21 September 2016

Neal Albert
NSW OEH
Level 13, 59-61 Goulburn Street, Sydney
Sydney, NSW 2000

Dear Neal,

Our ref: 2870-02-04-v01

Mungindi Regional Hydraulic Model Setup and Calibration Report (Stages 1 & 2)

1 INTRODUCTION

Water Technology was commissioned by the NSW Office of Environment and Heritage (OEH) to prepare and calibrate a regional 2D TUFLOW hydraulic model of Mungindi. The purpose of the model is to provide the OEH with a regional scale flood model using the latest modelling techniques, topographic data and flood data. The model will be used to assist in development planning, flood risk management, flood mitigation and levee analysis.

1.1 Background

Mungindi is located on the border of New South Wales (NSW) and Queensland (QLD); approximately 500km west of Brisbane. The Barwon river splits the town between the northern (QLD) side and the southern (NSW) side. The Barwon River at Mungindi is part of an anastomosing river system whereby bifurcations and convergence of waterways occur both to the north (Weir River) and south (Boomi River) of the town. During large magnitude floods, flood water flows around, as well as through the centre of the Mungindi township. Most of the town's residents are protected by two flood levees; one on each side of the river. Current levees were originally constructed between 1977 and 1988. Since then, in some areas, they have been upgraded or extended. These levees are designed to protect the town from floods greater than the 100yr ARI flood (Lawson and Treloar, 2004). Figure 1 shows the Mungindi township with the town levee system and the Barwon River shown.

The Barwon River is part of the Border Rivers catchment with a total catchment area of approximately 44,100 square kilometres to Mungindi (BoM, 2016). Figure 1 shows the Border Rivers network, with Mungindi highlighted on the far west of the map. The Border Rivers system makes up approximately 4% of the Murray-Darling basin.

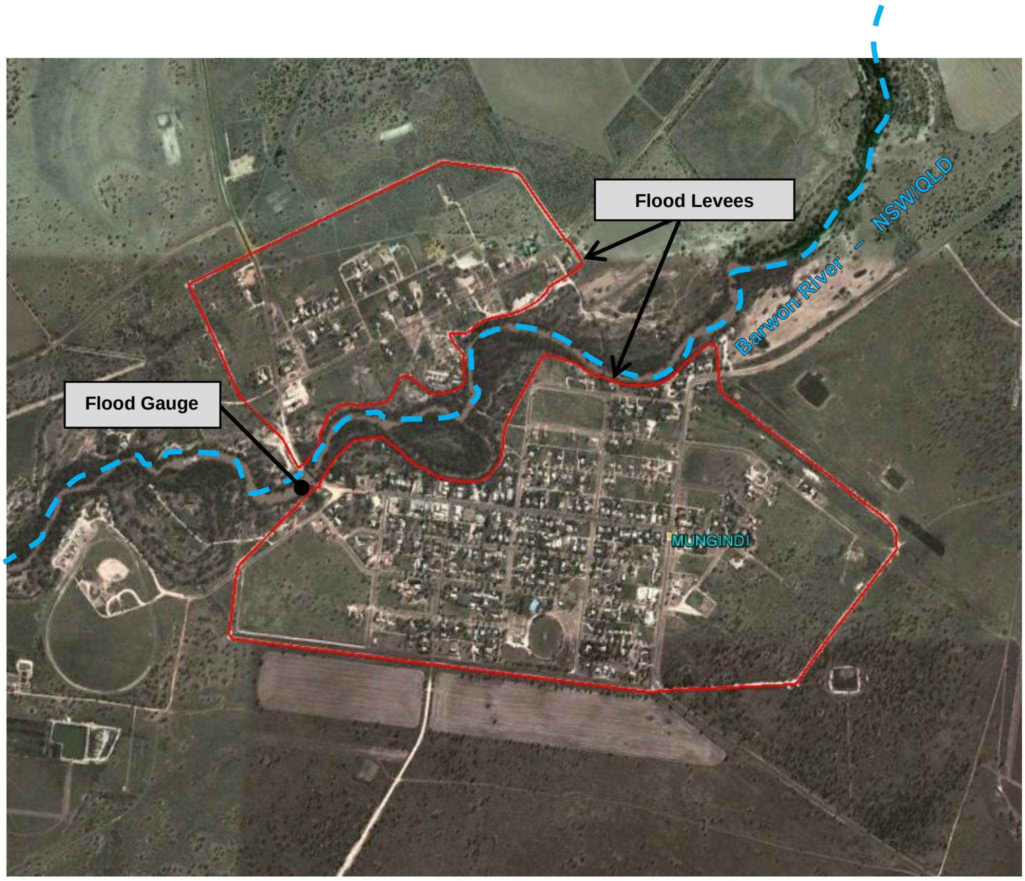

FIGURE 1 MUNGINDI TOWNSHIP AND FLOOD LEVEE LOCATIONS

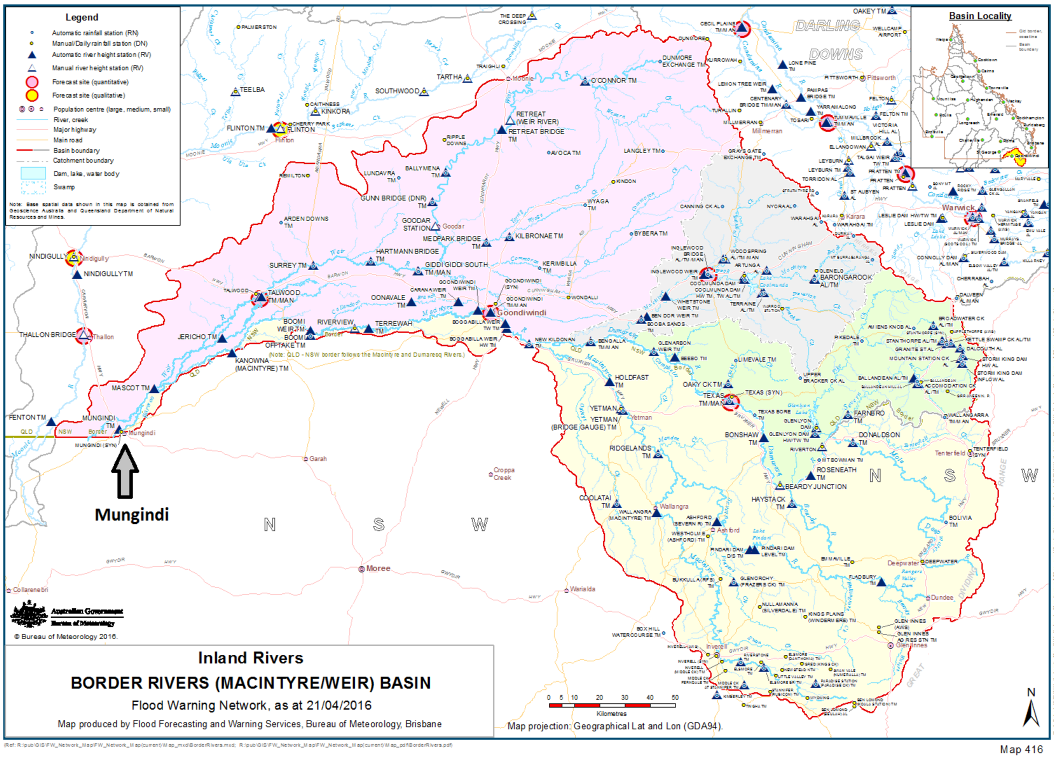

FIGURE 2 BORDER RIVERS FLOOD WARNING NETWORK (BOM, 2016)

1.2 Study Objectives

The study is divided into five stages:

- Stage 1:
  - Development of a Mungindi regional hydraulic Model (the hydraulic model).
  - Calibration of the hydraulic model to the 1976 flood.
- Stage 2:
  - Calibration of the hydraulic model to the 1996 flood.
- Stage 3:
  - Hydraulic modelling of the 1% AEP Design Flood.
- Stage 4:
  - Modelling and impact assessment of levee change scenarios for the 1% AEP flood.
- Stage 5:
  - Mapping and final reporting of stages 1-4 of the study.

This letter reports on stages 1 and 2; which cover model development and calibration to the 1976 and 1996 floods.

2 HYDROLOGY

Catchment hydrology was undertaken by BMT WBM as part of the development of the Border Rivers flood model. There is currently limited information available regarding the methodology and calibration undertaken by WBM; there is no report to reference. The extent of the smaller Mungindi regional model (developed for the study addressed in this letter) is within the model extent of the Border Rivers hydraulic model. Figure A1 Appendix A shows the location of the Mungindi regional model extent within the Border Rivers model flood result.

Inflows to the Mungindi regional model were extracted from the 1976 Border Rivers model. The BMT WBM Border Rivers model 1976 flows were adopted as the initial flows for both the 1976 and 1996 Mungindi floods (prior to calibration) (see Section 4.3). Of note, BMT WBM have not modelled the 1996 flood.

3 HYDRAULIC MODEL DEVELOPMENT

3.1 Overview

The following three models were developed for this study:

- 1976 historic model.
- 1996 historic model.
- Existing conditions (2016) model.

The existing conditions model is to be used in future modelling of design floods and test levee design options.

3.2 Software

A 2D TUFLOW GPU model of the Mungindi regional area was developed for this study. The TUFLOW GPU model was adopted as the drainage network around Mungindi and in the greater Border Rivers area behaves with complex flow dynamics over a very large area. The GPU version of TUFLOW generally resolves the hydraulic flow equations with much greater speed than the CPU version; at the expense of some functionality. The GPU model allowed for the use of a large model domain, relatively fine grid resolution and long modelled flood durations of up to 5 days.

3.3 Model Layout and Boundary Locations

The model extent and boundary locations are shown in Figure A2, Appendix A. The hydraulic model developed for this study covers an area of approximately 40km x 31km with a model grid resolution of 5m. The model has approximately 22 million computational points. The model inflow boundaries are approximately 20km upstream of Mungindi and include six separate inflow locations representing each of the watercourses shown on Figure A2 in Appendix A. The downstream boundary is located approximately 5km downstream of Mungindi and is split into 4 separate outflow locations. Model Topography

3.4 Model Topography

The hydraulic model topography was based on 1m LiDAR sourced from Geoscience Australia. The LiDAR was captured in late 2013 as part of the Border Rivers project. The total captured area was approximately 7,500 square kilometres. The LiDAR has a horizontal accuracy of ±0.45m and a vertical accuracy of ±0.15m.

3.4.1 Levees

The landscape within the Mungindi regional model extent contains a number of levees. These levees are used for flood protection of the town (the Mungindi town levee) and farms. During the 1976 flood only some sections of the Mungindi town levee system were present (WMA, 2009). After the town was inundated during the 1976 flood, Boomi Shire began construction of an upgraded levee for Mungindi. The levee project was completed in 1980. Further upgrades have taken place since then; including the expansion of the levee on the QLD side of the Barwon River. This expansion was completed in 2000.

The number of rural levees around Mungindi increased considerably between 1984 and 1996. Landsat imagery from 1984 shows less agriculture in the area than present; with no large ring tanks. Aerial photography of the 1996 flood shows many of the currently existing levees in place.

The following levee configuration was adopted for each of the Mungindi flood models:

- 1976
  - Current Mungindi town levee removed.
  - All current rural levees removed.
- 1996
  - Mungindi town levee reduced to the extent prior to the levee expansion on the Queensland side of Mungindi which (occurred in 2000).
  - All current rural levees present.
- Design Model
  - All current levees were left in the model.

To accurately represent the levees in the 5m model (in some cases the levees were fairly narrow), the levee crests were extracted from the 1m digital elevation model (DEM) and input explicitly. This technique removes any artificial gaps or dips that may be produced as a result of sampling the elevation as a 5m grid.

3.4.2 Carnarvon Highway and Mungindi Bridge

The LiDAR information captured in 2013 includes the new Mungindi bridge under construction; the bridge was completed in 2014. Along with the bridge, the abutments and bridge approach on the Carnarvon Highway were also upgraded. This involved increasing the road level by approximately 2m. For the 1976 and 1996 flood models, the new bridge and abutments were removed and reduced the road level to that prior to the upgrade. The original an upgraded bridge piers and deck were represented in the model as an area of higher roughness.

3.4.3 Model Roughness

Hydraulic model roughness, in the form of Manning's 'n' roughness coefficients, were estimated from aerial photography and site inspection. Low resolution Landsat imagery was used to refine the 1976 roughness map, in particular for the estimation of cropping areas, which were considerable less than that shown in the 2013 LiDAR data. Table 1 contains the adopted roughness categories and Manning's 'n' values used for this study. Figure A3 and A4, Appendix A shows maps of adopted hydraulic roughness values for the 1976 and 1996 flood models, respectively.

TABLE 1 ROUGHNESS CATEGORIES AND ADOPTED MANNING'S 'N' VALUES

Roughness Category	Manning's 'n' Value
Road (including verge)	0.03
Water Body	0.045
Light Grass	0.045
Low Density Vegetation	0.06
Medium Density Vegetation	0.07
Heavy/Riparian Vegetation	0.08
Residential Buildings	0.15
Industrial/Commercial Buildings	0.15

3.5 Hydraulic Structures

The Mungindi Bridge was the only major structure pertinent to the study. The bridge is on the Carnarvon Highway and connects the northern QLD side of Mungindi with the southern NSW Side. The bridge is approximately 100m upstream of the Mungindi stream gauge.

GPU modelling doesn't currently allow for the modelling of 1D structures. Therefore, the bridge was defined in the model as an area of high roughness to simulate the head loss as the water flows past the structure. Other minor structures were considered not relevant to the flooding (in a regional sense) were not included in the model.

4 CALIBRATION AND RESULTS

4.1 Available Calibration Data

The following calibration information was available for the 1976 and 1996 flood models:

- 1976
  - Flood level of 160.95m AHD at the Mungindi Flood Gauge (BoM No. 052068).
- 1996
  - Flood level of 160.83m AHD at the Mungindi Flood Gauge (No. 052068).
  - Aerial imagery taken during the flood.
  - Four recorded water level marks around Mungindi.
  - Gauging information obtained during the 2013 flood.

4.2 Methodology

The Mungindi regional hydraulic model was calibrated to the 1976 and 1996 floods. Separate flood models were developed for each historic flood. Different topography and roughness layouts were adopted to reflect the changes between the time periods.

Methods of calibration were limited. The largest uncertainty in the model was the inflows. Unfortunately, minimal information was available regarding the Border Rivers flood model; in particular the design and calibration. Further, the 1976 Border Rivers flood model contained a number of large rural levees upstream of Mungindi. Landsat imagery and anecdotal evidence suggests there were significantly less, or possible no levees present at the time of the 1976 flood. The effect of these levees on the flood timing, peak discharge and flow distribution of the Border Rivers flood model at Mungindi is unclear. Therefore, calibration relied upon scaling the 1976 Border Rivers flow estimates. Given the large uncertainty in the flow estimates no calibration of the model parameters was undertaken (e.g. Manning's 'n').

4.3 Model Inflows

The 1976 Mungindi regional flood model was run using the flows extracted from Border Rivers flood model. Initial calibration showed the model was under-predicting the flood level at the Mungindi flood gauge for the 1976 flood. It was determined that the model inflows were likely to be underestimating the flow in 1976. Therefore, all Mungindi 1976 flood model inflows were increased by 20%.

The 1996 flood model adopted the 1976 Border Rivers discharge with no change. No factoring of the flow was required. Table 2 shows the adopted inflows for the 1976 and 1996 calibration models and the factor applied to the 1976 Border Rivers flood model discharge. Figure A2, Appendix A, shows the inflow locations.

TABLE 2 ADOPTED HISTORIC MODEL INFLOW

Inflow Location	Peak Inflow (m^3/s)	
	1976	1996
Factor applied to Border Rivers 1976 Model	**1.2**	**1.0**
Weir River	127	106
Barwon River	458	381
Crooked Creek	250	208
Boomangarra (primary) Creek	213	178
Boomangarra (secondary) Creek	287	239
Boomi River	1,200	1,000
Whalan Creek	768	640
TOTAL	**3,303**	**2,752**

4.4 Results

4.4.1 1976 Flood Model Calibration

The 1976 Mungindi regional hydraulic model was calibrated against a recorded flood level at the Mungindi flood gauge. Table 3 shows the calibration result. A difference of -0.14m is within an acceptable margin considering the high level of uncertainty around model inflow and model topography (levees).

TABLE 3 MUNGINDI 1976 FLOOD GAUGE COMPARISON

Historic Flood	Recorded Water Level	Modelled Water Level	Difference
	(m AHD)		(m)
1976	160.95	160.81	-0.14

4.4.2 1996 Flood Model Calibration

4.4.2.1 Flood Gauge Comparison

The calibrated model flood level at the Mungindi gauge is 0.05m above the recorded level as shown in Table 4.

TABLE 4 MUNGINDI 1976 FLOOD GAUGE COMPARISON

Historic Flood	Recorded Water Level	Modelled Water Level	Difference
	(m AHD)		(m)
1996	160.83	196.88	+0.05

4.4.2.2 Recorded Flood Mark Comparison

The location of the recorded flood marks and calibration results are shown on Figure B1, Appendix B and in Table 5, respectively. Five peak flood marks were recorded after the 1996 flood. The flood marks were within 3km of Mungindi; with two marks to the north-east on Mungindi-Goondiwindi Road and three marks to the south-east on the Carnarvon Highway. The following is of note:

- Table 5 shows all three flood marks on the Carnarvon Highway were modelled lower than recorded.
- The modelled peak flood level at the southern point (location E) is higher than the northern point (location D). The recorded flood levels at points C and E have the same peak level with a lower peak level recorded between these marks (location D). This does not seem plausible and may suggest an error in the recorded flood level.
- The Carnarvon Highway acts as a weir during large floods. It is unclear whether the flood marks were recorded on the upstream or downstream side of the Carnarvon Highway.
- The flood levels on the Carnarvon Highway are influenced by flood levels in the Boomi River to the south east of Mungindi. The 1976 inflows were used for the 1996 flood. The flow distribution in time and space may not be the same as with the 1996 floods.

TABLE 5 1996 RECORDED FLOOD LEVEL CALIBRATION

Location	MAP ID (See Figure B1)	Recorded Water Level	Modelled Water Level	Difference
		(m AHD)		(m)
Mungindi-Goondiwindi Road	A	161.43	161.37	-0.06
	B	161.33	161.34	+0.01
Carnarvon Highway	C	161.16	160.73	-0.43
	D	160.99	160.82	-0.17
	E	161.16	160.86	-0.30

4.4.2.3 Mungindi Gauging Comparison

A comparison of stage-discharge results for the main channel of the Barwon River at the Mungindi flood gauge was undertaken. The four sets of data that were compared were:

- Flood gauging undertaken during the 1996 flood.
- Flood gauging undertaken during the 2013 flood.
  - Similar magnitude to the 1996 flood with a peak level of 160.7m AHD (0.18m below the 1996 flood).
- DPI Mungindi flood gauge rating.
- Mungindi regional flood model rating.

Figure 3 shows the comparison between the datasets. The datasets show correlation indicating the Mungindi regional hydraulic model was representing the conveyance in the main channel of the Barwon River with an acceptable level of accuracy. Given the uncertainty in the data, in particular the model inflows, the results were considered acceptable.

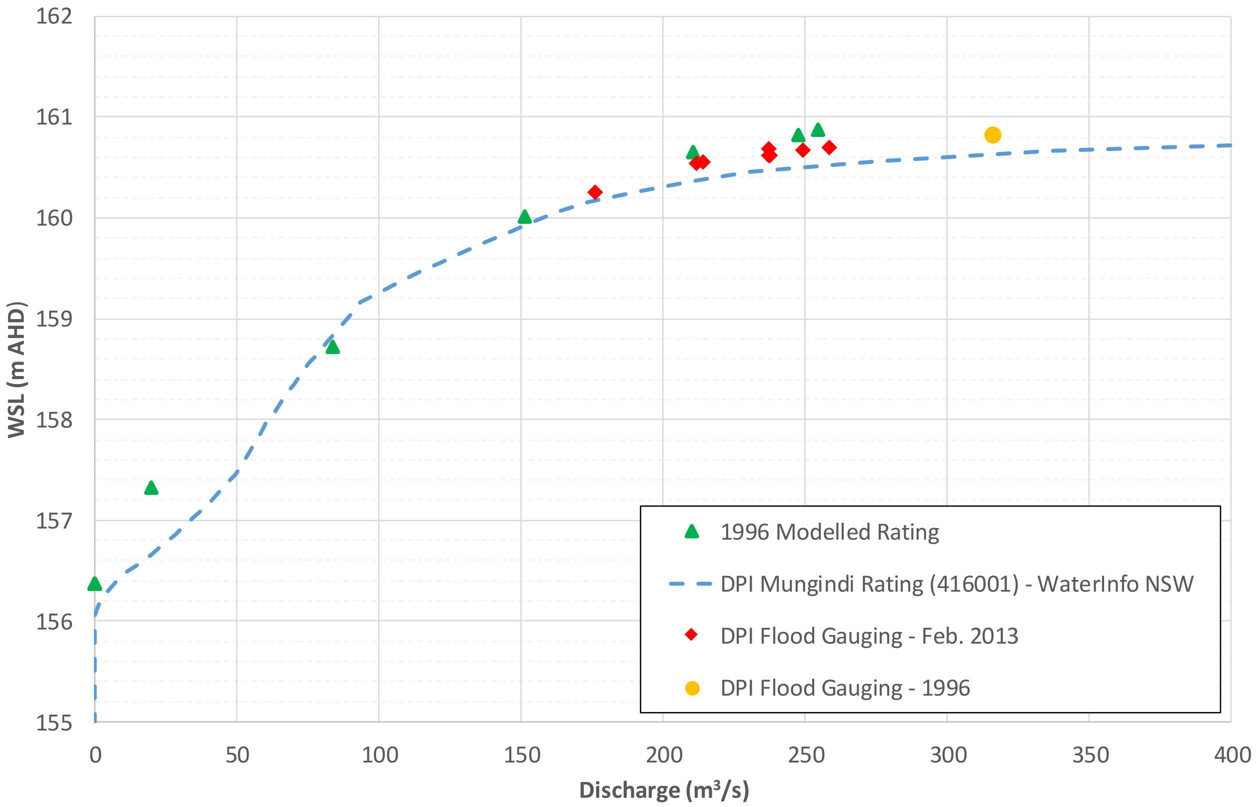

FIGURE 3 MUNGINDI GAUGING COMPARISON

4.5 1976 and 1996 Flood Results

Figure B2 and B3 in Appendix B show the modelled flood depth and water surface level contours for the 1976 and 1996 floods, respectively.

5 CONCLUSION

The Mungindi regional model was calibrated to the 1976 and 1996 floods. There is substantial uncertainty in the model hydrology. In addition, no model hydrology was available for the 1996 flood. If was no possible to reduce this model uncertainty. The hydrology is a function of the interaction of multiple non-linear processes. That is, similar flood behaviour could be observed with a range of different catchment and rainfall conditions. With the limited information available, it was not possible to separate these processes. Therefore, it was meaningless to attempt a detailed calibration. Instead, the model inflows were factored to provide an acceptable match between modelled and observed water surface levels.

Yours sincerely

Dr Richard Walton
Senior Principal Engineer

WATER TECHNOLOGY PTY LTD

6 REFERENCES

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Cutler (2013), *Internal Memo – Subject: 416001 Barwon River @ Mungindi – High Stage Rating & Current Flood Gauging Situation*, NSW Department of Primary Industries.

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APPENDIX A
HYDRAULIC MODEL SETUP

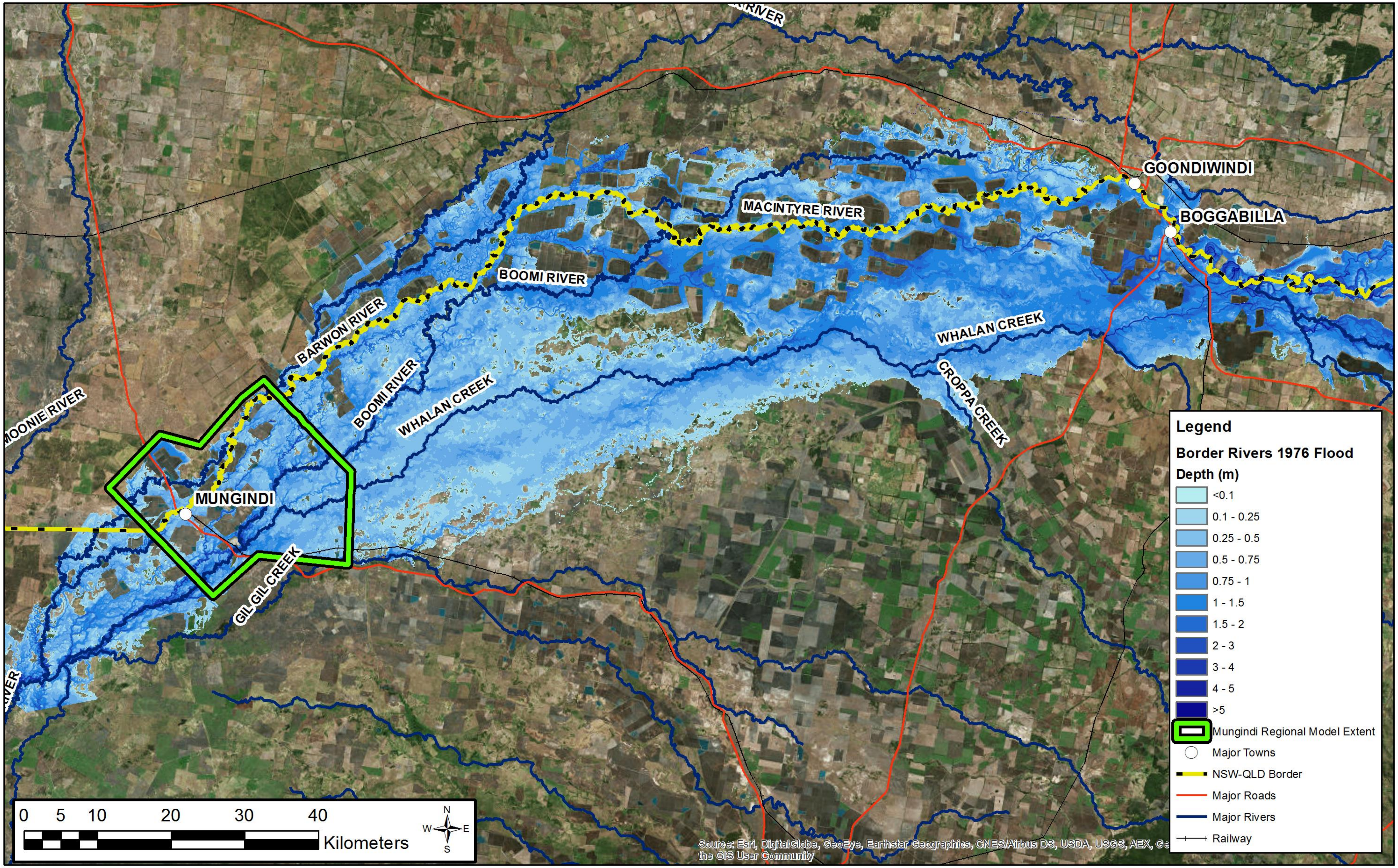

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FIGURE A1 BORDER RIVERS 1976 FLOOD DEPTH AND MUNGINDI REGIONAL FLOOD MODEL EXTENT

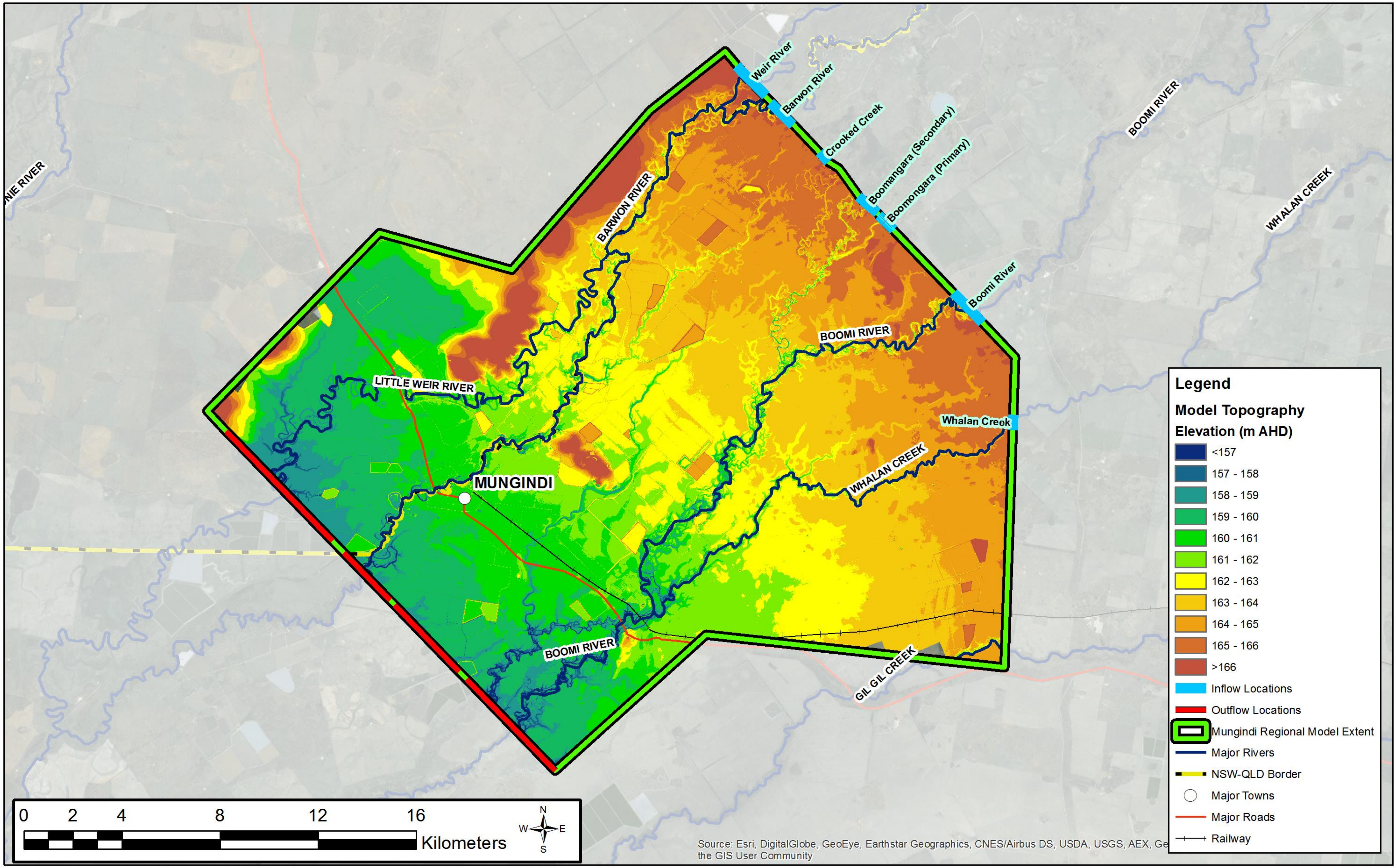

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FIGURE A2 MUNGINDI REGIONAL FLOOD MODEL LAYOUT

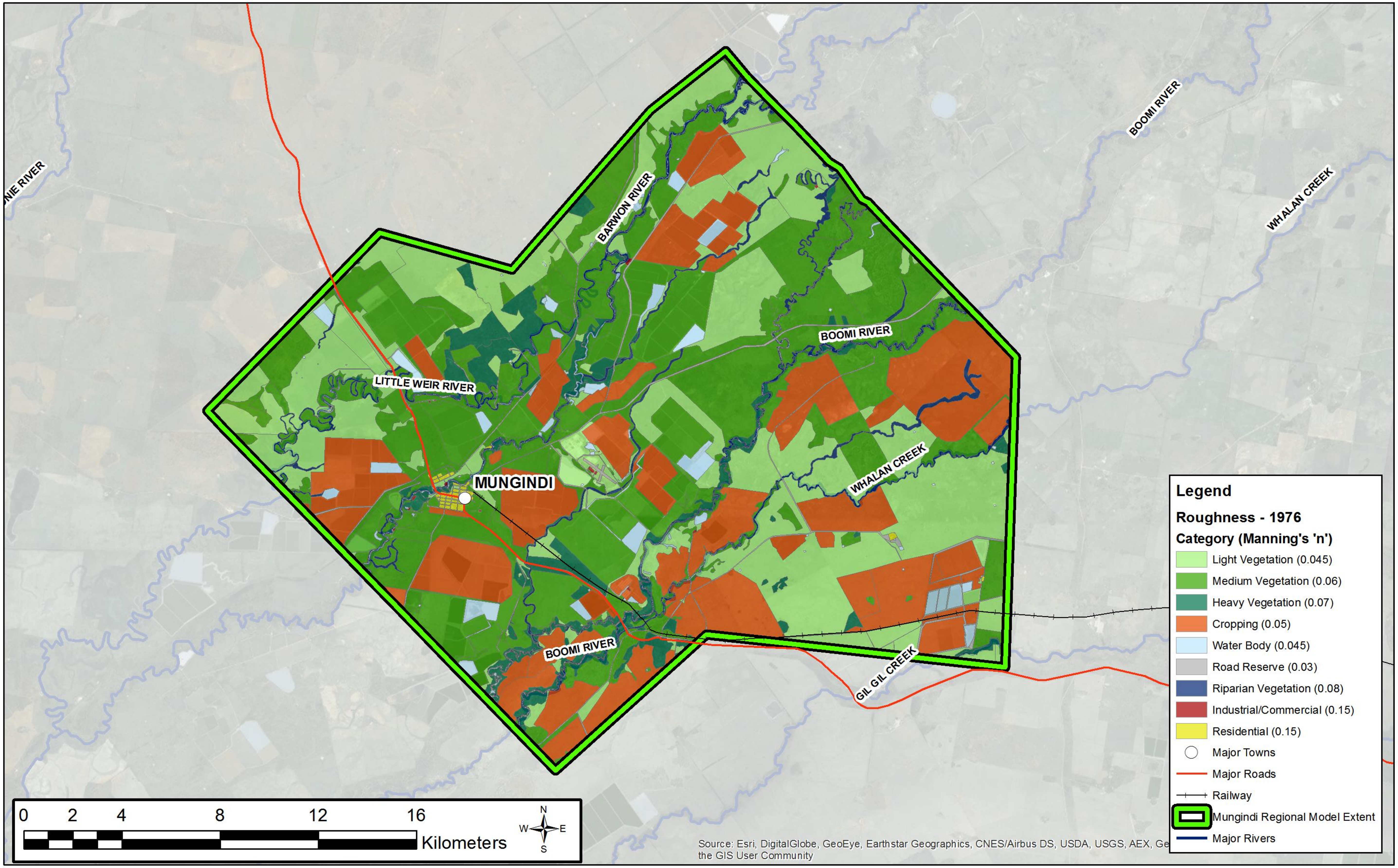

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FIGURE A3 1976 ROUGHNESS MAP

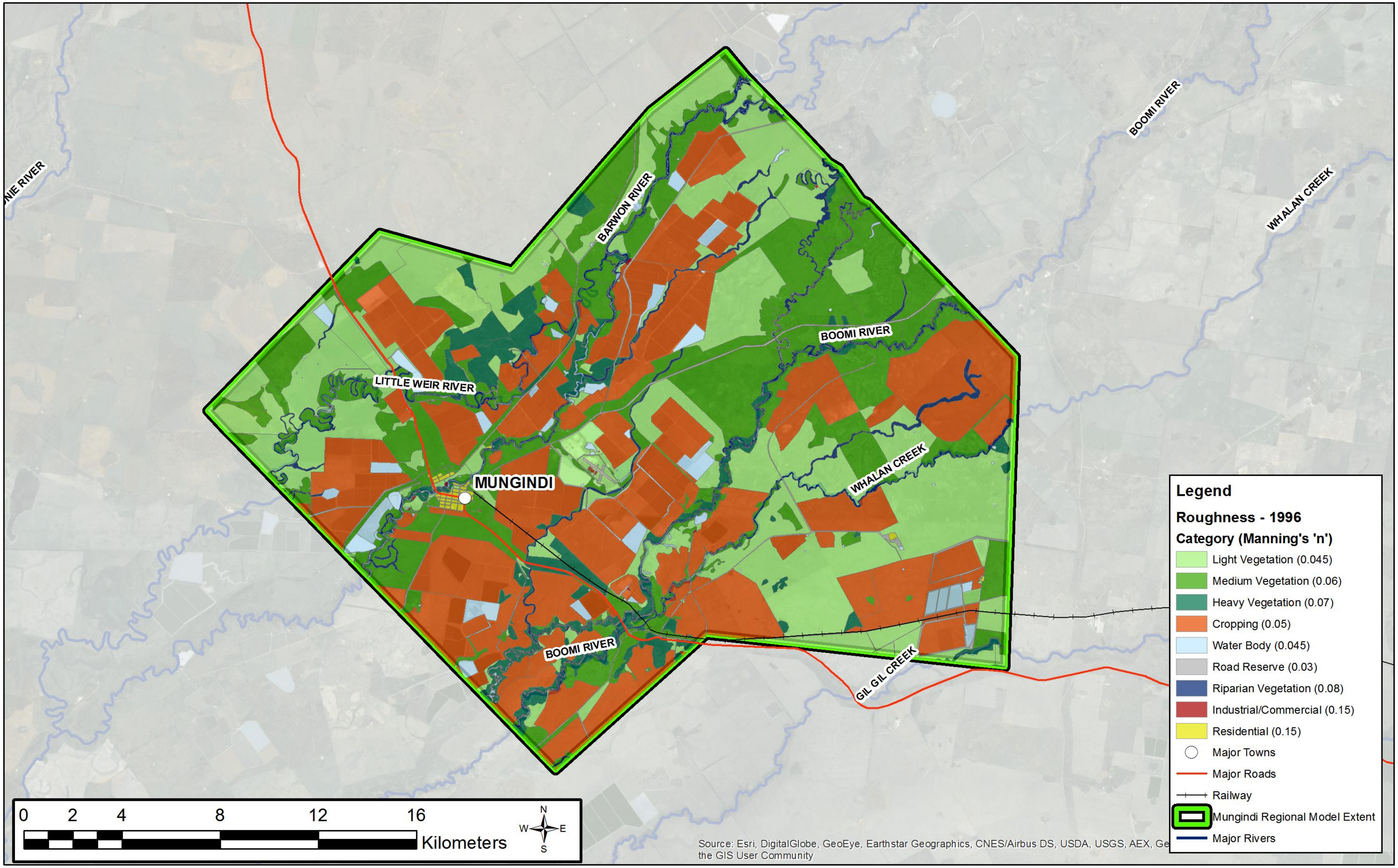

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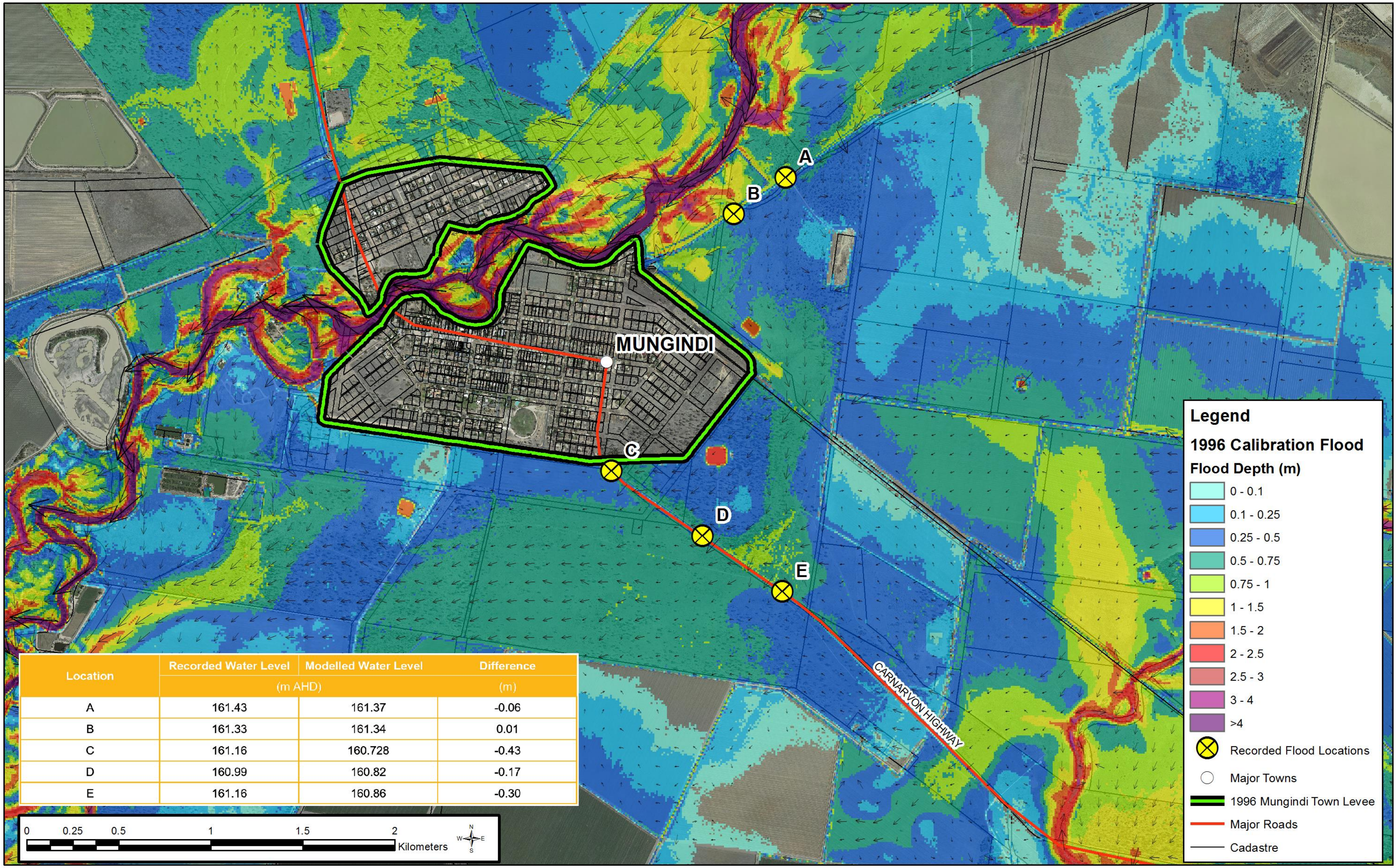
FIGURE A4 1996 ROUGHNESS MAP

APPENDIX B
CALIBRATION AND FLOOD MAPS



Location	Recorded Water Level	Modelled Water Level	Difference
	(m AHD)		(m)
A	161.43	161.37	-0.06
B	161.33	161.34	0.01
C	161.16	160.728	-0.43
D	160.99	160.82	-0.17
E	161.16	160.86	-0.30

FIGURE B1 1996 FLOOD DEPTH AND RECORDED FLOOD HEIGHT CALIBRATION RESULTS

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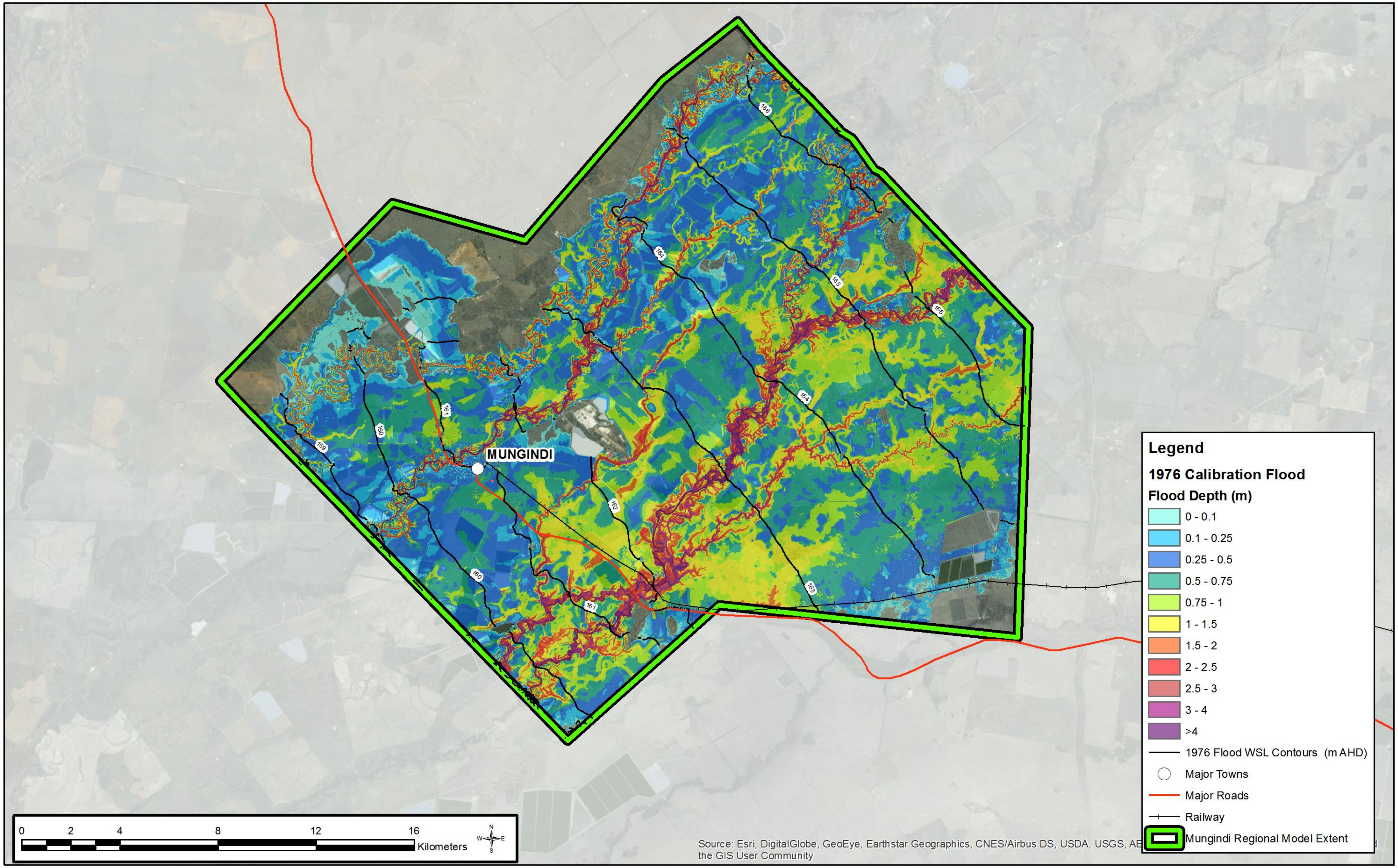

FIGURE B2 1976 MODELLED FLOOD DEPTH AND WATER SUFACE LEVEL

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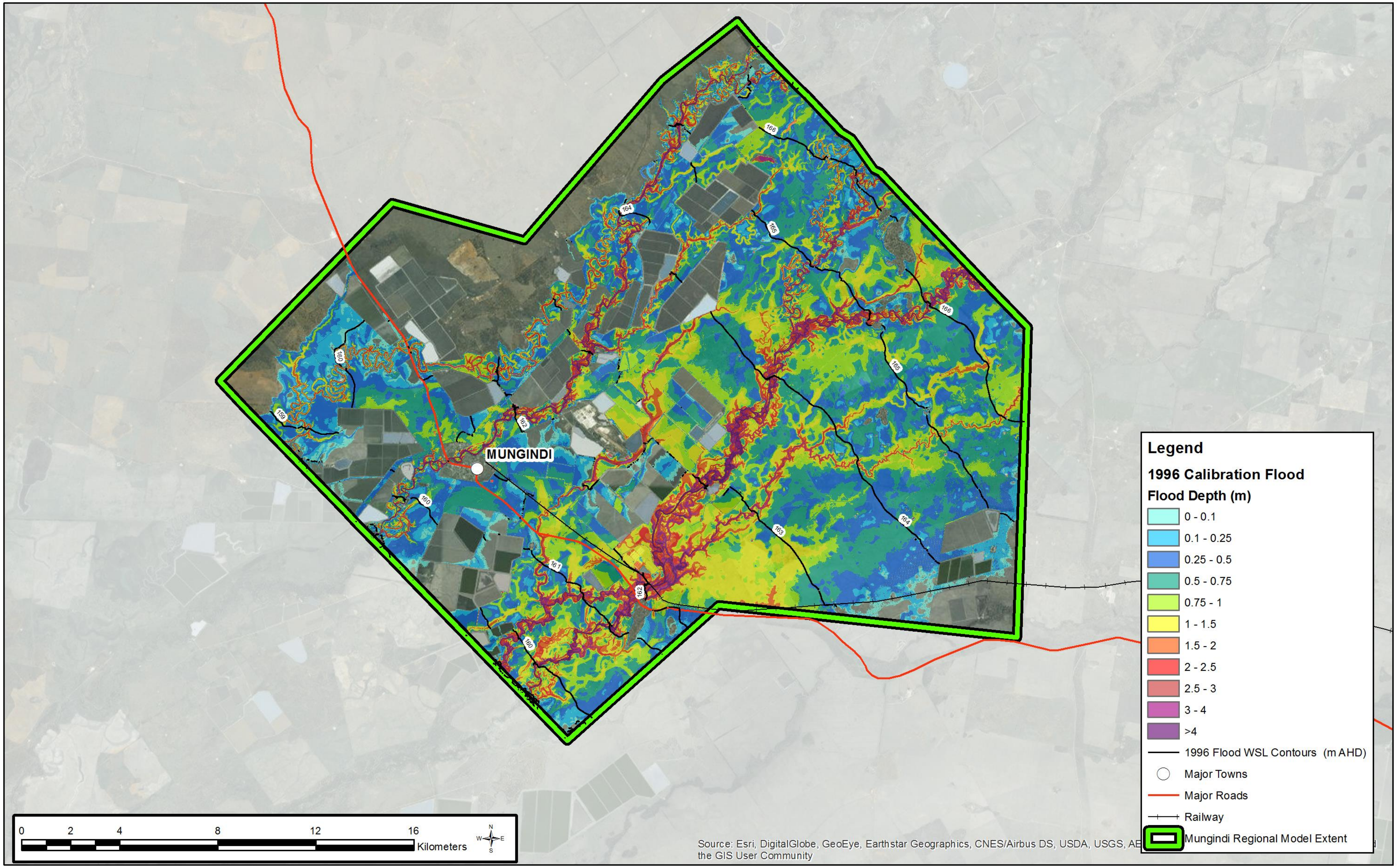

FIGURE B3 1996 MODELLED FLOOD DEPTH AND WATER SURFACE LEVEL

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