NATIONAL RESEARCH
FLAGSHIPS

Water for a Healthy Country

The River Murray Floodplain Inundation Model (RiM-FIM)

Hume Dam to Wellington

Overton, I.C., McEwan, K., Gabrovsek, C. and Sherrah, J.R.

CSIRO Water for a Healthy Country Technical Report

CSIRO

The River Murray Floodplain Inundation Model (RiM-FIM)

Hume Dam to Wellington

Overton, IC[1], McEwan, K[1], Gabrovsek, C[1], and Sherrah, JR[2]

[1]CSIRO Land and Water, Urrbrae, South Australia

[2]Cognitive Systems Pty Ltd

CSIRO Water for a Healthy Country Technical Report 2006

The Water for a Healthy Country Flagship is a national research partnership between CSIRO, state and federal governments, private and public industry and other research providers.

The Flagship was established in 2003 as part of CSIRO's National Research Flagships initiative. From 2004 to 2011 the initiative will receive $305 million in primary funding from the Australian Government's Backing Australia's Ability program.

The work contained in this report is a collaboration between the Flagship and CSIRO Division of Land and Water

Citation: Overton, IC, McEwan, K, and Sherrah, JR (2006) The River Murray Floodplain Inundation Model – Hume Dam to Lower Lakes. CSIRO Water for a Healthy Country Technical Report 2006. CSIRO: Canberra.

For further information contact:
Ph: 02 6246 4565
Fax: 02 6246 4564

www.csiro.au

Publisher: CSIRO

Printed 2006

Acknowledgements

The development of the River Murray Floodplain Inundation Model (RiM-FIM) has had a long history. Originally commissioned in 1997 by SA Water and first produced by Mapping and Beyond Pty Ltd. It has undergone three revisions/redevelopments since then, the second by Mapping and Beyond and a third and fourth by CSIRO Land and Water.

Floodplain Inundation Model I – 1997

Funded by the Murray Darling Basin Commission, sponsored by SA Water and the SA Department of Environment and Natural Resources and produced by Mapping and Beyond Pty Ltd.

Credits to: Ian Overton[1,2], Brenton Erdman[3], Bob Newman[4], Nicolie Sykora[3], Susanne Slegers[1], Matthew Sandercock[1], Jamie Sherrah[7] and Ben Raymond[7].

Floodplain Inundation Model II – 2000

Funded and sponsored by the SA Department of Water Resources and produced by Mapping and Beyond Pty Ltd.

Credits to: Ian Overton[1,2], Jane Lawley[1], Matthew Sandercock[1] and Tony Herbert[5].

Floodplain Inundation Model III – 2004

Funded by the National Action Plan for Salinity and Water Quality, sponsored by the River Murray Catchment Water Management Board and produced by CSIRO Land and Water.

Credits to: Ian Overton[6,2], Chris Smitt[6] and Jamie Sherrah[7].

Floodplain Inundation Model IV – 2006

Funded by the CSIRO Flagship Project – Water for a Healthy Country Flagship, sponsored by the Ecological Outcomes Project within the River Murray Region and produced by CSIRO Land and Water.

Credits to: Ian Overton[6,2], Kerryn McEwan[6], Christina Gabrovsek[6] and Jamie Sherrah[7].

[1]Mapping and Beyond Pty Ltd

[2]University of Adelaide

[3]SA Water

[4]Murray-Darling Basin Commission

[5]South Australian Department of Water, Land and Biodiversity Conservation

[6]CSIRO Land and Water

[7]Cognitive Systems Pty Ltd

Executive Summary

The River Murray Floodplain Inundation Model (RiM-FIM) was created as a research and decision support tool for environmental flow management in the River Murray. The project has been funded, commissioned and developed by several organisations since beginning in 1997. RiM-FIM encompasses the River Murray floodplain from Hume Dam at Albury (Victoria) to Lake Alexandrina at Wellington (South Australia). This is the entire length of the regulated section of the River Murray (~2,155 km).

The model was developed using a Geographical Information System (GIS), remote sensing and hydrological modelling. Floodplain inundation extents were detected from satellite imagery for a range of flows and interpolated to model flood growth patterns. The RiM-FIM predicts the extent of flooding on the River Murray floodplain from a range of river flows and weir levels. It is useful for predicting the extent of inundation on the River Murray floodplain (~606,000 ha) including the flow regimes of wetlands and floodplain vegetation. It allows for spatial and quantitative analysis of the flood extents to be used as an input into the management decision process.

TABLE OF CONTENTS

TABLE OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

CTF	–	Commence to Fill
DSS	-	Decision Support System
FIRU	–	Floodplain Inundation Response Unit
GIS	–	Geographical Information System
Landsat ETM	-	Landsat Enhanced Thematic Mapper
Landsat 7 TM	-	Landsat 7 Thematic Mapper
MDBC	-	Murray Darling Basin Commission
NSWWWG	-	New South Wales Wetlands Working Group
RiM-FIM	-	River Murray Floodplain Inundation Model
RMFST	-	River Murray Flow and Salt Transport
WaSH	-	Wet At Same Height

1 INTRODUCTION

The River Murray is Australia's largest river and plays a vital role in Australia's economic and environmental resources. The Murray Darling Basin catchment occupies one seventh of Australia and contributes 70% of Australia's irrigated crops and pastures. It provides 100% of Adelaide's water supply in dry months along with being a major water supply to the towns in the basin.

Management of the River Murray has been implemented to mitigate large floods and to protect infrastructure, while maintaining storages for regular water supply to irrigators. Concerns over river health have increased the attention on environmental flow strategies over the past decade. The focus is on releasing and managing flows to provide environmental benefits to the floodplain, wetlands and in-stream water quality. Previous studies on modelling river flow and inundation have been undertaken for wetlands on the Darling River in New South Wales (Shaikh et al. 2001) and floodplains on Roanoke River in North Carolina (Townsend and Walsh 1998) and Murrumbidgee River (Frazier *et al.* 2003). Floodplain inundation mapping has previously been conducted on sections of the River Murray in South Australia (Overton *et al.,*1999, Overton, 2005) however, no quantitative tool existed for measuring the extent of floodplain inundation for the entire regulated length of the River Murray (~2155 km) and associated floodplain of approximately 606,000 ha. The River Murray Floodplain Inundation Model (RiM-FIM) was developed to provide such a tool and to offer input into the management decision process on the environmental benefits of flood inundation for the River Murray.

RiM-FIM was developed using a spatial information system framework that allowed the integration of non-spatial river flow models with the extent of flood inundation. Riverine ecosystems benefit from spatial analysis studies because they encompass three important temporally dynamic spatial dimensions (along the channel, river height and floodplain width) and the physical and ecological processes taking place are complex. Many investigations have studied the longitudinal (upstream and downstream) dimension examining the ecological impacts of river regulation on native flora, fauna and the physical changes occurring in the littoral zone (Stanford *et al.,* 1996). However long term modification of flow rates, changes to the frequency of flooding events and alteration to the timing of flows have now been identified to cause degradation beyond the littoral zone into both the lateral and vertical dimensions (Young, 2001). This is particularly prevalent in the River Murray ecosystem where rising saline groundwater has contributed to land degradation throughout the region and increased accession of saline groundwater to the river (Jolly, 1996). Furthermore the semi-arid nature of the Murray floodplain means that the variability in the size and timing of flows is extreme and un-predictable (Walker and Thoms, 1993).

Consequently, river regulation in the River Murray has severely impacted the balance of physical and ecological processes that maintain the unique riverine environment. Managing the river system to balance social, economic and environmental requirements, when resources are scarce, requires quantitative analytical tools (Young *et al.,* 2000). This report describes the development of the (RiM-FIM) to predict the effect of flow management options on floodplain inundation.

2 THE RIVER MURRAY HYDROLOGY

Rim-FIM covers the entire regulated length of the River Murray (approximately 2,154 km) and its floodplain approximately 870,000 ha) from the Hume Dam, near Albury in Victoria, to Wellington, in South Australia (Figure 1). The river falls from 192 m above sea level at Hume Dam to 3.3 m above sea level at Lock 1 and is highly regulated by fourteen weirs and locks and several storage facilities (Figure 2).

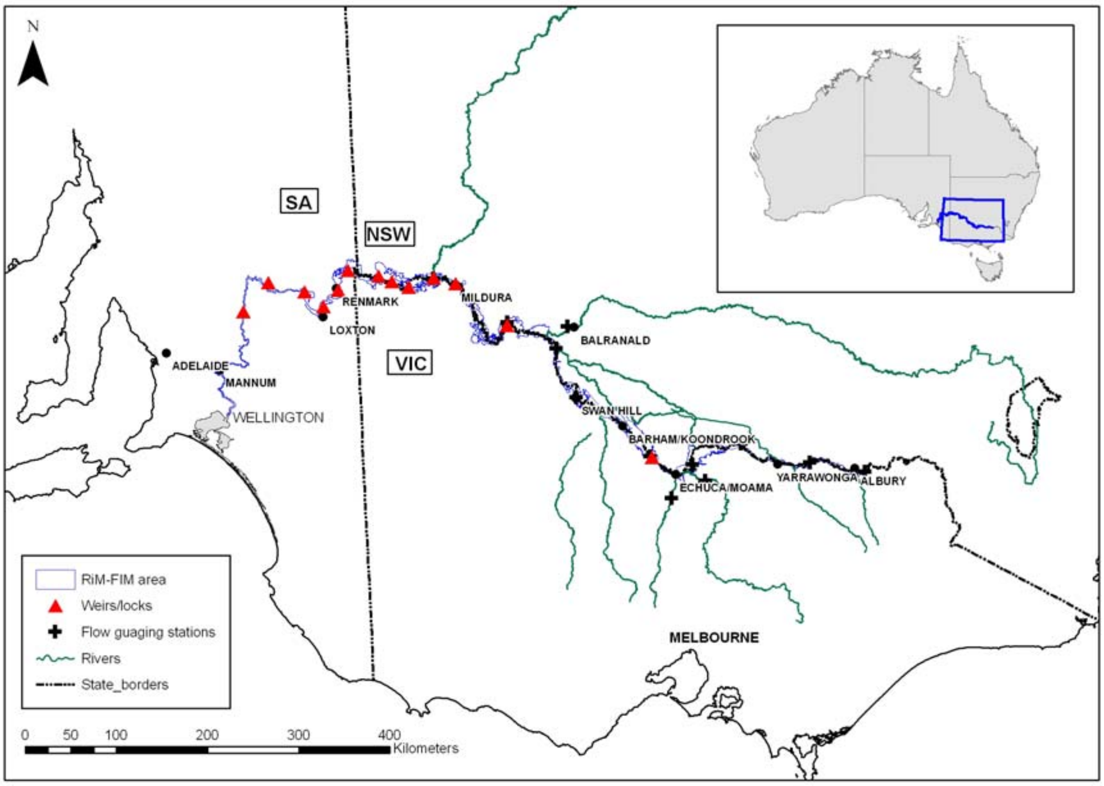


Figure 1. The RIM-FiM area covering the regulated River Murray from Hume Dam to Wellington

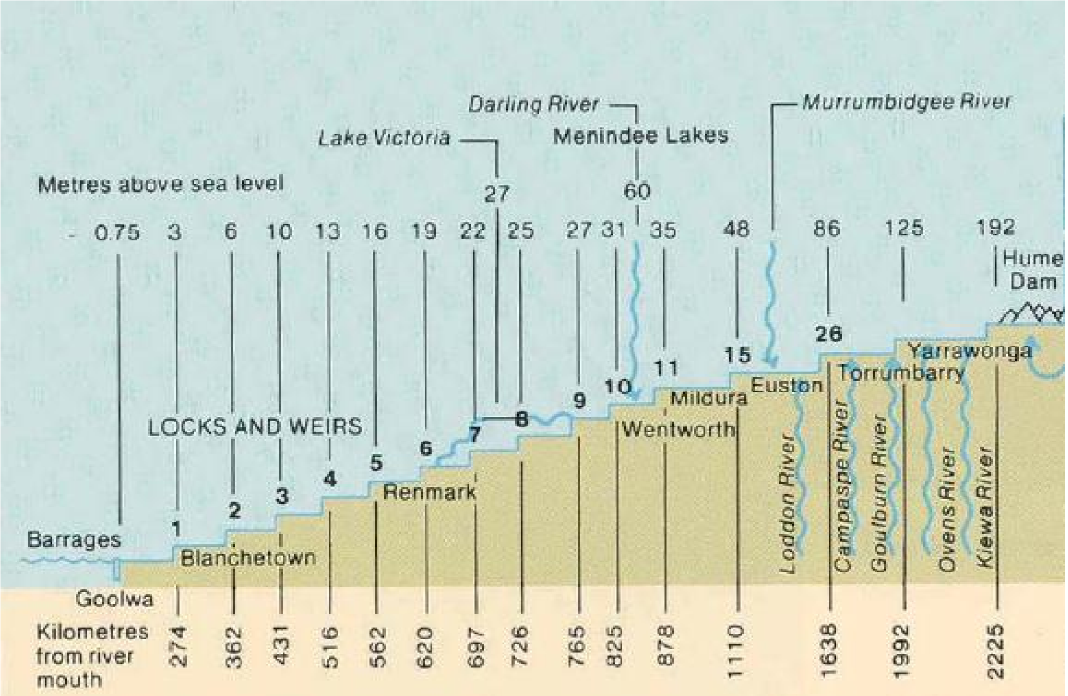


Figure 2. Longitudinal section of the River Murray (Source MDBC).

From downstream of the Hume Dam to Swan Hill the river meanders in a shallow channel through the Riverine Plains. The Kiewa, Ovens, Goulburn, Campaspe and Loddon Rivers enter the Murray in this section from Victoria. Large Red Gum forests occur in this section (Figure 3).

Figure 3. Barmah Forest showing an area of Red Gum forest in flood.

From just north of Swan Hill to Overland Corner (just downstream of Lock 3) the Murray passes though the semi-arid Mallee zone. The river flows through large floodplains between 2 km and 10 km wide, is dominated by anabranches and oxbows which contain extensive permanent wetlands (Pressey, 1986; Walker and Thoms, 1993) (Figure 4). The Murrumbidgee and Darlings Rivers enter the Murray in this section from NSW. From Lock 11 to Lock 3 the river floodplain is less frequently flooded and the floodplain areas are a discharge site for the regional saline groundwater system of the Murray- Darling Basin.

Figure 4. Pipe Clay Creek, SA, an anabranch of the River Murray (source DWLBC).

Downstream of Overland Corner the floodplain becomes constricted in the Murray gorge. The floodplain narrows to 1.5-2 km wide and the river is characterised by long straight stretches and elongated wetlands (Eastburn, 1990)(Figure 5).

Figure 5. Limestone cliffs of the Murray Gorge near Nildottie, South Australia

2.1 River Murray Floodplain Zones

A floodplain boundary was required for the development of the RIM-FIM to be used as a River Murray study boundary. The 1956 flood boundary in South Australia (sourced from the South Australian Government Department of Environment and Heritage and was used for the section of the River Murray in South Australia. In New South Wales and Victoria the 1956 flood boundary was provided by the Murray Darling Basin Commission. Gaps in this boundary occurred where ground data on the extent of the flood was not available. In other areas individual ground recorded points were connected with straight lines to form the boundary. The original 1956 flood boundary was edited by overlaying the boundary onto 1996 aerial photography and identifying the new floodplain boundary by the extent of the visible floodplain edge indicated by vegetation on the aerial photograph. In some cases the extent of the 1956 flood boundary covered agricultural and populated areas that have since been protected against such floods. In creating the River Murray floodplain layer a degree of judgment was used to exclude these areas and follow the more 'active' floodplain based on vegetation.

River Murray flows are dependent on releases from Hume Dam, as well as, the flows into the River from the major tributaries and outflows from irrigation and water storage extractions. The flow in each reach of the River is dependent on the management of the Locks and weirs. Figure 6 shows a range of flows from Hume Dam down the River when the travel time is considered. This represents the flow wave which can be very different for similar releases from Hume Dam. This means that a single flow input at the top of the system cannot be used to predict area of inundation for the whole system.

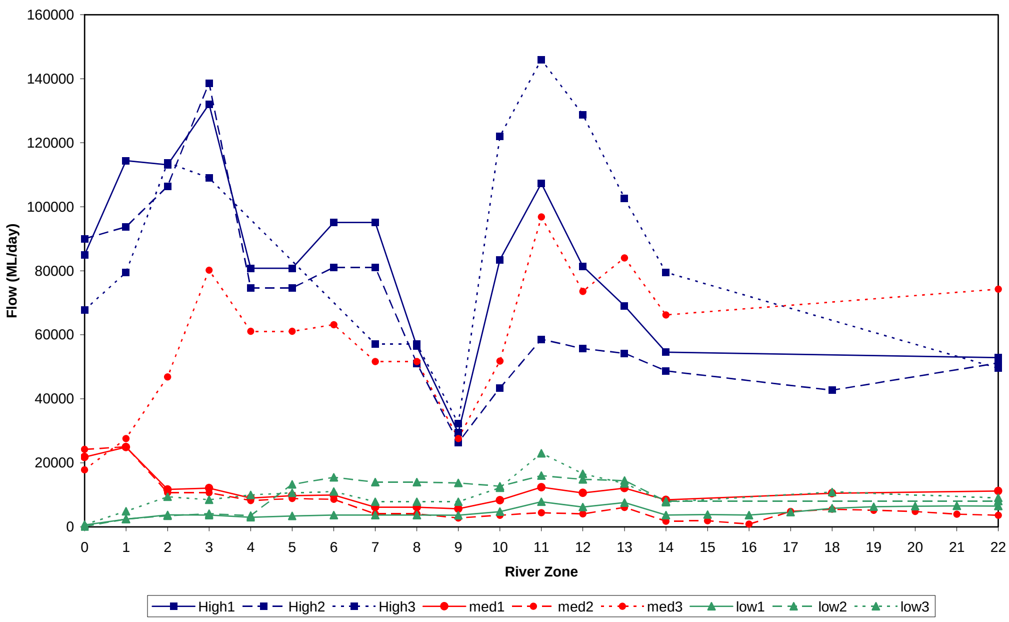


Figure 6. Graph showing high, medium and low flow (three flow waves of each) from Hume Dam to Wellington with consideration given to flow travel times.

To account for this variation, the River Murray and its floodplain was divided into twenty-two zones (Table 1) from Hume Dam in Victoria to Wellington in South Australia. Creating 22 zones (Figure 8).

The zone boundaries were determined by a combination of the following,

- the location of flow gauging stations,
- the location of river infrastructure (weirs) (Figure 7),

- the location of significant flow changes due to input from tributaries The flow volumes from the rivers Goulburn, Campaspe, Wakool, Murrumbidgee and Darling into the River Murray were deemed to have significant flow values to impact on decisions of zone placement, and
- the spatial extent of satellite imagery.

Figure 7. The location of weir structures, such as Lock 6, were used to determine the zone boundaries.

Table 1. River zones and gauging information

Zone	Description	Gauging Point	Area (ha)	Comments
1	Hume Dam to Lake Mulwala	Corowa	31509	
2	Lake Mulwala to 45 km d/s	Tocumwal	6863	Zone extent limited by satellite image extent.
3	Barmah	Tocumwal	78223	
4	Downstream Barmah to Goulburn/Murray junction	Barmah	15860	Flow above 35,000 ML/day is from Goulburn input.
5	Goulburn/Murray junction to Campaspe/Murray junction	Barmah and McCoys Bridge (Goulburn)	4231	Flow for this zone is the sum of flow from the 2 gauging stations.
6	Campaspe/Murray junction to Lock 26	Barmah, McCoys Bridge (Goulburn), Rochester (Campaspe)	9957	Flow for this zone is the sum of flow from the 3 gauging stations with allowance for travel time.
7	Lock 26 (Torrumbarry) to d/s of Gunbower	d/s of Torrumbarry weir	89975	Flows over 60,000 ML/day are not gauged. Flows greater than this were estimated by adding flow from the rivers.
8	D/s of Gunbower to Swan Hill	d/s of Torrumbarry weir	48599	
9	Swan Hill to Murray/Wakool junction	d/s of Swan Hill	27440	
10	Murray/Wakool junction to Murrumbidgee/Murray junction	d/s of Murray/Wakool	10062	
11	Murrumbidgee/Murray junction to Lock 15 (Euston)	d/s of Murray/Wakool junction & Balranald (Murrumbidgee)	48232	
12	Lock 15 to Lock 10 (Wentworth)	Euston weir d/s	91781	
13	Lock 10 to Lock 9	Lock 10 d/s of flow and height of Lock 9	33499	
14	Lock 9 to Lock 8	Lock 9 d/s of flow and height of Lock 8	22627	
15	Lock 8 to Lock 7	Lock 8 d/s of flow and height of Lock 7	30825	
16	Lock 7 to Lock 6	Lock 7 d/s of flow and height of Lock 6	35577	South Australian Border used as a break point for S.A. model. Gauging station number AS426200.
17	Lock 6 to Lock 5	Lock 6 d/s of flow and height of Lock 5	20568	
18	Lock 5 to Lock 4	Lock 5 d/s of flow and height of Lock 4	16505	
19	Lock 4 to Lock 3	Lock 4 d/s of flow and height of Lock 3	22850	
20	Lock 3 to Lock 2	Lock 3 d/s of flow and height of Lock 2	7135	
21	Lock 2 to Lock 1	Lock 2 d/s of flow and height of Lock 1	9535	
22	Lock 1 to Lower Lakes	Lock 1 d/s of flow and height of barrages	22763	
		d/s = downstream	**869735**	

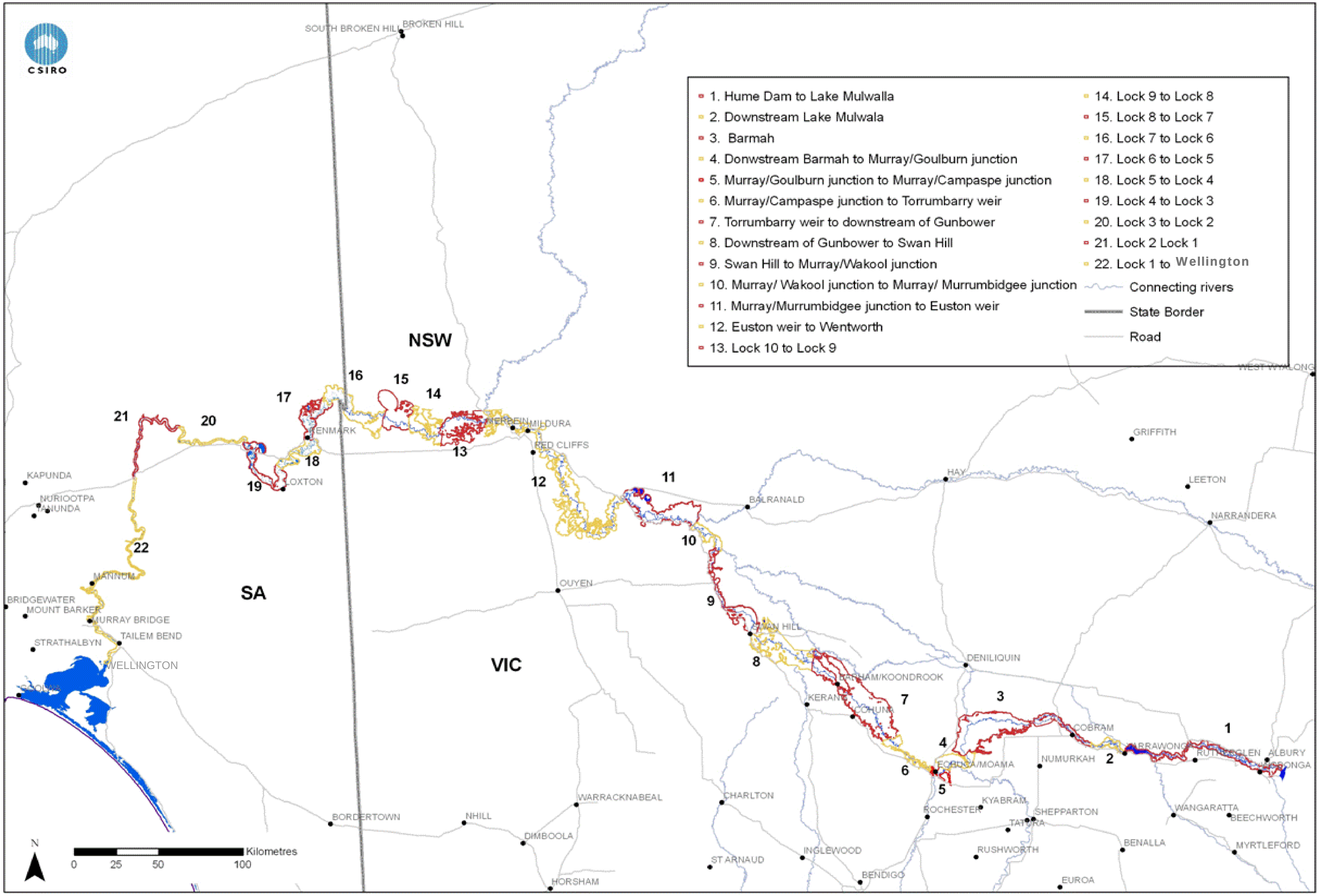


Figure 8. The twenty-two zones of the River Murray floodplain, from Hume dam in Victoria to Wellington in South Australia

2.2 River Murray Flows and Travel Times

Flow travel time for each zone was calculated from MDBC data (Crabb, 1997). An estimation of flow travel times within each zone is given in Table 2. The data presents an approximation of the time a flow wave (a change in flow rate) takes to get from one zone to the next. There is no accompanying information on the size of the flow wave for these travel times however indications are that it is for regular flow (within bank flow). Wave speed is will decrease at high (overbank) flows as water spreads out onto the floodplain due to increase resistance to flow and storage effects (Jacobs, 1990).

Table 2. Estimated river flow travel time for the 22 RiM-FIM zones (for regular flow).

Zone	Description	Upper km	Lower km	River km length	Travel time (days)
1	Hume Dam to Lake Mulwala	2225	2002	223	4
2	Lake Mulwala to image edge (u/s Tocumwal)	2002	1957	45	1
3	U/s Tocumwal to Barmah	1957	1762	195	3
4	Downstream Barmah to Goulburn/Murray junction	1762	1736	46	0.5
5	Goulburn/Murray junction to Campaspe/Murray junction	1736	1715	21	0.5
6	Campaspe/Murray junction to Torrumbarry Weir	1715	1638	77	1.5
7	Torrumbarry to downstream of Gunbower	1638	1482	156	3
8	Downstream of Gunbower to Swan Hill	1482	1402	80	1
9	Swan Hill to Murray/Wakool junction	1402	1282	120	1.5
10	Murray/Wakool junction to Murray/ Murrumbidgee junction	1282	1235	47	0.5
11	Murray/ Murrumbidgee junction to Lock 15 (Euston weir)	1235	1117	118	2
12	Lock 15 to Lock 10 (Wentworth weir)	1117	830	287	5
13	Lock 10 to Lock 9	830	770	60	1
14	Lock 9 to Lock 8	770	729		0.5
15	Lock 8 to Lock 7	729	700	29	0.5
16	Lock 7 to Lock 6	700	620	80	0.5
17	Lock 6 to Lock 5	620	562	58	0.5
18	Lock 5 to Lock 4	562	516	46	0.5
19	Lock 4 to Lock 3	516	432	84	1
20	Lock 3 to Lock 2	432	363	69	0.5
21	Lock 2 to Lock 1	363	274	89	1
22	Lock 1 to Wellington	274	67	207	5
	N.b u/s = upstream				

2.3 Hydrological Modelling for South Australia

Hydrological flow models were integrated with RiM-FIM to enable the output data from the hydrological models to feed directly into RiM-FIM. This GIS model queries look-up tables for the required hydrological parameters which are then linked to the spatial layers in the GIS.

This type of loose coupling allows existing hydrological models to be run without reprogramming within the GIS (Karami and Houston 1996; Sui and Maggio 1999). This procedure proved to be an effective and economical approach, as the hydrological parameters are fixed values.

2.3.1 River Murray Flow Model

The channel flow component of the Flood Inundation Model in South Australia was development from,

- river height measurements at certain distancea from the mouth of the river for certain flows; and
- river flow measurements at gauging stations (Figure 9).

There were insufficient measuring points along the river to establish a relationship between river height and flow. To offset this a modelled series of backwater curves was also produced. These consisted of a series of water surface elevation curves between locks for a steady uniform flow and were computed by MURLEV, part of the River Murray Flow and Salt Transport (RMFST) computer model (Water Studies 1992). Figure 9 shows the flow curves derived from this method for a section of the river from the border to Lock 2. A relationship was then established between flow rate and river height. Where flow rate equates to a river height at weir pool level.

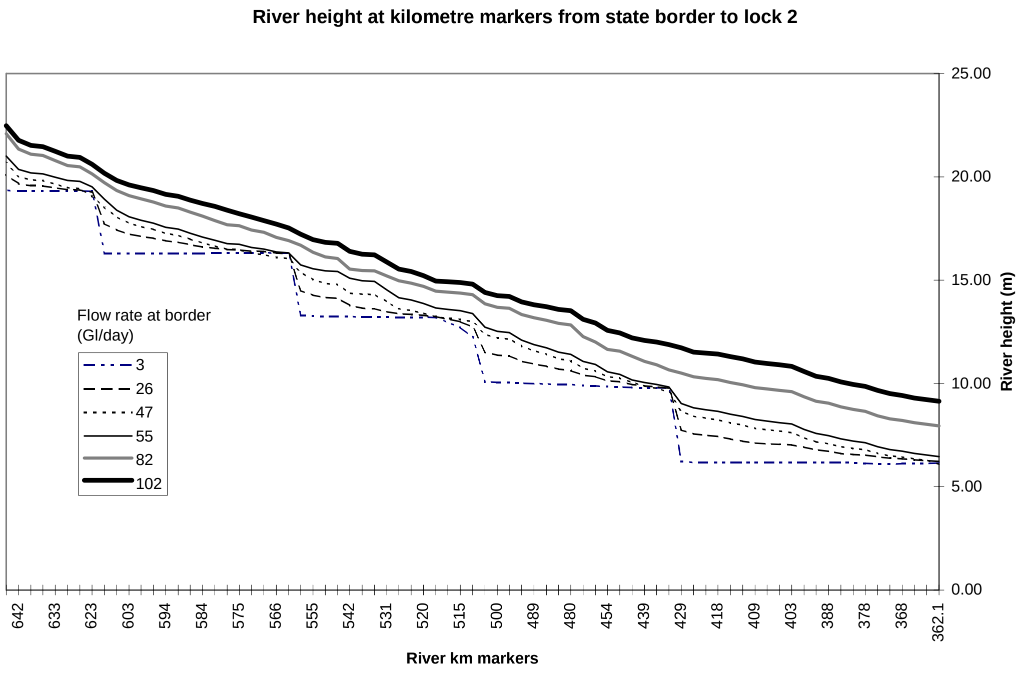


Figure 9. River levels from Lock 2 to the SA/NSW border for various flows.

The locking of the river has resulted in water level being held at higher levels than under unregulated (natural) conditions. The use of backwater curves describes the behaviour of locked rivers as compared to a pre-locking scenario where flow is downhill and unrestrained. River heights near the mouth of the river are much lower than those near the S.A./Vic border due to downfall flow of the river and its attenuation. Once flow levels have reached 60,000 ML/day the river is above the maximum height of the locks and backwater curves become straight.

2.3.2 Floodplain Inundation Response Units

As river heights can be manipulated by the six locks, predominantly independent of each other, the floodplain needed to be divided up into regions that could be related to the local conditions in the river. The floodplain was segmented into a number of Floodplain Inundation units, which are regions on the floodplain that flood in response to a particular point along the river referred to as the trigger point. These Floodplain Inundation Units were identified by considering the potential flood behaviour and discreet regions generated by the river morphology.

As a height difference of several metres can occur between the upper and lower pool levels of the weirs, behaviour of the flow path around the weir is complex. A weir manipulation trial at Lock 5 demonstrated that the area around the Lock responded to changes in the river height below the Lock. There is very little difference between the river height within two kilometre intervals in the modelled backwater curves which implies that there is probably an error margin of approximately two triggers up or downstream in the assignment of a FIRU to a trigger. Each polygon in the vector data set for a particular reach now contained attributes for reach, FIRU, flow and trigger.

Once the data had been converted to polygons in the GIS it was clear that each FIRU contained small areas of floodplain that flood at the same particular flow. These areas were termed “Wet at Same Height” (WaSH) areas as they will inundate at the same river height for a given trigger point due to their flat elevation. These WaSH area are likely to have the same or similar vegetation as the distribution of floodplain vegetation communities is strongly related to flooding frequency.

2.3.3 Hydrological Inputs to the Model

Different flow rates at the New South Wales border produce certain river elevations along the river. It is predominantly the local river height that determines whether the river will break the banks and flood an adjacent area (FIRU). Other factors such as antecedent conditions were not modelled. In the hot dry summer period a flow rate at the border will be further reduced downstream than in wetter months as water is evaporated and extracted from the river and less is replaced by rainfall. Curves were generated which show the attenuation of flow at each weir for a given month. Figure 10 shows an example of the change in flow rate to each of the weirs given a particular month.

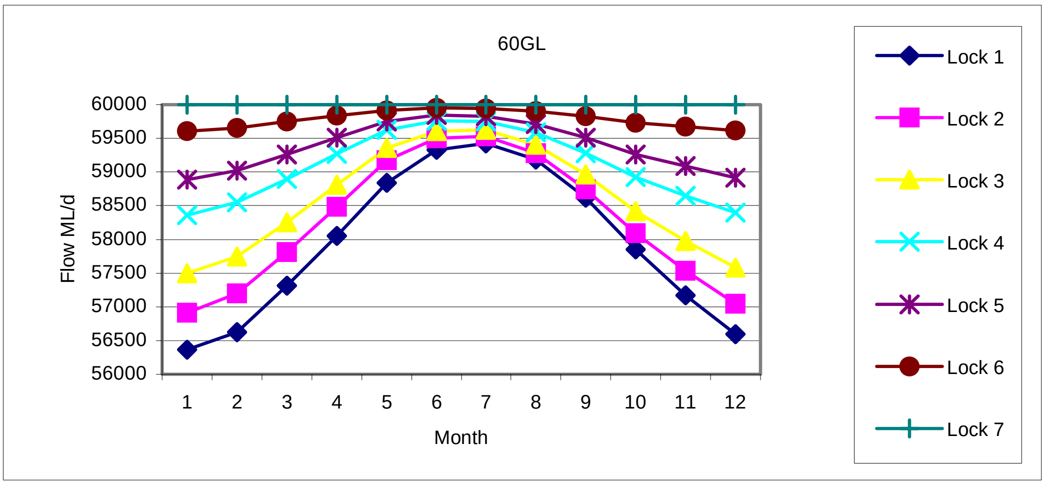


Figure 10. Example of seasonal attenuation curves for a 60,000 ML/day flow at the New South Wales border.

The RMSFT Model was used to generate backwater curves for a range of weir manipulations and flow values. The model estimates the stage discharge matrices used to route the inflow hydrograph down a river. For a nominated water level and discharge at the Lock the backwater model defines the upstream water levels to the next Lock. In this way discharge relationships can be derived between the water levels at the downstream and upstream ends of a river segment. Using Microsoft Excel the river level and discharge relationships for each Lock reach were established. Figure 11 shows the backwater curve for the weir pool of Lock 3 at a level of five centimetres above normal pool level. The precision of the model is five centimetres in the river height predictions.

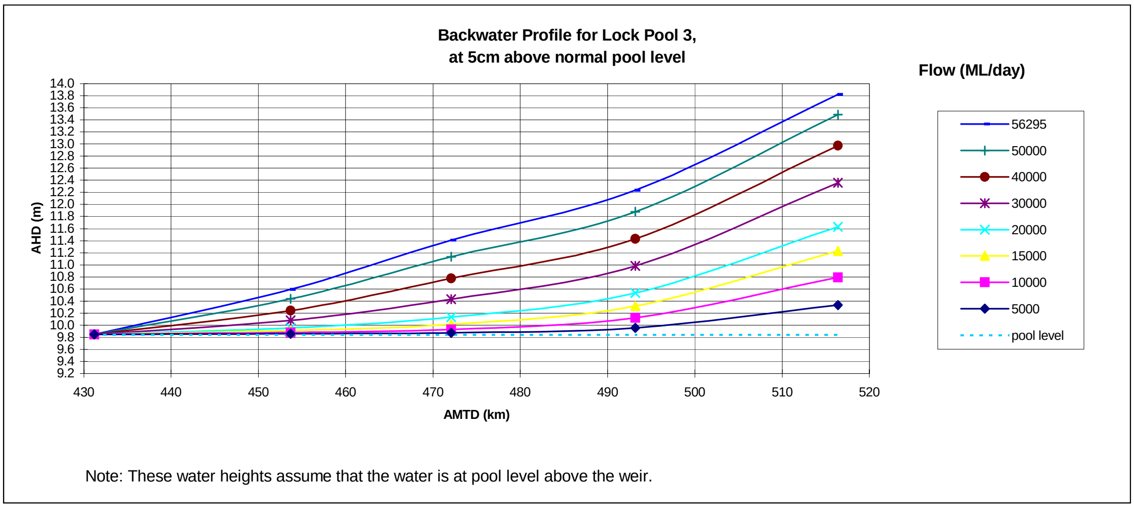


Figure 11. Example of a backwater profile for Lock 3.

3 FLOODPLAIN INUNDATION MAPPING

3.1 Introduction

The project aimed to create a decision support system (DSS) to predict the effect of flow management options on floodplain inundation. This DSS is called the River Murray Floodplain Inundation Model (RiM-FIM). RiM-FIM is a GIS model that allows the user to manipulate the flow (and weir heights in South Australia) to forecast the effect of their consequential inundation on the floodplain. Thereby acting as an environmental decision making tool. A full description of the development of the Floodplain Inundation Model for South Australia is presented in Overton (2005).

The steps involved in developing this model can be seen in the flow diagram in Figure 12 below.

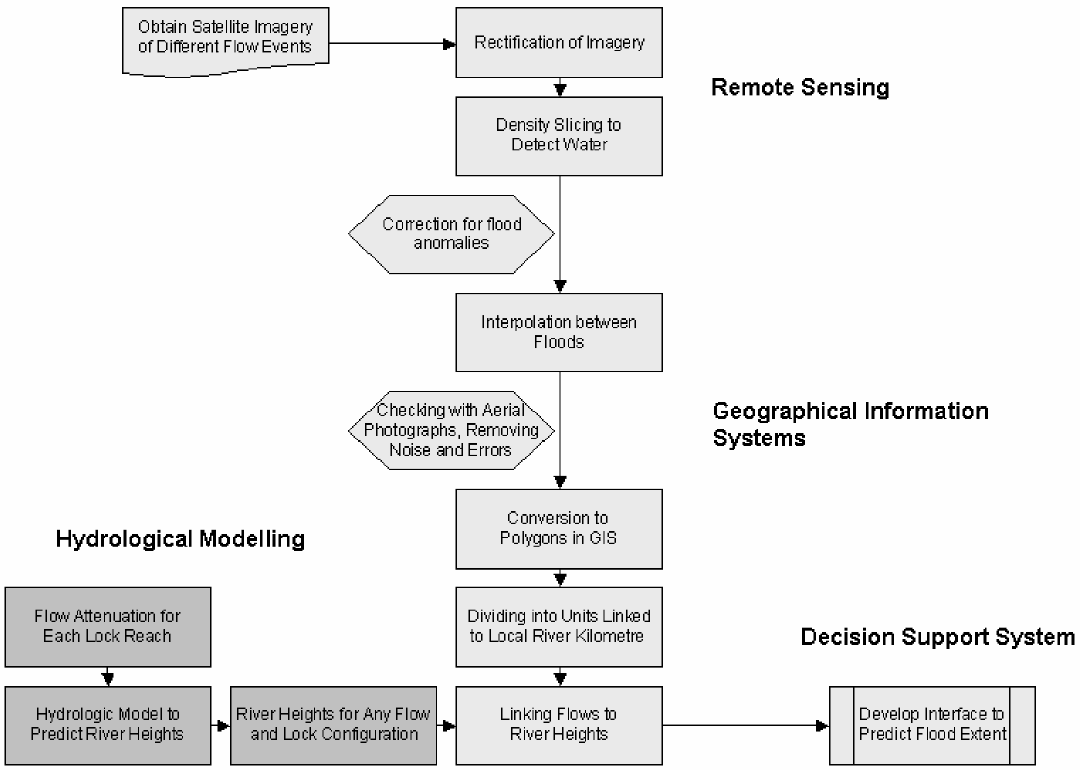


Figure 12. Flow diagram of the process of building the Floodplain Inundation Model for South Australia.

3.2 Mapping Floodplain Inundation

Remote sensing is particularly useful for monitoring flood extents because it provides basic data more cheaply and efficiently than ground based methods (Whitehouse 1989). Previous studies to determine the aerial extent of flooding have commonly involved optical satellite image analysis (Usachev 1983; Walker *et.al*. 1986; Townsend and Walsh 1998, Overton *et al*. 1999; Shaikh *et al*. 2001; Sheng et al. 2001; Frazier *et al*. 2003), radar remote sensing (Townsend and Walsh 1998) or an integration of remote sensing and GIS (Brivio *et al.* 2002). These methods have proved to be very useful and economical for large area flood analysis. More detailed studies have used digital elevation models to create a floodplain surface that can be inundated at certain river heights (Townsend and Walsh 1998). Elevation methods are particularly useful for predictive studies of changing flow paths through the floodplain by manipulating flow barriers. However surface modelling may not give the best representation of flood inundation, as there are numerous impediments and small channels across a predominantly flat floodplain. The modeling of flood inundation from surface elevation also requires detailed information on stage heights, backwater curves, flow impedances and roughness coefficients as simple height levels are insufficient in this dynamic environment.

Most studies have identified water bodies in the landscape through image classification procedures on multi-band imagery (Munyati 2000). To reduce costs, most of the information required for flood mapping can be obtained from satellite image bands that detect reflected light from the earth's surface in the mid-infrared wavelength. Radiation in this region is almost completely absorbed by water and hence images show sharp contrast between the high reflectance in soil and vegetation on dry areas and the very low reflectance of water (Whitehouse 1989).

This study used Landsat TM imagery. This imagery was selected to provide good coverage and resolution of the study area. The resolution of the imagery is 30 metres ie the image is made up of 30 m x 30 m pixels. Landsat TM Band 5 (mid-infrared) was chosen as the band used for a process called density slicing which is conducted in a GIS (Figure 13). Density slicing was used to determine the presence of surface water. Landsat MSS and Landsat 7 ETM+ satellite imagery and sensor data were also used when Landsat TM imagery was not available.

Water is detected by isolating the pixels within the image that have a very low reflectance value, indicating that the light was absorbed and not reflected, for this band. However other features, especially shadow, also have very low reflectance in this region of the light spectrum. Detecting water from dark shadow is not possible using a single band image. This problem is compounded by the slightly higher reflectance of turbid or shallow water leading to these features being detected as non-water. The assessment on the cut-off value of percentage reflectance for determining surface water in a single band image (referred to as a density slice) is a judgement made by the analyst based on the histogram (figure 4) and image characteristics. Frazier and Page (2000) found that a simple density slice on Band 5 achieved an overall accuracy of 96.9 percent when compared to aerial photographic interpretation and proved as successful in delineating water as a six band maximum likelihood classification (a multi-band statistical analysis commonly used in Remote Sensing for image classification). Figure 13 shows the cut-off made for one of the images in the study area.

Despite the problems involved in individual pixel mis-classification, the method of density slicing a single mid-infrared band to detect surface water has been successfully used in previous studies and represents an economical method for determining flooding over large areas (Sheng et al. 2001).

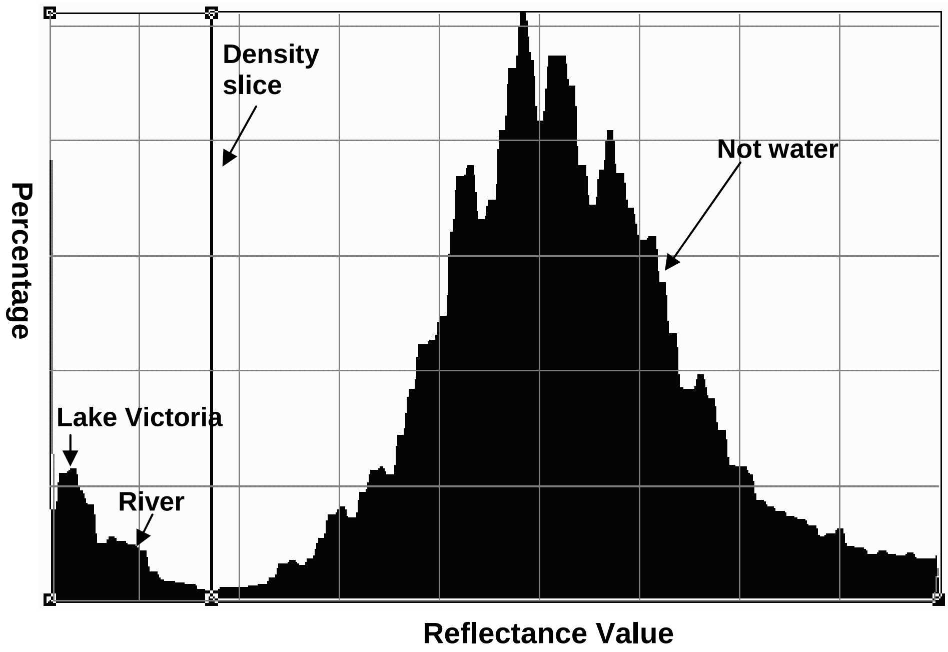


Figure 13. Histogram of a 102 GL/day flow with the central line indicating the point at which the reflectance value is split to indicate water or not water. Two low reflectance value peaks represent Lake Victoria (with deep water) and the River Murray (with shallow turbid water).

3.3 Image Analysis

Seventy-eight satellite images from Landsat 7 ETM and ETM+ were identified as suitable for this project. They were selected based on several criteria:

- they were located on a rising limb of the hydrograph (Figure 14),
- there must not have been a greater sized flood within the last 6 months (this will leave standing bodies of water);
- they must not contain any upper or lower level cloud cover that shadows any portion of the River Murray floodplain; and
- they were captured by the Landsat TM scanner so that all images have 30 metre pixels.

The images used, the dates and the relevant flows are presented in Appendix A.

The images chosen represent the largest flow events that where captured in the available satellite scenes. Figure 15 shows the maximum flow recorded since 1970 in each zone and the maximum flow event captures in the imagery.

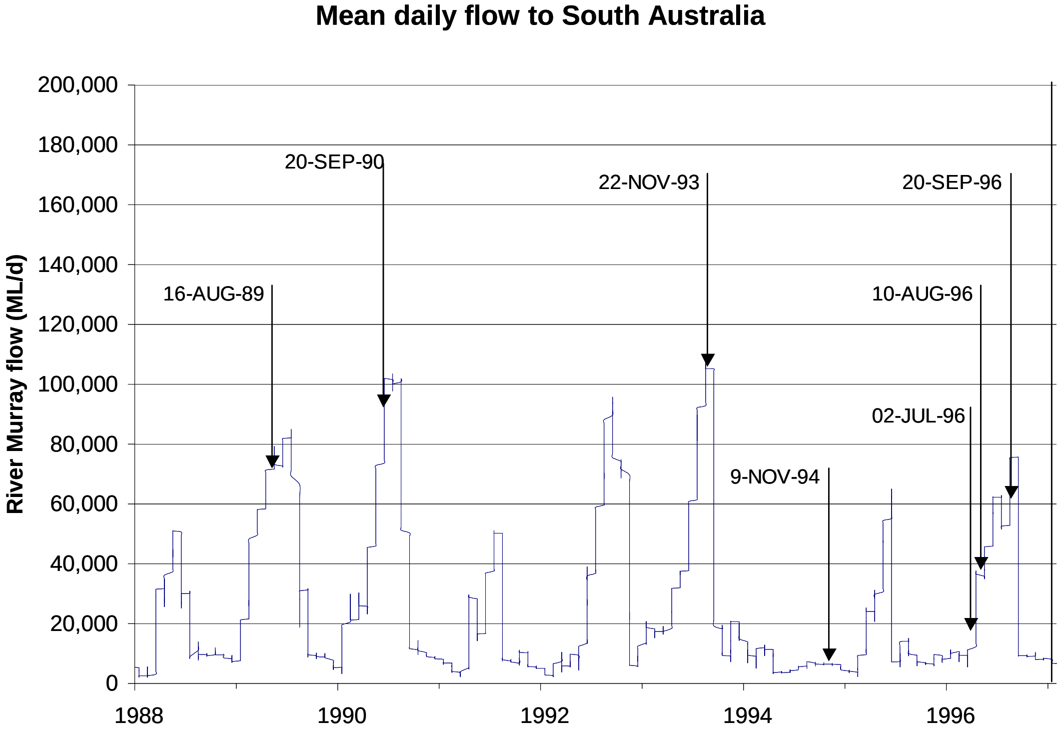


Figure 14. Hydrograph for the images selected for a section of the study area.

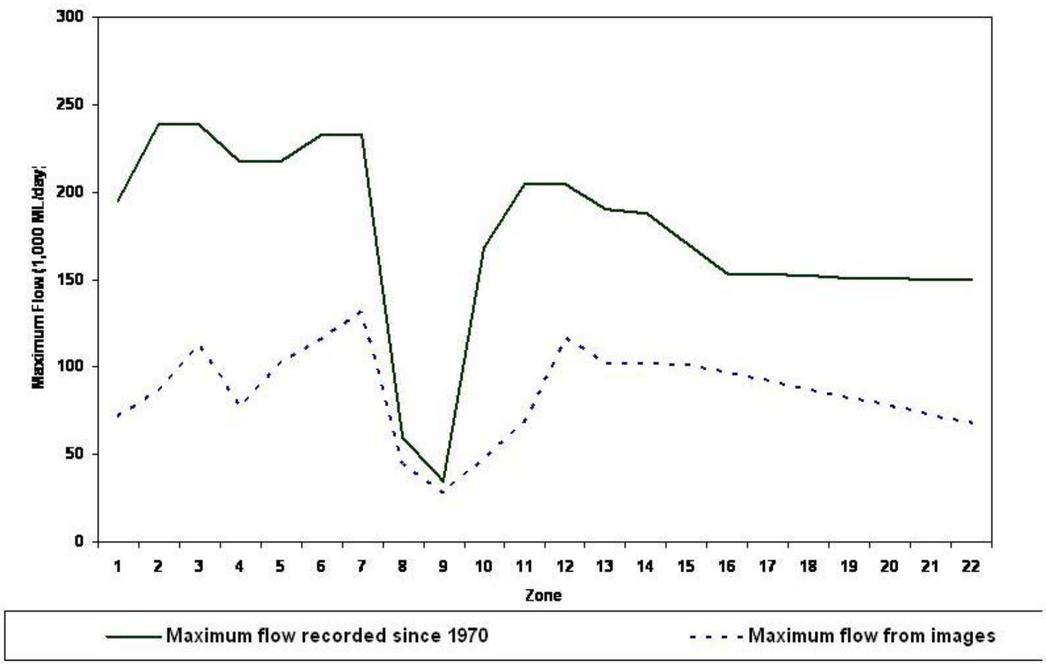


Figure 15. Maximum flow, recorded since 1970, and the maximum flow event from satellite imagery used for RiM-FIM for each zone.

Image enhancement makes important features captured within the satellite image more interpretable to the human eye. By selecting different bands on the Landsat TM image sensor you are able to detect certain features. For the purposes of this project water was to be identified, a wavelength was selected that reflects water and is adsorbed by most other objects. Band 5 on the Landsat TM image sensor operates in the far infrared part of the spectrum and on its own clearly shows water features (Figure 16). The technique used in the GIS to enhance the wet and dry pixels is stepped through briefly as follows:

- turn off green and blue bands,
- set the red band to Band 5,
- open and edit the image histogram, perform a density slice by adjusting the breakpoint editor to highlight surface water features (Figure 17),
- compare the new image with air photo's to make sure that only surface water has been highlighted, and
- re-code the image and save out as a binary image. Set water to 1 and everything else to 0.

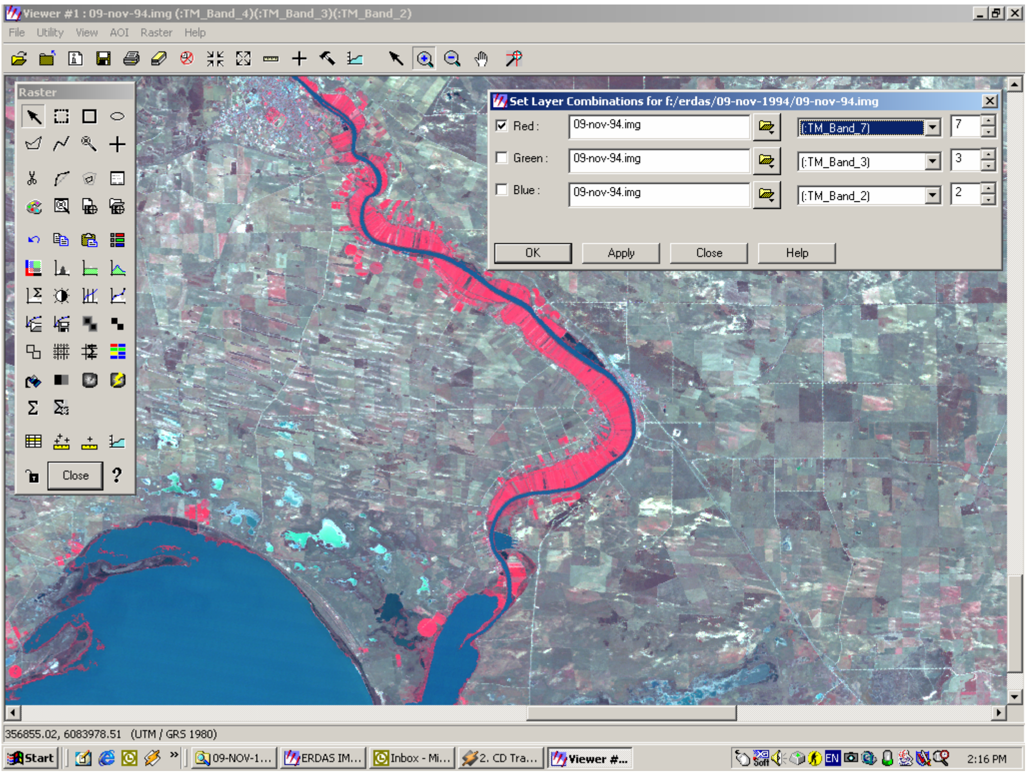


Figure 16. Editing Layer combinations (Red – Band 5; Green – Band 3, Blue – Band 2) to highlight surface water within the landscape.

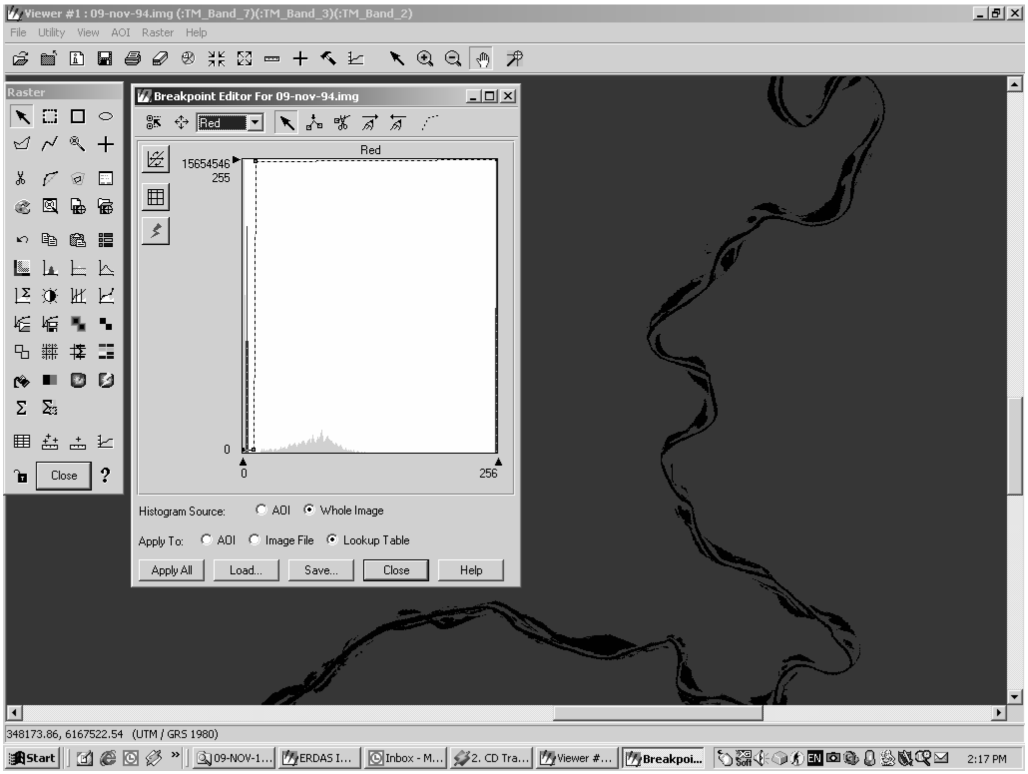


Figure 17. Breakpoint Editing – the dialog box shows an adjustment in the red band to distinguish between water induced by irrigation and floodplain surface water.

The satellite images were registered to map grid co-ordinates so that flood masks (flood extents) would be adjoining and superimposed upon each other within the GIS. Registration was performed using map co-ordinates, digital data, and image to image rectification. The latter could only be performed when the first image was registered. The overlaying and adjoining of the different flow images to model incremented flood growth was successful and was the result of accurate image registration.

Registration accuracy was visually recorded as plus or minus one pixel. This was considered acceptable for two reasons, the large scale of the project and that Landsat pixels do not exactly align spatially in different scenes. A final image composite was created for the whole study area.

One of the limitations of overlaying registered images is that errors compound with each additional flood overlay. This limitation is of special concern in this study as individual pixels are being monitored over time for flooding or lack of flooding. Spatial errors in the registration caused a shadowing effect on the edges of the flood extent in some cases. The accuracy of the final image composite needs to be assessed as a discontinuous binary surface and therefore the square error matrix was not suitable (Remmel and Perera 2002).

4 THE FLOODPLAIN INUNDATION MODEL

4.1 Integrating Flood Events

Once the images had been reclassified (1 = water and 0 = not water) the data was imported into a GIS package and reclassified to their corresponding flow value. The raster calculator was then used to combine all the images with the resultant image containing all the separate attributes. A conditional statement was used to combine these images. The statement expression was written such that if the lower flow showed the surface to be wet at its maximum extent then use the lower value, otherwise use the current value.

After the anomalies were removed the floodplain inundation images were used to determine the exact extent of flooding that would occur at a given flow. Flood extent anomalies can occur from the identification of water that is not hydrologically connected to the river, such as remnants from previously larger flows, rainfall events, irrigation practices or miss-classified pixels. These areas were removed in order to determine the exact extent of flooding that would occur at a particular flow. The process involved removing any identified water outside the 1956 flood boundary, the largest flood event in recorded history. The process also involved investigating the relationship between images of increasing flow rate. It was necessary to remove water that was identified to be present at lower flows but not at higher flows. The choice of imagery on rising hydrographs assisted with the reduction in such anomalies. There will be an ongoing process of editing the flood masks as new information becomes available from satellite imagery, aerial photography and ground recordings. Satellite imagery does not detect every pixel of water within the scene as some areas are covered by vegetation or have high turbidity or shallow depth. For this reason, the areas that lie within the river channel itself and areas classified as permanent wetlands (Pressey 1986) were assigned a unique code.

Whilst satellite images were obtained to provide a range of flood events (flow intervals), it was necessary to consider flows between these events to provide a more continuous predictive model. Interpolation between the discrete flow intervals was performed to produce finer intervals of flood extent.

The extents of the flood masks of each flow from the satellite imagery provided a boundary line of equal flood extent. These pixels were interpolated to obtain the flow at all other pixels in the image. There are many ways to perform this kind of interpolation. The true situation is defined by the local topography of the area which is unknown in this case. Therefore interpolation of the flow level is similar to the problem of interpolating the landscape height at each point. Kriging is the most common surface interpolation method (Burrough 1986) but is influenced by areas outside the adjacent known boundaries of the two closest satellite masks. It was decided instead to use an image morphological process called a 'marker-based watershed segmentation algorithm' rather than traditional interpolation methods to ensure that the information from each satellite image was preserved. The "watershed algorithm" is commonly used in mathematical morphological problems and is often used in relation to topographic analysis of digital elevation models (Soille and Vincent 1991). The advantage of this method over other approaches to contour interpolation is that it can be applied to very noisy data with broken contours. This was the case here since the data is quantised so coarsely.

Flood interpolation was undertaken by dividing the combined satellite mask image up into regions of constant minimum flow. By assessing each zone independently the interpolated values were guaranteed of lying within the minimum and maximum flow bounds. In each zone the contours of equal flow were interpolated from the boundary points, at which the minimum flow is known. This contour interpolation is repeated iteratively, each time based on the contours that have already been estimated. Each contour is interpolated using a flooding simulation extending from the next higher and lower boundaries. Regions having the minimum flow value or representing land that did not flood at the largest flow were not included and were used as the lower and upper limit of interpolation accordingly.

The difficulty in applying the watershed algorithm to flood interpolation is in choosing the "source" and "sink" points. The sink points are those adjacent to the region that have the next highest quantised flow level. The source points are those adjacent points that have the highest flow that is lower than the sink points for this region. The location of the sink and source points were chosen to model the behaviour of flood growth across the floodplain but also to represent the filling of wetlands from a single inflow channel. A set of colour aerial photographs of a 70,000 ML/day flood were used to validate the growth behaviour of floods and a small number of edits were made to the final Floodplain Inundation grid.

4.2 GIS Development

The result of the interpolation stage was a raster grid of cell values that represent the commence-to-flow based on the flows on the day of the satellite images. This grid was then filtered to remove noise and converted to a polygon coverage. Filtering is a technique used to enhance the quality of digital imagery by changing the values of cells in raster images and can be used to ease the computation burden of raster to vector conversion by removing isolated pixels (Trotter 1991). Filtering uses neighbouring cells to determine the value of the cell in question. Filtering can sharpen or smooth images to emphasise features or reduce the effect of anomalies (Wilkinson 1996).

To remove anomalies in the interpolated flood masks, such as higher or lower value pixels in the middle of lakes, a filter was used which replaced the value of each pixel with the value of the eight nearest neighbours. This only occurs if there is a clear majority of neighbouring cells with a different value than the cell in question.

The raster data (pixel based data) was converted to vector data (area or shape based data) to reduce the data redundancy and allow for easy retrieval, updating and generalisation of graphics and attributes that are especially important if equations are to be used to generate models. The polygons in the RiM-FIM are areas of the floodplain that commence to flood at the same river height or river flow (WaSH areas).

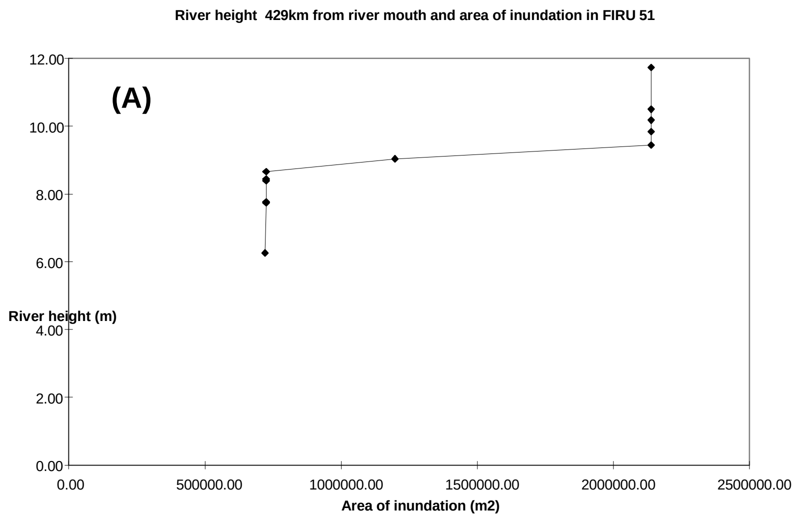
4.3 Linking Floodplain Inundation and Wetland Commence-To-Fill Data

The New South Wales Wetlands Working Group (NSWWWG) has developed a database of wetlands in the Victoria and New South Wales portion of the River Murray, the River Murray Wetlands Database. This database contained commence-to-fill values for each wetland along the River Murray. A number of errors exist in the database, for example Lake Wallpola which is known to be permanently inundated has a commence to fill value of 33,000 ML/day. Such errors in the database meant that it could not be used to override the satellite derived RiM-FIM, so it was used as a guide to improve the RiM-FIM output.

Any permanent water including the River Murray was extracted from the NSWWWG Database. The river channel was selected on its name under the "name" field. Permanent wetland records were selected under the "hydrology" field in the database. This field is the hydrological category as outlined by Pressey (1986). Wetlands with a hydrological value of "1" were designated as permanent. The flow or commence to fill value given to permanent water is 5000 ML/day. (The AUSLIG 250K waterbodies dataset was also investigated for permanent water, however it was found to be inappropriate as the scale was too rudimentary for the purposes of this model).

4.4 Decision Support System for South Australia

The height of the river at trigger points are affected by river regulation, the satellite derived inundation; and the interpolation process. Originally flow values derived from the satellite images were regressed against the range of river heights for each trigger point. This produced a spread of data points across the range of actual flow values. However, because area inundated is extremely sensitive to slight alterations in river height it was decided that a relationship between river height and area of Floodplain Inundation should be used in each FIRU. This relationship has the potential to be improved with further image acquisition and statistical analysis. The model will always be limited to the spatial resolution at which it was acquired which in this instance is 30 metres. If a change in the height of the river results in less than a 30 metre change at the flood boundary the area of inundation will not increase. The resultant area inundated versus river height curves. Figure 18 shows the relationship of the river height to the local topography of the floodplain in two regions.



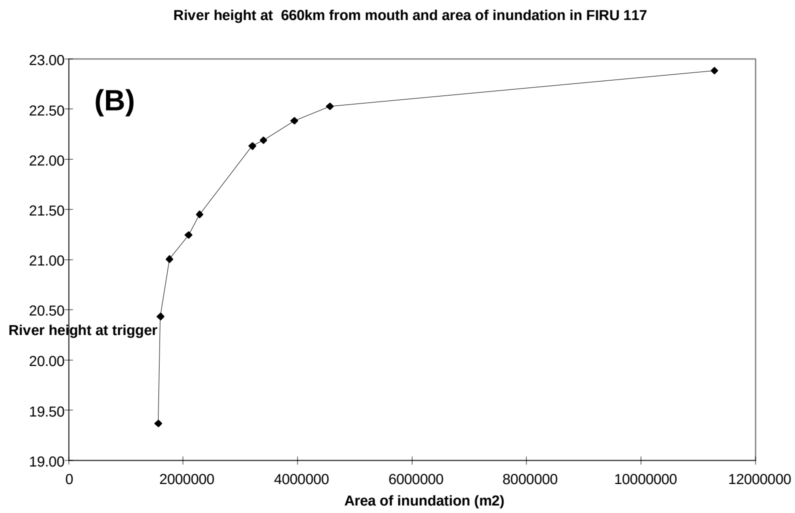


Figure 18. Area of inundation versus river height a) Lock 2 to 3 (gorge); b) Lock 6 to 7 (wider floodplain).

Figure 18A shows the relationship between river height and area inundated in the gorge between Lock 2 and 3. The height of the river continues to increase without breaking its banks until it reaches approximately eight and a half metres above sea level (Australian Height Datum). As the water flows onto the floodplain there is a gradual increase until the river level rises to hit the outer trench. Figure 18B shows the nature of a typical floodplain area between Lock 6 and 7. Here the river height increases until it breaks its banks and continues to increase as it fills up billabongs and then gradually tapers out as the water spreads over the floodplain. These curves were used to code the flood masks with a river height which would cause the EFH to be inundated. Software code was used to assign the height of the river to the EFH for all FIRUs using the FIRU trigger as the point that would cause this EFH to flood.

A user interface was then designed with input fields to prompt the user for flow values at the border. Once these inputs were added an Avenue script is automatically launched. The script sets out to select all the river heights in the map layer that are lower than the local river height predicted. The result is a GIS map of the floodplain showing those areas flooded by that flow regime. Figure 19 shows the output of the GIS Floodplain Inundation model after user input.

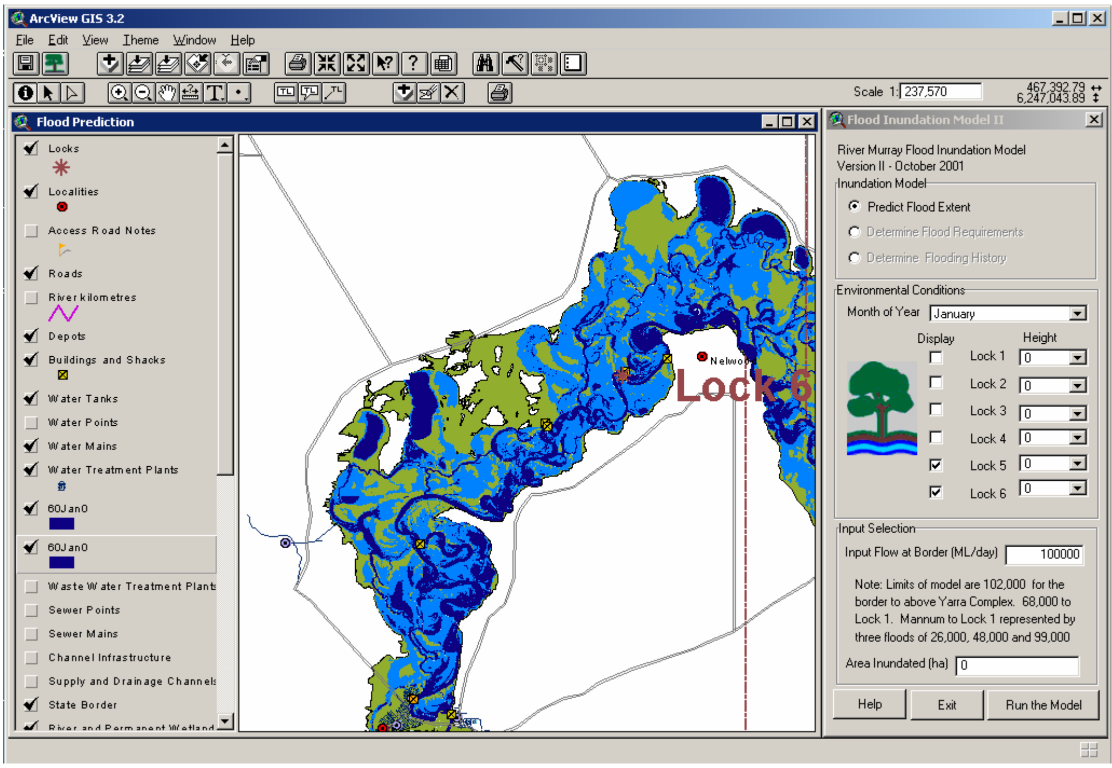


Figure 19. Example output of the GIS Floodplain Inundation Model showing an area around Lock 6 at Chowilla with two flood predictions of 60,000 ML/day (dark) and 100,000 ML/day (light).

The initial stages of the project provided EFH units and river heights at particular triggers. The hydrological model parameters made it possible to simulate a flow event from the border under different weir configurations for certain months of the year. The GIS provided the map of the area inundated. The decision support system (DSS) contains layers such as riparian vegetation, transport infrastructure, water infrastructure and major wetlands.

The inputs to the DSS include the user defined flow at the border; the weir configurations of all six weirs; and the month of year. The outputs of the model are river heights for each trigger kilometre and the area of inundation.

5 VEGETATION AND WETLAND INUNDATION

5.1 Predicting Area of Vegetation Inundated

To predict areas of inundation according to vegetation type vegetation data from Margules *et al.*, (1990) was amalgamated into eight categories of interest. The categories are detailed below (bracketed numbers indicate Margules' structural vegetation classes).

- **Red Gum Forest / Woodland (1 + 2).**

  The dominant structural species are *Eucalyptus camaldulensis* (River Red Gum) and *E. blakelyi* (Forest Red Gum), height ranges from 10-25 m (woodland) to 15-45 m (forest), and with a density of less than 25 % (woodland) to >20% (forest)

- **Red Gum/ box forest and woodland (3).**

  Dominant structural species are *E. camaldulensis*, *E. blakelyi*, *E. microcarpa* (Grey Box), *E. melliodora* (Yellow Box), *E. largiflorens* (Black Box), and *E. albens* (White Box). Height ranges from 12 to 20 m with a density of < 35%.

- **Mixed box woodland (4)**.

  Dominant structural species are *E. microcarpa* (Grey Box), *E. melliodora* (Yellow Box), *E. largiflorens* (Black Box), *E. albens* (White Box) and *E. polyanthemos* (Red box). Height ranges from 12 to 18 m with a density of 1-50%.

- **Black Box woodland (5).**

  The dominant structural species is *E. largiflorens* (Black Box), height is in the range 10-14 m and a density of 10-30 %.

- **River Cooba (8).**

  Dominant structural species is *Acacia stenophylla* (River Cooba), which has a height range of 10-15 m and a density of 1-20 %.

- ***Lignum (11).***

  Muehlenbeckia cunninghamii (Lignum), height < 10 m, density -10-30%.

- **Saline shrubs (12).**

  Dominant structural speices include *Halosarcia spp.* (Samphires), *Pachycornia triandra*, *Atriplex nummularia* (Old man saltbush), *Atriplex vesicaria* (Bladder saltbush), *Chenopodium nitrariaceum* (Nitre goosefoot), *Enchylaena tomentosa* (Ruby saltbush), *Sclerostegia tenuis* (Slender g;asswort) and *Maireana pyramidata* (Black bluebush). Height is < 10 m.

- **Horticulture and Agriculture (15 & 16**).

These eight vegetation classes were assessed against the RiM-FIM to investigate their preferred flow bands. The results are shown for each zone in Appendix B.

5.2 Predicting area of Wetlands Inundated

The River Murray and wetland coverages (location and shapes) for South Australia, Victoria and New South Wales were supplied by the MDBC. The commence to fill for the wetlands was determined using the RiM-FIM or using data from the New South Wales Wetlands Working Group which had recorded data for some wetlands. Figure 20 displays a section of wetlands, containing flow data, within zone 1.

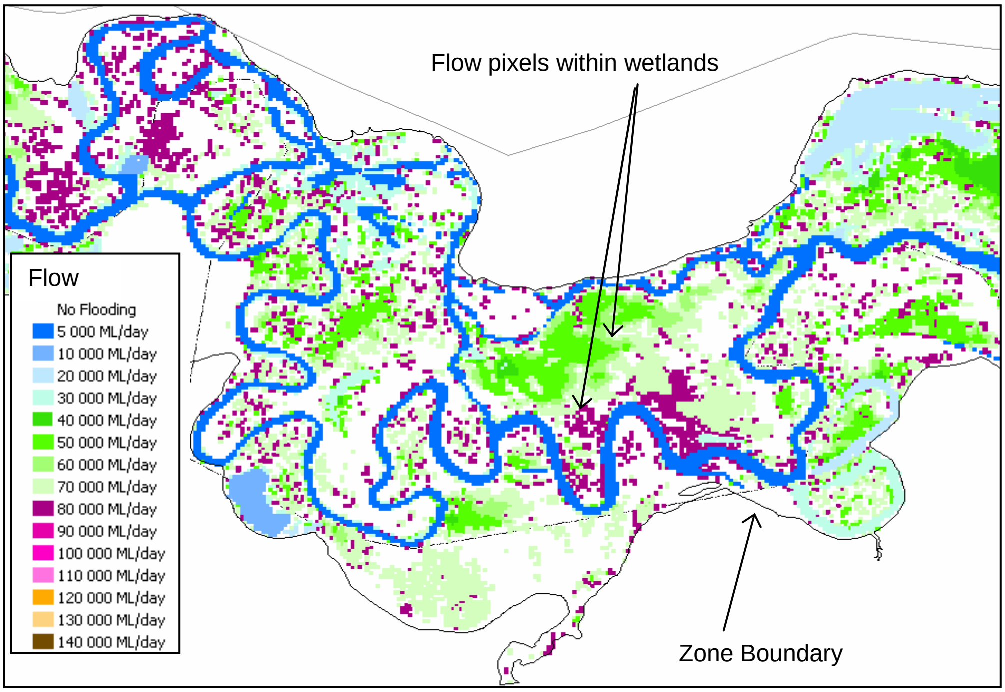


Figure 20. A section of wetlands containing flow data within zone 1.

The cumulative number of wetlands inundating under certain flow regimes and the cumulative area of wetlands inundated under certain flow regimes were analysed. The number of wetlands was estimated by searching for the minimum pixel value within each wetland and summating the total number of wetlands found to contain that pixel value. Appendix B lists tables and graphs showing cumulative number of wetlands flooded for prescribed flows for each zone.

Wetland areas inundated at certain flood volumes were calculated by searching for the designated flows and summating their pixel areas. These results are listed in tables and graphs for each zone in Appendix B.

6 CONCLUSION

This technical report describes the development of the first four versions of the River Murray Floodplain Inundation Model (RiM-FIM). A map of flood growth was successfully completed by interpolating between known flood event boundaries identified from satellite imagery. This flood growth map was linked to a hydrological model in South Australia to determine the river height for given flows and weir manipulations and to river flows only in Victoria and New South Wales. The RiM-FIM allows the user to manipulate river flows, and the River Murray weirs in South Australia, to predict areas of inundation. The RiM-FIM can be used for map overlay analysis with vegetation, wetlands, infrastructure etc and predict results from "what if" scenarios for scientific research and policy management.

The model has been successfully used to predict floodplain inundation in a weir manipulation trial (Department of Water, Land and Biodiversity Conservation, South Australia 2002) and has been used as the basis for the development of a flow management strategy for the River Murray in South Australia (SKM and Mapping and Beyond 2002). The model has also provided a useful surface elevation model for further floodplain modelling work.

The model can be useful in identifying commence-to-fill, and therefore flow regimes, for areas on the floodplain including wetlands and vegetation communities. It can also be used to look at the change in flow regime from 'natural' to 'current' conditions for floodplain habitats, wetlands and to analyse changes in vegetation health.

Further research on the behaviour of floods on the floodplain and in wetlands is required before it can be used as a temporal model. The GIS model can be further advanced by incorporating flow patterns and losses across the floodplain, by including surface elevation and wetlands as sources and sinks, to create a more dynamic model of flooding (Costelloe, 2002). Current modelling work on floodplain vegetation health affected by soil salinisation, will in the future be linked to RiM-FIM to improve the models usefulness as a decision support system. The model can be furthered improved by incorporating river height values for New South Wales and Victoria, as has been achieved in South Australia. The river heights can be derived from surface elevation models using the extent of inundation linked to river flow.

RiM-FIM is a steady state model that predicts the extent of flooding from a given flow on the first day of the flood. It does not consider the effect of antecedent conditions or the effect of flood duration. Further research on the wetting and drying behaviour of the floodplain and its wetlands needs to be incorporated into the model to be able to predict time sequences for management scenarios. The RiM-FIM should be compared to outputs from existing hydrodynamic models of some sections of the River Murray to test its applicability to floodplain scale modelling of flood inundation. The RiM-FIM satellite derived inundation steps provide a resource to calibrate new hydrodynamic models.

BIBLIOGRAPHY

Brivio, P.A., Colombo, R., Maggi, M. and Tomasoni, R. (2002). Integration of Remote Sensing Data and GIS for Accurate Mapping of Flooded Areas. International Journal of Remote Sensing, **23**(3), 429-441.

Burrough, A.P. (1986). Principles of Geographical Information Systems for Land Resources Assessment. Oxford University Press.

Costelloe, J. F.; Grayson, R. B.; Argent, R. M., and Mcmahon, T. A. (2003). Modelling the Flow Regime of an Arid Zone Floodplain River, Diamantina River, Australia. Environmental Modelling & Software; **18**(8-9).693-703.

Crabb, P. (1997). Murray-Darling Basin Resources. The Murray-Darling Basin Commission, Canberra.

Department of Water, Land and Biodiversity Conservation, South Australia, 2002, Lock 5 Flow Enhancement Trial. Murray-Darling Division, Report No. 1, September 2002.

Eastburn, D. (1990) The River, In *The Murray*. (Eds Norman Mackay, and David Eastburn) Murray Darling Basin Commission, Canberra.

Frazier, P.S., Page, K.J., Louis, J., Briggs, S. and Robertson, A. (2003). Relating Wetland Inundation to River Flow Using Landsat TM Data. International Journal of Remote Sensing **24 (**19), 3755-3770.

Hendriks, P. and Dirk, V., 2000, From Geographical Information Systems to Spatial Group Decision Support Systems: A Complex Itinerary. Geographical and Environmental Modelling, 4, (1).

Jacobs, T. (1990). River Regulation. *In* The Murray. (Eds Norman Mackay, and David Eastburn) Murray Darling Basin Commission, Canberra.

Jankowski, P., Andrienko, N. and Andrienko, G. (2001). Map-centred Exploratory Approach to Multiple Criteria Spatial Decision Making. International Journal of Geographical Information Science, **15 (**2), 101-127.

Jolly, I.D. (1996). Chapter 18: The Effects of River Management on the Hydrology and Hydroecology of Arid and Semi-Arid Floodplains. *In* Floodplain Processes. (Eds Anderson, M.G., Walling, D.E. and Bates, P.D.) John Wiley and Sons Ltd, New York. Pp 577-609.

Karami, H.A. and Houston, B.H. (1996). Evaluating Strategies for Integrating Environmental Models with GIS: Current Trends and Future Needs. Computers, Environment and Urban Systems, **20 (**6), 413-425.

Margules and Partners, P and J Smith Ecological Consultants, and Victorian Department of Conservation, Forests and Lands. (1990). River Murray Riparian Vegetation Study. Murray Darling Basin Commission, Canberra.

Munyati, C. (2000). Wetland Change Detection on the Kafue Flats, Zambia, by Classification of a Multitemporal Remote Sensing Image Dataset. International Journal of Remote Sensing, **21** (9), 1787-1806.

Overton I, Newman B., Erdmann B., Sykora N., Slegers S. (1999). Modelling floodplain inundation under natural and regulated flows in the Lower River Murray. *In Proceedings* of the Second Australian Stream Management Conference: the Challenge of Rehabilitating Australia's Streams, Adelaide (Eds. I. Rutherfurd and R. Bartley), CRC for Catchment Hydrology, Melbourne.

Overton, I.C. (2005). Modelling Floodplain Inundation on a Regulated River: Integrating GIS, Remote Sensing and Hydrological Models. River Research and Applications. **21** (9), 991-1001.

Pressey R.L. (1986). Wetlands of the River Murray below Lake Hume. Environmental Report 86/1. Murray-Darling Basin Commission, Canberra.

Remmel, T.K. and Perera, A.H. (2002). Accuracy of Discontinuous Binary Surfaces: A Case Study Using Boreal Forest Fires. International Journal of Geographical Information Science **16** (3), 287-298.

Shaikh, M., Green, D. and Cross, H., 2001, A Remote Sensing Approach to Determine the Environmental Flows for Wetlands of the Lower Darling River, New South Wales, Australia. International Journal of Remote Sensing, 22, 9, 1737-1751.

Sheng, Y., Gong, P. and Xiao, Q. (2001). Quantitative Dynamic Flood Monitoring with NOAA AVHRR. International Journal of Remote Sensing, **22** (9), 1709-1724.

SKM and Mapping and Beyond. (2002), Decision Support System for Managing Flows in the River Murray, South Australia. Report prepared for the River Murray Catchment Management Board, the South Australian Department of Water, land and Biodiversity Conservation, and the Natural Heritage Trust.

Stanford J.A, Ward J.V, Liss W.J, Frissell C.A, Williams R.N, Lichatowich J.A, Countant, C.C. (1996), A general protocol for restoration of regulated rivers. Regulated Rivers: Research and Management, 12, 391- 413.

Sui, D.Z. and Maggio, R.C. (1999), Integrating GIS with hydrological modelling: practices, problems and prospects. Computers, Environment and Urban Systems, **23**, 33-51.

Taylor, K., Walker, G. and Abel, D. (1999).A framework for Model Integration in Spatial Decision Support. International Journal of Geographical Information Science, **13** (6), 3-555.

Townsend, P.A. and Walsh, S.J. (1998). Modelling Floodplain Inundation using an Integrated GIS with Radar and Optical Remote Sensing. Geomorphology, **21**, 295-312.

Trotter C. (1991). Remotely-sensed data as an information source for geographical information systems in natural resource management: a review. International Journal of Geographical Information Systems, **5** (2), 225-239.

Vincent, L. and Soille, P. (1991). Watersheds in Digital Spaces: an Efficient Algorithm Based on Immersion Simulations. IEEE Transactions on Pattern Analysis and Machine Intelligence **13** (6), 583-598.

Walker K.F and Thoms M.C. (1993) Environmental effects of Flow Regulation on the Lower River Murray, Australia. Regulated Rivers: Research and Management, **8**, 103-119.

Walker R.D, Aubrey M.C and Fraser, S.J. (1986). Remote Sensing in Australia. Canbec Press Pty Ltd, Melbourne.

Water Studies. (1992). River Murray Flow Model, Vol. 3. User Manual. Department of Engineering and Water Supply, June 1992. 92/12.

Whitehouse, G. (1989) Flood monitoring and Floodplain Studies. *In*: 'Remote Sensing in Hydrological and Agrometeorological Applications'. (Ed. de Vries, D.) COSSA Publications, Canberra.

Wilkinson, G.G. (1996). A review of the current issues in the integration of GIS and Remote Sensing data. International Journal of Geographic Information Systems, **10** (1), 85-101.

Young, W.J. (Ed). (2001). Rivers as Ecological Systems: The Murray-Darling Basin. Murray Darling Basin Commission, Canberra, Australia.

APPENDIX A: SATELLITE IMAGES

Scene ID Path/Row	Date	Relevant Flow (ML/day)	Density Slice Value in Band 7	Comments
Zone 1				
92/85	21-12-1987	25,000	18	
92/85	26-10-1990	44,000	8	This scene was on a rising hydrograph but followed a greater sized flood 2 months previous (following scene), it was necessary to use the scene due to the absence of a midrange flow scene.
92/85	23-08-1990	67,000	7	
92/85	29-10-2000	71,000	17	
Zone 2				
92/85	21-12-1987	10,000	18	
92/85	26-10-1990	38,000	8	This scene was on a rising hydrograph but followed a greater sized flood 2 months previous (following scene), it was necessary to use the scene due to the absence of a midrange flow scene.
92/85	23-08-1990	69,000	7	
92/85	29-10-2000	86,000	17	
Zone 3				
93/85	01-08-2000	15,000	12	
93/85	15-09-1996	33,000	8	
93/85	23-09-1993	62,000	9	
93/85	22-10-1992	113,000	9	
Zone 4				
93/85	23-10-1998	11,000	9	
93/85	22-08-1993	23,000	5	
Zone 5				
93/85	02-08-2000	11,000	12	
93/85	15-09-1996	33,000	8	
93/85	28-09-1989	44,000	7	
93/85	22-10-1992	71,000	9	
93/85	23-09-1993	102,000	9	
Zone 6				
93/85	02-08-2000	11,000	12	
93/85	15-09-1996	35,000	8	
93/85	28-09-1989	46,000	7	
93/85	22-10-1992	70,000	9	
93/85	23-09-1993	116,000	9	
Zone 7				

93/85	23-10-1998	10,000	9	
93/85	23-08-1989	40,000	7	
93/85	22-10-1992	73,000	9	
93/85	23-09-1993	132,000	9	
Zone 8				
94/85	15-11-1998	8,000	13	
94/85	15-08-1988	24,000	7	
94/85	17-07-1989	38,000	4	
94/85	03-09-1989	45,000	8	
Zone 9				
94/85	15-11-1998	9,000	13	
94/85	18-07-1995	20,000	4	
94/85	03-09-1989	28,000	8	
Zone 10				
94/85	15-11-1998	12,000	13	
94/85	15-08-1988	29,000	7	
94/85	03-09-1989	48,000	8	
Zone 11				
94/85	15-11-1998	13,000	13	
94/85	18-07-1995	30,000	4	
94/85	15-08-1988	46,000	7	
94/85	17-07-1989	79,000	4	
94/85	03-09-1989	87,000	8	
Zone 12				
95/84	29-03-1993	11,000	10	
95/84	14-04-1993	20,000	9	
95/84	22-08-1988	38,000	9	
95/84	20-10-1992	58,000	12	
95/84	26-09-1989	82,000	12	
95/84	29-09-1990	117,000	12	
Zone 13-15				
95/84	09-11-1994	6,000		Flows recorded at gauging station 426200 at the South Australian border for all images Zone 13-22
95/84	08-05-1990	28,000		
95/84	12-08-1996	38,000		
95/84	21-9-1993	47,000		
95/84	07-10-1993	66,000		
95/84	26-09-1989	80,000		
95/84	29-09-1990	102,000		
Zone 16-19				

96/84	30-08-1994	3,000		
96/84	20-11-1989	26,000		
96/84	11-10-1992	38,000		
96/84	27-10-1986	44,000		
96/84	03-08-1990	47,000		
96/84	02-09-1995	55,000		
96/84	23-11-1996	68,000		
96/84	31-07-1989	71,000		
96/84	16-08-1989	77,000		
96/84	03-10-1989	82,000		
96/84	26-10-1990	102,000		
Zone 20-22				
97/84	23-08-1994	4,000		
97/85	09-11-1994	5,000	25	Missing Mannum to Wellington
96/84	02-07-1996	13,000	7	
97/84	20-05-1989	27,000		
97/84	10-08-1996	37,000	9	
97/84	25-07-1990	41,000		
97/84	20-09-1996	57,000	18	
96/84	23-11-1996	68,000		
96/84	16008-1989	78,000	5	Missing Mannum to Wellington
96/84	20-09-1990	93,000	20	Missing Mannum to Wellington
97/84	22-11-1993	109,000	25	

APPENDIX B: ZONE STATISTICS

This appendix contains statistical information for each of the twenty two zones including:

1. Flow travel time and river length of zone
2. Map of zone showing zone boundary, permanent water, the maximum flood from the satellite images and gauging stations.
3. Area of inundation at 10,000 ML/day flow increments.
4. Wetland area of inundation at 10,000 ML/day flow increments.
5. Number of wetlands inundated at 10,000ML/day flow increments.
6. Percentage of vegetation type inundated at 10,000 ML/day flow increments.

Two graphs of the last three points have been created to display the nature of this statistical data. The first graph shows wetland inundation statistics and the second graph shows type of vegetation inundated.

Zone1

Description	Area (ha)	River km length	Travel time (days)
Hume Dam to Lake Mulwala	31509	223	4

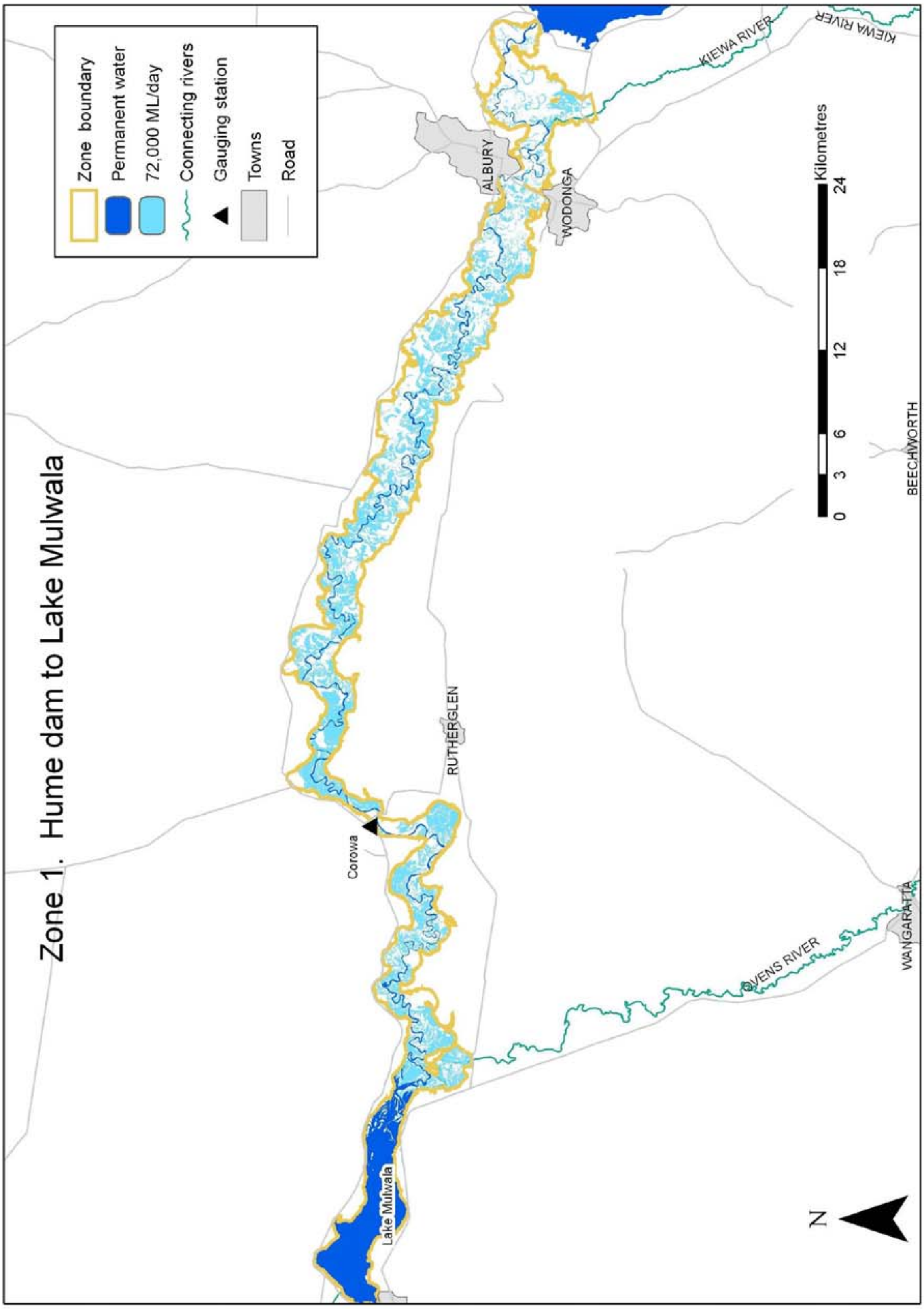


Figure 21. Zone 1 showing permanent water and maximum flood from satellite image.

Table 3. Zone 1: area of inundation at 10,000 ML/day flow increments.

Flow (1000 ML/day)	Cumulative area of inundation (Hectares)	Cumulative area of inundation (%)
5	6083	19
10	6323	20
20	6747	21
30	8307	26
40	8742	28
50	10968	35
60	11926	38
70	15491	49
>70	31509	100

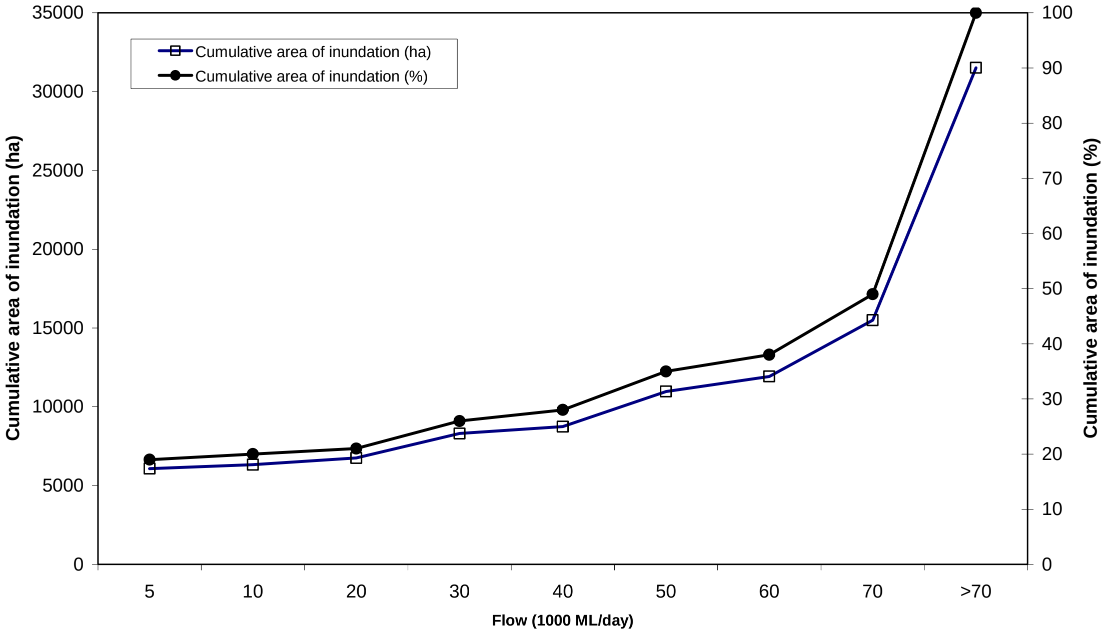


Figure 22. Zone 1 - Area of inundation.

Table 4. Zone 1: number of wetlands inundated and area of wetlands inundated at 10,000ML/day flow increments.

Flow (1000 ML/day)	Cumulative number of wetlands inundated	Cumulative number of wetlands inundated (%)	Cumulative area of wetland inundation (Hectares)	Cumulative area of wetland inundation (%)
5	236	33	5923	71
10	263	36	6143	74
20	331	46	6525	78
30	548	76	7500	90
40	585	81	7664	92
50	692	96	7832	94
60	696	96	7851	94
70	714	99	8005	96
80	721	100	8133	98
>80	722	100	8324	100

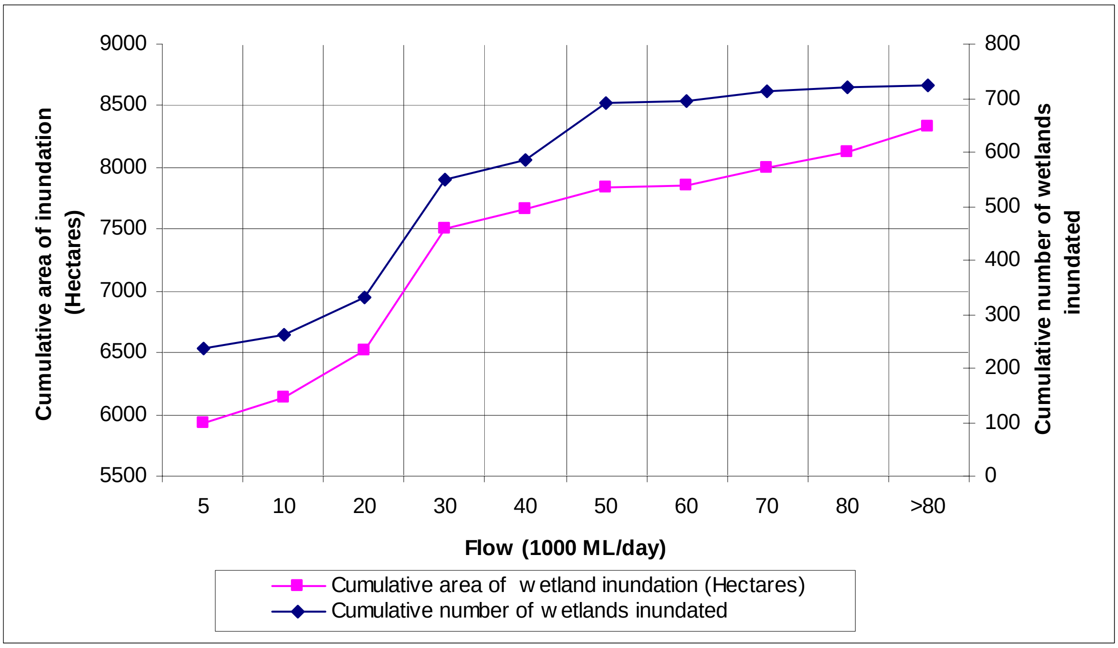


Figure 23. Zone 1 - Wetland inundation statistics

Table 5: Zone 1 - Percentage of vegetation type inundated at 10,000 ML/day flow increments.

Flow (1000 ML/day)	% Red Gum	% Red Gum/Black Box	% Mixed box	% Saline shrubland	% Agriculture/ horticulture
5	6	3	9	1	3
10	6	3	9	1	4
20	8	4	11	1	4
30	14	10	13	2	7
40	15	11	15	2	8
50	25	15	21	11	17
60	28	19	23	12	22
70	45	43	35	45	35
>70	100	100	100	100	100

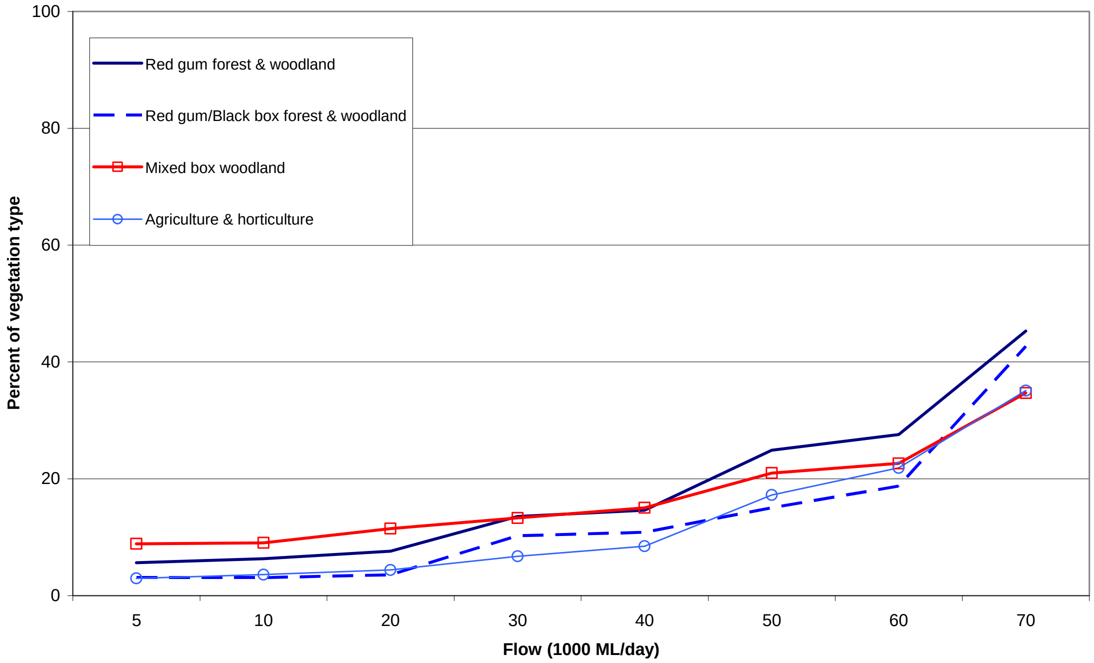


Figure 24. Zone 1 - Percentage of vegetation type inundated

Zone 2

Description	Area (ha)	River km length	Travel time (days)
Lake Mulwala to image edge (u/s Tocumwal)	6863	45	1

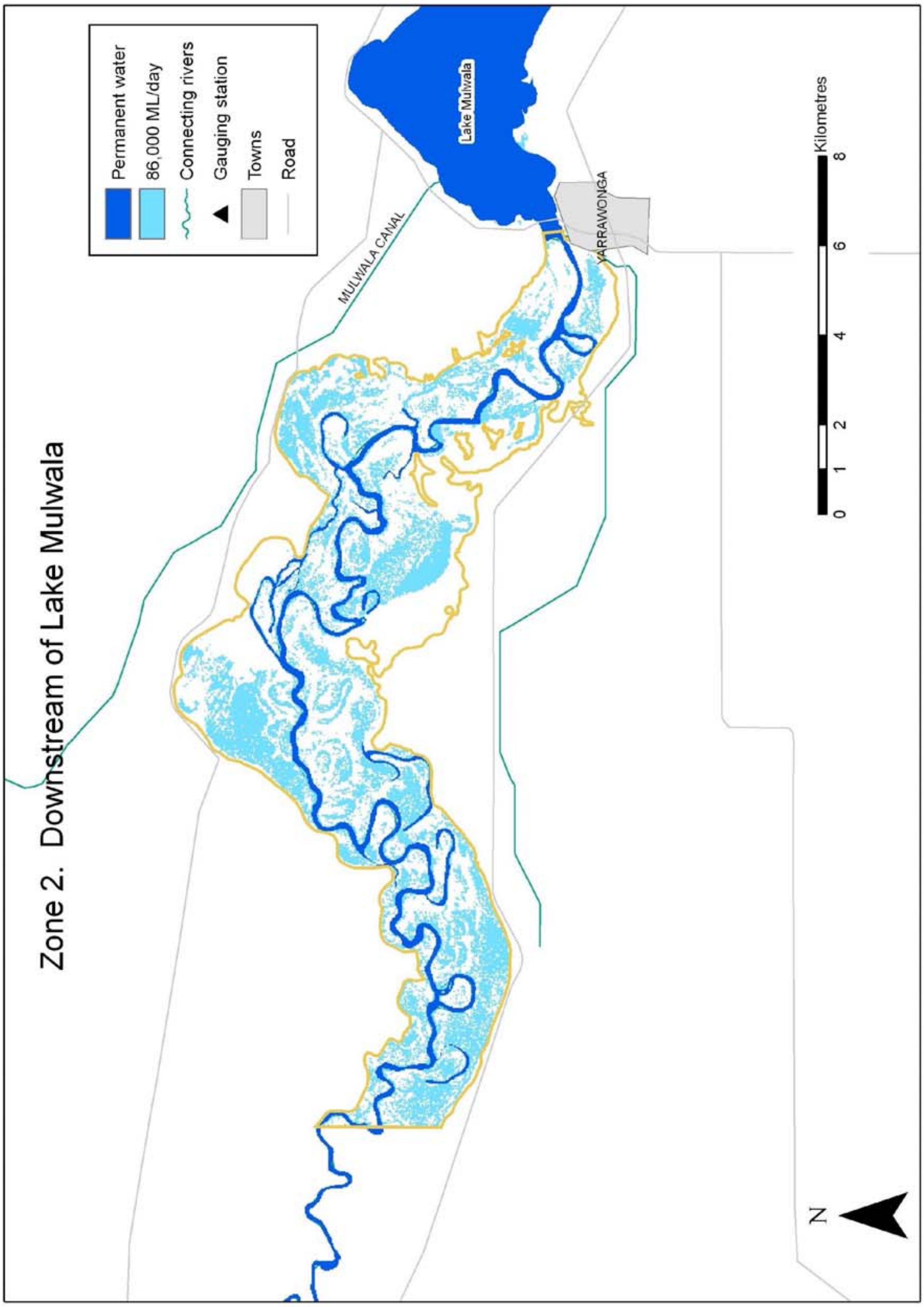


Figure 25. Zone 2 permanent water and maximum flood from satellite image.

Table 6. Zone 2 - Area of inundation at 10,000 ML/day flow increments.

Flow (1000 ML/day)	Cumulative area of inundation (Hectares)	Cumulative area of inundation (%)
5	659	10
10	719	10
20	733	11
30	754	11
40	901	13
50	915	13
60	1022	15
70	2489	36
80	2496	36
>80	6863	100

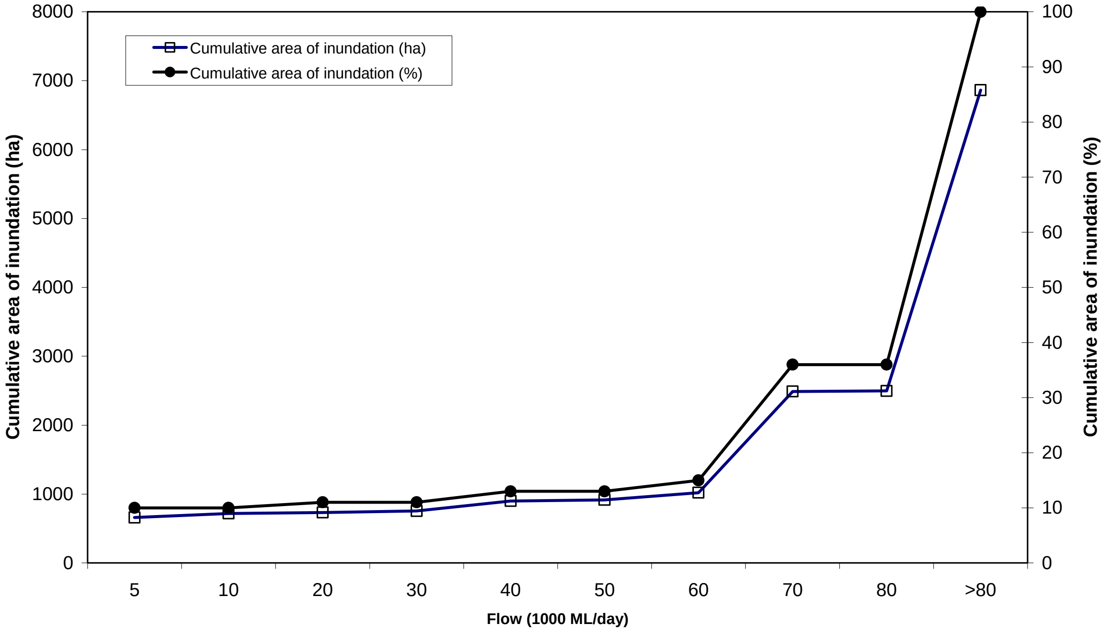


Figure 26. Zone 2 - Area of inundation.

Table 7. Zone 2 - Number of wetlands inundated and area of wetlands inundated at 10,000ML/day flow increments.

Flow (1000 ML/day)	Cumulative number of wetlands inundated	Cumulative number of wetlands inundated (%)	Cumulative area of wetland inundation (Hectares)	Cumulative area of wetland inundation (%)
5	37	25	0	0
10	59	25	35	11
20	64	40	47	15
30	70	43	64	20
40	102	47	136	43
50	103	69	144	45
60	105	70	161	50
70	145	71	271	85
80	145	98	276	86

90	148	98	291	91
>90	148	100	935	100

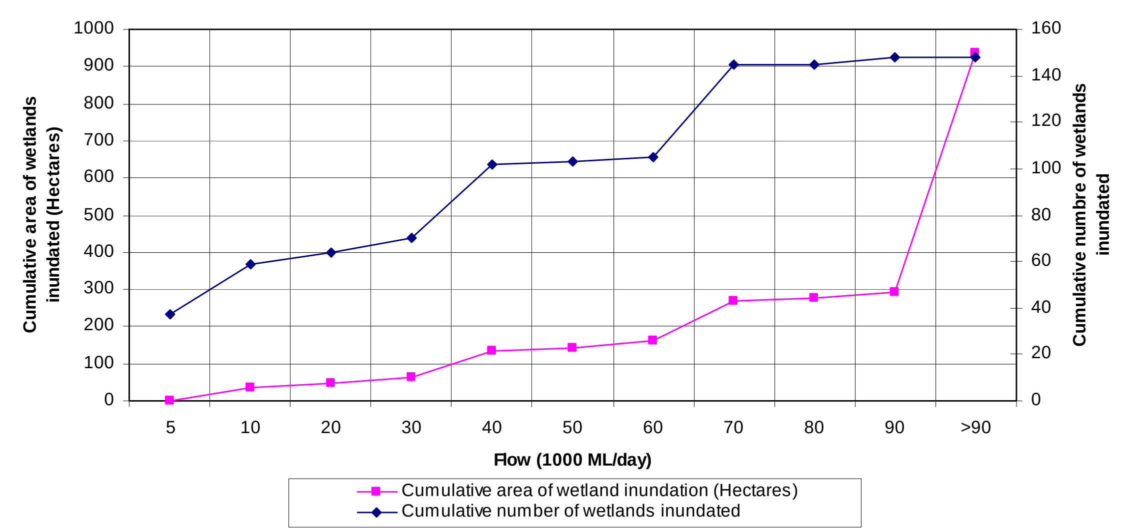


Figure 27. Zone 2 - Wetland inundation statistics

Table 8. Zone 2 - Percentage of vegetation type inundated at 10,000 ML/day flow increments.

Flow (1000 ML/day)	% Red Gum	% Red Gum/Box	% Mixed box	% Agriculture/ horticulture
5	9		3	1
10	10		3	1
20	10		3	1
30	10		3	1
40	12	1	4	1
50	12	1	4	1
60	13	2	5	1
70	39	16	15	4
80	39	16	15	4
>80	100	100	100	100

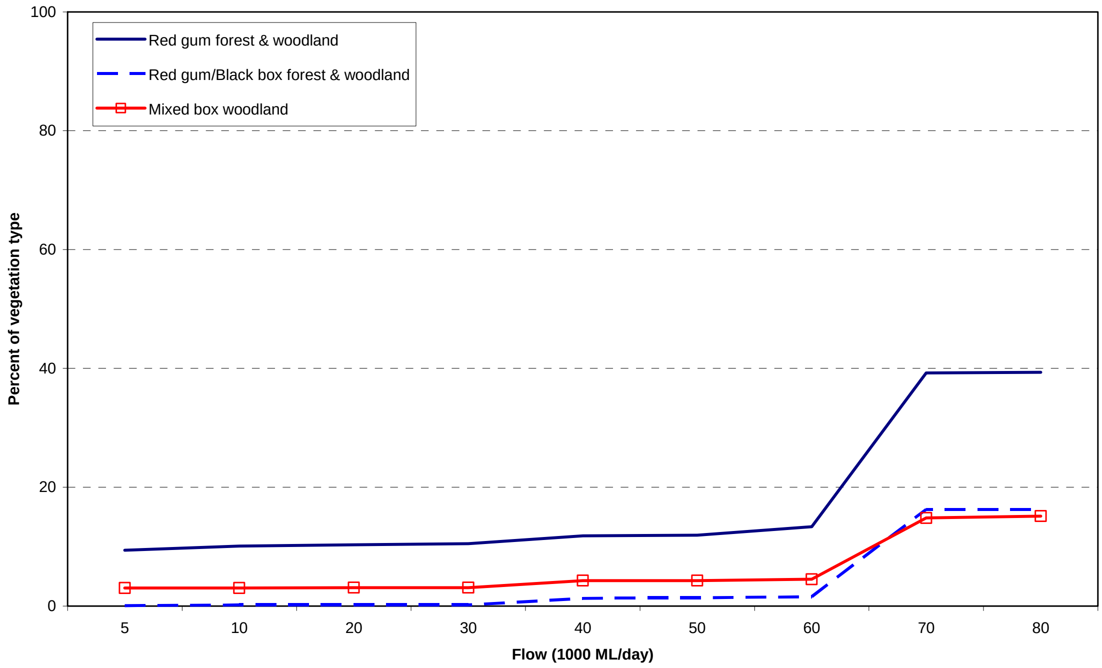


Figure 28. Zone 2 - Percentage of vegetation type inundated

Zone 3

Description	Area (ha)	River km length	Travel time (days)
U/s Tocumwal to Barmah	78233	195	3

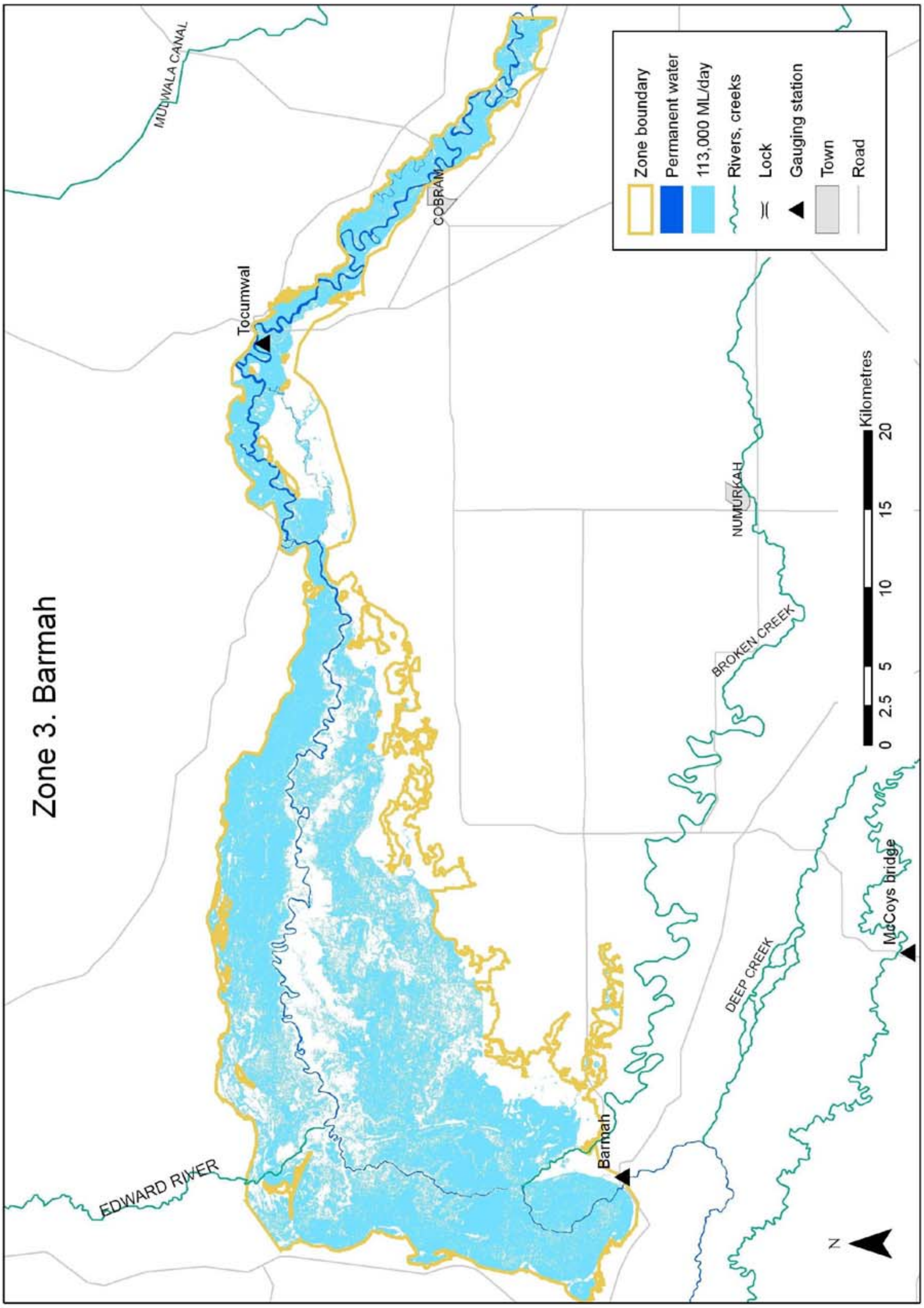


Figure 29. Zone 3 permanent water and maximum flood from satellite image.

Table 9. Zone 3 - Area of inundation at 10,000 ML/day flow increments.

Flow (1000 ML/day)	Cumulative area of inundation (Hectares)	Cumulative area of inundation (%)
5	1693	2
10	1795	2
20	4591	6
30	6112	8
40	17395	22
50	27345	35
60	28611	37
70	41653	53
80	41967	54
90	43781	56
100	44121	56
110	44238	57
>110	78233	100

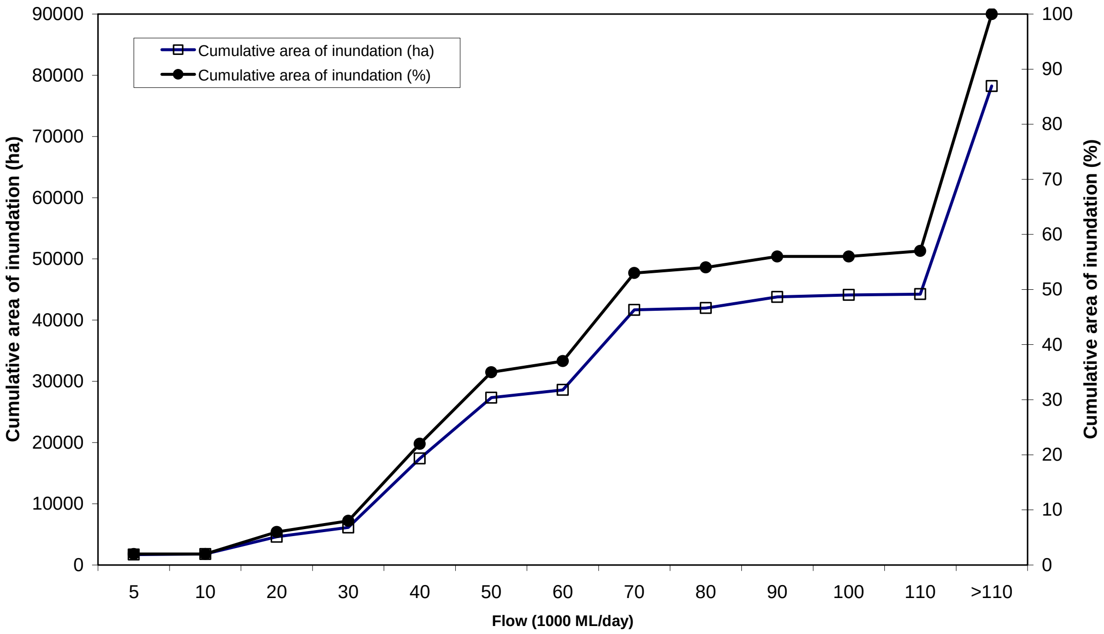


Figure 30. Zone 3 - Area of inundation.

Table 10. Zone 3 - Number of wetlands inundated and area of wetlands inundated at 10,000ML/day flow increments.

Flow (1000 ML/day)	Cumulative number of wetlands inundated	Cumulative number of wetlands inundated (%)	Cumulative area of wetland inundation (Hectares)	Cumulative area of wetland inundation (%)
5	51	11	1471	25
10	57	12	1544	26
20	238	49	2732	47
30	247	51	3133	53

40	387	80	3742	64
50	411	85	4000	68
60	413	85	4042	69
70	449	93	4512	77
80	451	93	4576	78
90	454	94	4587	78
100	460	94	4590	78
110	454	94	4591	78
120	460	95	4626	79
>120	485	100	5865	100

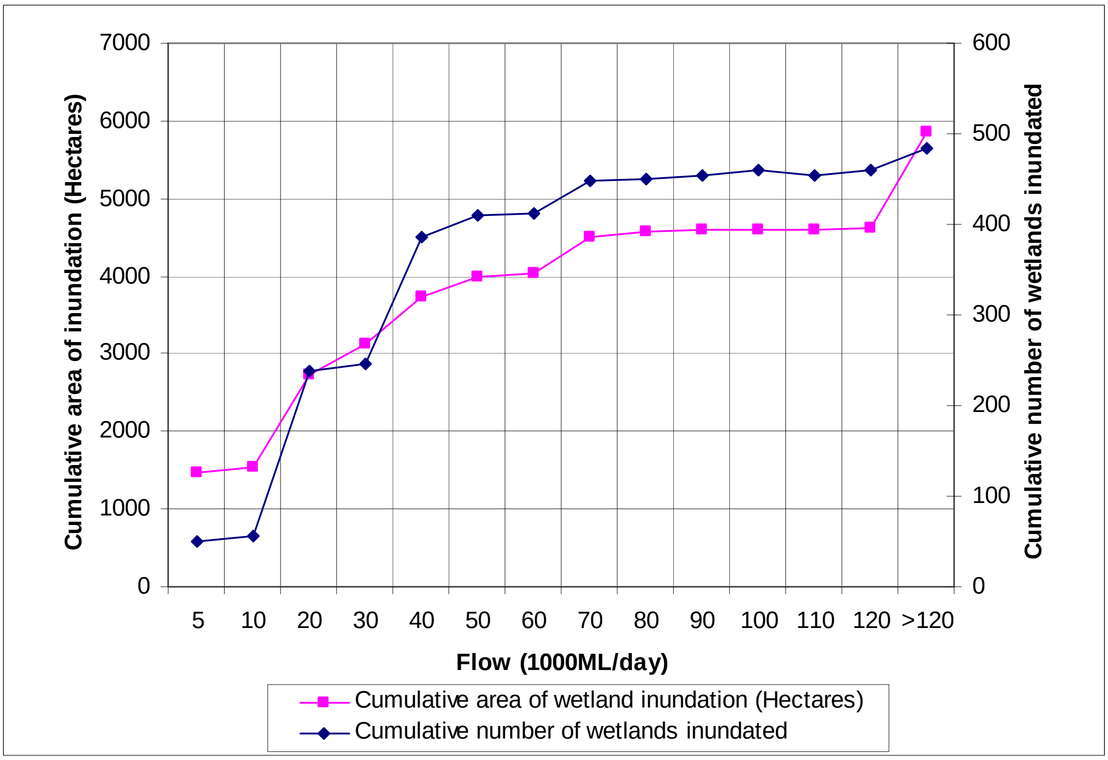


Figure 31. Zone 3 - Wetland inundation statistics

Table 11. Zone 3 - Percentage of vegetation type inundated at 10,000 ML/day flow increments.

Flow (1000 ML/day)	% Red Gum	% Red Gum/Box	% Mixed box	% Agriculture/ horticulture
5	2	4		
10	2	4		
20	4	5		
30	13	5	1	
40	24	6	3	1
50	39	10	17	5
60	41	13	21	5
70	62	27	38	8
80	62	30	38	8
90	65	49	41	10
100	65	56	41	11

110	65	58	42	11
>110	100	100	100	100

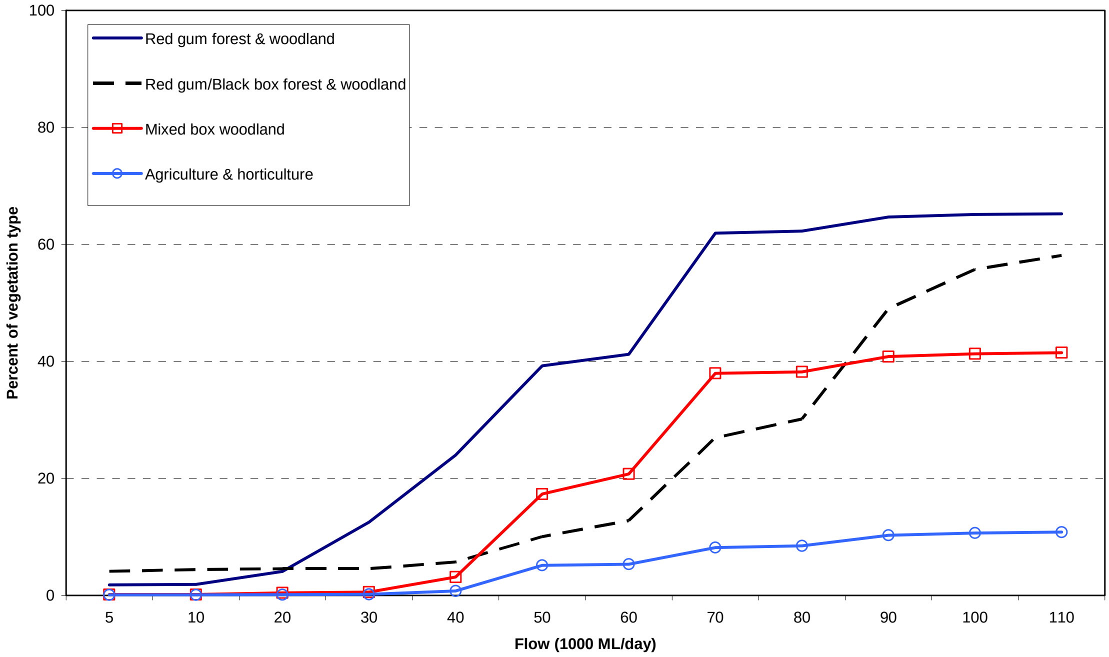


Figure 32. Zone 3 - Percentage of vegetation type inundated

Zone 4

Description	Area (ha)	River km length	Travel time (days)
Downstream Barmah to Goulburn/Murray junction	15860	46	0.5

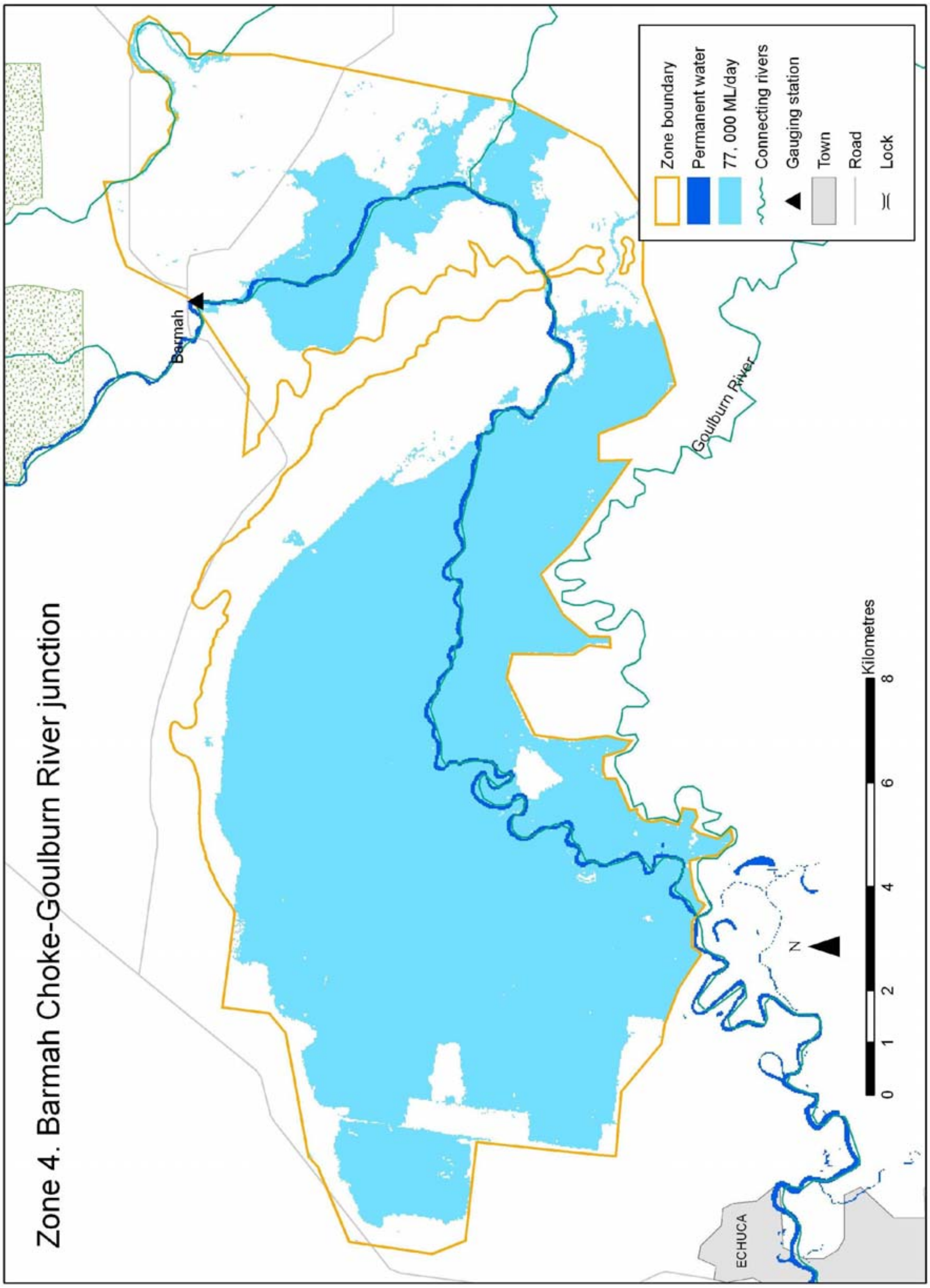


Figure 33. Zone 4 showing permanent water and maximum flood from satellite image.

Table 12. Zone 4 - Area of inundation at 10,000 ML/day flow increments

Flow (1000 ML/day)	Cumulative area of inundation (Hectares)	Cumulative area of inundation (%)
5	237	1
10	243	2
20	274	2
30	2169	14
40	2411	15
50	6770	43
60	8397	53
70	9427	59
>70	15860	100

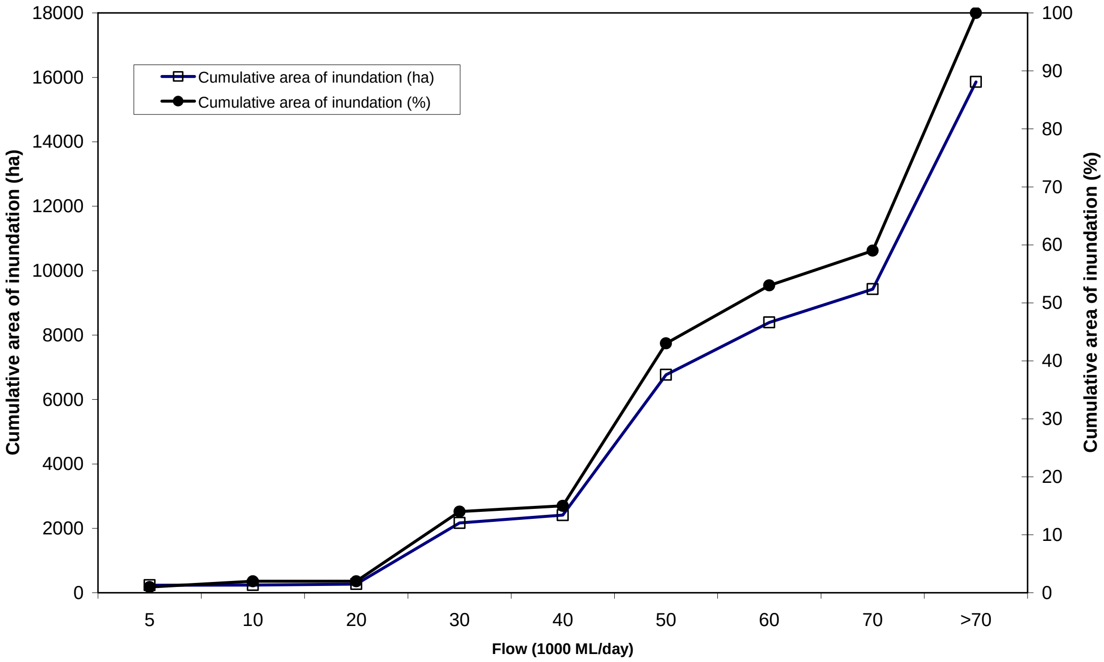


Figure 34. Zone 4 - Area of inundation.

Table 13. Zone 4 - Number of wetlands inundated and area of wetlands inundated at 10,000ML/day flow increments.

Flow (1000 ML/day)	Cumulative number of wetlands inundated	Cumulative number of wetlands inundated (%	Cumulative area of wetland inundation (Hectares)	Cumulative area of wetland inundation (%)
5	5	11	217	57
10	6	13	222	59
20	9	20	246	65
30	34	74	279	74
40	34	74	286	75
50	42	91	332	88
60	44	96	363	96
70	44	96	365	96
80	46	100	378	100

>80	46	100	379	100

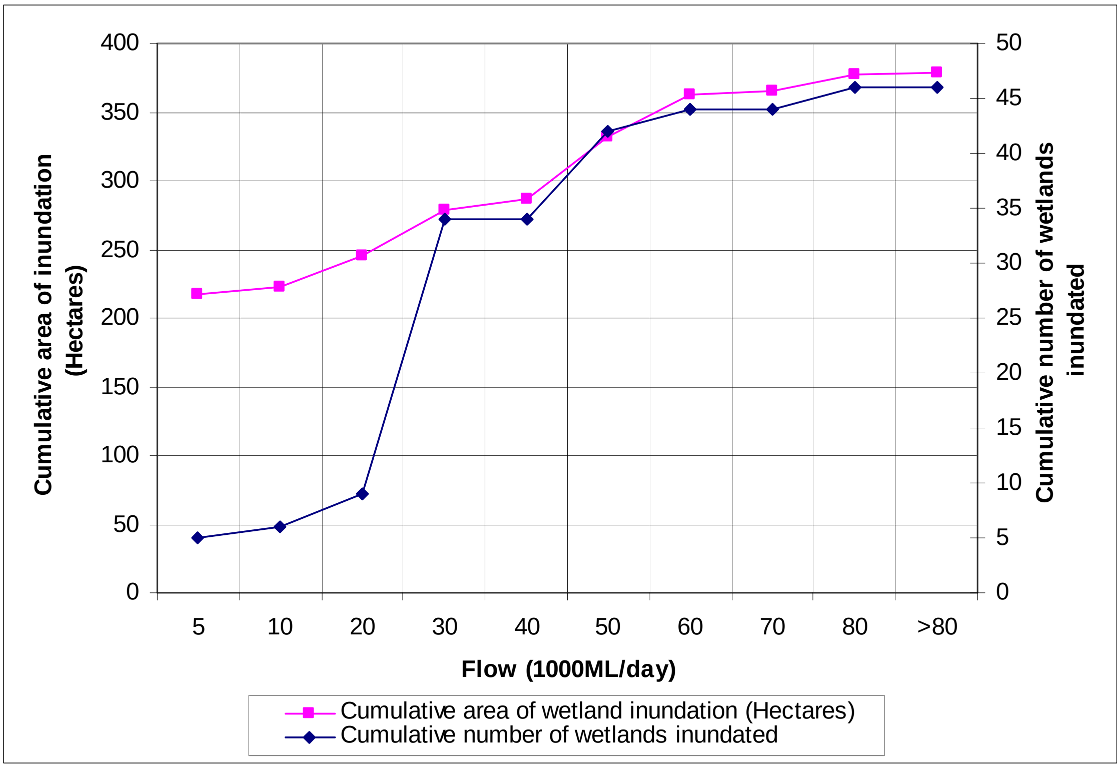


Figure 35. Zone 4 - Wetland inundation statistics.

Table 14. Zone 4 - Percentage of vegetation type inundated at 10,000 ML/day flow increments.

Flow (1000 ML/day)	% Red Gum	% Black Box	% Red Gum/ Box	% Mixed box	% Agriculture/ horticulture
5	1		1		
10	1		1		
20	1		1		
30	45		6	4	1
40	47		7	5	2
50	80		59	67	16
60	93		72	80	22
70	95	9	80	83	29
>70	100	100	100	100	100

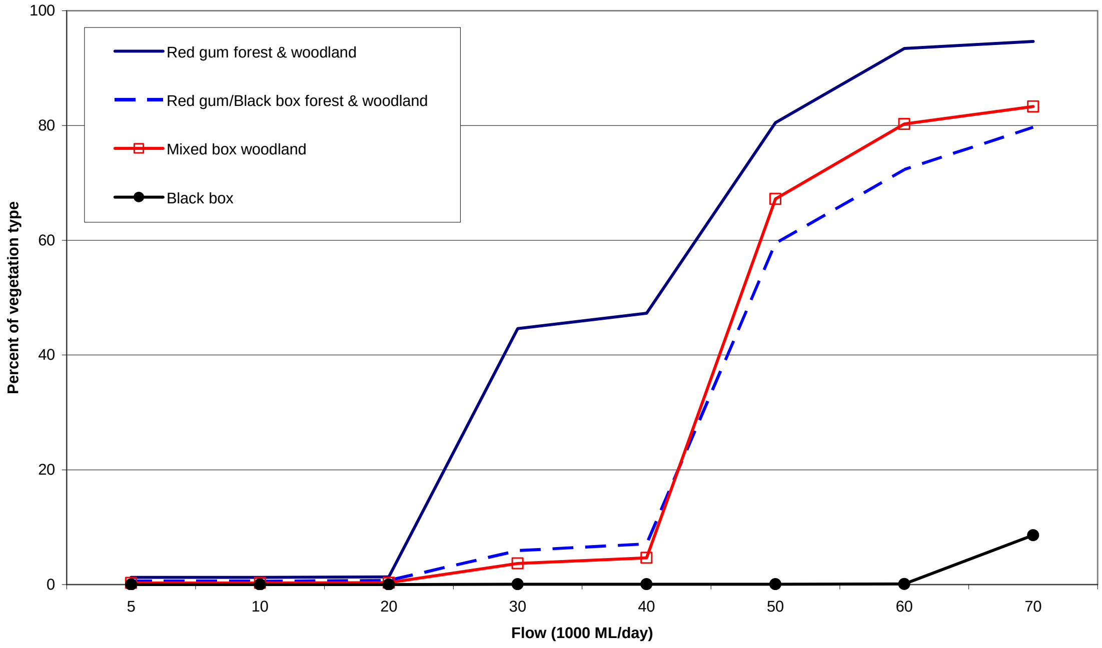


Figure 36. Zone 4 - Percentage of vegetation type inundated

Zone 5

Description	Area (ha)	River km length	Travel time (days)
Goulburn/Murray junction to Campaspe/Murray junction	4231	21	0.5

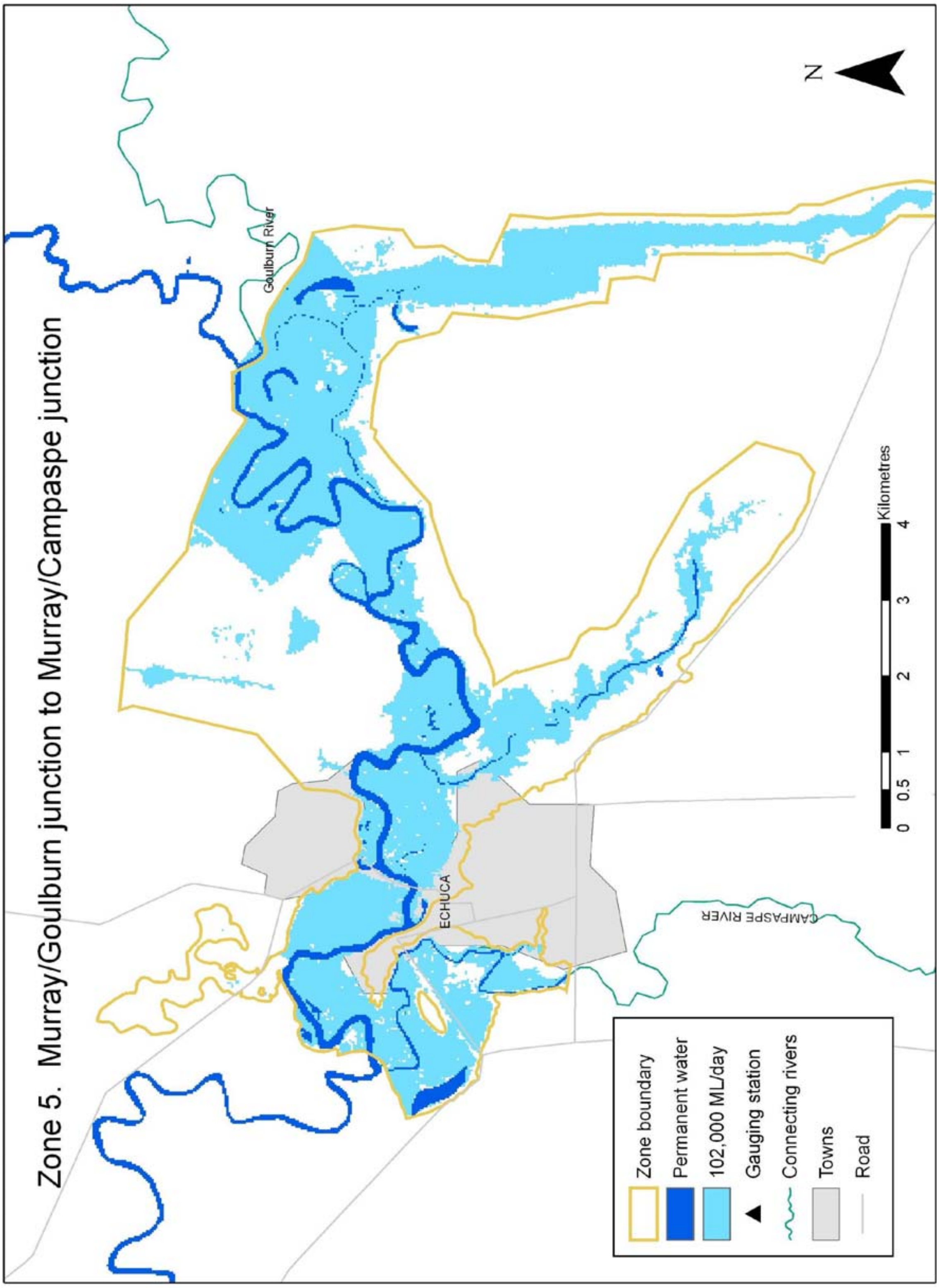


Figure 37. Zone 5 showing permanent water and maximum flood from satellite image.

Table 15. Zone 5 - Area of inundation at 10,000 ML/day flow increments.

Flow (1000 ML/day)	Cumulative area of inundation (Hectares)	Cumulative area of inundation (%)
5	258	6
10	259	6
20	277	7
30	277	7
40	290	7
50	331	8
60	395	9
70	612	15
80	1229	29
90	1593	38
100	1779	42
>100	4231	100

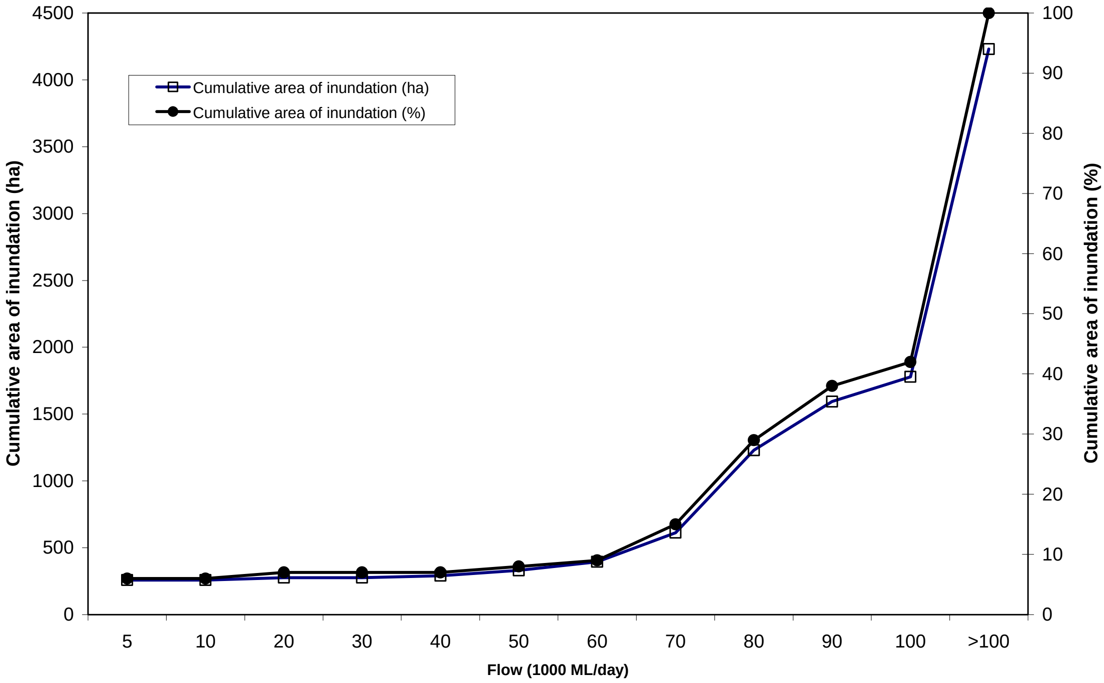


Figure 38. Zone 5 - Area of inundation.

Table 16. Zone 5 - Number of wetlands inundated and area of wetlands inundated at 10,000ML/day flow increments.

Flow (1000 ML/day)	Cumulative number of wetlands inundated	Cumulative number of wetlands inundated (%)	Cumulative area of wetland inundation (Hectares)	Cumulative area of wetland inundation (%)
5	33	100	230	90
10	33	100	231	90
20	33	100	233	91
30	33	100	233	91
40	33	100	235	92

50	33	100	237	93
60	33	100	238	93
70	33	100	238	93
80	33	100	248	97
90	33	100	248	97
100	33	100	248	97
110	33	100	256	100
>110	33	100	256	100

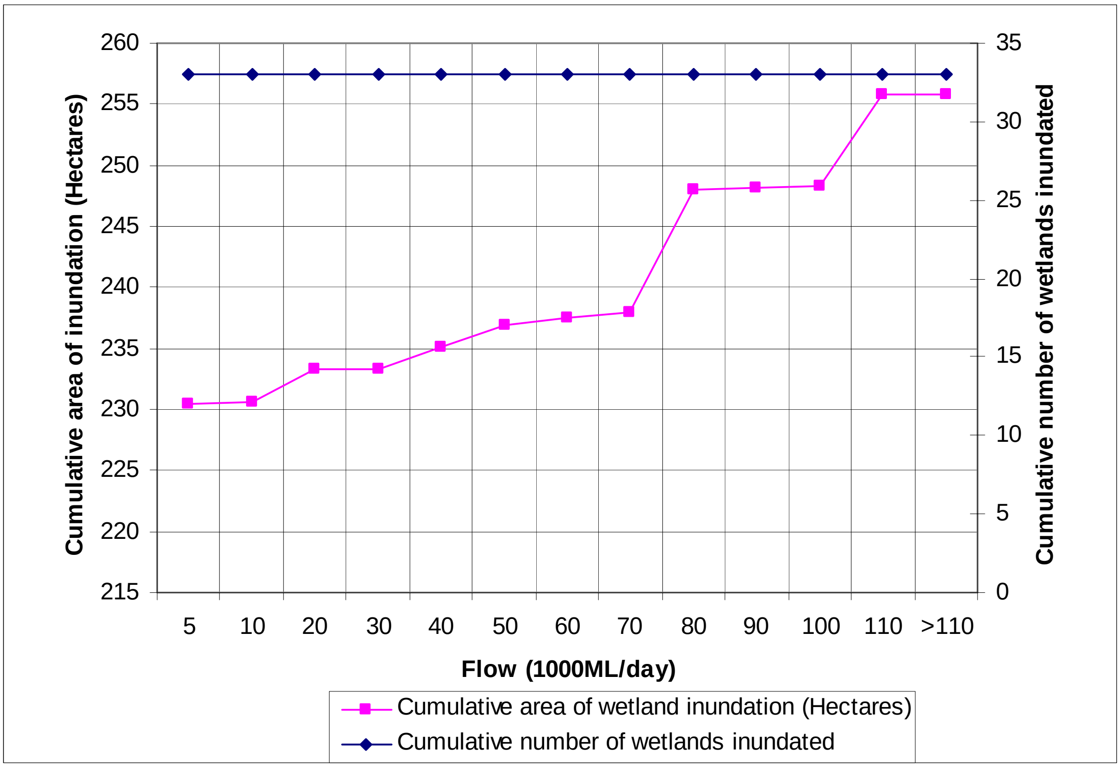


Figure 39. Zone 5 - Wetland inundation statistics.

Table 17. Zone 5 - Percentage of vegetation type inundated at 10,000 ML/day flow increments.

Flow (1000 ML/day)	% Red Gum	% Red Gum/Box	% Mixed box	% Agriculture/ horticulture
5	10	5	2	2
10	10	5	2	2
20	11	5	2	2
30	11	5	2	2
40	12	5	2	2
50	15	5	2	2
60	19	8	2	2
70	35	16	10	3
80	62	43	29	8
90	75	61	37	15
100	78	73	48	19
110	91	88	60	26
>110	100	100	100	100

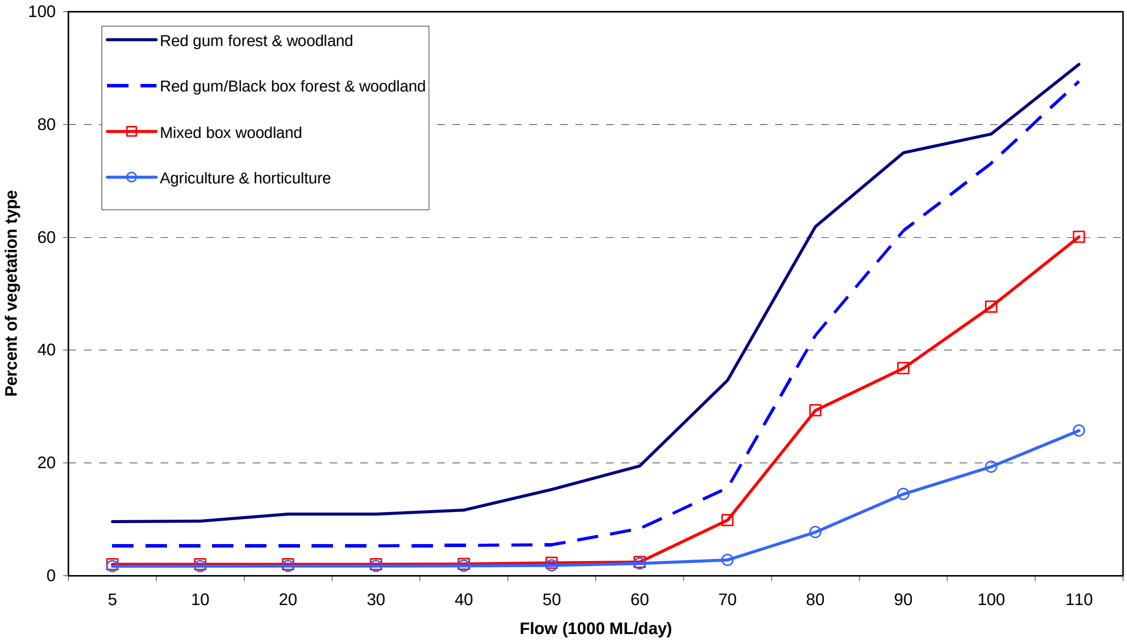


Figure 40. Zone 5 - Percentage of vegetation type inundated.

Zone 6

Description	Area (ha)	River km length	Travel time (days)
Campaspe/Murray junction to Torrumbarry Weir	9957	77	1.5

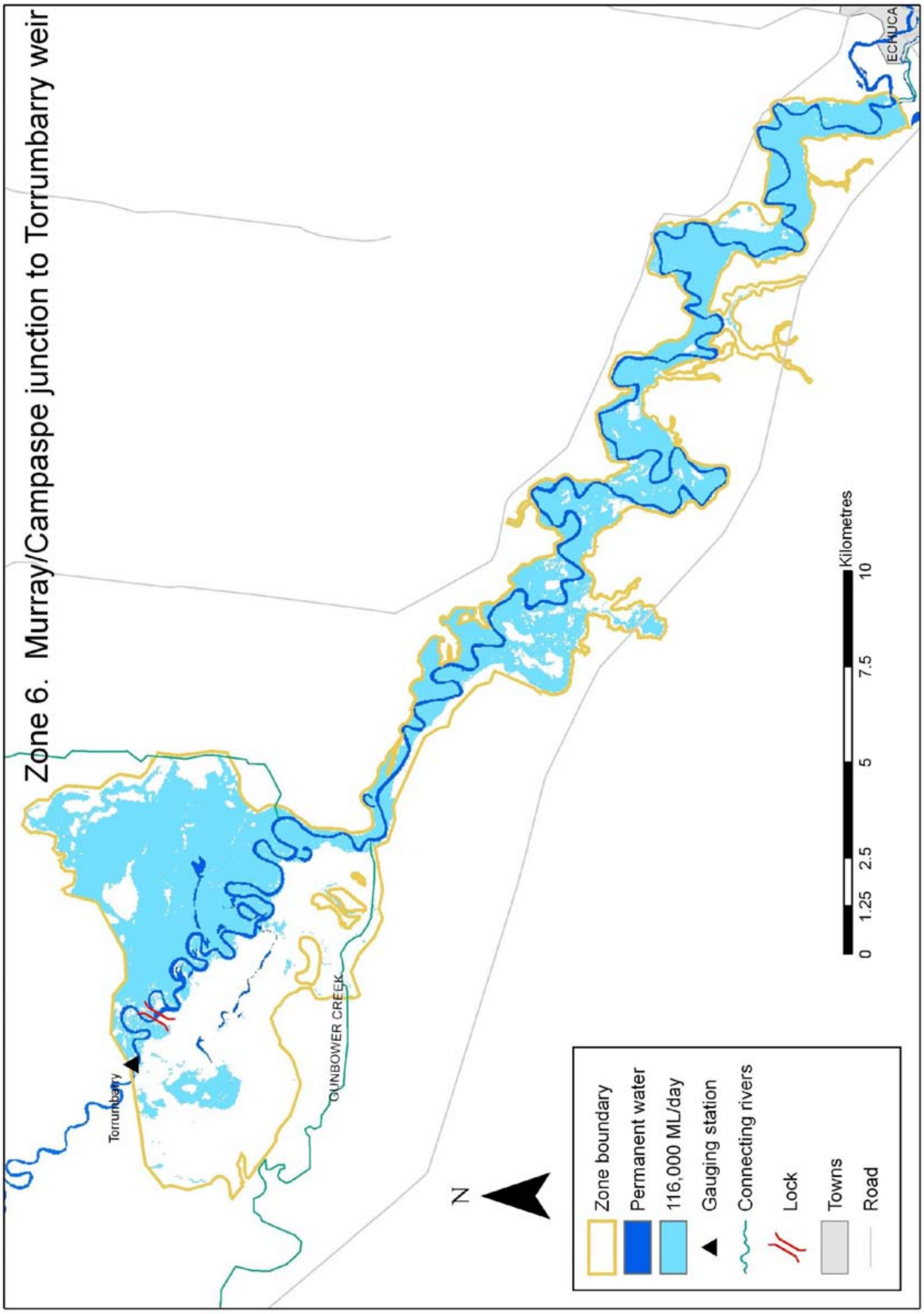


Figure 41. Zone 6 showing permanent water and maximum flood from satellite image.

Table 18. Zone 6 - Area of inundation at 10,000 ML/day flow increments.

Flow (1000 ML/day)	Cumulative area of inundation (Hectares)	Cumulative area of inundation (%)
5	728	7
10	738	7
20	866	9
30	866	9
40	956	10
50	1140	11
60	1819	18
70	3391	34
80	3564	36
90	3815	38
100	4946	50
110	5102	51
>110	9957	100

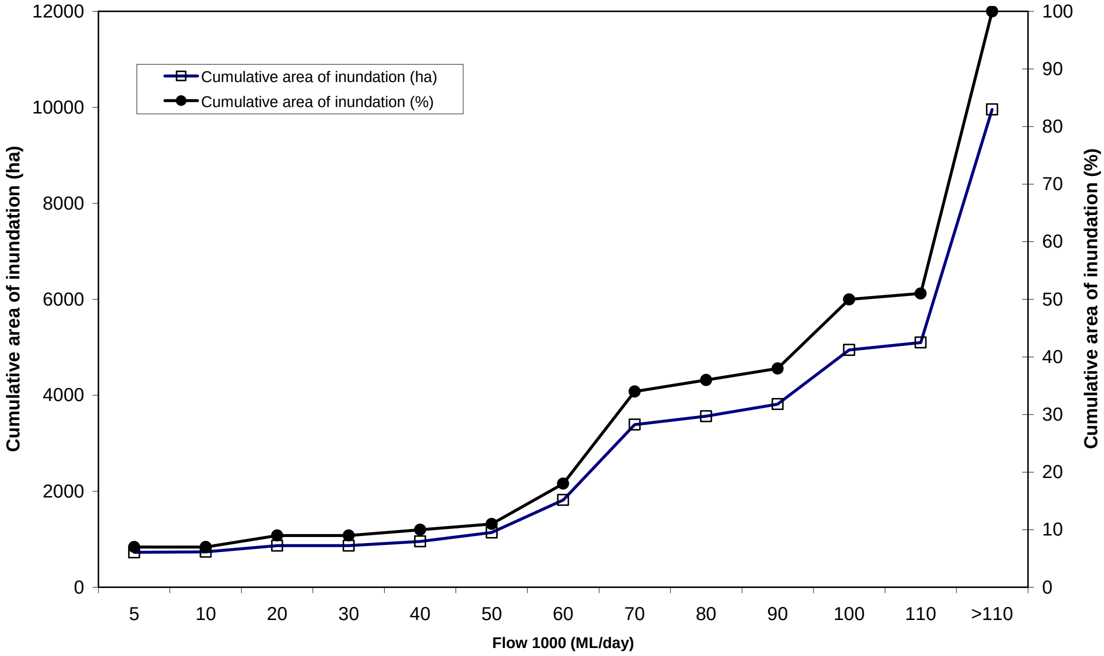


Figure 42. Zone 6 - Area of inundation.

Table 19. Zone 6 - Number of wetlands inundated and area of wetlands inundated at 10,000ML/day flow increments.

Flow (1000 ML/day)	Cumulative number of wetlands inundated	Cumulative number of wetlands inundated (%)	Cumulative area of wetland inundation (Hectares)	Cumulative area of wetland inundation (%)
5	33	20	669	58
10	45	27	676	58
20	65	39	741	64
30	66	40	746	65
40	92	56	779	67

50	101	61	826	71
60	112	68	834	72
70	135	82	872	75
80	135	82	873	75
90	135	82	874	76
100	137	83	876	76
110	137	83	877	76
120	142	86	906	78
>120	165	100	1156	100

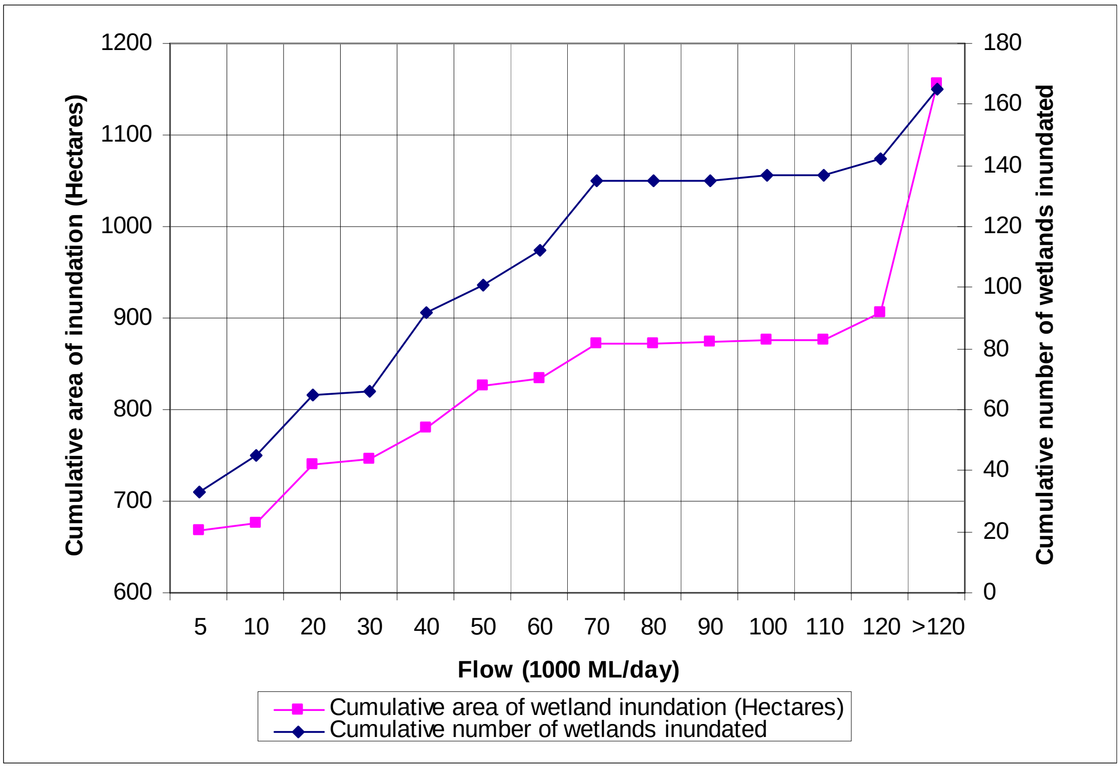


Figure 43. Zone 6 - Wetland inundation statistics.

Table 20. Zone 6 - Percentage of vegetation type inundated at 10,000 ML/day flow increments.

Flow (1000 ML/day)	% Red Gum	% Black Box	% Red Gum/Box	% Mixed box	% Agriculture/ horticulture
5	11		7	4	2
10	11		7	4	2
20	12		8	4	3
30	12		8	4	3
40	14	1	8	5	3
50	17	9	9	6	3
60	22	32	10	15	4
70	54	56	33	30	10
80	57	60	38	32	11
90	61	63	43	33	13
100	73	77	65	43	21

110	75	78	67	44	23
>110	100	100	100	100	100

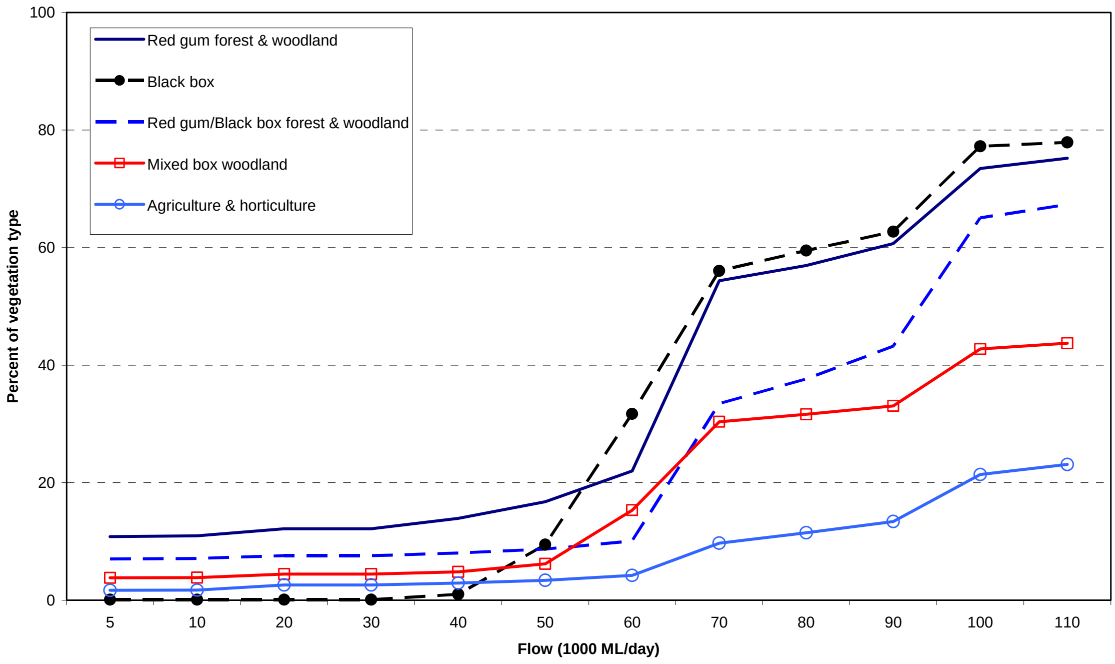


Figure 44. Zone 6 - Percentage of vegetation type inundated.

Zone 7

Description	Area (ha)	River km length	Travel time (days)
Torrumbarry to downstream of Gunbower	89970	156	3

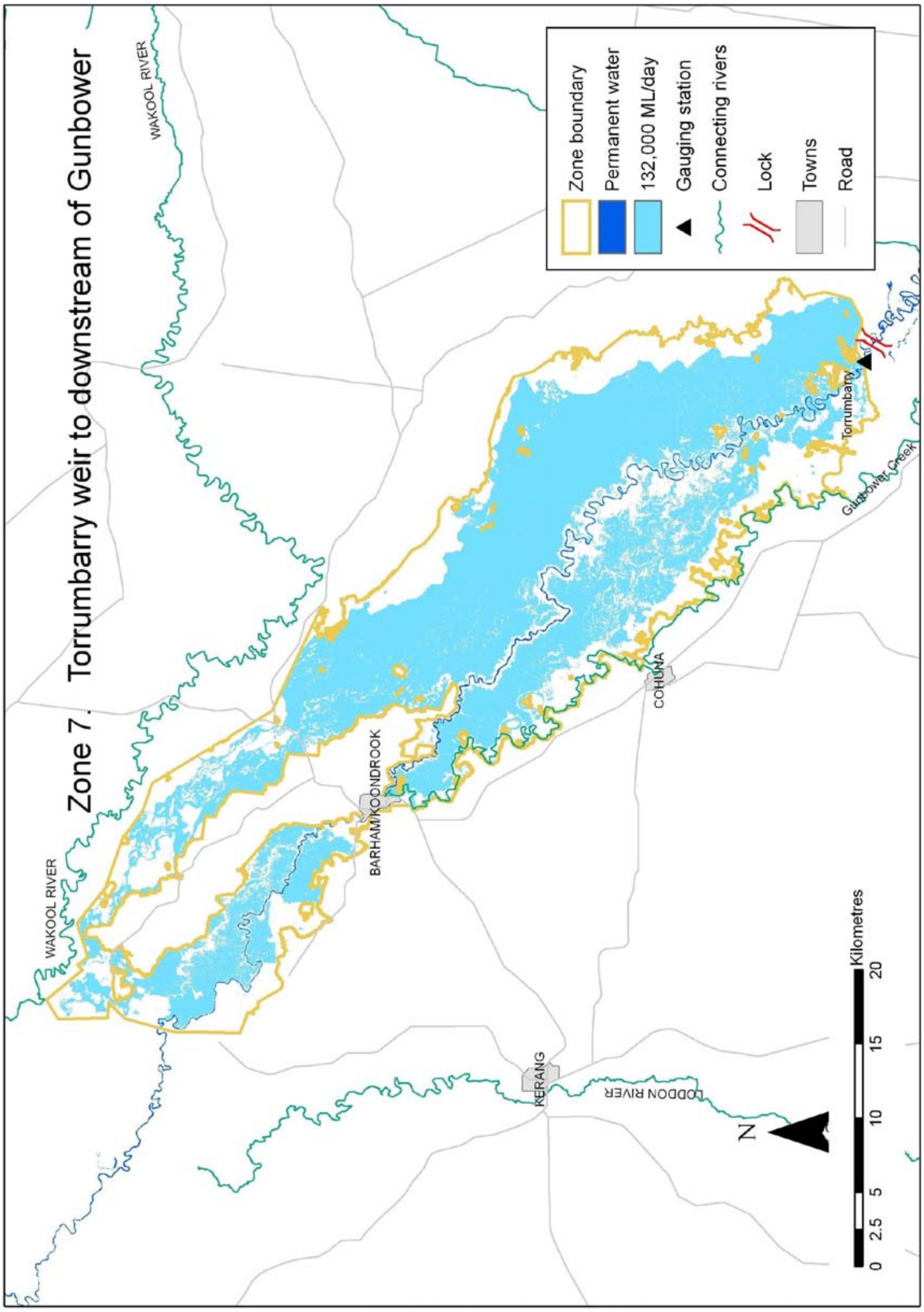


Figure 45. Zone 7 showing permanent water and maximum flood from satellite image.

Table 21. Zone 7 - Area of inundation at 10,000 ML/day flow increments.

Flow (1000 ML/day)	Cumulative area of inundation (Hectares)	Cumulative area of inundation (%)
5	1040	1
10	1560	2
20	1703	2
30	1724	2
40	1779	2
50	3913	4
60	5023	6
70	6549	7
80	45359	50
90	46032	51
100	46447	52
110	49457	55
120	50397	56
130	58427	65
>130	89970	100

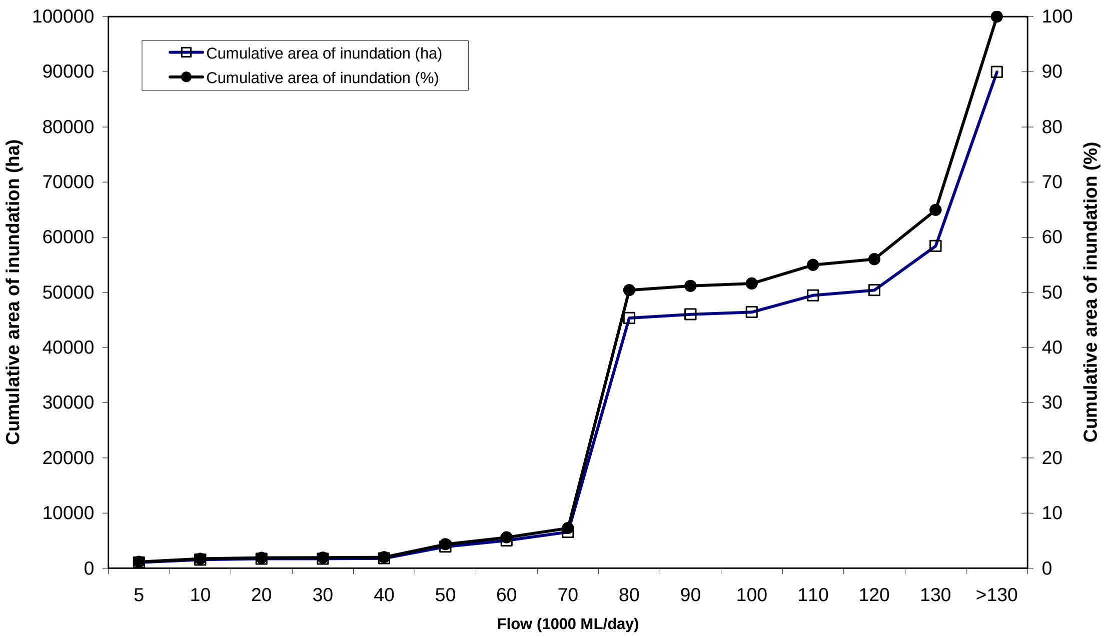


Figure 46. Zone 7 - Area of inundation.

Table 22. Zone 7 - Number of wetlands inundated and area of wetlands inundated at 10,000ML/day flow increments.

Flow (1000 ML/day)	Cumulative number of wetlands inundated	Cumulative number of wetlands inundated (%)	Cumulative area of wetland inundation (Hectares)	Cumulative area of wetland inundation (%)
5	33	20	669	58
10	45	27	676	58
20	65	39	741	64

30	66	40	746	65
40	92	56	779	67
50	101	61	826	71
60	112	68	834	72
70	135	82	872	75
80	135	82	873	75
90	135	82	874	76
100	137	83	876	76
110	137	83	877	76
120	142	86	906	78
>120	165	100	1156	100

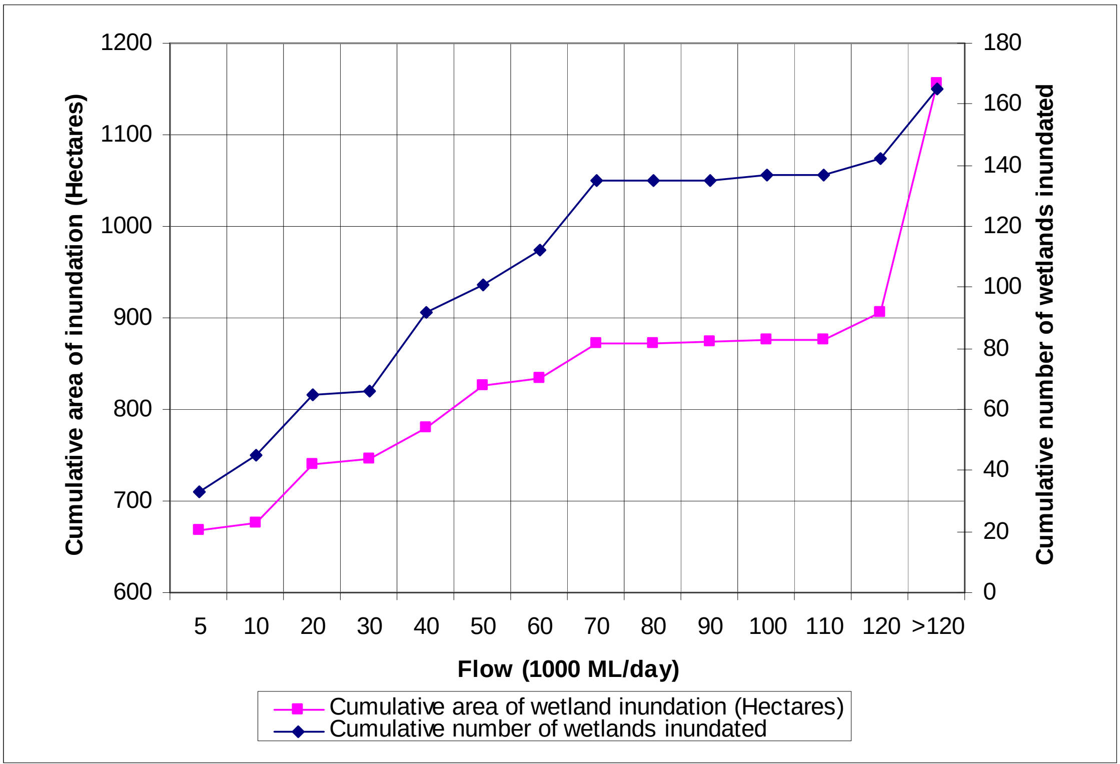


Figure 47. Zone 7 - Wetland inundation statistics.

Table 23. Zone 7 - Percentage of vegetation type inundated at 10,000 ML/day flow increments.

Flow (1000 ML/day)	% Red Gum	% Black Box	% Red Gum/ Box	% Mixed box	% Lignum	% Agriculture/ horticulture
5			27	2	7	2
10	3		27	2	7	3
20	3		27	3	7	3
30	3		27	3	7	3
40	5		27	3	7	3
50	5		28	3	7	3
60	6		28	3	8	3
70	6		28	7	10	3
80	27		36	47	18	14
90	30		40	47	18	14

100	32		41	48	18	14
110	40		42	51	19	14
120	46		42	51	19	14
>120	100	100	100	100	100	100

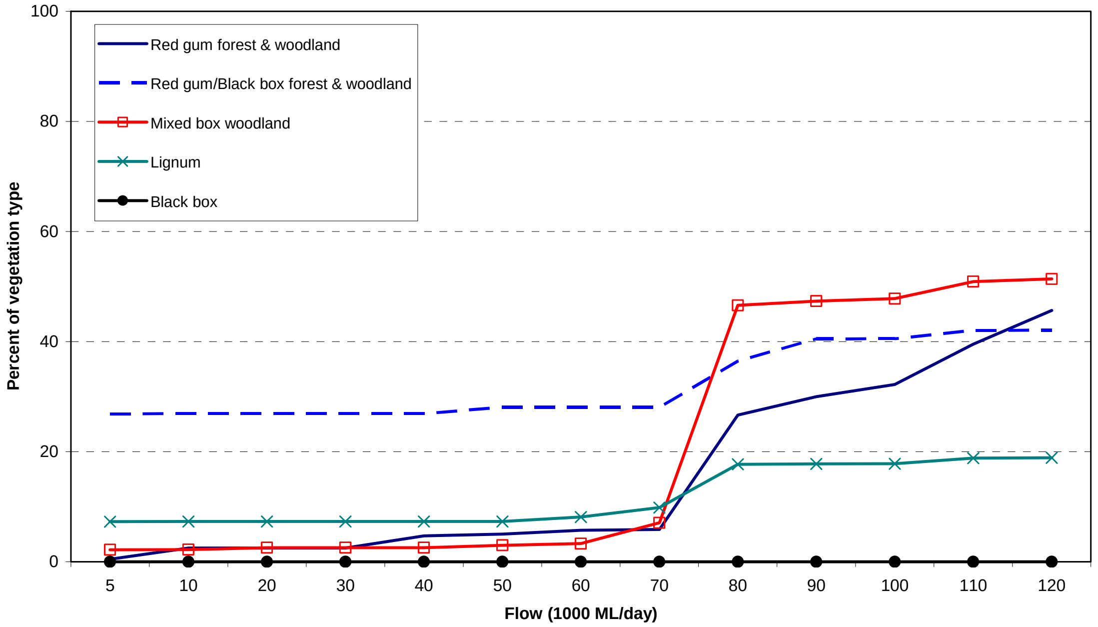


Figure 48. Zone 7 - Percentage of vegetation type inundated.

Zone 8

Description	Area (ha)	River km length	Travel time (days)
Downstream of Gunbower to Swan Hill	48599	80	1

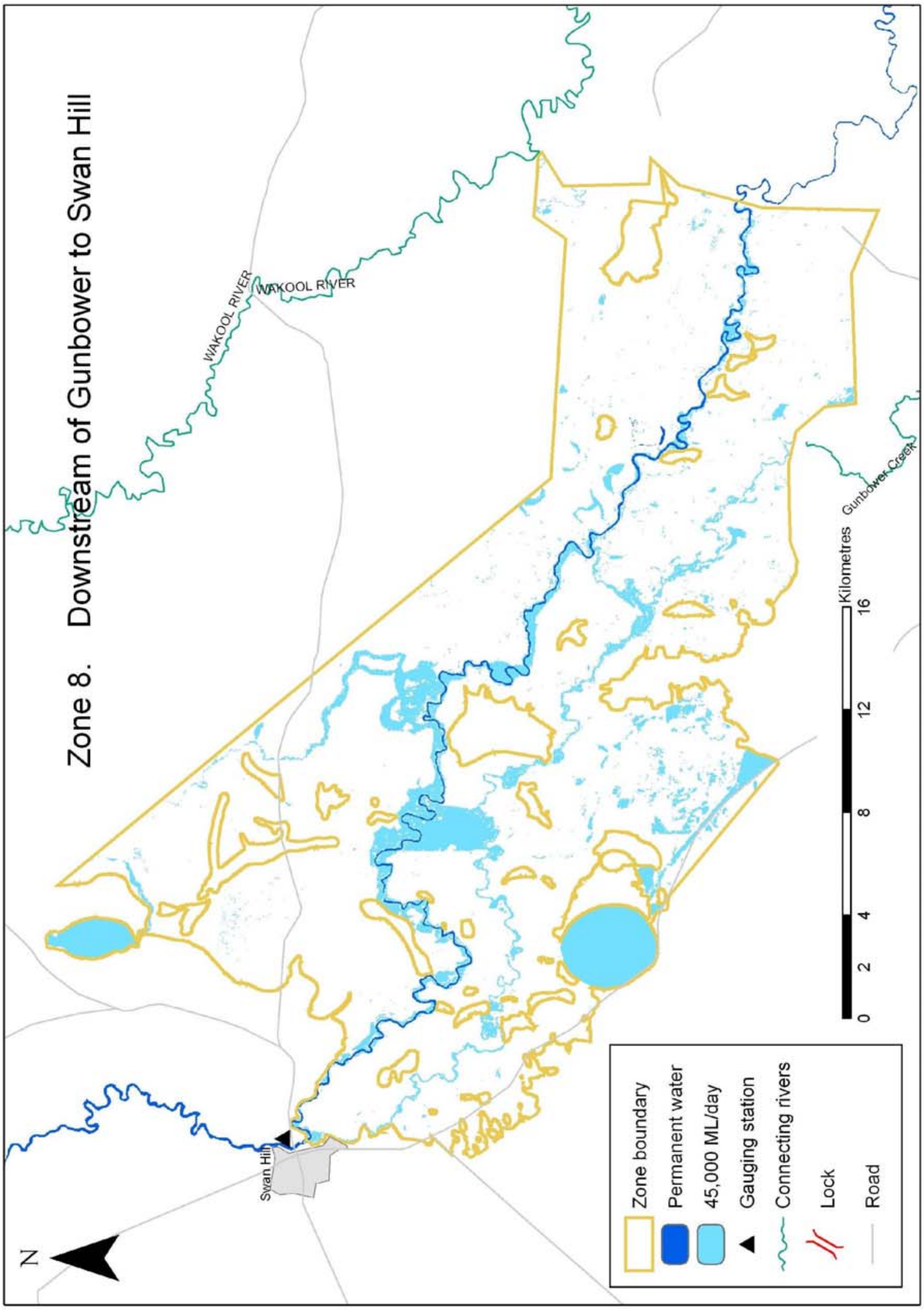


Figure 49. Zone 8 showing permanent water and maximum flood from satellite image.

Table 24. Zone 8 - Area of inundation at 10,000 ML/day flow increments.

Flow (1000 ML/day)	Cumulative Area of inundation (Hectares)	Cumulative area of inundation (%)
5	896	2
10	2265	5
20	2292	5
30	2666	5
40	3558	7
>40	48599	100

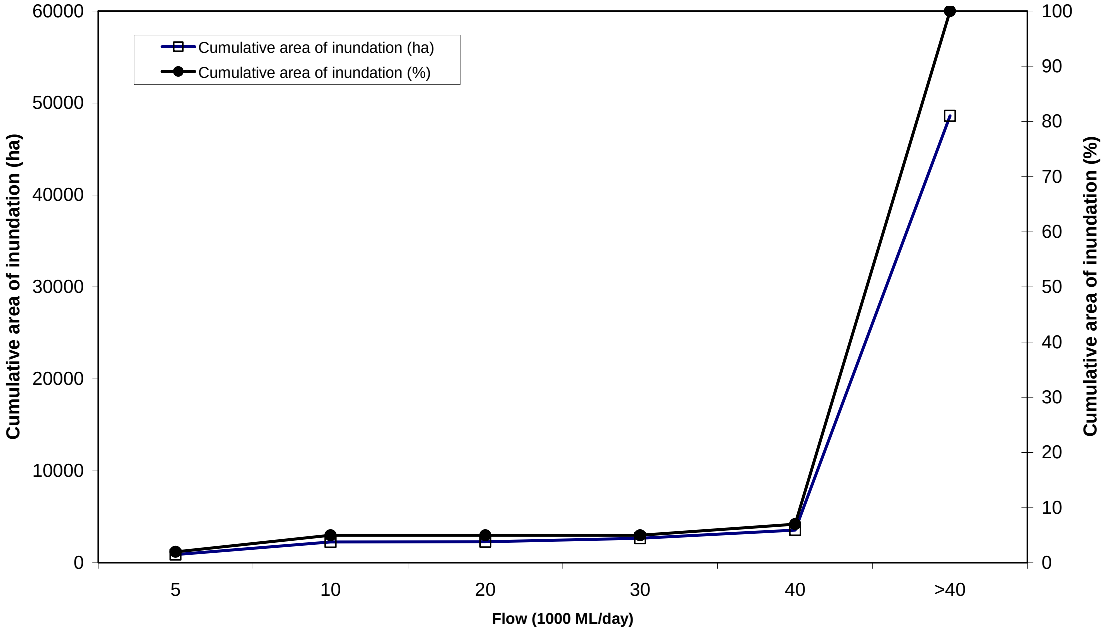


Figure 50. Zone 8 - Area of inundation.

Table 25. Zone 8 - Number of wetlands inundated and area of wetlands inundated at 10,000ML/day flow increments.

Flow (1000 ML/day)	Cumulative number of wetlands inundated	Cumulative number of wetlands inundated (%)	Cumulative area of wetland inundation (Hectares)	Cumulative area of wetland inundation (%)
5	23	17	850	24
10	39	29	2122	61
20	41	31	2130	61
30	54	41	2191	63
40	66	50	2248	64
50	84	63	2413	69
>50	133	100	3487	100

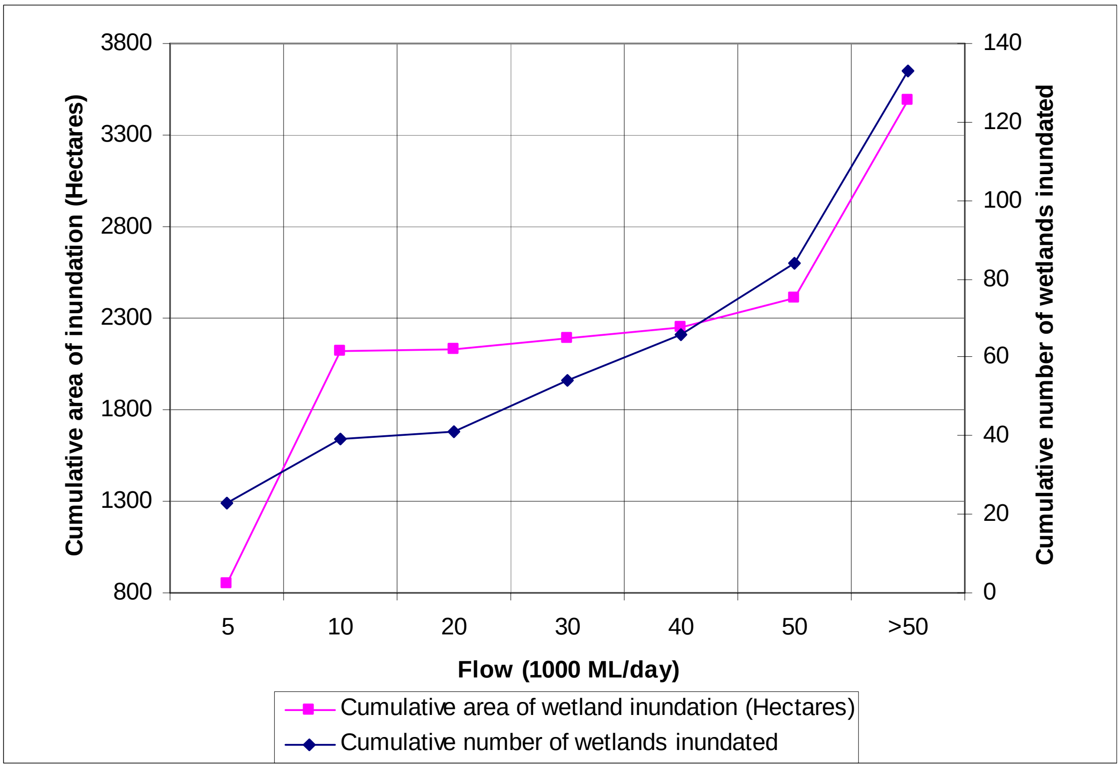


Figure 51. Zone 8 - Wetland inundation statistics.

Table 26. Zone 8 - Percentage of vegetation type inundated at 10,000 ML/day flow increments.

Flow (1000 ML/day)	% Red Gum	% Black Box	% Red Gum/ Box	% Mixed box	% Lignum	% Agriculture/ horticulture
5	4		2	1	1	
10	6		2	1	1	1
20	6		2	1	1	1
30	12		3	1	1	1
40	17	1	9	1	13	2
>40	100	100	100	100	100	100

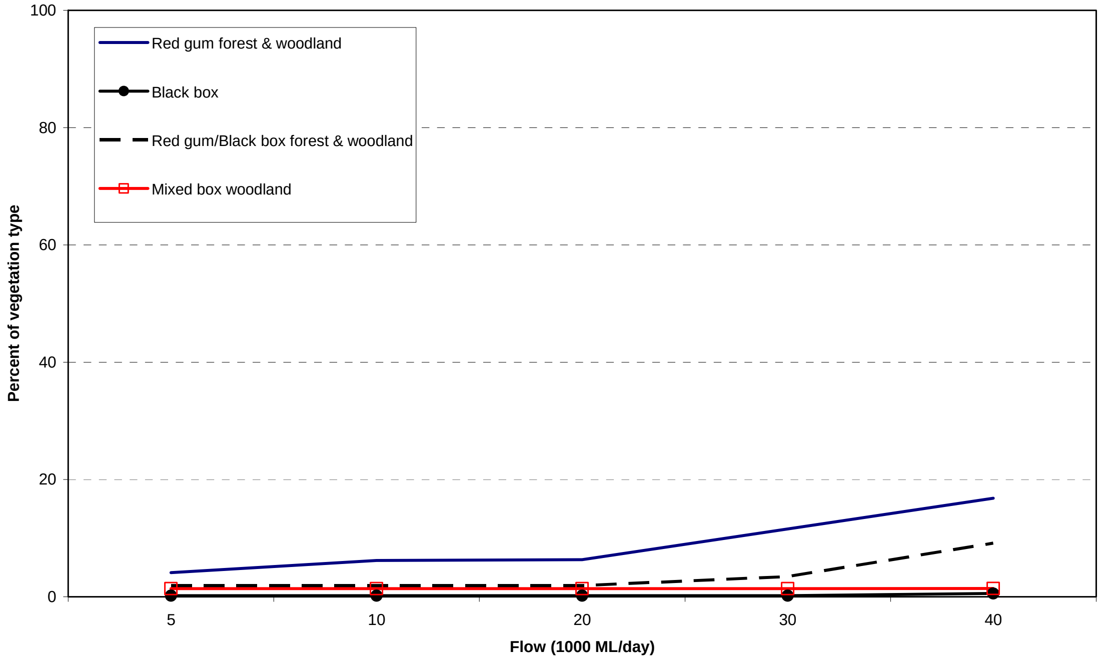


Figure 52. Zone 8 - Percentage of vegetation type inundated.

Zone 9

Description	Area (ha)	River km length	Travel time (days)
Swan Hill to Murray/Wakool junction	27440	120	1.5

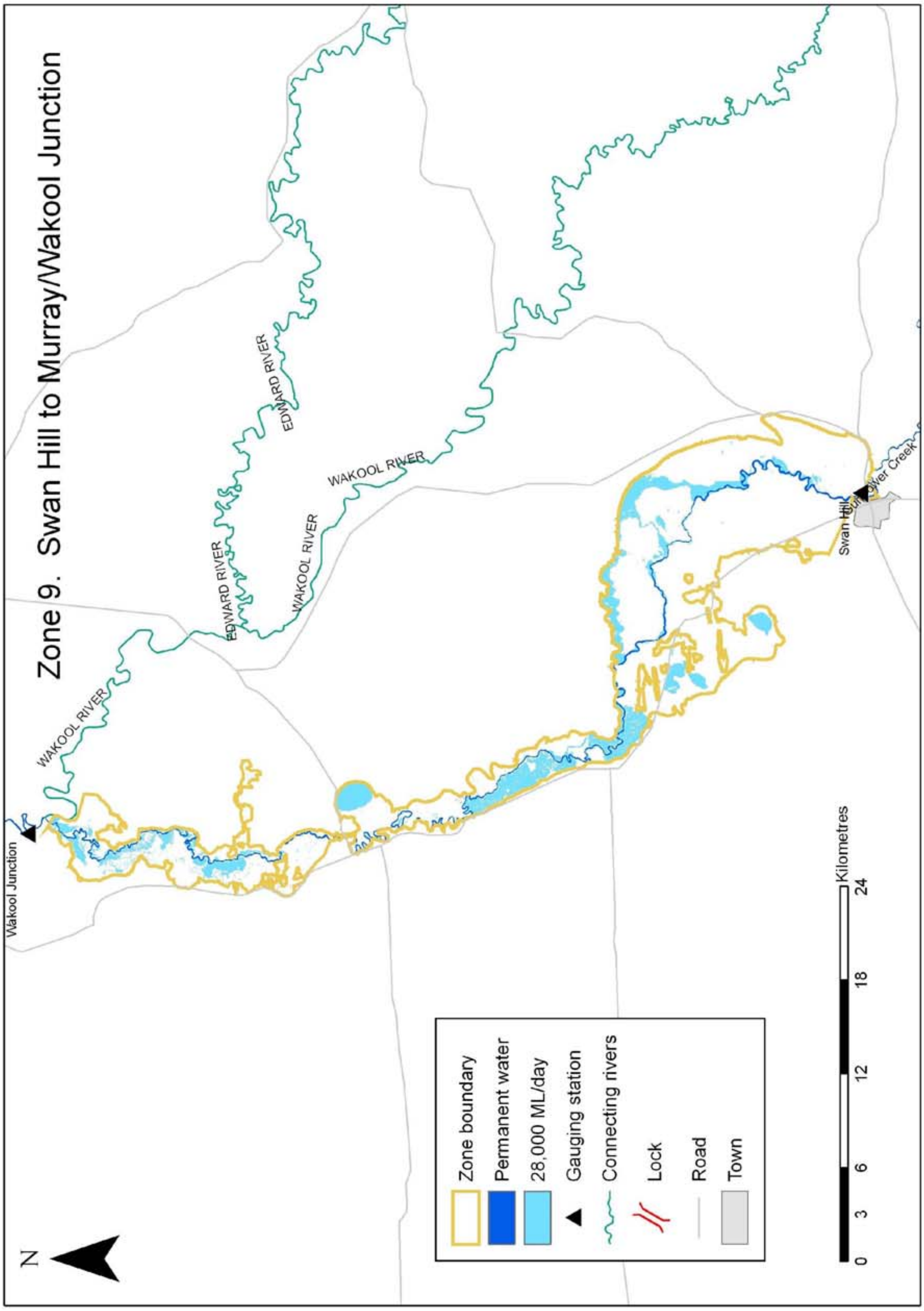


Figure 53. Zone 9 showing permanent water and maximum flood from satellite image.

Table 27. Zone 9 - Area of inundation at 10,000 ML/day flow increments.

Flow (1000 ML/day)	Cumulative area of inundation (Hectares)	Cumulative area of inundation (%)
5	932	3
10	1290	5
20	2145	8
>20	27440	100

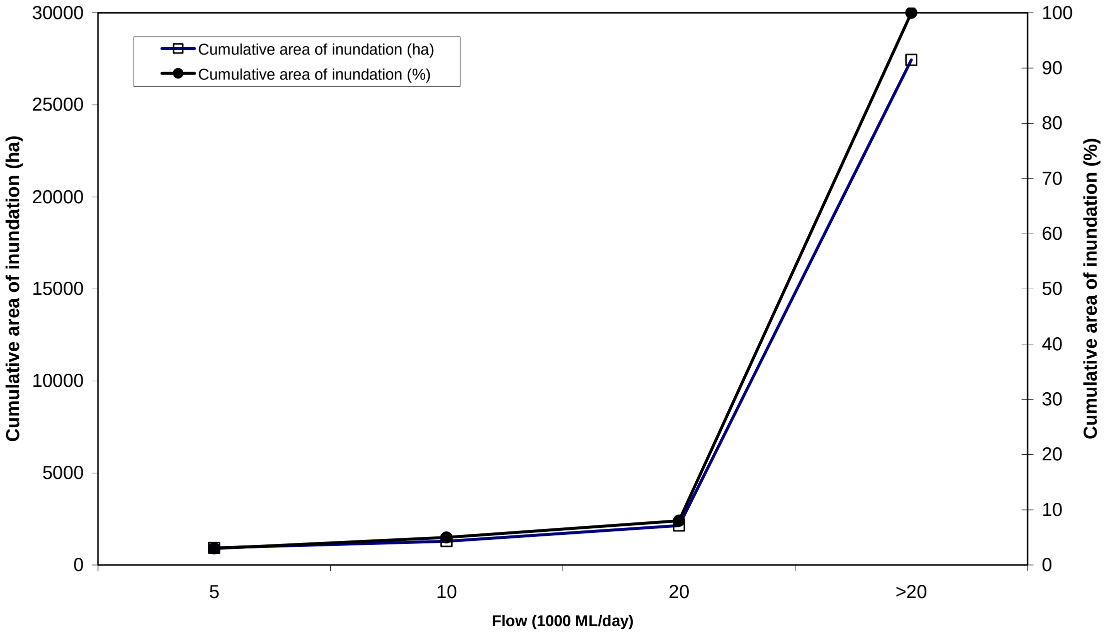


Figure 54. Zone 9 - Area of inundation.

Table 28. Zone 9 - Number of wetlands inundated and area of wetlands inundated at 10,000ML/day flow increments.

Flow (1000 ML/day)	Cumulative number of wetlands inundated	Cumulative number of wetlands inundated (%)	Cumulative area of wetland inundation (Hectares)	Cumulative area of wetland inundation (%)
5	16	14	859	37
10	31	27	1171	50
20	76	67	1483	64
30	85	75	1865	80
>30	114	100	2322	100

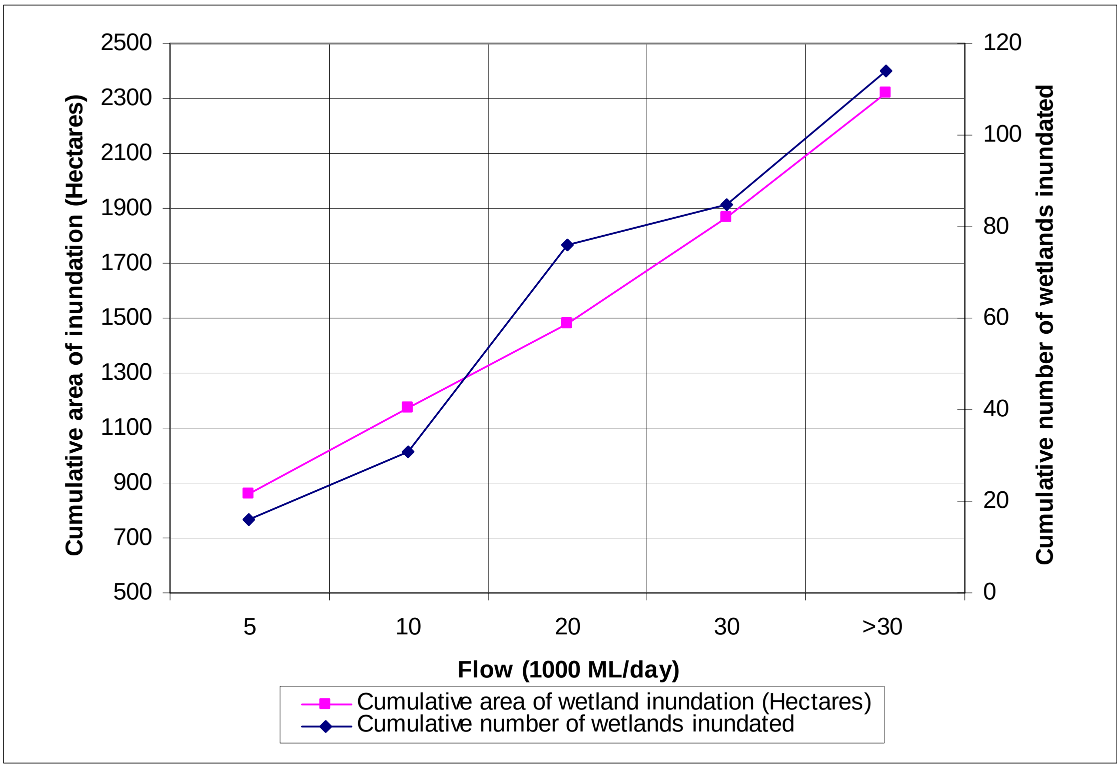


Figure 55. Zone 9 - Wetland inundation statistics.

Table 29. Zone 9 - Percentage of vegetation type inundated at 10,000 ML/day flow increments.

Flow (1000 ML/day)	% Red Gum	% Black Box	% Red Gum/Box	% Mixed box	% Agriculture/ horticulture
5	5	1	2		
10	5	1	2		
20	14	2	4	7	2
>20	100	100	100	100	100

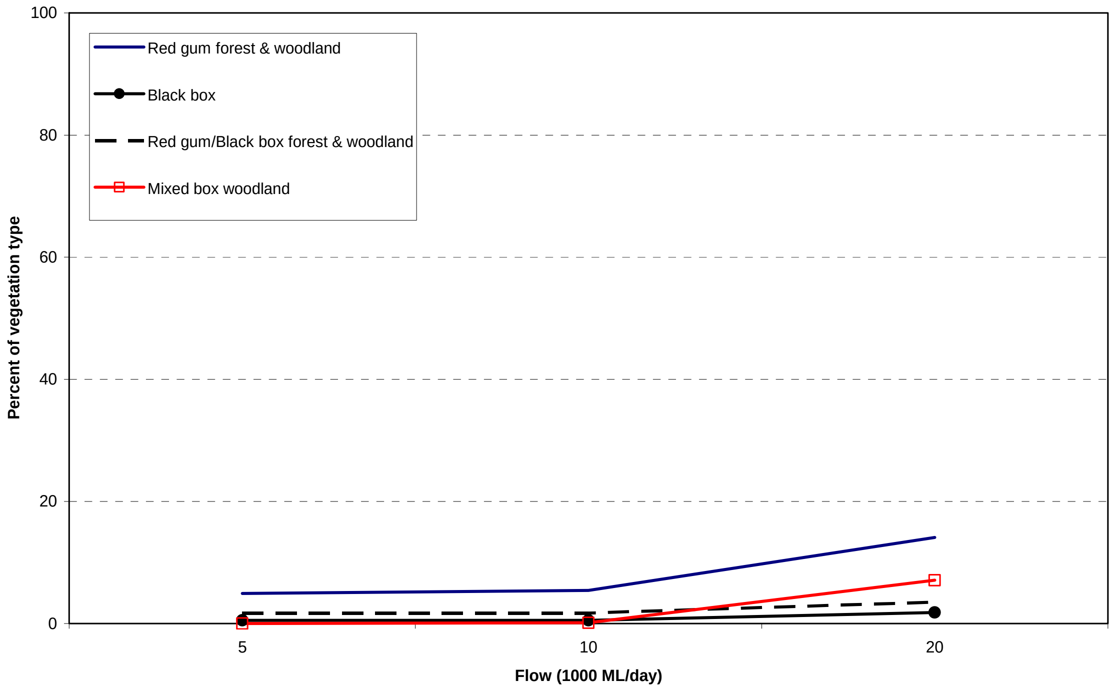


Figure 56. Zone 9 - Percentage of vegetation type inundated

Zone 10

Description	Area (ha)	River km length	Travel time (days)
Murray/Wakool junction to Murray/ Murrumbidgee junction	10062	47	0.5

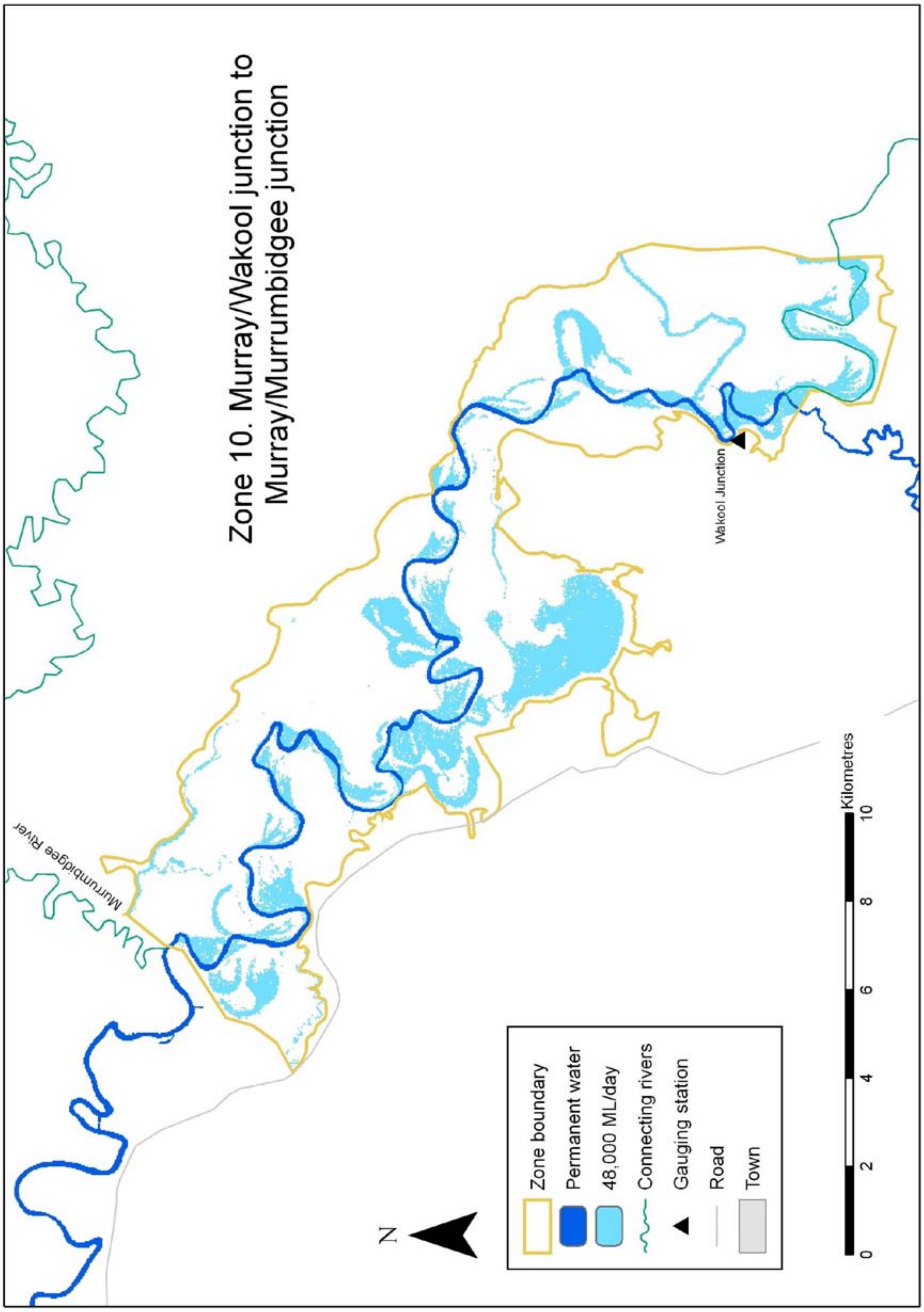


Figure 57. Zone 10 showing permanent water and maximum flood from satellite image.

Table 30. Zone 10 - Area of inundation at 10,000 ML/day flow increments.

Flow (1000 ML/day)	Cumulative area of inundation (Hectares)	Cumulative area of inundation (%)
5	479	5
10	490	5
20	628	6
30	983	10
40	1227	12
>40	10062	100

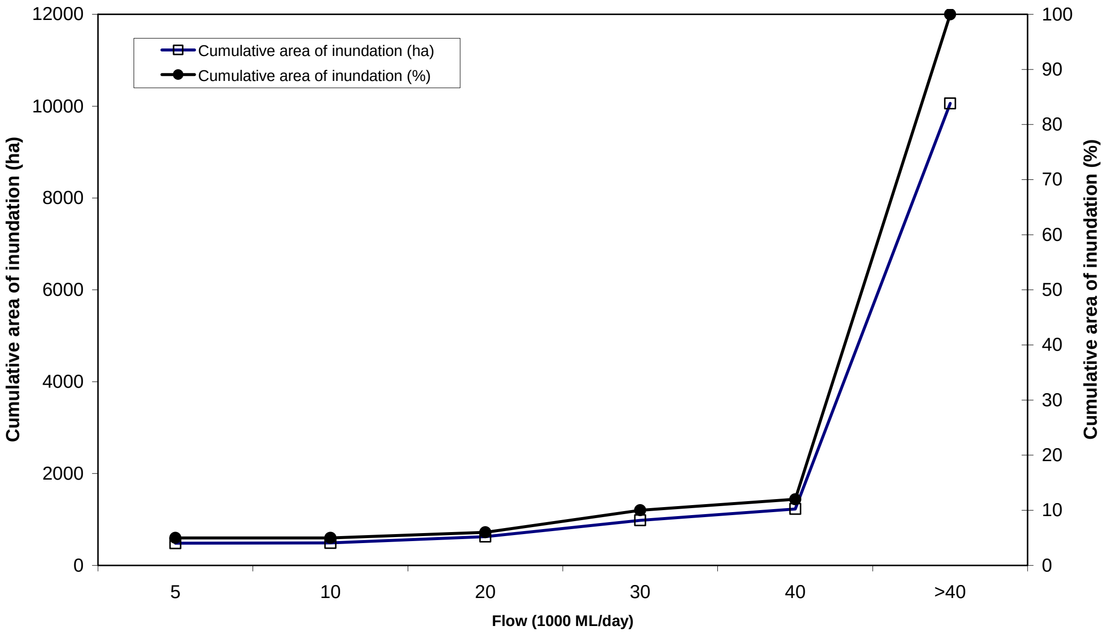


Figure 58. Zone 10 - Area of inundation

Table 31. Zone 10 - Number of wetlands inundated and area of wetlands inundated at 10,000ML/day flow increments.

Flow (1000 ML/day)	Cumulative number of wetlands inundated	Cumulative number of wetlands inundated (%)	Cumulative area of wetland inundation (Hectares)	Cumulative area of wetland inundation (%)
5	15	13	449	35
10	15	13	458	36
20	22	19	572	44
30	40	35	676	53
40	42	37	700	54
50	53	46	798	62
>50	114	100	1287	100

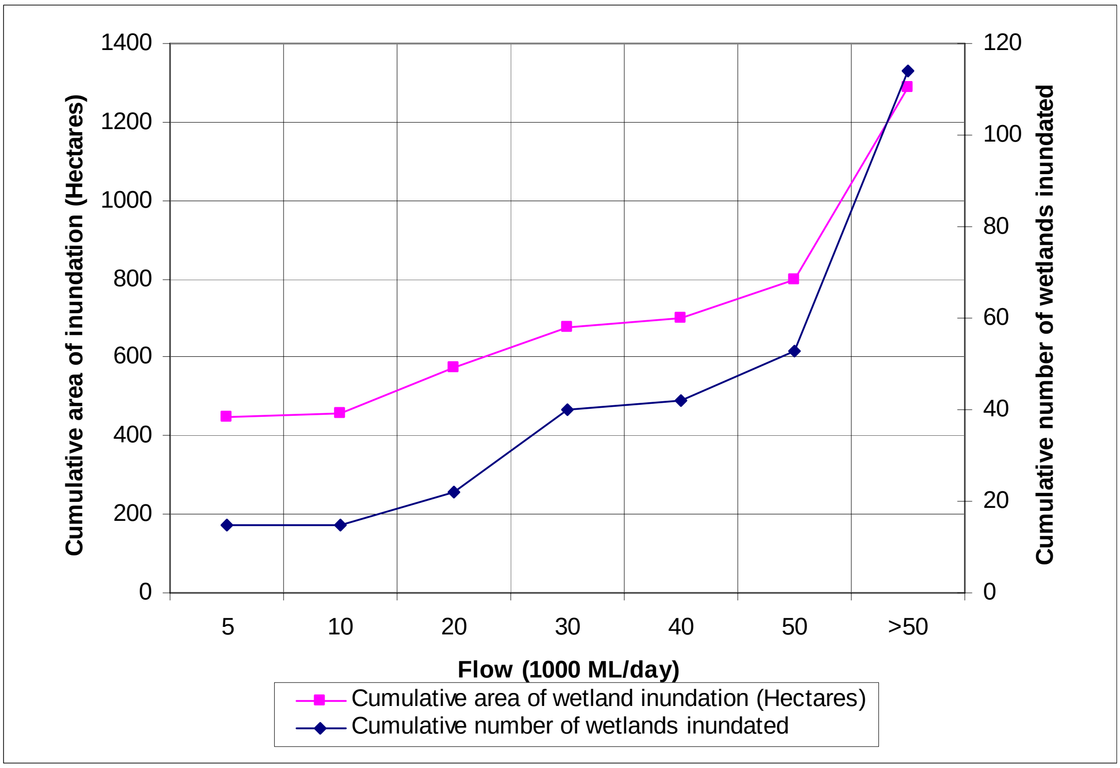


Figure 59. Zone 10 - Wetland inundation statistics.

Table 32. Zone 10 - Percentage of vegetation type inundated at 10,000 ML/day flow increments.

Flow (1000 ML/day)	% Red Gum	% Black Box	% Red Gum/ Box	% Mixed box
5	5	1		2
10	5	1		2
20	6	1	1	2
30	14	3	2	2
40	22	5	4	2
>40	100	100	100	100

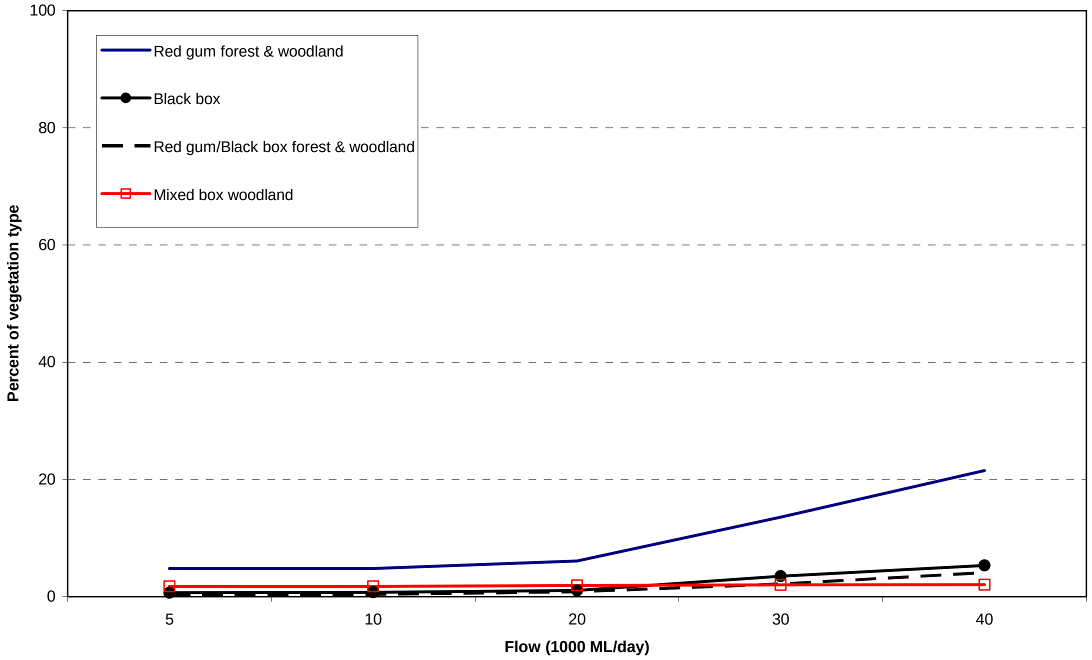


Figure 60. Zone 10 - Percentage of vegetation type inundated.

Zone 11

Description	Area (ha)	River km length	Travel time (days)
Murray/ Murrumbidgee junction to Lock 15 (Euston weir)	48232	118	2

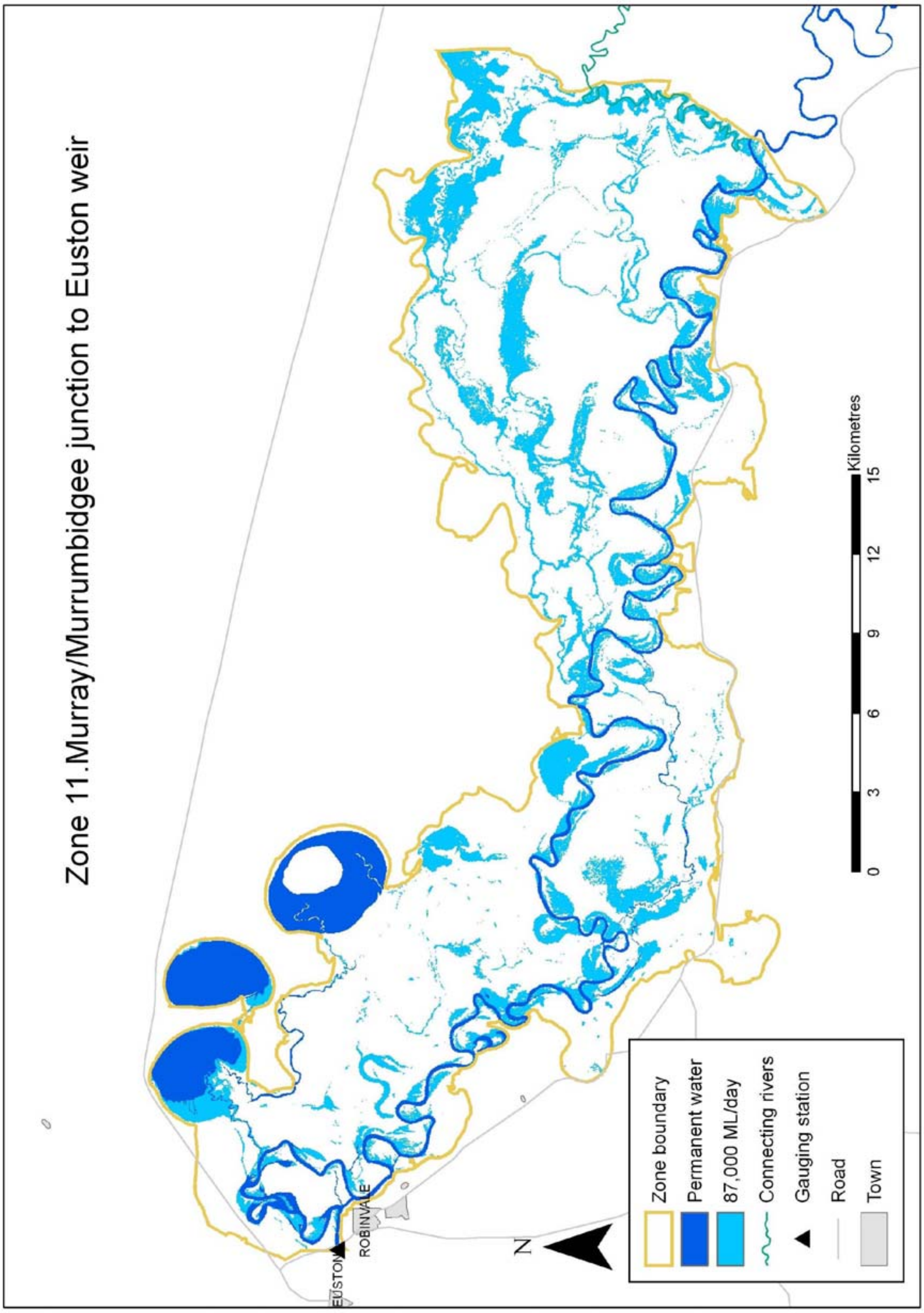


Figure 61. Zone 11 showing permanent water and maximum flood from satellite image.

Table 33. Zone 11 - Area of inundation at 10,000 ML/day flow increments.

Flow (1000 ML/day)	Cumulative area of inundation (Hectares)	Cumulative area of inundation (%)
5	4159	9
10	4182	9
20	4246	9
30	4417	9
40	4670	10
50	4880	10
60	4927	10
70	4975	10
80	7310	15
>80	48232	100

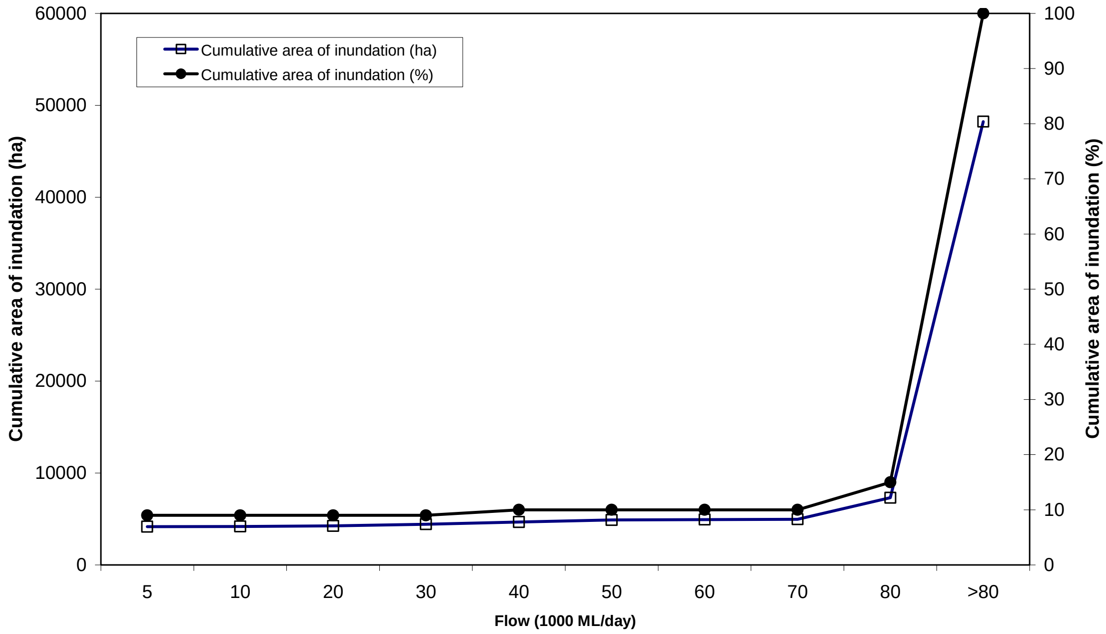


Figure 62. Zone 11 – Area of inundation.

Table 34. Zone 11 - Number of wetlands inundated and area of wetlands inundated at 10,000ML/day flow increments.

Flow (1000 ML/day)	Cumulative number of wetlands inundated	Cumulative number of wetlands inundated (%)	Cumulative area of wetland inundation (Hectares)	Cumulative area of wetland inundation (%)
5	58	17	4040	62
10	58	17	4060	62
20	66	20	4105	63
30	104	31	4207	64
40	114	34	4441	68
50	126	38	4483	69
60	146	44	4524	69
70	146	44	4559	70
80	222	66	5173	79

90	241	72	5324	82
>90	334	100	6528	100

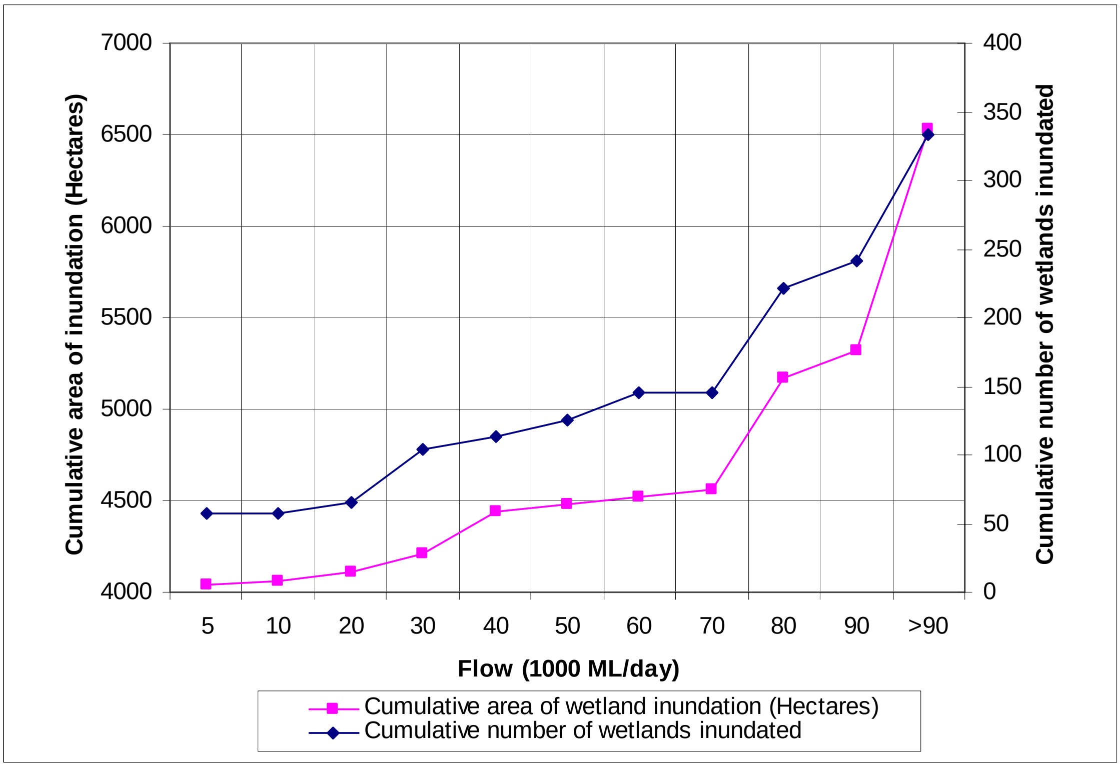


Figure 63. Zone 11 - Wetland inundation statistics.

Table 35. Zone 11 - Percentage of vegetation type inundated at 10,000 ML/day flow increments.

Flow (1000 ML/day)	% Red Gum	% Black Box	% Red Gum/ Box	% Lignum	% Agriculture/ horticulture
5	11	1	2	4	2
10	11	1	2	4	2
20	11	1	2	4	2
30	12	1	2	4	2
40	13	1	3	4	2
50	15	1	3	4	2
60	15	1	4	4	2
70	15	1	4	4	2
80	23	4	11	9	3
>80	100	100	100	100	100

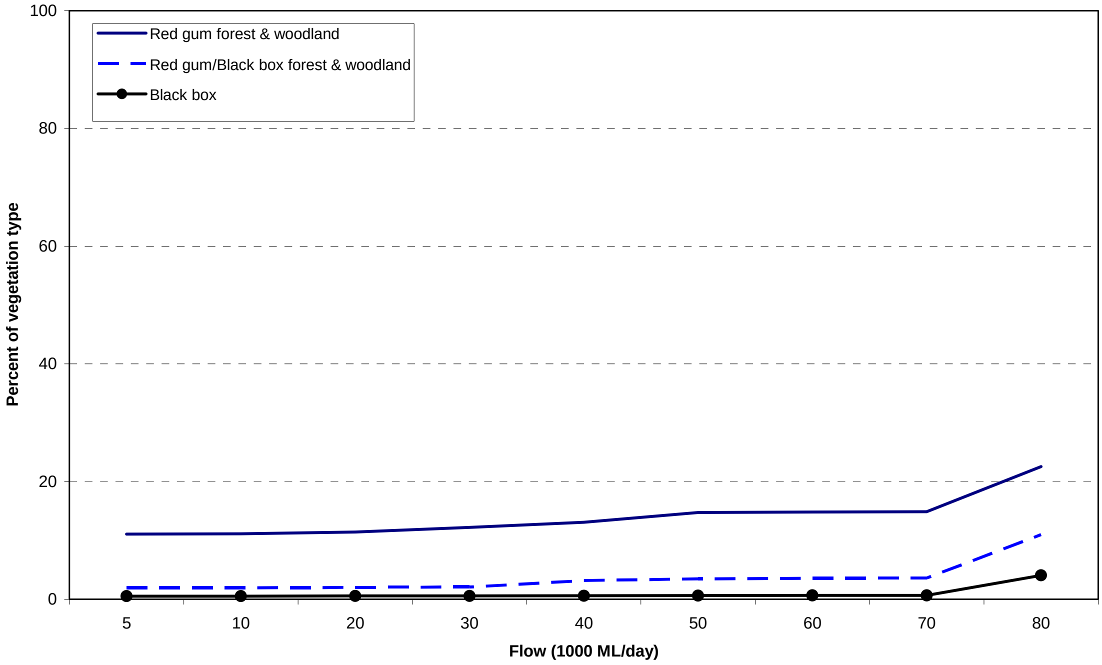


Figure 64. Zone 11 - Percentage of vegetation type inundated.

Zone 12

Description	Area (ha)	River km length	Travel time (days)
Lock 15 to Lock 10 (Wentworth weir)	91781	287	5

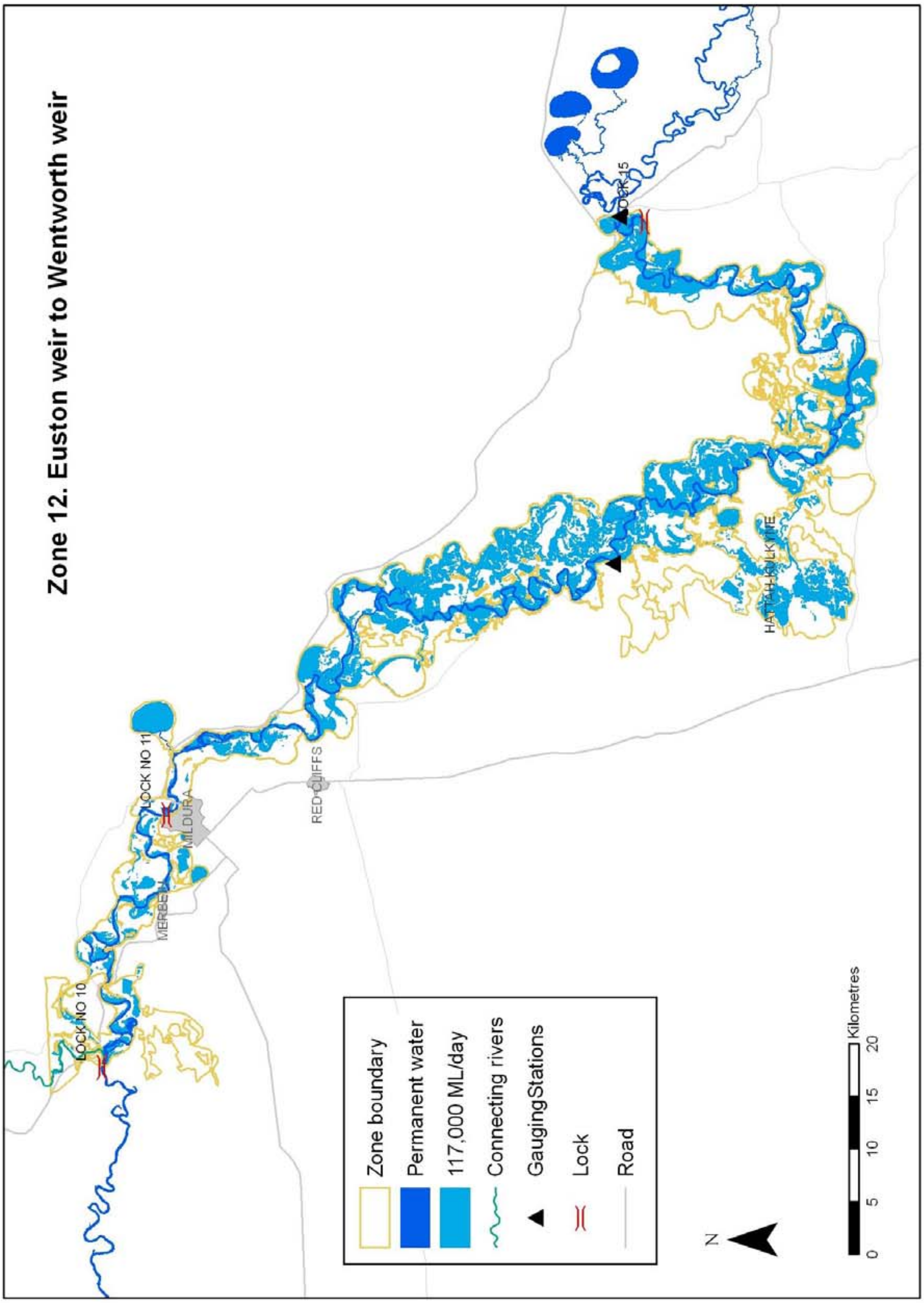


Figure 65. Zone 12 showing permanent water and maximum flood from satellite image.

Table 36. Zone 12 - Area of inundation at 10,000 ML/day flow increments.

Flow (1000 ML/day)	Cumulative area of inundation (Hectares)	Cumulative area of inundation (%)
5	5429	6
10	5564	6
20	6870	7
30	6973	8
40	8167	9
50	8411	9
60	10709	12
70	13324	15
80	16171	18
90	23910	26
100	28557	31
110	31198	34
>110	91781	100

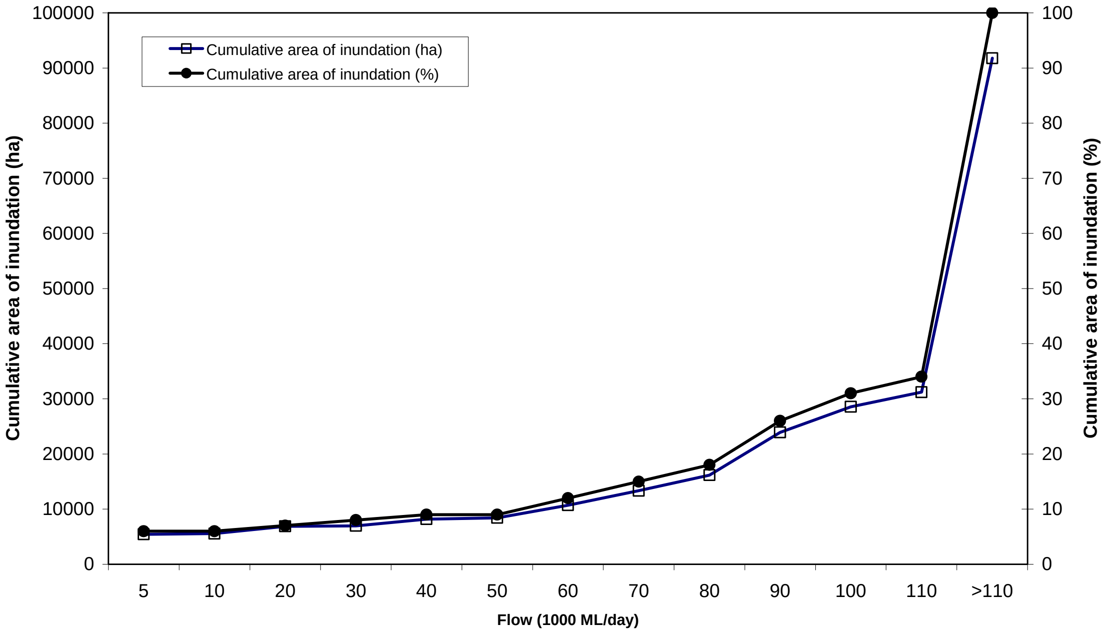


Figure 66. Zone 12 – Area of inundation.

Table 37. Zone 12 - Number of wetlands inundated and area of wetlands inundated at 10,000ML/day flow increments.

Flow (1000 ML/day)	Cumulative number of wetlands inundated	Cumulative number of wetlands inundated (%)	Cumulative area of wetland inundation (Hectares)	Cumulative area of wetland inundation (%)
5	64	9	5226	35
10	68	9	5341	36
20	139	19	6415	43
30	139	19	6426	43
40	182	25	7228	49
50	183	25	7244	49

60	242	34	7899	53
70	250	35	8465	57
80	316	44	9673	65
90	463	64	10922	74
100	481	67	11244	76
110	492	68	11344	76
120	563	78	11913	80
>120	722	100	14842	100

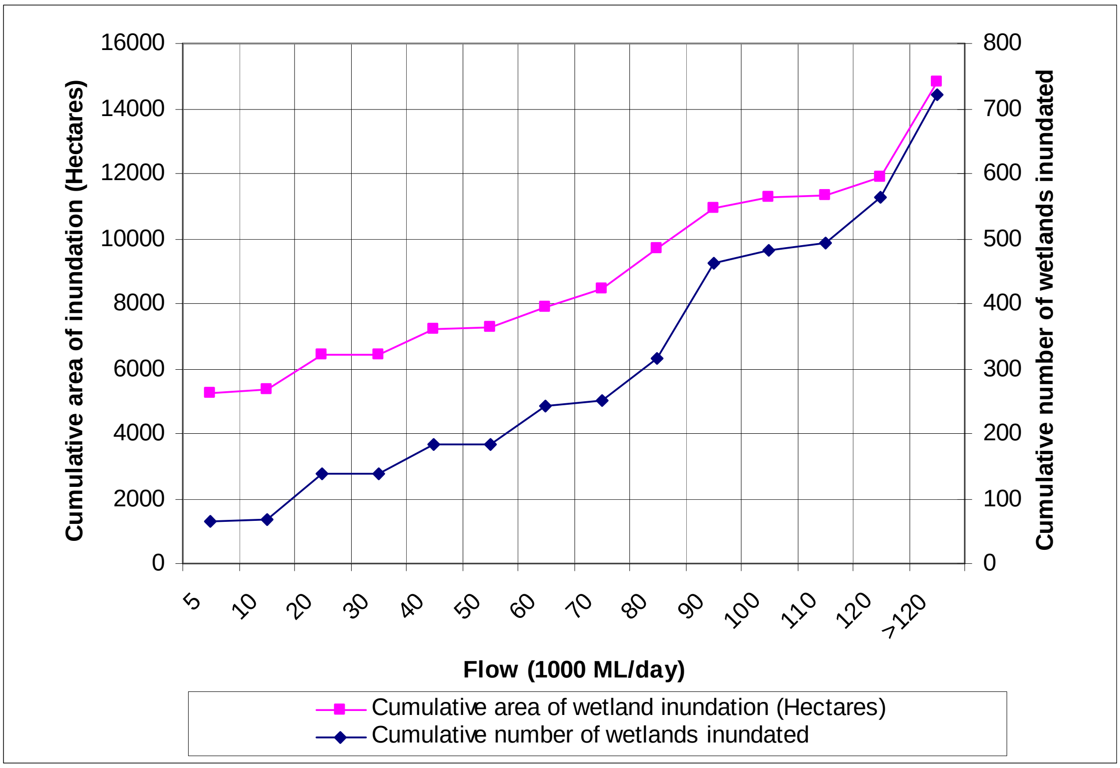


Figure 67. Zone 12 - Wetland inundation statistics.

Table 38. Zone 12 - Percentage of vegetation type inundated at 10,000 ML/day flow increments.

Flow (1000 ML/day)	% Red Gum	% Black Box	% Red Gum/ Box	% Cooba	% Saline shrubland	% Lignum	% Agriculture/ horticulture
5	5	1	2			24	1
10	6	1	2			24	1
20	7	1	2			24	1
30	7	1	2			24	1
40	10	2	3			24	1
50	11	2	3			24	1
60	18	3	7		1	28	1
70	27	4	12		1	38	1
80	33	6	17	2	1	49	2
90	49	13	32	23	1	63	4
100	56	20	40	24	1	67	6

110	58	25	42	44	1	69	8
>110	100	100	100	100	100	100	100

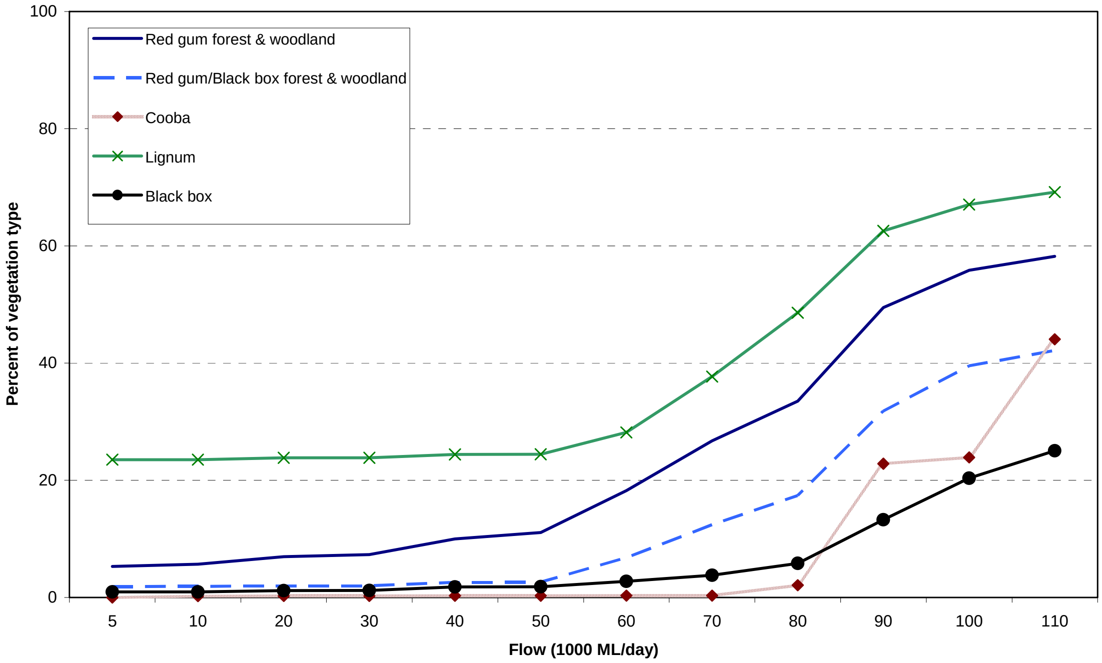


Figure 68. Zone 12 - Percentage of vegetation type inundated.

Zone 13

Description	Area (ha)	River km length	Travel time (days)
Lock 10 to Lock 9	33499	60	1

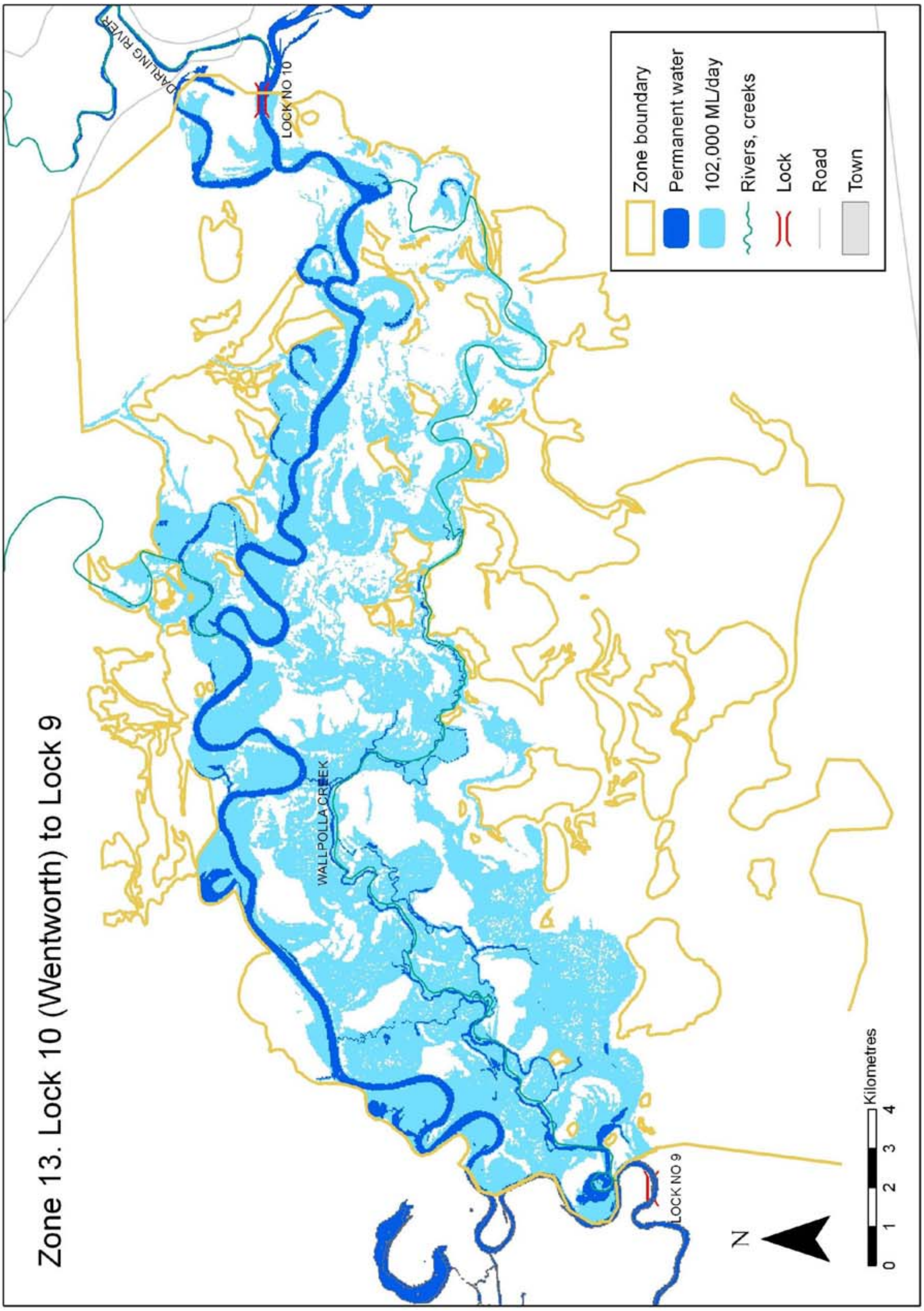


Figure 69. Zone 13 showing permanent water and maximum flood from satellite image.

Table 39. Zone 13 - Area of inundation at 10,000 ML/day flow increment.

Flow (1000 ML/day)	Cumulative area of inundation (Hectares)	Cumulative area of inundation (%)
6	1637	5
10	1637	5
20	1640	5
30	1681	5
40	2033	6
50	2274	7
60	2367	7
70	3816	11
80	6346	19
90	8571	26
100	9840	29
>100	33499	100

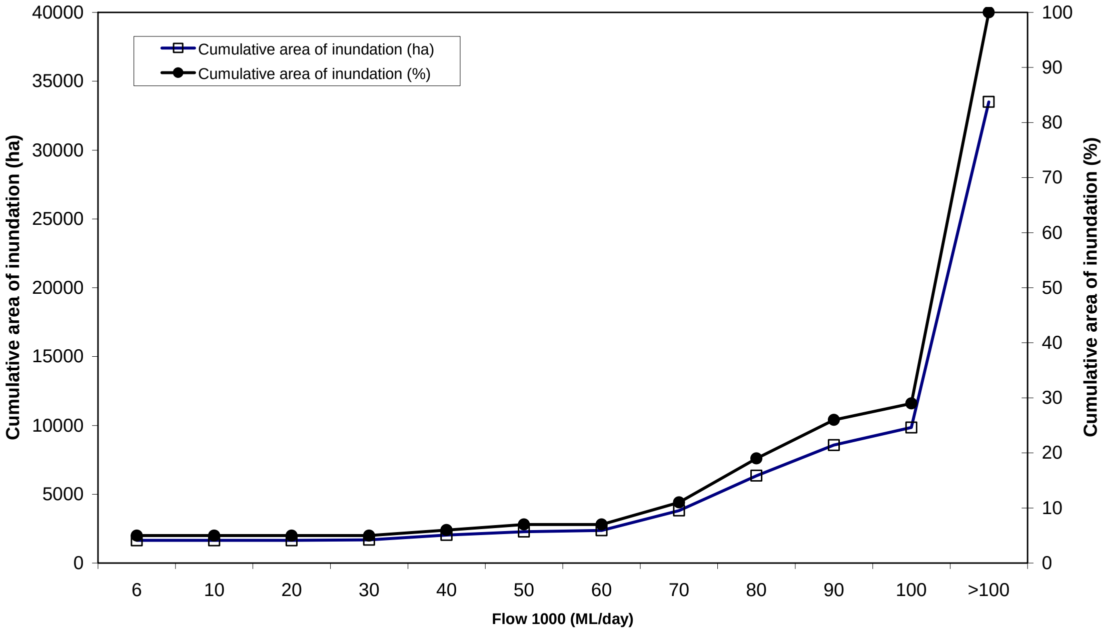


Figure 70. Zone 13 – Area of inundation.

Table 40. Zone 13 - Number of wetlands inundated and area of wetlands inundated at 10,000ML/day flow increments.

Flow (1000 ML/day)	Cumulative number of wetlands inundated	Cumulative number of wetlands inundated (%)	Cumulative area of wetland inundation (Hectares)	Cumulative area of wetland inundation (%)
5	0	0	0	0
10	85	21	1483	30
20	85	21	1485	30
30	89	22	1508	30
40	103	26	1612	32
50	132	33	1723	34
60	135	34	1742	35
70	194	49	2119	42

80	236	60	2732	55
90	255	64	3014	60
100	289	73	3168	63
110	304	77	3501	70
>110	396	100	5007	100

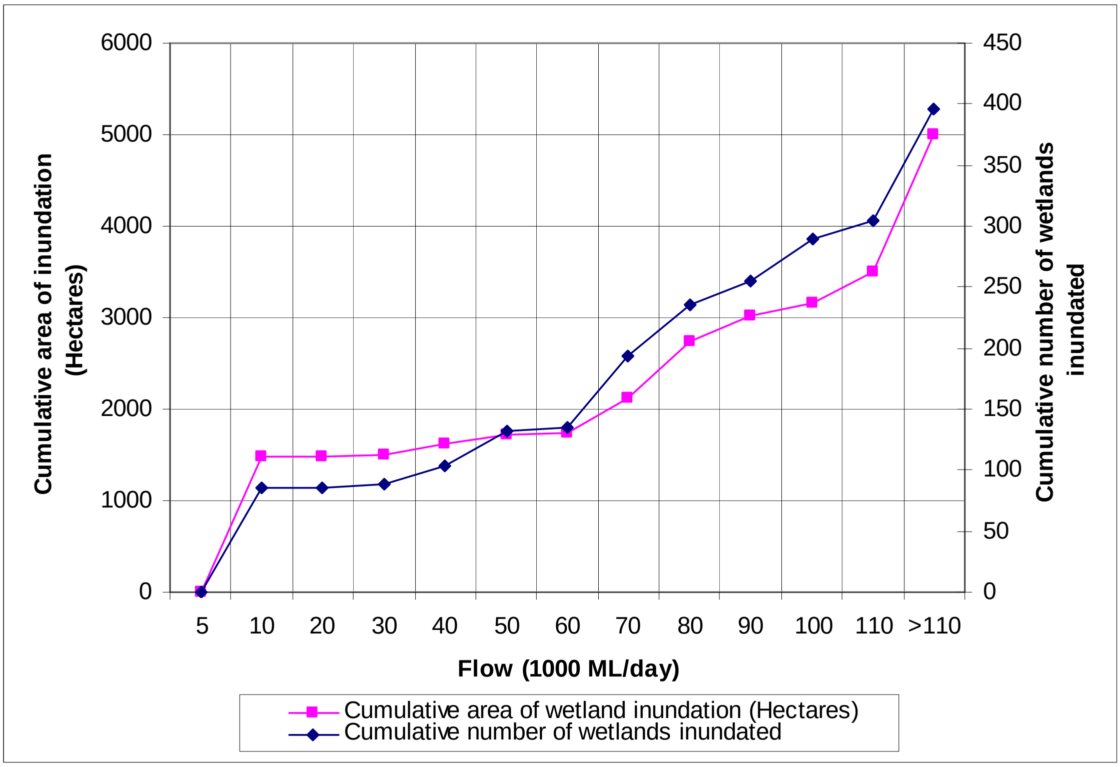


Figure 71. Zone 13 - Wetland inundation statistics.

Table 41. Zone 13 - Percentage of vegetation type inundated at 10,000 ML/day flow increments.

Flow (1000 ML/day)	% Red Gum	% Black Box	% Red Gum/ Box	% Cooba	% Saline shrubland	% Lignum	% Agriculture/ horticulture
6	21	2	10		1	4	4
10	21	2	10		1	4	4
20	21	2	10		1	4	4
30	21	2	10		1	5	4
40	25	3	13		1	6	4
50	28	3	14		1	8	5
60	30	3	15		1	9	5
70	50	6	29		1	21	8
80	63	11	45		2	39	13
90	75	17	56	1	3	61	20
100	77	24	57	28	5	66	21
>100	100	100	100	100	100	100	100

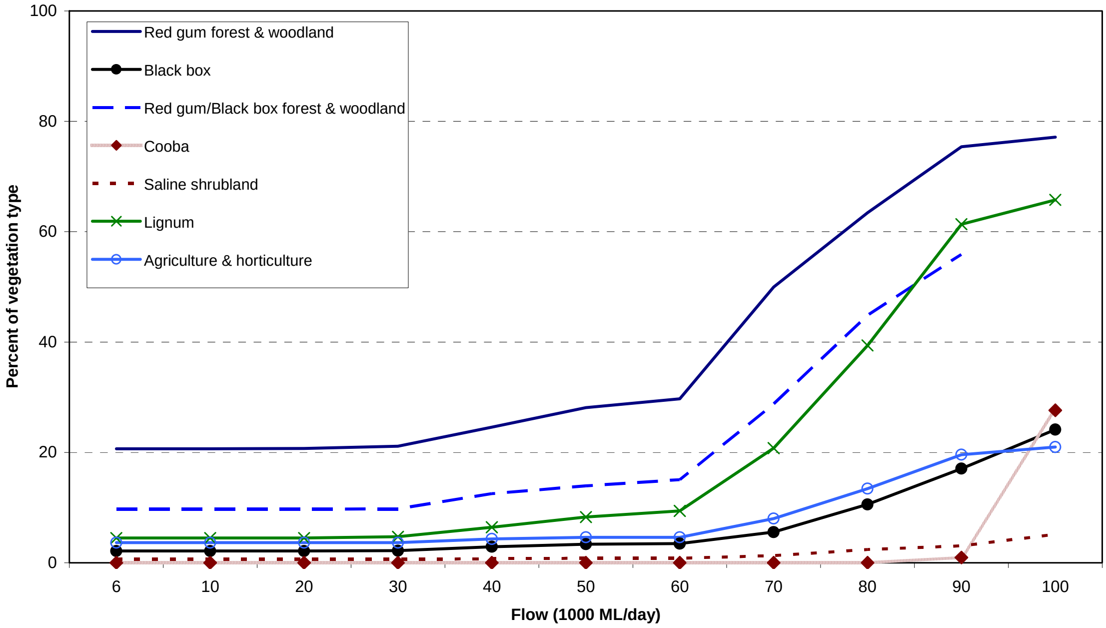


Figure 72. Zone 13 - Percentage of vegetation type inundated.

Zone 14

Description	Area (ha)	River km length	Travel time (days)
Lock 9 to Lock 8	22627	41	0.5

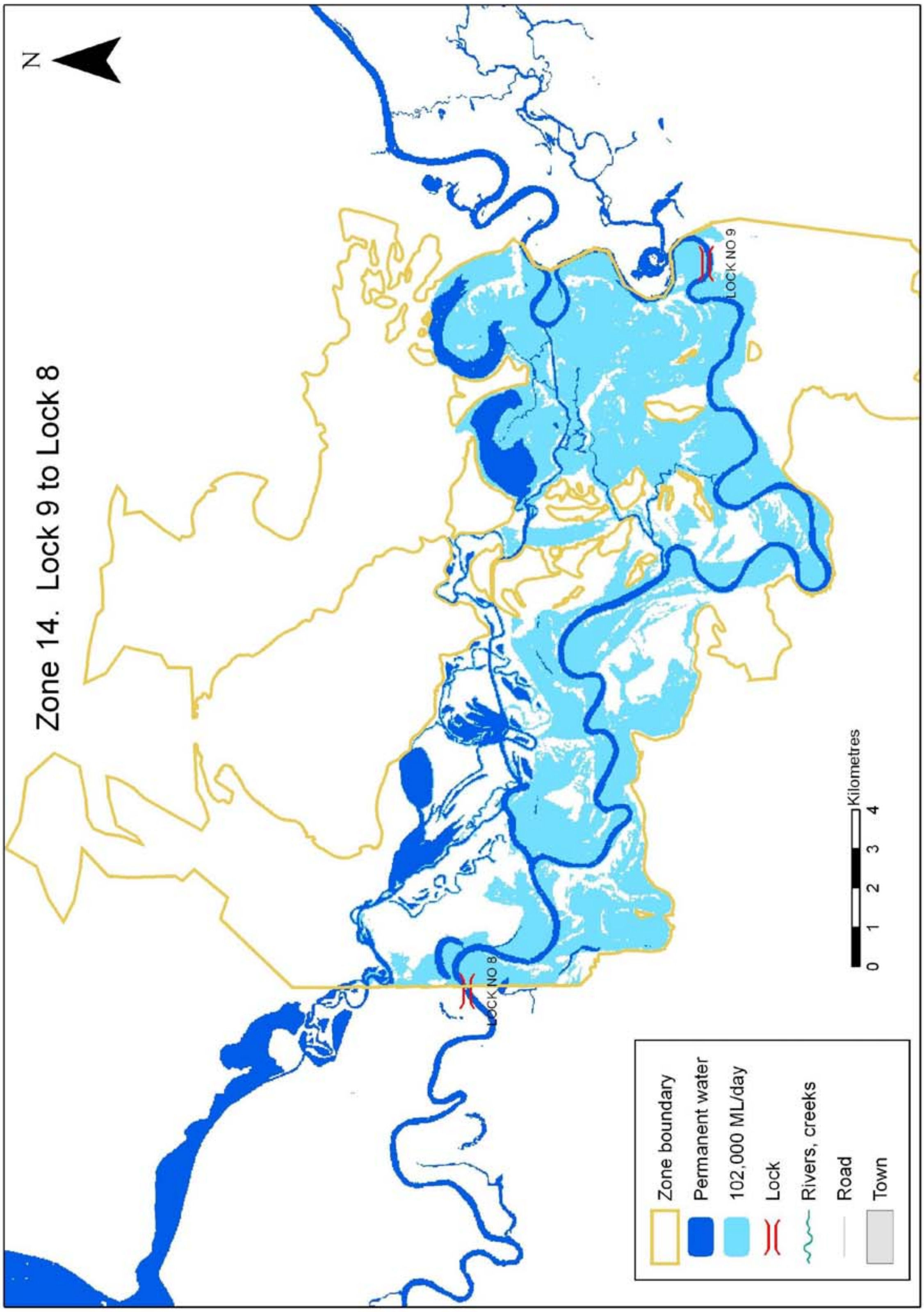


Figure 73. Zone 14 showing permanent water and maximum flood from satellite image.

Table 42. Zone 14 - Area of inundation at 10,000 ML/day flow increment.

Flow (1000 ML/day)	Cumulative area of inundation (Hectares)	Cumulative area of inundation (%)
6	2009	9
10	2012	9
20	2038	9
30	2308	10
40	2310	10
50	2425	11
60	3022	13
70	5311	23
80	5829	26
90	7546	33
100	7907	35
>100	22627	100

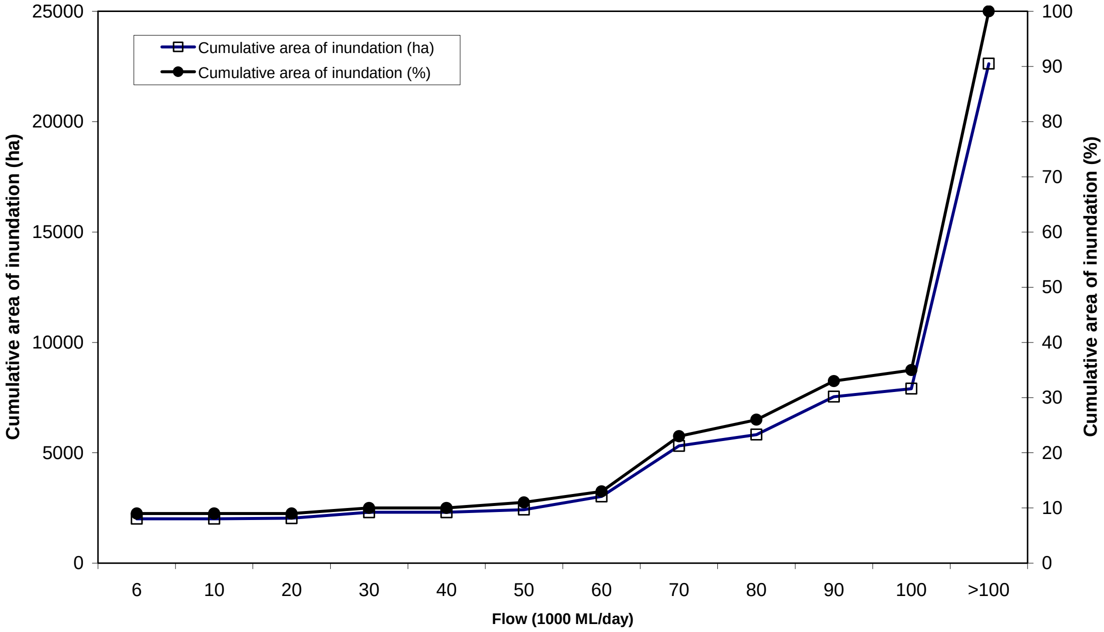


Figure 74. Zone 14 – Area of inundation.

Table 43. Zone 14 - Number of wetlands inundated and area of wetlands inundated at 10,000ML/day flow increments.

Flow (1000 ML/day)	Cumulative number of wetlands inundated	Cumulative number of wetlands inundated (%)	Cumulative area of wetland inundation (Hectares)	Cumulative area of wetland inundation (%)
5	0	0	0	0
10	104	56	1839	71
20	104	56	1849	71
30	109	59	1935	75
40	110	59	1935	75
50	127	68	1973	76
60	139	75	2070	80

70	164	88	2283	88
80	166	89	2334	90
90	173	93	2413	93
100	176	95	2439	94
110	177	95	2497	96
>110	186	100	2592	100

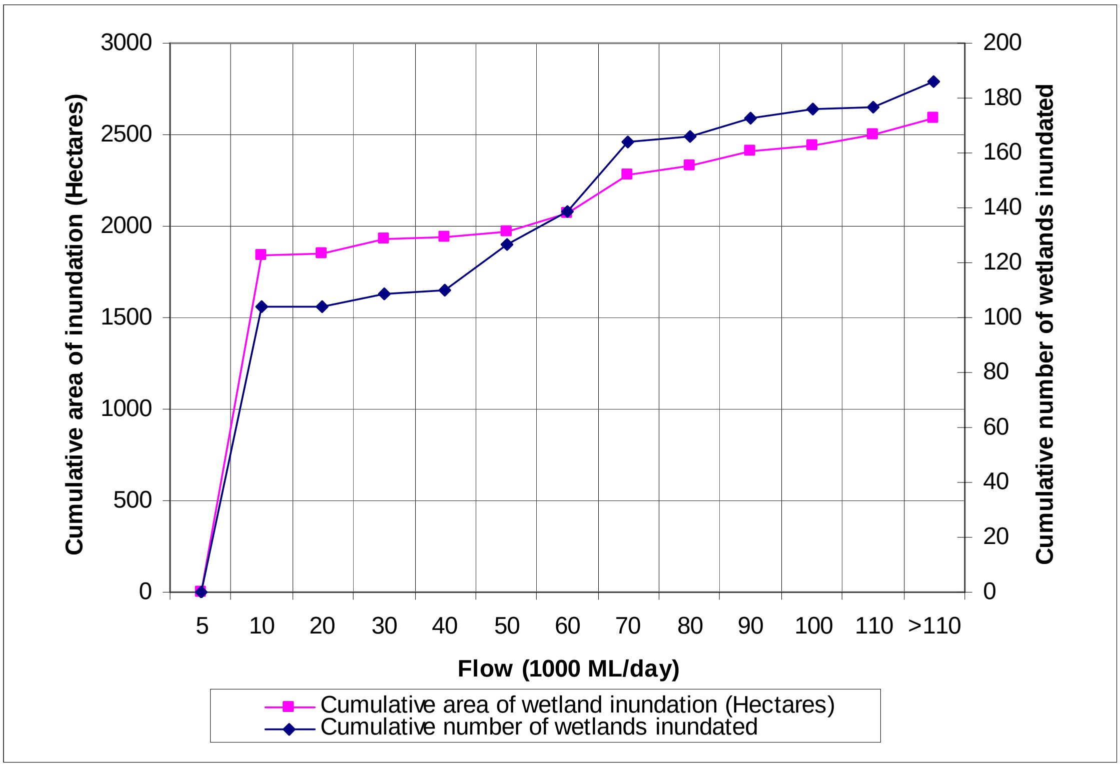


Figure 75. Zone 14 - Wetland inundation statistics.

Table 44. Zone 14 - Percentage of vegetation type inundated at 10,000 ML/day flow increments.

Flow (1000 ML/day)	% Red Gum	% Black Box	% Red Gum/ Box	% Cooba	% Saline shrubland	% Lignum
6	8	3	5	14		3
10	8	3	5	14		3
20	8	3	5	14		3
30	10	4	6	14		3
40	10	4	6	14		3
50	11	4	6	14		4
60	16	5	8	14	1	7
70	32	9	21	19	2	19
80	34	11	24	19	2	22
90	40	16	33	27	3	32
100	41	18	35	38	3	33
>100	100	100	100	100	100	100

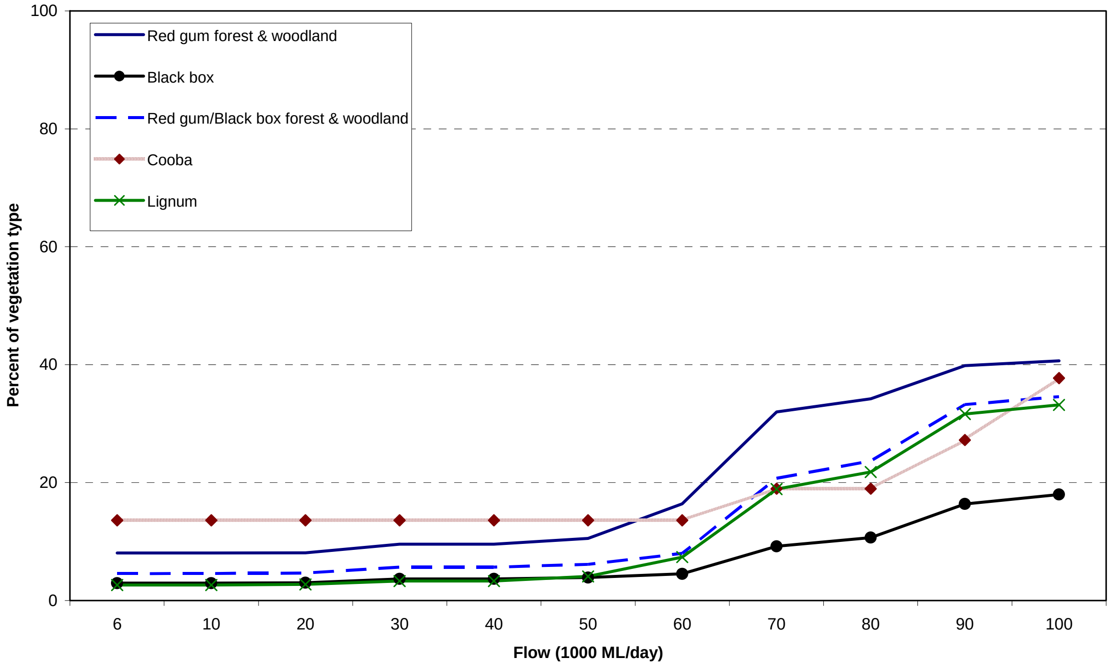


Figure 76. Zone 14 - Percentage of vegetation type inundated.

Zone 15

Description	Area (ha)	River km length	Travel time (days)
Lock 8 to Lock 7	30825	29	0.5

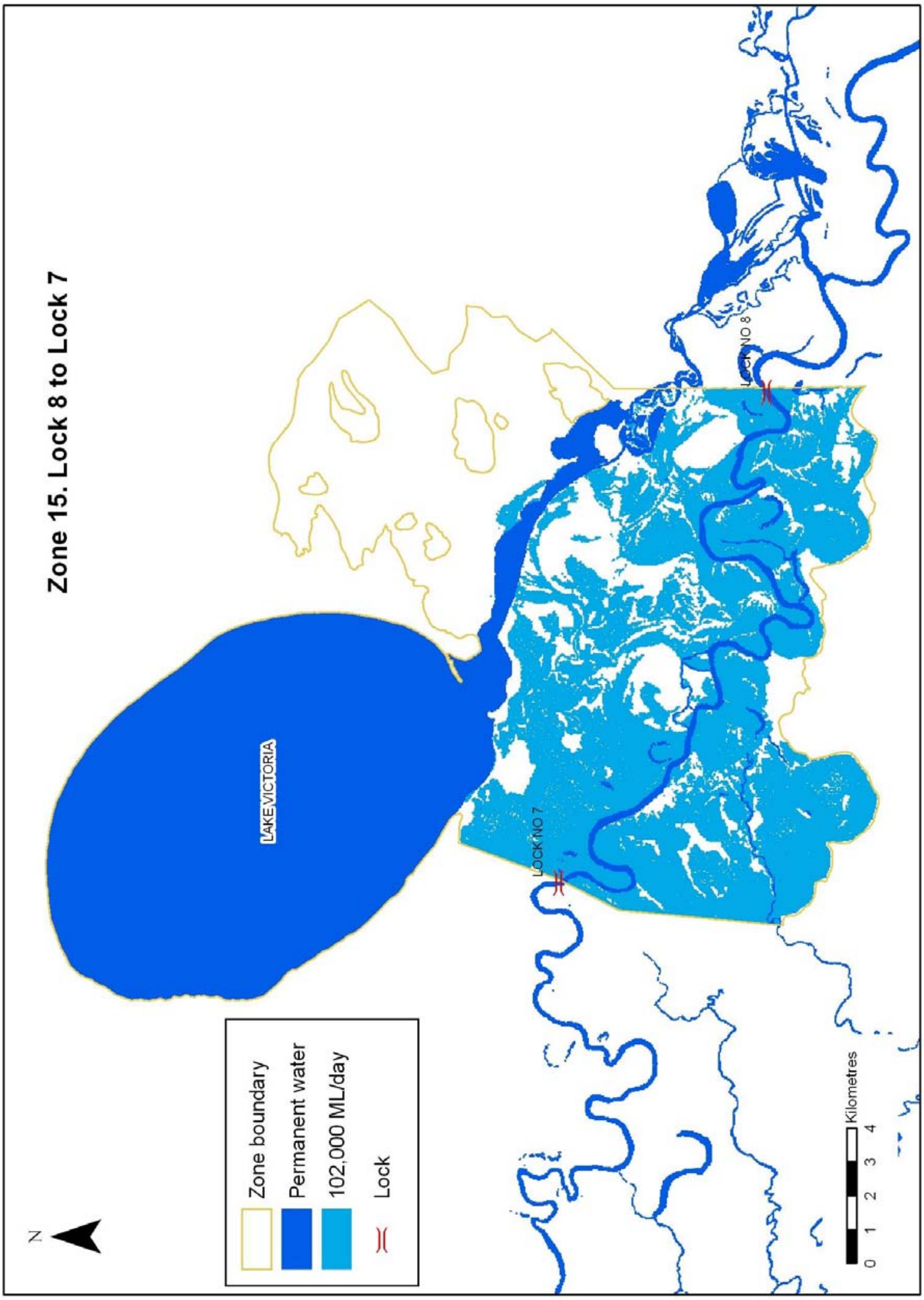


Figure 77. Zone 15 showing permanent water and maximum flood from satellite image.

Table 45. Zone 15 - Area of inundation at 10,000 ML/day flow increment.

Flow (1000 ML/day)	Cumulative area of inundation (Hectares)	Cumulative area of inundation (%)
5	11853	38
10	11969	39
20	12108	39
30	12271	40
40	12320	40
50	12471	40
60	13105	43
70	16020	52
80	17394	56
90	19338	63
100	20314	66
>100	30825	100

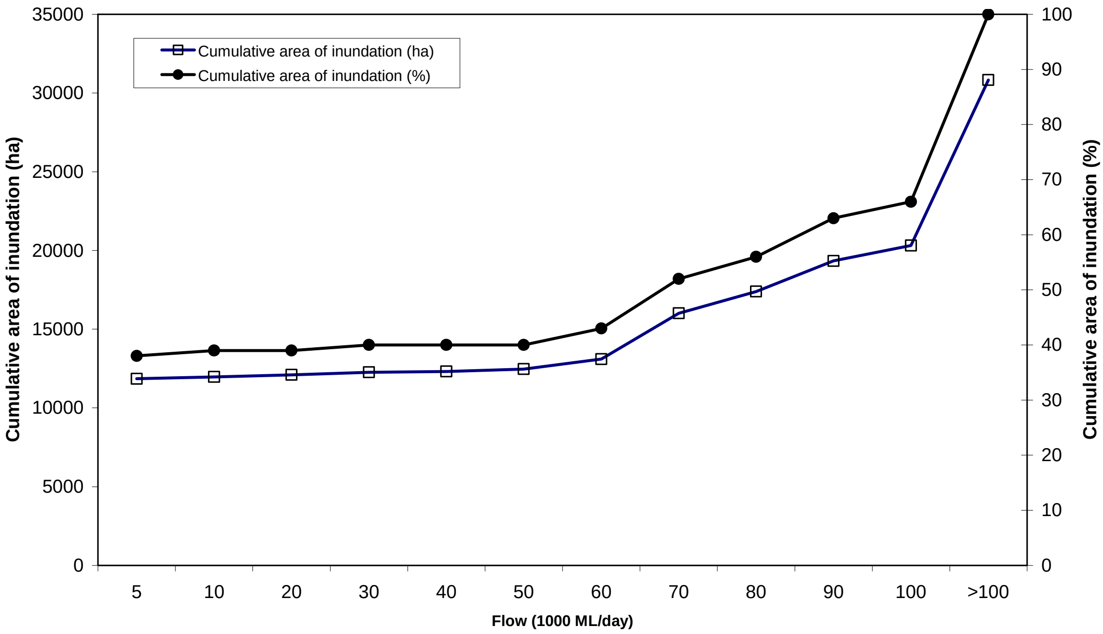


Figure 78. Zone 15 – Area of inundation.

Table 46. Zone 15 - Number of wetlands inundated and area of wetlands inundated at 10,000ML/day flow increments.

Flow (1000 ML/day)	Cumulative number of wetlands inundated	Cumulative number of wetlands inundated (%)	Cumulative area of wetland inundation (Hectares)	Cumulative area of wetland inundation (%)
5	51	23	11689	85
10	51	23	11804	86
20	51	23	11943	87
30	60	27	12094	88
40	69	31	12127	89
50	88	39	12205	89
60	132	59	12430	91

70	185	83	12909	94
80	192	86	13069	96
90	199	89	13191	96
100	210	94	13260	97
110	214	96	13440	98
>110	223	100	13683	100

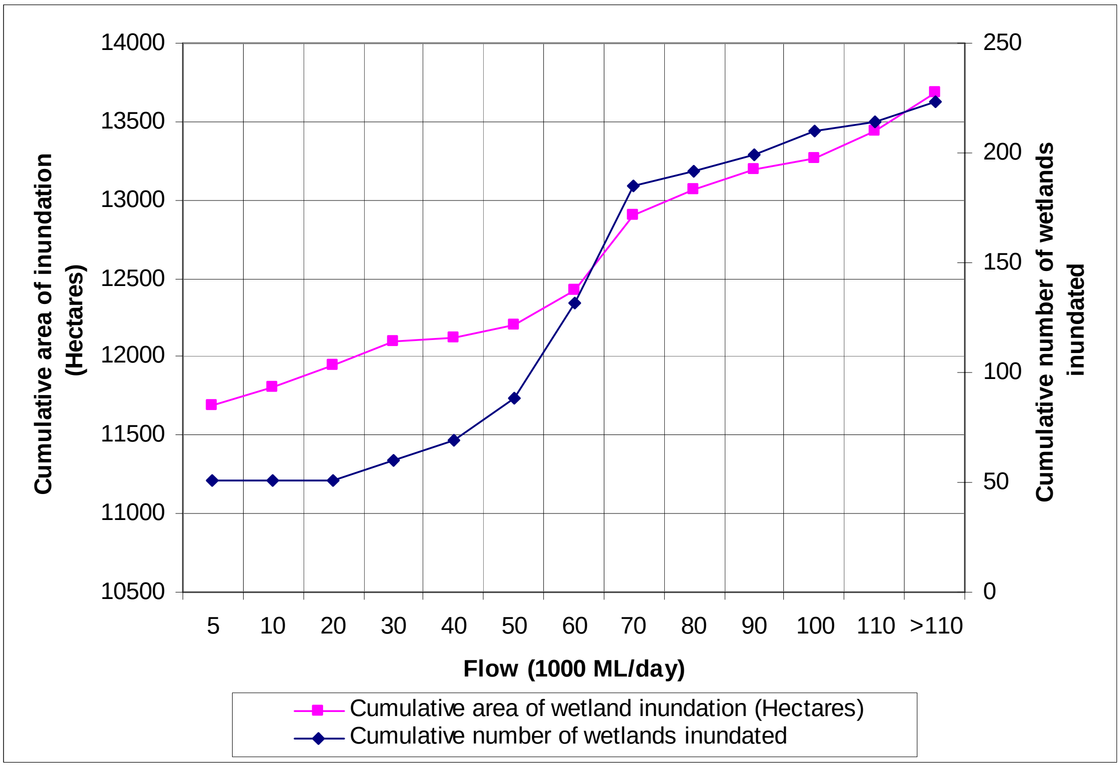


Figure 79. Zone 15 - Wetland inundation statistics.

Table 47. Zone 15 - Percentage of vegetation type inundated at 10,000 ML/day flow increments.

Flow (1000 ML/day)	% Red Gum	% Black Box	% Red Gum/ Box	% Saline shrubland	% Lignum
5	15	6	2	1	2
10	15	6	2	1	2
20	15	6	2	1	2
30	16	6	3	1	2
40	16	6	3	1	2
50	18	7	5	1	2
60	26	9	10	2	8
70	54	26	33	6	48
80	62	35	43	10	61
90	80	51	59	12	77
100	84	58	66	12	83
>100	100	100	100	100	100

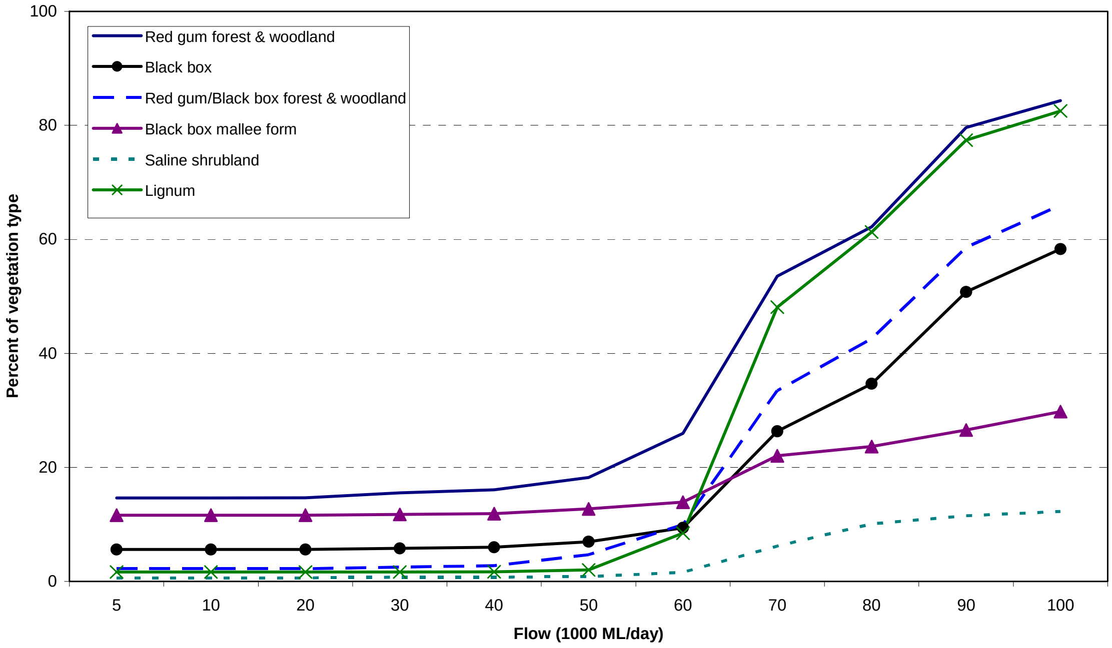


Figure 80. Zone 15 - Percentage of vegetation type inundated

Zone 16

Description	Area (ha)	River km length	Travel time (days)
Lock 7 to Lock 6	35577	80	0.5

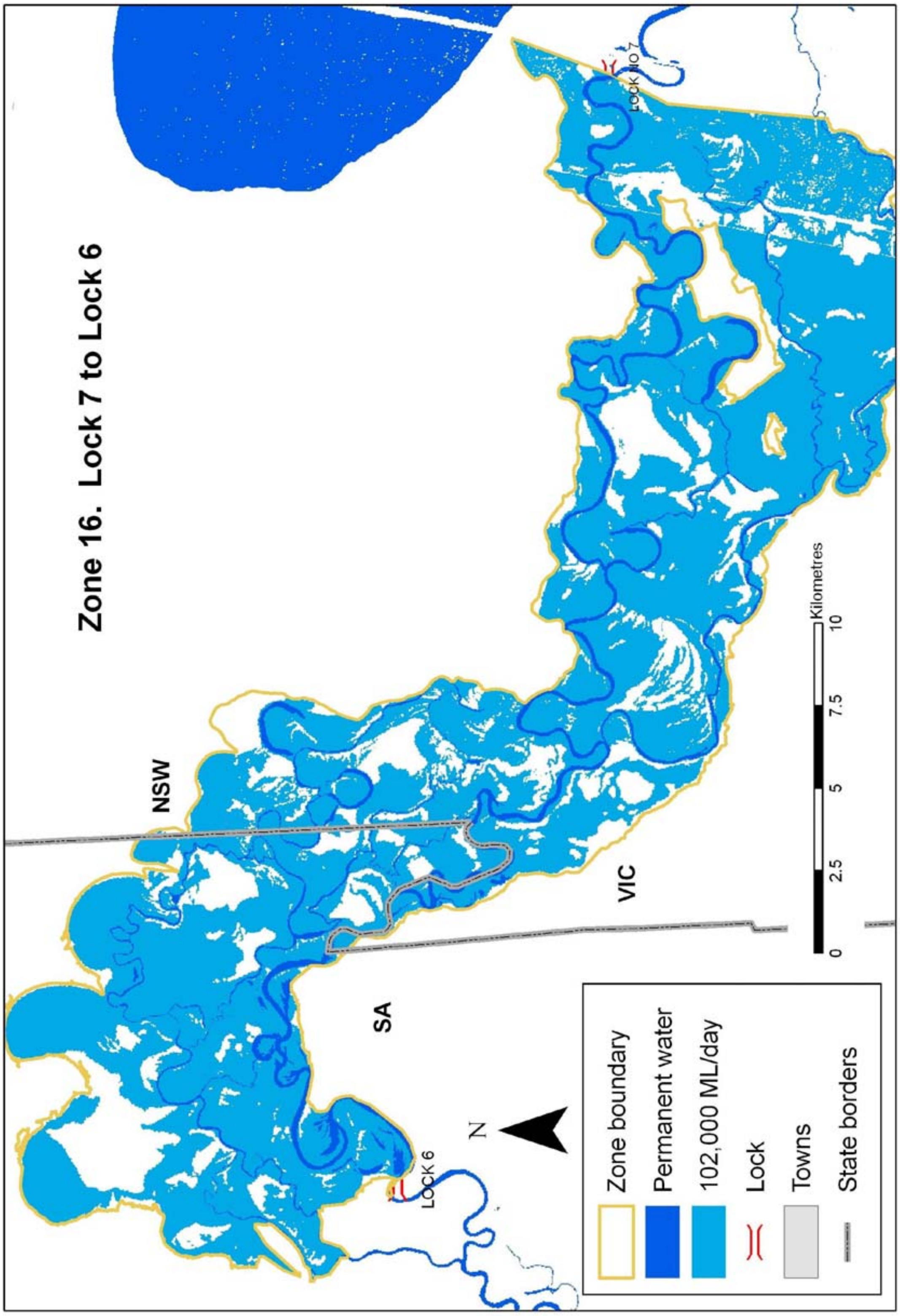


Figure 81. Zone 16 showing permanent water and maximum flood from satellite image.

Table 48. Zone 16 - Area of inundation at 10,000 ML/day flow increment.

Flow (1000 ML/day)	Cumulative area of inundation (Hectares)	Cumulative area of inundation (%)
5000	2402	7
10	2443	7
20	2471	7
30	2877	8
40	3231	9
50	5137	14
60	6733	19
70	12525	35
80	19447	55
90	23570	66
100	24485	69
>100	35577	100

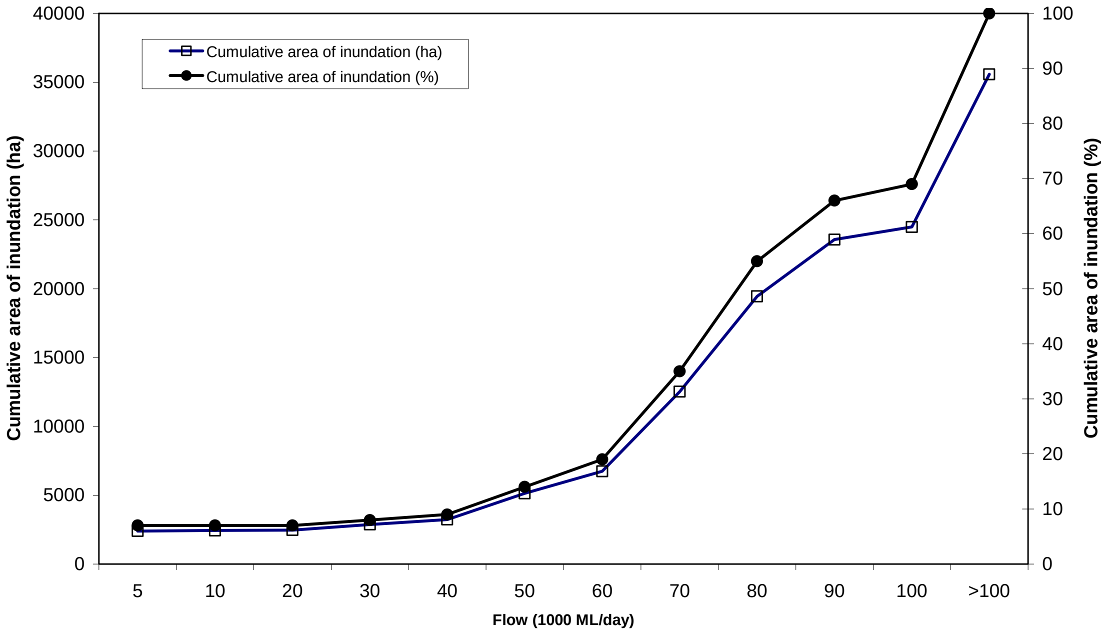


Figure 82. Zone 16 – Area of inundation.

Table 49. Zone 16 - Number of wetlands inundated and area of wetlands inundated at 10,000ML/day flow increments.

Flow (1000 ML/day)	Cumulative number of wetlands inundated	Cumulative number of wetlands inundated (%)	Cumulative area of wetland inundation (Hectares)	Cumulative area of wetland inundation (%)
5	87	28	1796	29
10	92	30	1826	30
20	94	30	1841	30
30	120	39	2092	34
40	135	43	2156	35
50	173	56	2611	42
60	201	65	3048	49
70	255	82	4220	68

80	284	91	5640	91
90	297	95	5827	94
100	300	96	5874	95
110	309	99	6031	98
>110	311	100	6185	100

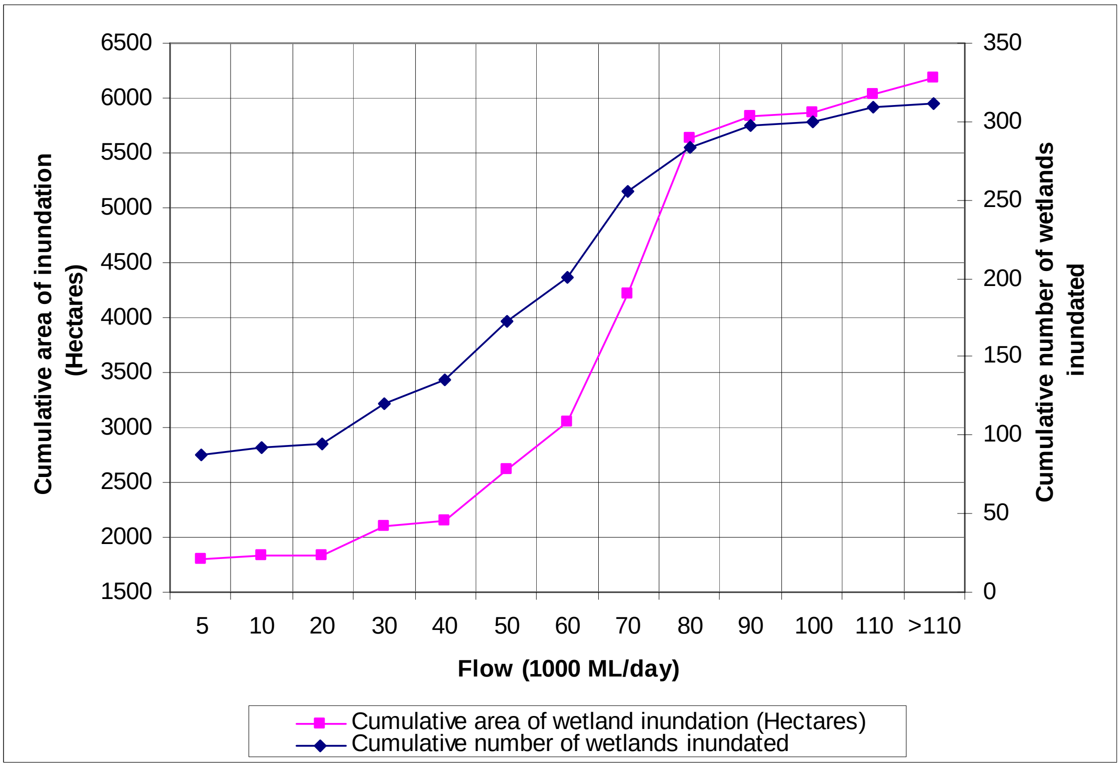


Figure 83. Zone 16 - Wetland inundation statistics.

Table 50. Zone 16 - Percentage of vegetation type inundated at 10,000 ML/day flow increments.

Flow (1000 ML/day)	% Red Gum	% Black Box	% Red Gum/ Box	% Cooba	% Saline shrubland	% Lignum
5	14	4	4	1	3	3
10	14	4	4	1	3	3
20	14	4	5	1	3	3
30	17	4	6	1	4	3
40	20	4	8	1	5	4
50	30	8	14	1	14	9
60	40	10	34	1	16	16
70	66	21	56	3	23	39
80	77	37	70	9	37	65
90	85	50	77	11	46	73
100	86	54	79	14	48	75
>100	100	100	100	100	100	100

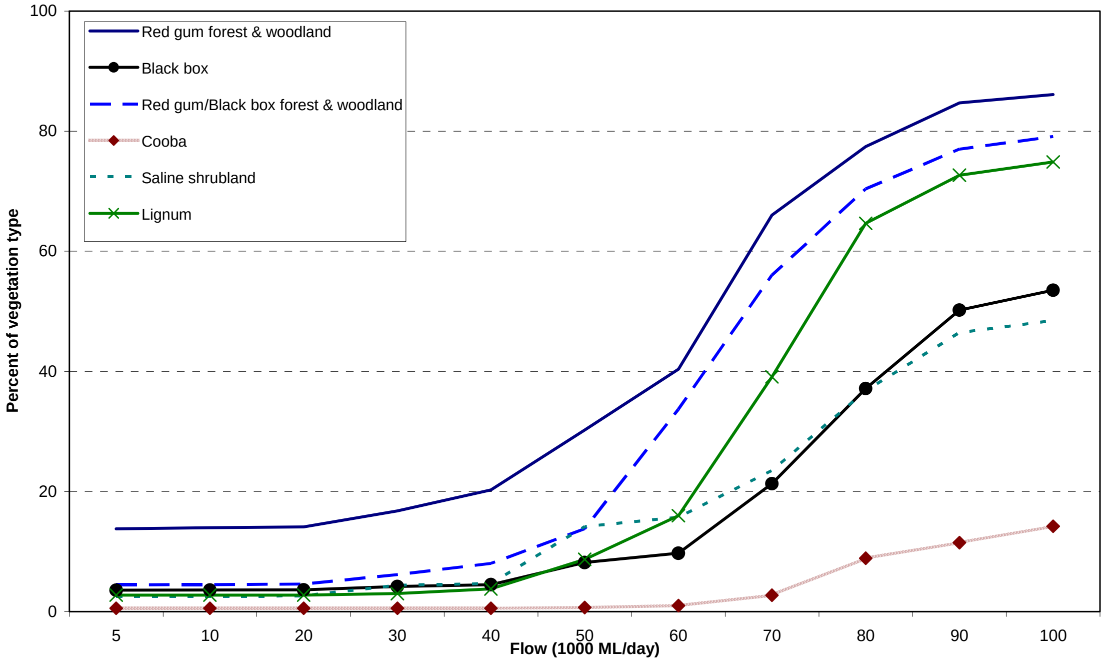


Figure 84. Zone 16 - Percentage of vegetation type inundated.

Zone 17

Description	Area (ha)	River km length	Travel time (days)
Lock 6 to Lock 5	20568	58	0.5

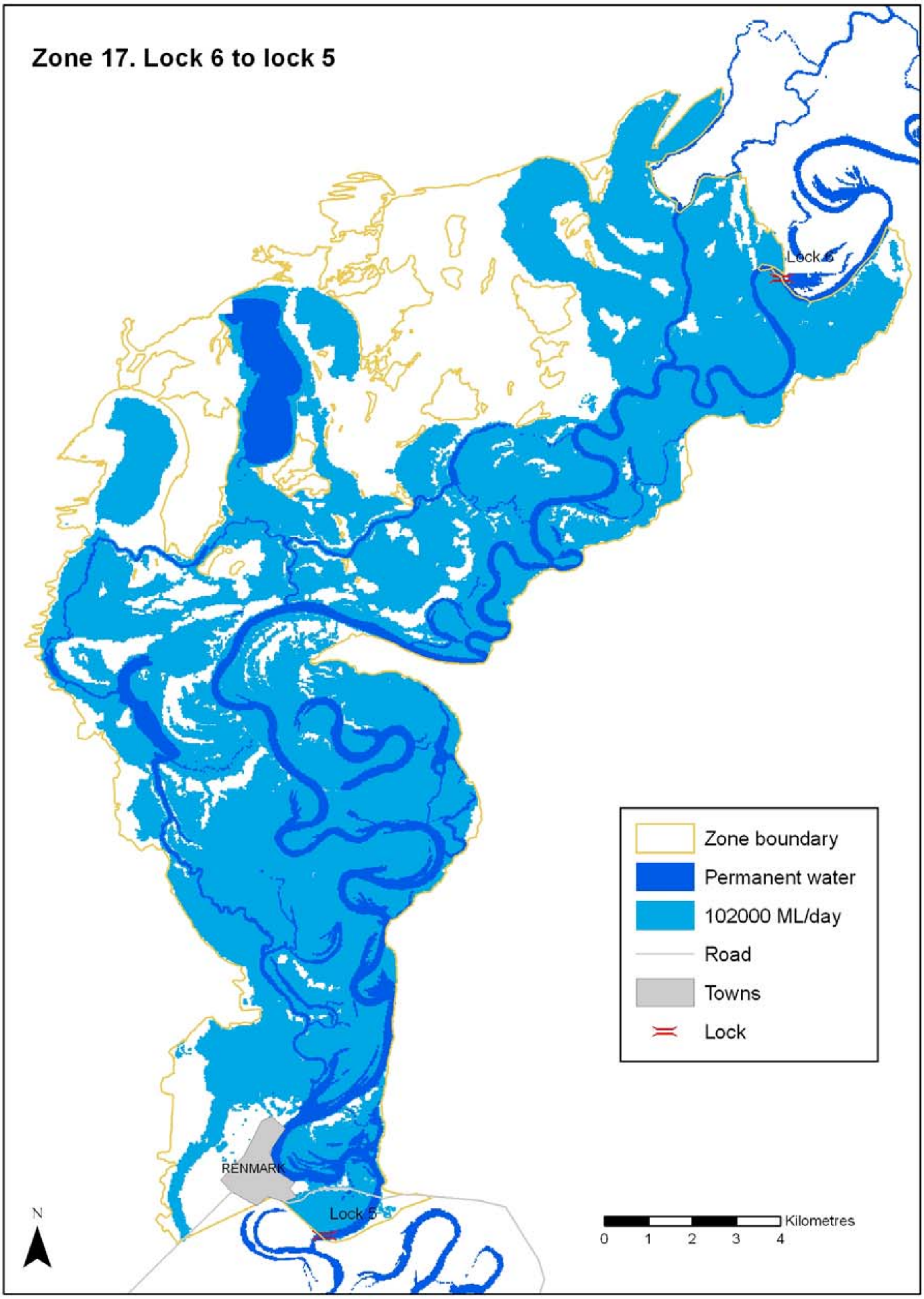


Figure 85. Zone 17 showing permanent water and maximum flood from satellite image.

Table 51. Zone 17 - Area of inundation at 10,000 ML/day flow increment.

Flow (1000 ML/day)	Cumulative area of inundation (Hectares)	Cumulative area of inundation (%)
5000	2471	12
10	2477	12
20	2536	12
30	2901	14
40	3450	17
50	4024	20
60	5451	27
70	8254	40
80	11062	54
90	12718	62
100	13110	64
>100	20568	100

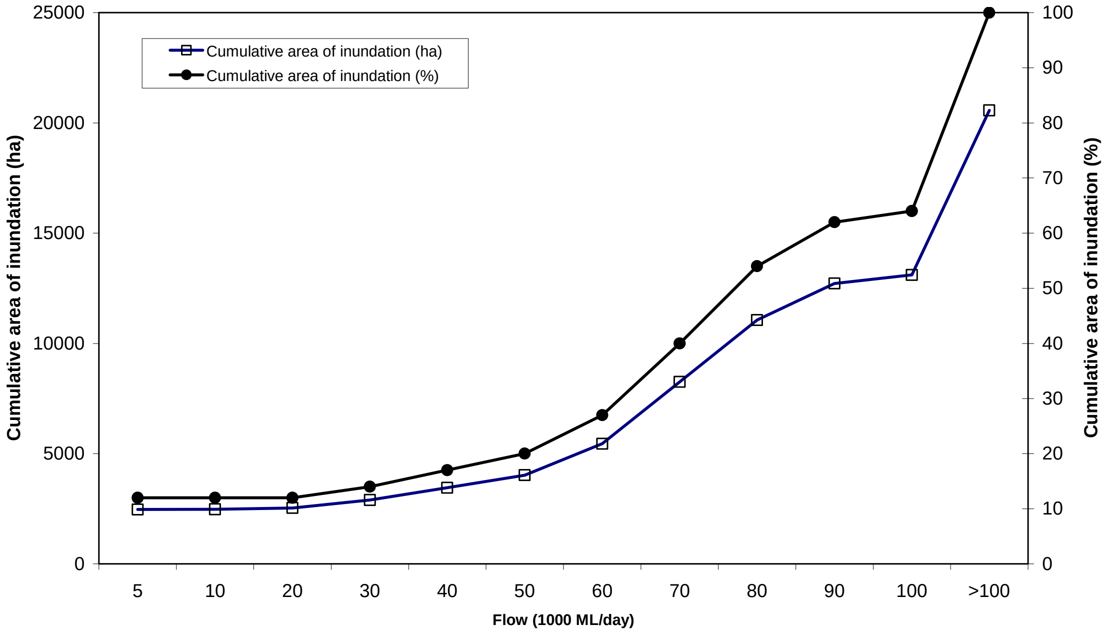


Figure 86. Zone 17 – Area of inundation.

Table 52. Zone 17 - Number of wetlands inundated and area of wetlands inundated at 10,000ML/day flow increments.

Flow (1000 ML/day)	Cumulative number of wetlands inundated	Cumulative number of wetlands inundated (%)	Cumulative area of wetland inundation (Hectares)	Cumulative area of wetland inundation (%)
5	46	41	2225	74
10	47	42	2227	74
20	58	51	2255	75
30	60	53	2493	83
40	64	57	2555	85
50	71	63	2602	86
60	86	76	2678	89
70	92	81	2907	97
80	101	89	2968	99

90	106	94	2984	99
100	111	98	2988	99
110	112	99	3000	100
>110	113	100	3009	100

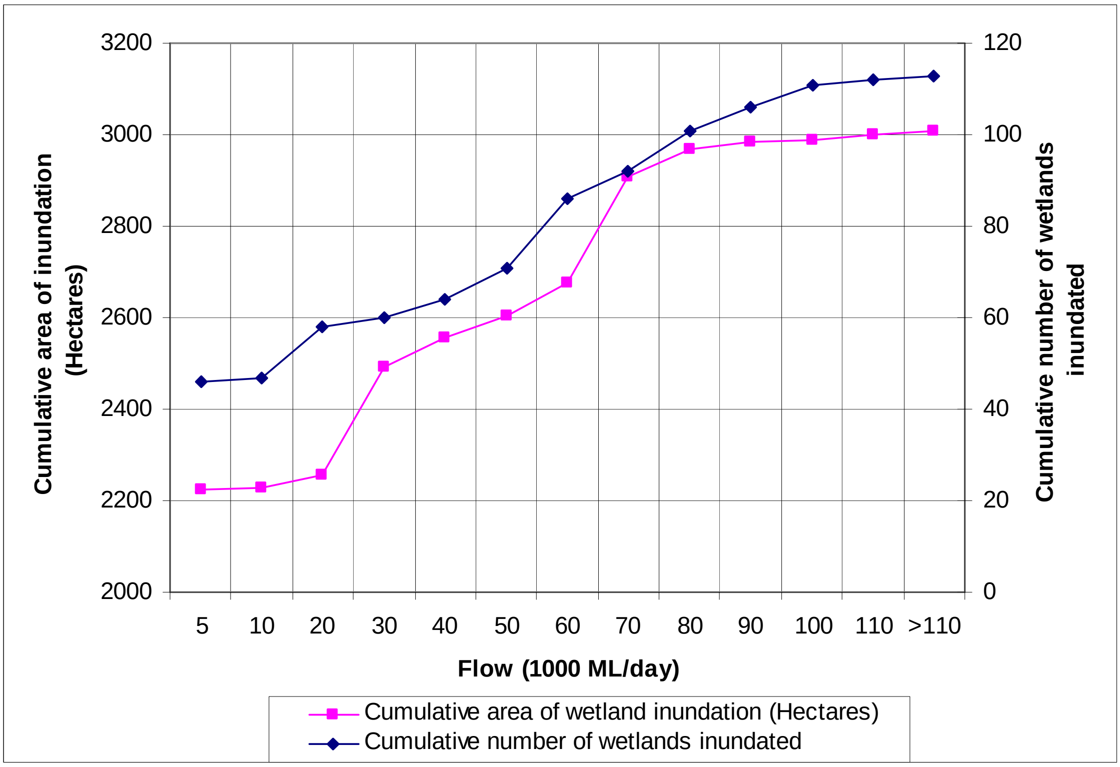


Figure 87. Zone 17 - Wetland inundation statistics.

Table 53. Zone 17 - Percentage of vegetation type inundated at 10,000 ML/day flow increments.

Flow (1000 ML/day)	% Red Gum	% Black Box	% Red Gum/Box	% Saline shrubland	% Lignum
5	17	4	7	2	3
10	17	4	7	2	3
20	17	4	7	2	3
30	20	5	8	2	4
40	27	6	9	2	6
50	34	8	10	3	8
60	51	12	25	6	22
70	69	21	45	13	53
80	81	36	81	20	80
90	87	46	88	30	91
100	88	49	92	31	93
>100	100	100	100	100	100

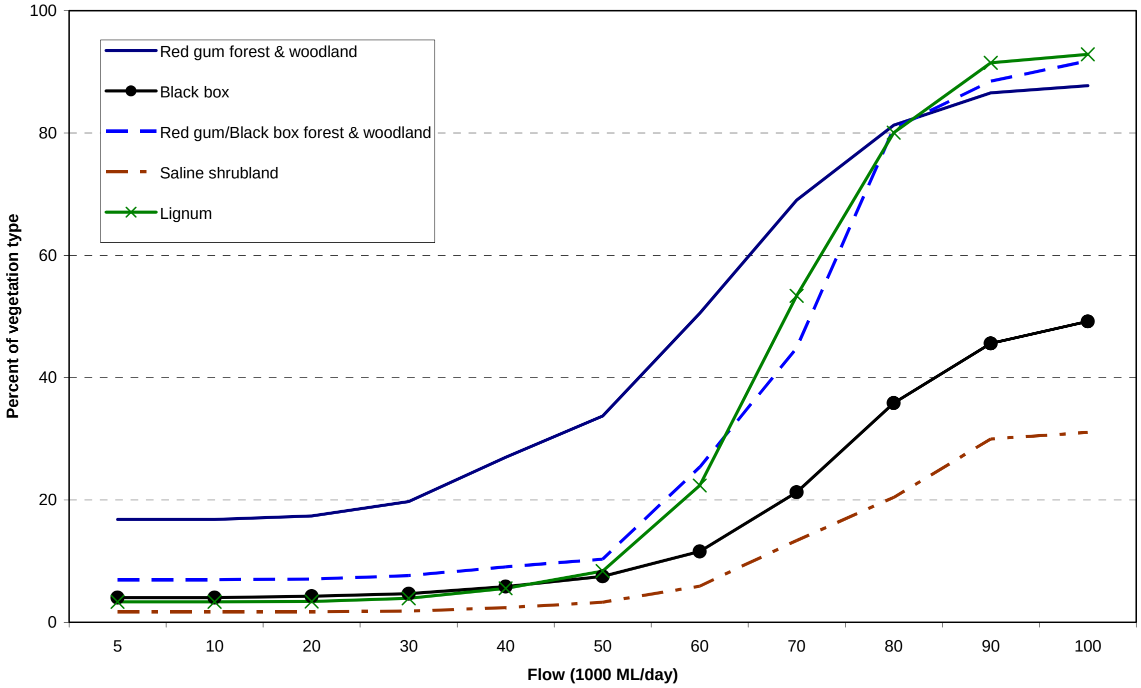


Figure 88. Zone 17 - Percentage of vegetation type inundated.

Zone 18

Description	Area (ha)	River km length	Travel time (days)
Lock 5 to Lock 4	16505	46	0.5

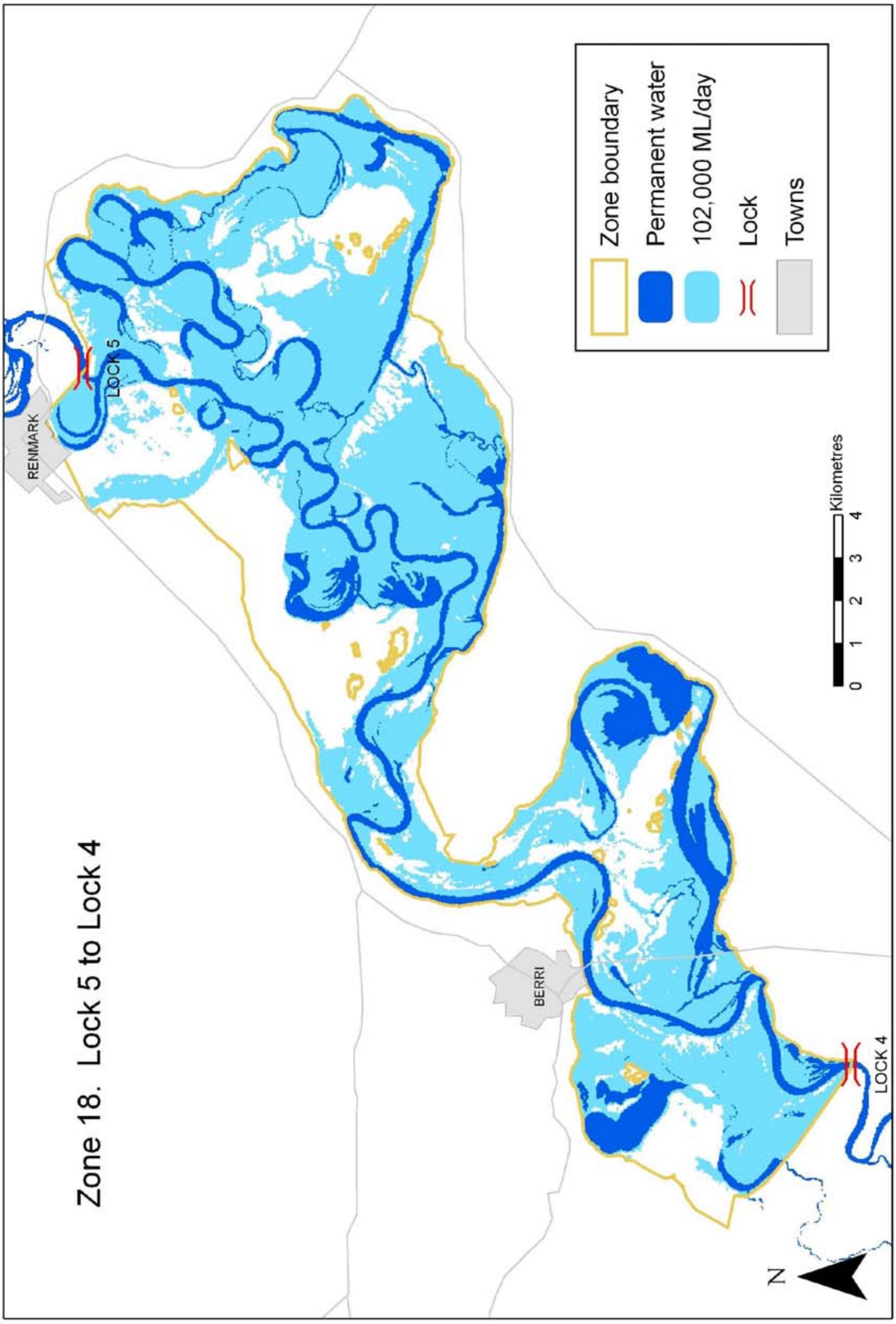


Figure 89. Zone 18 showing permanent water and maximum flood from satellite image.

Table 54. Zone 18 - Area of inundation at 10,000 ML/day flow increment.

Flow (1000 ML/day)	Cumulative area of inundation (Hectares)	Cumulative area of inundation (%)
5	2809	17
10	2809	17
20	3065	19
30	3179	19
40	3272	20
50	4141	25
60	4963	30
70	7302	44
80	9561	58
90	11196	68
100	11622	70
>100	16505	100

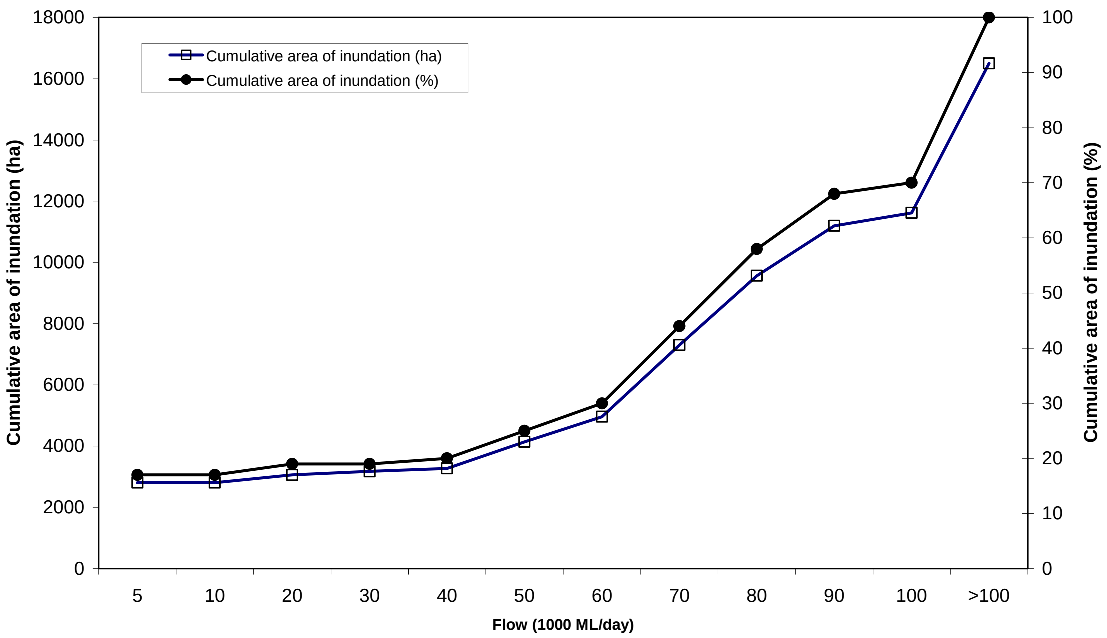


Figure 90. Zone 18 – Area of inundation.

Table 55. Zone 18 - Number of wetlands inundated and area of wetlands inundated at 10,000ML/day flow increments.

Flow (1000 ML/day)	Cumulative number of wetlands inundated	Cumulative number of wetlands inundated (%)	Cumulative area of wetland inundation (Hectares)	Cumulative area of wetland inundation (%)
5	62	30	2608	80
10	62	30	2608	80
20	85	40	2657	81
30	89	42	2679	82
40	90	43	2701	83
50	103	49	2792	86
60	132	63	2902	89

70	162	77	3070	94
80	188	90	3151	97
90	200	95	3208	98
100	202	96	3219	99
110	202	96	3234	99
>110	210	100	3260	100

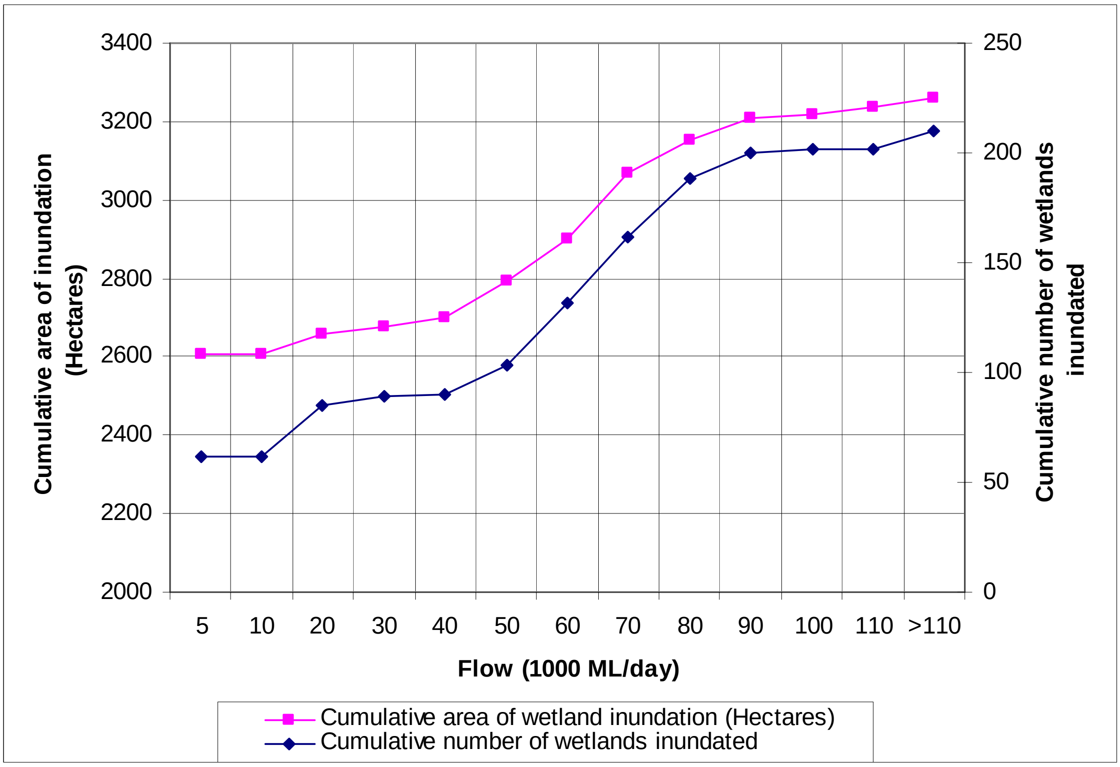


Figure 91. Zone 18 - Wetland inundation statistics.

Table 56. Zone 18 - Percentage of vegetation type inundated at 10,000 ML/day flow increments.

Flow (1000 ML/day)	% Red Gum	% Black Box	% Red Gum/Box	% Saline shrubland	% Lignum
5	20	7		5	8
10	20	7		5	8
20	24	7	1	5	10
30	26	8	1	6	11
40	27	8	1	6	12
50	36	10	3	9	20
60	46	13	4	14	27
70	71	20	38	19	55
80	86	32	76	31	78
90	90	40	88	41	89
100	92	54	89	42	90
>100	100	100	100	100	100

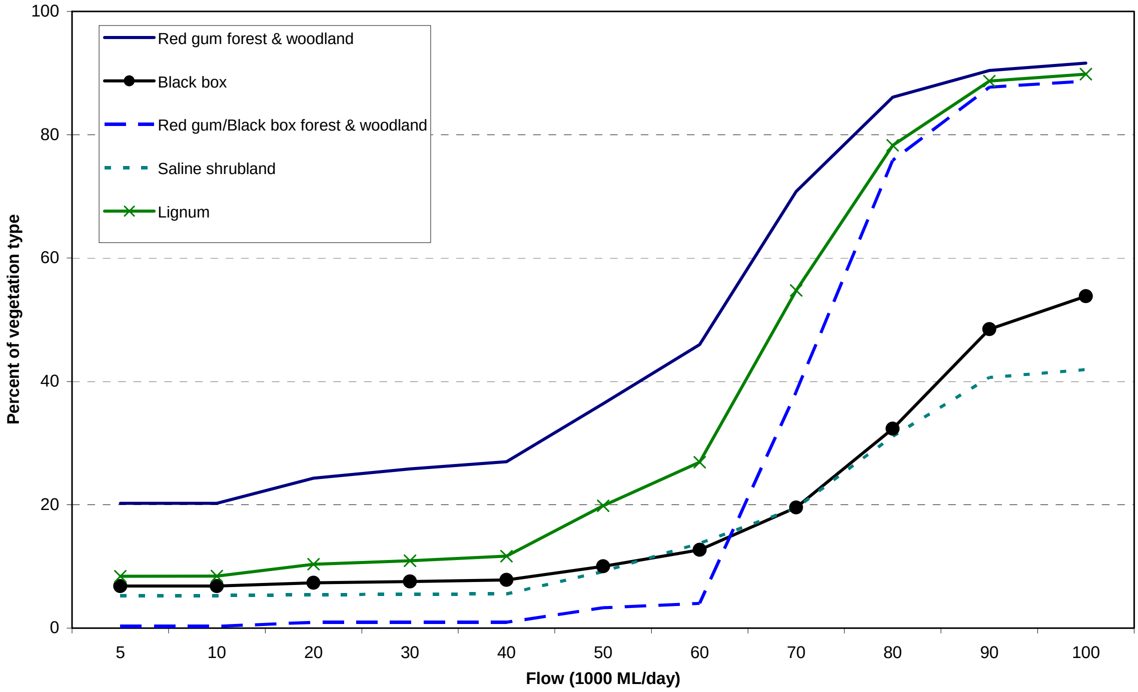


Figure 92. Zone 18 - Percentage of vegetation type inundated.

Zone 19

Description	Upper km	Lower km	River km length	Travel time (days)
Lock 4 to Lock 3	516	432	84	1

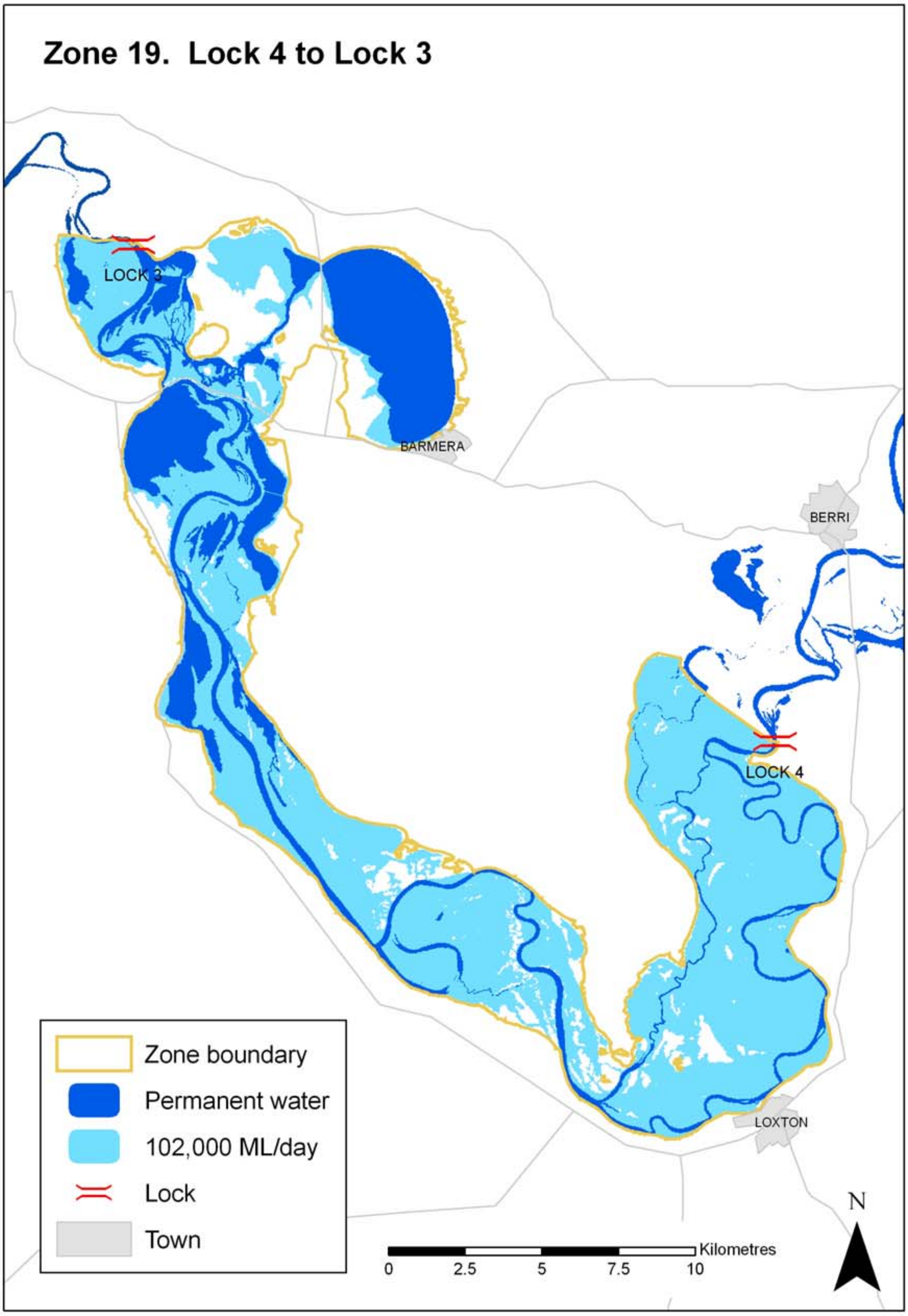


Figure 93. Zone 19 showing permanent water and maximum flood from satellite image.

Table 57. Zone 19 - Area of inundation at 10,000 ML/day flow increment.

Flow (1000 ML/day)	Cumulative area of inundation (Hectares)	Cumulative area of inundation (%)
5	5606	25
10	5775	25
20	5788	25
30	5857	26
40	6692	29
50	7338	32
60	9582	42
70	12723	56
80	16813	74
90	18476	81
100	19095	84
>100	22850	100

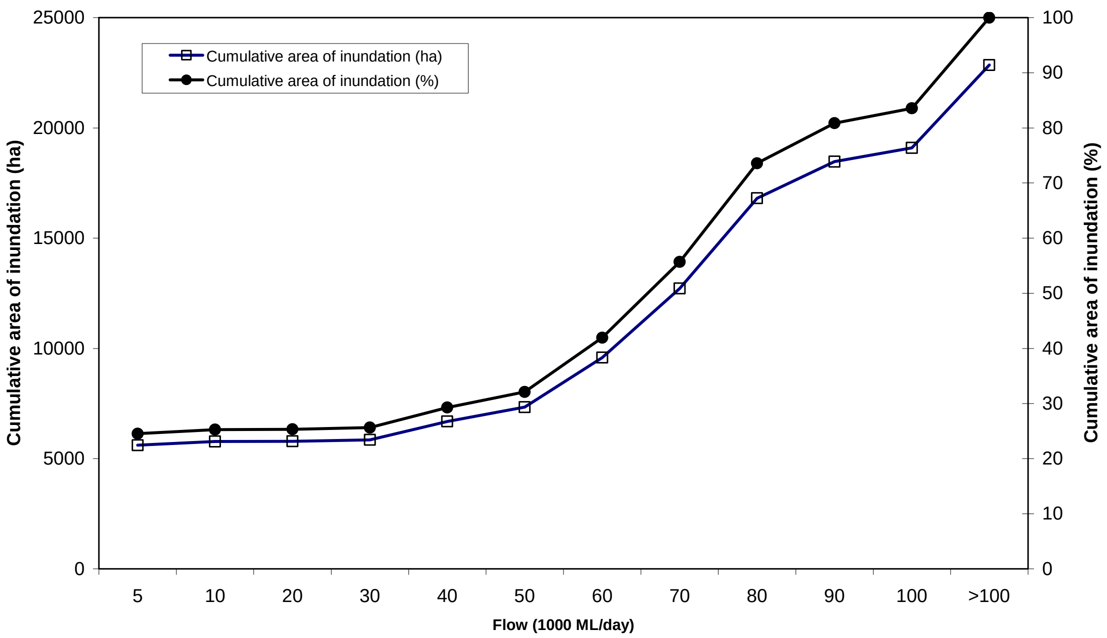


Figure 94. Zone 19 – Area of inundation.

Table 58. Zone 19 - Number of wetlands inundated and area of wetlands inundated at 10,000ML/day flow increments.

Flow (1000 ML/day)	Cumulative number of wetlands inundated	Cumulative number of wetlands inundated (%)	Cumulative area of wetland inundation (Hectares)	Cumulative area of wetland inundation (%)
5	43	22	5373	85
10	49	26	5525	87
20	49	26	5528	87
30	57	30	5553	87
40	69	36	5695	90
50	84	44	5780	91
60	118	61	5934	93

70	154	80	6097	96
80	185	96	6261	99
90	188	98	6301	99
100	189	98	6329	100
110	189	98	6345	100
>110	192	100	6351	100

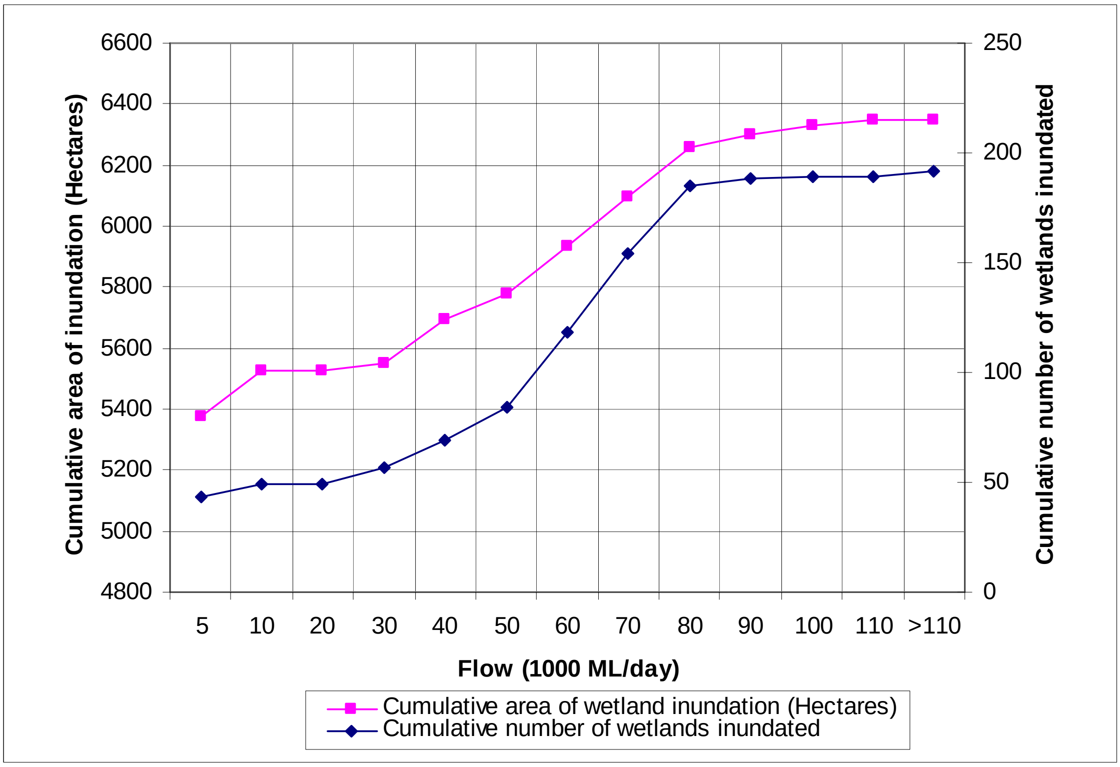


Figure 95. Zone 19 - Wetland inundation statistics.

Table 59. Zone 19 - Percentage of vegetation type inundated at 10,000 ML/day flow increments.

Flow (1000 ML/day)	% Red Gum	% Black Box	% Red Gum/Box	% Saline shrubland	% Lignum
5	14	8	2	6	7
10	15	8	2	7	7
20	15	9	2	7	7
30	16	9	2	7	8
40	19	10	2	8	13
50	25	11	3	10	21
60	42	16	20	17	45
70	64	25	42	27	69
80	87	51	80	57	91
90	91	66	92	66	95
100	93	70	98	69	98
>100	100	100	100	100	100

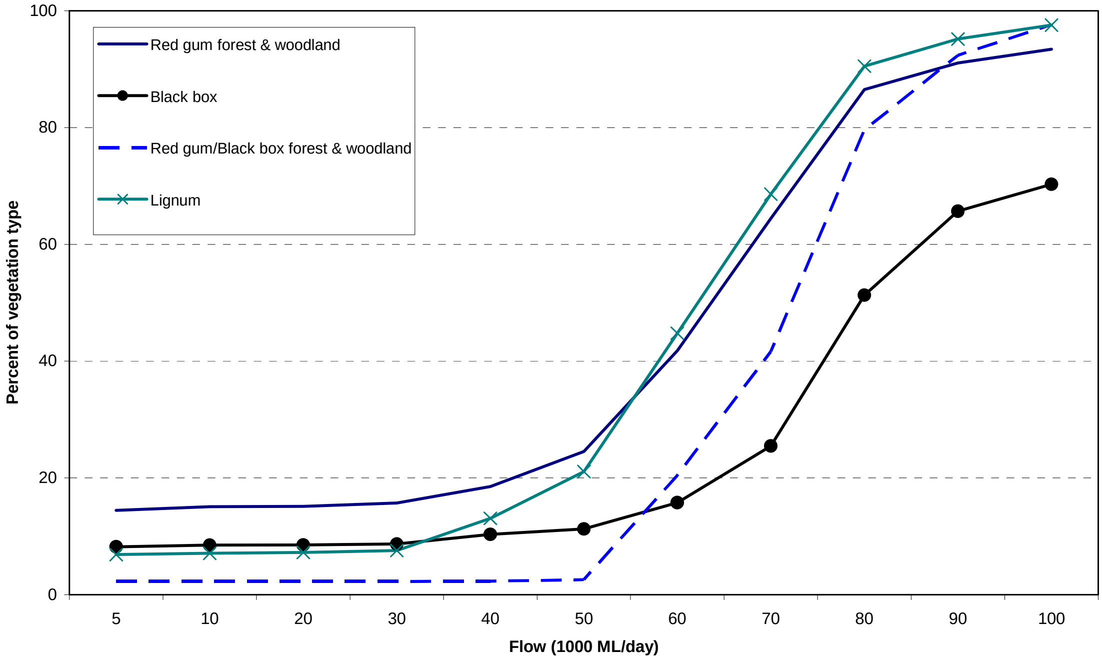


Figure 96. Zone 19 - Percentage of vegetation type inundated.

Zone 20

Description	Area (ha)	River km length	Travel time (days)
Lock 3 to Lock 2	7135	69	0.5

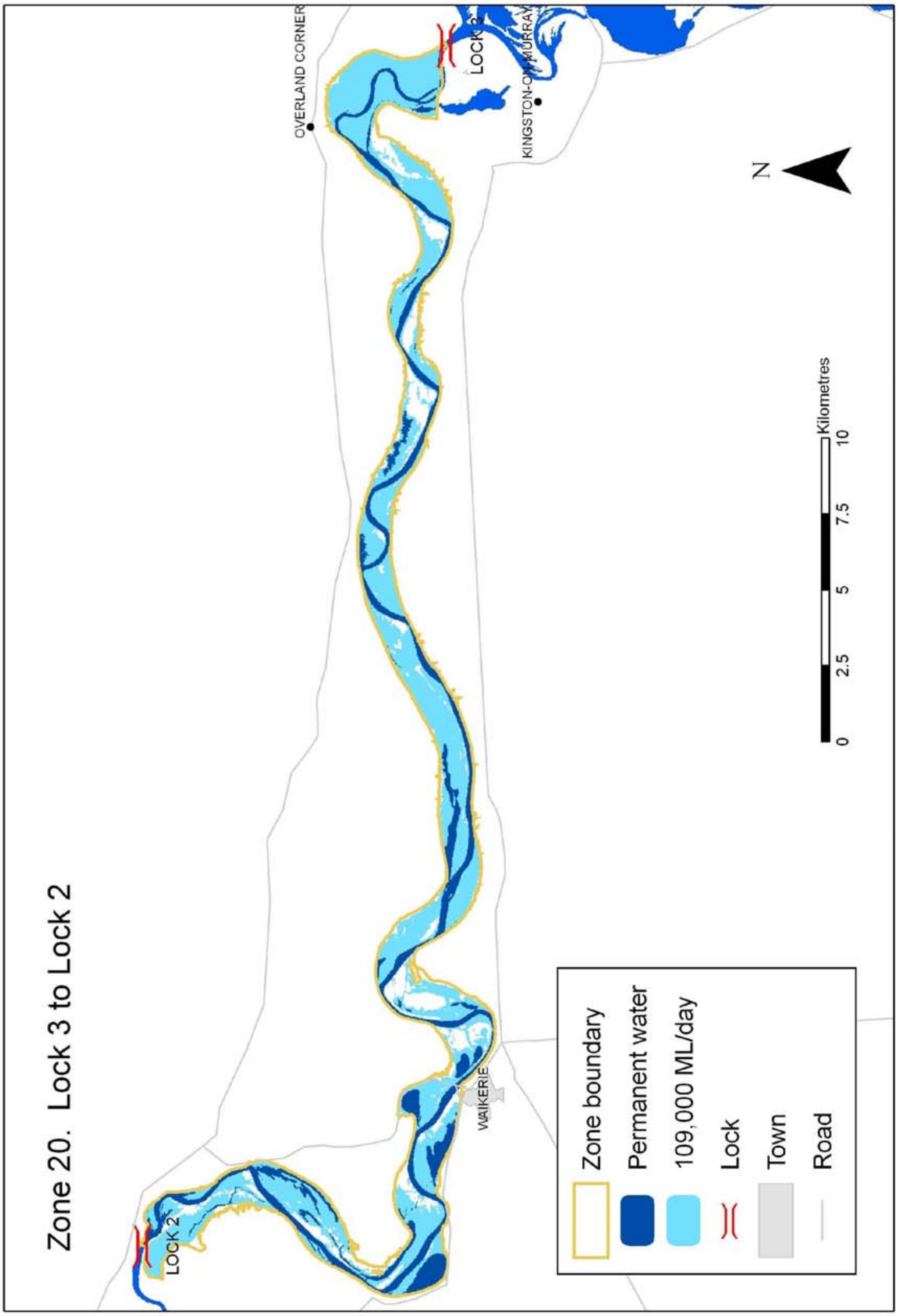


Figure 97. Zone 20 showing permanent water and maximum flood from satellite image.

Table 60. Zone 20 - Area of inundation at 10,000 ML/day flow increment

Flow (1000 ML/day)	Cumulative area of inundation (Hectares)	Cumulative area of inundation (%)
5	1772	25
10	1785	25
20	1848	26
30	1923	27
40	2026	28
50	2407	34
60	2912	41
70	3547	50
80	4341	61
90	4516	63
100	5094	71
>100	7135	100

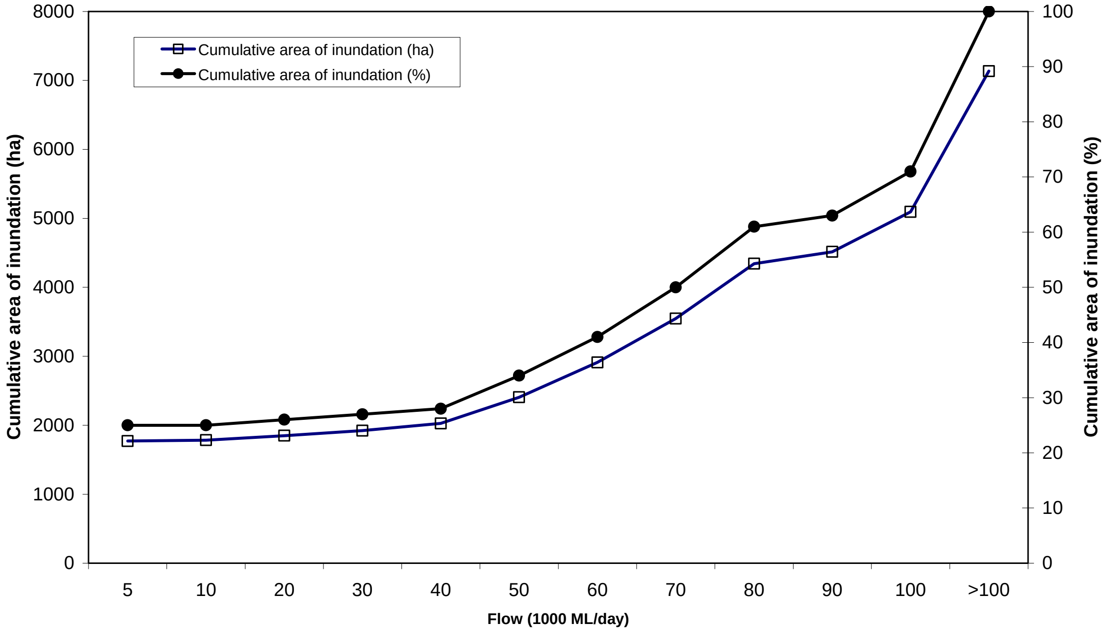


Figure 98. Zone 20 – Area of inundation.

Table 61. Zone 20 - Number of wetlands inundated and area of wetlands inundated at 10,000ML/day flow increments.

Flow (1000 ML/day)	Cumulative number of wetlands inundated	Cumulative number of wetlands inundated (%)	Cumulative area of wetland inundation (Hectares)	Cumulative area of wetland inundation (%)
5	51	38	1576	79
10	52	39	1589	80
20	58	43	1637	82
30	59	44	1679	84
40	64	48	1729	87
50	82	61	1790	90
60	103	77	1866	94
70	117	87	1901	96

80	128	96	1933	97
90	131	98	1941	98
100	134	100	1974	99
110	134	100	1987	100
>110	134	100	1988	100

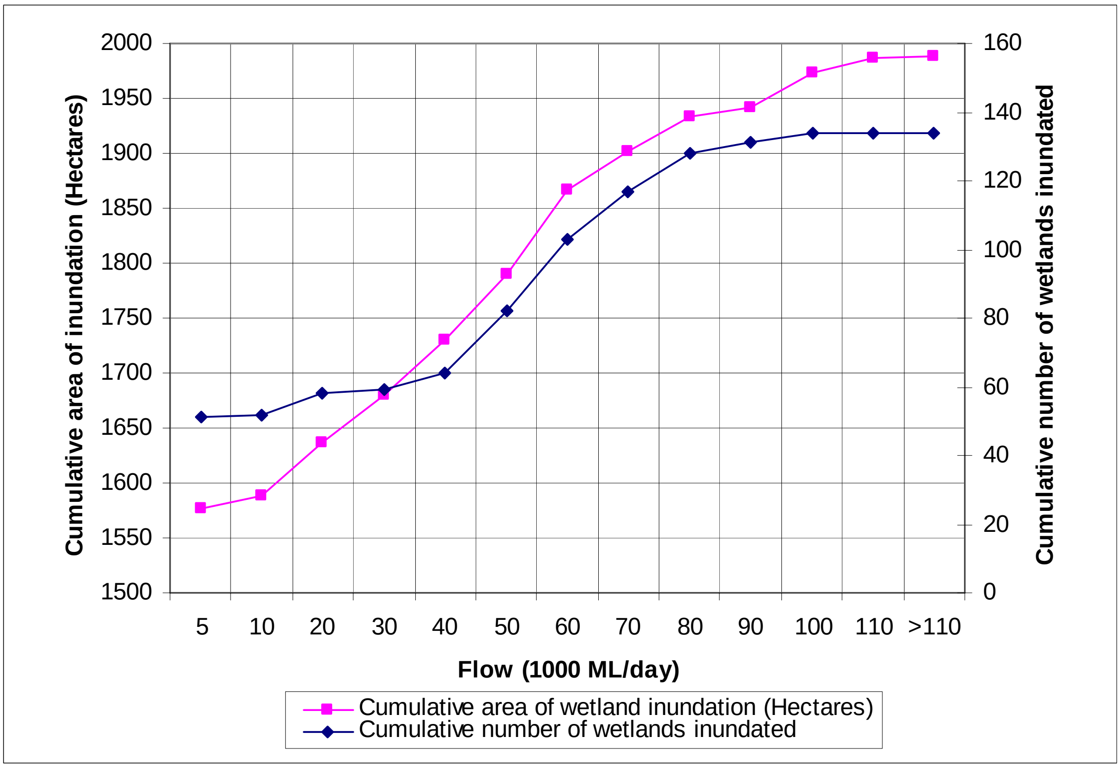


Figure 99. Zone 20 - Wetland inundation statistics.

Table 62. Zone 20 - Percentage of vegetation type inundated at 10,000 ML/day flow increments.

Flow (1000 ML/day)	% Red Gum	% Black Box	% Red Gum / Box	% Saline shrubland	% Lignum
5	13	8	4	7	6
10	13	8	4	7	6
20	14	8	5	7	6
30	16	8	5	7	6
40	17	9	6	8	7
50	25	10	6	29	21
60	35	13	7	34	32
70	46	20	7	57	50
80	57	35	19	70	73
90	60	39	29	73	80
100	71	52	57	76	91
>100	100	100	100	100	100

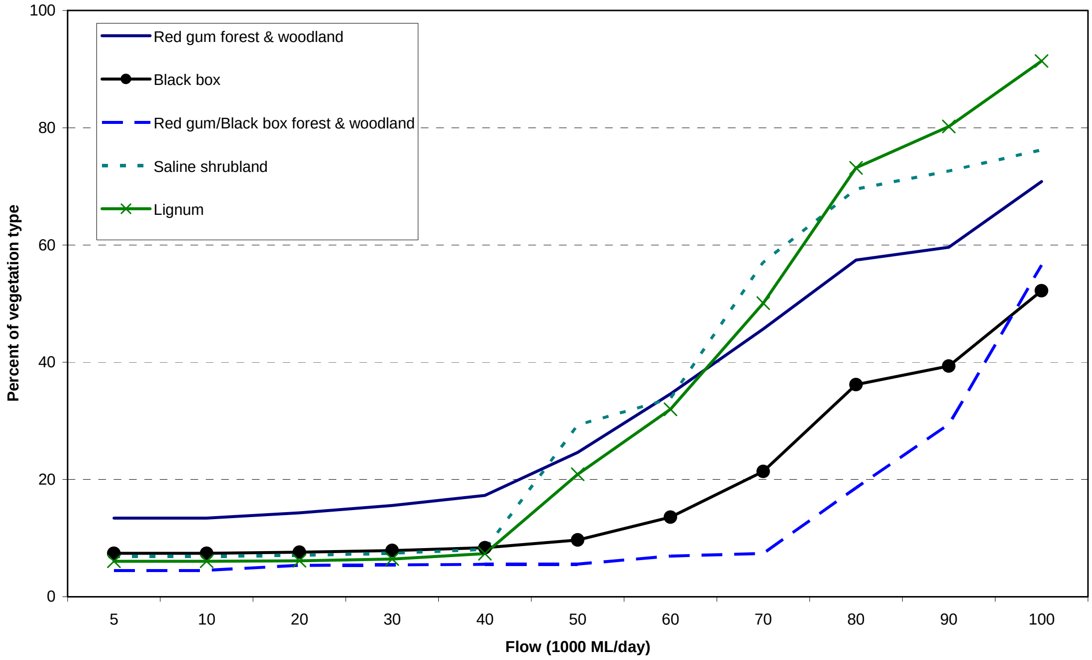


Figure 100. Zone 20 - Percentage of vegetation type inundated.

Zone 21

Description	Area (ha)	River km length	Travel time (days)
Lock 2 to Lock 1	9535	89	1

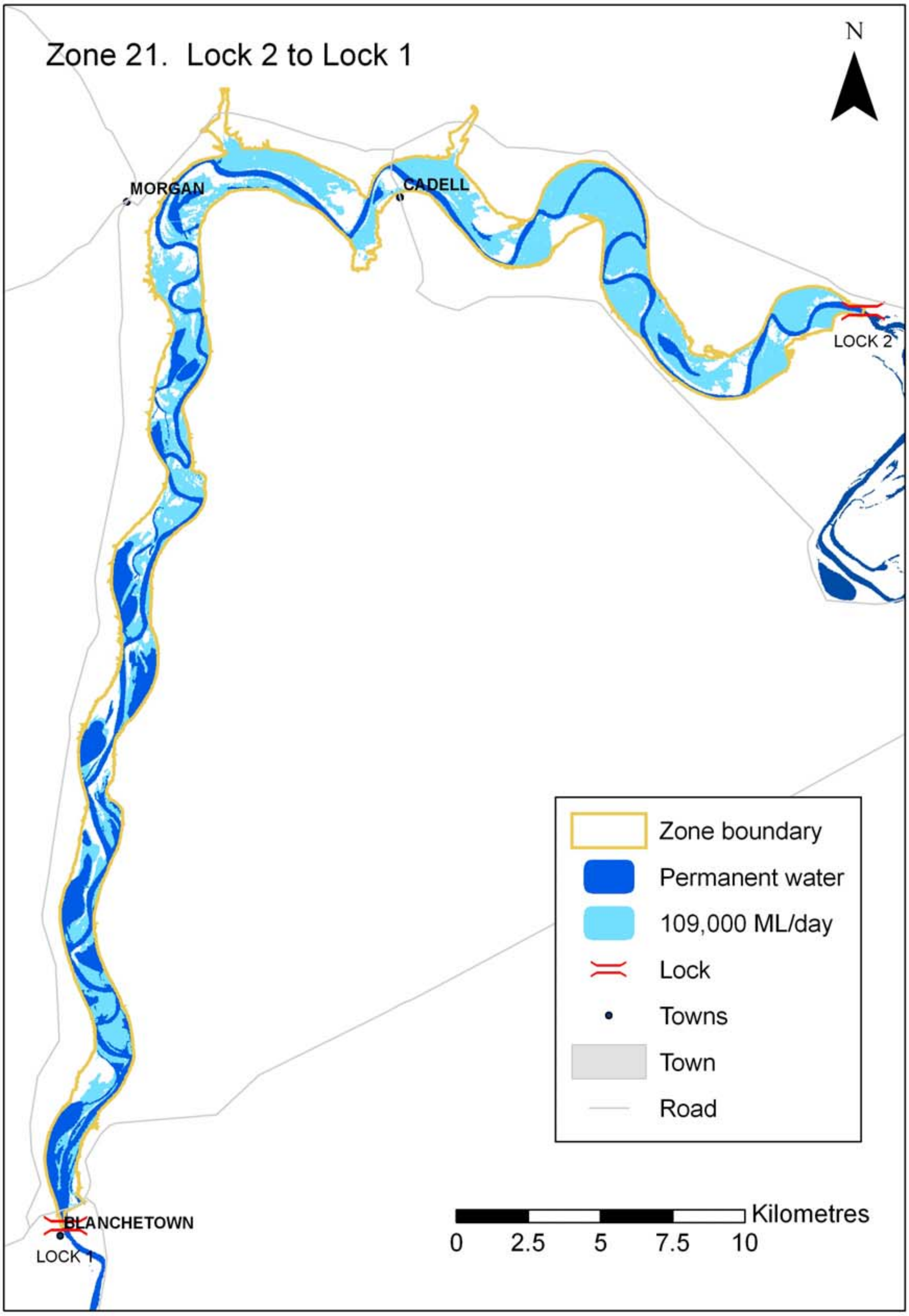


Figure 101. Zone 21 showing permanent water and maximum flood from satellite image.

Table 63. Zone 21 - Area of inundation at 10,000 ML/day flow increment.

Flow (1000 ML/day)	Cumulative area of inundation (Hectares)	Cumulative area of inundation (%)
5	2776	29
10	2776	29
20	2901	30
30	3084	32
40	3305	35
50	3439	36
60	3991	42
70	4242	44
80	4812	50
90	5211	55
100	6394	67
>100	9535	100

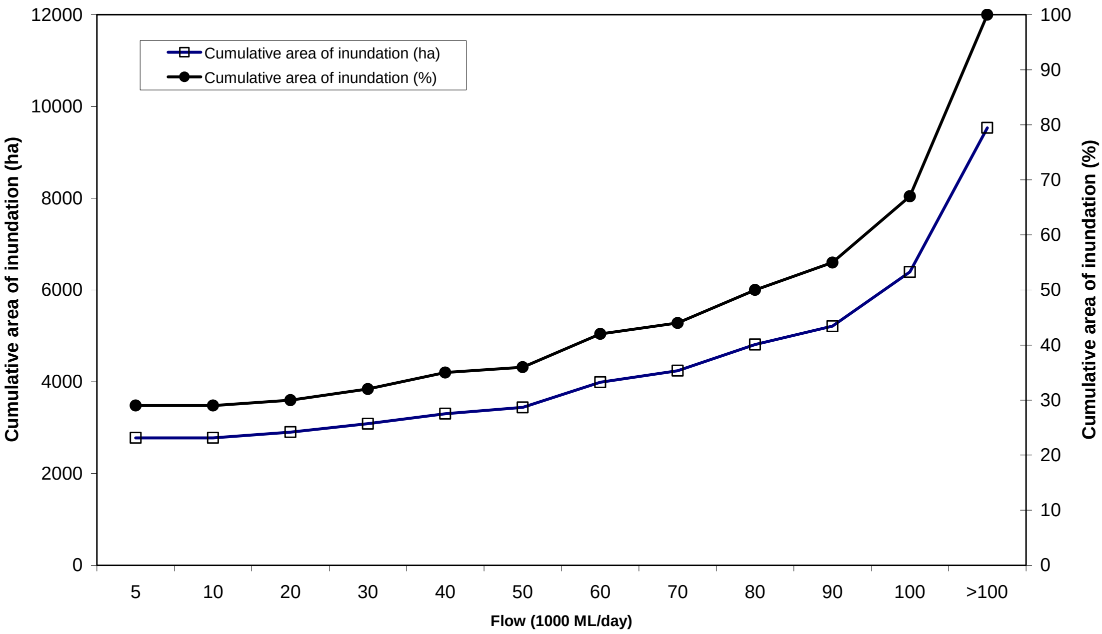


Figure 102. Zone 21- Area of inundation.

Table 64. Zone 21 - Number of wetlands inundated and area of wetlands inundated at 10,000ML/day flow increments.

Flow (1000 ML/day)	Cumulative number of wetlands inundated	Cumulative number of wetlands inundated (%)	Cumulative area of wetland inundation (Hectares)	Cumulative area of wetland inundation (%)
5	64	54	2491	80
10	65	55	2491	80
20	77	65	2531	81
30	80	68	2691	87
40	82	69	2778	89
50	83	70	2823	91
60	105	89	2965	95
70	109	92	2984	96
80	111	94	3005	97

90	112	95	3025	97
100	115	97	3083	99
110	118	100	3107	100
>110	118	100	3107	100

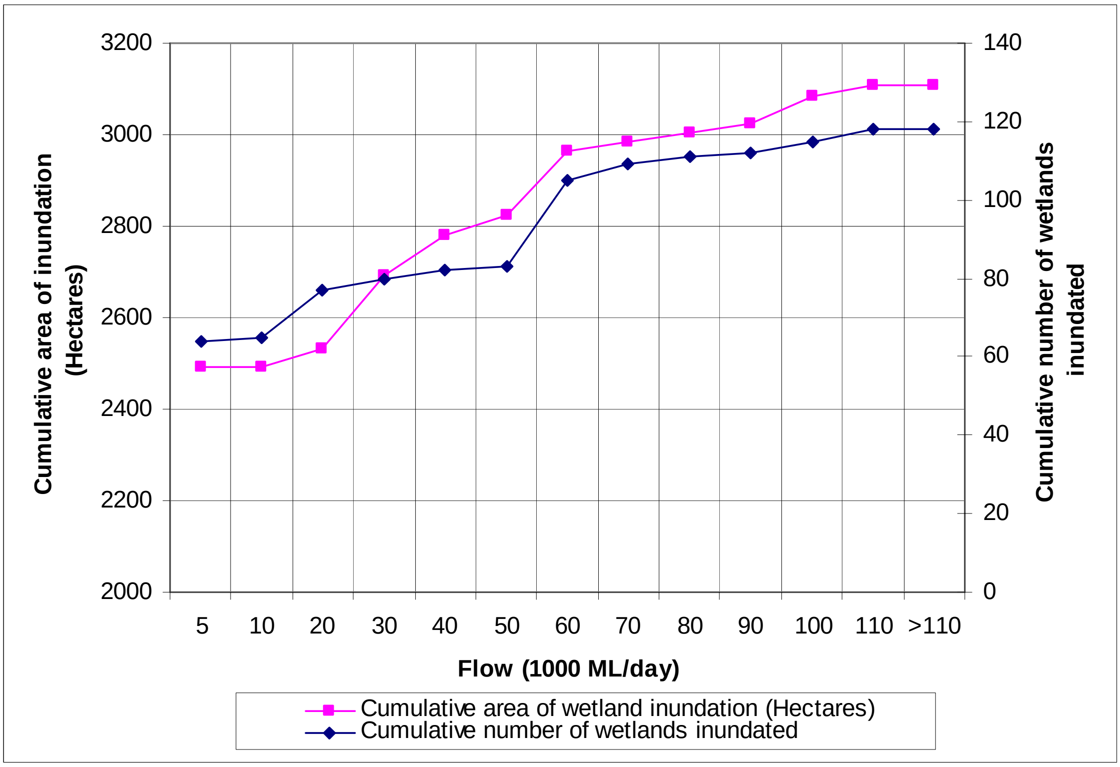


Figure 103. Zone 21 - Wetland inundation statistics.

Table 65. Zone 21 - Percentage of vegetation type inundated at 10,000 ML/day flow increments.

Flow (1000 ML/day)	% Red Gum	% Black Box	% Saline shrubland	% Lignum
5	23	7	5	9
10	23	7	5	9
20	25	8	5	10
30	26	8	5	11
40	32	8	5	13
50	33	9	5	16
60	41	13	6	26
70	43	15	7	34
80	50	21	7	48
90	55	25	9	59
100	74	42	14	78
>100	100	100	100	100

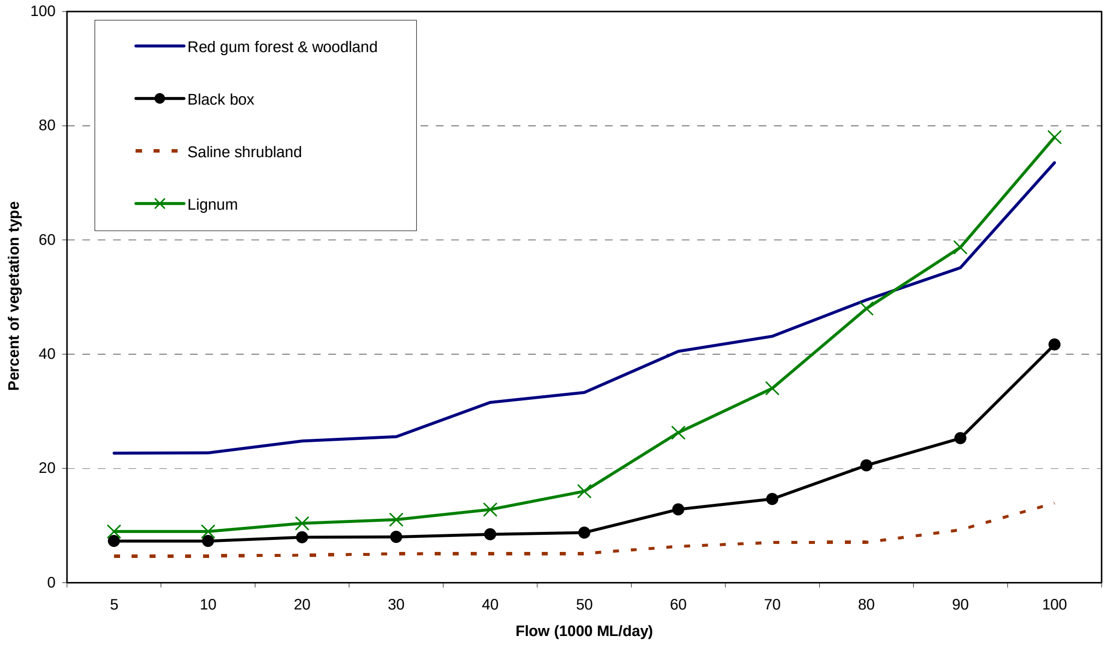


Figure 104. Zone 21 - Percentage of vegetation type inundated.

Zone 22

Zone	Description	Area (ha)	River km length	Travel time (days)
22	Lock 1 to Wellington	22763	207	5

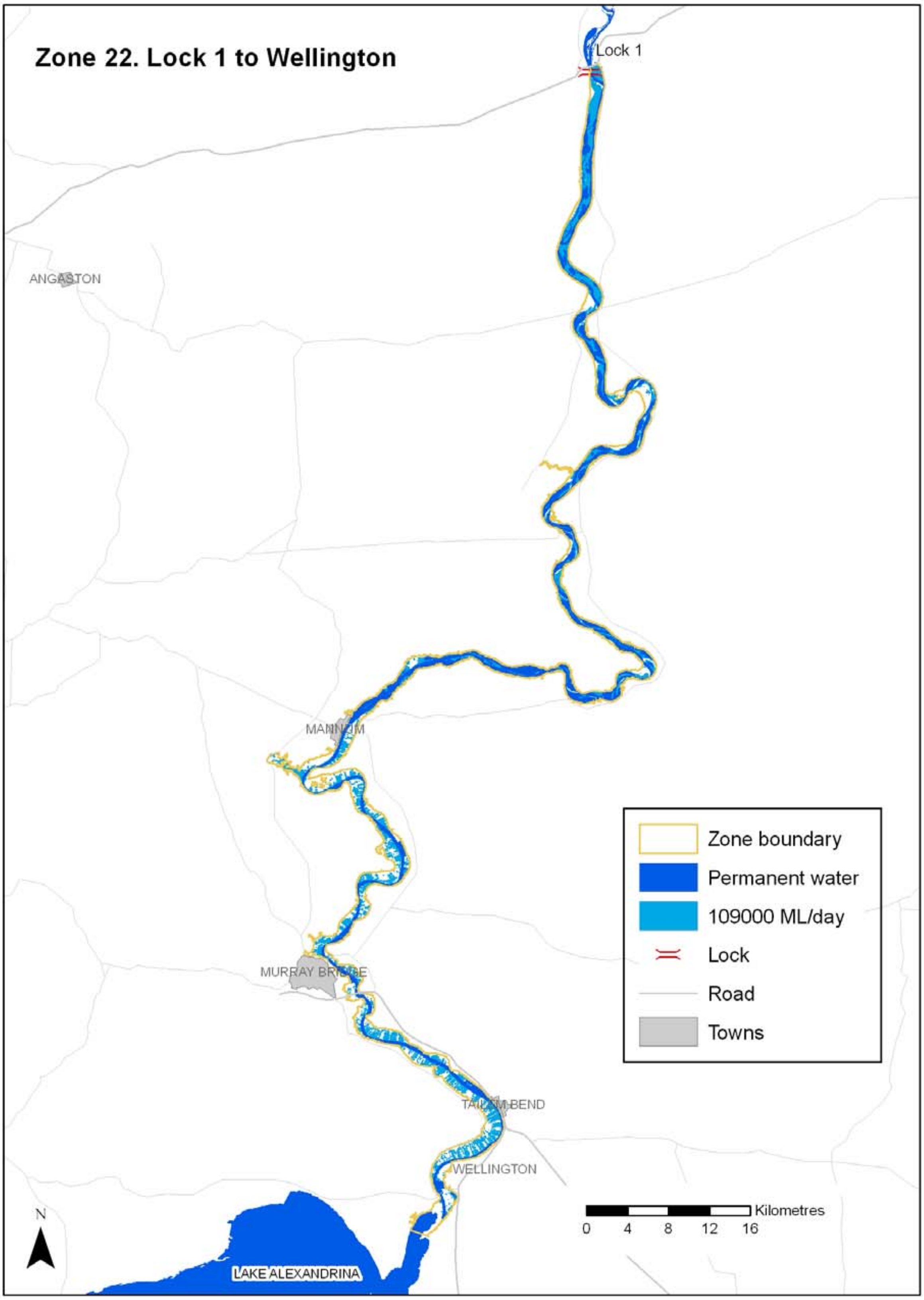


Figure 105. Zone 22 showing permanent water and maximum flood from satellite image.

Table 66. Zone 22 - Area of inundation at 10,000 ML/day flow increment.

Flow (1000 ML/day)	Cumulative area of inundation (Hectares)	Cumulative area of inundation (%)
5	6926	30
10	7001	31
20	7789	34
30	8091	36
40	8772	39
50	8940	39
60	10103	44
70	10106	44
80	10520	46
90	10609	47
100	12166	53
>100	22763	100

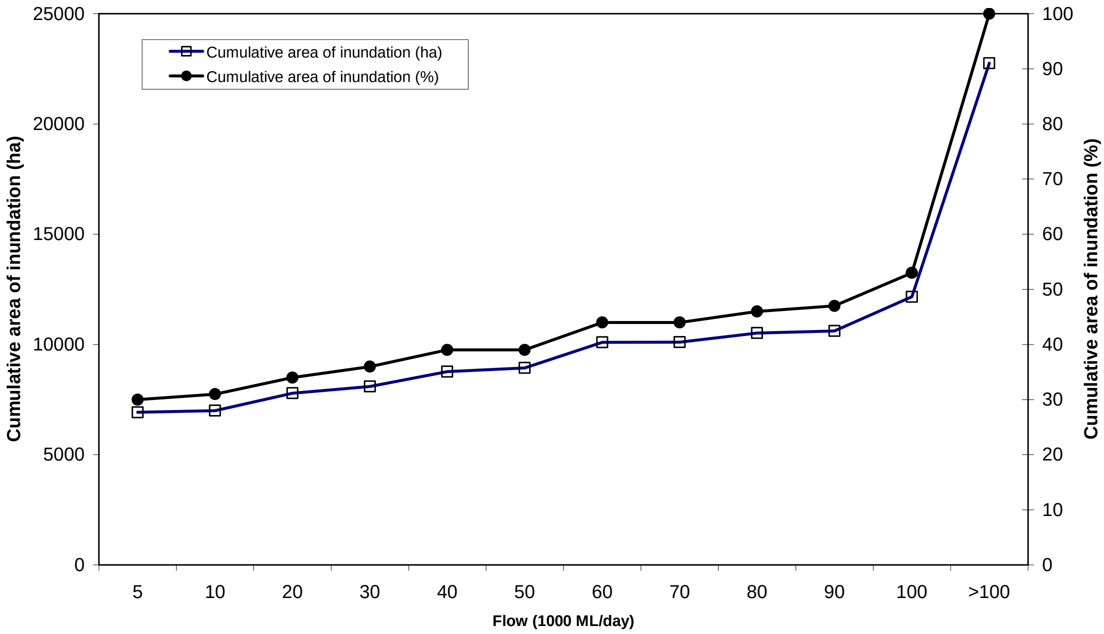


Figure 106. Zone 22 – Area of inundation.

Table 67. Zone 22 - Number of wetlands inundated and area of wetlands inundated at 10,000ML/day flow increments.

Flow (1000 ML/day)	Cumulative number of wetlands inundated	Cumulative number of wetlands inundated (%)	Cumulative area of wetland inundation (Hectares)	Cumulative area of wetland inundation (%)
5	127	86	6369	82
10	128	87	6419	82
20	134	91	6748	87
30	137	93	6958	89
40	141	96	7265	93
50	141	96	7300	94
60	144	98	7404	95

70	144	98	7405	95
80	144	98	7438	95
90	144	98	7444	96
100	146	99	7650	98
110	147	100	7790	100
>110	147	100	7790	100

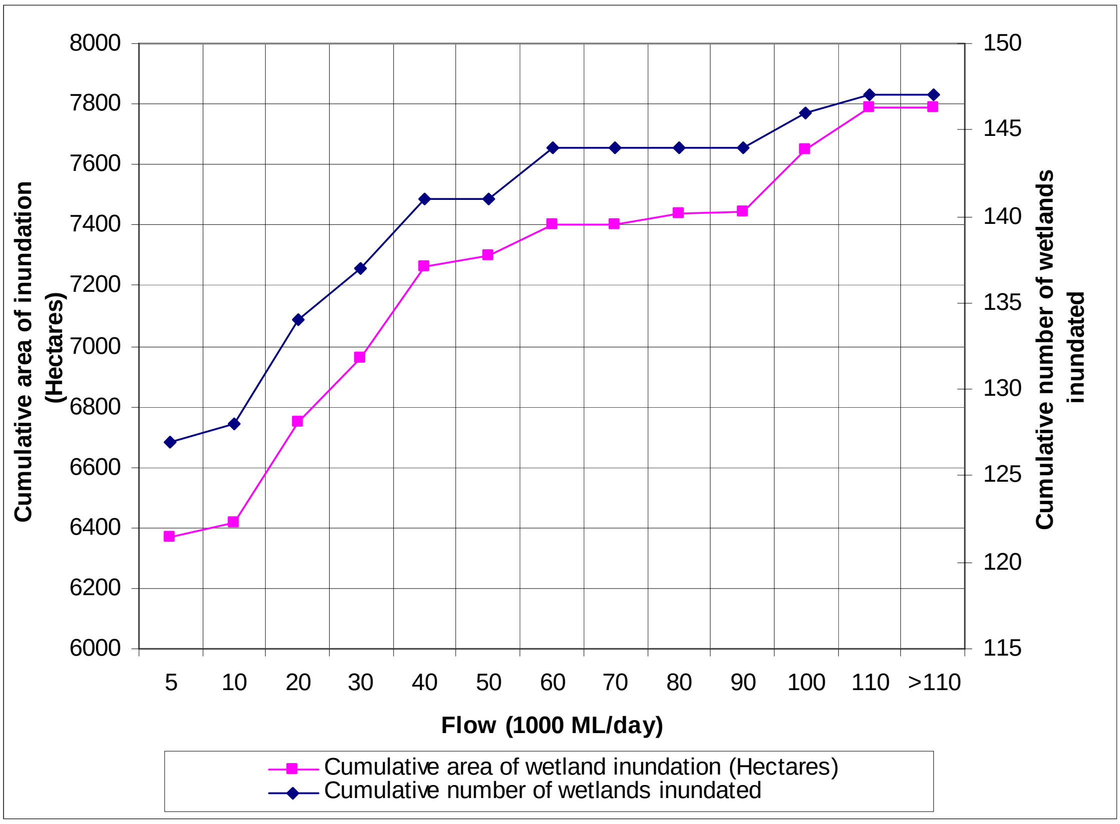


Figure 107. Zone 22 - Wetland inundation statistics.

Table 68. Zone 22 - Percentage of vegetation type inundated at 10,000 ML/day flow increments.

Flow (1000 ML/day)	% Red Gum	% Black Box	% Saline shrubland	% Lignum	% Agriculture/ horticulture
5	34	26	13	18	4
10	35	26	13	18	4
20	43	33	18	27	5
30	45	35	19	32	5
40	53	38	21	43	5
50	55	39	22	46	5
60	61	43	28	54	12
70	61	43	28	54	12
80	67	47	30	62	12
90	68	48	31	64	12
100	80	59	41	83	16
>100	100	100	100	100	100

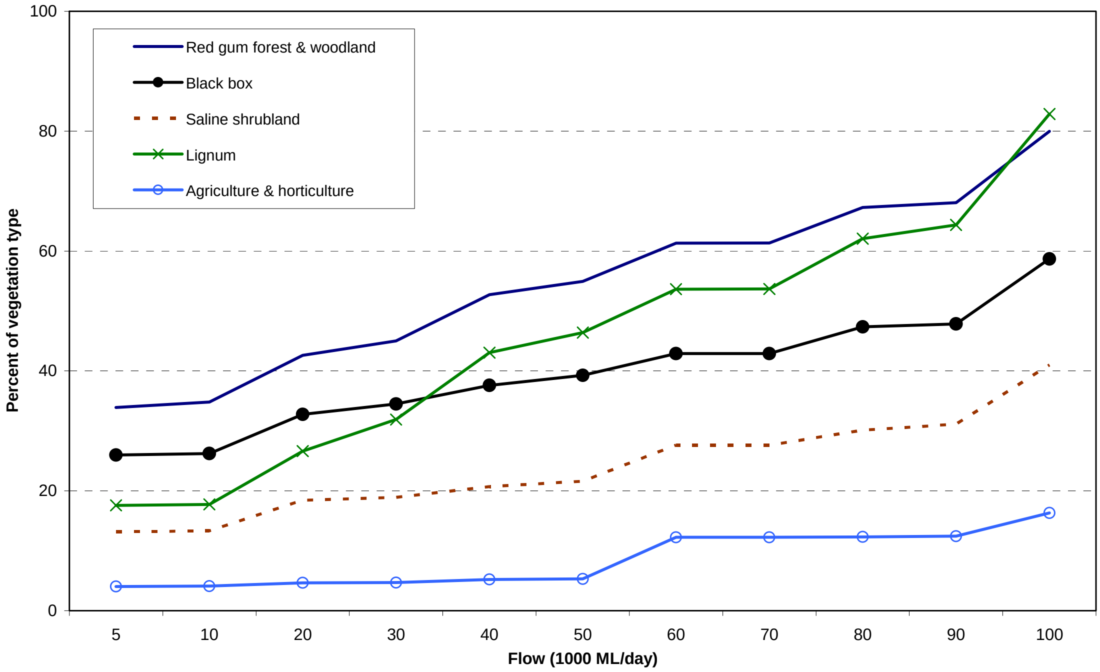


Figure 108. Zone 22 - Percentage of vegetation type inundated.