	17980	29253	61.5	27884	64.5
	NSW	17027	36131	52.7	33014	57.7
7	VIC	20894	29253	71.4	27884	74.9
	NSW	21134	36131	58.5	33014	64.0
8	VIC	23618	29253	80.7	27884	84.7
	NSW	26355	36131	72.9	33014	79.8

Table A1-1 13,000 ML/d, 30 day, Victorian Regulators Open (Sandspit, Bull Paddock, Stewarts Kitchen, 70% Gulf Creek)

VIC Vegetation Classification	Inundated Area (Ha)	Forest Reserve (Ha)	% Forest Reserve	Active Floodplain (Ha)	% Active Floodplain
Aquatic Herbland	182	209	86.8%	209	86.8%
Floodplain grassy and sedgy wetlands	655	835	78.4%	834	78.5%
Floodplain Riparian Woodlands	5	391	1.4%	357	1.5%
Floodplain Wetland Aggregate	13	21	63.7%	21	63.9%
Floodway distributaries (creeks etc)	241	664	36.2%	623	38.6%
Grassy Riverine Forest - Swamp Forest Complexes	626	3351	18.7%	3351	18.7%
Grassy Riverine Forests	131	1757	7.5%	1713	7.6%
Mosaic of Codes 2 and 11	25	1151	2.2%	1132	2.2%
Open Water	122	122	100.0%	122	100.0%
Riverine Grassy Woodlands	8	2450	0.3%	1749	0.5%
Riverine Swamp Forest Complexes	227	505	44.9%	502	45.1%
Riverine Swamp Forests	2023	5374	37.7%	5267	38.4%
Riverine Swampy / Grassy Woodland Mosaic	3	361	0.7%	304	0.8%
Riverine Swampy Woodlands	17	1738	1.0%	1700	1.0%
Sandhills and semi-arid woodlands	-	13	-	-	-
Sedgy Riverine Forest - Swamp Forest Complexes	447	3198	14.0%	3173	14.1%
Sedgy Riverine Forests	112	5337	2.1%	5315	2.1%
Sedgy Riverine Forests / Riverine Grassy Woodland Mosaic	2	147	1.3%	132	1.5%
Tall Marsh	369	723	51.0%	717	51.5%
Woodlands of Plains and Rises	6	906	0.6%	663	0.9%
Total	5212	29253	17.8%	27884	18.7%

NSW Vegetation Classifications	Inundated Area (Ha)	Forest Reserve (Ha)	% Forest Reserve	Active Floodplain (Ha)	% Active Floodplain
Box (pure or mixed)	-	1726	-	1294	-
Cypress Pine	-	292	-	54	-
Forestry Plantation	-	151	-	151	-
Forestry Plantation Type 1	-	12	-	2	-
Forestry Plantation Type 2	-	90	-	-	-
Forestry Plantation Type 3	-	3	-	0	-
Mixed River Red Gum and Box	-	374	-	314	-
Open Plain or Swamp	1525	4125	45.3%	3363	37.0%
River Red Gum, Site Quality 1	200	8766	2.4%	8363	2.3%
River Red Gum, Site Quality 2	312	16630	2.0%	15899	1.9%
River Red Gum, Site Quality 3	21	3831	0.6%	3448	0.5%
Unknown Type (Red Gum Types)	-	8	-	7	-
Water Body	11	124	9.5%	119	9.1%
Total	2070	36131	6.3%	33014	5.7%

Table A1-2 13,000 ML/d, 30 day, NSW Regulators Open (All expect Mary Ada)

VIC Vegetation Classification	Inundated Area (Ha)	Forest Reserve (Ha)	% Forest Reserve	Flood Plain Area (Ha)	% Active Flood Plain
Aquatic Herbland	104	209	49.4%	209	49.5%
Floodplain grassy and sedgy wetlands	202	835	24.2%	834	24.2%
Floodplain Riparian Woodlands	2	391	0.6%	357	0.7%
Floodplain Wetland Aggregate	1	21	2.5%	21	2.5%
Floodway distributaries (creeks etc)	50	664	7.6%	623	8.1%
Grassy Riverine Forest - Swamp Forest Complexes	113	3351	3.4%	3351	3.4%
Grassy Riverine Forests	8	1757	0.4%	1713	0.4%
Mosaic of Codes 2 and 11	0	1151	0.0%	1132	0.0%
Open Water	122	122	100.0%	122	100.0%
Riverine Grassy Woodlands	4	2450	0.1%	1749	0.2%
Riverine Swamp Forest Complexes	2	505	0.3%	502	0.3%
Riverine Swamp Forests	107	5374	2.0%	5267	2.0%
Riverine Swampy / Grassy Woodland Mosaic	-	361	-	304	-
Riverine Swampy Woodlands	0	1738	0.0%	1700	0.0%
Sandhills and semi-arid woodlands	-	13	-	0	-
Sedgy Riverine Forest - Swamp Forest Complexes	3	3198	0.1%	3173	0.1%
Sedgy Riverine Forests	5	5337	0.1%	5315	0.1%
Sedgy Riverine Forests / Riverine Grassy Woodland Mosaic	1	147	0.4%	132	0.5%
Tall Marsh	76	723	10.5%	717	10.6%
Woodlands of Plains and Rises	0	906	0.0%	663	0.0%
Total	798	29253	2.7%	27884	2.9%

NSW Vegetation Classification	Inundated Area (Ha)	Forest Reserve (Ha)	% Forest Reserve	Flood Plain Area (Ha)	% Active Flood Plain
Box (pure or mixed)	10	1726	0.6%	1294	0.8%
Cypress Pine - White Cypress Pine or Black Cypress Pine	-	292	-	54	-
Forestry Plantation 1	-	151	-	151	-
Forestry Plantation Type 2	-	12	-	2	-
Forestry Plantation Type 3	-	90	-	-	-
Forestry Plantation Type 4	-	3	-	0	-
Mixed River Red Gum and Box	3	374	0.9%	314	1.0%
Open Plain or Swamp	1507	4125	36.5%	3363	44.8%
River Red Gum, Site Quality 1	1928	8766	22.0%	8363	23.1%
River Red Gum, Site Quality 2	1361	16630	8.2%	15899	8.6%
River Red Gum, Site Quality 3	73	3831	1.9%	3448	2.1%
Unknown Type (Red Gum Types)	-	8	-	7	-
Water Body	51	124	40.9%	119	42.7%
Total	4934	36131	13.7%	33014	14.9%

Table A1-3 15,000 ML/d, 30 day, All Victorian Regulators Open

VIC Vegetation Classification	Inundated Area (Ha)	Forest Reserve (Ha)	% Forest Reserve	Flood Plain Area (Ha)	% Active Flood Plain
Aquatic Herbland	201	209	95.9%	209	96.0%
Floodplain grassy and sedgy wetlands	746	835	89.3%	834	89.4%
Floodplain Riparian Woodlands	5	391	1.2%	357	1.3%
Floodplain Wetland Aggregate	14	21	67.2%	21	67.4%
Floodway distributaries (creeks etc)	359	664	54.1%	623	57.6%
Grassy Riverine Forest - Swamp Forest Complexes	1451	3351	43.3%	3351	43.3%
Grassy Riverine Forests	461	1757	26.2%	1713	26.9%
Mosaic of Codes 2 and 11	281	1151	24.4%	1132	24.8%
Open Water	122	122	99.9%	122	100.0%
Riverine Grassy Woodlands	22	2450	0.9%	1749	1.3%
Riverine Swamp Forest Complexes	343	505	67.9%	502	68.3%
Riverine Swamp Forests	3208	5374	59.7%	5267	60.9%
Riverine Swampy / Grassy Woodland Mosaic	6	361	1.6%	304	1.9%
Riverine Swampy Woodlands	49	1738	2.8%	1700	2.9%
Sandhills and semi-arid woodlands	-	13	-	0	-
Sedgy Riverine Forest - Swamp Forest Complexes	838	3198	26.2%	3173	26.4%
Sedgy Riverine Forests	395	5337	7.4%	5315	7.4%
Sedgy Riverine Forests / Riverine Grassy Woodland Mosaic	14	147	9.6%	132	10.7%
Tall Marsh	547	723	75.7%	717	76.3%
Woodlands of Plains and Rises	13	906	1.4%	663	1.9%
Total	9075	29253	31.0%	27884	32.5%

NSW Vegetation Classification	Inundated Area (Ha)	Forest Reserve (Ha)	% Forest Reserve	Flood Plain Area (Ha)	% Active Flood Plain
Box (pure or mixed)	-	1726	-	1294	-
Cypress Pine - White Cypress Pine or Black Cypress Pine	-	292	-	54	-
Forestry Plantation	-	151	-	151	-
Forestry Plantation 1	-	12	-	2	-
Forestry Plantation 2	-	90	-	-	-
Forestry Plantation 3	-	3	-	0	-
Mixed River Red Gum and Box	-	374	-	314	-
Open Plain or Swamp	1992	4125	48.3%	3363	59.2%
River Red Gum, Site Quality 1	691	8766	7.9%	8363	8.3%
River Red Gum, Site Quality 2	1351	16630	8.1%	15899	8.5%
River Red Gum, Site Quality 3	59	3831	1.5%	3448	1.7%
Unknown Type (Red Gum Types)	-	8	-	7	-
Water Body	11	124	9.2%	119	9.6%
Total	4795	36131	13.3%	33014	14.5%

Table A1-4 15,000 ML/d, 30 day, All NSW Regulators Open

VIC Vegetation Classification	Inundated Area (Ha)	Forest Reserve (Ha)	% Forest Reserve	Flood Plain Area (Ha)	% Active Flood Plain
Aquatic Herbland	124	209	59.0%	209	59.0%
Floodplain grassy and sedgy wetlands	358	835	42.8%	834	42.9%
Floodplain Riparian Woodlands	5	391	1.3%	357	1.4%
Floodplain Wetland Aggregate	1	21	6.2%	21	6.2%
Floodway distributaries (creeks etc)	163	664	24.5%	623	26.1%
Grassy Riverine Forest - Swamp Forest Complexes	289	3351	8.6%	3351	8.6%
Grassy Riverine Forests	29	1757	1.7%	1713	1.7%
Mosaic of Codes 2 and 11	11	1151	1.0%	1132	1.0%
Open Water	121	122	99.4%	122	99.4%
Riverine Grassy Woodlands	5	2450	0.2%	1749	0.3%
Riverine Swamp Forest Complexes	45	505	8.9%	502	9.0%
Riverine Swamp Forests	447	5374	8.3%	5267	8.5%
Riverine Swampy / Grassy Woodland Mosaic	-	361	-	304	-
Riverine Swampy Woodlands	1	1738	0.0%	1700	0.0%
Sandhills and semi-arid woodlands	-	13	-	0	-
Sedgy Riverine Forest - Swamp Forest Complexes	18	3198	0.6%	3173	0.6%
Sedgy Riverine Forests	42	5337	0.8%	5315	0.8%
Sedgy Riverine Forests / Riverine Grassy Woodland Mosaic	1	147	0.5%	132	0.5%
Tall Marsh	165	723	22.9%	717	23.1%
Woodlands of Plains and Rises	-	906	-	663	-
Total	1825	29253	6.2%	27884	6.5%

NSW Vegetation Classification	Inundated Area (Ha)	Forest Reserve (Ha)	% Forest Reserve	Flood Plain Area (Ha)	% Active Flood Plain
Box (pure or mixed)	26	1726	1.5%	1294	2.0%
Cypress Pine - White Cypress Pine or Black Cypress Pine	0	292	0.2%	54	0.8%
Forestry Plantation	-	151	-	151	-
Forestry Plantation 1	-	12	-	2	-
Forestry Plantation 2	-	90	-	-	-
Forestry Plantation 3	-	3	-	0	-
Mixed River Red Gum and Box	16	374	4.2%	314	5.0%
Open Plain or Swamp	1605	4125	38.9%	3363	47.7%
River Red Gum, Site Quality 1	#REF!	8765.7	32.4%	8363.1	34.0%
River Red Gum, Site Quality 2	2092	16630	12.6%	15899	13.2%
River Red Gum, Site Quality 3	89	3831	2.3%	3448	2.6%
Unknown Type (Red Gum Types)	-	8	-	7	-
Water Body	68	124	55.2%	119	57.6%
Total	6739	36131	18.7%	33014	20.4%

Table A1-5 25,000 ML/d, 30 day, All Regulators Open

VIC Vegetation Classification	Inundated Area (Ha)	Forest Reserve (Ha)	% Forest Reserve	Flood Plain Area (Ha)	% Active Flood Plain
Aquatic Herbland	205	209	98.0%	209	98.1%
Floodplain grassy and sedgy wetlands	783	835	93.7%	834	93.8%
Floodplain Riparian Woodlands	92	391	23.4%	357	25.6%
Floodplain Wetland Aggregate	18	21	85.0%	21	85.3%
Floodway distributaries (creeks etc)	438	664	66.0%	623	70.3%
Grassy Riverine Forest - Swamp Forest Complexes	2753	3351	82.1%	3351	82.1%
Grassy Riverine Forests	1032	1757	58.8%	1713	60.3%
Mosaic of Codes 2 and 11	719	1151	62.4%	1132	63.5%
Open Water	122	122	100.0%	122	100.0%
Riverine Grassy Woodlands	95	2450	3.9%	1749	5.4%
Riverine Swamp Forest Complexes	413	505	81.7%	502	82.2%
Riverine Swamp Forests	4037	5374	75.1%	5267	76.7%
Riverine Swampy / Grassy Woodland Mosaic	9	361	2.4%	304	2.8%
Riverine Swampy Woodlands	228	1738	13.1%	1700	13.4%
Sandhills and semi-arid woodlands	-	13	-	0	-
Sedgy Riverine Forest - Swamp Forest Complexes	1694	3198	53.0%	3173	53.4%
Sedgy Riverine Forests	1651	5337	30.9%	5315	31.1%
Sedgy Riverine Forests / Riverine Grassy Woodland Mosaic	22	147	14.8%	132	16.5%
Tall Marsh	618	723	85.5%	717	86.3%
Woodlands of Plains and Rises	28	906	3.1%	663	4.2%
Total	14955	29253	51.1%	27884	53.6%

NSW Vegetation Classification	Inundated Area (Ha)	Forest Reserve (Ha)	% Forest Reserve	Flood Plain Area (Ha)	% Active Flood Plain
Box (pure or mixed)	47	1726	2.7%	1294	3.6%
Cypress Pine - White Cypress Pine or Black Cypress Pine	1	292	0.2%	54	1.1%
Forestry Plantation	13	151	8.9%	151	8.9%
Forestry Plantation 1	-	12	-	2	-
Forestry Plantation 2	-	90	-	-	-
Forestry Plantation 3	-	3	-	0	-
Mixed River Red Gum and Box	21	374	5.5%	314	6.6%
Open Plain or Swamp	2295	4125	55.6%	3363	68.2%
River Red Gum, Site Quality 1	4335	8766	49.5%	8363	51.8%
River Red Gum, Site Quality 2	5766	16630	34.7%	15899	36.3%
River Red Gum, Site Quality 3	743	3831	19.4%	3448	21.5%
Unknown Type (Red Gum Types)	-	8	-	7	-
Water Body	72	124	57.7%	119	60.3%
Total	13291	36131	52.7%	33014	57.7%

Table A1-6 35,000 ML/d, 30 day, All Regulators Open

VIC Vegetation Classification	Inundated Area (Ha)	Forest Reserve (Ha)	% Forest Reserve	Flood Plain Area (Ha)	% Active Flood Plain
Aquatic Herbland	206	209	98.4%	209	98.4%
Floodplain grassy and sedgy wetlands	789	835	94.4%	834	94.6%
Floodplain Riparian Woodlands	138	391	35.4%	357	38.7%
Floodplain Wetland Aggregate	18	21	85.3%	21	85.5%
Floodway distributaries (creeks etc)	460	664	69.3%	623	73.8%
Grassy Riverine Forest - Swamp Forest Complexes	3074	3351	91.8%	3351	91.7%
Grassy Riverine Forests	1291	1757	73.5%	1713	75.4%
Mosaic of Codes 2 and 11	864	1151	75.0%	1132	76.3%
Open Water	122	122	100.0%	122	100.0%
Riverine Grassy Woodlands	147	2450	6.0%	1749	8.4%
Riverine Swamp Forest Complexes	447	505	88.5%	502	89.0%
Riverine Swamp Forests	4449	5374	82.8%	5267	84.5%
Riverine Swampy / Grassy Woodland Mosaic	17	361	4.7%	304	5.6%
Riverine Swampy Woodlands	490	1738	28.2%	1700	28.8%
Sandhills and semi-arid woodlands	-	13	-	0	-
Sedgy Riverine Forest - Swamp Forest Complexes	2188	3198	68.4%	3173	69.0%
Sedgy Riverine Forests	2566	5337	48.1%	5315	48.3%
Sedgy Riverine Forests / Riverine Grassy Woodland Mosaic	23	147	15.6%	132	17.4%
Tall Marsh	637	723	88.1%	717	88.8%
Woodlands of Plains and Rises	53	906	5.9%	663	8.1%
Total	17980	29253	61.5%	27884	64.5%

NSW Vegetation Classification	Inundated Area (Ha)	Forest Reserve (Ha)	% Forest Reserve	Flood Plain Area (Ha)	% Active Flood Plain
Box (pure or mixed)	88	1726	5.1%	1294	6.8%
Cypress Pine - White Cypress Pine or Black Cypress Pine	4	292	1.3%	54	7.1%
Forestry Plantation	83	151	54.8%	151	54.8%
Forestry Plantation 1	-	12	-	2	-
Forestry Plantation 2	-	90	-	-	-
Forestry Plantation 3	-	3	-	0	-
Mixed River Red Gum and Box	32	374	8.7%	314	10.3%
Open Plain or Swamp	2474	4125	60.0%	3363	73.6%
River Red Gum, Site Quality 1	5180	8766	59.1%	8363	61.9%
River Red Gum, Site Quality 2	7873	16630	47.3%	15899	49.5%
River Red Gum, Site Quality 3	1217	3831	31.8%	3448	35.3%
Unknown Type (Red Gum Types)	-	8	-	7	-
Water Body	76	124	61.0%	119	63.7%
Total	17027	36131	52.7%	33014	57.7%

Table A1-7 45,000 ML/d, 30 day, All Regulators Open

VIC Vegetation Classification	Inundated Area (Ha)	Forest Reserve (Ha)	% Forest Reserve	Flood Plain Area (Ha)	% Active Flood Plain
Aquatic Herbland	207	209	98.6%	209	98.7%
Floodplain grassy and sedgy wetlands	797	835	95.4%	834	95.6%
Floodplain Riparian Woodlands	167	391	42.8%	357	46.8%
Floodplain Wetland Aggregate	19	21	91.3%	21	91.6%
Floodway distributaries (creeks etc)	486	664	73.2%	623	78.0%
Grassy Riverine Forest - Swamp Forest Complexes	3236	3351	96.6%	3351	96.6%
Grassy Riverine Forests	1510	1757	86.0%	1713	88.1%
Mosaic of Codes 2 and 11	947	1151	82.3%	1132	83.7%
Open Water	122	122	100.0%	122	100.0%
Riverine Grassy Woodlands	333	2450	13.6%	1749	19.0%
Riverine Swamp Forest Complexes	472	505	93.4%	502	93.9%
Riverine Swamp Forests	4916	5374	91.5%	5267	93.3%
Riverine Swampy / Grassy Woodland Mosaic	94	361	26.2%	304	31.0%
Riverine Swampy Woodlands	949	1738	54.6%	1700	55.8%
Sandhills and semi-arid woodlands	-	13	-	0	-
Sedgy Riverine Forest - Swamp Forest Complexes	2519	3198	78.8%	3173	79.4%
Sedgy Riverine Forests	3320	5337	62.2%	5315	62.5%
Sedgy Riverine Forests / Riverine Grassy Woodland Mosaic	24	147	16.2%	132	18.1%
Tall Marsh	662	723	91.5%	717	92.3%
Woodlands of Plains and Rises	115	906	12.6%	663	17.3%
Total	20894	29253	71.4%	27884	74.9%

NSW Vegetation Classification	Inundated Area (Ha)	Forest Reserve (Ha)	% Forest Reserve	Flood Plain Area (Ha)	% Active Flood Plain
Box (pure or mixed)	150	1726	8.7%	1294	11.6%
Cypress Pine - White Cypress Pine or Black Cypress Pine	6	292	2.1%	54	11.2%
Forestry Plantation	120	151	79.3%	151	79.3%
Forestry Plantation 1	-	12	-	2	-
Forestry Plantation 2	-	90	-	-	-
Forestry Plantation 3	-	3	-	0	-
Mixed River Red Gum and Box	68	374	18.3%	314	21.8%
Open Plain or Swamp	2758	4125	66.9%	3363	82.0%
River Red Gum, Site Quality 1	6208	8766	70.8%	8363	74.2%
River Red Gum, Site Quality 2	10053	16630	60.5%	15899	63.2%
River Red Gum, Site Quality 3	1686	3831	44.0%	3448	48.9%
Unknown Type (Red Gum Types)	-	8	-	7	-
Water Body	85	124	68.5%	119	71.5%
Total	21134	36131	58.5%	33014	64.0%

Table A1-8 60,000 ML/d, 30 day, All Regulators Open

VIC Vegetation Classification	Inundated Area (Ha)	Forest Reserve (Ha)	% Forest Reserve	Flood Plain Area (Ha)	% Active Flood Plain
Aquatic Herbland	207	209	98.8%	209	98.9%
Floodplain grassy and sedgy wetlands	809	835	96.9%	834	97.0%
Floodplain Riparian Woodlands	194	391	49.5%	357	54.2%
Floodplain Wetland Aggregate	20	21	96.7%	21	97.0%
Floodway distributaries (creeks etc)	518	664	78.1%	623	83.2%
Grassy Riverine Forest - Swamp Forest Complexes	3305	3351	98.6%	3351	98.6%
Grassy Riverine Forests	1666	1757	94.8%	1713	97.2%
Mosaic of Codes 2 and 11	1005	1151	87.3%	1132	88.8%
Open Water	122	122	100.0%	122	100.0%
Riverine Grassy Woodlands	823	2450	33.6%	1749	47.1%
Riverine Swamp Forest Complexes	483	505	95.7%	502	96.2%
Riverine Swamp Forests	5118	5374	95.2%	5267	97.2%
Riverine Swampy / Grassy Woodland Mosaic	258	361	71.6%	304	85.0%
Riverine Swampy Woodlands	1397	1738	80.4%	1700	82.2%
Sandhills and semi-arid woodlands	-	13	-	0	-
Sedgy Riverine Forest - Swamp Forest Complexes	2784	3198	87.1%	3173	87.8%
Sedgy Riverine Forests	3949	5337	74.0%	5315	74.3%
Sedgy Riverine Forests / Riverine Grassy Woodland Mosaic	27	147	18.1%	132	20.2%
Tall Marsh	696	723	96.2%	717	97.1%
Woodlands of Plains and Rises	235	906	26.0%	663	35.5%
Total	23618	29253	80.7%	27884	84.7%

NSW Vegetation Classification	Inundated Area (Ha)	Forest Reserve (Ha)	% Forest Reserve	Flood Plain Area (Ha)	% Active Flood Plain
Box (pure or mixed)	311	1726	18.0%	1294	24.0%
Cypress Pine - White Cypress Pine or Black Cypress Pine	20	292	6.9%	54	37.2%
Forestry Plantation	144	151	95.4%	151	95.4%
Forestry Plantation 1	-	12	-	2	-
Forestry Plantation 2	-	90	-	-	-
Forestry Plantation 3	-	3	-	-	-
Mixed River Red Gum and Box	159	374	42.5%	314	50.6%
Open Plain or Swamp	2946	4125	71.4%	3363	87.6%
River Red Gum, Site Quality 1	7333	8766	83.7%	8363	87.7%
River Red Gum, Site Quality 2	12782	16630	76.9%	15899	80.4%
River Red Gum, Site Quality 3	2547	3831	66.5%	3448	73.9%
Unknown Type (Red Gum Types)	1	8	7.3%	7	7.9%
Water Body	113	124	90.8%	119	94.8%
Total	26355	36131	72.9%	33014	79.8%

APPENDIX B STEADY FLOW SCENARIOS, VEGETATION-INUNDATION MAPPING

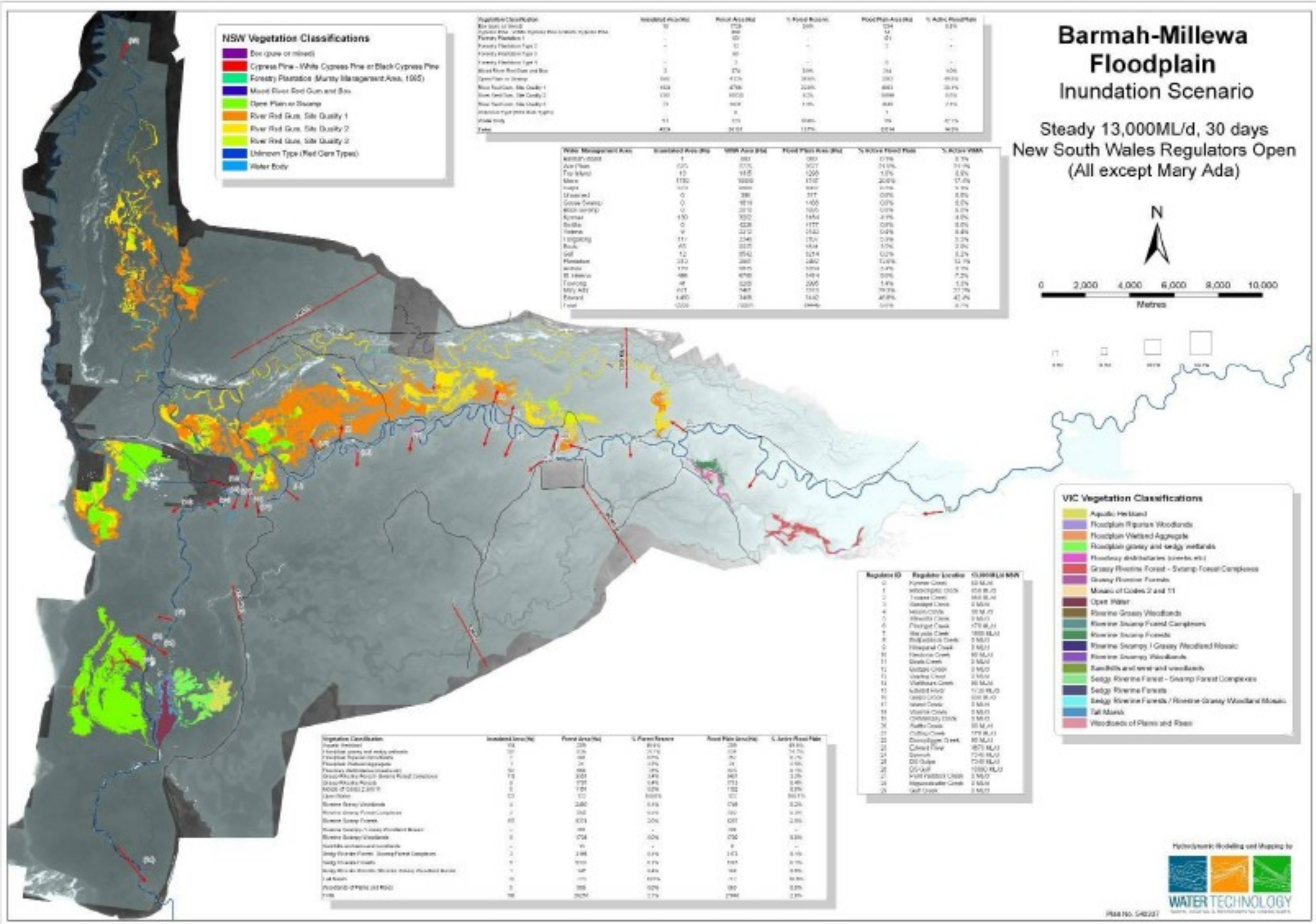


Figure B1-1 Inundation Scenario Steady 13,000 ML/d, NSW regulators open (except Mary Alda)

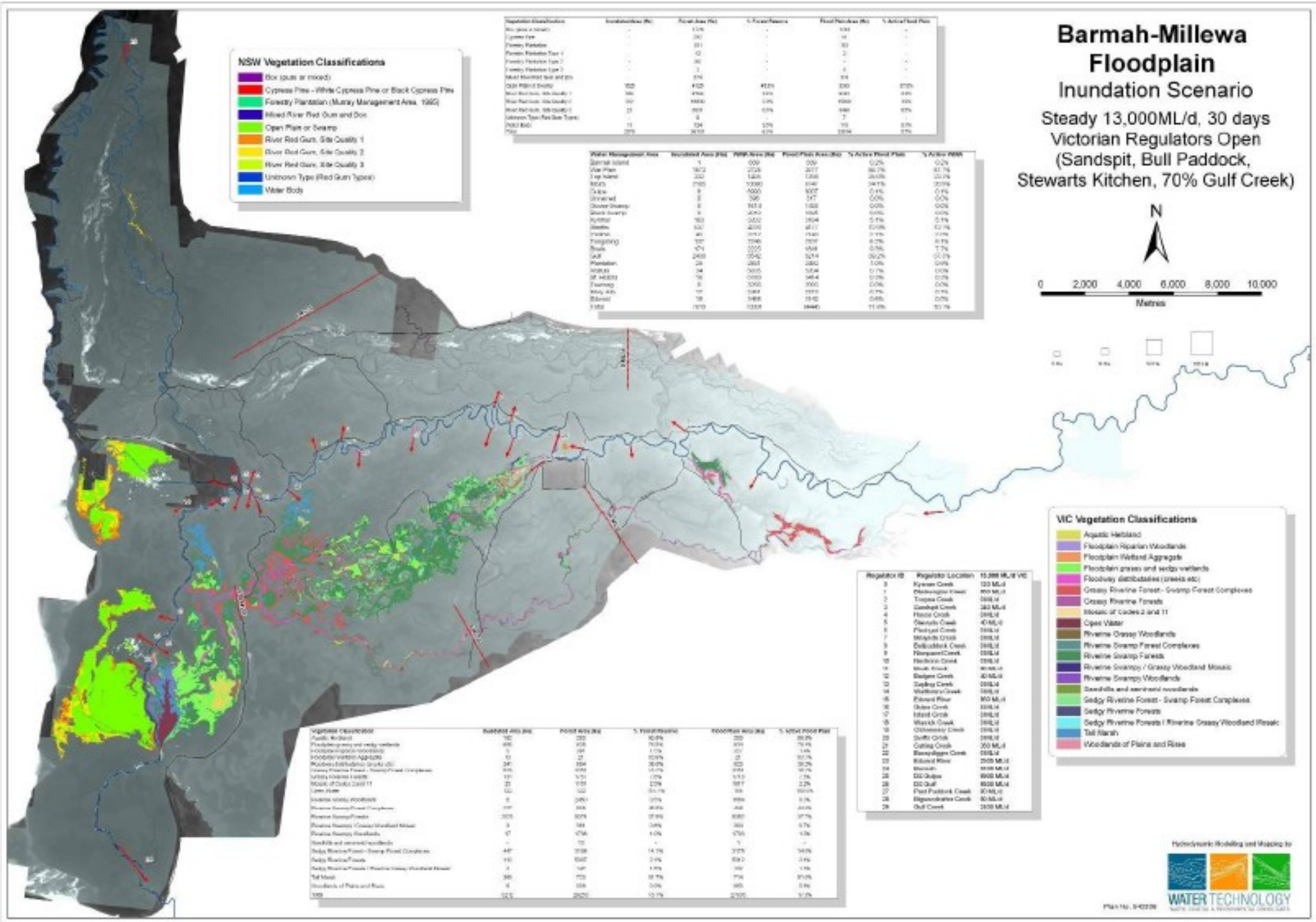
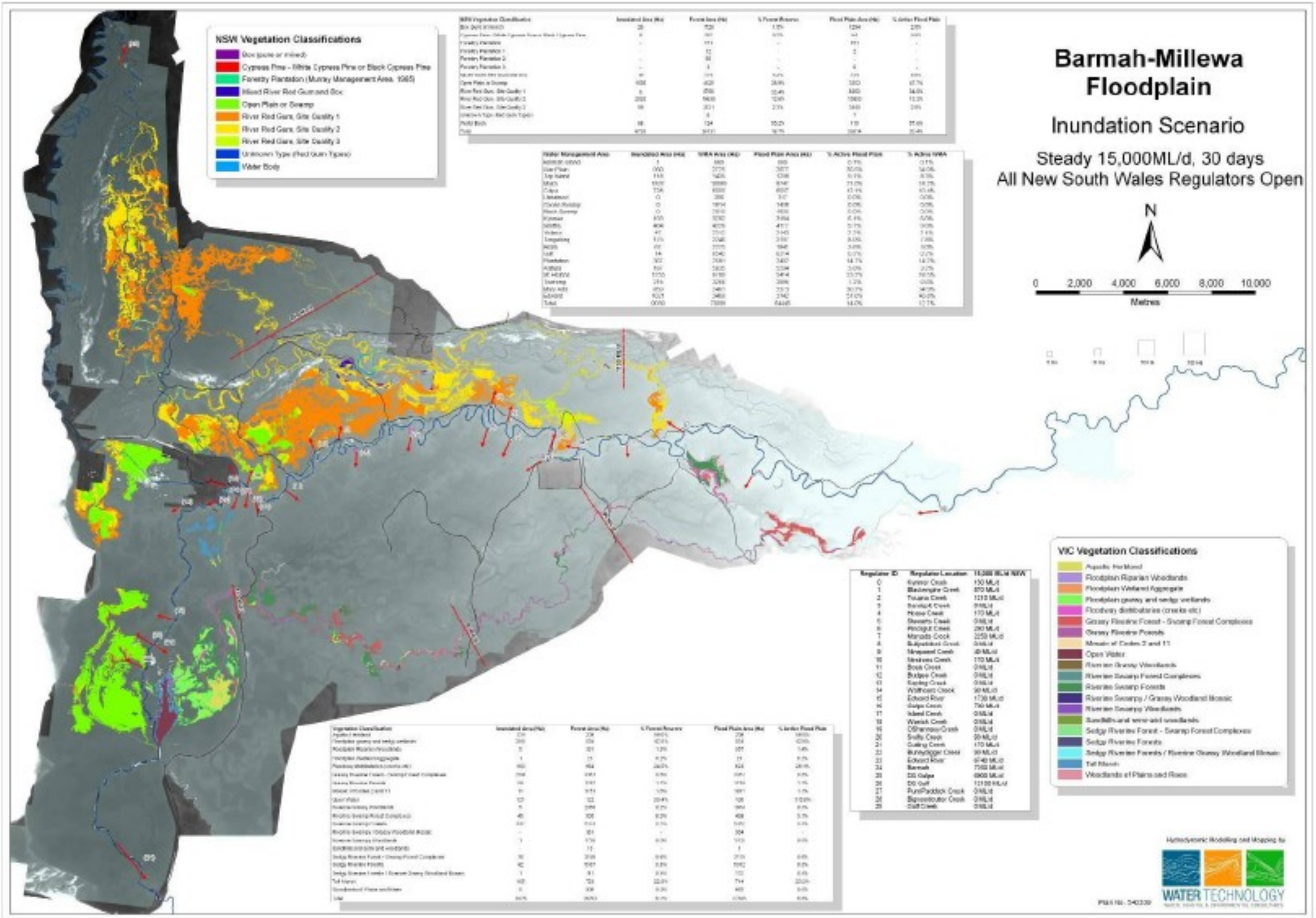
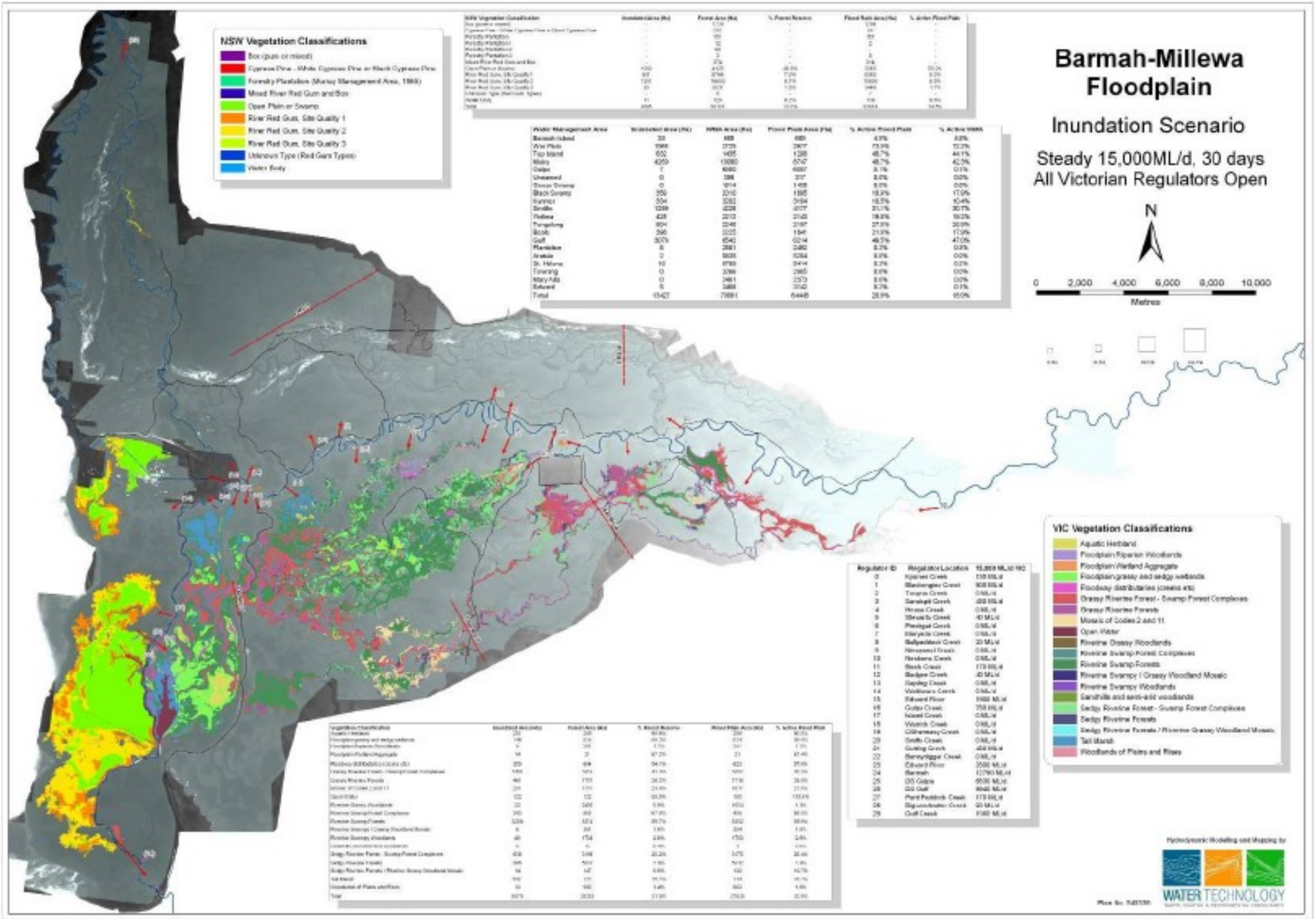


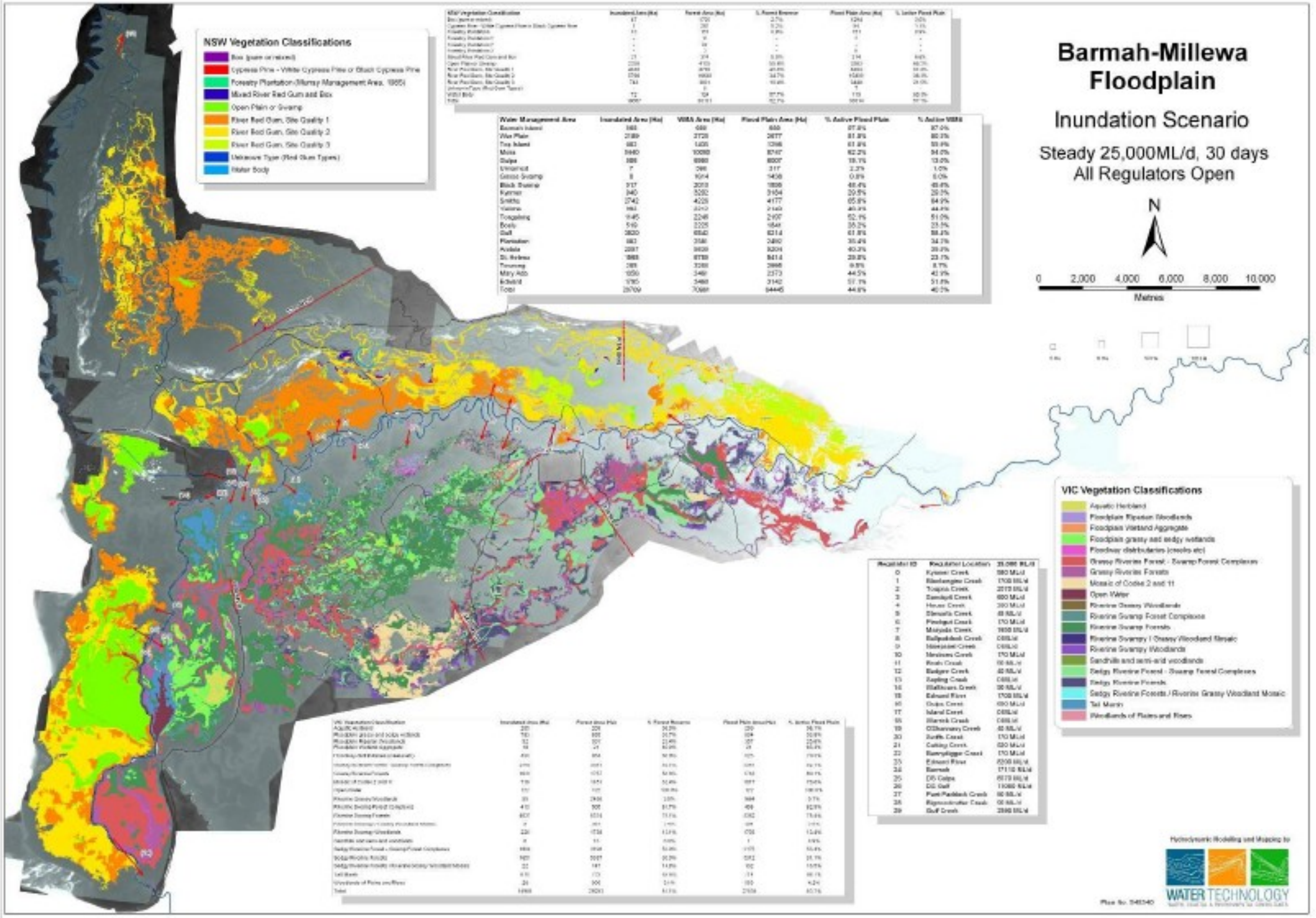
Figure B1-2 Inundation Scenario Steady 13,000 ML/d, VIC regulators open (except Sandspit, Bull Paddock, Stewarts Kitchen, 70% Gulf Creek)



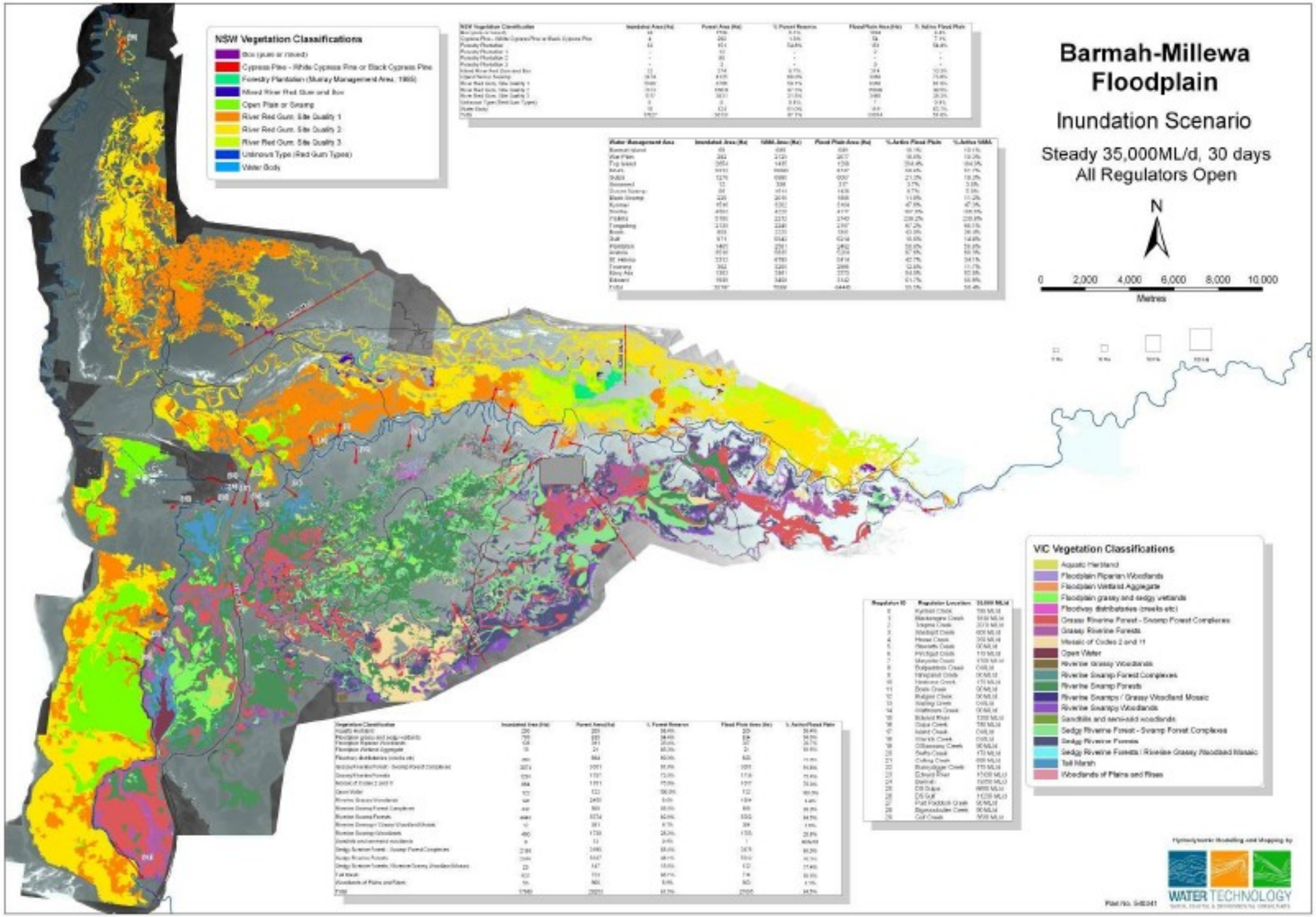
Appendix B1-3 Inundation Scenario Steady 15,000 ML/d, NSW - All regulators open



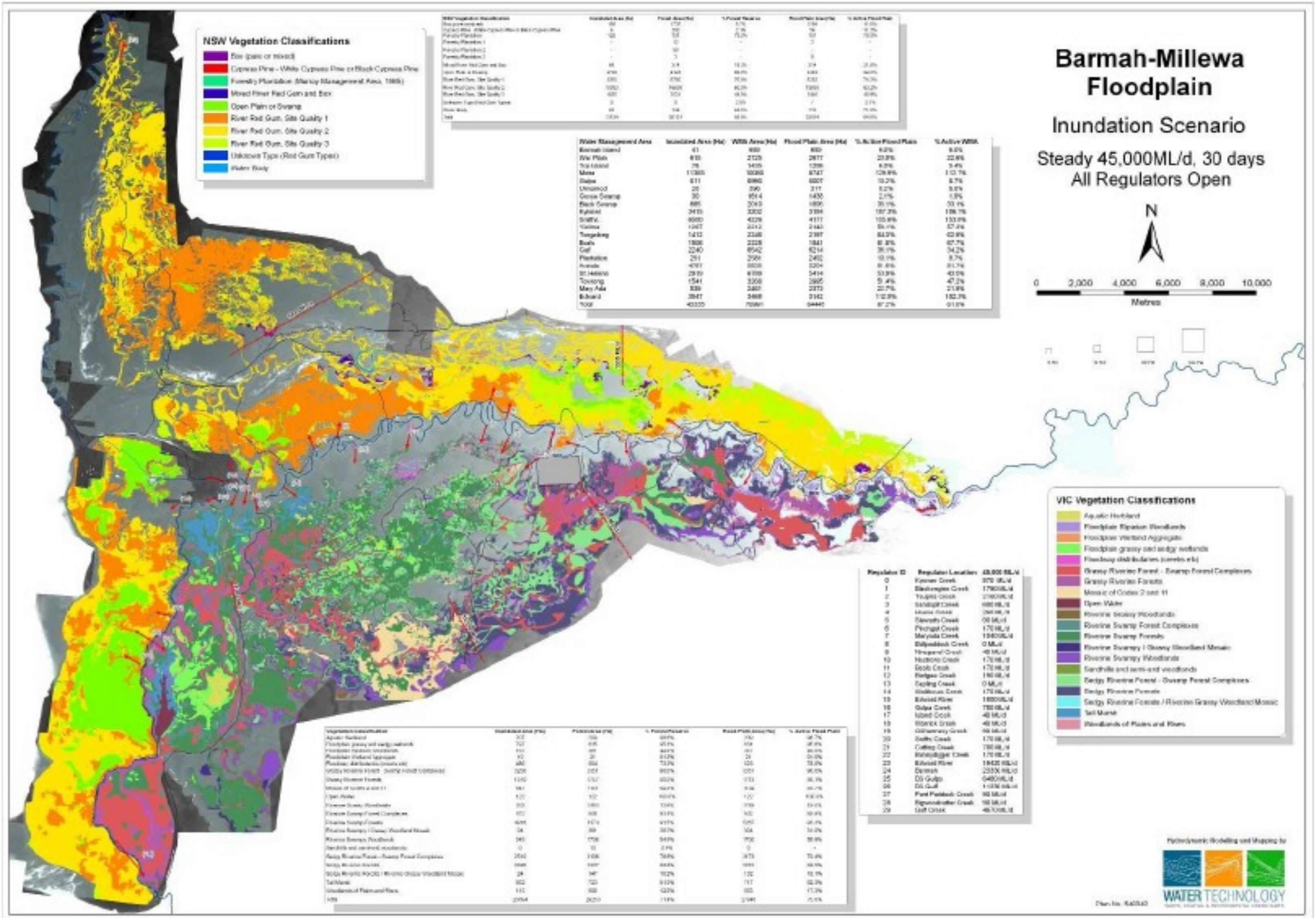
Appendix B1-4 Inundation Scenario Steady 15,000 ML/d, VIC - All regulators open



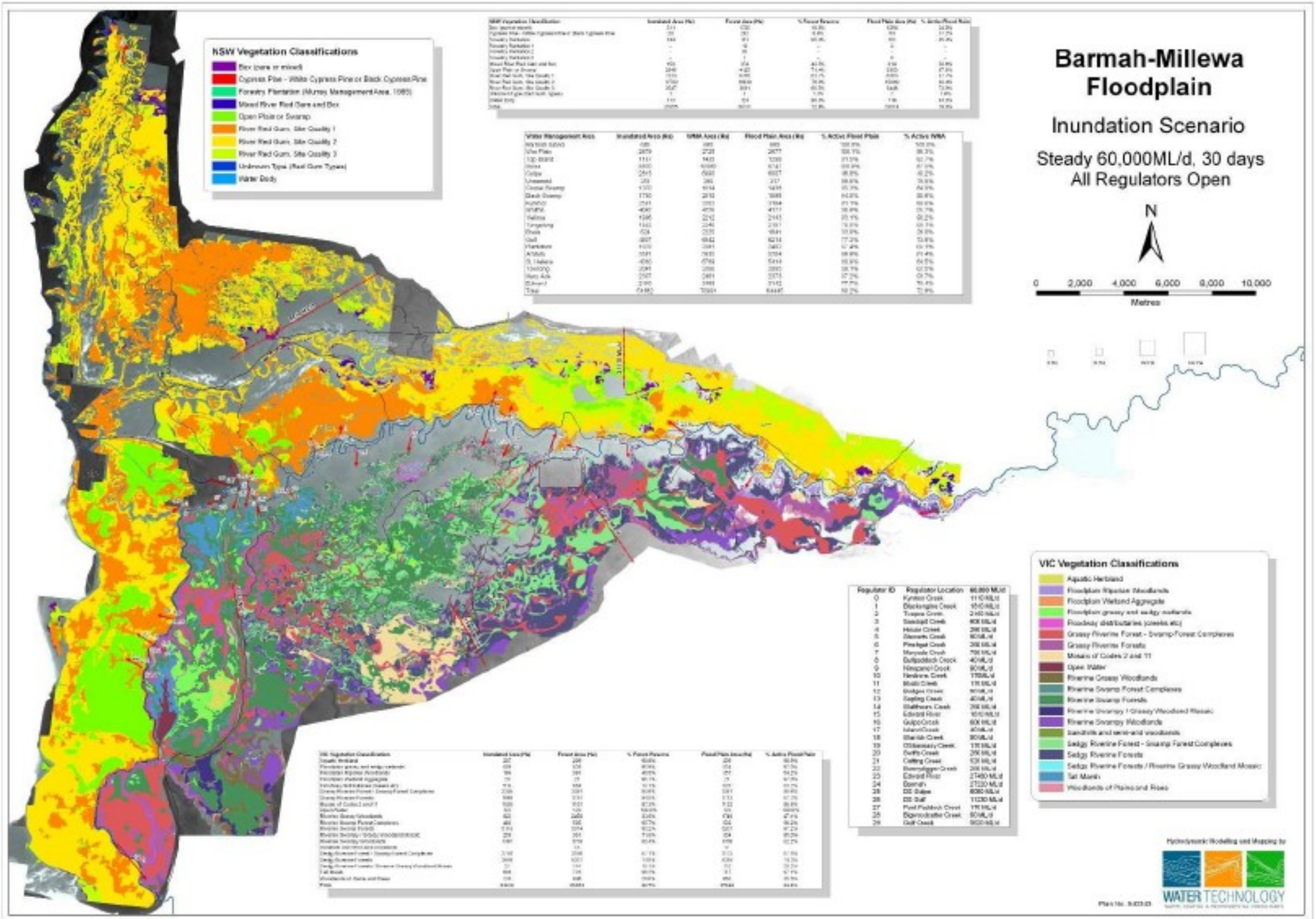
Appendix B1-5 Inundation Scenario Steady 25,000 ML/d, All regulators open



Appendix B1-6 Inundation Scenario Steady 35,000 ML/d, All regulators open



Appendix B1-7 Inundation Scenario Steady 45,000 ML/d, All regulators open



Appendix B1-8 Inundation Scenario Steady 60,000 ML/d, All regulators open

APPENDIX C CORRESPONDANCE

Memo

To:	Geoff Earl Guy Tierney	From:	Ben Tate/Warwick Bishop
Cc:		Date:	30/11/06
Subject:	Barmah Millewa ALS Banding Issue		

Introduction

The following document outlines investigations into the issues related to the observed banding of the Barmah Millewa ALS data, 2001.

The main source of topographic information utilised in the development of the Barmah-Millewa hydraulic model was the topographic survey data collected for the Murray Darling Basin Commission using the Light Detection and Ranging (LiDAR) airborne remote sensing technique. This technique allows for the rapid collection of topographic data over large areas. The raw LiDAR data had an average spacing of 2.4 m and a nominal vertical accuracy of 0.15 m Root Mean Square Error (RMSE) and horizontal accuracy of 1.0 m RMSE. The raw LiDAR data was processed to separate "ground strikes" from vegetation and other obstacles and interpolated onto 1 m and 10 m grids.

Overall, the digital elevation model developed from the LiDAR data provides excellent topographic detail of the study area from which to base the hydraulic model. However, two sources of error do exist in the LiDAR data that affect the potential accuracy of the hydraulic model. These error sources and their impact on the hydraulic model are discussed below:

- The presence of thick reed-beds in some wetlands in the study area prevents the LiDAR instrument signal from penetrating the beds and subsequently returns heights in these areas that are not consistent with the general topography of the wetlands. From a hydraulic modelling perspective this source of error is not particularly significant as the height values in these areas can be interpolated from the surrounding heights of the unaffected sections of the wetlands. It is also possible to supplement the LiDAR with ground survey.
- The more significant of the two errors is the so-called "banding" evident in the data between some flight-path swathes (overlapping parallel flight paths along which data is collected). In some instances a distinct "step" in the general surface elevation between the adjacent flight-path swathes of up to 300 mm is evident. It is understood that this source of error has largely been eliminated in subsequent data capture projects using better LiDAR data post-processing techniques, however it is not known if the earlier LiDAR data used in this project could be reprocessed to minimise this source of error. From a hydraulic modelling perspective this error is potentially significant as it creates an artificial linear feature that can affect the pattern and/or depth of flooding over long distances and large areas.

The remainder of this document explores the affect of the banding on the topography and the model results. We have undertaken a number of analyses in order to attempt to identify and quantify the impact of LiDAR banding on the hydraulic model results.

Analysis and Results

The banding is visually quite evident in the Barmah Millewa LiDAR, running from north-east to south-west. Due to the variation in the topography, the banding of the LiDAR is most pronounced when visualised using different colour ramps and at different scales. Figure 5 and Figure 6 below illustrate the banding of the LiDAR in a 2D plan view for the Victorian side, the Barmah Forest side of the study area. Figure 7 shows three of the bands in a rotated 3D view, looking along the banding lines from the south-east to the north-west.

A number of cross-sections perpendicular to the banding lines were taken and examined to illustrate the affect of the banding in more detail. Due to the slight natural variation in the topography it is difficult to distinguish the changes in topography due to the banding from that of the natural variation in elevation. An example of one of the cross-sections taken is shown in Figure 8.

A test of the affect of the banding on typical hydraulic model results is shown in Figure 9, with a long-section running downstream through the floodplain from Stewarts & Bullpaddock Creeks to Snag Creek. This suggests the model results are not significantly affected by the LiDAR banding as there is no consistent flood level response at each of the banding points. This could be explained by the interpolation of the topography onto an 80 m grid, effectively smoothing out any local effects of the topography banding. This does not necessarily suggest that banding has no impact on the model results, but that any impact is very difficult to distinguish given the errors introduced are of the same order as the general rise and fall of the topography through the forest.

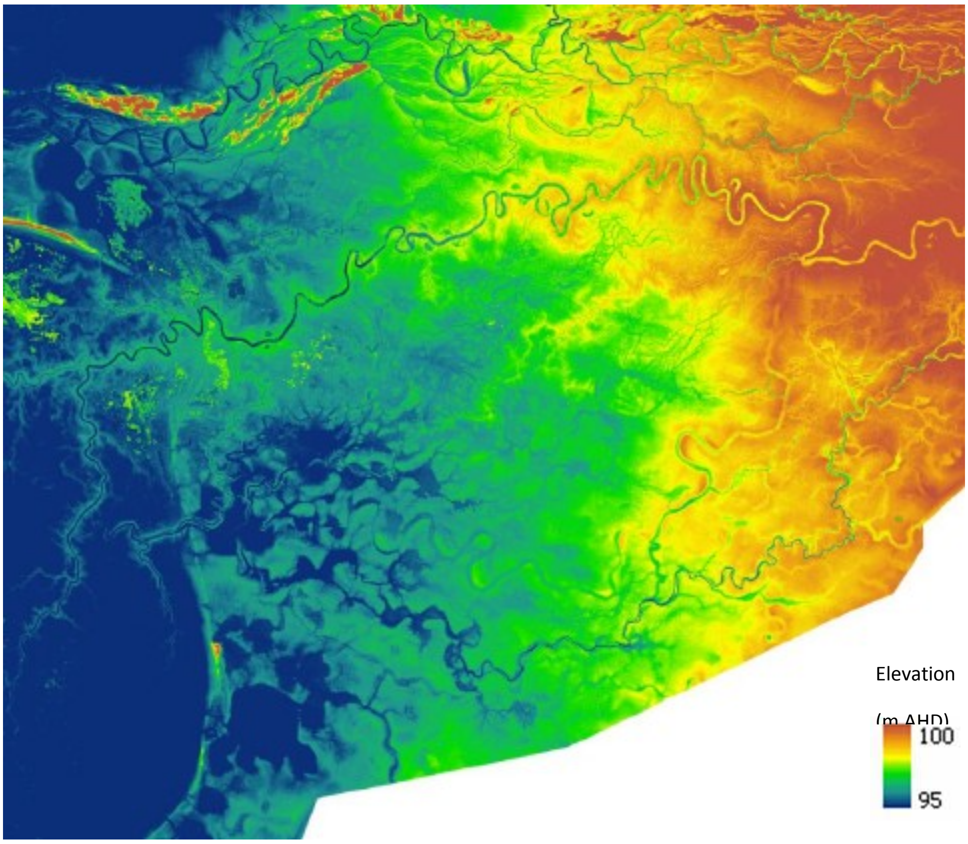


Figure 5 Barmah Millewa LiDAR Banding

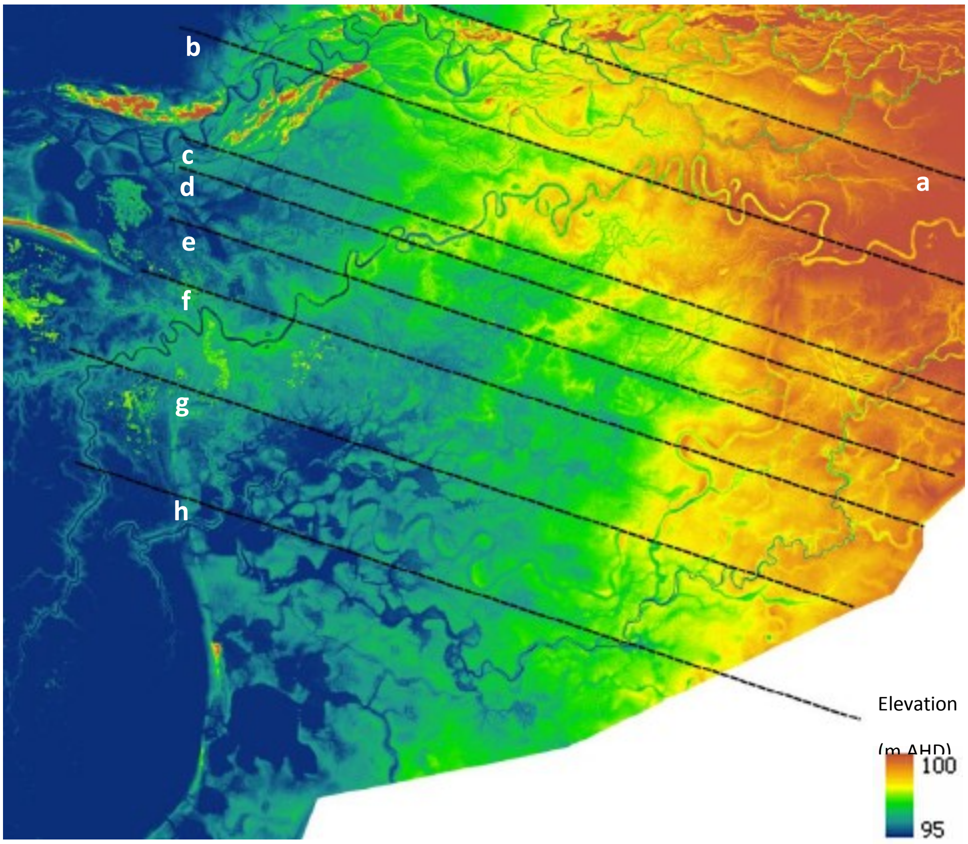


Figure 6 Selection of Major LiDAR Banding Lines

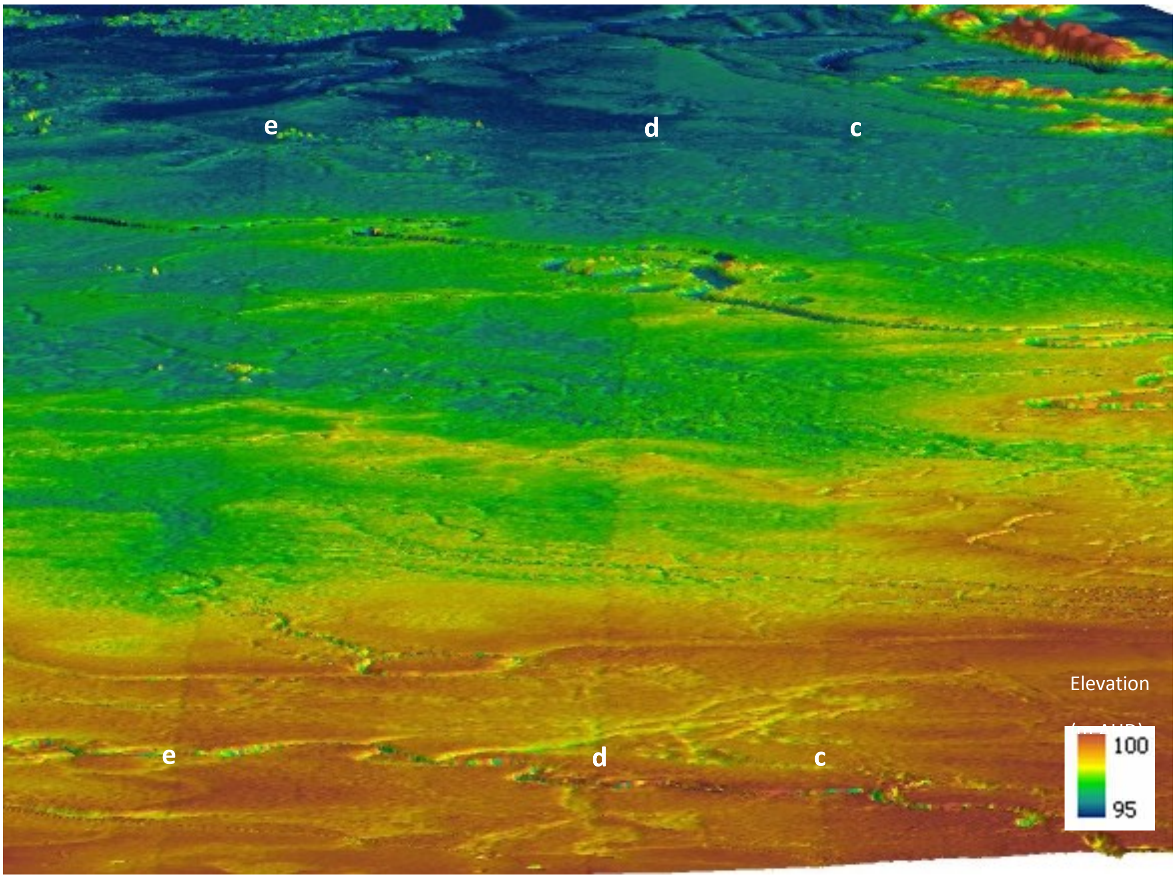


Figure 7 LiDAR Banding Lines c, d & e in 3D Looking South-East to North-West

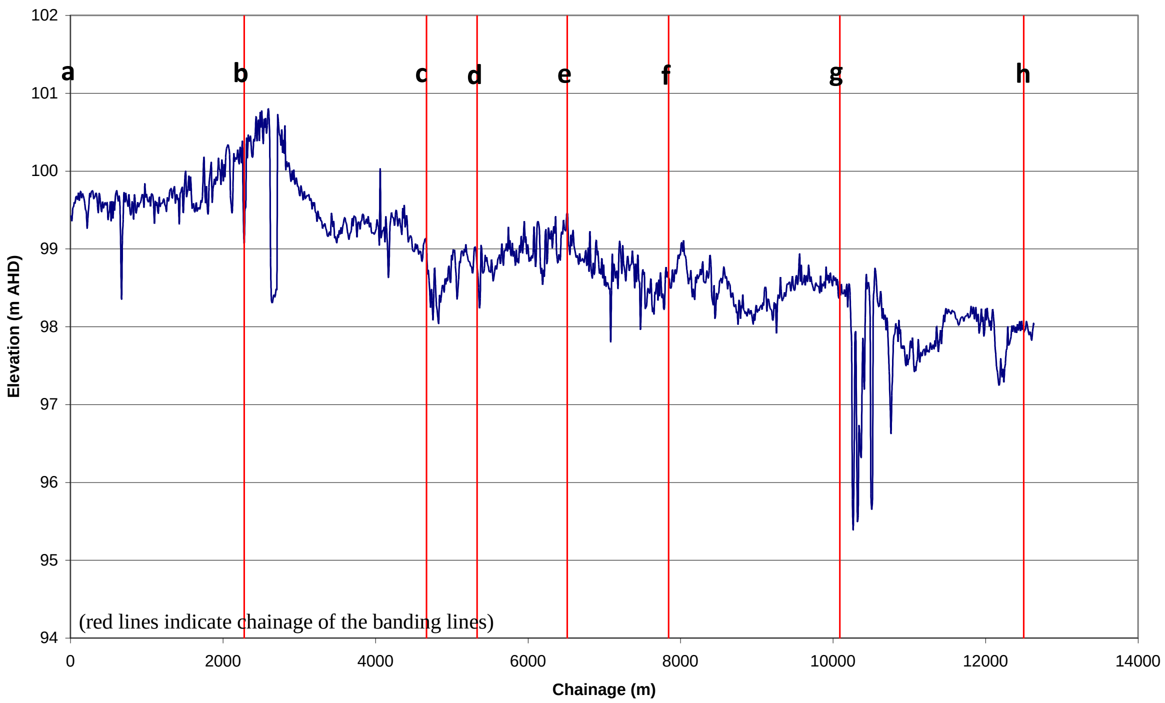


Figure 8 Example of a Cross-Section Perpendicular to the LiDAR Banding Lines

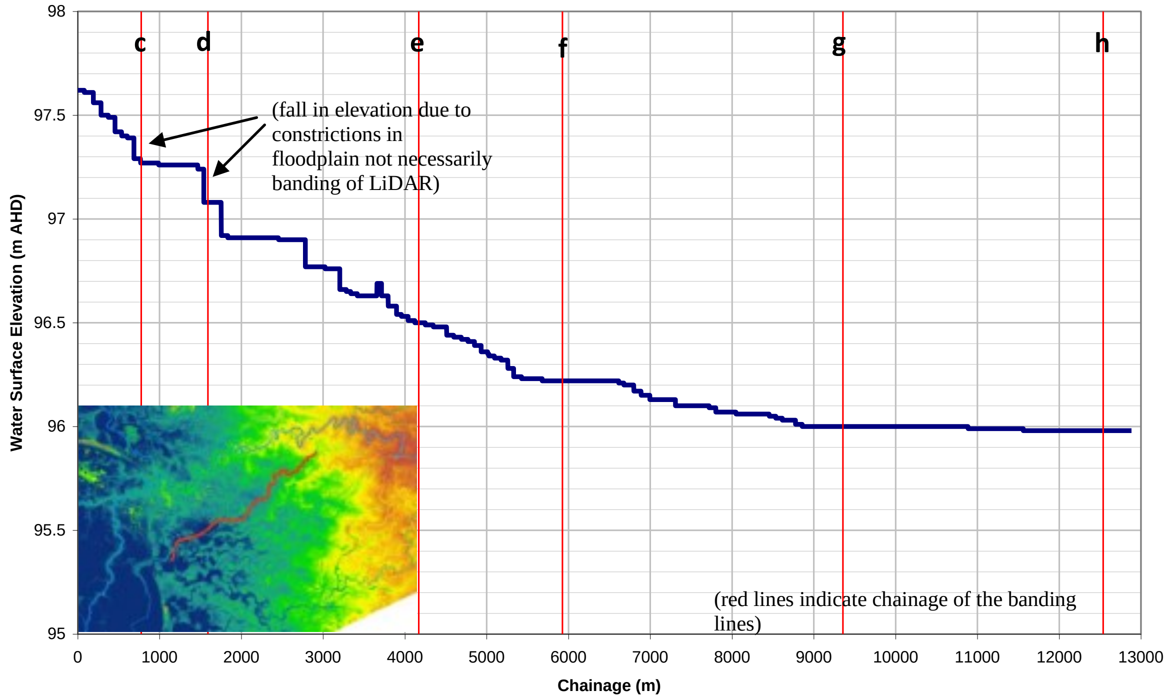


Figure 9 Long-Section Running Downstream Through the Floodplain from Stewarts & Bullpaddock Creeks to Snag Creek.

Recommendations

As can be seen in the above figures, the banding of the LiDAR is quite noticeable from a visual perspective and we have been able to quantify vertical shifts of up to 300 mm along the "banding lines". However, from the data analysed to date it is difficult to observe any significant affect on the model results due to banding. This is primarily due to the smoothing out of any banding affect when interpolating the topography onto an 80 m grid.

Whilst we have strong concerns regarding the LiDAR banding noted above, based on the hydraulic requirements for this current model it is difficult to demonstrate a convincing case for reflying or reprocessing the LiDAR data over the Barmah Millewa Forest. However, when taking other factors into account, there is a stronger case for looking at this more closely. For example the present banded data provides a credibility issue for any investigations that are based upon it. This is due to the clearly visible banding patterns on a colour plan plot of the area. Additionally, if a finer detail, more local investigation is carried out in the future local discrepancies around the banding lines may become more apparent.

More definitive results could potentially be produced for this matter by undertaking a local, fine grid model of a sub-area within the forest. This could have the benefit of more closely matching the native resolution of the LiDAR data with the results and hence would be better placed to highlight any adverse impacts of the banding itself.

We hope this information is useful. Please contact us if you require any further information.

Regards,
Ben Tate/Warwick Bishop

Memo

To:	Geoff Earl Guy Tierney	From:	Ben Tate/Warwick Bishop
Cc:		Date:	18/12/06
Subject:	Barmah Millewa ALS Banding Issue		

Introduction

The following document outlines investigations into the issues related to the observed banding of the Barmah Millewa ALS data, 2001. It follows on from the previous document dated 30th November 2006 (Memo_ALS_Banding_061130.pdf).

Discussion

The banding of the LiDAR is quite noticeable from a visual perspective both in the topography and in the model results. From data analysed to date it is difficult to demonstrate a significant impact on modelled water surface elevation due to the banding as the events analysed are large flood events that inundate and drown out the effects of the banding. When the results are displayed with the colour shaded by depth, this is when the banding is most obvious. However the depth is directly related to the topography, and the variation in the topography is often much more pronounced than the banding itself, making it very difficult to quantify the impact of the banding.

As discussed in the previous memo regarding the banding, we believe that the banding issue would become more of a problem if the LiDAR is to be used for a high resolution small scale study. We tested this by setting up a 10m grid MIKE21 model of a NSW section of floodplain as shown in Figure 10 and Figure 11. The model was setup with a source point pumping water onto the floodplain simply to demonstrate the way the banding affects the results for lower flows.

As can be seen in the results in Figure 12 to Figure 15, at low flows banding shifts in the topography prevent water from spreading over the floodplain as would naturally be the case. Instead the banding lines effectively form levees containing the water within the bands. This demonstrates that the incidence of banding in the LiDAR data has a significant effect on hydraulic model results for studies of small scale and high resolution.

As discussed previously, the impacts of banding are difficult to resolve within the present coarse hydraulic model grid (80 m). However the results presented here clearly demonstrate that the topographic errors induced by the banding have an impact on high resolution hydraulic modeling within the forest.

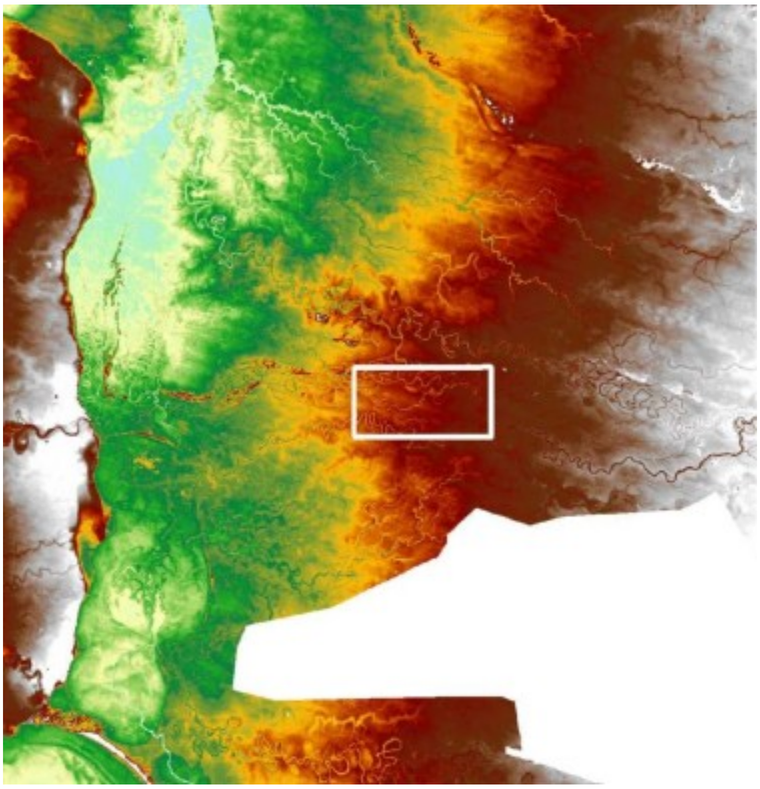


Figure 10 - MIKE21 model location

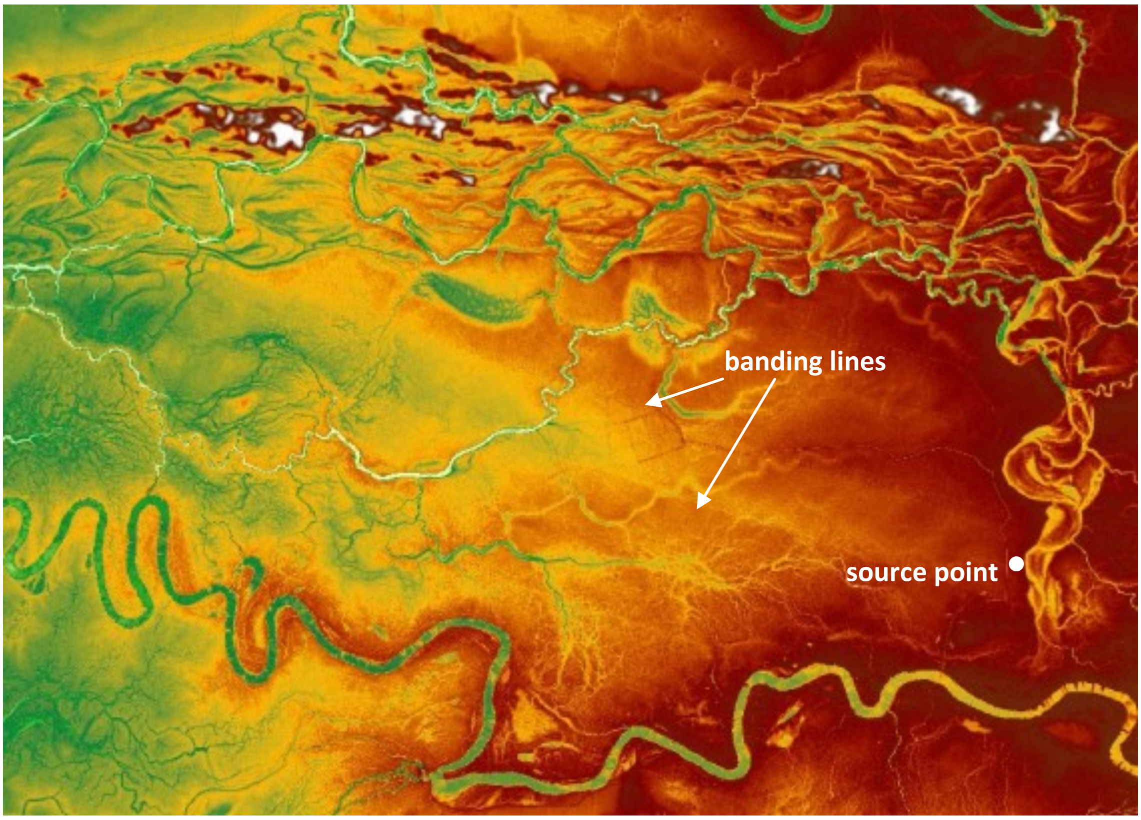


Figure 11 - MIKE21 model structure

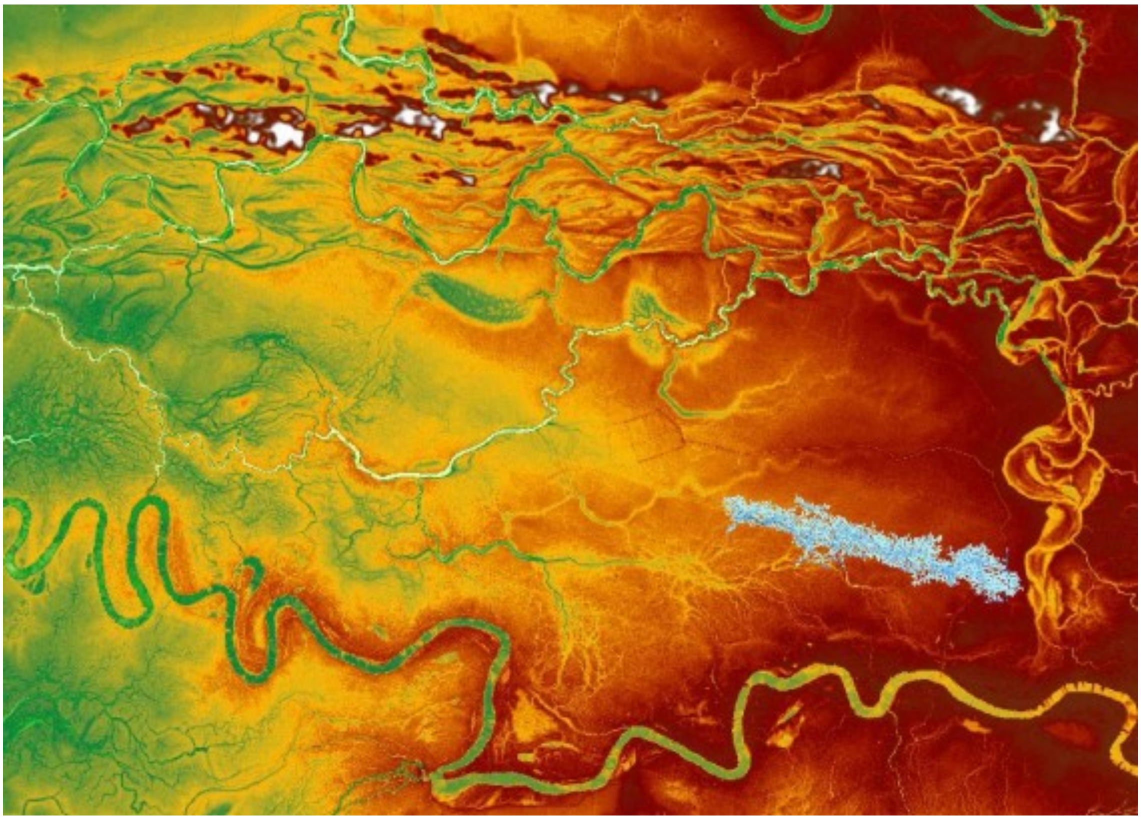


Figure 12 MIKE21 model results (time step 1)

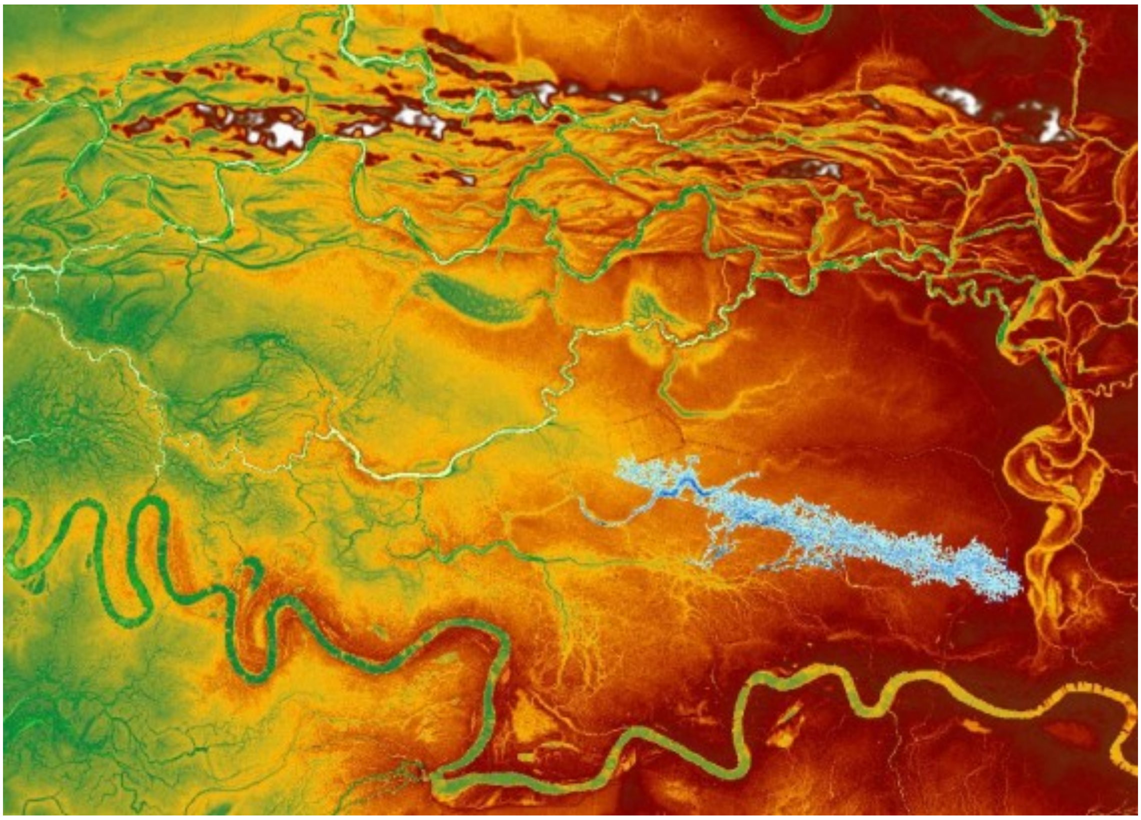


Figure 55 MIKE21 model results (time step 2)

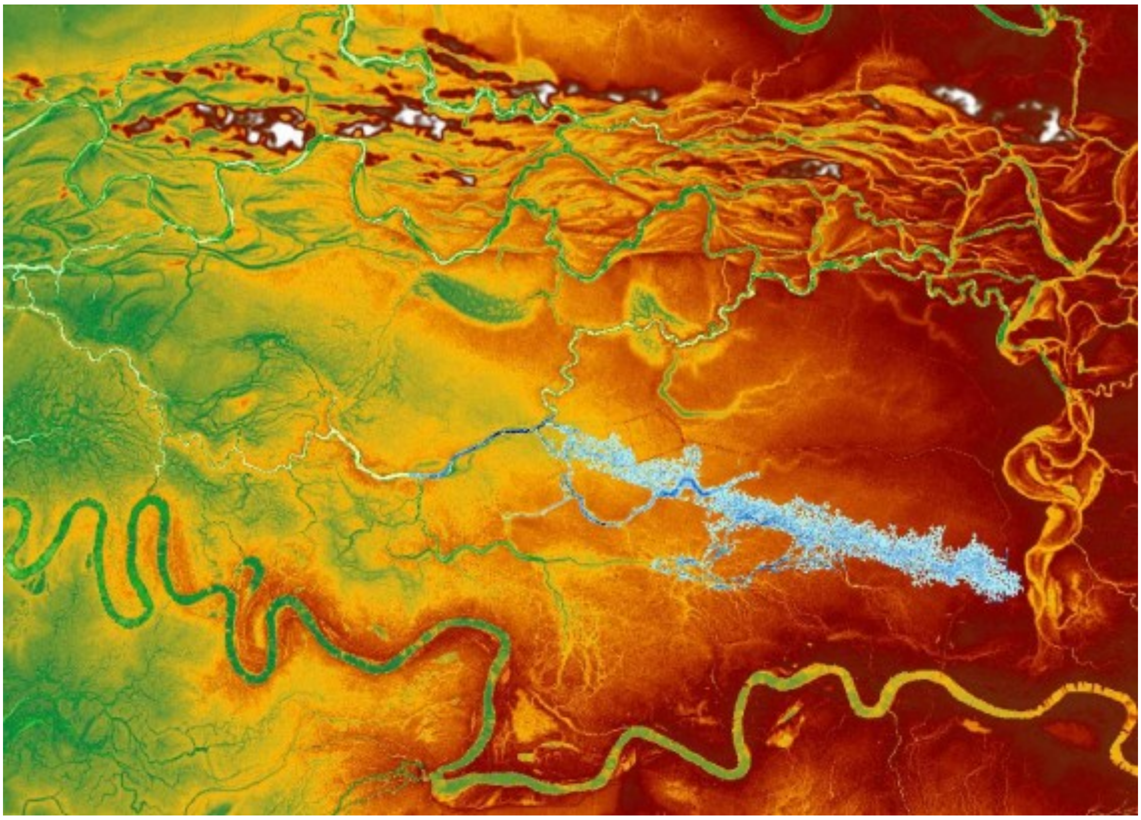


Figure 56 MIKE21 model results (time step 3)

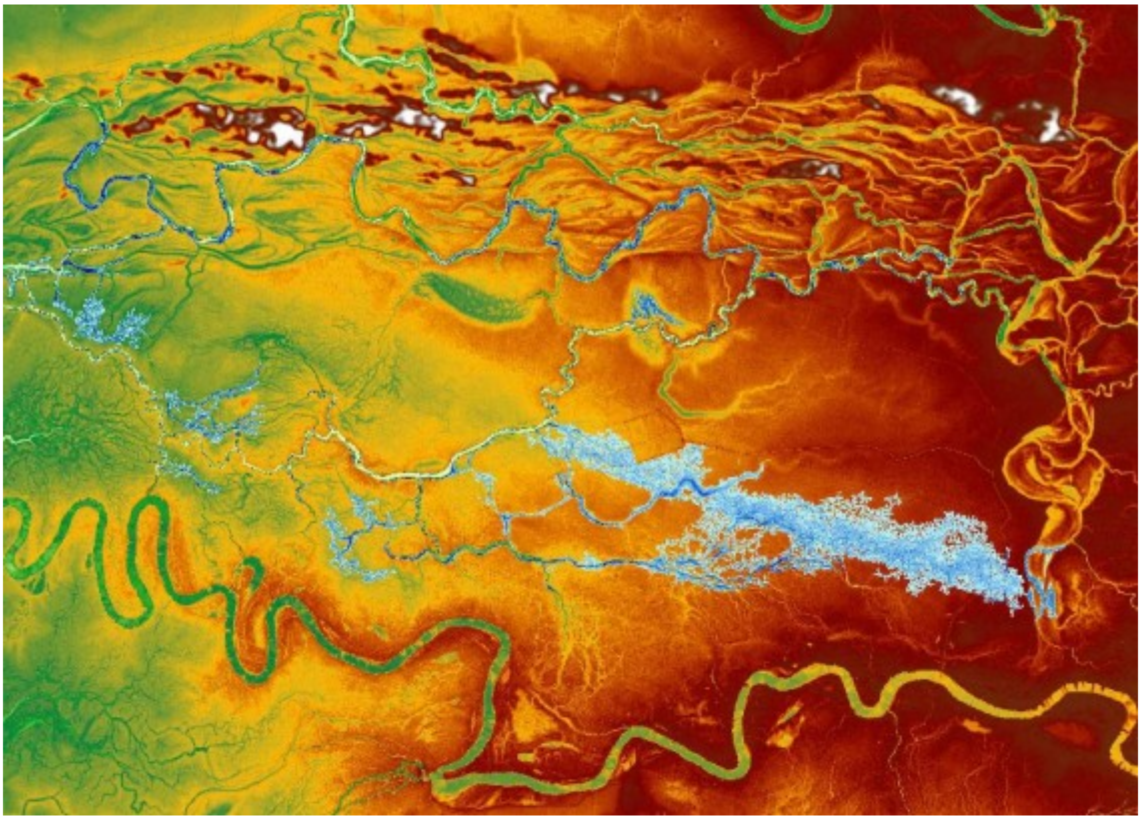


Figure 15 MIKE21 model results (time step 4)

It is understood that Goulburn-Broken CMA are currently looking at a series of tenders to fly LiDAR for the Goulburn River with re-flying the Barmah Forest as a possible variation. The possibility of reprocessing the current LiDAR is also being analysed. If the CMA intends to use the current LiDAR for small scale studies such as the test model described above, then it is recommended that the banding issue be looked at closely and addressed through either the reprocessing or the re-flying of LiDAR. This decision will be driven somewhat by the effectiveness of reprocessing and the cost of reprocessing versus re-flying.

If you would like to discuss this document further or require any assistance in the decision making process for reprocessing or re-flying the LiDAR then please contact us to discuss.

Regards,

Ben Tate/Warwick Bishop

APPENDIX D REGULATOR SUMMARY

Modelled Regulators

Regulator Name	Data Source
Big Wood Cutter Creek	SKM 2005
Boals Creek	SKM 2005
Budgee Creek	Estimated
Bull Paddock Creek	SKM 2005
Bunny Digger Creek	SKM 2005
Cutting Creek	Estimated
Edward River	Estimated
Gulf Creek	1-SRWSC120490
Gulf Creek 2	2-SRWSC120490
Gulpa Creek	Estimated
House Creek	SRWSC108845
Island Creek	SKM 2005
Mary Ada Creek	SKM 2005
Nestrons Creek	SKM 2005
Nine Panel Creek	SKM 2005
O'Shannasy Creek	SKM 2005
Pinch Gut Creek	SKM 2005
Punt Paddock Creek	SKM 2005
Sandspit Creek	SKM 2005
Sapling Creek	SKM 2005
Stewarts Creek	SKM 2005
Swifts Creek	SKM 2005
Toupna Creek	Estimated
Walt Hours Creek	SKM 2005
Warrick Creek	SKM 2005