UNDERSTANDING WETLAND HABITATS AT REACH TO CATCHMENT SCALES

Namoi Wetland Remote Sensing

Prepared for
Cotton Catchment Communities CRC and Namoi CMA

4 May 2010

Understanding Wetland Habitats at Reach to Catchment Scales

NAMOI WETLAND REMOTE SENSING

PREPARED FOR	**Cotton-CRC, Namoi CMA**
PROJECT NO	**09ARMGIS-0001**
DATE	May 10

DOCUMENT TRACKING

ITEM	DETAIL
Project Name	Understanding Wetland Habitats at Reach to Catchment Scales
Project Number	09ARMGIS-0001
File location	S:\Synergy\projects\09ARMGIS\09ARMGIS-0001 Namoi Wetland Habitat Mapping\Report\Final reports
Prepared by	Hamish Mackinnon
	Paul Frazier
Approved by	Paul Frazier
Status	Final
Version Number	8
Last saved on	4 May 2010

ACKNOWLEDGEMENTS

This document has been prepared by Eco Logical Australia Pty Ltd with support from the Cotton Catchment Communities CRC, Namoi CMA and DECCW.

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Executive Summary

This project developed multi-scale remote sensing techniques to determine the location, extent and hydrological function of wetlands in the Namoi catchment. The project was broken into three distinct components that each examined wetland and riverine habitats at different scales. A medium-resolution lowland wetland component used multi-temporal Landsat TM data to relate river flow height to wetland inundation for a 40 km reach of the Namoi River around Wee Waa. The upland wetlands section sought to refine techniques to map upland wetland extent in the upper Namoi catchment using multi-source datasets, including SPOT 5 data, Landsat TM and a medium resolution DEM. The final section of the project developed and assessed very high-resolution LiDAR and airborne image data for describing riverine habitats on a 1 km reach of the Namoi River below Wee Waa.

The medium resolution section successfully developed and applied methods to map wetland extent and relate river flow to wetland inundation for a 40 km reach of the Namoi River. Analysis of the downstream attenuation of floods in the reach using historical gauge data showed that upstream flood peaks could be used to predict downstream flood behaviour in a reliable manner. Further a discharge range between 35,000 and 75,000 ML/Day was identified as critical to a substantial increase in wetland inundation.

The development of semi-automated techniques for mapping upland wetlands proved unsuccessful using the available datasets. The variation in wetland cover caused by a broad range of farm management practices caused too much spectral variation in satellite imagery to permit useful application of semi-automated processes. In addition, currently available DEM data are too coarse for mapping of these generally narrow features. However, manual mapping of these features based on visual interpretation of 2.5 m pixel merged SPOT 5 data coupled with appropriate mapping rules can be applied to substantially refine to current mapping of upland wetland features.

The use of high-resolution LiDAR and digital image data proved successful for mapping riverine habitats at very fine scales. The topographic data provided by the LiDAR permitted the identification of the channel top boundary and hence separation on in-channel and overbank environments. This topographic data also allowed the mapping of key habitats that could be defined by slope, elevation and general shape characteristics. Linking the habitat map to the 3d DEM surface permitted the map to be linked to river stage height data and hence historical habitat inundation patterns could be examined.

Key recommendations to arise out of this project are:

- Extend the medium resolution wetland inundation mapping technique beyond the 40 km reach to other key reaches in the catchment. The availability of free Landsat TM data greatly reduces any costs of key data for this study.
- Undertake a project to map the extent and location of upland wetlands in the Namoi catchment. This study has shown that existing wetland databases significantly under estimate

wetland extent in the upland region of the catchment. A project that focused specifically on mapping upland wetlands with appropriate mapping rules and scale would provide a much more accurate map of the upland wetlands in the region.

- High-resolution data and techniques to relate flow to inundation proved successful for the study reach analysed in this project. The key recommendation from this study is to investigate potential new research into understanding riverine habitat function following inundation events so that the 3d habitat inundation model can be developed into a 3d riverine habitat function model.

Introduction

1.1 BACKGROUND

Recent reviews of the principles underlying the management of large rivers stress the need for a better understanding of the relationships between elements of the flow regime and ecological processes. Each review has focused on the re-instatement of elements of the natural flow regime as a goal for river restoration. As such, environmental flows are assuming a central role in the management of Australian rivers. The recent and continuing reforms of the Australian water industry, with a greatly strengthened intent to achieve ecological as well as economic sustainability, have created a political will to improve river management. What we lack is the knowledge to operate river systems in a more ecologically responsive way. Where we do have relevant information it is frequently not in the form of protocols and decision criteria which can be incorporated into the operating rules for the river system at an appropriate spatial scale. This has resulted in severe technical and knowledge-based obstacles to the effective implementation and ecological assessment of environmental flows.

1.2 PROJECT AIMS

This project aimed to develop better understanding of the environmental flow regime(s) necessary to restore and sustain the health of the target river by using a GIS-based model of the relationship between river flows and ecosystem processes to predict outcomes of a range of environmental flow scenarios in the Namoi catchment (Figure 1). Specific project objectives were to:

- Develop new methods of using medium-resolution remotely sensed data (eg Landsat) to map floodplain, wetland and riparian habitats and quantify the inundation regime of each habitat;
- Develop new methods to map the location, extent and function of upland wetlands in the Namoi catchment.
- Develop new methods of using high-resolution remotely sensed data to map in-channel riverine habitats and quantify the inundation regime of each habitat;

1.3 REPORT STRUCTURE

As the project consisted of three main sections this report is split into three distinct components:

- Medium-Resolution Lowland Wetland Inundation Mapping
- Upland Wetlands Developing Mapping Methods
- High-resolution Habitat Mapping and Inundation Modelling

1 Location

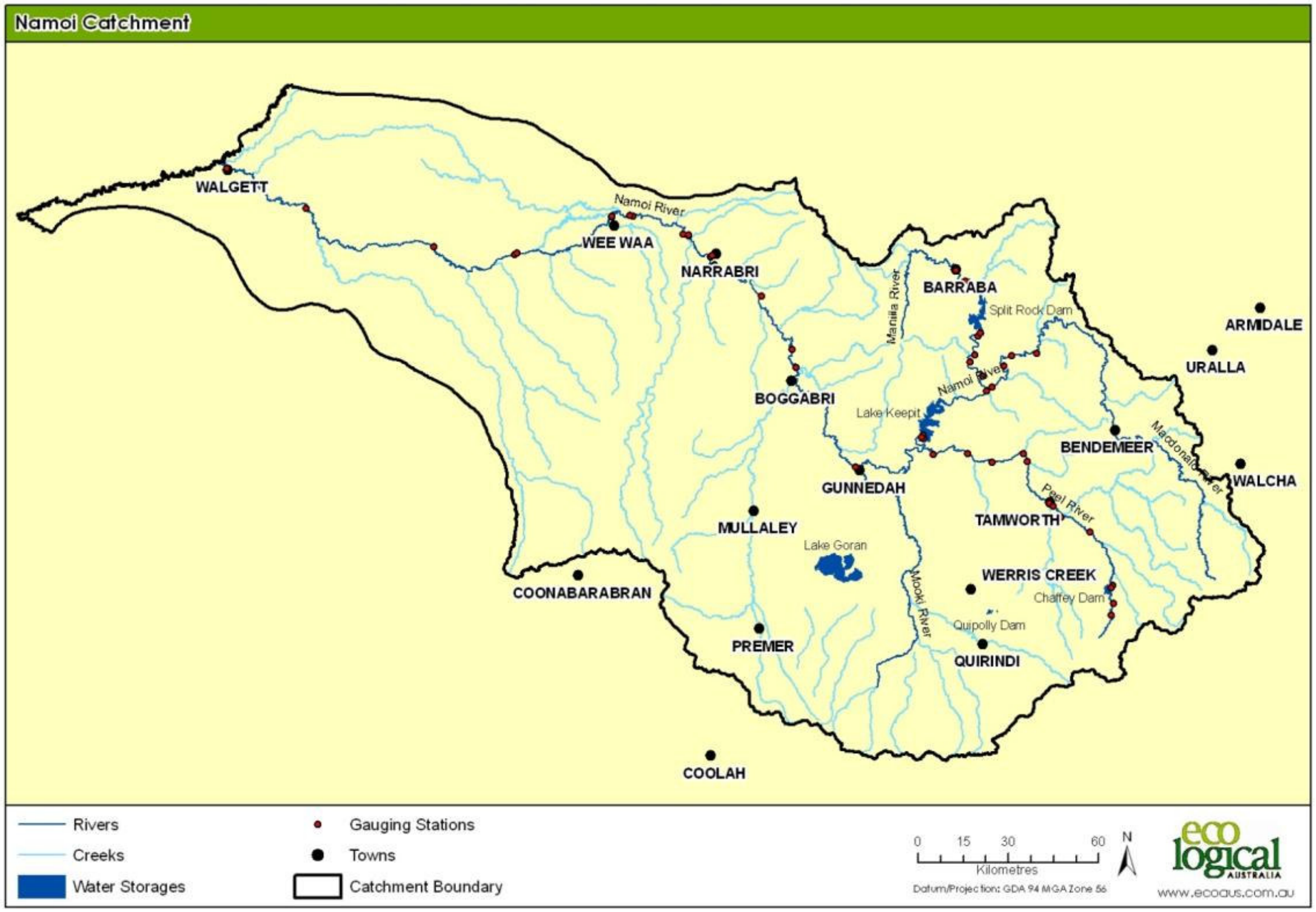

Figure 1: Map of the Namoi Catchment

2 Medium-resolution Wetland Mapping (Lowland)

2.1 AIM

The aim of this component was to develop and verify methods of using medium-resolution remotely sensed data (Landsat TM) to map floodplain wetland inundation stages.

2.2 METHODS

2.2.1 River reach selection

An approximate 40 km long river reach, around Wee Waa, was selected for this component of the project (Figures 2 and 3). The reach was selected because: it is in a lowland area; contains a large number of previously mapped wetlands; has good gauge records for the upper and lower sections of the reach; and had a good selection of Landsat images available via the archive.

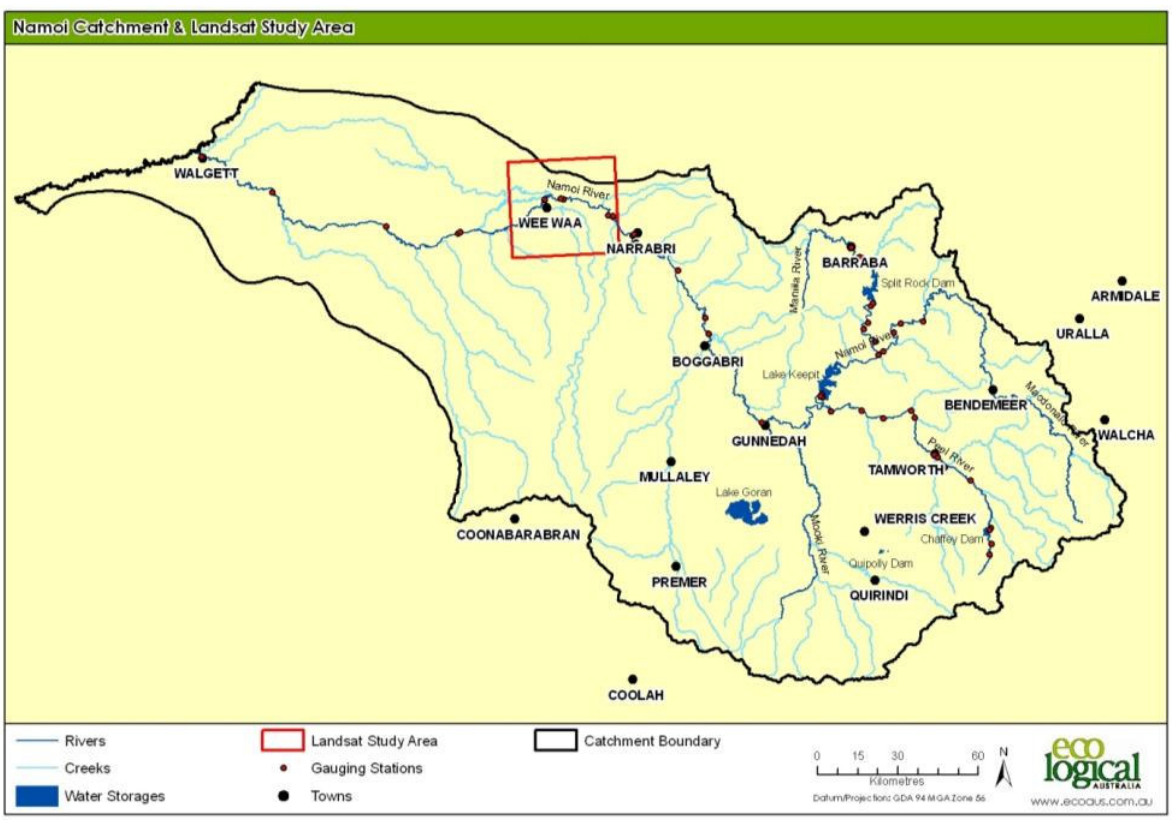

Figure 2: Location of study area within the Namoi catchment

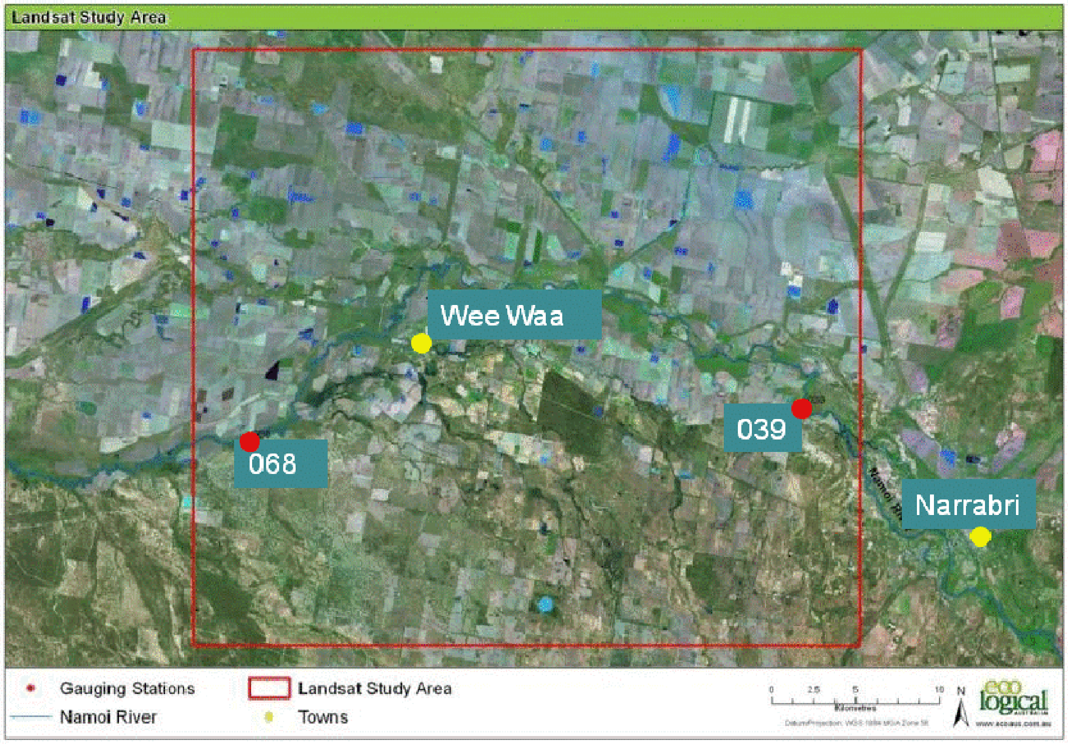

Figure 3: Location of study area within the lowland region. Gauge locations indicated.

2.2.2 Description of reach hydrology

This river reach contains a river gauge at the upstream end (419039 – Namoi at Mollee) and downstream end (419068 – Namoi at Weeta Weir). For the duration of this report the gauge 419039 is referred to as 039 and the the gauge 419068 is referred to as 068. Daily mean flow data from 1970 to 2008 for each of these gauges were extracted from the *PINNEENA* database for further analysis. These data were analysed for to describe annual exceedance probability and downstream flood passage behaviour.

<u>Annual Exceedence Probability (Annual flood analysis)</u>

Annual exceedance probability analysis was undertaken to gain understanding of the return period of floods in the region. The highest daily discharge for each year and gauge was extracted (where records were available), tabulated and ranked in decreasing order (with the largest flood having a rank of 1 the second largest a rank of 2 and so on). There were 39 recorded floods by the 039 gauge and 30 recorded floods by the 068 gauge. The data were than analysed according to the Annual Exceedence Probability formula:

$$\text{AEP}=\frac{m-0.4}{N+0.2}$$

Where: AEP = Annual exceedence probability

m = rank of the flood in the series (largest flood having m=1)

N = number of years on record

This reciprocal of the AEP was then calculated to give the flood return period (Tables 1 and 2).

Table 1: Annual exceedence probability for the 039 gauge on the Namoi River

YEAR	MAX	RANK	AEP	1/AEP	YEAR	MAX	RANK	AEP	1/AEP
1974	187920.1	1	0.0153	65.3	1993	17598.54	21	0.5255	1.9
1984	185707.3	2	0.0408	24.5	1986	16376.53	22	0.5510	1.8
1998	185070.9	3	0.0663	15.1	1983	16266.25	23	0.5765	1.7
1976	175353.4	4	0.0918	10.9	1988	14557.5	24	0.6020	1.7
2000	173398.8	5	0.1173	8.5	1975	11802.4	25	0.6276	1.6
1971	133827.6	6	0.1429	7.0	2001	11237.52	26	0.6531	1.5
1977	99996.75	7	0.1684	5.9	1981	10229.46	27	0.6786	1.5
2004	72510.20	8	0.1939	5.2	1973	8729.76	28	0.7041	1.4
1992	68172.23	9	0.2194	4.6	1995	7824.89	29	0.7296	1.4
1997	64558.25	10	0.2449	4.1	1979	6748.64	30	0.7551	1.3
1989	51484.3	11	0.2704	3.7	2007	6244.92	31	0.7806	1.3
1990	45252.62	12	0.2959	3.4	1970	6116.44	32	0.8061	1.2
1991	39223.39	13	0.3214	3.1	1972	4788.85	33	0.8316	1.2
1978	34634.11	14	0.3469	2.9	1982	4109.19	34	0.8571	1.2
2008	34038.01	15	0.3724	2.7	2003	3958.62	35	0.8827	1.1
2005	32147.53	16	0.3980	2.5	2002	3546.04	36	0.9082	1.1
1996	27147.48	17	0.4235	2.4	1980	3099.75	37	0.9337	1.1
1987	19341.18	18	0.4490	2.2	2006	3035.07	38	0.9592	1.0
1985	19204.29	19	0.4745	2.1	1994	1815.56	39	0.9847	1.0
1999	17725.72	20	0.5000	2.0					

Table 2: Annual exceedence probability for the 068 gauge on the Namoi River

YEAR	MAX	RANK	AEP	1/AEP	YEAR	MAX	RANK	AEP	1/AEP
2000	64518.73	1	0.0199	50.3	1988	12238.54	16	0.5166	1.9
1984	59408.95	2	0.0530	18.9	1987	11872.8	17	0.5497	1.8
1998	56252.77	3	0.0861	11.6	1986	11711.26	18	0.5828	1.7
2004	38104.96	4	0.1192	8.4	1999	11013.86	19	0.6159	1.6
1992	27035.96	5	0.1523	6.6	1995	8998.68	20	0.6490	1.5
1997	26824.64	6	0.1854	5.4	1993	7931.59	21	0.6821	1.5
1989	24122.54	7	0.2185	4.6	1981	7317.24	22	0.7152	1.4
1991	23631.11	8	0.2517	4.0	1979	6383.22	23	0.7483	1.3
1990	23283.53	9	0.2848	3.5	1982	4373.69	24	0.7815	1.3
2005	17385.99	10	0.3179	3.1	2007	4052.13	25	0.8146	1.2
1983	16044.36	11	0.3510	2.8	2003	3684.56	26	0.8477	1.2
1985	15748.39	12	0.3841	2.6	1980	1856.06	27	0.8808	1.1
1996	14050.52	13	0.4172	2.4	2002	942.69	28	0.9139	1.1
2001	13468.71	14	0.4503	2.2	2006	828.34	29	0.9470	1.1
2008	12542.61	15	0.4834	2.1	1994	521.69	30	0.9801	1.0

Downstream flood passage behaviour

Analysis of downstream flood passage behaviour was undertaken by examining the behaviour of flood hydrology for all floods that occurred between 1970 and 2008. Floods above 10000 ML/day at the 068 gauge were considered floods and the flood peak discharge was recorded at both the 039 and 068 gauges (eg Figure 4). These records were tabulated and a flood peak attenuation graph was created (Figure 5).

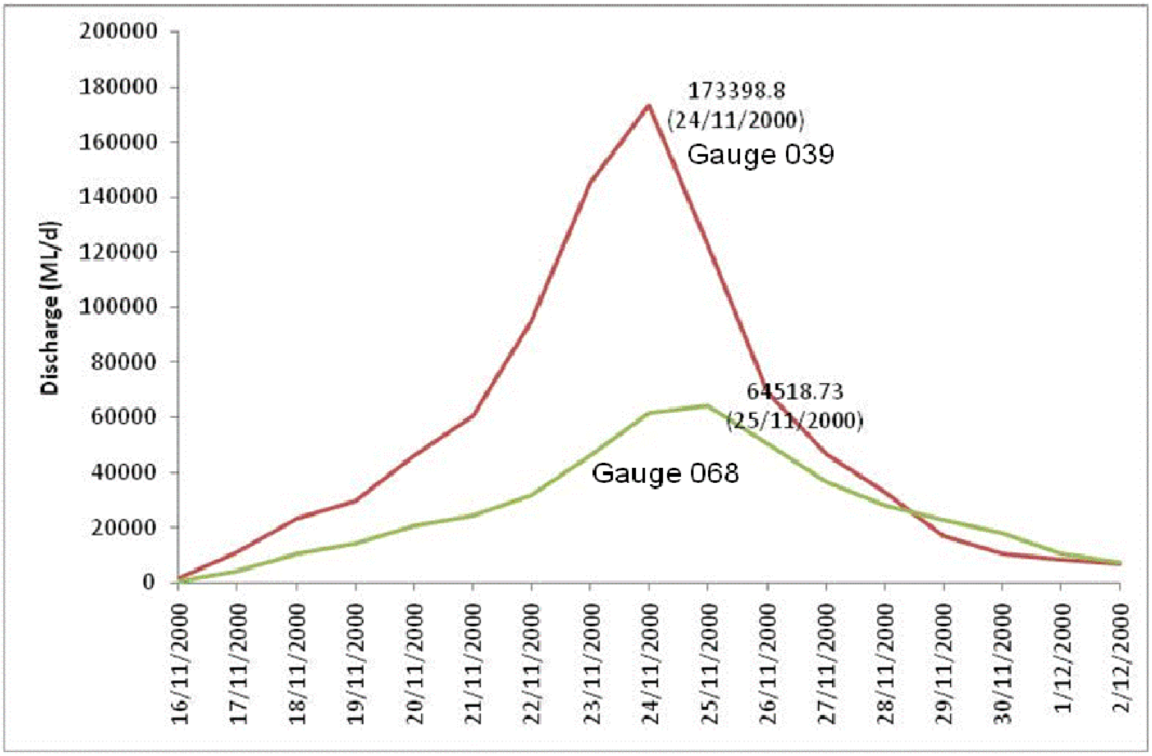

Figure 4: Flood event in the year of 2000 with the peak discharge at each gauge.

Table 3: Flood readings from 039 and 068 gauges

Flood Date	039 Peak	Flood Date	068 Peak		Flood Date	039 Peak	Flood Date	068 Peak
29/05/1983	15687.33	30/05/1983	15250.33		14/02/1992	68172.23	16/02/1992	27035.96
10/09/1983	16266.25	11/09/1983	16044.36		12/07/1993	17598.54	13/07/1993	11547.3
21/01/1984	11460.77	22/01/1984	15605.96		7/01/1996	14400.42	8/01/1996	10445.15
3/02/1984	185707.3	4/02/1984	59408.95		31/07/1996	27147.48	1/02/1996	15396.9
27/02/1984	32699.84	29/02/1984	21340.59		4/09/1996	14324.47	5/09/1996	9908.03
1/08/1984	80799.25	2/08/1984	32391.33		9/12/1996	15098.34	10/12/1996	11311.86
12/11/1984	21333.12	15/11/1984	18030.46		1/02/1997	41252.74	3/02/1997	22575.4
15/12/1985	19204.29	16/12/1985	15748.39		17/02/1997	64558.25	19/02/1997	26824.64
20/07/1986	16376.53	30/07/1986	11711.26		3/03/1997	14864.13	4/03/1997	10242.02
5/01/1987	19341.18	5/01/1987	11872.8		28/06/1998	33679.18	30/06/1998	16533.7
21/08/1987	10021.28	22/08/1987	9314.81		25/07/1998	185070.9	26/07/1998	56252.77
9/07/1988	14557.5	10/07/1988	12238.54		29/08/1998	32633.22	31/08/1998	19187.42
17/04/1989	30829.88	18/04/1989	18727.94		10/09/1998	105991.3	11/09/1998	42630.31

20/05/1989	23536.22	22/05/1989	16804.89		29/09/1998	15453.51	30/09/1998	11546.43
10/06/1989	51484.3	11/06/1989	24120.52		9/04/1999	17725.72	10/04/1999	11013.86
5/08/1989	26003.26	6/08/1989	16704.57		9/03/2000	2640.25	12/03/2000	10945.14
24/04/1990	39851.92	27/04/1990	19205.22		24/11/2000	173398.8	25/11/2000	64518.73
1/08/1990	31057.35	8/07/1990	10766.98		2/02/2001	11237.52	3/02/2001	13468.71
9/08/1990	45252.62	11/08/1990	23283.53		18/01/2004	18545.55	21/01/2004	12225.2
6/09/1990	19900.41	7/09/1990	15433.35		29/01/2004	15807.89	30/01/2004	9676.7
19/09/1990	14525.53	20/09/1990	11668.99		12/12/2004	75510.2	13/12/2004	38104.96
1/02/1991	32672.69	2/02/1991	15807.1		29/12/2004	11372.25	30/12/2004	7987.9
24/05/1991	39223.39	25/05/1991	23631.11		2/07/2005	32147.53	3/07/2005	17385.99
13/06/1991	35535.23	14/06/1991	18101.84		4/12/2008	34038.01	5/12/2008	12020.8
13/07/1991	28932.39	14/07/1991	16440.11		18/12/2008	23891.74	19/12/2008	12002.75

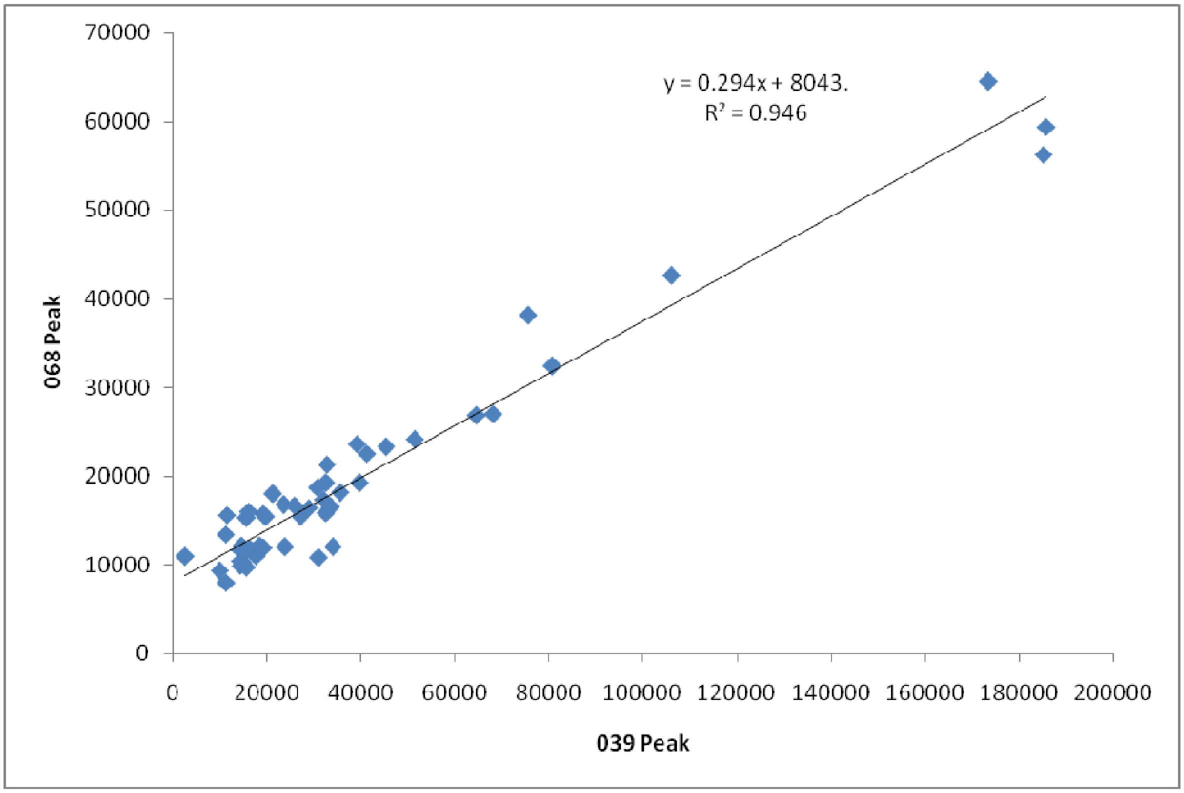

Figure 5: Flood peak attenuation between 039 and 068 gauges on the Namoi River

Figure 5 indicates that downstream flood behaviour is relatively predictable between gauge 039 and 068. These data show a consistent trend that can be predicted reliably using a straight line function (r^2 0.946). This reliable behaviour provides a basis for continued study of the relationship between upstream gauge reading and within reach floodplain wetland inundation stage.

2.2.3 Image selection

All archived Landsat TM images were cross-checked against the hydrological data at each gauges to assess the best image data sets that could be used to describe flood inundation behaviour. The before-flood and after-flood sets of Landsat images were acquired for a range of flood magnitudes to determine the commence-to-fill stage of floodplain wetlands of the Namoi River.

Six separate floods were selected for analysis (Table 4). The smallest flood analysed had a peak of 18546 MLd^{-1} at 039 in 2004, with the other floods progressively larger up to a flood peak discharge of 173399 MLd^{-1} in 2000.

Table 4: Images selected before and after flood events to determine wetland inundation, including the peak discharge of the flood.

Image sets		Flood peak discharge (MLd^{-1})			Flood peak discharge (MLd^{-1})		
Before-flood image date	**After-flood image date**	GAUGE 039	AEP	DATE	GAUGE 068	AEP	DATE
6/10/2000	9/12/2000	173399	8.5	24/11/2000	64519	50.3	25/11/2000
24/11/2003	27/01/2004	18546	2.0	18/01/2004	12225	1.9	20/01/2004
26/11/2004	28/12/2004	72510	5.2	12/12/2004	38105	8.4	13/12/2004
6/06/2005	24/07/2005	32148	2.5	2/07/2005	17386	3.1	3/07/2005
20/10/2008	25/02/2009	34038	2.7	4/12/2008	12546	2.1	5/12/2008

2.2.4 Image Processing

Each selected image was downloaded from the archived web site (landsat.gsfc.nasa.gov/data/ accessed 9/3/10). These images were compared to rectified SPOT 5 data covering the area using six well defined ground control points. Each image was found to be rectified to a precision of greater than 1 pixel and thus re-rectification was not needed.

Band 5 of each image was then density sliced to map the water extent on each image (Frazier and Page 2000). Each before-flood and after flood image set was then analysed to determine if wetlands had recieved water from the particular flood under examination (Frazier et al 2003).

All of the band 5 images were then clipped to a common area (Figures 6 and 7).

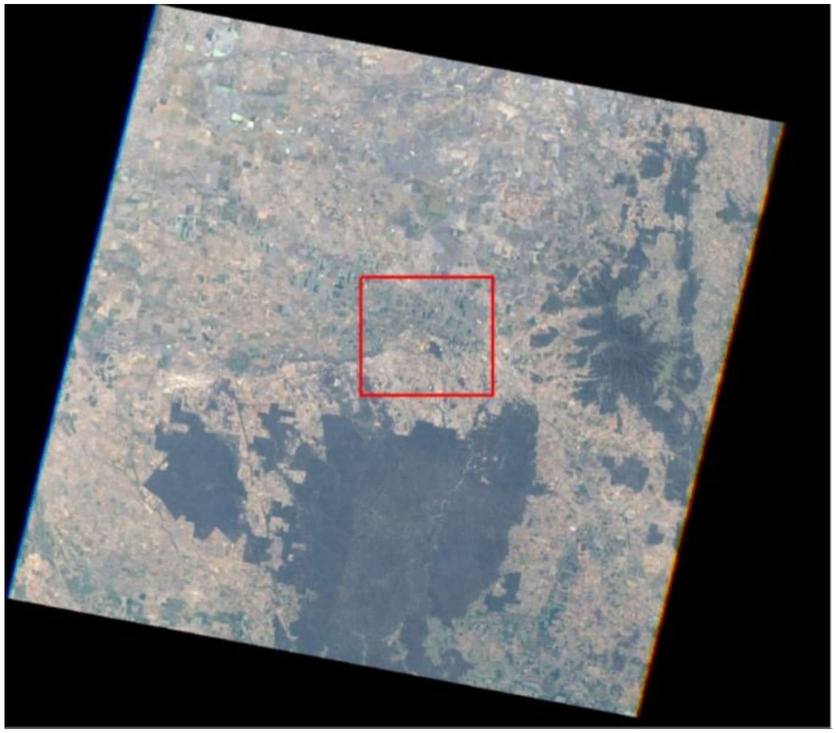

Figure 6: Raw Landsat image and highlighted area of interest.

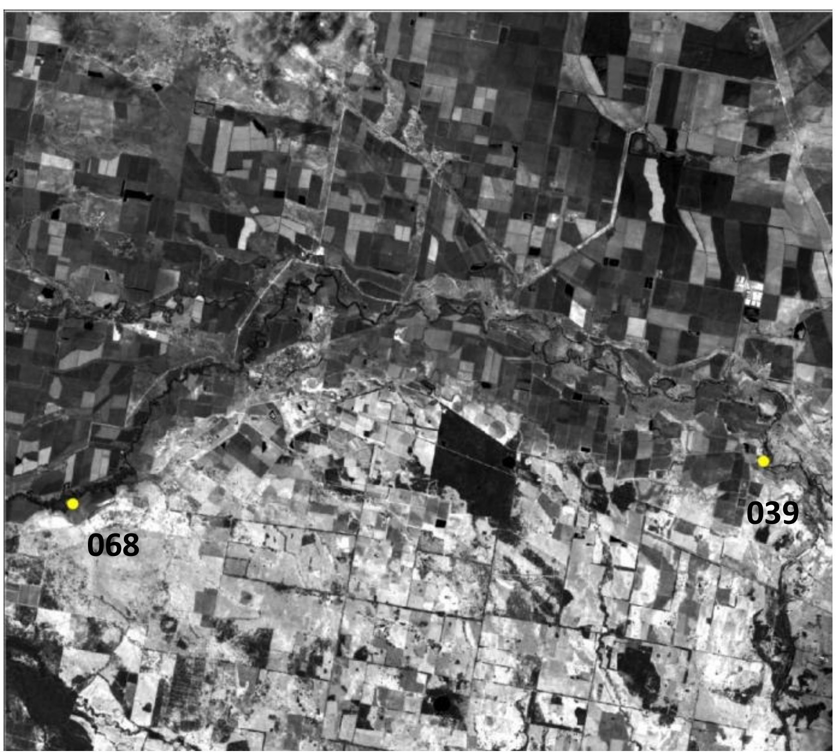

Figure 7: Cropped Landsat image, with gauges.

2.2.5 Wetland inundation analysis

To create a comprehensive wetland layer for the region the existing wetland mapping was overlayed on the density sliced image captured after the largest flood on record. This combined dataset was then used to eliminate obviously artificial wetlands and update the wetland map layer. This data layer was use as the base maximum wetland layer for the reach (Figure 8).

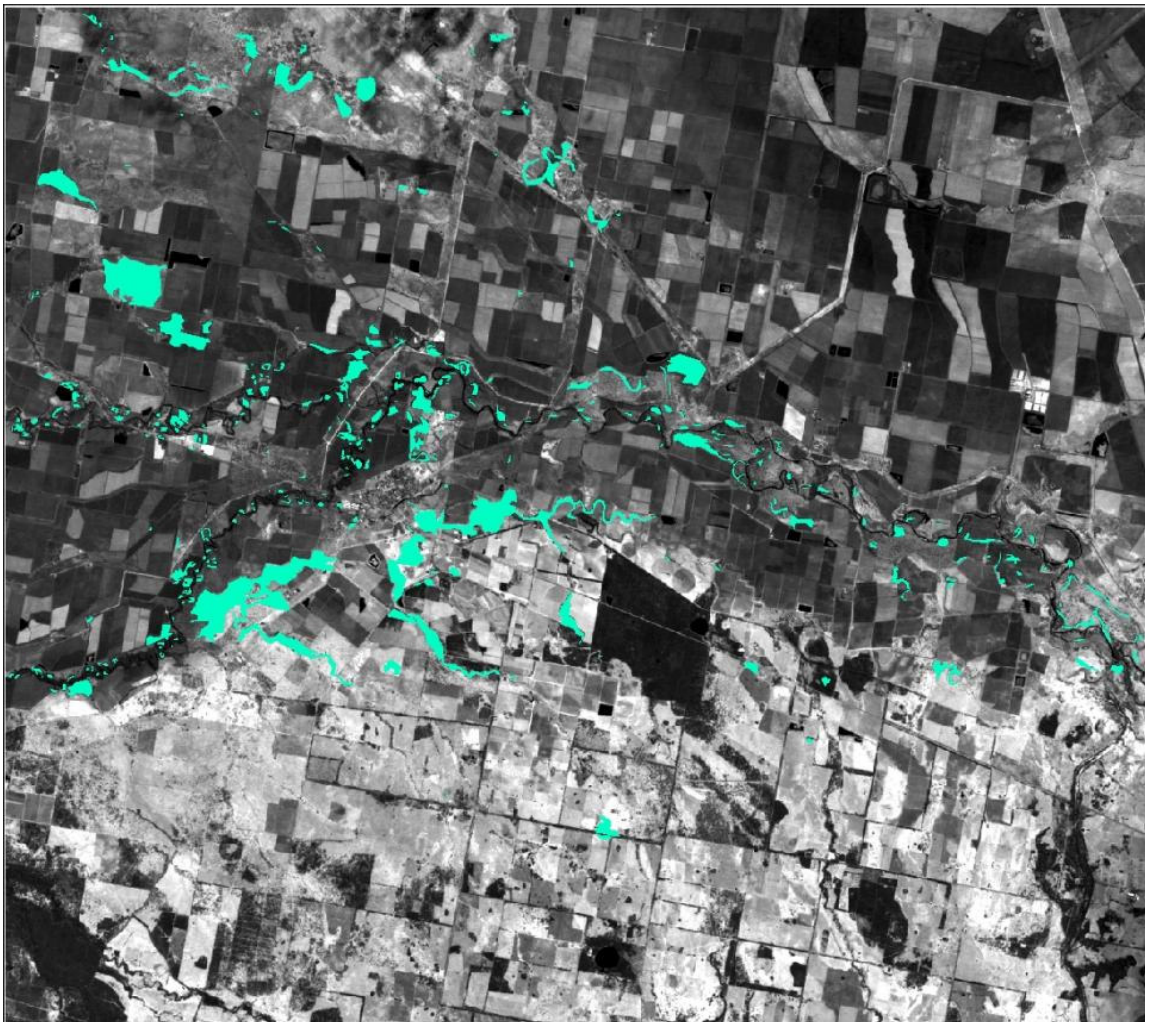

Figure 8: Base wetland layer

The base wetland extent layer was used as a template to compare each Landsat image set. Comparisons were made in an iterative loop initially working with the images associated with the largest flood and the progressively analysing images associated with the next smaller flood until all before and after-flood sets were analysed (Frazier et al 2003).

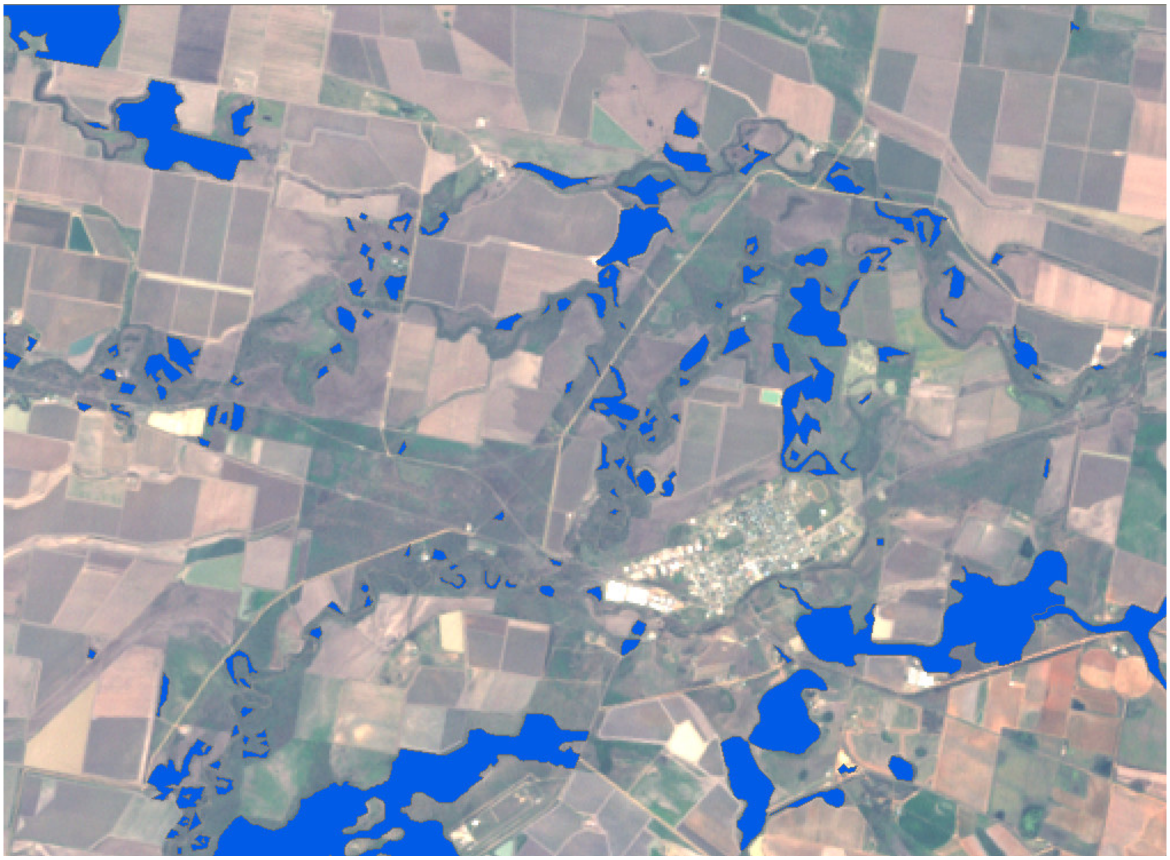

Figure 9: Subset of the wetland inundation caused by the largest flood (173,399 ML/d 9/12/2000)

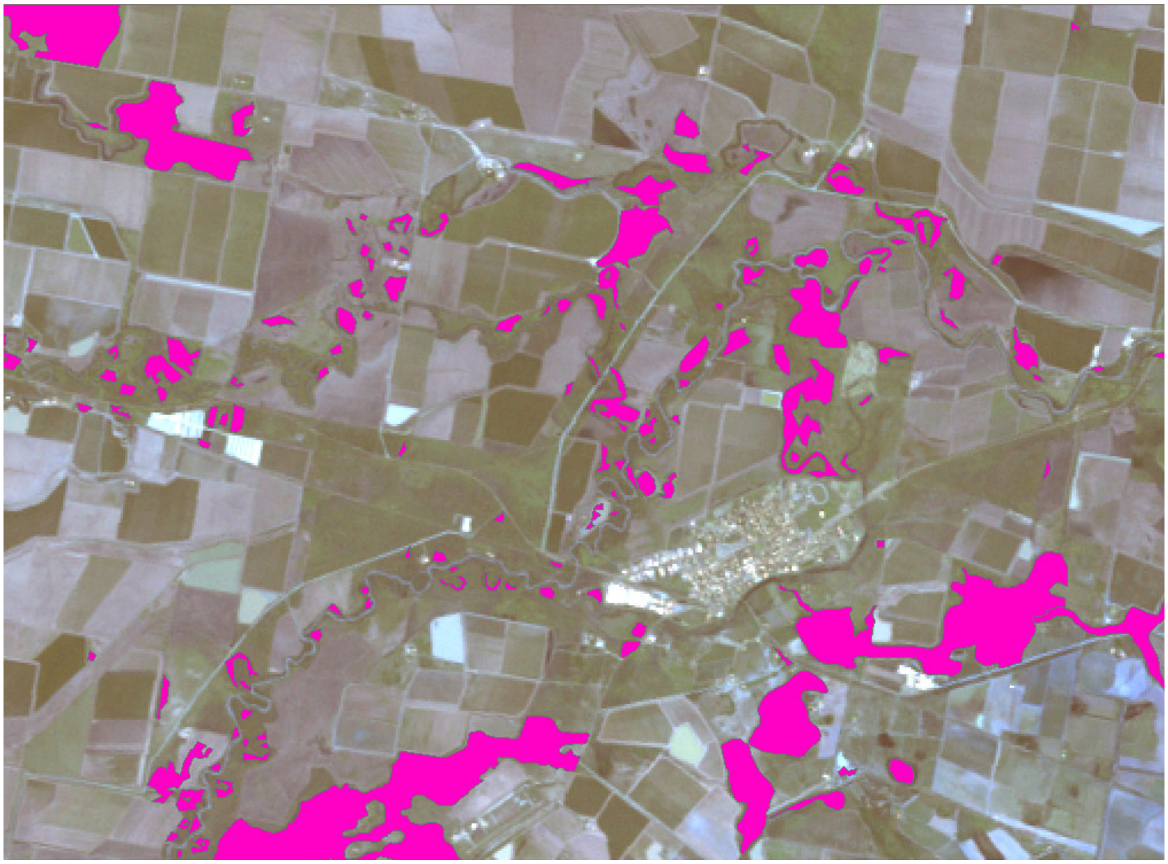

Figure 10: Subset of the wetland inundation caused by the 72,510 ML/d flood (28/12/2004)

Figure 11: Subset of the wetland inundation caused by the 34,038 ML/d flood (25/02/2009)

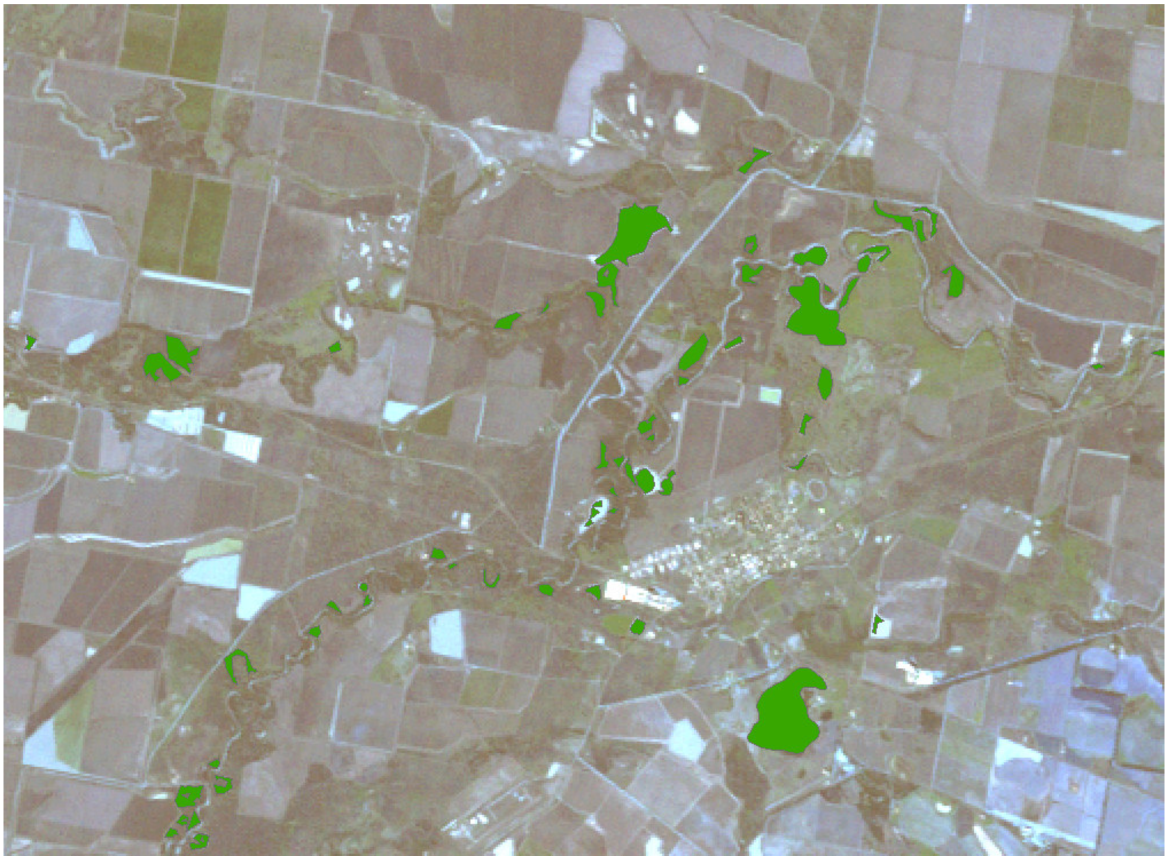

Figure 12: Subset of the wetland inundation caused by the 32,148 ML/d flood (24/07/2005)

Figure 13: Subset of the wetland inundation caused by the 18,546 ML/d flood (27/01/2004)

2.3 RESULTS

The resulting information provides a reach-scale dataset that links wetland inundation to river discharge in (ML/d) or stage (m) (Table 6, Figure 14). The largest flood inundated 322 individual wetlands or 3162 ha of wetlands in the reach. The flood peak discharge and inundated wetland area showed a 2-part relationship (Figure 14), with the smaller floods inundating considerably fewer wetlands than the 2 larger floods. It is likely that in this reach bankfull river stage falls between 34000 and 72500 ML/d as it appeared that a flood greater than bankfull stage inundated almost all of the wetlands in the reach.

Table 5: The relationship between wetland inundation and flood peak discharge

Flood Date	Flood Peak	Number of Inundated Wetlands	Area of Inundated Wetlands (ha)
9/12/2000	173398.8	322	3161.92
28/12/2004	72510.21	315	3156.69
25/02/2009	34038.01	148	1036.81
24/07/2005	32147.53	143	1020.17
27/01/2004	18545.55	113	965.49

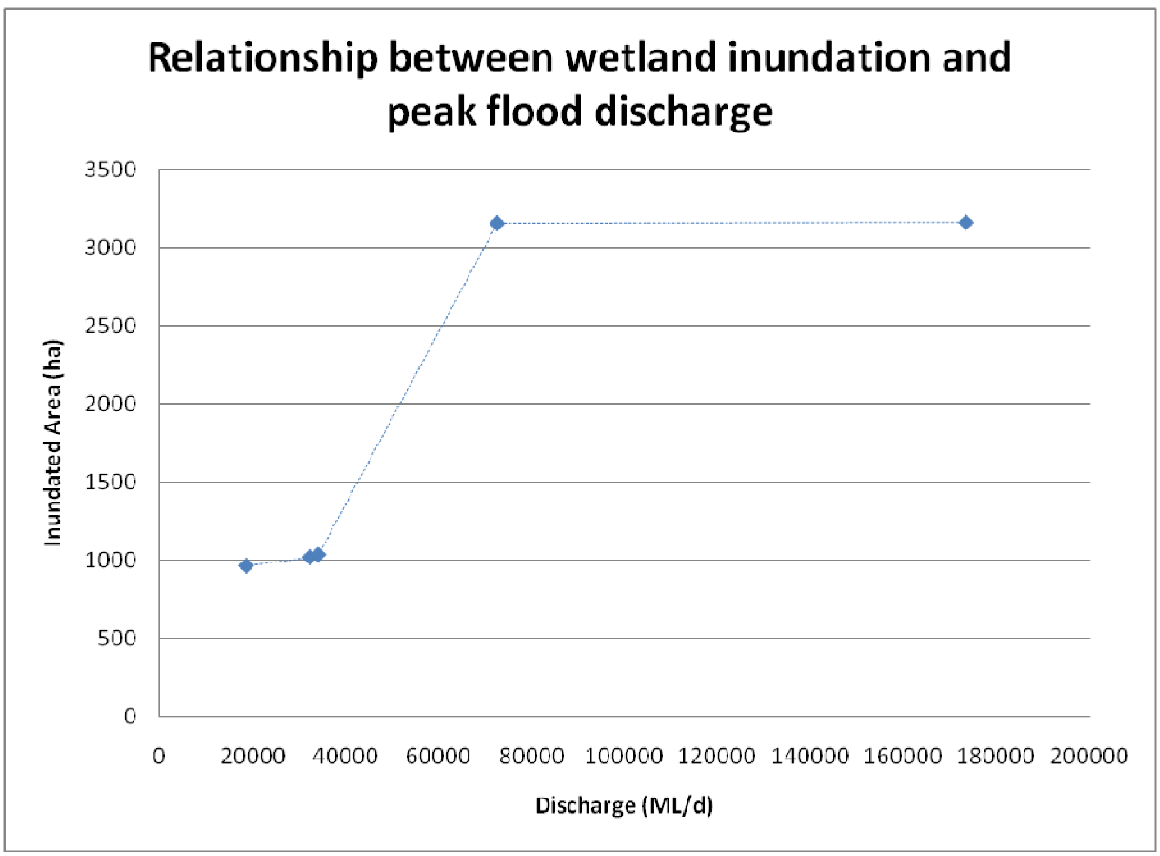

Figure 14: Graphical representation between the area of wetland inundation and flood peak discharge

2.4 CONCLUSIONS AND LIMITATIONS

The wetland inundation river discharge relationship developed in this 40 km reach of the Namoi River shows the potential of this technique to be extended to the entire lowland section of the Namoi River and its tributary and distributary network.

Hydrological analysis showed that flood attenuation behaviour was predictable at a reach-scale. The Landsat TM satellite archive proved sufficient to provide data for a range of floods in the reach and image analysis procedures provided useful information on inundation extent. The combined analysis of hydrological and image data was able to provide a reach-scale dataset to describe to the relationship between wetland inundation and river discharge in this reach.

While the technique provided useful information, it is important to note the main limitations that arose during the study. These include:

- Landsat capture at time periods up to several months before or after the flood event.
- A unique density slice value was required for each image as the data were not calibrated for radiometric consistency.
- Manual editing of some wetland shapes and the river polygon was required as the transfer from image processing to GIS software caused several errors
- Eliminating artificial wetlands was undertaken manually to delete obvious errors (eg water storages and paddocks), however, this will have eliminated some wetlands that have been altered by artificial land forming but that may have ostensibly natural function.
- The data created by this method are necessarily stepped as they are limited to actual flood events. This can result in large differences between peak discharges of floods
- The technique relies on consistent downstream attenuation flood behaviour. In general this relationship holds (Figure 5, Table 5); however, there can be considerable variation in this behaviour too. In this study the 34,038 and 32,148 ML/d floods become 12,546 and 17,386 ML/d floods respectively as they progress downstream. This means that the initially larger flood became significantly smaller than the smaller flood at some stage in the reach. This discrepancy can be reduced by analysing a larger number of flood events as data and time permit.

2.5 RECOMMENDATIONS

This project component demonstrated that the technique of using before and after-flood images linked to the hydrological record can produce useful, reach-scale, wetland inundation river discharge information for the lowland reaches of the Namoi catchment. The technique was developed and implemented over a 40 km river reach and produced useful information at a scale appropriate resolution.

This report recommends the extension of this technique to the entire lowland section of the Namoi catchment as resources permit.

3 Upland Wetlands Mapping

3.1 AIM

The aim of this component of the project was to develop methods to map the location and extent of upland wetlands within the Namoi catchment.

3.2 STUDY AREA

The upland areas of the Namoi catchment were defined as those areas above 700 m ASL (Figure 15). For the purpose of this project component data analysis was restricted to these areas.

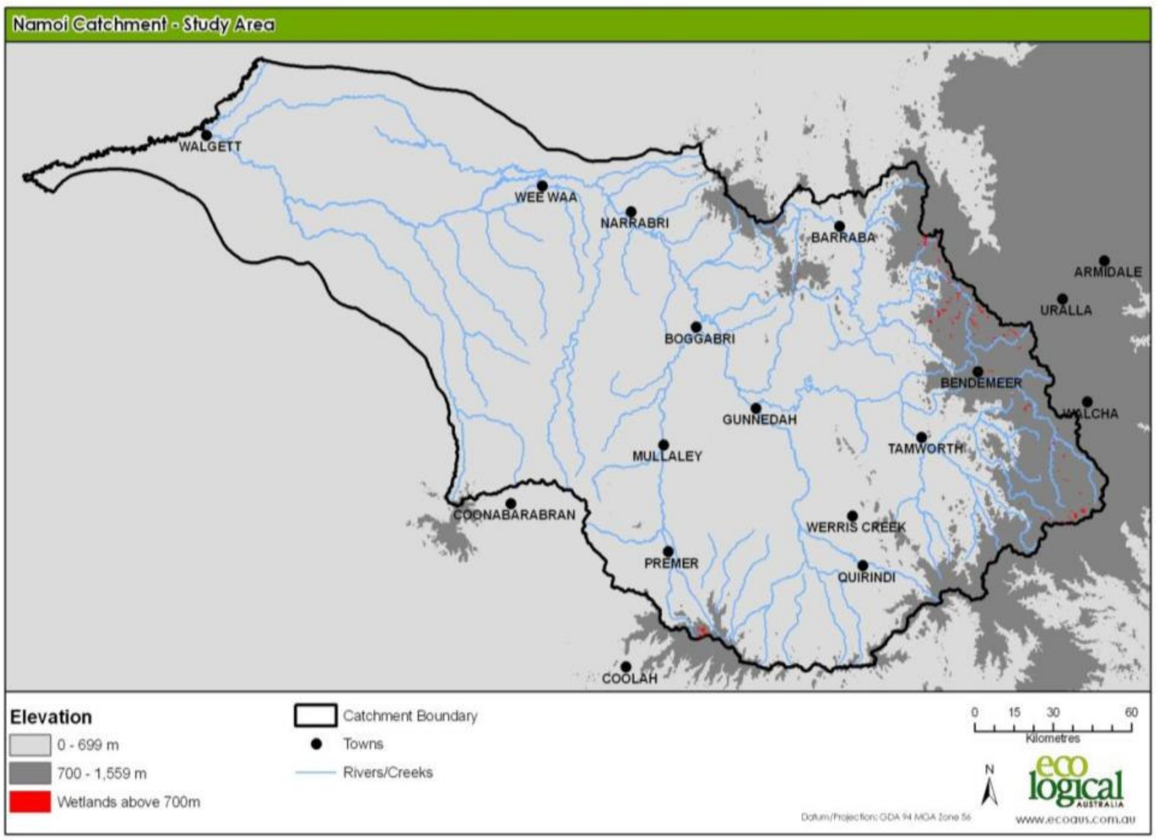

Figure 15: Namoi catchment, including upland area and existing wetland mapping

3.3 CURRENT UPLAND WETLAND MAPPING AND LIMITATIONS

ELA (2008) conducted a project to map wetlands across the entire Namoi catchment area, including the upland area. This mapping project used a combination of existing mapping, SPOT 5 and Landsat TM imagery to map wetlands in the catchment. However, the upland wetland mapping was found to provide a significant underestimate of wetland area because of the 1 ha minimum mapping unit, long-thin nature of upland wetlands, general lack of water on these wetland types and the diverse land use and land management carried out on these wetland areas.

Existing mapping and earlier examination of the limitations of the existing mapping (ELA 2008; 2009a) identified lacustrine (river-fed) and palustrine (ground water-fed) as well as artificial upland wetland types (Table 6).

Table 6: Functional upland wetland groups within the Namoi catchment

FUNCTIONAL GROUPS	DESCRIPTION
Artificial with no ecological significance	Constructed water storages with no surrounding vegetation, often very large features connected to irrigation channels or artificial bodies of water with no ecological significance.
Artificial with some ecological significance	Highly modified natural features with some surrounding vegetation, includes large farm dams with habitat value or artificial bodies of water with some ecological significance.
Lacustrine, temperate inland, river-fed/ floodplain	Lacustrine, temperate inland, river-fed/floodplain. These are large permanently wet open bodies of water, usually lakes or large dams.
Palustrine, temperate inland, groundwater	Palustrine, temperate inland, groundwater. These are primarily vegetated non-channel environments, such as billabongs, swamps, bogs and springs.

3.4 METHODS

Three sequential methods were employed for this component of the project. Initially, existing reports, available datasets, mapping and field work data were examined and analysed to identify the potential for automated or semi-automated catchment-scale mapping techniques to be developed. Secondly, key datasets were interrogated to describe the variability in known wetland areas as a guide to developing mapping keys. Finally, a trial mapping region of 40 km by 20 km was remapped to examine the potential for the region to be remapped to identify upland wetland areas.

3.4.1 Data review and analysis

Three existing reports ELA (2008; 2009a, b) and associated datasets were re-examined and analysed to focus specifically on the upland wetland areas and, where possible, to redefine the likely function groups of the identified wetlands.

3.4.2 Dataset interrogation

Catchment wide datasets including multi-source satellite imagery (SPOT 5, Landsat TM) and digital elevation models (DEMs) were collated and their characteristics and potential to assist mapping was described (Table 8).

The SPOT 5 composite and catchment-wide DEM were considered to have the best potential to aid in the semi-automated mapping of upland wetlands in the region. In particular the topographic information provided by the DEM were analysed to describe a selection of 10 known wetland areas and determine if persistent and unique trends were evident. For each wetland a long-profile section and two 500 m cross-sections were created to bisect each wetland into thirds (Figure 16). Elevation points where taken from each section from the underlying DEM. Each set of section points was exported into an Excel spreadsheet for further analysis.

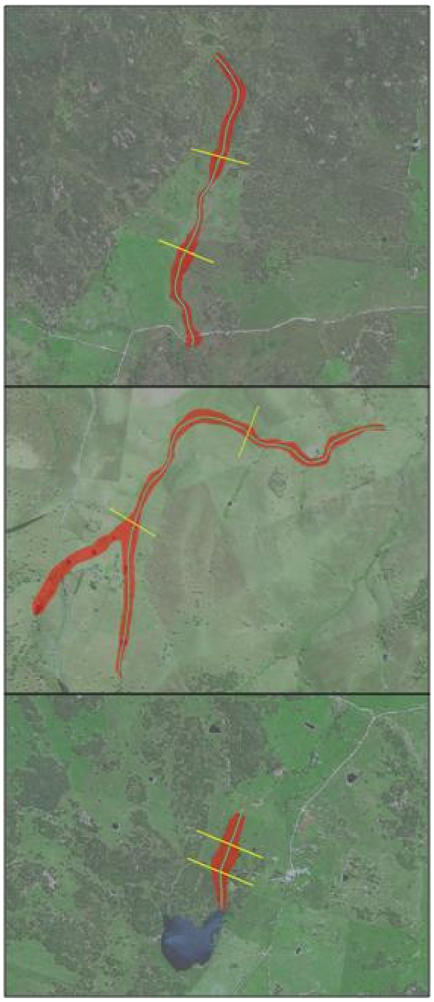

Figure 16: Selected wetlands, including cross-sections and long-sections

3.4.3 Manual Upland Wetland Mapping

An area of 40 km by 20 km was selected for trial upland wetland mapping. Refined mapping rules were designed to facilitate feature mapping. These rules were:

- Likely occurrence in drainage line or identified stream area
- Often containing different vegetation communities than surrounding slope areas (generally greener tone)
- Often but not always associated with small open water bodies
- Generally long and thin according to surrounding topography
- Mapping scale of 1:15,000 to make use of the inherent SPOT 5 data resolution
- Minimum mapping unit of 0.25 ha.

3.5 RESULTS

3.5.1 Data review

Re-examination and consideration of the data collected by ELA (2009b,c) revealed that it is likely that at least four (4) hydrological types of upland wetland exist in the Namoi catchment, namely: floodplain wetlands – associated with river or creek; basin-like closed depressions; water courses (water concentration zones); and altered (dammed). However, as with most natural systems the boundaries between these wetland types is often not sharp, with some wetland containing features typical of two or more wetland types.

<u>Floodplain wetland</u>

Several rivers and streams in the upland section of the Namoi catchment have built up floodplain areas with associated wetlands (Figures 17, 18). These floodplain wetlands are hydrologically linked to the river systems and receive the majority of their water is delivered when floods exceed the river channel capacity and spill into the wetland. These wetlands are found only on rivers and streams with flows large and persistent enough to have developed floodplains.

Figure 17: Floodplain wetlands: a) associated with the Macdonald River; b) a small wetland adjacent to a relatively large but intermittent stream

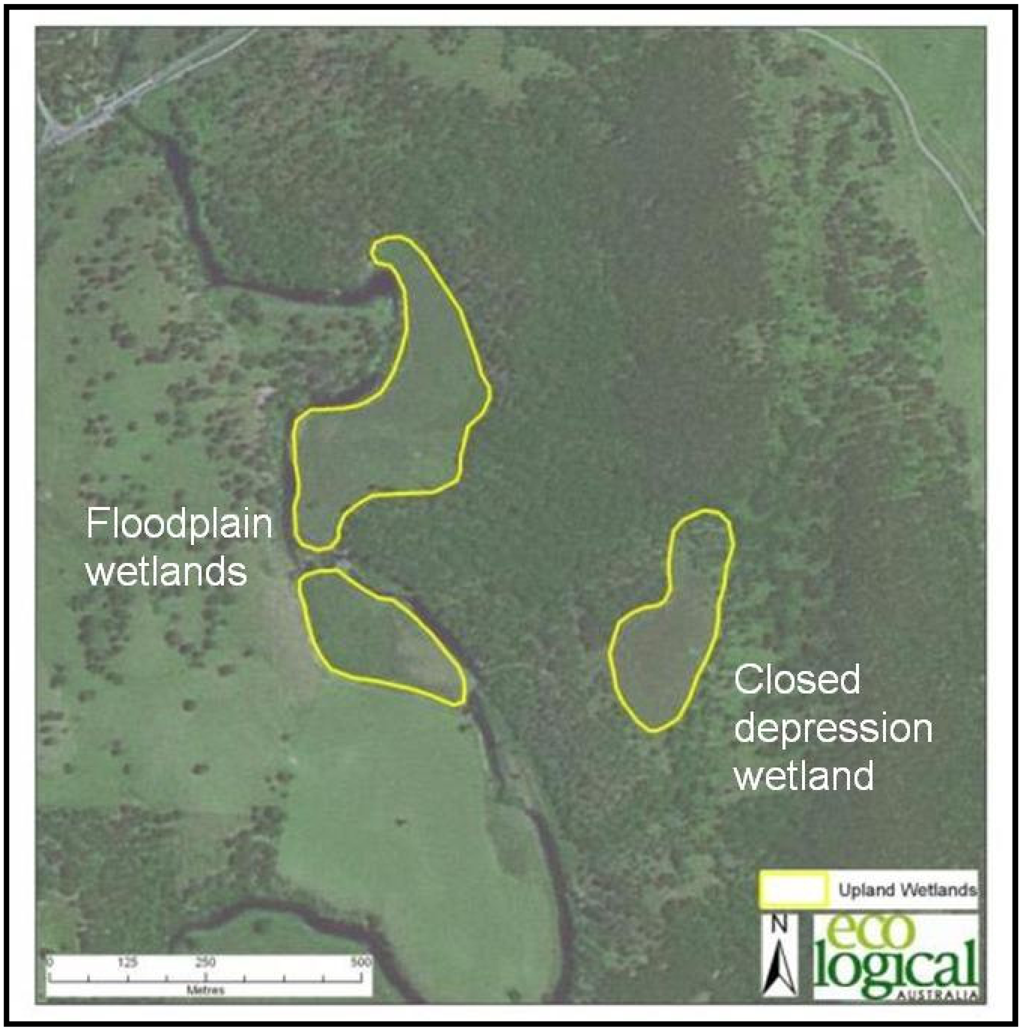

Figure 18: Floodplain wetlands associated with the upper Peel River.

<u>Closed depressions</u>

One likely closed depression wetland type was observed in the upland wetland mapping (Figure 18). This wetland is situated woodland and is at least 250 m from the Macdonald River. No field checking has been undertaken to verify the primary water source for this wetland but it is likely that the water is derived from rainfall directly over the wetland's catchment.

<u>Water courses</u>

Water course type wetlands are the dominant type of upland wetlands in the Namoi catchment. The wetlands derive water from their local catchments and occupy zone where water concentration through topographic confinement lead to wetter regimes than the surrounding areas (Figure 19). These wetlands often contain vegetation species (rushes and reeds) that are consistent with wetland environments, although land management (generally grazing) has probably altered the species composition. These wetland may or may not contain networks of small, naturally occurring open ponds (chain of ponds) (Figure 19 b) Little is documented about the nature of these wetlands but it is likely that they have organic rich soils, relatively high water tables and originally consisted primarily of grassland vegetation communities.

Figure 19: Water course wetlands: a) grassy communities in the water course; b) small open pond within the wetland.

<u>Altered</u>

Farm dams occur frequently throughout the upland area of the catchment (Figure 20a). These features are designed to capture water so are located in water concentration zones that were likely water course type upland wetlands prior to alteration. Damming has captured water and created much larger areas of open water. Other alterations include roads of various sizes (paved dual carriage way to farm tracks) which have created areas that retain water and have developed wetland characteristics. In some places roads have intersected with existing upland wetlands and altered the original function of the wetland (Figure 20b). Other types of alterations include large dam infrastructure, small on-farm alterations, small structures associated with town/village water supply.

The degree of alteration varies greatly from wetland to wetland.

Figure 20: Altered wetlands: a) Farm dam on a water course; b) upstream of a road that has intersected a water course wetland creating an open pool wetland.

3.5.2 Data interrogation

Interrogation of the SPOT 5, Landsat TM and DEM data was undertaken to describe the potential of each dataset to assist with mapping upland wetlands. For the SPOT 5 and DEM data areas of know upland wetlands were examined and details of distinguishing features described. For the Landsat TM a similar approach was undertaken but the same area was examined for separate relatively wet and dry images (Table 8).

Table 7: Catchment wide datasets

Data Source	Characteristics	Mapping potential
SPOT 5	State-wide dataset through NSW govt Composed of multiple datasets spanning approximately 1 year One image date for each individual pixel Merged product (Pan and MS) with 2.5 m derived resolution Panchromatic band with native 5 m pixels Multi-Spectral bands with 10 m pixels (Green, Red, NIR and MIR)	Consistent coverage across the target area Appropriate resolution for mapping at 1:10,000 or smaller Merged product appropriate for visual identification and mapping of wetlands
Landsat TM	Multiple dates available for free download Imagery repeat every 16 days (weather permitting) from 1989 Pixel size generally 30 m (at capture) 7 Multi-spectral bands (Blue, Green, Red, NIR, 2*MIR and Thermal)	Consistent coverage across the target area Appropriate resolution for mapping at 1:50,000 or smaller Pixel size too coarse for broad use for mapping upland wetlands Multi-temporal sequences did not assist mapping potential
DEM	3 second Approximately 25 m pixels and 5 m vertical resolution	Consistent coverage across the target area Appropriate resolution for mapping at 1:50,000 or smaller Pixel size too coarse for semi-automated mapping

The preliminary investigation found that Landsat TM was too coarse (pixels ~ 30 m) to assist with mapping in spite of the superior spectral and temporal resolution.

The DEM was used to describe the topography of 10 wetland areas (Figures 21-25). The wetlands were generally found to be a concave shape across the valley, with some of the wetlands 'hanging', meaning that they didn't occupy the entire concave region of the valley. The long-sections had slopes less than 3 degrees throughout the wetlands, with most of the wetlands being associated with 2nd and 3rd order streams.

Given the narrow nature of the wetlands and range of topographic areas they occupy it was decided that the current datasets were not capable of being used to develop automated or semi-automated mapping methods.

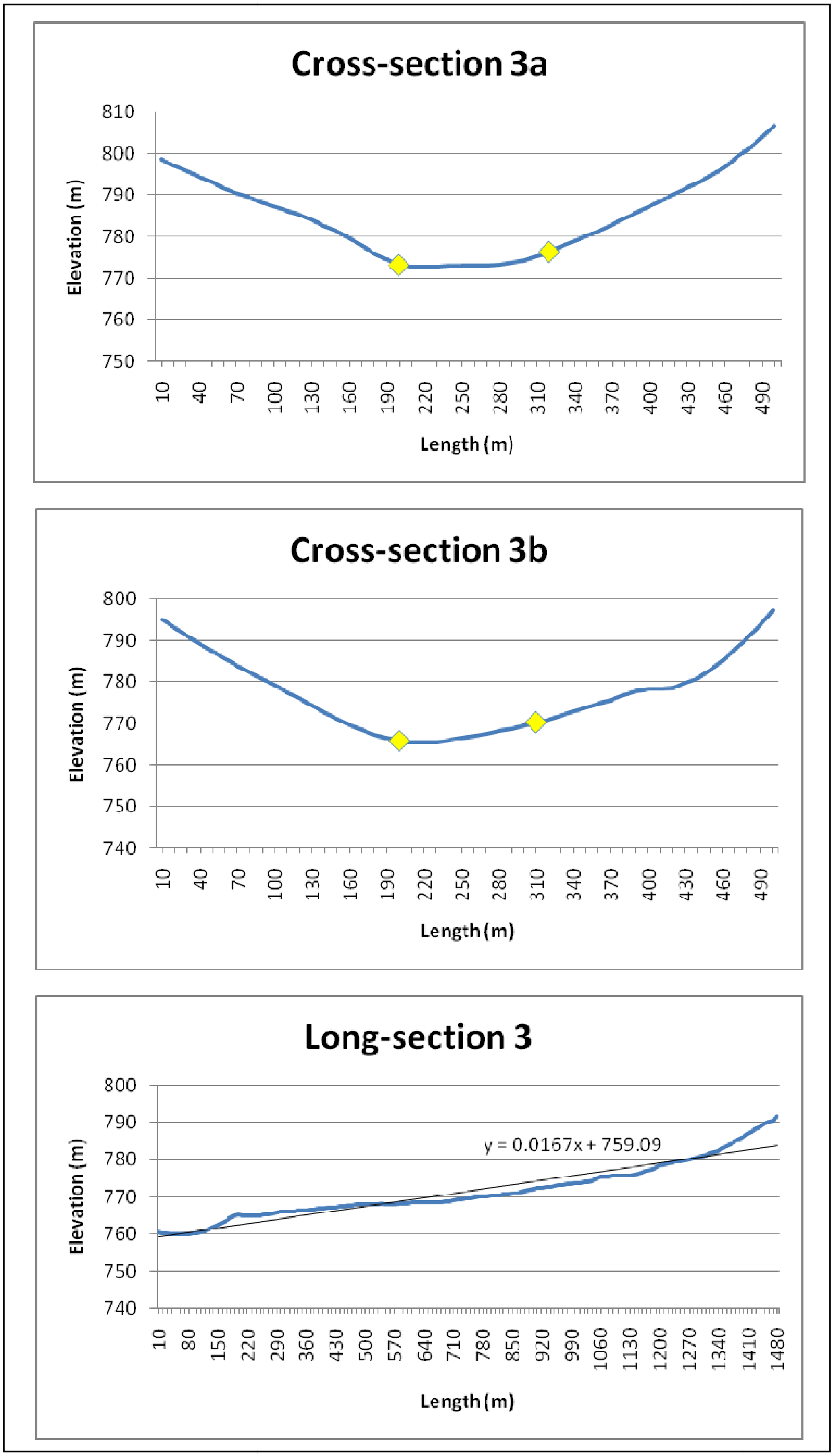

Figure 21: Sections from wetland No. 3 (Y axis units are in metres, X axis units are in metres)

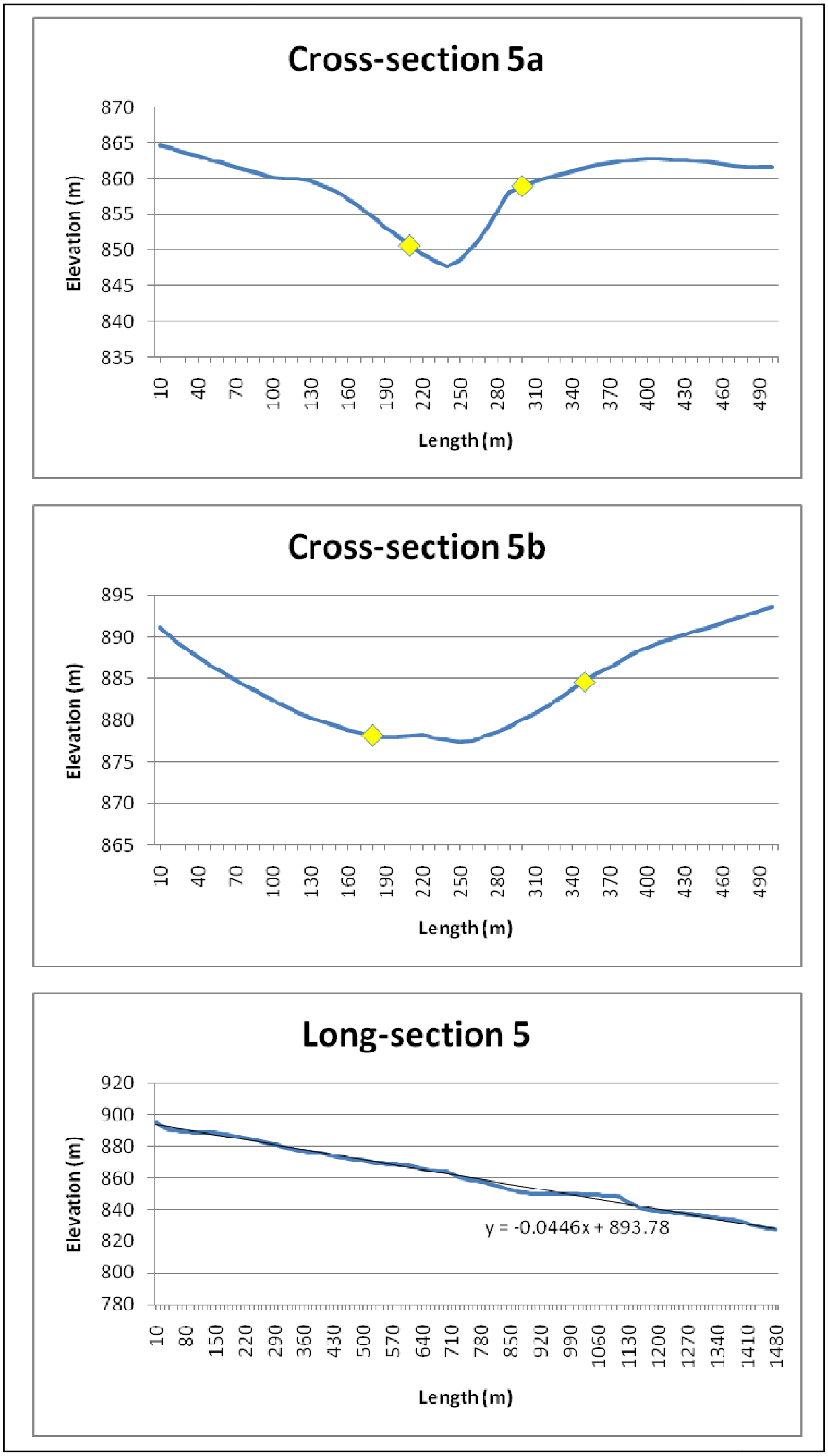

Figure 22: Sections from wetland No. 5 (Y axis units are in metres, X axis units are in metres)

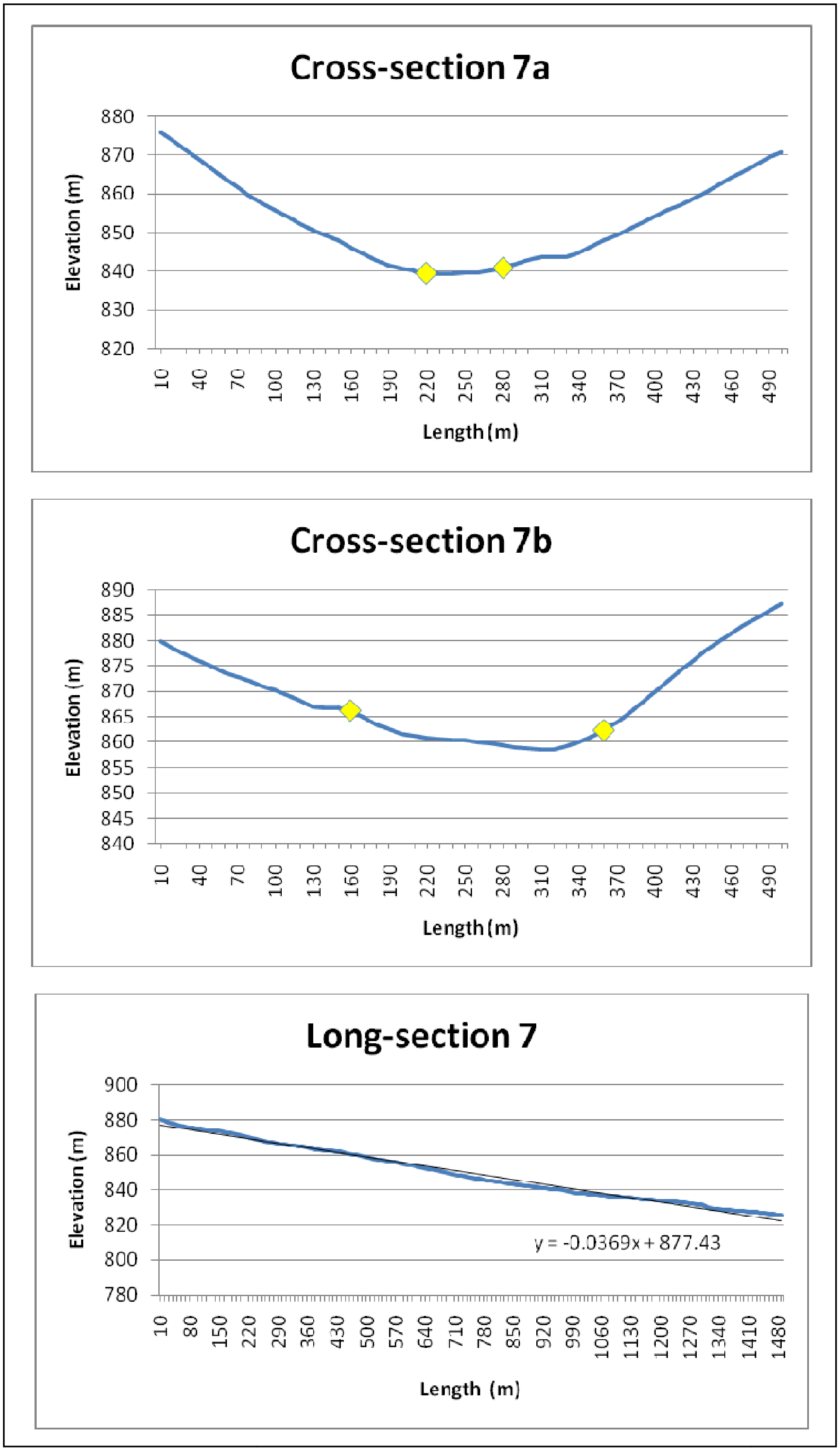

Figure 23: Sections from wetland No. 7 (Y axis units are in metres, X axis units are in metres)

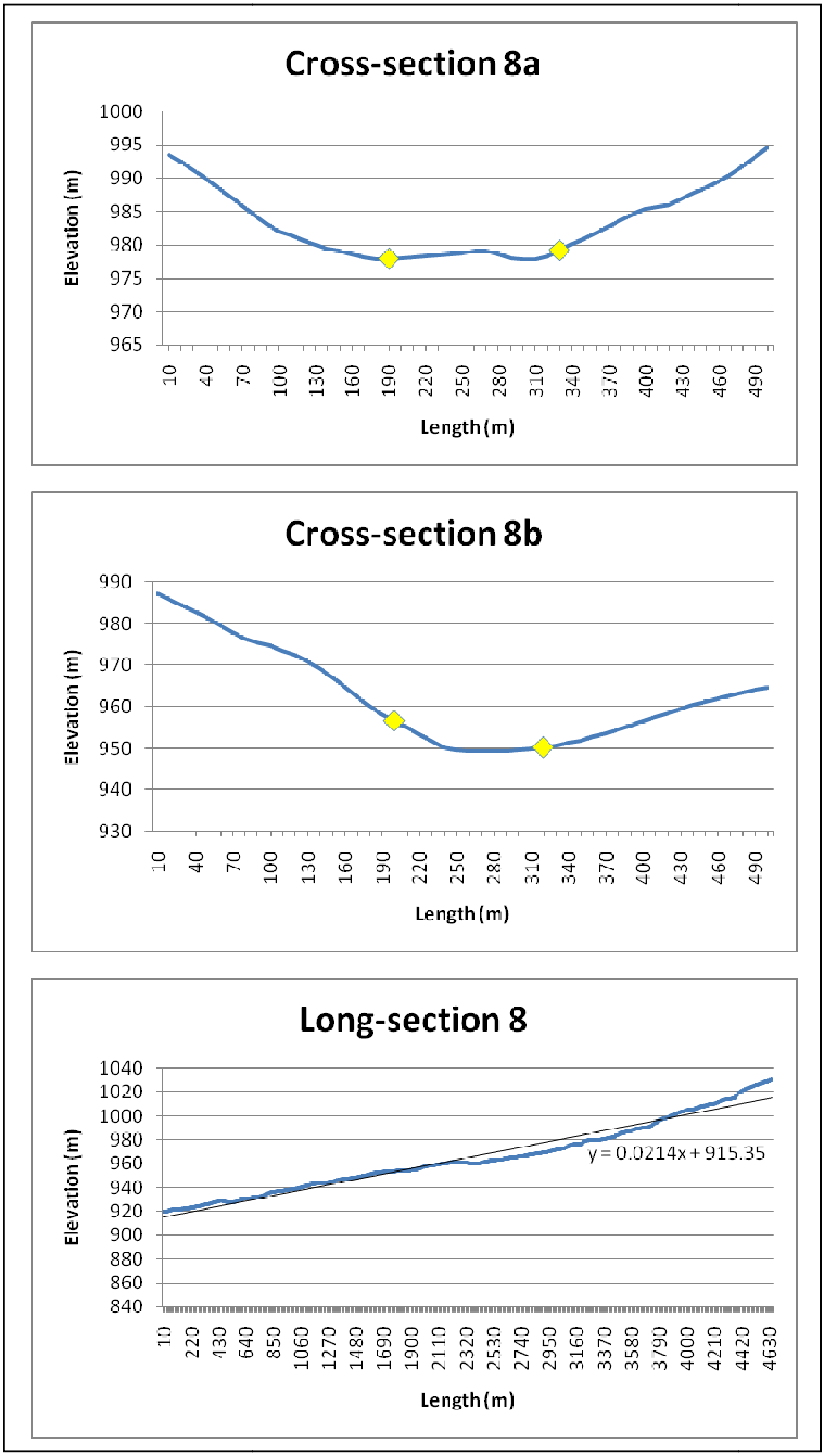

Figure 24: Sections from wetland No. 8 (Y axis units are in metres, X axis units are in metres)

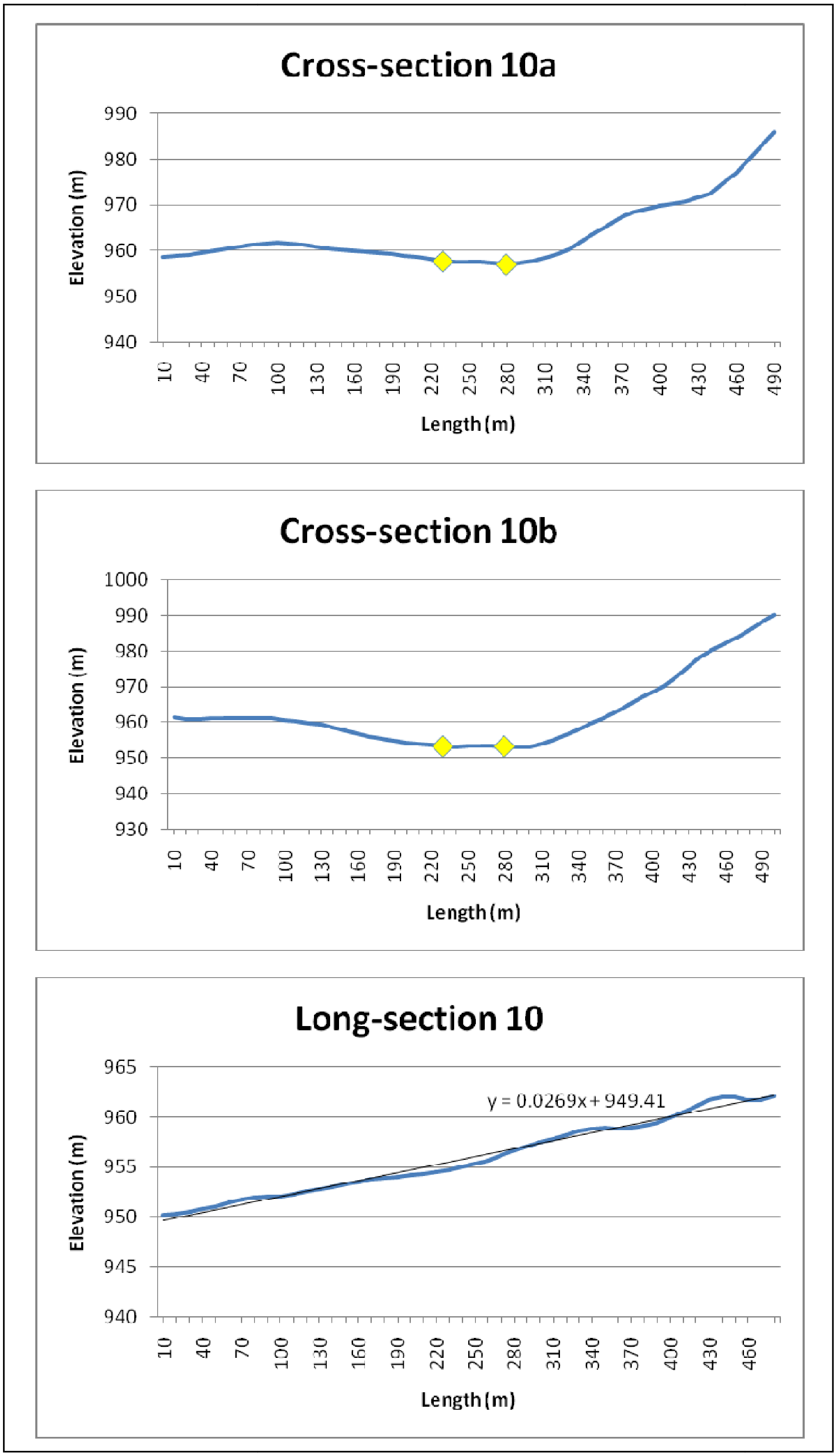

Figure 25: Sections from wetland No. 10 (Y axis units are in metres, X axis units are in metres)

3.5.3 Manual Upland Wetland Mapping

Given the limitations of the catchment-wide datasets a trial project was undertaken to specifically map upland wetlands using the SPOT 5 as the primary dataset with stream network and DEM used to assist mapping. In addition mapping rules designed specifically capture upland wetlands greater than 0.25 ha in size were developed and applied (Figure 26).

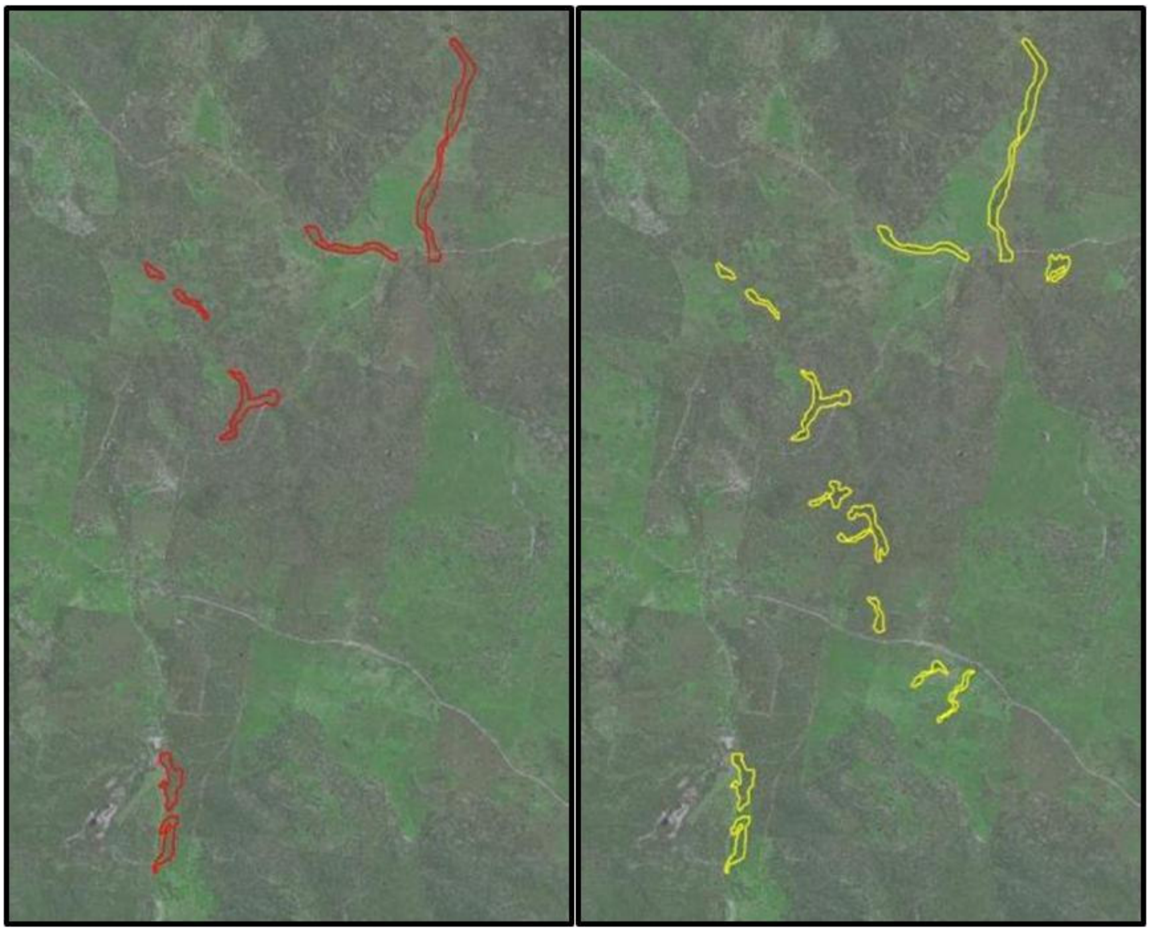

Figure 26: Subset of the original upland wetland mapping (left) and updated upland wetland mapping (right)

3.6 CONCLUSIONS

With the current datasets it is unlikely that an accurate upland wetland map can be developed using automated or semi-automated techniques. It is likely that future improvements in DEM and satellite pixel resolution will assist with upland wetland mapping. However, these data are currently too expensive for application across the entire catchment.

SPOT 5 data, augmented with other GIS layers (eg stream networks, DEM and existing wetland be taken to develop and apply a mapping rule-set that focuses specifically on these upland features and they often have characteristics that are dissimilar to ‘typical flat wetland areas’.

3.7 RECOMMENDATIONS

The mapping of the upland wetland areas in the Namoi can be greatly improved with a specific mapping project that combines GIS-based mapping of the upland area using existing SPOT 5 data, a specific mapping rule-set and targeted field verification. Current mapping is likely to underestimate the extent of upland wetlands by 50-100%; an updated mapping dataset will assist catchment managers to make informed decisions with an improved map. It is recommended that the CMA fund a project designed specifically to update upland wetland mapping in the catchment.

The single closed depression wetland is likely to provide an ecosystem unique in the Namoi catchment. It is recommended that the CMA undertake a brief field investigation to this site to identify its primary water source and likely unique characteristics to assess its suitability for further investigation.

4 High-resolution Habitat Mapping and Modelling

4.1 INTRODUCTION

Optimising the delivery of environmental and irrigation flows to maximise benefits to the environment while maintaining agricultural production requires detailed understanding of the relationship between river flow and riverine habitat inundation. For Australian rivers we simply do not have information on this relationship at sufficient resolution to accurately inform optimal flow delivery regimes. Newly available high-resolution remotely sensed data provides the opportunity to understand riverine habitats and their relationship to flow regimes at resolutions capable of assisting river managers to optimise flow delivery regimes. These high-resolution data include LiDAR (or Airborne Laser Scanning (ALS)) that provides digital elevation models (DEMs) with sub metre pixels sizes and approximately 0.15 m elevation resolution. High-resolution digital imagery including data from airborne and satellite systems provide sub-metre pixels size data. The aim of this section of the report is to develop and verify methods of using high-resolution remotely sensed data to map in-channel riverine habitats and quantify the inundation regime of each habitat.

4.2 LOCATION

Over the summer of 2008/2009 the Murray Darling Basin Authority Sustainable Rivers Audit (MDBA) funded a project to collect high resolution LIDAR and airborne digital image data over the Namoi catchment. One of the sites (site 14) overlapped with the study area used for the medium resolution lowland wetland mapping undertaken as a part of this overall project. The MDBA made these data available for this study. The data were collected over an approximate 1 km river reach downstream of Wee Waa (Figure 27). This site is also approximately 4 km upstream of the Weeta Weir gauge site providing an opportunity to use accurate gauge information for a period of over 30 years.

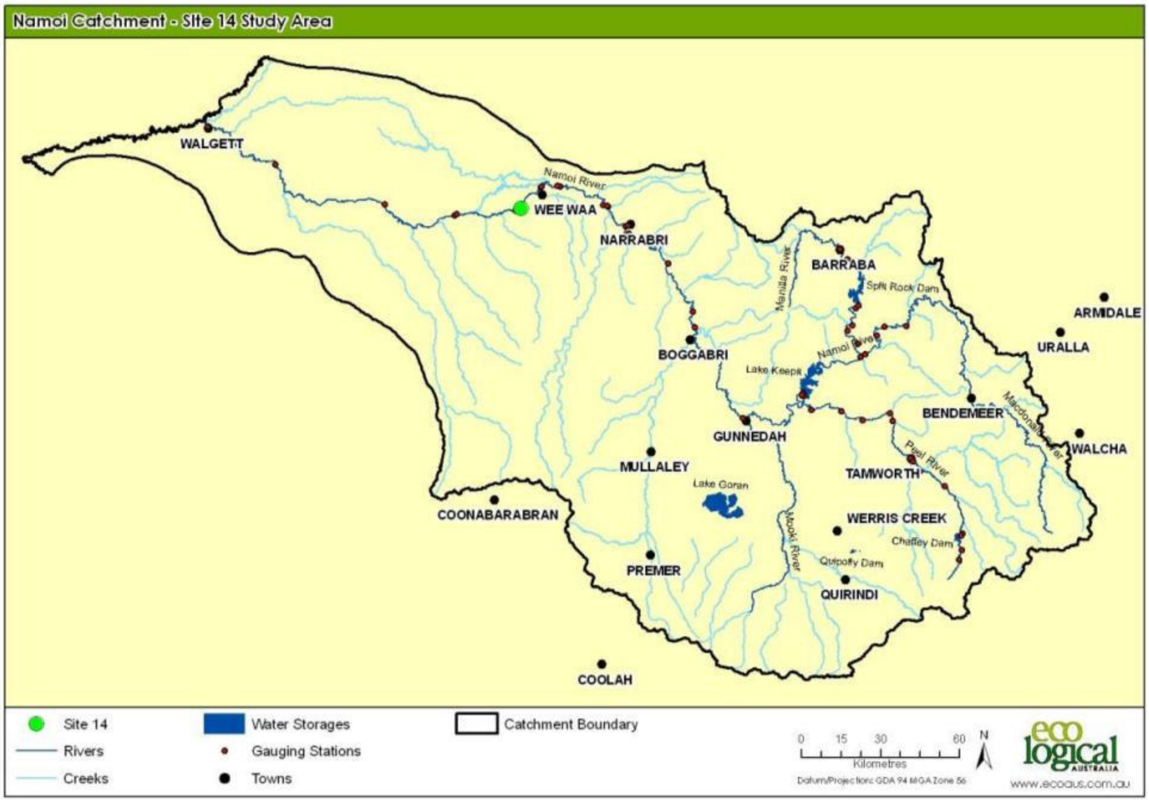

Figure 27: Location of the high-resolution study site downstream of Wee Waa.

4.3 DATASETS

4.3.1 LiDAR data

The LiDAR data were captures using the Harrier 56 LiDAR and aerial imaging system (Figure 28). It is an integrated system consisting of 1) Riegl LiDAR scanning instrument, 2) Rollie 39 mega-pixel camera and 3) Applanix POS/AV 410 Inertial Motion System and 12 channel, dual frequency GPS. The Harrier 56 LiDAR system incorporates the Applanix POS/AV 410 IMU and 12 channel, dual frequency GPS. The specifications are:

- IMU sampling rate: 300 Hz
- IMU accuracy: 0.008/0.008/0.015 (roll/pitch/heading)
- IMU accuracy: 0.005 (velocity)
- GPS: 12 channel dual frequency, low noise, 10 Hz raw data

This system was setup to capture approximately 4-6 elevation points per m^2 providing extremely high resolution ground elevation and information of above ground features including forest and woodland canopy height and foliar density information.

The LiDAR data were captured on the 18/10/2008.

4.3.2 Image data

Imagery was captured in 16bit format using Rollie 39 mega pixel camera (Figure 28). The imagery was ortho-rectified against LiDAR DEM using airborne GPS and IMU X, Y displacements were calculated for each sortie using a set of ground control points and applied to ortho photos. The image data were captured with a raw pixel size of 0.15 m; however, the data were resampled to 0.3 m pixel size following ortho-rectification.

Images were colour balanced and mosaiced into strips for the site.

The image data were captured at the same time as the LiDAR data on the 18/10/2008.

Figure 28: Site high-resolution study site. High resolution image data overlaying lower resolution Landsat TM data, the LiDAR data cover the same area as the high resolution image data.

4.3.3 Hydrographic data

Weeta Weir gauge is situated approximately 4 km downstream of the study area. Gauge data from 27/10/1978 to the 4/1/2008 were extracted as daily mean stage heights for further analysis. To align the gauged stage data with the LiDAR based elevation data the gauge data were adjusted to AHD.

4.4 METHODS

4.4.1 Mapping large woody debris (LWD)

LWD are crucial habitat features in riverine environments, however, given the nature of LWD they have proven difficult to map using traditional remote sensing datasets and techniques. Given the ultra high-resolution and multi-source nature of the datasets available for this project a trial was conducted to assess the potential to map LWD using these data.

This component of the project involved:

- Field survey to map the location, size and canopy cover of LWD in a test area;
- LiDAR analysis – including DEM and slope analysis;
- Object oriented classification of the digital image data;
- Visual mapping of LWD using on-screen digitizing of the digital image

Field Survey

Field survey was undertaken on an inner bend of the river in the study area on the 5/11/2009 (Figure 29). All LWD > 10 cm diameter were mapped using a differential GPS system (Figure 29). In addition to location the LWD diameter, percentage foliage cover above and a digital photograph of each LWD located were recorded.

The location and diameter of each mapped log was entered into the GIS for subsequent accuracy assessment (Figure 29).

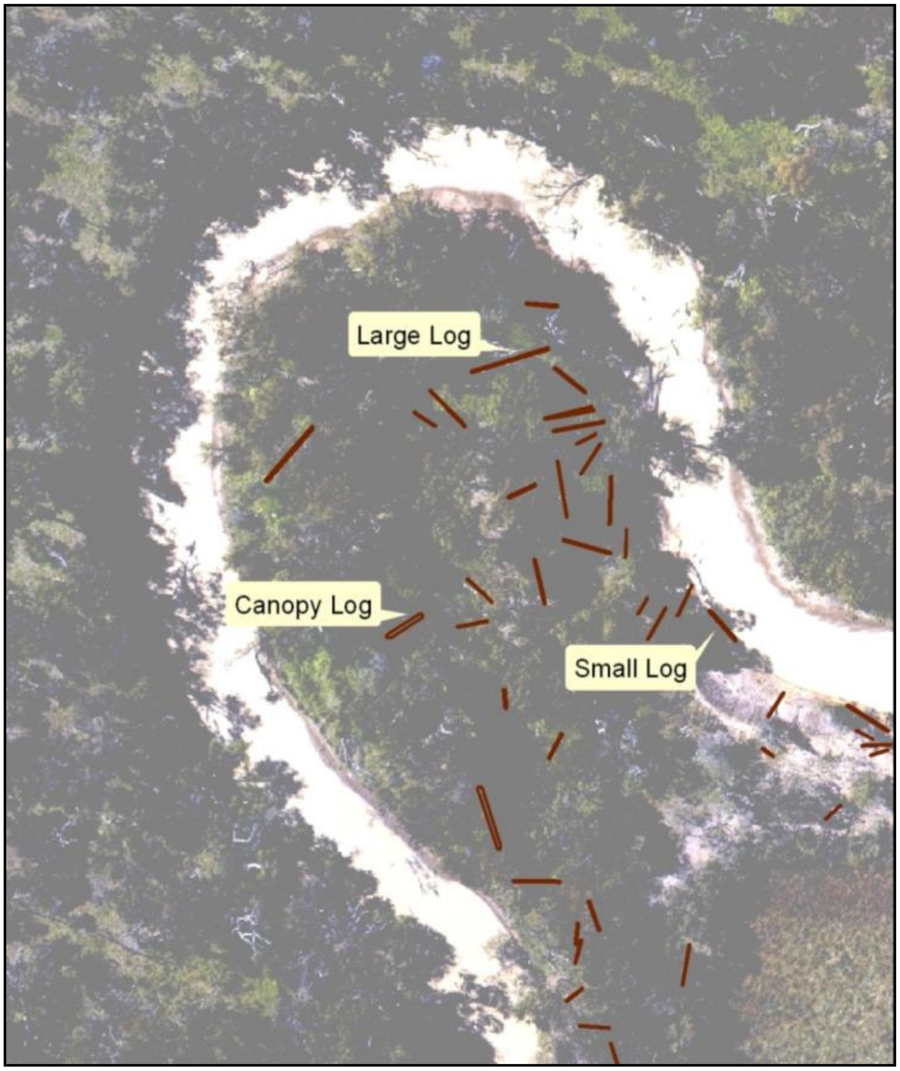

Figure 29: LWD field data.

LiDAR analysis

The LiDAR data were analysed to determine if the data could be used to map LWD. The raw data were separated into ground and non-ground points. They were then over-layed onto the GIS representation of the field data to determine the number of LiDAR strikes on each occurrence of LWD. The field data were also compared to a derived DEM and slope layer. A final assessment of the potential of these data for mapping LWD was undertaken using 3d visualization of the point cloud associated with several LWD features.

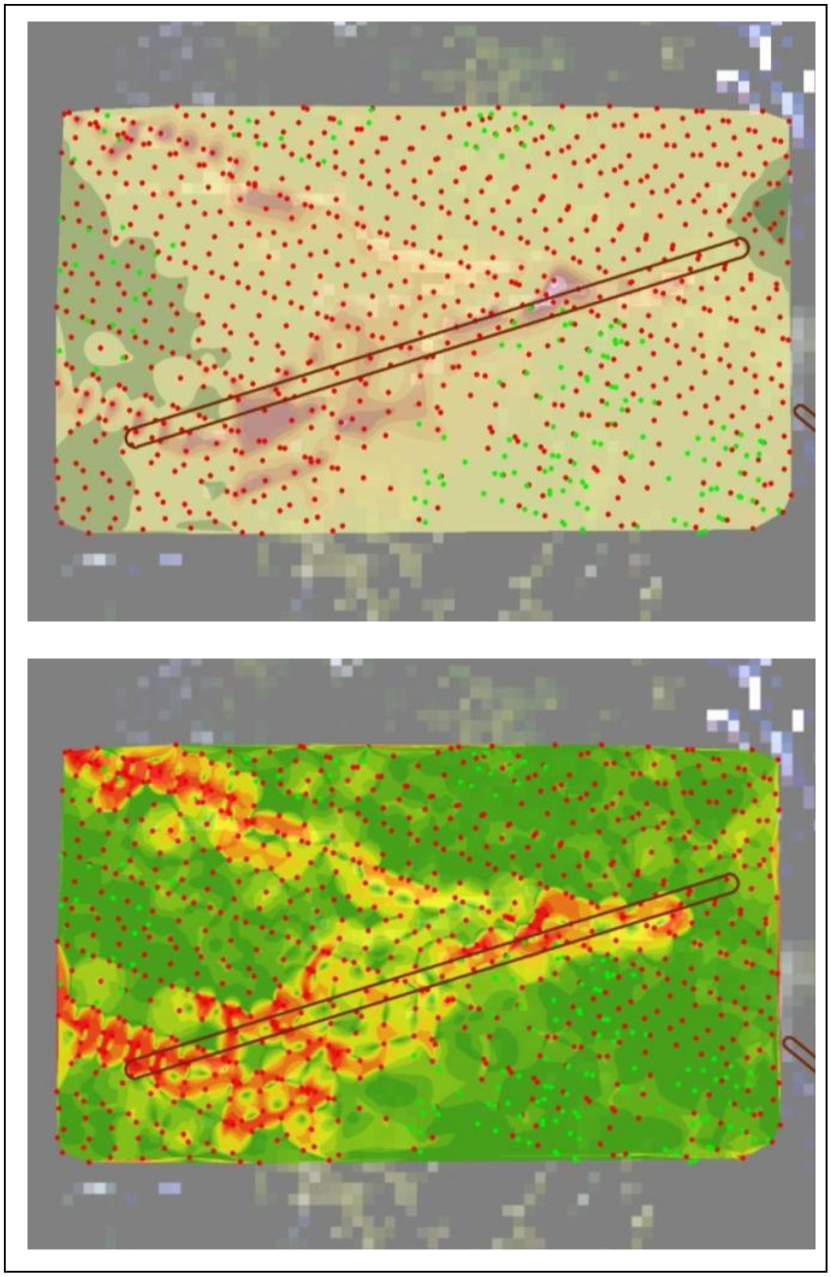

Figure 30: DEM (top) and Slope (bottom) images showing field survey LWD representation.

Object oriented analysis

Using the feature extraction function of ENVI 4.6 an object oriented approach to map LWD using the image data was undertaken. The software was used to develop training "segments" using the spectral, spatial and textural characteristics of several known sites of LWD. The software was then used to attempt to map all other occurrences of LWD in the image area.

Visual LWD mapping

An independent expert in aerial photograph interpretation was instructed to map all occurrences of LWD that they could map from the zoomed image data displayed on a high-resolution screen using ArcGIS functionality. This expert had no prior knowledge of the location of LWD from the field survey and had not visited the site prior to completing the mapping.

Accuracy assessment

Data mapped as LWD by the visual and object oriented mapping processes and the enhanced DEM and slope layers were over-layed on the field-based GIS data. Each instance where the derived or mapped data agreed with the field data was recorded as correct, where the field data showed LWD but the mapped data did not was recorded as incorrect. As the field data were not a complete census of LWD instances where mapped or derived data showed LWD where the field data did not could not be verified so were ignored, however, these occurrences were very few.

4.4.2 Riverine habitat mapping

A multi-step approach to mapping riverine habitats was undertaken using the LiDAR and image data. The first step was to derive a channel bank line to separate in-channel from overbank regions using the GIS data. These regions were then analysed separately to map various habitat types in each region. The operating processing steps were:

- Map water bodies using the zero or low intensity returns from the LiDAR data. As previously discussed the water level at the time of data capture was quite high in the channel (Figure 31a)
- Apply a 15 m buffer to the water polygon to enclose the entire bank top region (Figure 31b)
- The slope data from LiDAR data were then used to highlight the obvious break of slope between the floodplain and the channel (Figure 31c)
- A line of best fit was then digitised to delineate the channel top and separate the in-channel from overbank regions (Figure 31d)
- In-channel areas were further separated into bar, bench and bank regions using the following criteria:
    - Bar areas were below the 180 m AHD (low in the channel) and were regions of slopes < 5 degrees
    - Benches were areas above 180 m AHD and were regions of slopes < 5 degrees
    - All other non-water regions were labelled channel bank
- Overbank areas were separated into vegetated and non-vegetated areas. Object oriented analysis using the ENVI software was used to map bare areas (non-vegetated areas) all other areas were considered vegetated.

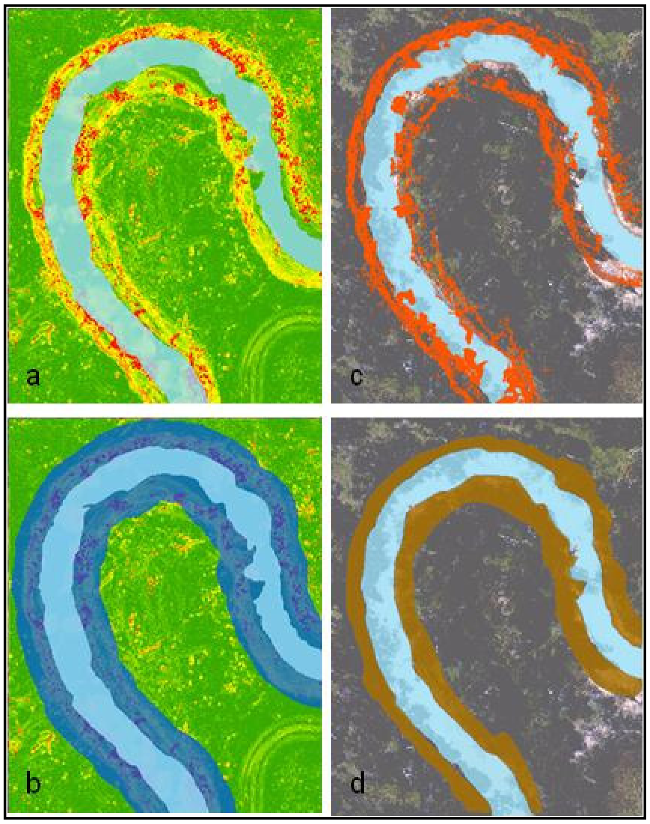

Figure 31: Steps used to delineate the channel top a) generate slope layer to examine break of slope; b) place 15 m buffer on water layer to set channel top zone; c) highlight areas of high slope in channel top zone; d) visually fit channel top line using line of best fit.

4.4.3 Relating flow to habitat inundation

The hydrographic stage data from the Weeta Weir gauge were adjusted to AHD so that they could be related to the DEM and habitat map data. To facilitate processing the hydrographic stage data were grouped into 0.5 m ranges from 177m (gauge zero) to above the maximum DEM value, giving 16 stage ranges. These daily stage data were then analysed to determine: the number of unique flow events in each stage range; the number of days flow was in each stage range; and the percentage of total time in the record that stage was in each range.

The habitat map was then segmented into stage ranges using the DEM data. The total area of each habitat feature in each stage zone was determined.

These data were then linked by stage range to derive information on the historical habitat inundation in the study area.

4.5 RESULTS

4.5.1 Large woody debris mapping

Mapping LWD was unsuccessful using any of the 4 methods attempted. Total accuracy ranged from 0% to 11.6%. The combination of relatively small size and low relative elevation from the ground surface, little or no spectral variation between LWD and other ground cover including vegetative litter and cover from the native red gum woodland made it impossible to reliably detect all but the very largest occurrences of LWD in areas with no canopy cover.

Table 8: LWD accuracy assessment results

Method	% Correct	% Incorrect
LiDAR Slope	11.4	88.6
LiDAR DEM	0	100
Visual Mapping	5.7	94.3
ENVI OO	11.6	88.4

While this attempt at automated or semi-automated proved unsuccessful the LiDAR based analysis did show some potential for future potential with higher frequency point spacing. The number of LiDAR strikes on the indentified LWD ranged from 2 to 59 points. Larger incidences of LWD logically intercepted a greater number of LiDAR strikes. Inspection of the LiDAR data and derived surfaces showed local variation in the data that could be interpreted as LWD. Figures 30-32 show the derived surfaces, field survey photograph and 3D visualisation of large log mass with less than 30 percent foliar cover. However, even with large LWD, like this, automated mapping is still currently impossible.

Figure 32: Large mass of LWD in relatively open canopy area

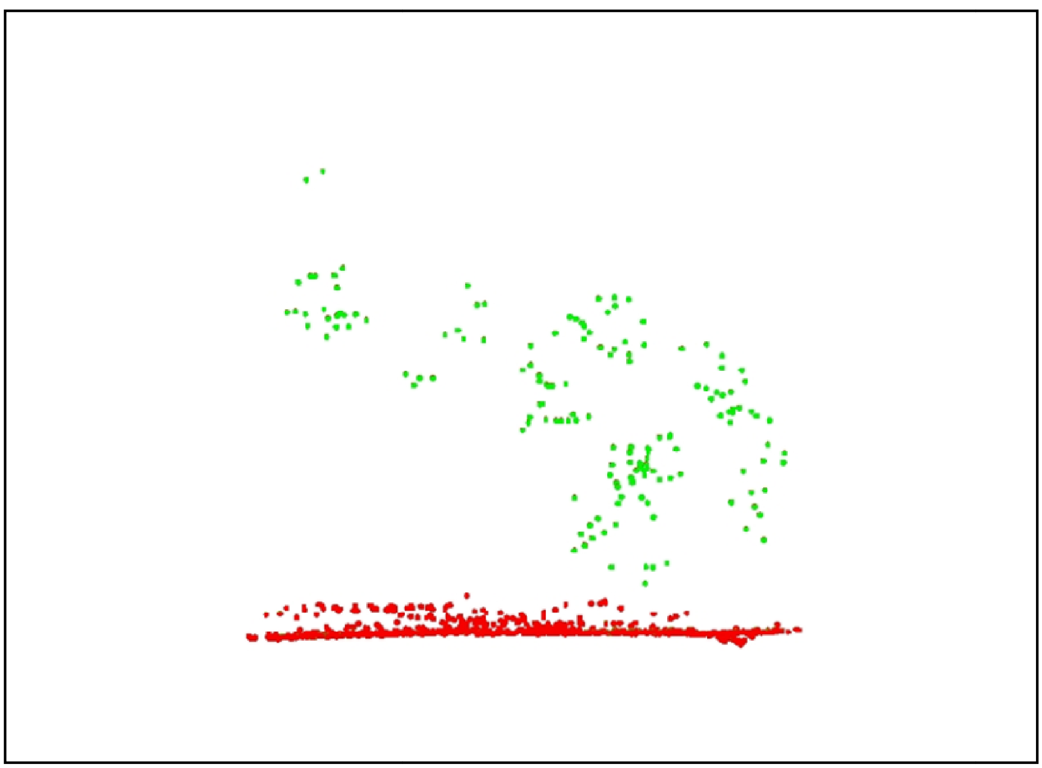

Figure 33: 3d representation of the LiDAR points over the LWD shown in Figures 30 and 32. Red points are ground strikes, green points are non-ground strikes.

4.5.2 Riverine habitat mapping

A combination of LiDAR based topographic analysis and digital image classification provided a high-resolution 3d riverine habitat map for the reach (Figure 34). Key landscape features could be represented as continuous landscape components at horizontal (approximately 1 m) and vertical resolution (< 0.5 m).

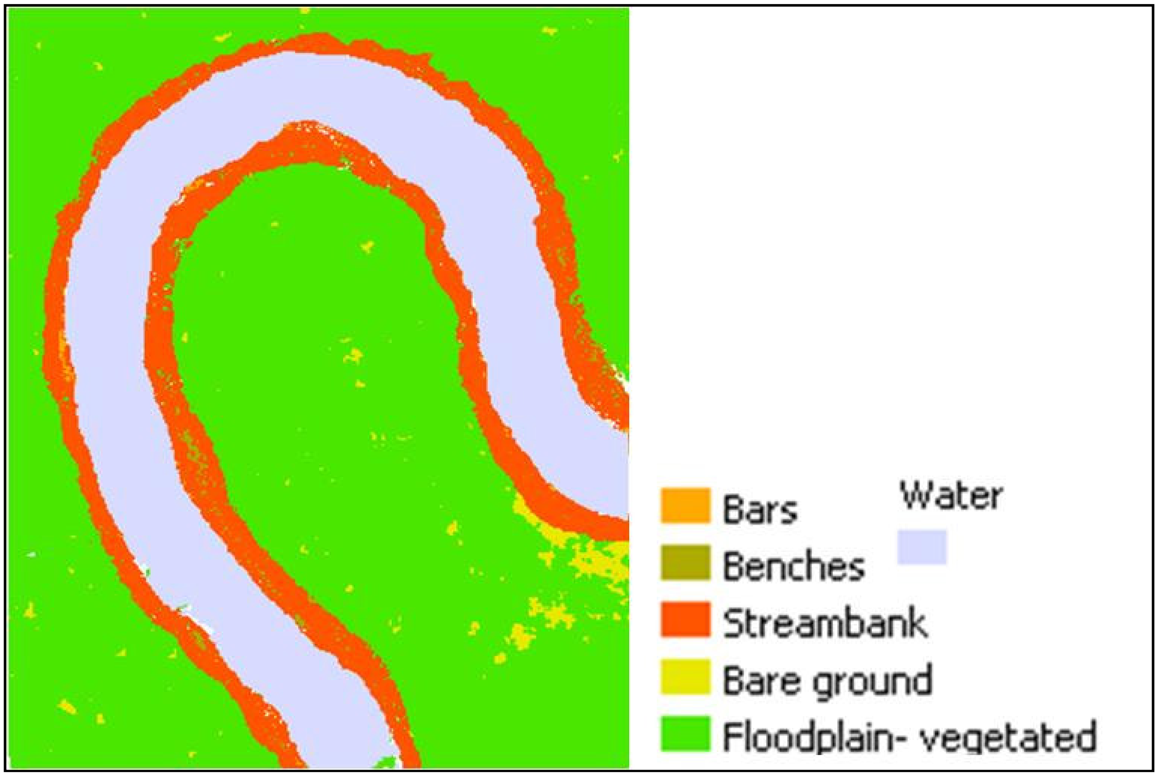

Figure 34: Plan view of the final riverine habitat map.

4.5.3 Inundation modelling

As the habitat map was tied to the high resolution DEM created by the LiDAR data it could be separated into elevation ranges that in turn were related to river gauge stage ranges (Figure 35). The area of each habitat type could then be related to gauge stage and historical inundation patterns (eg frequency, duration etc) could be created (Tables 9, 10, 11)

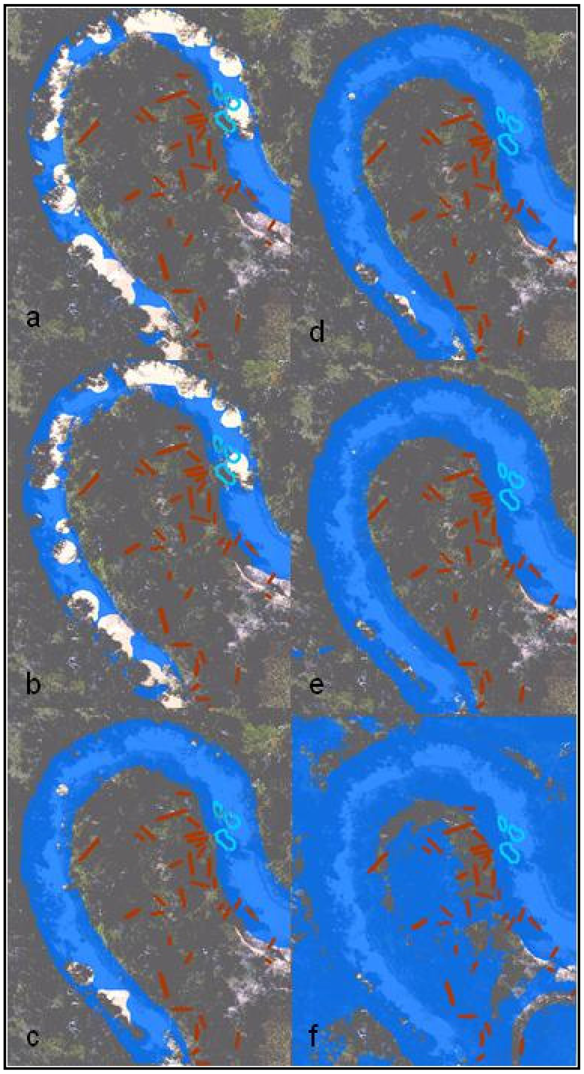

Figure 35: Modelled inundation in 1 m steps from a) 180 m to f) 185 m.

Table 9: Relationship between DEM elevation and gauge stage including analysis of inundation frequency, duration and % time from 27/10/1978 to 4/1/2008.

Gauge stage/DEM Height (m AHD)	Frequency	Days	% time (30 years)
177.0-177.5	97	2520	25.89
177.5-178	334	4415	45.35
178-178.5	348	1537	15.79
178.5-179	194	355	3.65
179-179.5	120	185	1.90
179.5-180	104	131	1.35
180-180.5	78	101	1.04
180.5-181	60	83	0.85
181-181.5	61	77	0.79
181.5-182	48	53	0.54
182-182.5	42	51	0.52
182.5-183	38	43	0.44
183-183.5	54	63	0.65
183.5-184	34	98	1.01
184-184.5	7	18	0.18
184.5-185	3	5	0.05

Table 10: Relationship between gauge stage and habitat area.

Gauge stage/DEM Height (m AHD)	Bank (m^2)	Bar (m^2)	Bench (m^2)	Floodplain vegetated (m^2)	Floodplain bare (m^2)
177-179.5	0.57	2.7	0	0	0
179.5-180	5.95	3.05	0	0	0
180-180.5	294.32	43.23	0	0	0
180.5-181	723.96	72.97	0	0	0.02
181-181.5	1860.55	72.97	0	0	38.04
181.5-182	2561.77	72.97	0	0	58.66
182-182.5	3213.02	72.97	0	0	85.61
182.5-183	3857.53	72.97	0	0	95.8
183-183.5	4527.81	72.97	0	8.44	108.25
183.5-184	5233.83	72.97	0.03	60.8	141.78
184-184.5	5233.83	72.97	45.86	3126.13	141.78
184.5-185	5233.83	72.97	271.67	16378.53	141.78
185-185.5	5233.83	72.97	462.5	22669.65	141.78

Table 11: Area of riverine habitat inundation by inundation days from 27/10/1978 to 4/1/2008.

Gauge stage/DEM Height (m AHD)	**Inundation Days**	Inundated Bank (m^2d)	Inundated Bar (m^2d)	Inundated Bench (m^2d)	Inundated FP-veg (m^2d)	Inundated FP-bare (m^2d)
177-179.5	8807	5019.99	23778.9	0	0	0
179.5-180	185	1100.75	564.25	0	0	0
180-180.5	131	38555.92	5663.13	0	0	0
180.5-181	101	73119.96	7369.97	0	0	2.02
181-181.5	83	154425.7	6056.51	0	0	3157.32
181.5-182	77	197256.3	5618.69	0	0	4516.82
182-182.5	53	170290.1	3867.41	0	0	4537.33
182.5-183	51	196734	3721.47	0	0	4885.8
183-183.5	43	194695.8	3137.71	0	362.92	4654.75
183.5-184	63	329731.3	4597.11	1.89	3830.4	8932.14
184-184.5	98	512915.3	7151.06	4494.28	306360.74	13894.44
184.5-185	18	94208.94	1313.46	4890.06	294813.54	2552.04
185-185.5	5	26169.15	364.85	2312.5	113348.25	708.9

4.6 RECOMMEDATIONS

This project component clearly indicates the potential of the high-resolution datasets to be used to create three dimensional riverine habitat models and inform river flow patterns for environmental outcomes. This study has focussed on a small river reach; however, there is clear support for extending this research to other key reaches on the Namoi and similar river systems. The technology of LiDAR and high resolution imagery are developing rapidly and the costs, resolution and tools to analyse these data are continually improving.

At this stage the technology for mapping riverine habitat and relating the habitat to gauged flow records has been established. High-resolution LiDAR data provide the 3D information required to accurately link a surface location with elevation and hence establish the relationship between location and gauged river flow height. The LiDAR data also assist with mapping of habitat features particularly those that relate to topographic elements of landform or tree canopy. The LiDAR data in conjunction with high resolution imagery permit the development of a high-resolution 3D habitat map that can be produced at a reach scale.

To optimise river flow releases for environmental outcomes and consumptive use we need to link this 3D habitat inundation information to environmental and ecological process such as water quality function and key species breeding and survival. Further research into the link between inundation pattern and environmental and ecological processes is recommended as a key extension to this field of study.

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