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Nagambie Flood Study – Final Report

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Nagambie Flood Study – Final Report

Prepared for:	Goulburn Broken CMA
Prepared by:	BMT WBM Pty Ltd (Member of the BMT group of companies)

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Synopsis:	**This report provides the methodology and results, including the flood mapping, of the Nagambie Flood Study.**	

REVISION/CHECKING HISTORY

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1 Introduction

BMT WBM Pty Ltd (BMT WBM) was commissioned by the Goulburn Broken Catchment Management Authority (GBCMA) to undertake hydrologic modelling of the catchments draining to Nagambie, and to assist in the development of a hydraulic model which will be used to prepare floodplain mapping of the Nagambie townships and local surrounds.

This study requires the development of both hydrological and hydraulic models to undertake flood mapping of the study area. Rainfall-runoff modelling of the study area was undertaken with the RORB hydrological modelling package. The outputs from RORB will provide inputs into the hydraulic model (TUFLOW). The purpose of this report is to document the development and results of the hydrologic and hydraulic modelling.

1.1 Background

The aim of the hydrological modelling is to calculate runoff at locations throughout the study area to apply the TUFLOW hydraulic model. When determining the hydrological response of the study area, there are a number of factors that need to be considered. These include catchment characteristics, design rainfalls and model parameters determined through model calibration.

The level of development, hence the proportion of impervious ground within a catchment, is an important factor in the generation of runoff. The current levels of development in a catchment can be determined from existing information such as aerial photography and Council GIS layers. Future development, or the ultimate development, can be determined from planning schemes. The method for determining these values is set out in Section 4.2.5.

Catchment and sub-catchment areas together with other physical catchment characteristics are determined from topographic information. The method for determining these values is set out in Section 4.2.

The hydrological model requires design rainfall events to produce design flood events. These design rainfall events are determined using standard methodologies published in Australian Rainfall and Runoff (ARR) (Institute of Engineers, 1999).

It is expected that future rainfall intensities for rare events will increase, with research suggesting that rainfall will increase by 32% in and around Melbourne by 2030. The MW Technical Specification requires flood studies to increase rainfall intensity by 32% to account for the expected increase in future rainfall intensities, and this has been adopted for this study. This is further outlined in Section 4.2.8.

Once the physical characteristics of a catchment have been determined and design rainfall calculated it is necessary to determine the hydrological model parameters. These parameters can be determined through standard relationships or, more commonly, through calibration. The approach to calibration is dependent on the available data. If there is sufficient data available, the hydrological model should be calibrated to this data. As a minimum this would require streamflow data at one location. However, there was no streamflow data available within the study area. For this reason the hydrological model was calibrated to the Rational Method.

The Rational Method is a well-established method for determining runoff in ungauged catchments and standard methods to achieve this are published in ARR. The rational method calculation is set out in Section 4.1.

1.2 Study Objectives

The objective of the study was to create a hydrologic model of the catchment to model the rainfall-runoff process, as well as a 1D/2D dynamically linked TUFLOW hydraulic model to undertake flood mapping of the catchment. The results from the coupled hydrologic and hydraulic model (the flood model) were used to create flood mapping and flood risk products required as well as informing potential flood mitigation strategies. This suite of products was used to improve the understanding of flooding and flood risk in Nagambie, now and for the future conditions.

The flood model was run for the Scenarios and Events listed under the appropriate heading below.

Specifically, the study aimed to deliver:

- Flood mapping products for the four scenarios and AEP events listed below for the following variables:
  - Peak flood levels
  - Peak flood depths
  - Peak flood velocities; and
  - Flood Hazard.
- The following flood risk products
  - Flood mapping products that are suitable to define planning scheme flood overlays.
  - Recommendations for flood related planning conditions.
  - Tabulated property flood likelihood.
  - Flood damages assessment using the Rapid Appraisal Method (RAM).
  - Recommendations for structural flood mitigation measures.

1.2.1 Study Scenarios and Events

A number of design events and different scenarios as listed in Table 1-1 and described in more detail below.

- **Base:**
  - Existing rainfall conditions; with
  - Current levels of development.
- **Developed:**
  - Existing rainfall conditions; with

- Ultimate development conditions – in line with future rezoning and development anticipated around Nagambie.

- **Climate Change A:**
  - Existing rainfall conditions intensified by 32%; with
  - Current (Base) levels of development.
- **Climate Change B:**
  - Existing rainfall conditions intensified by 32%; with
  - Ultimate (Developed) levels of development.

Table 1-1 Required Modelling Scenarios

Scenario	ARI							
	5 year	10 year	20 year	50 year	100 year	200 year	500 year	PMP
Base	✓	✓	✓	✓	✓	✓	✓	✓
Developed	✓	✓	✓	✓	✓	✓	✓	✓
Climate Change A	✓	✓	✓	✓	✓	✓	✓	
Climate Change B	✓	✓	✓	✓	✓	✓	✓	

1.3 Study Approach

The study involved the following five key stages:

- data collection;
- hydrological modelling;
- hydraulic modelling;
- flood mapping and deliverables; and
- reporting.

2 Catchment Description

The Nagambie catchment, shown in Figure 2-1, is located in north-central Victoria approximately 120 kilometres north of Melbourne. The catchment discharges to Lake Nagambie, which is on the Goulburn River, and straddles the Goulburn Valley Highway. There are four main watercourses within the catchment, all of which pass through the town of Nagambie before discharging to Lake Nagambie. Combined, the four catchments cover an area of 4753 hectares within the Strathbogie Shire Council local government area (LGA). All four catchments feature noticeable drainage lines and depressions that are likely to have been part of the Goulburn River floodplain historically; however, they now occur as a complex system of interacting shallow gradient natural depressions. The surrounding region is significantly flat and primarily used for agricultural purposes.

The town of Nagambie is sufficiently elevated that it is not subject to flooding from the Goulburn River and Lake Nagambie, and so the purpose of the hydraulic modelling is to simulate flooding from runoff from the four local catchments draining to Nagambie. Therefore, the hydrological model will provide estimates of flows into the Flood Mapping Area (FMA) from the four catchments, as well as runoff within the FMA. The FMA, as provided by GBCMA and shown on Figure 2-2, is bounded by Cemetery Road to the south, Habel Road to the east, and Racecourse Road to the north. The Western boundary is predominantly dominated by Lake Nagambie. The FMA represents the approximate extent of the TUFLOW hydraulic model. The hydraulic modelling will account for cross catchment flows and the complex nature of the drainage channels (numerous anabranches, bifurcations and confluences) that exist within the Nagambie catchment.

Four catchment outlets discharge into Lake Nagambie from within the FMA. The outlet at Elloura Estate and the outlet at Bryde Street are both discharge points for the main catchment of Nagambie. A third outlet exists to the west of Nagambie Township along Vickers Road whilst the fourth outlet discharges into Lake Nagambie adjacent to Nagambie Hospital.

The Main Catchment originates between the Goulburn River and the Avenel-Nagambie Road. This catchment covers 2621 hectares and is traversed by the new Nagambie bypass. The Main Catchment crosses the Goulburn Valley Highway multiple times and flows down through the Elloura Estate to discharge into Lake Nagambie.

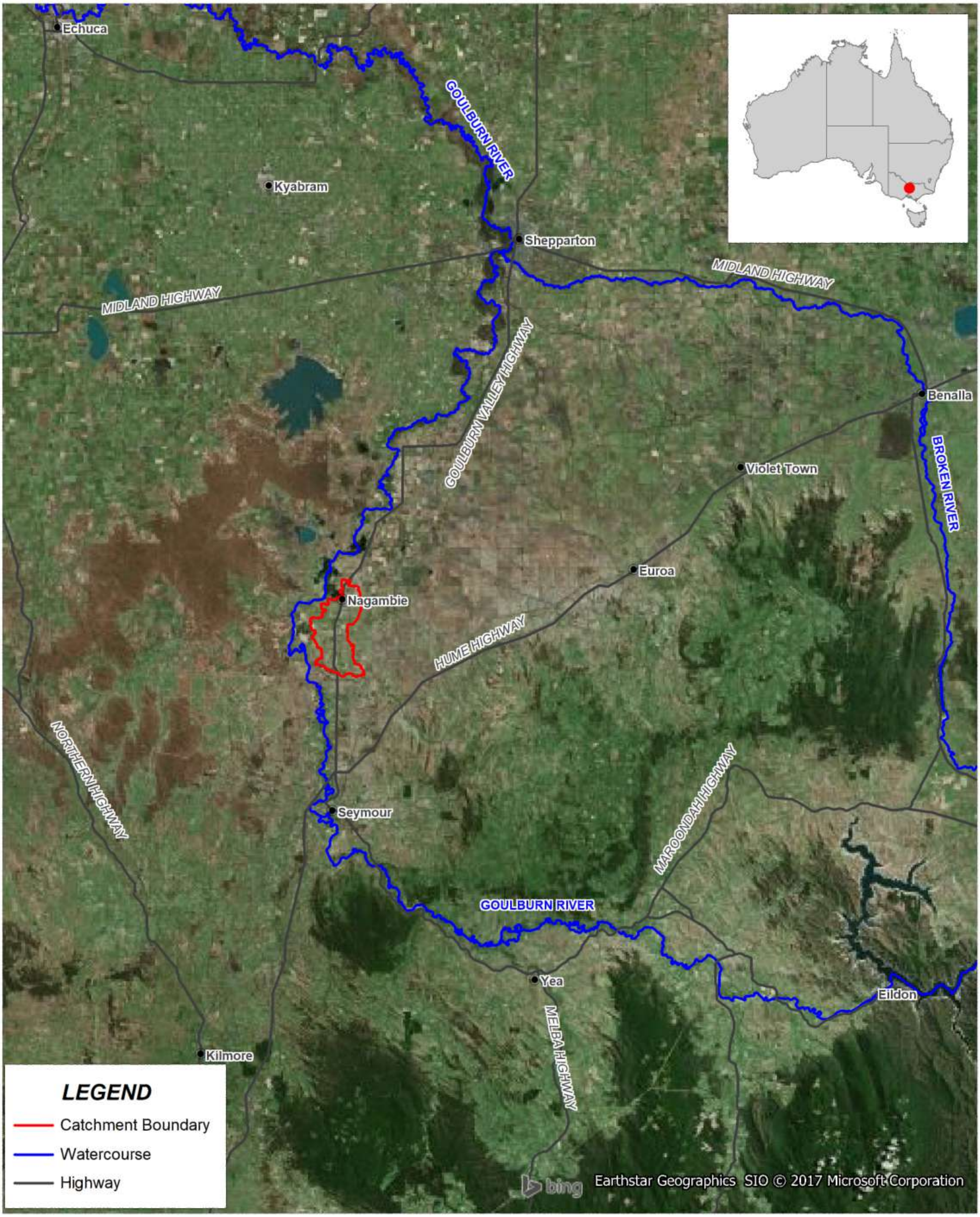
The Bryde Street catchment covers 987 hectares, begins at Nagambie-Locksley Road and discharges to Lake Nagambie at Bide Street. Whilst this catchment is not truly independent from the Main Catchment, a separate hydrological model was developed for this catchment with the intention that cross catchment flows will be accounted for in the hydraulic model. The Bryde Street Catchment is a natural depression which crosses the railway line on the eastern boundary of Nagambie Township and then weaves its way through the town before crossing the Goulburn Valley Highway and discharging into Lake Nagambie.

The West Catchment covering 987 hectares, drains from Mitchellstown Road in the south and is bounded by the Goulburn River to the west and the Goulburn Valley Highway to the east.

The North Catchment is the smallest of the four catchments and it discharges into Lake Nagambie adjacent to the Nagambie Hospital. It covers 159 hectares on the northern boundary of Nagambie Township. Originating in agricultural land adjacent the Goulburn Valley Highway it enters

Nagambie Township via a progression of retarding basins, then crosses the Goulburn Valley Highway and residential areas before discharging into Lake Nagambie.

The predominant landuse within the catchment is rural farmland, although the township of Nagambie covers approximately 240 hectares in the lower reaches of the combined catchments. The Nagambie Township contains predominately residential zoned land, with some commercial business and industrial zones.



Title:
Nagambie Catchment Locality

Figure: 2-1

Rev: A

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Approx. Scale

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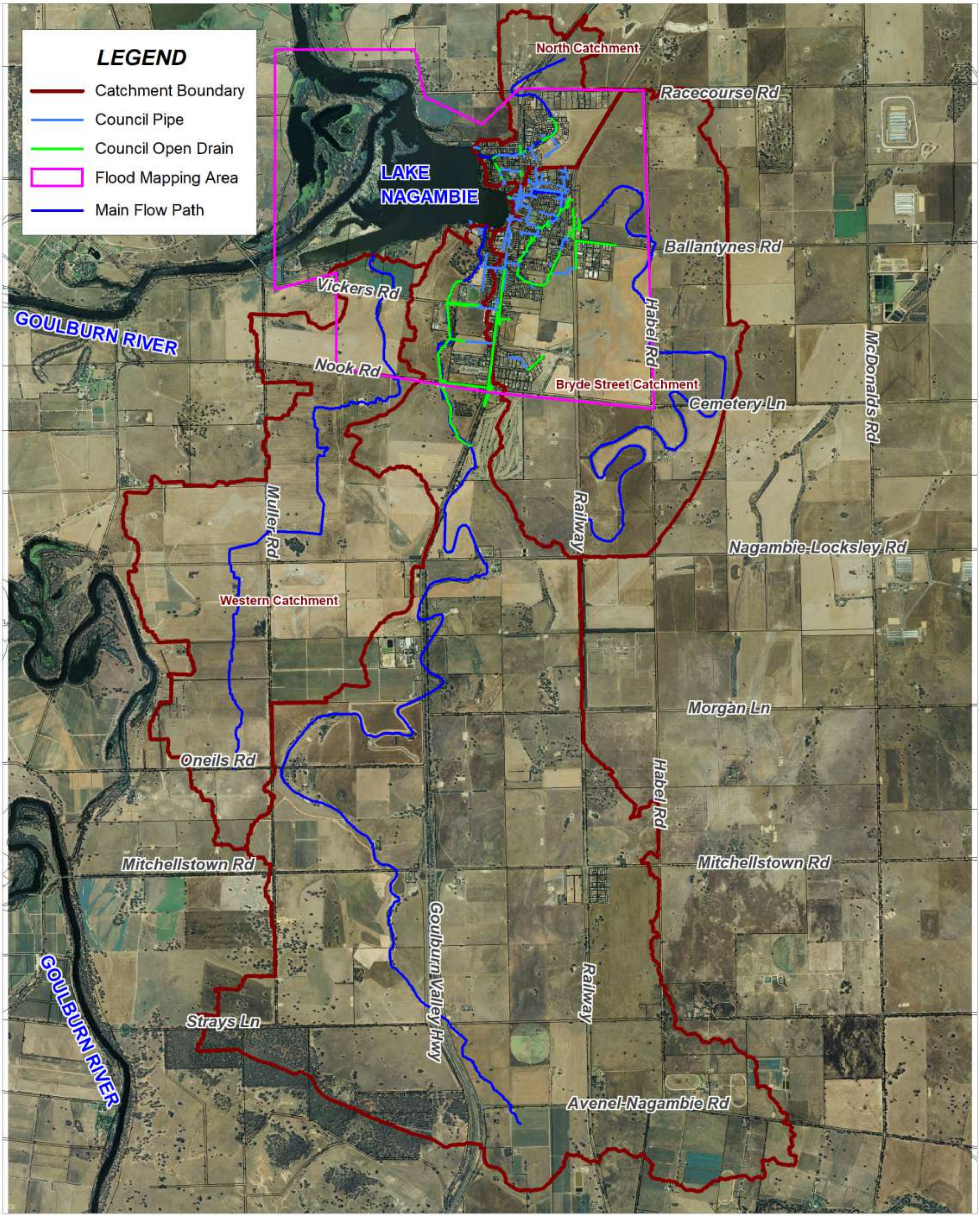

Title:
Nagambie Catchment Plan

Figure: 2-2

Rev: A

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Approx. Scale

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3 Data Collation

This section documents the data that has been collated by BMT WBM to date for the Study. BMT WBM has obtained information from a number of agencies and sources, including:

- Goulburn Broken Catchment Management Authority (GBCMA);
- Strathbogie Shire Council (Council); and
- Department of Environment, Land, Water and Planning (DELWP).

3.1 Topographic Data

For the Study 0.5m gridded LiDAR was provided by GBCMA to form the basis of the Digital Elevation Model (DEM) which was used for both the hydrologic and hydraulic modelling components of the Study. The extent of the available LiDAR was less than the hydrologic catchment boundaries and formed the basis of the extent of the hydraulic model. The extent of the available LiDAR is shown in Figure 3-1. The additional topographic data (hydrologically reinforced SRTM DEM) used to define the catchment extents was sourced from GeoScience Australia.

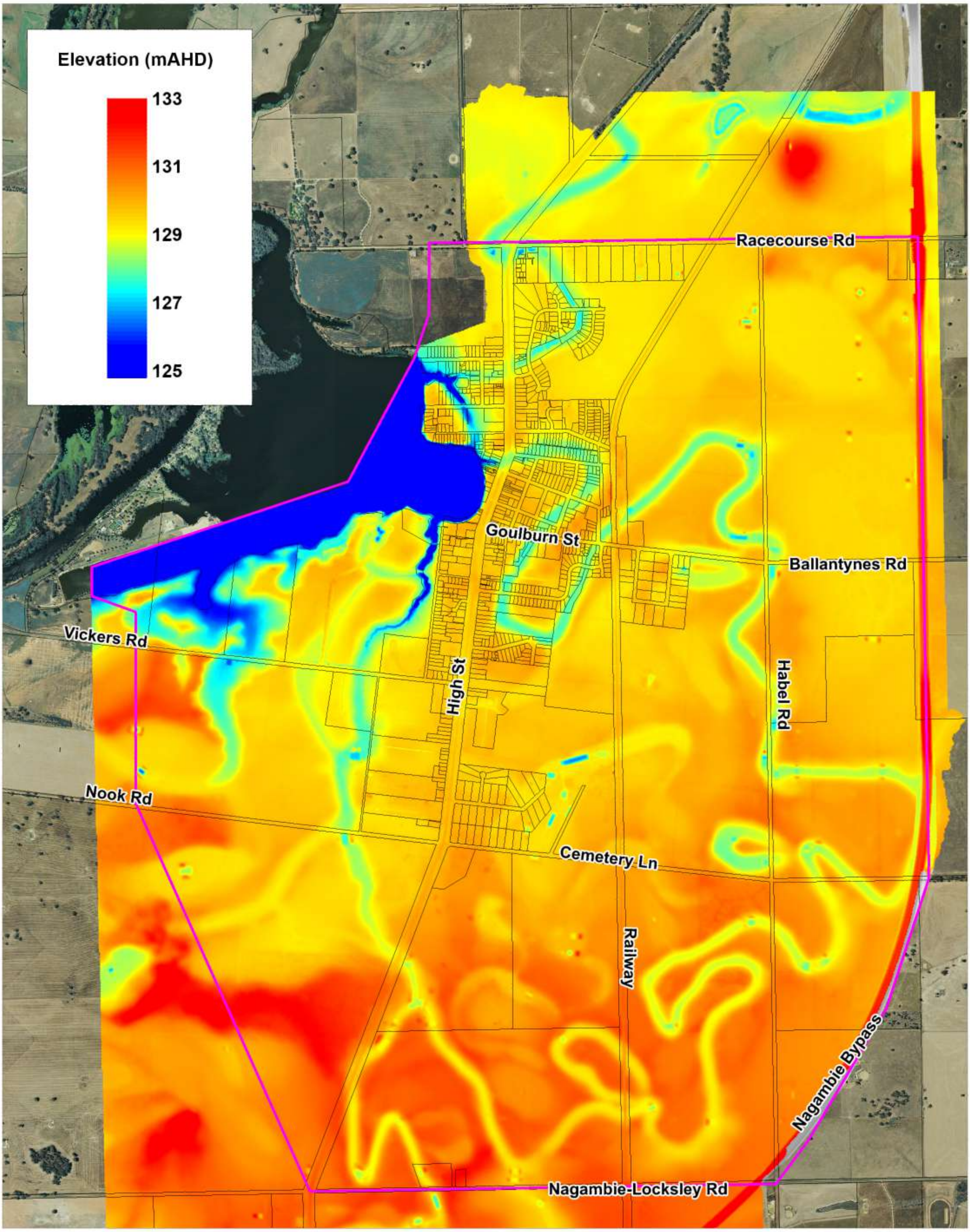
3.2 Aerial Photography

Aerial Photography of the catchment is an important tool for verifying catchment characteristics such as land use, building footprints and other structures. During the hydrologic modelling stage this information was used, along with the planning scheme overlays, to estimate the fraction imperviousness of the catchment. Similarly, when developing the hydraulic model this information was used to assign the Manning’s values (roughness) to the catchment and any blockages caused by buildings.

For the Study one geo-referenced tile covering the Nagambie was provided by GBCMA.

3.3 Planning Scheme

The planning scheme layers were used in conjunction with the aerial photography and on-ground photography to define the current land use of the catchment. The planning scheme layers were used in both the hydrologic and hydraulic model to define factors such as fraction impervious and Manning's values (roughness). This was supplied by GBCMA and covers the study area.



Title:

Nagambie Flood Study
Digital Elevation Model (DEM)

Figure: 3-1

Rev: A

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3.4 Drainage Infrastructure

Underground drainage, as well as culvert and open channel information, was used during the hydraulic modelling component of the flood study. It is important to incorporate any assets in the hydraulic model using as accurate information as possible. Locating the asset in the wrong location may disconnect it from the main flow channel. Whilst applying incorrect attributes (width/height/inverts/weirs/drops/etc) may result in incorrect flows passing through the structure. This may result in either elevated or depressed flooding upstream and over the road as well as elevated or depressed water levels downstream depending on which attributes are incorrect.

Drainage information was supplied by Council. On-Site confirmation of drainage assets, including the identification of missing assets was undertaken by GBCMA and BMT WBM staff during the numerous site visits.

3.5 Historic Flooding

Due to the lack of stream or flow gauges within the catchment it was not possible to undertake a traditional model calibration. During the stakeholder engagement activities, there were no historic flood marks or flood information identified.

3.6 Streamflow Data

There are no stream flow gauges available within the catchment that could be used to calibrate or verify the hydrologic and hydraulic models.

4 Hydrologic Modelling

The flood response of a catchment can be characterised by undertaking rainfall-runoff modelling. Rainfall-runoff modelling or hydrological modelling, of the catchment draining to Nagambie was undertaken with the RORB hydrological modelling package. The results of the RORB hydrologic model were calibrated to peak flows derived using the Rational Method. The outputs from the RORB model will provide inputs for the TUFLOW hydraulic model.

Hydrologic models of the Nagambie catchment have previously been developed as part of a flood investigation focussed on the Nagambie Bypass. Consequently, this model lacked the required definition in the lower parts of the catchment, and therefore, a new RORB model was developed to meet the requirements of this study.

4.1 Rational Method

4.1.1 Description

The Rational Method, as outlined by Book VIII of Australian Rainfall and Runoff (AR&R) (1999), has been used to calculate the peak flow from the catchment. The Rational Method is an established method for determining the peak flow from urban and rural catchments. Considering the nature of Nagambie catchment, the rural approach to implementing the Rational Method has been used for the majority of the catchment.

The Rational Method equation is:

$$Q_Y = C_Y I_{t_c,Y} A$$

Equation 4.1

where Q_Y is the peak flow with an Annual Recurrence Interval (ARI) of Y years, C_Y is the runoff coefficient for a flood with an ARI of Y years, I is the Y-year ARI rainfall intensity for a duration of t_c, and A is the catchment area.

A description of each of these parameters and variables is provided below.

4.1.2 Time of Concentration

The time of concentration (t_c) is the travel time for runoff to reach the outlet from the furthest part of the catchment. The catchments are a mix of rural and urban, and so t_c was calculated separately for each area and then summed to give the total t_c at different locations within the catchments and at their outlets. In the rural parts of the catchments t_c was calculated using the Adams equation (from AR&R for Victorian catchments), and in the urban areas it was calculated using Manning's equation for open channel areas and the Colebrook White formulae for pipe full flow.

In the Adams equation, the t_c is a function of the catchment area as shown below.

$$t_c = 0.76A^{0.38}$$

Equation 4.2

The Manning's equation for overland flow in open channels is shown below, where; L is the length of channel, *n* is Manning's roughness coefficient, R is the wetted perimeter and S is the slope of the channel.

$$t_c = \frac{Ln}{R^{2/3}S^{1/2}}$$

Equation 4.3

Due to the very low gradient across the catchment, the Manning's equation twice resulted in very low flow velocities of approximately 0.2m/s. The average velocity throughout the catchment resulting from the Adams equation was typically between 1.0m/s and 1.5m/s. Therefore, a velocity of 1.0m/s was adopted where the Manning's equation returned a velocity below 1.0m/s. These flows are noted in Appendix A. Where underground drainage assets exist, the Colebrook White formulae for pipe full flow was used to determine the t_c.

The calculated t_c values at key locations of the main catchment have been provided in Table 4-1. These locations are also displayed in Figure 4-1.

Table 4-1 Calculated t_c Values

Location	t_c (mins)
Catchment Outlet (Elloura Estate)	168
Golfcourse Confluence	152
O'Neils Road	109
Nagambie Bypass	103

4.1.3 Runoff Coefficient

The 10 year ARI runoff coefficient (C_{10}) was derived from the relationship between C_{10} and fraction impervious presented in Book VIII of AR&R (1999). C_{100} was derived from the C_{10} using the frequency factors in Table 1.6 in AR&R Book VIII. The resulting values for each of the catchments are shown in Table 4-2.

Table 4-2 Nagambie Runoff Coefficient Values

	C_{10}	C_{100}
Main Catchment (Elloura Estate)	0.16	0.20
Bryde Street Catchment	0.22	0.28
West Catchment	0.15	0.20
North Catchment	0.34	0.42

4.1.4 Rainfall

Design rainfall was determined using the methodology outlined in ARR. This method requires the determination of Intensity Frequency Duration (IFD) parameters from standard maps published for all of Australia. These parameters are then used to determine the IFD relationship.

Storm data was based on IFD parameters sourced from the Bureau of Meteorology IFD program (Bureau of Meteorology, 2011) for the location 36.820°S, 145.153°E; a central location in the overall catchment. The adopted values for the catchment are presented in Table 4-3. The full IFD Table is provided in Appendix C.

Table 4-3 IFD Parameters

<table>
<tr><th colspan="2">IFD Parameter</th><th>Base Case</th></tr>
<tr><td rowspan="6">Rainfall Intensity (mm/hr)</td><td>2 Year ARI, 1 Hour Duration</td><td>21.90</td></tr>
<tr><td>2 Year ARI, 12 Hour Duration</td><td>3.93</td></tr>
<tr><td>2 Year ARI, 72 Hour Duration</td><td>0.98</td></tr>
<tr><td>50 Year ARI, 1 Hour Duration</td><td>45.69</td></tr>
<tr><td>50 Year ARI, 12 Hour Duration</td><td>6.95</td></tr>
<tr><td>50 Year ARI, 72 Hour Duration</td><td>1.95</td></tr>
<tr><td colspan="2">Skew Coefficient</td><td>0.21</td></tr>
<tr><td colspan="2">Geographical Factor F2</td><td>4.32</td></tr>
<tr><td colspan="2">Geographical Factor F50</td><td>15.05</td></tr>
<tr><td colspan="2">Zone</td><td>2</td></tr>
</table>

4.1.5 Results

The 100 Year ARI Rational Method parameters and results at key locations within the catchments are shown in Table 4-4. As the AR&R method for rural catchments has been used, the fraction impervious is not a required parameter and the varying C_{10} value as listed in Table 4-2 is adopted based on the geographical location of the catchment.

Table 4-4 Rational Method Parameters and Results for the 100 year ARI event

Location	Area (ha)	t_c (mins)	Intensity (mm/h)	Runoff Coefficient	Q (m^3/s)
Main Catchment					
O'Neils Rd	987	108.8	34.9	0.20	18.7
Nagambie Bypass	849	102.8	36.5	0.20	16.8
Golfcourse Confluence	2387	152.2	26.9	0.20	34.8
Outlet	2621	168.2	24.9	0.20	37.0
Bryde St Catchment					
Railway	667	93.8	39.1	0.20	14.1
Bryde Street	987	133.4	29.8	0.28	22.8
West Catchment					
Muller Rd	408	77.8	45.1	0.20	10.0
West Outlet	987	108.8	34.9	0.20	18.7
North Catchment					
Racecourse Rd	66	39.0	71.0	0.20	2.5
Nth Outlet	159	60.5	54.7	0.42	10.2

4.2 RORB Model

Rainfall runoff modelling is a method utilised to estimate the amount of runoff produced by a catchment for a given rainfall event, taking into account the hydrologic characteristics of that catchment.

RORB simulates the linkages between sub-catchments as reach storages with the storage discharge relationship defined by the following equation;

$$S = 3600kQ^m$$

where 'S' represents the storage (m^3), 'Q' is the discharge (m^3/s), 'm' is a dimensionless exponent and 'k' is non-dimensional empirical coefficient. 'k' is defined by the product of the catchment value 'k_c' and the individual reach k_i. Both m and k_c are defined as calibration parameters. As per the RORB manual, in the absence of calibration events, an *m* value of 0.8 is adopted.

4.2.1 Model Description

The RORB model incorporates an area of approximately 4753 hectares. To ensure accurate representation of the hydrological response of the overall catchment, the model was divided into four sub-models (each representing the catchment of an outlet) and 95 individual sub-catchments. Conceptual reaches (approximate overland flow paths) were defined for each sub-catchment and the fraction impervious values for the catchment were defined using aerial photography and the Planning Scheme. Whilst there were formal storages identified in the catchment (including a series of retarding basins in the North Catchment and numerous farm dams), it was determined that the effects of these storages will be better modelled in the hydraulic model as opposed to the hydrologic model. Consequently, there were no storages included in the hydrologic model.

4.2.2 Catchment Delineation

The catchment delineation was completed using several techniques. Initially the catchment boundary was defined by the CatchmentSIM computer program using a 1m gridded Digital Elevation Model (DEM) developed from the LiDAR data provided by GBCMA. This boundary was then refined using contours and taking into account other influences including:

- major roads and flow paths; and
- relevant council drainage networks.

The LiDAR provided by GBCMA was originally used by VicRoads for the development of the Nagambie Bypass. As such, whilst covering the vast majority of the Nagambie catchment in good detail, the western region of the catchment, between the Goulburn Valley Highway and the Goulbourn River, is not contained within the data set. With no detailed LiDAR available to cover this area, BMT WBM, after discussion with GBCMA, has used the hydrologically conditioned SRTM-derived 1 second DEM. This has allowed an approximate boundary to be established for the western portion of the catchment, however, there is a significant difference in elevation between the VicRoads LiDAR and the SRTM-derived DEM. As there is no other information available, the combination of the two available DEMs provides the best possible representation of the catchment.

As discussed in Section 2, the overall catchment modelled is comprised of four outlets within the Flood Mapping Area. The total area of the Nagambie hydrologic model was determined to be approximately 4753 hectares. The catchment size for each outlet is shown in Table 4-5

Table 4-5 Outlet Catchment Areas

Catchment Name	Outlet	Catchment Area (ha)
Main Catchment	Elloura Estate	2621
Bryde Street Catchment	Bryde Street	987
West Catchment	Western Catchment	987
North Catchment	Nagambie Hospital	159

4.2.3 Sub-Catchment Definition

Similar to the development of the catchment boundary, the sub-catchments, illustrated in Figure 4-1, were developed using a variety of techniques. Initially the sub-catchments were defined using the CatchmentSIM computer program and the DEM. The sub-catchments were refined using topographic data including roads, identified overland flow paths and contours, and the local drainage networks where appropriate. It was assumed that the flow was predominately overland, although where there were Council pipes of a significant size; these were taken into consideration when defining the sub-catchments where appropriate. The hydrological model will provide flow boundaries for the hydraulic model, and so sub-catchment outlets were positioned appropriately. The sub-catchment definition also allowed for flows to be extracted from the hydrological model at key flow locations including at the drain confluences, key hydraulic structures (including railway and road embankments) and major roads.

Where possible, a minimum of three to four sub-catchments were defined upstream of any of Strathbogie Shire Council assets. Additionally, uniformity in sub-catchment area and shape was sought after. The catchment was divided into 95 sub-catchments and 158 reaches.

4.2.4 Reach Types

The following reach types were used in the RORB model setup:

- Reach Type 1 = natural flow path (eg farmland, rural areas).
- Reach Type 2 = unlined flow path (eg through residential property/fences)
- Reach Type 5 = dummy reach (used to connect all outlets into one model).

Where the flow was found to be in an unlined channel or where the majority of the flow was through residential/commercial properties, Reach Type 2 has been used. Where flow would be largely contained within farmland Reach Type 1 has been used. Reach alignments and types are shown in Figure 4-1

4.2.5 Fraction Impervious

The upper portion of the Nagambie catchment is predominately rural, whilst the lower portion is comprised of a mix of residential and business land uses in and around the township itself. The fraction impervious (FI) values for the Nagambie catchment were determined using the existing planning scheme zones (as per the Planning Schemes Zones MapInfo table provided by GBCMA and Strathbogie Shire Council).

The fraction impervious values were then reviewed against aerial photography provided by Strathbogie Shire Council and Google Earth imagery for each zone to ensure accurate representation of the catchment. Table 4-6 outlines the FI for each planning scheme zone across the catchment.

The Ultimate FI represents the full extent of future development allowed under the current zoning and uses values recommended by Melbourne Water.

Table 4-6 Planning Scheme Zone Fraction Impervious

Planning Scheme Zone	Existing Planning Zone FI	Ultimate Planning Zone FI
Farm Zone (FZ)	0.05	0.2
Residential Zone (R1Z)	0.35	0.6
Major Roads (RDZ1)	0.7	0.9
Minor Roads (RDZ2)	0.6	0.8
Industrial Zone (IN1Z)	0.9	0.95
Business Zone (B1Z)	0.8	0.95
Public Park and Recreation Zone (PPRZ)	0.1	0.2
Railway (PUZ4)	0.7	0.8
Nagambie Recreation Centre (PUZ6)	0.2	0.9
Comprehensive Development Zone (CDZ1)	0.5	0.8

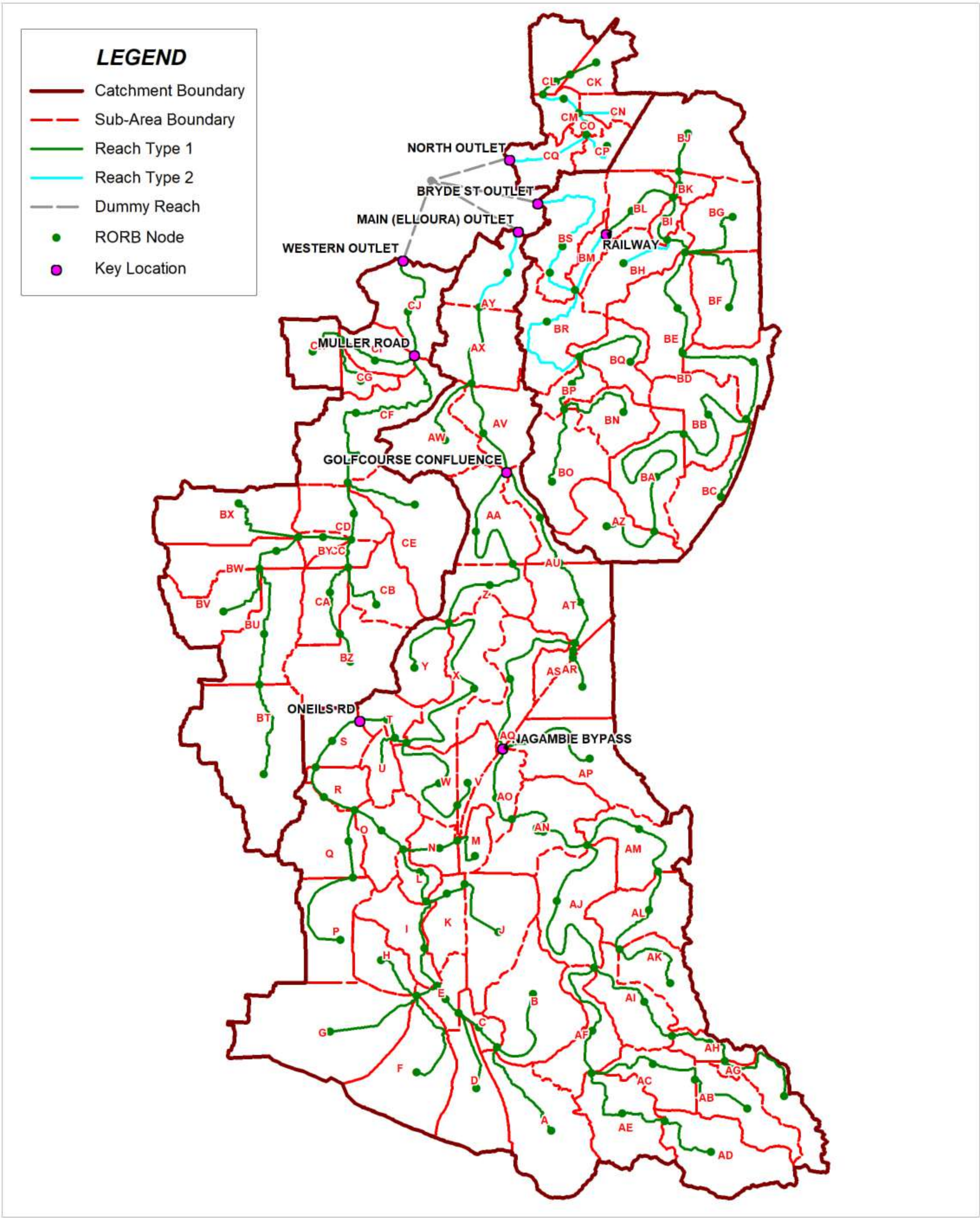
4.2.6 Retarding Basins and Storages

The North Nagambie catchment includes an interconnected series of retarding basins. Nine retarding basins are located along the drainage line from the intersection of the Goulburn Valley Highway and Racecourse Road through the recently developed housing estate along McGregor Avenue before entering the council pipes under the Goulbourn Valley Highway. These retarding basins have not been included in the hydrologic model as the hydraulic model will account for attenuation and storage effects of these retarding basins.

The effects of flood storage behind roads and other flow obstructions will be taken into account by the hydraulic model.

4.2.7 Diversions

The Nagambie RORB model does not include any piped diversions. The TUFLOW hydraulic model covers the entire extent of the Strathbogie Shire Council drainage system and the effects of Council's pipe network will be accounted for dynamically within the 2D-1D hydraulic model.



Title:

Nagambie
RORB Model Schematisation

Figure: **4-1**

Rev: **A**

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4.2.8 Intensity Frequency Duration (IFD) Parameters

As presented in Section 4.1.4, the IFD parameters were sourced from the Bureau of Meteorology IFD program (Bureau of Meteorology, 2011).

The Increased Rainfall Intensity scenario is based on the existing AR&R rainfall intensity parameters factored by 32% as discussed with GBCMA. In addition, the F2 and F50 geographic factors were also adjusted using the methodology applied by Melbourne Water. Table 4-7 presents the IFD parameters for both the base case and increased rainfall intensity scenarios.

Table 4-7 IFD Parameters (Base Case and Increased Rainfall Intensity Scenario)

IFD Parameter		Base Case	Increased Rainfall Intensity Scenario
Rainfall Intensity (mm/hr)	2 Year ARI, 1 Hour Duration	21.90	28.91
	2 Year ARI, 12 Hour Duration	3.93	5.19
	2 Year ARI, 72 Hour Duration	0.98	1.29
	50 Year ARI, 1 Hour Duration	45.69	60.31
	50 Year ARI, 12 Hour Duration	6.95	9.17
	50 Year ARI, 72 Hour Duration	1.95	2.57
Skew Coefficient		0.21	0.21
Geographical Factor F2		4.32	4.44
Geographical Factor F50		15.05	16.82
Zone		2	2

4.2.9 Loss Model

RORB generates rainfall excess (runoff) by subtracting losses at each time-step from the rainfall occurring in that time period. The “initial loss followed by a continuing loss” loss model was adopted. To maintain consistency with the previous Hydrology Analysis and Drainage Design Strategy for the Goulburn Valley Highway Nagambie Bypass (GHD, 2009), the adopted initial loss and continuing losses for pervious areas were 15mm and 2.0mm/hr respectively. For impervious areas, RORB has a “hardwired” initial loss of 0 mm and runoff coefficient of 0.9.

4.2.10 Model Calibration

There are no stream gauges in the catchment, so the RORB model was calibrated to the Rational Method. RORB can be calibrated by varying the pervious area, initial loss, continuing loss, reach type, k_c and m. An initial loss of 15 mm, continuing loss of 2.0mm/hr and m of 0.8 were adopted as per previous studies. The k_c value was the only parameter adjusted during the calibration process.

The k_c was varied such that the peak discharge from the RORB model approximated that of the Rational Method at the catchment outlet for the 100y ARI flood event.

Using the recommended and widely adopted approach (Adams equation) for regional Victoria from Book 4 of Australian Rainfall and Runoff, the Rational Method approach determined a time of concentration (t_c) and the resultant peak discharge for the rural areas of the catchment (the vast majority of the area) as a function only of the catchment area and does not take into account catchment shape, slope, or connectivity of reaches within each sub-catchment.

The Nagambie Catchment is somewhat unusual in its hydrological characteristics, including multiple bifurcations within a relatively flat rural landscape. As a result, calibration with the RORB model is quite difficult, as the two key points of inflow (Nagambie Bypass and O'Neils Road) to the hydraulic model, whilst having similar area, have distinctly different topographic characteristics.

Several approaches for the selection of the k_c value were trialled, including:

- Adjusting k_c to achieve a match between the Rational Method and RORB peak flows at the Elloura Catchment outlet;
- the RORB recommended value;
- the Victoria Equation for catchments < 800mm per annum;
- the Pearse Equation from Victorian Data;
- Adjusting k_c to achieve a match between the Rational Method and RORB peak flows at the Nagambie Bypass; and
- Adjusting k_c to achieve a match between the Rational Method and RORB peak flows at O'Neils Road

In each of the above approaches, the peak flows from RORB were compared to the Rational Method flows at the four locations referred to in Section 4.1.3; the catchment outlet (Elloura Estate), the golf course confluence, O'Neils Road, and Nagambie Bypass.

From the analysis undertaken, none of the above approaches returned an acceptable calibration to the Rational Method at all four locations. Consequently, two additional methods of selecting k_c were applied. These methods were:

- Adjusting k_c to achieve a match between the Rational Method and RORB peak flows at the Nagambie Bypass; and
- Adjusting k_c to achieve a match between the Rational Method and RORB peak flows at O'Neils Road

The key external inflows to the hydraulic model are at the Nagambie Bypass and at O'Neils Road. Although both of these locations occur within the one overall catchment (the Main Catchment), the use of inter-station area was adopted so that these two sub-catchments could be calibrated separately using different k_c values, as determined above.

The internal inflow boundaries to the hydraulic model downstream of these points are intended to be applied within the TUFLOW model as Sub Area inflows with no routing, the k_c value for the rest of the catchment is of lesser importance. To determine the best approximation for the k_c throughout the rest of the Elloura Outlet catchment, the average k_c of the two catchments forming the main inflows was used for the remainder of the catchment. For the West Catchment, Bryde St Catchment and the North Catchment, the individual k_c was determined by calibrating the peak flows to the Rational Method at each outlet.

The adopted k_c parameters for each catchment are shown in Table 4-8, whilst Table 4-9 compares the calibrated RORB model results to the Rational Method flows at various locations within the catchment.

Table 4-8 RORB Parameters

	O'Neils Road	Nagambie Bypass	Elloura Estate Outlet	Bryde St Outlet	West Outlet	North Outlet
Storm Data	See Section 4.2.8					
Catchment Area (km^2)	9.9	8.5	26.2	9.9	9.9	1.6
Initial Loss (mm)	15.0					
Continuing Loss (mm/hr)	2.0					
m	0.8					
k_c	10.40	8.24	9.32	9.86	9.50	2.71
Fraction Impervious	See Section 4.2.5					
Reach Type	1		1, 2		1	1,2

Table 4-9 Rational Method and RORB comparisons

Location	100y ARI Peak Discharge (m^3/s)		Difference (%)
	RORB	Rational Method	
MAIN CATCHMENT			
O'Neils Rd	18.7	18.7	0%
Nagambie Bypass	16.8	16.8	0%
Golfcourse Confluence	27.0	34.8	-22%
Outlet	27.2	37.0	-26%
BRYDE ST CATCHMENT			
Railway	17.0	14.1	21%
Bryde St	22.8	22.8	0%
WEST CATCHMENT			
Muller Rd	13.8	10.0	38%
West Outlet	18.7	18.7	0%
NORTH CATCHMENT			
Nth Outlet	10.2	10.2	0%

4.2.11 PMF Flows

The RORB model was used to generate probable maximum flood (PMF) flow hydrographs, which required the development of the probable maximum precipitation (PMP). The PMP was developed using the methodologies described in the *"Guidebook to the Estimation of Probable Maximum Precipitation: Generalised Southeast Australia Method"* and *"The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method"*.

The Generalised Short-Duration Method (GSDM) is limited to the 3 hour duration storm event for inland catchments which includes the Nagambie catchment, whilst the Generalised Southeast Australia Method (GSAM) is only relevant for rainfall event durations 24 hours and longer. The intervening durations were determined in accordance with the GSAM guidebook and the resulting estimated PMP depth was applied to both the 3 hour temporal pattern and the 24 hour temporal pattern within the RORB model. The higher value of the two results has been included within this report as appropriate. The PMF Summary worksheets are provided in Appendix C and the peak hydrographs for key locations within the catchment are shown in Figure 4-9. Peak flows in key locations are included in Table 4-10 and Table 4-11.

4.3 Hydrologic Modelling Results Summary

4.3.1 Base Case Scenario

A summary of the peak discharge output from the RORB hydrologic model for the Base Case Scenario is shown in Table 4-10. The critical storm duration hydrographs at each location are shown in Figure 4-2 through Figure 4-9 respectively.

Table 4-10 Scenario A – Base Case Predicted Peak Discharges

Event	Critical Flow Path Peak Discharge (m^3/s)						
	ONeils Road	Nagambie Bypass	Elloura Outlet	Railway	Bryde St Outlet	West Outlet	North Outlet
5y	6.6	5.8	9.2	6.1	10.9	6.4	3.9
10y	8.6	7.7	12.2	8.0	10.9	8.4	4.9
20y	11.5	10.2	16.5	10.6	14.4	11.4	6.3
50y	15.4	13.6	22.4	14.0	19.0	15.3	8.4
100y	18.7	16.8	27.2	17.0	22.8	18.7	10.2
200y	22.2	20.2	32.7	20.4	26.9	22.3	12.1
500y	27.1	25.1	40.3	25.3	33.3	27.2	15.0
PMF	160.9	155.9	274.4	133.1	190.8	165.5	65.9

4.3.2 Developed Case Scenario

A summary of the peak discharges output from the RORB hydrologic model for the ultimate developed case within the existing planning scheme is shown in Table 4-11.

Table 4-11 Developed Case Predicted Peak Discharges

Event	Critical Flow Path Peak Discharge (m^3/s)						
	ONeils Road	Nagambie Bypass	Elloura Outlet	Railway	Bryde St Outlet	West Outlet	North Outlet
5y	7.8	6.8	11.5	7.1	9.9	7.6	4.5
10y	9.9	8.6	14.6	8.9	12.4	9.7	5.6
20y	12.9	11.2	18.9	11.6	15.9	12.7	7.0
50y	16.8	14.7	25.1	15.0	20.4	16.7	9.2
100y	20.2	17.9	30.4	18.1	24.4	20.2	11.0
200y	23.7	21.3	35.9	21.5	28.6	23.7	12.9
500y	28.7	26.3	43.4	26.5	35.0	28.8	16.0
PMF	162.6	157.2	277.9	134.4	192.3	167.2	66.9

4.3.3 Climate Change Scenarios

A summary of the peak discharges for Climate Change Scenario A and B are shown in Table 4-12 and Table 4-13 respectively. As above, the critical storm duration hydrographs at each location are shown in Figure 4-10 through Figure 4-16 respectively.

Other than the different IFD parameters all other files and parameters, i.e. catchment definition, k_c and *m*, were the same as used for the Base Case Scenario or Developed Case Scenario as appropriate.

Table 4-12 Climate Change A – Increased Rainfall Intensity Predicted Peak Discharge

Event	Critical Flow Path Peak Discharge (m^3/s)						
	ONeils Road	Nagambie Bypass	Elloura Outlet	Railway	Bryde St Outlet	West Outlet	North Outlet
5y	11.7	10.0	17.3	10.4	14.5	11.6	6.2
10y	14.6	12.6	21.6	13.0	18.0	14.5	7.7
20y	18.8	16.3	28.1	16.8	22.8	18.8	9.7
50y	24.3	21.4	36.8	21.6	29.1	24.4	12.7
100y	29.0	25.8	44.0	26.0	34.7	29.0	15.1
200y	33.9	30.6	51.7	30.8	41.0	34.1	18.1
500y	40.8	37.4	62.2	37.9	50.2	41.2	22.4

Table 4-13 Climate Change B - Increased Rainfall Intensity Predicted Peak Discharge

Event	Critical Flow Path Peak Discharge (m^3/s)						
	ONeils Road	Nagambie Bypass	Elloura Outlet	Railway	Bryde St Outlet	West Outlet	North Outlet
5y	13.1	11.0	20.0	11.4	15.9	12.9	6.9
10y	16.0	13.7	24.6	14.1	19.4	16.0	8.4
20y	20.3	17.4	31.2	17.9	24.4	20.2	10.5
50y	25.8	22.5	40.0	22.7	30.8	25.9	13.4
100y	30.6	27.0	47.3	27.2	36.3	30.6	16.1
200y	35.5	31.8	55.0	32.1	42.9	35.7	19.1
500y	42.4	38.7	65.5	39.1	52.0	42.8	23.4

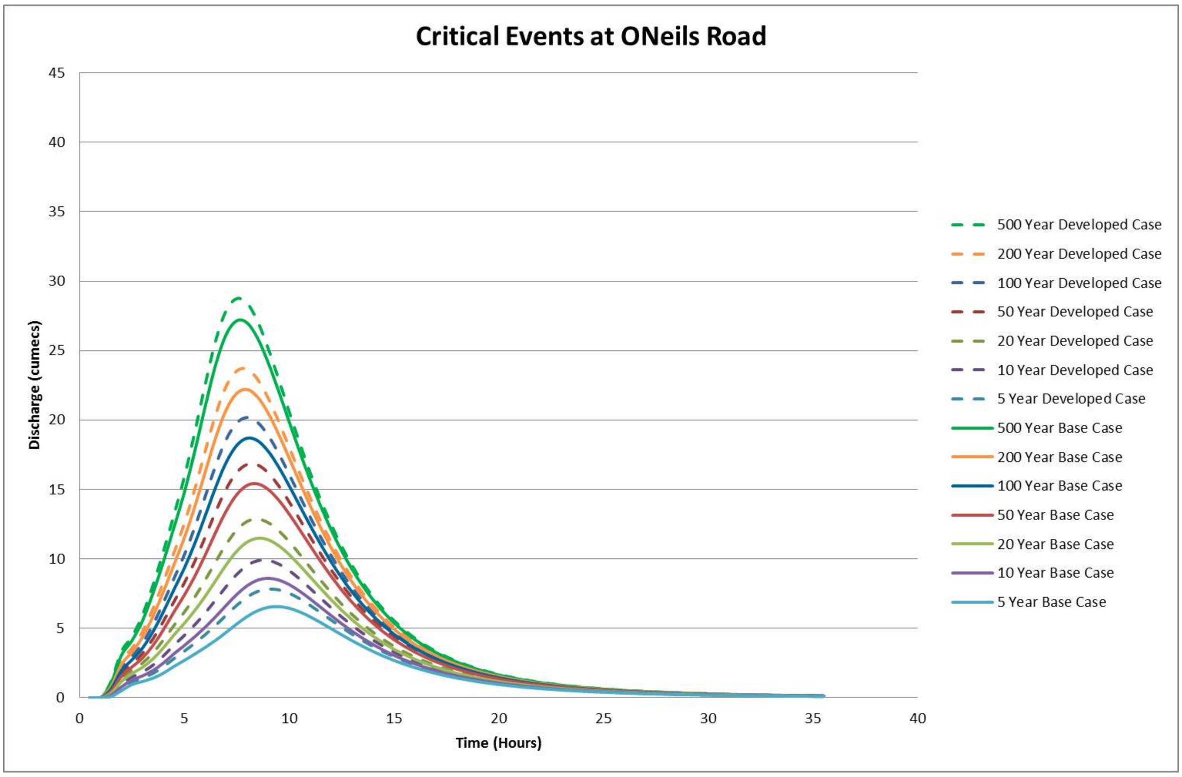

Figure 4-2 Critical Events at ONeils Road

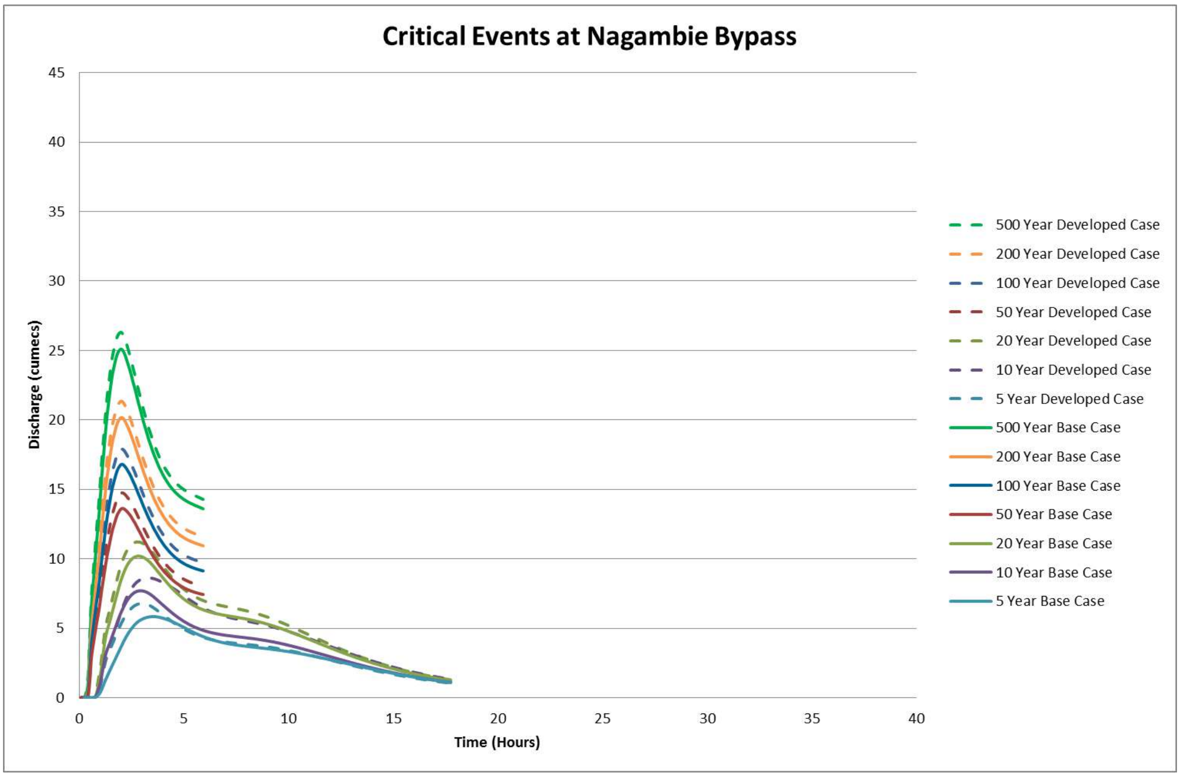

Figure 4-3 Critical Events at Nagambie Bypass

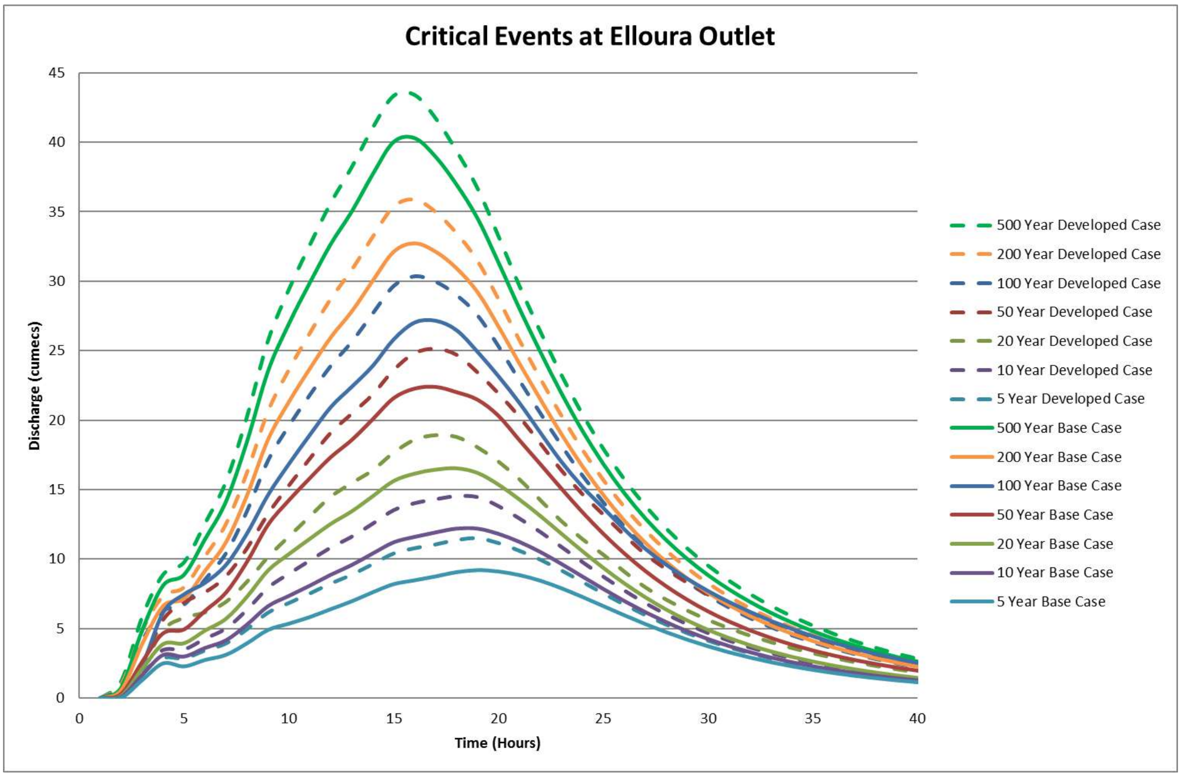

Figure 4-4 Critical Events at Elloura Outlet

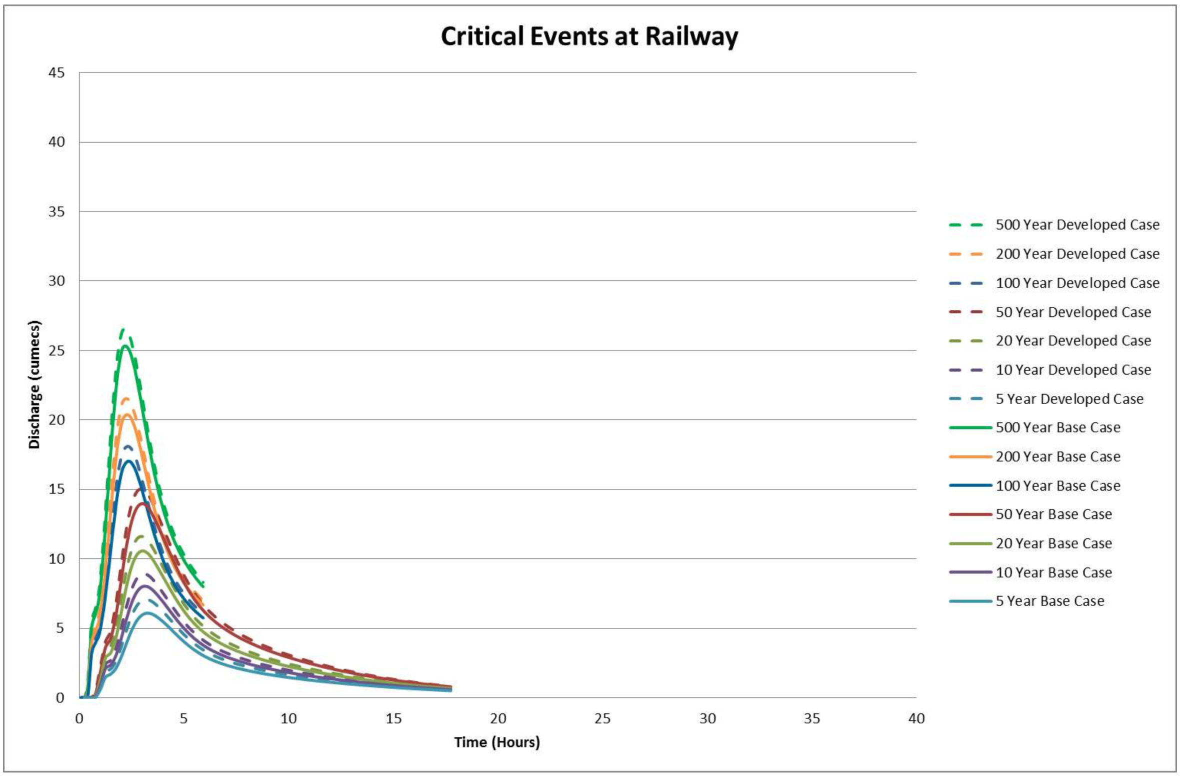

Figure 4-5 Critical Events at Railway

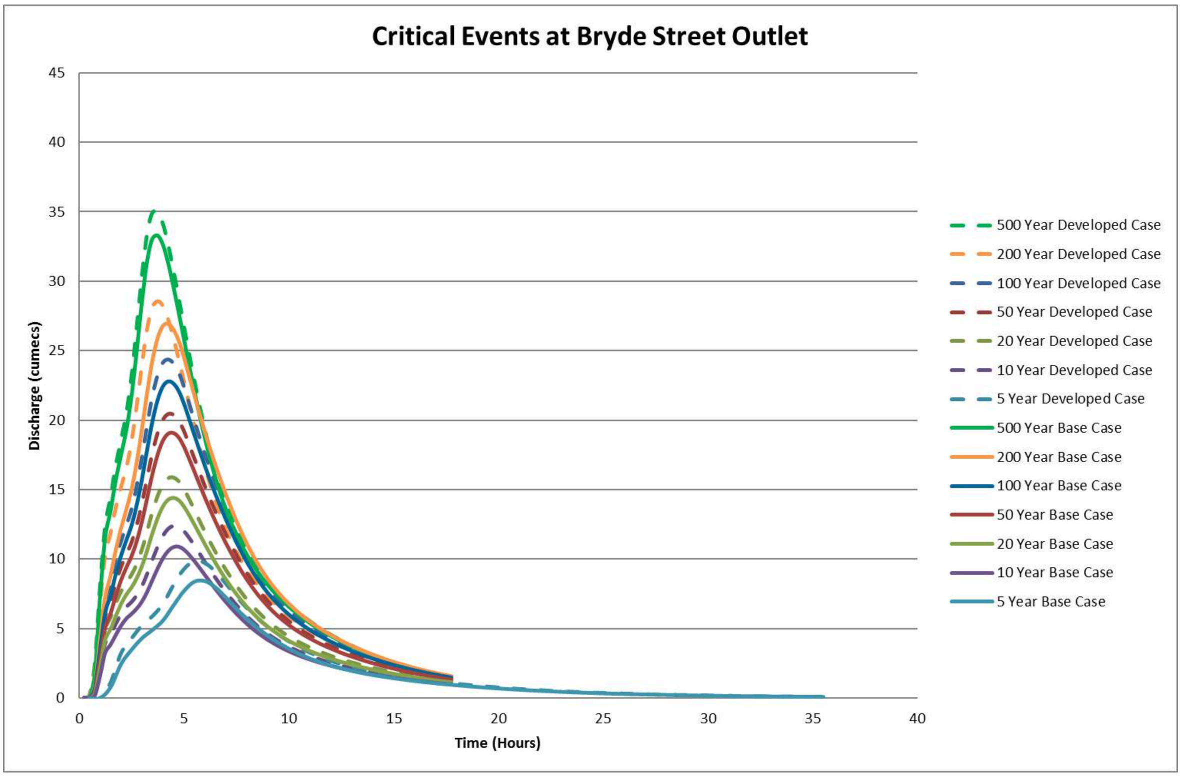

Figure 4-6 Critical Events at Bryde Street Outlet

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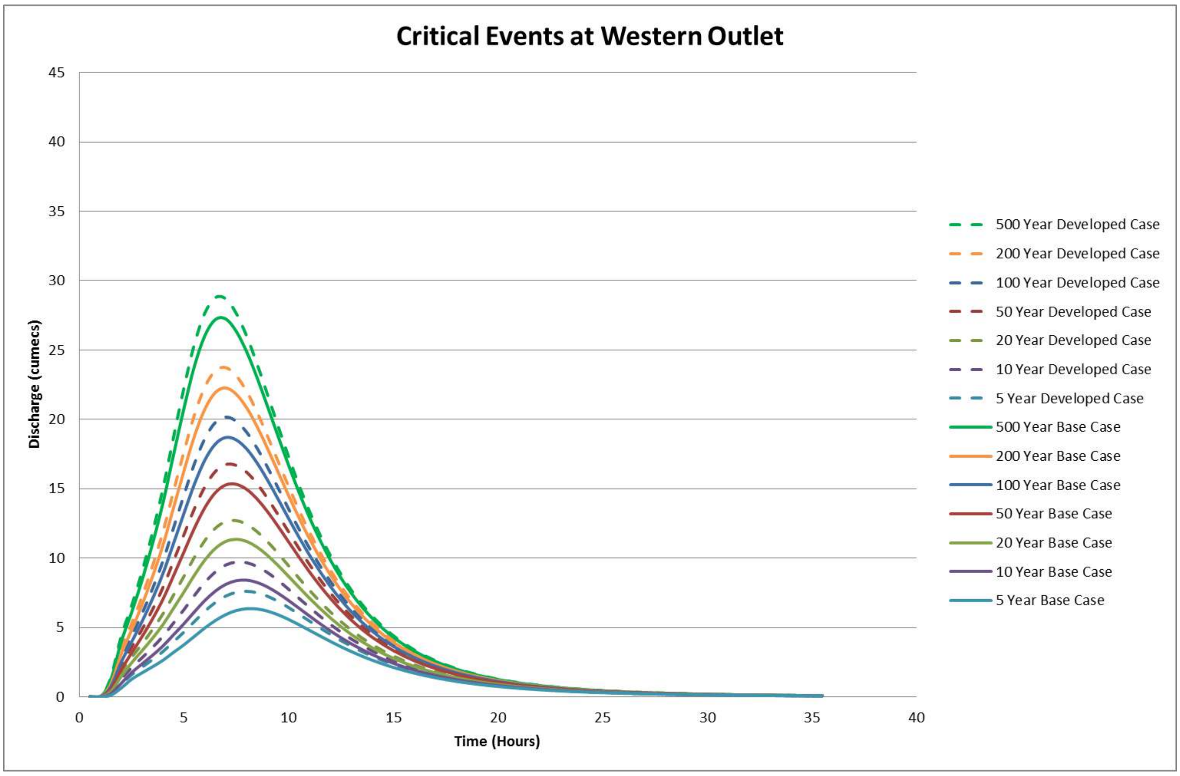


Figure 4-7 Critical Events at Western Outlet

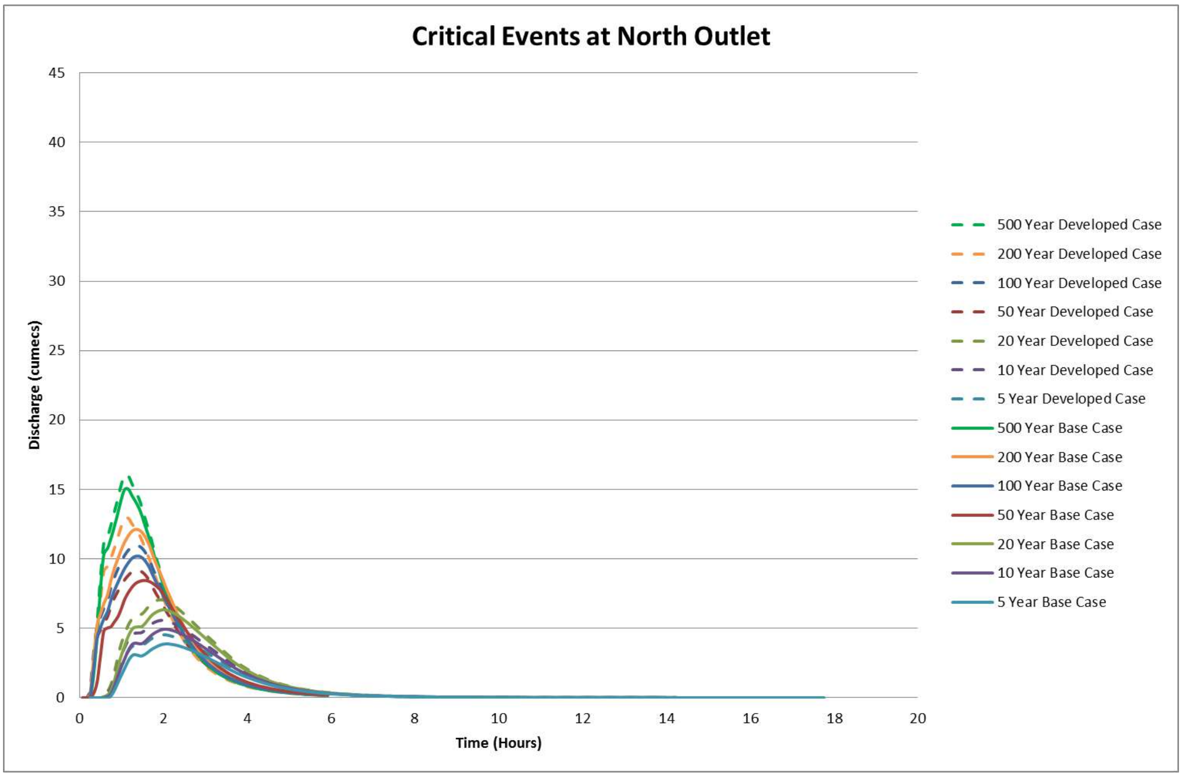


Figure 4-8 Critical Events at North Outlet

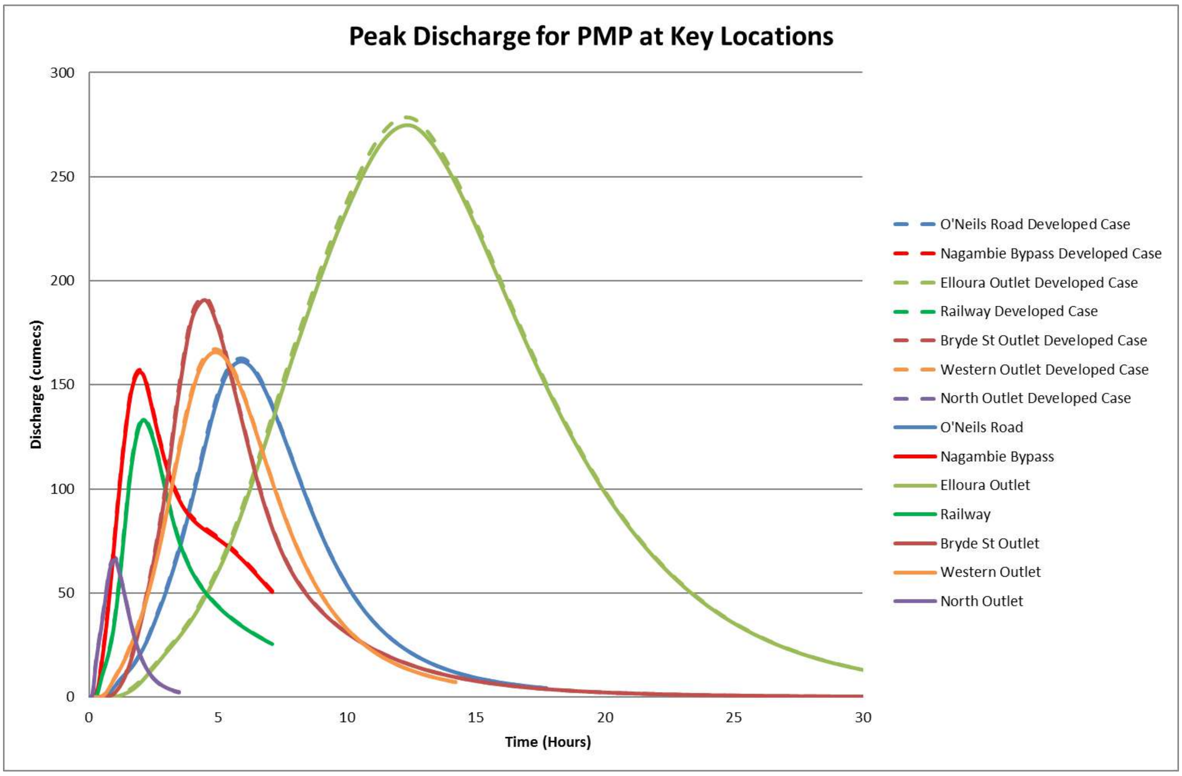


Figure 4-9 Peak Discharge for PMF at Key Locations

4.4 Climate Change Scenarios: Base Case and Developed Case Peak Hydrographs

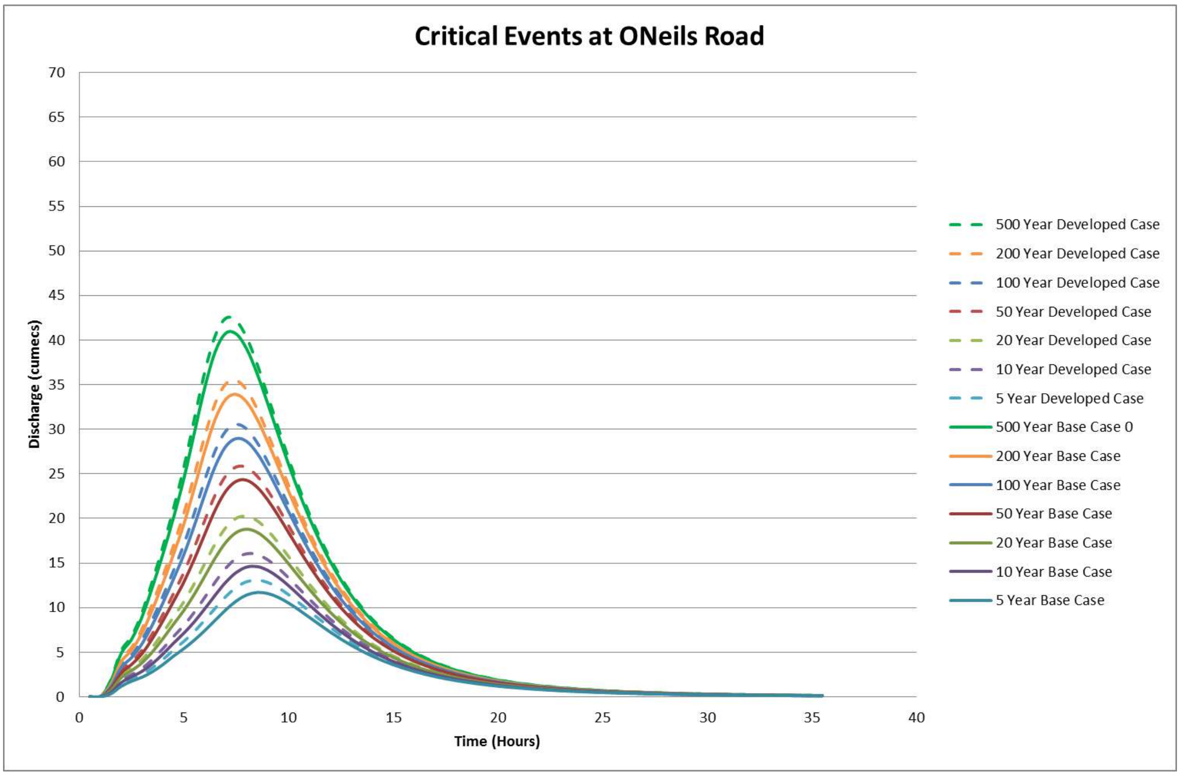


Figure 4-10 Critical Climate Change Events at ONeils Road

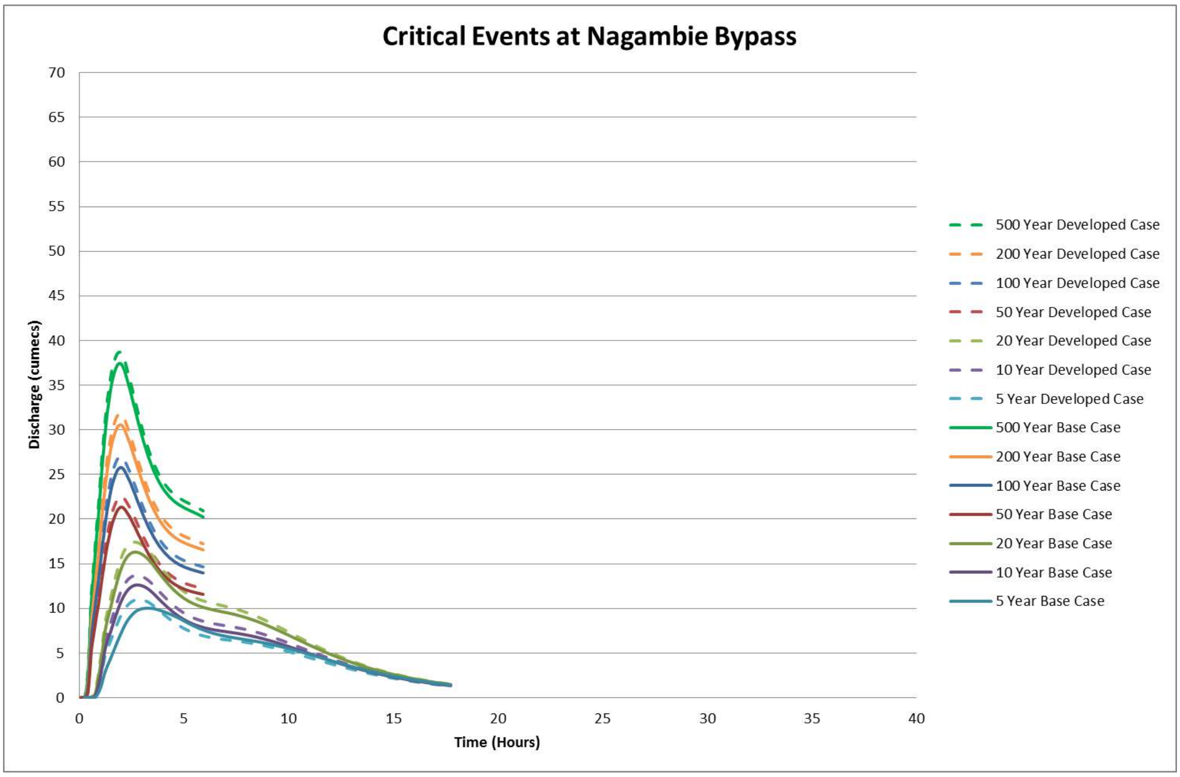


Figure 4-11 Critical Climate Change Events at Nagambie Bypass

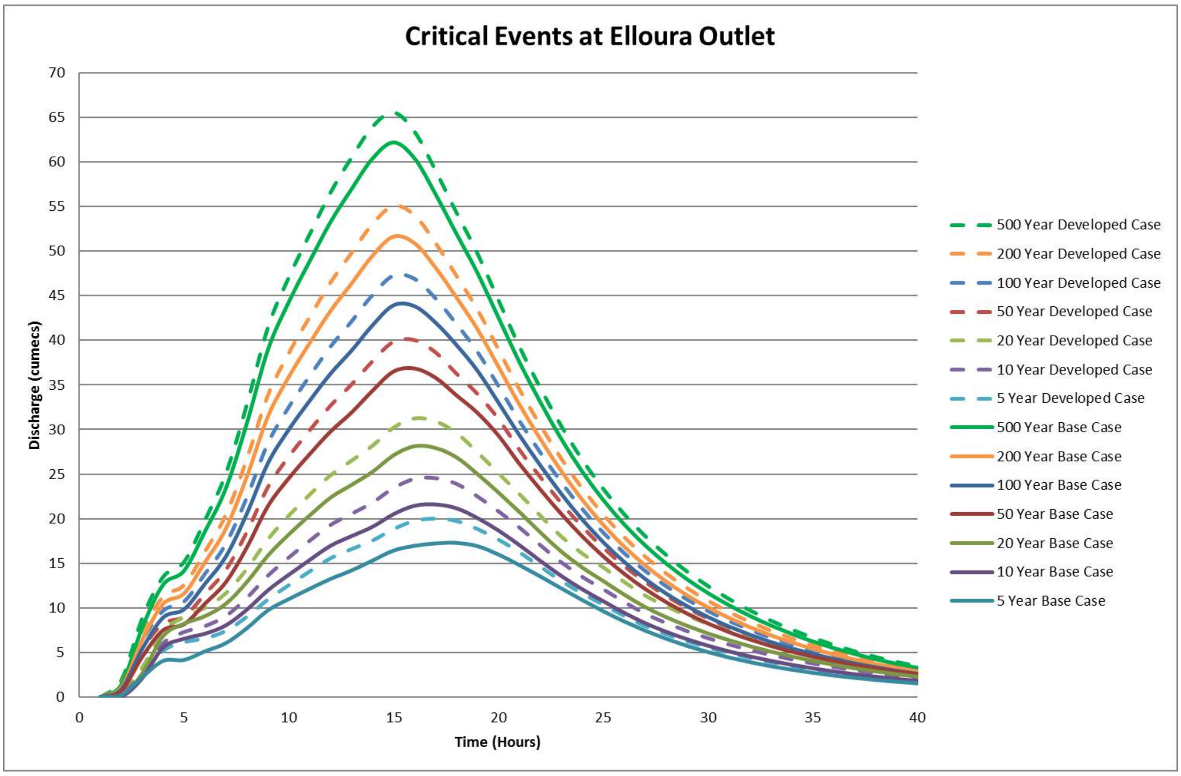


Figure 4-12 Critical Climate Change Events at Elloura Outlet

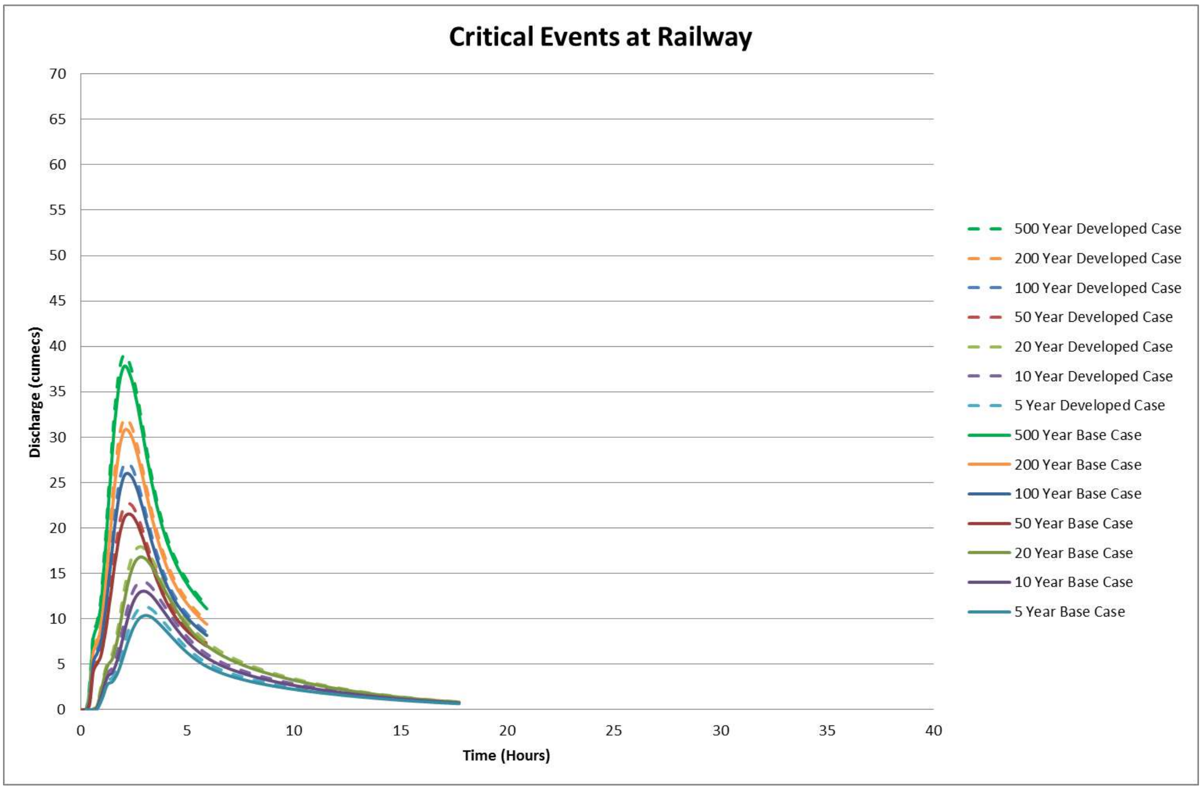


Figure 4-13 Critical Climate Change Events at Railway

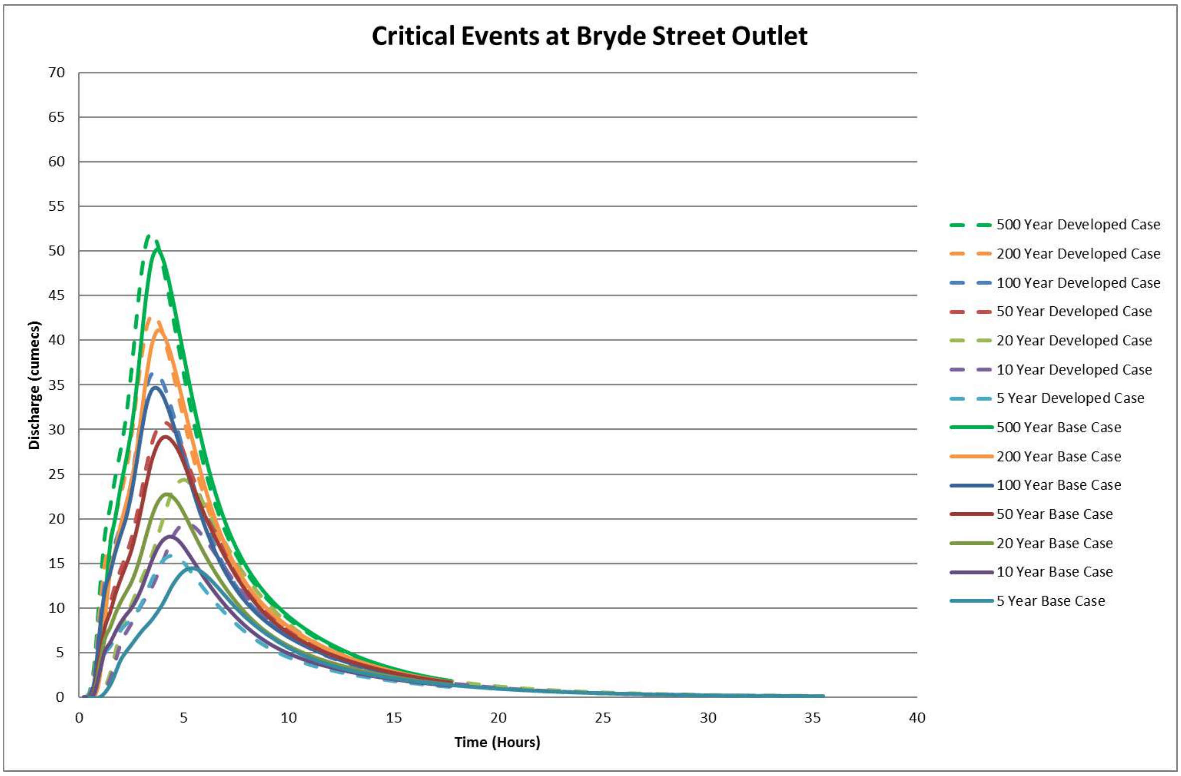


Figure 4-14 Critical Climate Change Events at Bryde Street Outlet

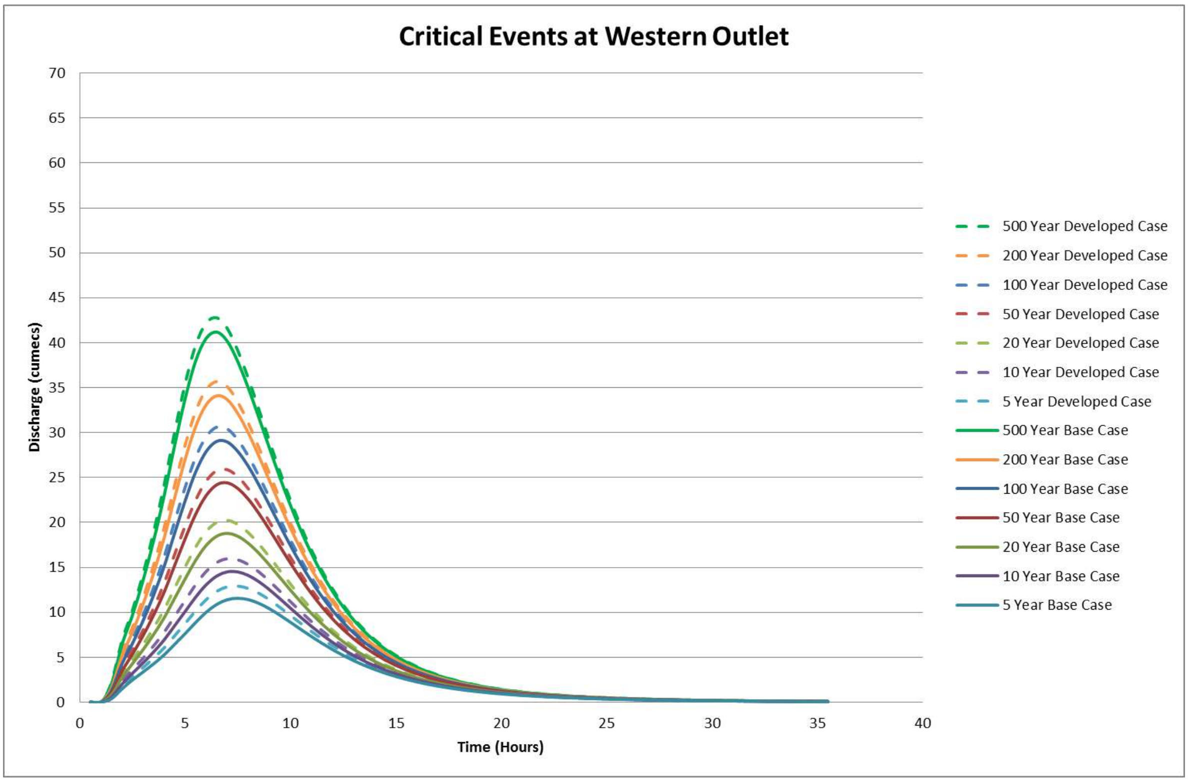


Figure 4-15 Critical Climate Change Events at Western Outlet

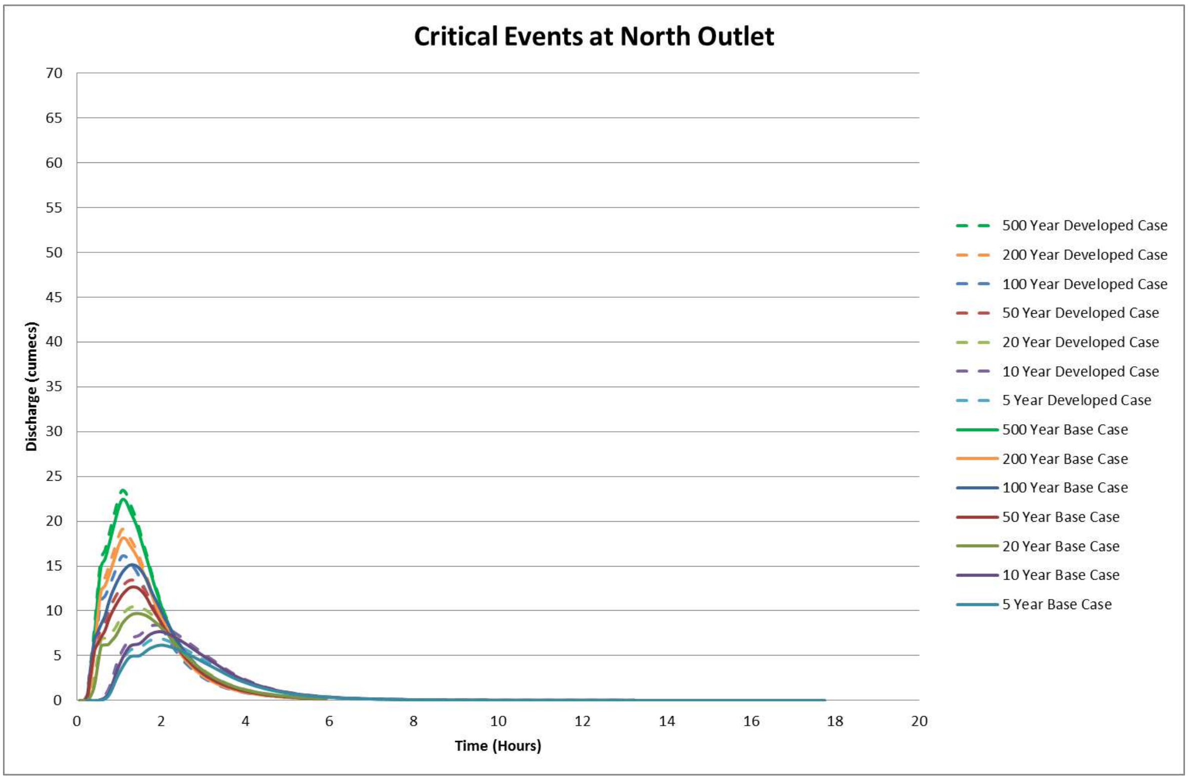


Figure 4-16 Critical Climate Change Events at North Outlet

4.5 Comparison to Previous Models

GHD Pty Ltd (2009) had previously completed a hydrological analysis and drainage design strategy for the Goulburn Valley Highway Nagambie Bypass. GHD's analysis identified a 6.9m^3/s peak flow at the Nagambie bypass as a result of their hydrological modelling using the RAFTS hydrologic modelling software. BMT WBM has a peak flow of 16.8m^3/s at the same location. The catchment area upstream of this location is consistent between the GHD report and the BMT WBM analysis, whilst the initial and continuing losses are also consistent between the two models.

The findings in this report are calibrated to the Rational Method for Victorian Rural Catchments as documented in the AR&R guidelines and consistent with the study methodology as suggested within the Detailed Proposal of Services submitted by BMT WBM.

The flows determined by BMT WBM have been adopted for this study.

5 Hydraulic Modelling

This section provides a description of the TUFLOW modelling process for the Nagambie Flood Study. A 1D / 2D dynamically linked TUFLOW hydraulic model of the Nagambie Catchment was developed with the ultimate aim of flood mapping the catchment for the 5, 10, 20, 50 and 100 year ARI and PMP events for existing conditions and climate change scenario.

This report accompanies the preliminary flood mapping for the 5, 10, 20, 50 and 100 year ARI events and the PMP for the existing conditions. The following sections detail the development of the hydraulic model used to produce the preliminary 5, 10, 20, 50 and 100 year ARI flood extents and flood depths. The inflows to this hydraulic model were taken from a hydrologic RORB model of the catchment, details and results of which are documented in the previous sections of this report.

The hydraulic model of Nagambie was developed in partnership between the GBCMA and BMT WBM, with GBCMA staff undertaking the majority of the modelling under the supervision of BMT WBM staff.

5.1 Model Description

The Nagambie hydraulic model was schematised as a dynamically linked 1D / 2D TUFLOW model. The model was designed to cover the broad township of Nagambie, as well as some of the rural outskirts of the town. The area modelled was extended beyond the study area to minimise boundary effects and to incorporate a number of drainage confluences and bifurcations upstream of the Nagambie township in the hydraulic model.

Strathbogie Shire Council's underground drainage networks, as well as a number of culverts underneath the railway and major roads/highways, were as 1D network elements in the hydraulic model.

The floodplain topography and other significant hydraulic features such as retarding basins were represented within the 2D domain. The model topography was developed from the provided LiDAR data, including broad catchment survey, detailed study area survey and design survey for the Nagambie Bypass. A 5 m high resolution grid was adopted for the catchment as it provided a suitable balance between the outputs of the study, whilst retaining suitable run times for the various hydraulic models.

Inflow boundaries were distributed throughout the model to ensure a 'realistic' distribution of rainfall throughout the study area. External boundaries were applied upstream of the study area as appropriate. For those sub-areas within the 2D domain, the inflow hydrographs were distributed to the manholes (or inflow points) and along drainage paths. The downstream boundary (Lake Nagambie) for the TUFLOW model was provided by GBCMA and was set to a fixed water level.

Details of the model setup and application are described below and shown in Figure 5-1.

5.2 Model Development

The following sections provide an overview of methodology and assumptions used to establish the key elements of the hydraulic model.

5.2.1 Topography

For the development of the DEM to be used in the hydraulic model, various topographic data sets were utilised. These datasets included:

- A LiDAR data set with a vertical accuracy of 150 mm providing coverage over the entire study area,
- A LiDAR data set with a vertical accuracy of 100 mm providing coverage of the flood mapping area,
- A design surface for the Nagambie Bypass, and
- A design surface for the Elloura Estate

In addition to the topographic datasets listed above, field survey was obtained to ensure accurate representation of the retarding basin crests located in the vicinity of McGregor Avenue.

5.2.2 Surface Roughness

The roughness layer, or Manning's 'n' layer, was based on areas of different land-use type determined from aerial photography and site inspections. The adopted Manning's 'n' coefficients are summarised in Table 5-1 and the layer is shown in Figure 5-2. The values used are based on standard texts such as *Open Channel Hydraulics* (Chow 1959) and have been sensibility checked against photos and observations of BMT WBM and GBCMA staff taken during the site inspections

Table 5-1 2D Domain Manning’s ‘n’ Coefficients

Land Use	Manning's 'n'
Roads	0.022
Ponds and Water Bodies	0.030
Farm Paddocks	0.060
Building Footprints (Residential / Commercial / Industrial)	3.000
Residential / Commercial / Industrial Land (excluding building footprints)	0.200
Sporting Ovals	0.030
Dense Riparian Vegetation	0.200
Waterways	0.035
Sparse Vegetation	0.080

5.2.3 Hydraulic Structures

Throughout the Nagambie catchment there are a number of hydraulic structures and controls. Notably these are largely limited to culverts and bridges along the roads and railway. As noted previously the Nagambie catchment includes a number of retarding basins within the North Nagambie catchment, as well as a number of defacto-storages from road and rail embankments.

There are very few bridges within the catchment, with most drainage structures consisting of either circular or box culverts underneath roads and the railway. Two approaches have been adopted for this study to model these hydraulic structures.

For circular and box culverts the preferred approach for this investigation was the use of 1D elements inserted and dynamically linked to the 2D domain.

For bridges, the modelling approach adopted for this study was to model the structure in the 2D domain using TUFLOW's layered flow constriction. The layered flow constriction allows for typical bridge characteristics such as bridge deck height and thickness as well as any blockages associated with guard or hand rails to be incorporated directly in the 2D domain. From these structures the losses are assigned to the grid cells, additional losses associated with piers can be incorporated where appropriate on an individual basis.

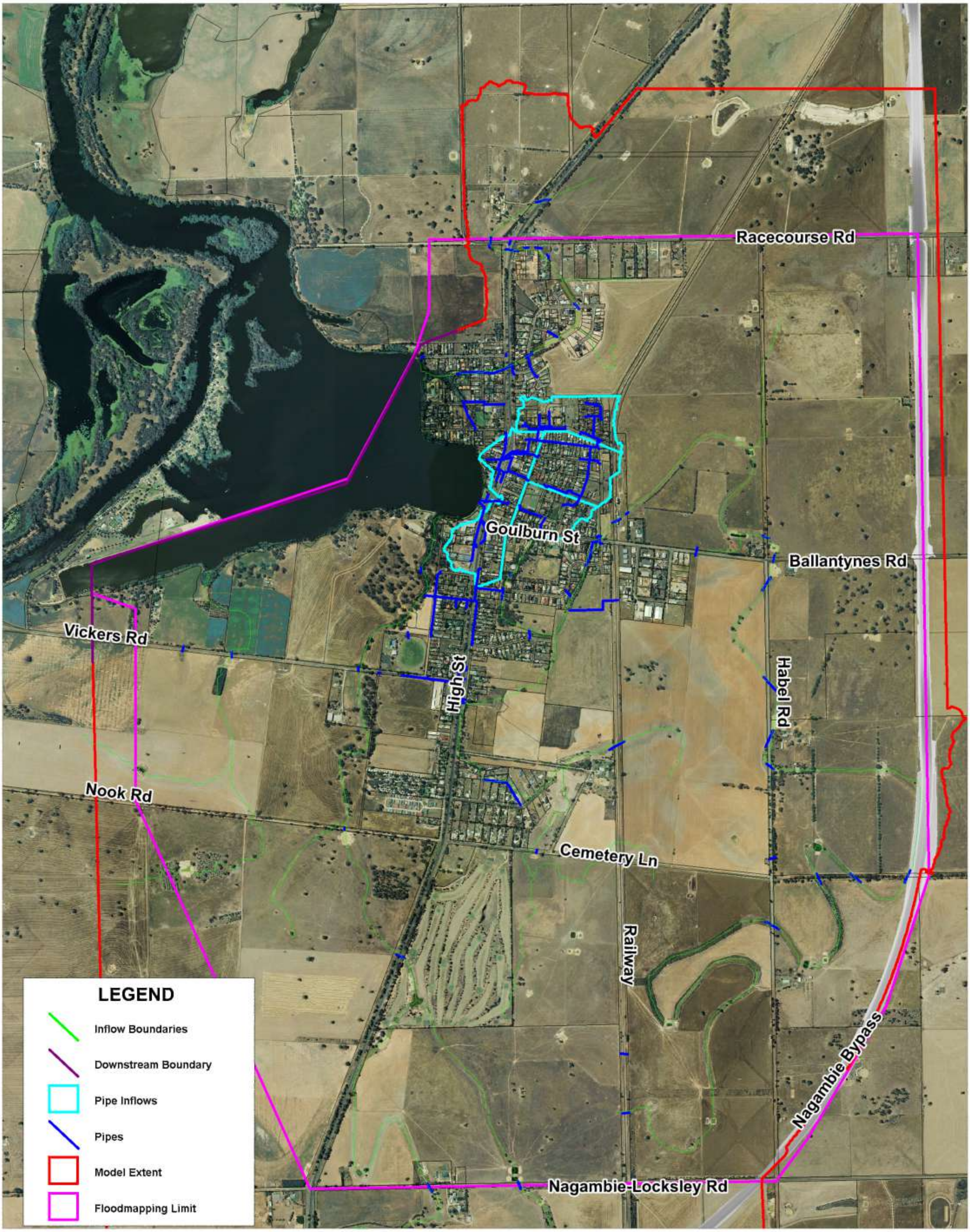
TUFLOW has a number of modelling options available for both the 2D and 1D domains that allow for structure geometry and associated losses to be included. The loss values adopted for this study are based on standard values from sources including the *TUFLOW User Manual* (BMT WBM, 2010) and *Waterway Design: A Guides to the Hydraulic Design of Bridges, Culverts and Floodways* (Austroads 1994).

5.2.4 Boundary Conditions

The TUFLOW model has been developed to use inflow boundaries obtained from the RORB hydrologic modelling stages of the flood model development as described in Section 4.2. There are two main types of boundaries used in the Nagambie hydraulic model, external and internal flow boundaries as shown in Figure 5-1.

As the 2D model does not include the entire contributing catchment, there are a number of external boundaries at the southern extent of the hydraulic model to represent these inflows. The downstream boundary is located in Lake Nagambie and all of the contributing catchment drain to this location.

The internal inflow boundaries are used to input "excess rainfall", that is, the rainfall after the initial and continuous losses have been removed. The rainfall excess is taken from the output of the RORB hydrologic model. The RORB output flow boundaries used for the hydraulic model input are the "downstream sub-catchment hydrographs". These are the flows leaving each subcatchments. These flows include some routing within the RORB model to account for the time for the rainfall excess to reach the main stream channels but do not account for the routing time from the main channel to the subcatchment outlet. This routing time is accounted for within the hydraulic model. These rainfall excess flows have been applied to the hydraulic model as flow versus time boundaries applied to the 2D model domain. The internal inflow boundaries have been model as source over area boundaries that allow for the excess rainfall to be distributed over a specified area allowing for greater definition in flood behaviour.



Title:

Nagambie Flood Study
TUFLOW Model - Model Setup

Figure: 5-1

Rev: A

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Approx. Scale

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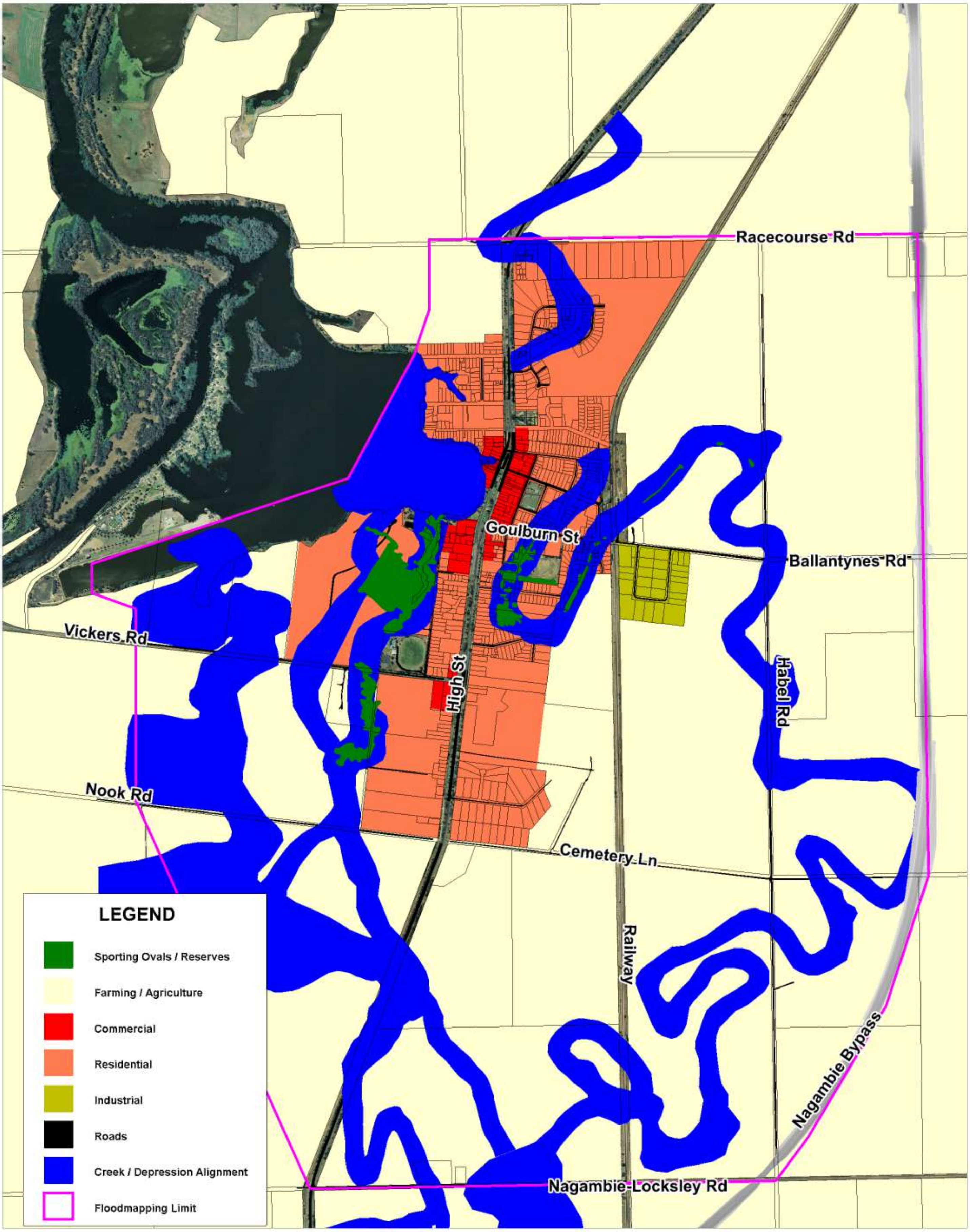

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Nagambie Flood Study
TUFLOW Model - Manning's 'n' Roughness

Figure: 5-2

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5.3 Design Event Modelling

Design events are hypothetical floods representing a probabilistic estimate based on a probability analysis of flood and rainfall data. It is important to note that this does imply that the design rainfall will always results in the design flood event at any time that the estimated flood would occur. There are other factors such as catchment roughness and soil moisture content that contribute to defining a design event.

The design events modelled for the catchment are the 5 year, 10 year, 20 year, 50 year, 100 year, 200 year and 500 year annual recurrence intervals (ARI) design events. In addition the probable maximum flood (PMF) event, based on the probable maximum precipitation (PMP) rainfall event is to be modelled.

5.4 Verification of Hydraulic Model

The Nagambie Township does not include any river gauges and there are no known flood marks available for use in a hydraulic model calibration. Hence, there is no method available to definitively state that the model is able to replicate the flooding patterns in the region. However, local knowledge is an invaluable tool which can be used to confirm the nature of the flooding throughout the catchment and provide a degree of confidence in the model results.

Throughout the course of the study, local landholders on the steering committee provided continual comments on the flood mapping. Additionally, BMT WBM and GBCMA met with members of Council's works team based at the Nagambie depot. During this session, Council was able to confirm a number of elements of the flood mapping and provided some details of the flood response actions that they undertake to minimise the flooding within the Nagambie Township. Whilst there were no flood levels available for varication, the local landholders and Council were able to confirm the flooding patterns shown in the mapping were consistent with their observations and experiences of flooding in Nagambie.

6 Modelling Quality Assurance

To ensure that results and outcomes that have been established as part of the Nagambie Flood Study and can be used for any future assessments or works to be undertaken within the Nagambie floodplain, an extensive Quality Assurance (QA) program has been undertaken. This includes independent internal review of all modelling and reporting outputs, and in some instances, external review of the presented results and reporting.

A comprehensive independent internal review was undertaken on the Nagambie flood model for both the hydrologic and hydraulic modelling components, an overview of which is provided below.

6.1 Hydrologic (RORB) Model Review

The independent hydrologic (RORB) model review included, but is not limited to, the following checks:

- The methodology of the model development and calibration and validation process was checked for suitability and agreed upon.
- The catchment definition, sub-catchment breakup, reach alignments and reach types were appropriate for the catchment characteristics.
- That the RORB model was developed correctly to ensure that input data, both catchment characteristics and rainfall was appropriately represented in the model.
- A review of the model calibration and validation output results, including a review of the adopted parameters for design event modelling.

6.2 Hydraulic (TUFLOW) Model Review

The independent hydraulic (TUFLOW) model review included, but is not limited to, the following checks:

- The methodology of the model development and calibration and validation process was checked for suitability and agreed upon.
- That the TUFLOW model was developed correctly to ensure that input data appropriately represented in the model.
- That the topography, surface roughness and hydraulic structures were appropriately represented with the hydraulic model.
- The boundary conditions were correctly modelled ensuring that flow is entering and leaving the model appropriately and not influencing the model results, i.e. imposing boundary effects within the study area.

That the volume and conservation of mass errors present within the TUFLOW model were within acceptable limits as to not influence results.

7 Flood Mapping and Results

This section provides a brief overview of the floodplain mapping process used in the Nagambie Flood Study and presents a selection of the existing conditions mapping outputs.

TUFLOW produces a geo-referenced data set defining peak water levels, depth, velocities and hazard throughout the model domain at the corners of its computational cells. This data is imported into GIS to generate a digital model of the flood properties and produce the required flood mapping outputs.

7.1 Existing Case

7.1.1 Flood Depth Mapping

Flooding within the Nagambie region is generally confined to the numerous depressions within and surrounding the township. Upstream of the railway, there a number of large natural storages that fills extensively with water. The flood waters entering the township are heavily controlled by the culvert underneath the railway adjacent to Goulburn Street. Flood depth throughout the catchment is presented in Figure 7-1 and Figure 7-2 for the 5 year ARI to 100 year ARI flood events respectively. A complete set of flood depth maps are provided in Appendix D.

There are a number of properties through the Nagambie Township that are impacted by flooding of various magnitudes. The impacted properties are generally located alongside the main drainage depression; however, there are also a number of properties along Goulburn Street, Prentice Street, Filson Street, Marie Street, Vine Street and Young Street that experience inundation during the 1% AEP flood event. Without flood level survey, it cannot be determined whether the building on these properties are flooded above the floor level.

The depth of flooding along the main depression can exceed 0.5 metres during the more frequent flood events (5 year ARI flood event), whilst during the 100 year ARI flood event, flood depths over both Goulburn Street, Vine Street, Vickers Road and the Goulburn Valley Highway can exceed 0.2 metres. However, the railway is generally free from flooding and consequently acts as a significant control for flooding in the region. A number of the unsealed roads in the catchment experience significant inundation during flood events which could result in reduced access for landowners and emergency services during times of flooding.

7.1.2 Flood Velocity Mapping

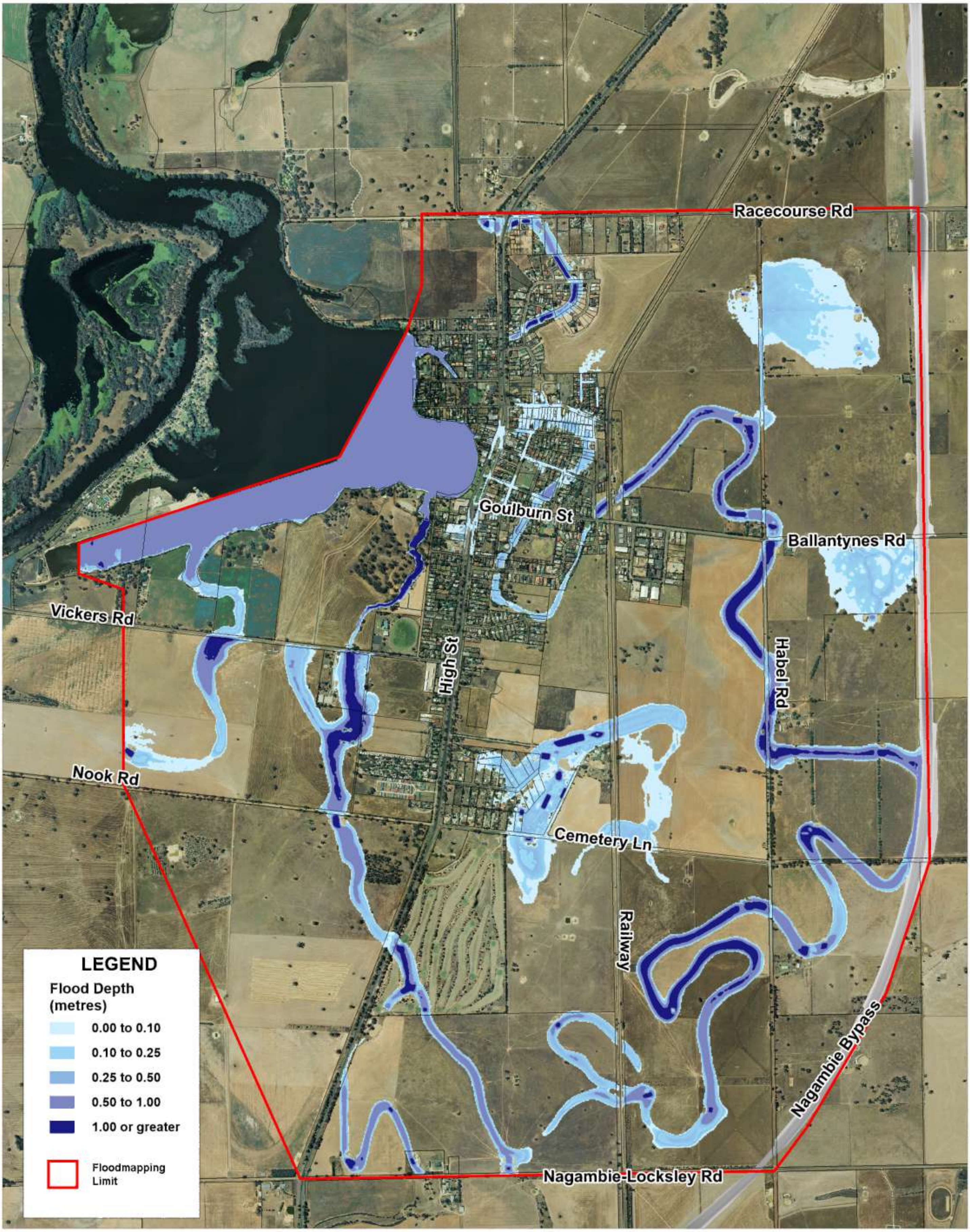
Existing conditions flood velocity is mapped for the 1% AEP event at peak flood level. The flood velocity mapping is designed to depict both the magnitude and direction of the flow velocities. The 1% AEP flood velocity is shown in Figure 7-3. A complete set of flood velocity maps are provided in Appendix E.

Flood velocity mapping is useful in determining the areas of flood risk, identifying flowpaths and identifying the direction of flow.

As discussed above, the catchment is generally quite flat in nature with widespread but shallow flooding. As such, flood velocities within the catchment were typically very slow, rarely exceeding

0.25 m/s. Due to the concentration of floodwaters in the defined flowpaths and depressions throughout the catchment, the velocities are higher than elsewhere in the catchment, including sections where velocities can exceed 1.0 m/s.

Where flow was observed to flow through residential or commercial properties velocities rarely exceeded 0.1 m/s.



Title:

Nagambie Flood Study
5 Year ARI Peak Flood Depth - Existing Conditions

Figure: 7-1

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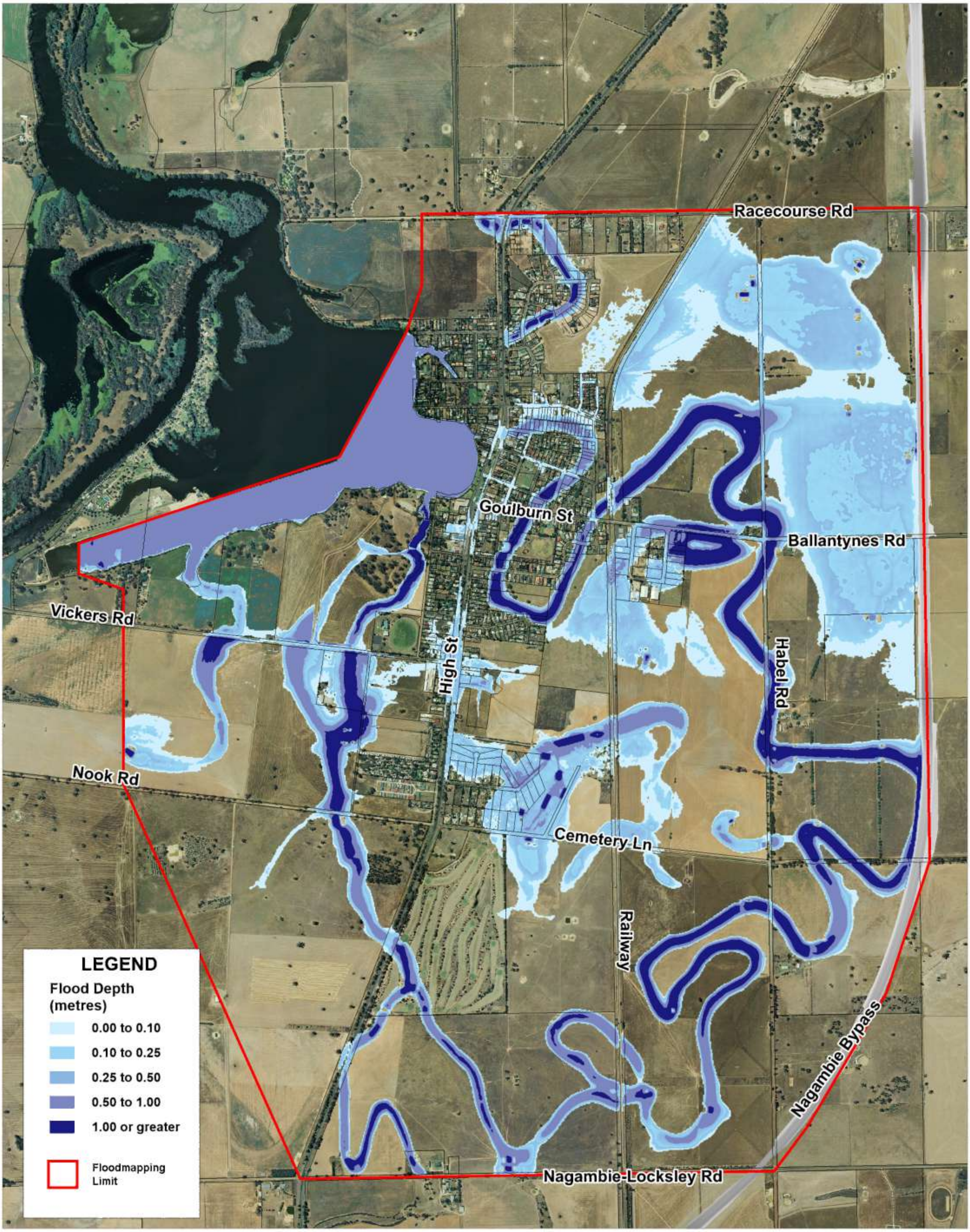

Title:
Nagambie Flood Study
100 Year ARI Peak Flood Depth - Existing Conditions

Figure: 7-2

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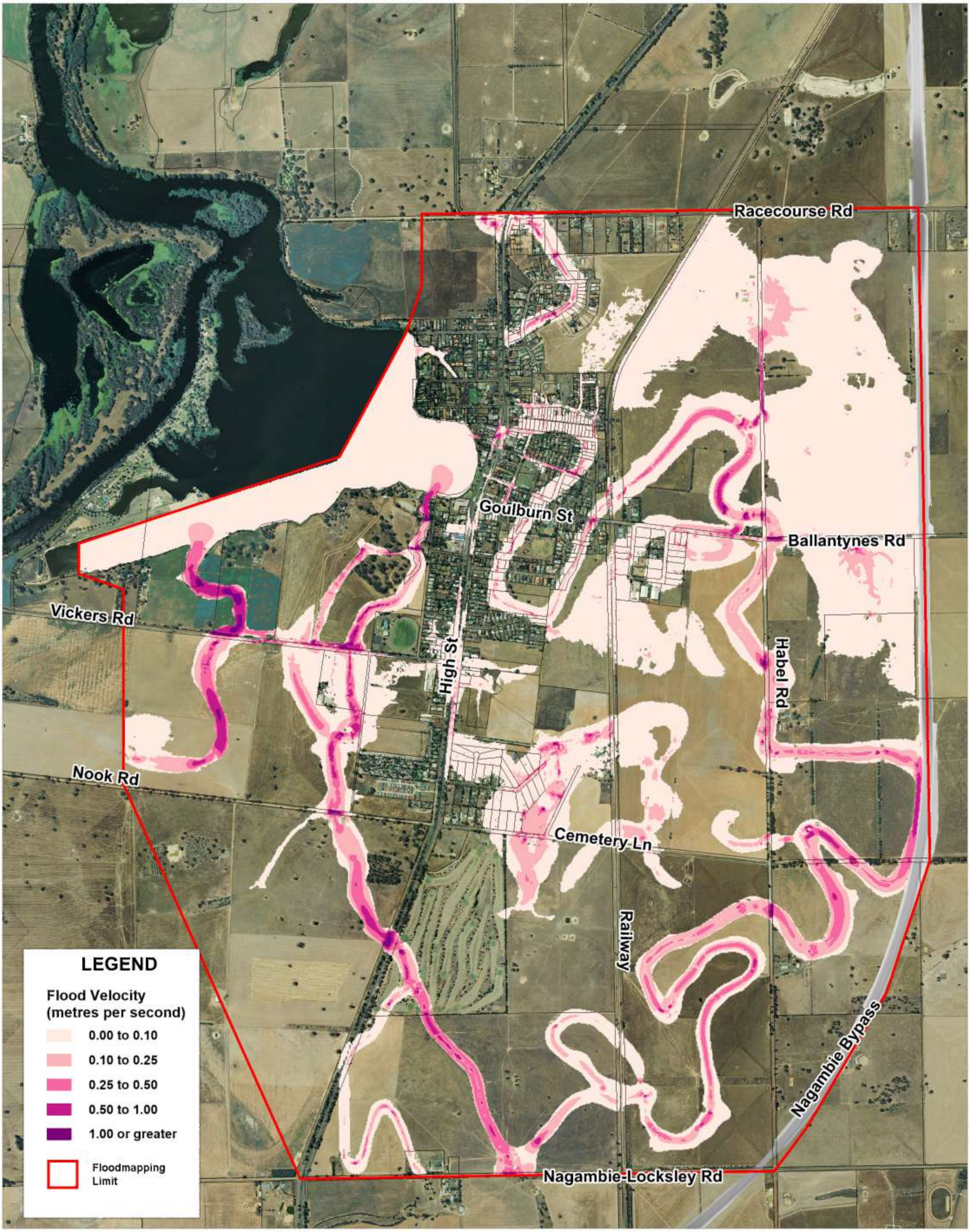

Title:

Nagambie Flood Study

100 Year ARI Peak Flood Velocity - Existing Conditions

Figure: **7-3**

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7.2 Developed Case

7.2.1 Flood Depth Mapping

Flooding within Nagambie township is generally very widespread throughout the catchment with large portions of the catchment taking considerable time to drain, if at all without the aid of pumping. Flood depths throughout the catchment are presented in Figure 7-4 for the 100 year ARI flood event.

The purpose of this analysis will allow planners to gain an understanding of the potential impact that increased urbanisation of the catchment could have on the study area and make future decisions accordingly.

A complete set of flood depth maps are provided in Appendix D.

7.2.2 Flood Impact Mapping

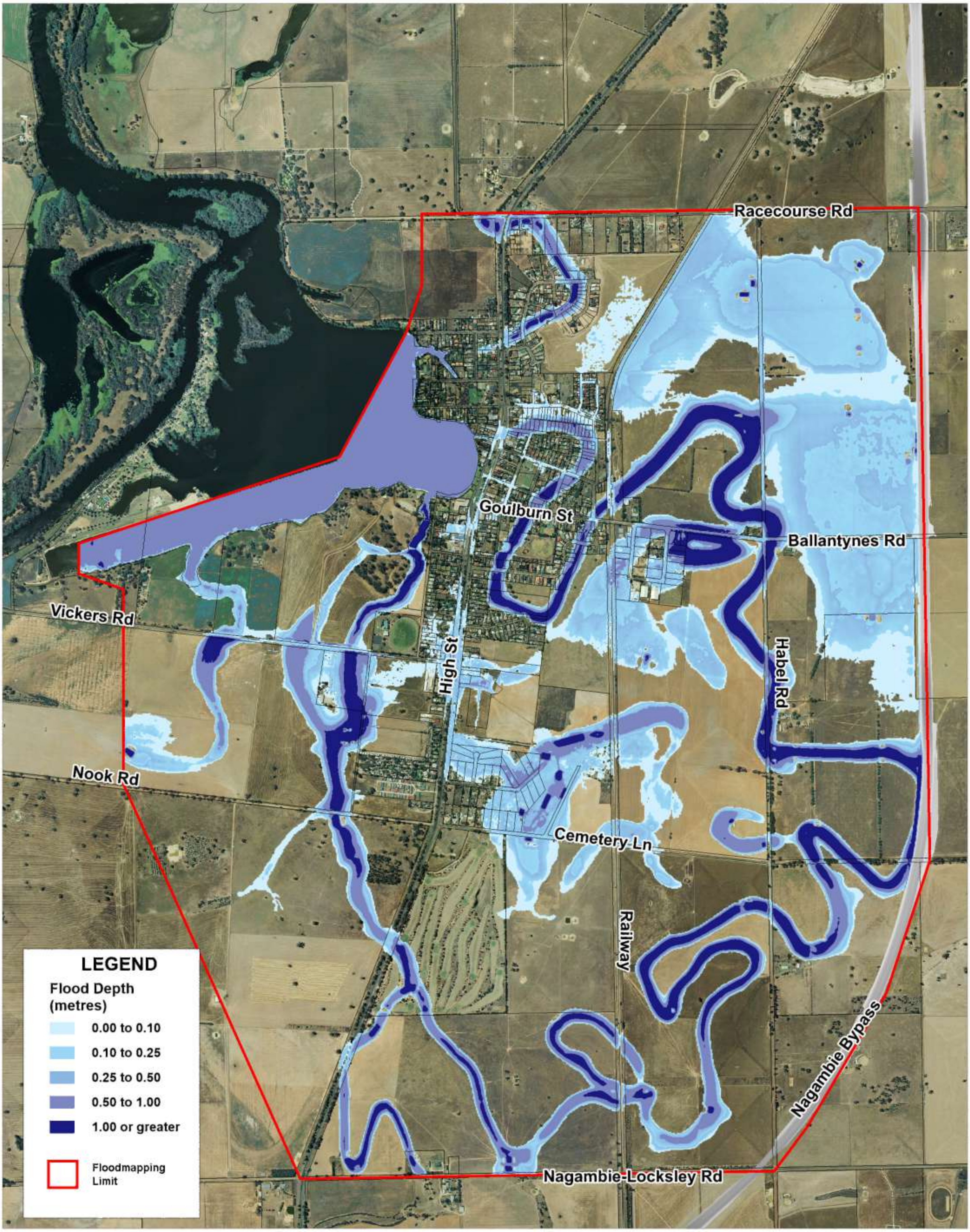
The change in flood level as a consequence of development is shown in Figure 7-5. Whilst there are some significant increases in flood level, there is not a significant increase in the flood extent. The mapping shows no new flow paths initiate as a result of the proposed increase in development and there is no major extension of the flood extent within the currently developed portion of Nagambie.

7.2.3 Flood Velocity Mapping

Developed conditions flood velocity is mapped for the 1% AEP event at peak flood level. The flood velocity mapping is designed to depict both the magnitude and direction of the flow velocities. The 1% AEP flood velocity is shown in Figure 7-6.

Despite the increased flood depths due to the increased development, the magnitudes of flood velocities are largely unchanged from the existing case.

A complete set of flood velocity maps are provided in Appendix E.



Title:

Nagambie Flood Study
100 Year ARI Peak Flood Depth - Developed Conditions

Figure: **7-4**

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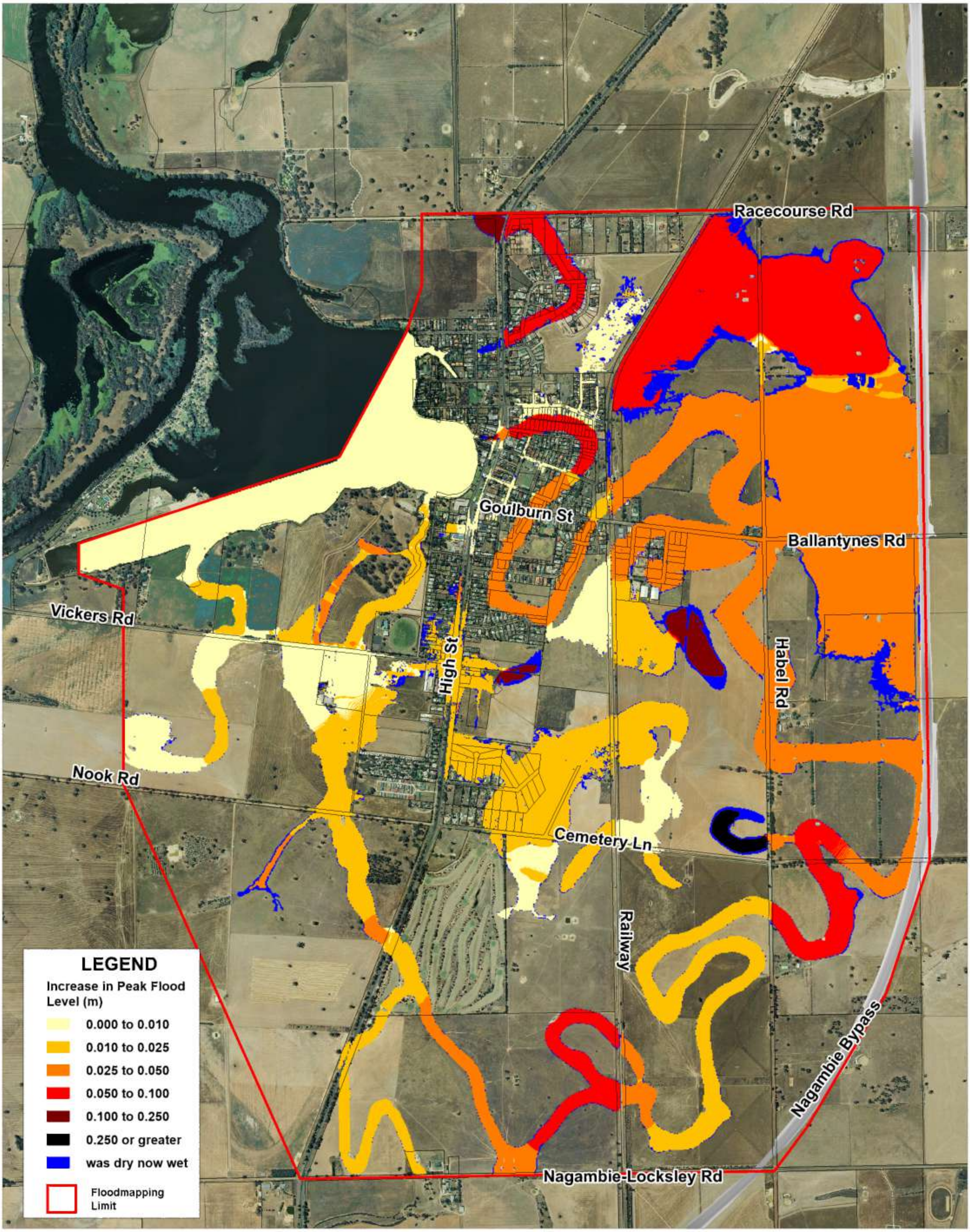

Title:

Nagambie Flood Study
100 Year ARI Peak Flood Impact - Developed Conditions

Figure: 7-5

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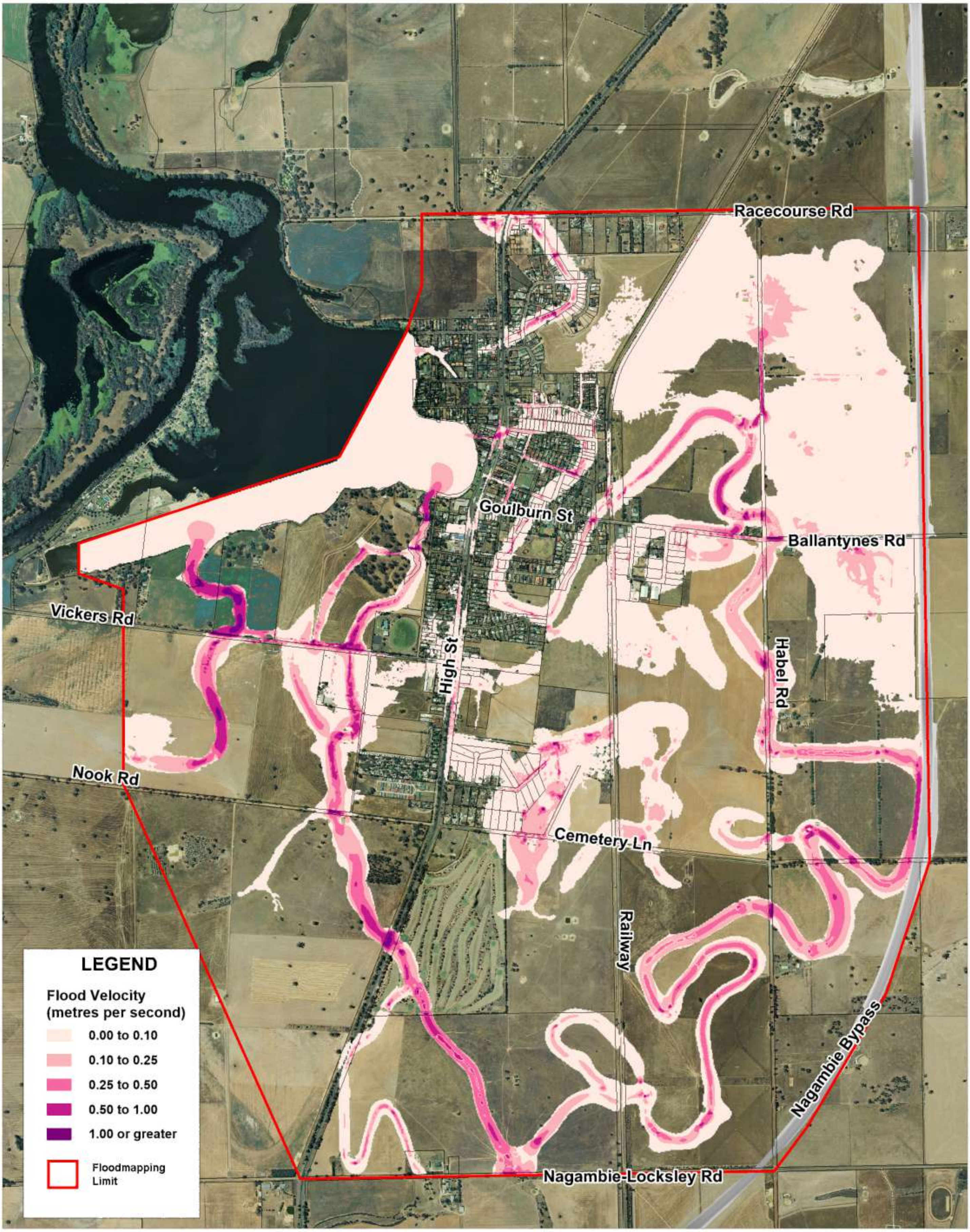

Title:

Nagambie Flood Study
100 Year ARI Peak Flood Velocity - Developed Conditions

Figure: 7-6

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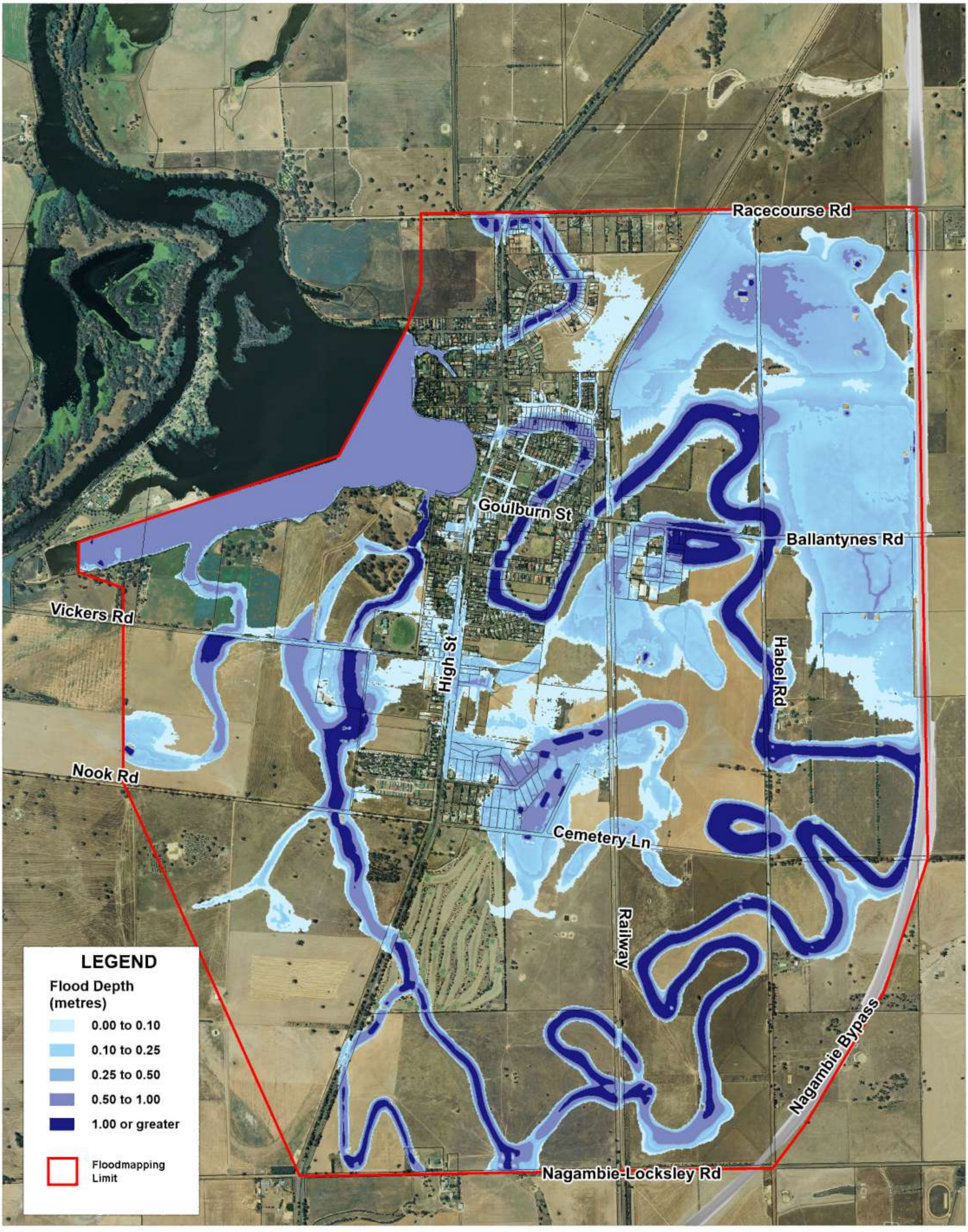
7.3 Existing Case Climate Change Sensitivity

Climate change sensitivity modelling was undertaken for the catchment for increased rainfall intensities of 32% for the 1% AEP flood event, the results of which are presented in Figure 7-7 (flood depth) and Figure 7-8 (flood level increase). For details on the adjusted parameters refer to Section 4.3.3.

The purpose of this analysis will allow planners to gain an understanding of the potential impact that climate change could have on the study area and make future decisions accordingly. The mapping shows increased flood levels across the entire study, generally up to 0.25 metres (although there are some isolation sections with greater increases). There is an increased flood extent shown across parts of the catchment, with the majority of the increased flood extent occurring in land currently zoned as ‘Farm Zone’.

A complete set of flood depth maps are provided in Appendix D.

A complete set of flood velocity maps are provided in Appendix E.



Title:

Nagambie Flood Study
100 Year ARI Peak Flood Depth - Climate Change

Figure: 7-7

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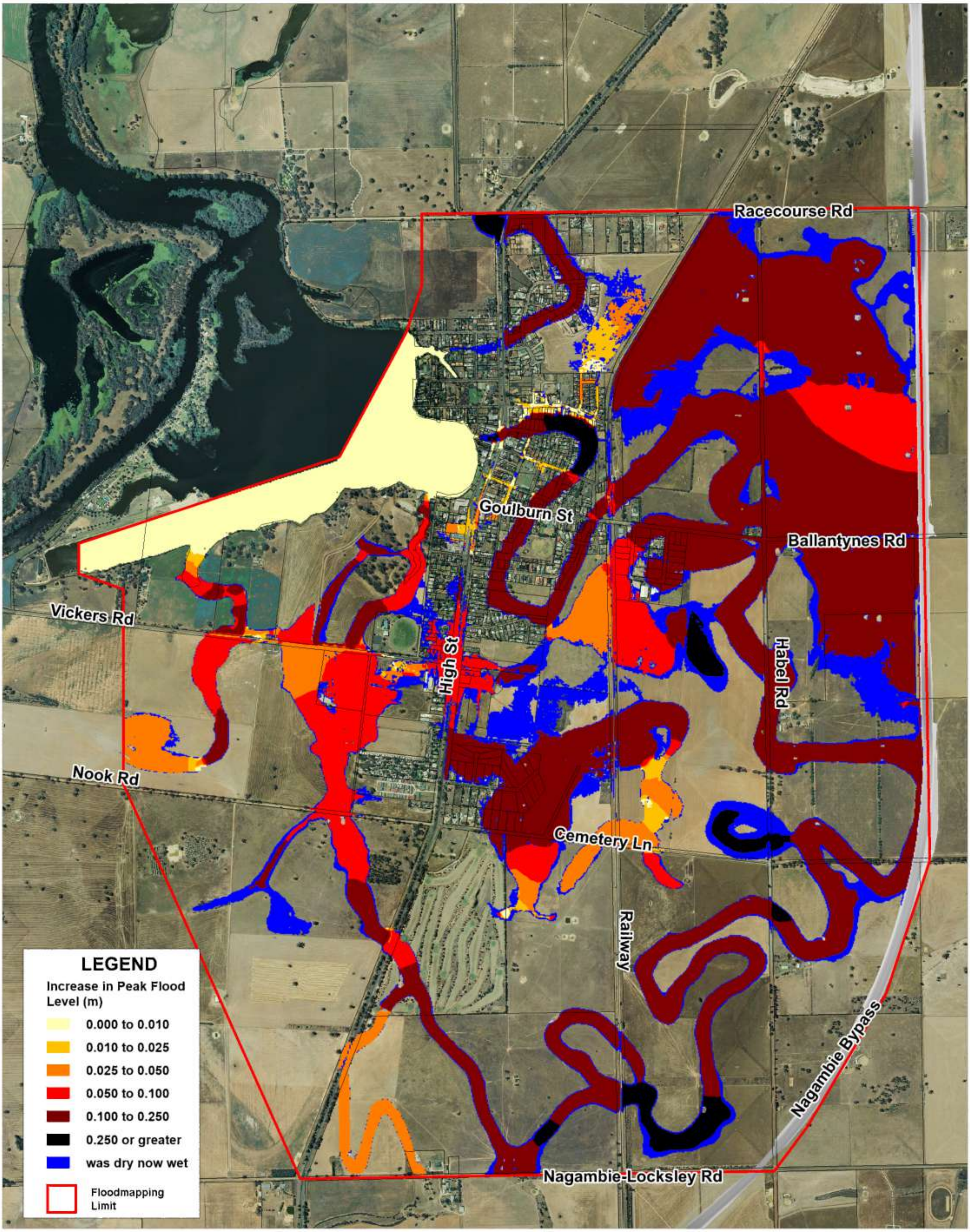

Title:

Nagambie Flood Study

100 Year ARI Peak Flood Impact - Climate Change

Figure: **7-8**

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7.4 Developed Case Climate Change Sensitivity

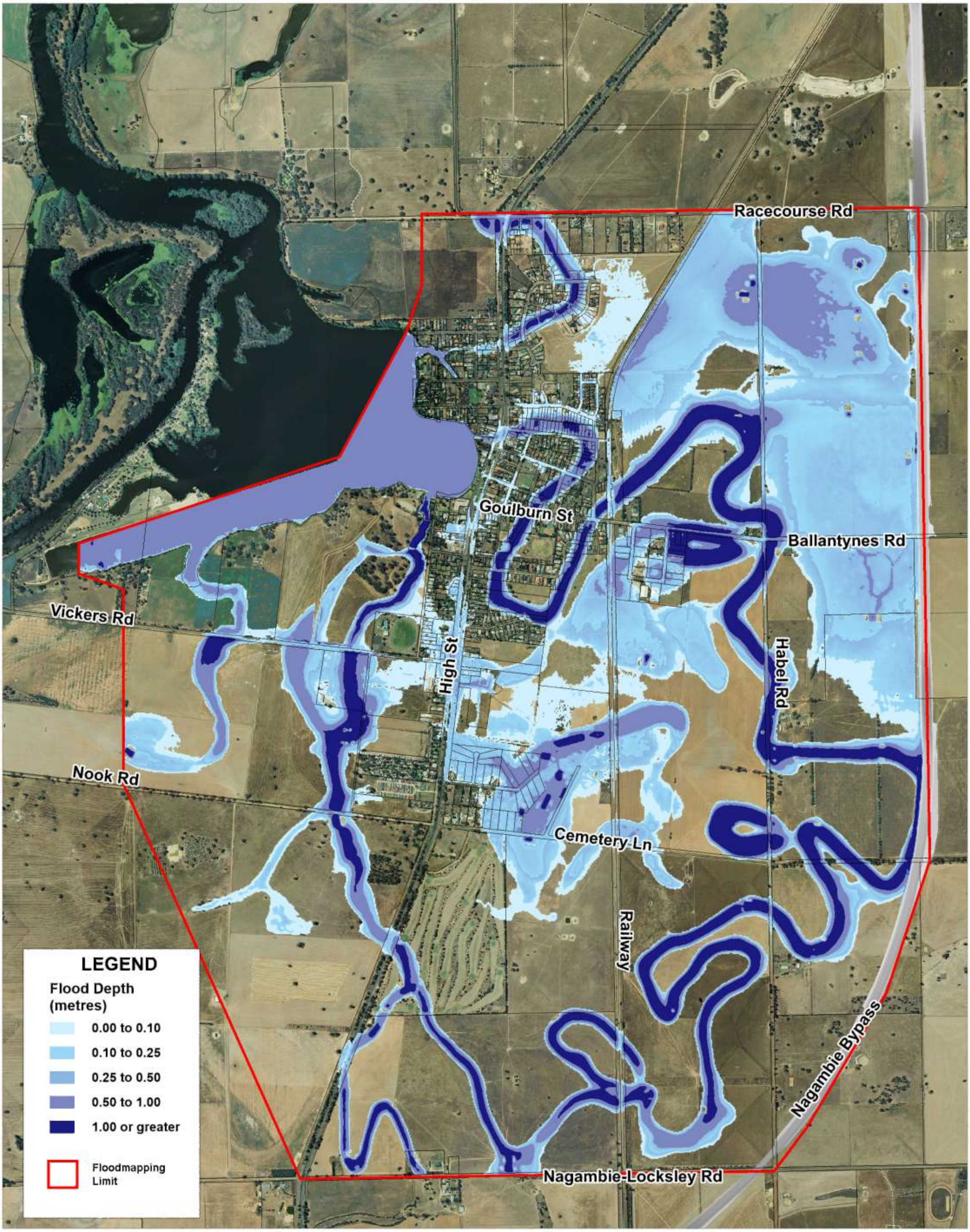
A worst case combined assessment investigating the impact of ultimate development in addition to an increase in rainfall intensity of 32% was undertaken for the catchment for the 1% AEP flood event, the results of which are presented in Figure 7-9 (flood depth) and Figure 7-10 (flood level increase). For details on the adjusted parameters refer to Section 4.3.3.

The purpose of this analysis will allow planners to gain an understanding of the potential impact that climate change, in combination with climate change could have on the study area and make future decisions accordingly. The flood impact mapping (Figure 7-10) shows the difference between the developed climate change scenario (Figure 7-9) and the climate change scenario (Figure 7-7).

The mapping shows increased flood levels across the entire study, generally up to 0.25 metres (although there are some isolation sections with greater increases). There is an increased flood extent shown across parts of the catchment, with the majority of the increased flood extent occurring in land currently zoned as 'Farm Zone'.

A complete set of flood depth maps are provided in Appendix D.

A complete set of flood velocity maps are provided in Appendix E.



Title:

Nagambie Flood Study

100 Year ARI Peak Flood Depth - Developed Climate Change

Figure: **7-9**

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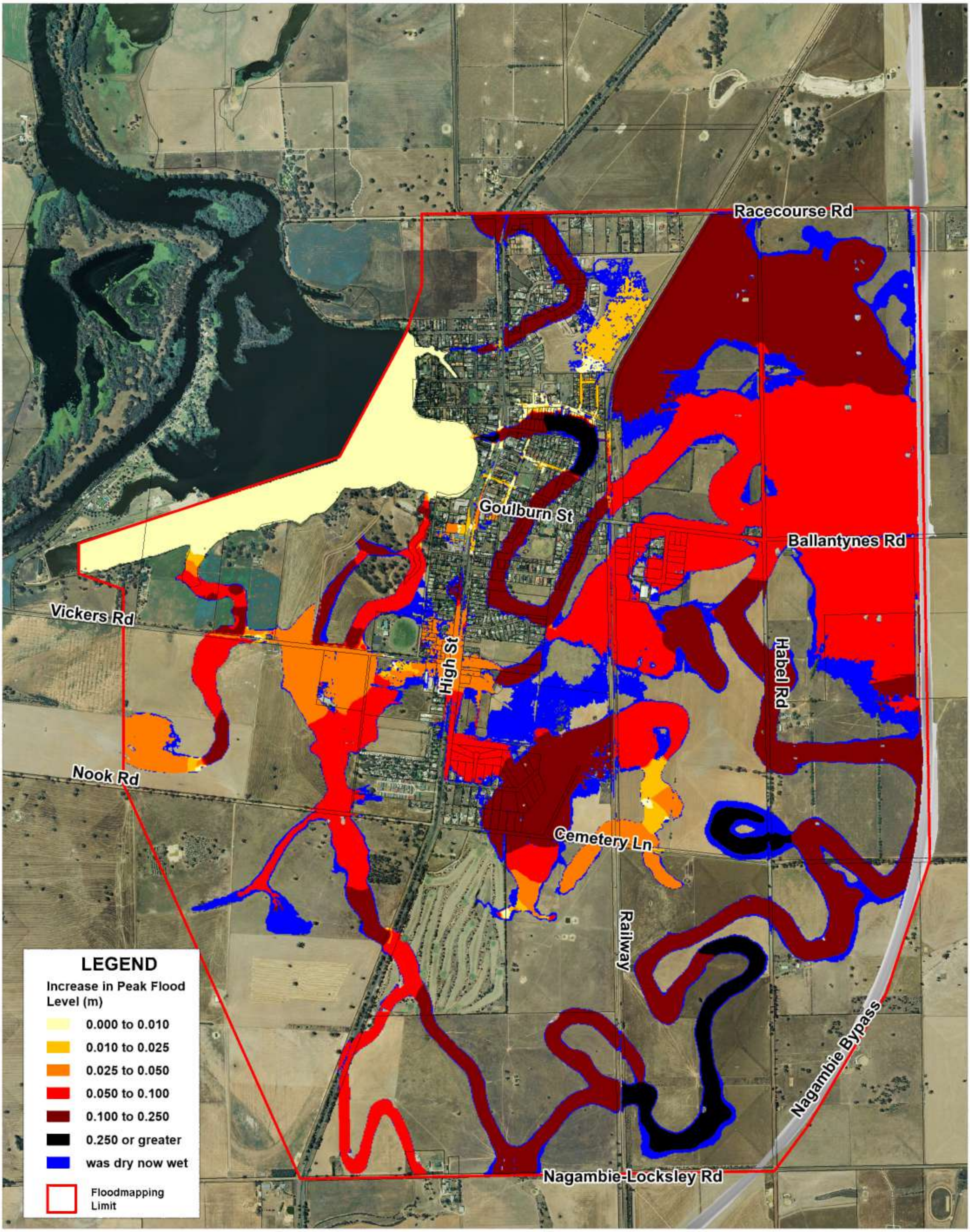

Title:

Nagambie Flood Study
100 Year ARI Peak Flood Impact - Developed Climate Change

Figure: 7-10

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7.5 Flood Hazard Mapping

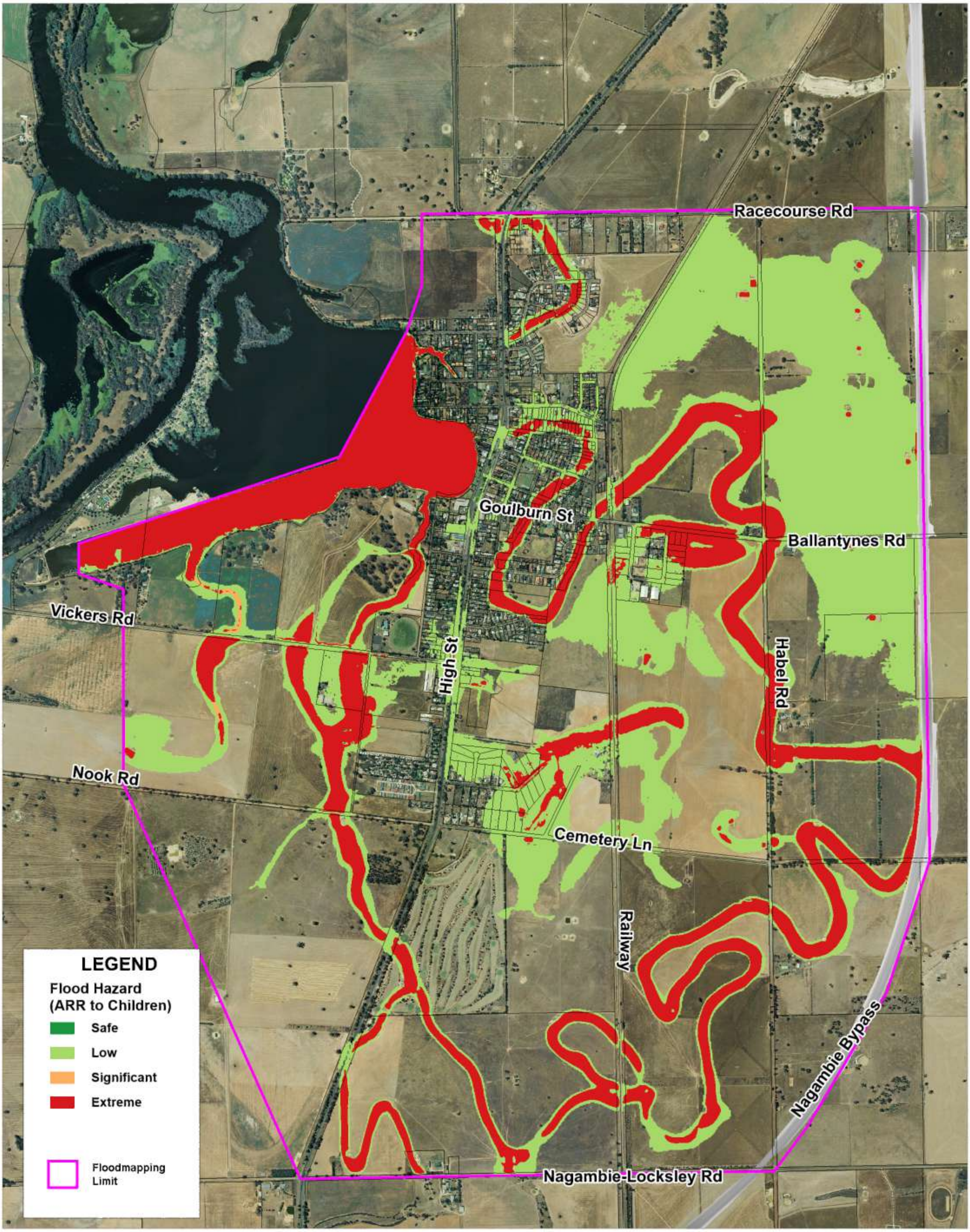
Peak flood hazard is based on the results from the 1% AEP event for each scenario. The flood hazard is presented spatially in Figure 7-11 for existing conditions.

Hazard mapping was undertaken using a methodology from the ARR revision project (Engineers Australia 2010) based on flow hazard regimes Hazardous to Children. Hazard is defined in terms of the depth and velocity-depth product as follows:

- Safe - velocity x depth equal to 0.0 m^2/s (no flooding);
- Low Hazard - velocity x depth less than 0.4 m^2/s (0.0 – 0.4 m^2/s);
- Significant Hazard - velocity x depth less than 0.6 m^2/s (0.4 – 0.6 m^2/s); and
- Extreme Hazard - depth greater than 500 mm and/or velocity x depth greater than 0.6 m^2/s (>0.6m^2/s).

Whilst flooding is extensive throughout the catchment the depths of flows are often shallow and slow moving. As a result, the vast majority of the catchment is classified as a low hazard to children. High hazard is driven primarily by the depth rather than depth/velocity product and is primarily located along the known flow paths and depressions through the catchment. High hazard to children also occurs within a number of road reserves.

A complete set of flood hazard maps are provided in Appendix F.



Title:

Nagambie Flood Study
100 Year ARI Peak Flood Hazard - Existing Conditions

Figure: **7-11**

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7.6 Property Risk Mapping

Existing conditions flood risk mapped for the peak flood level for each scenario investigated. The flood risk to property is presented spatially in Figure 7-12 and a summary of the number of properties within each flood risk category are summarised in Table 7-1. Risk mapping was undertaken using a methodology that was defined by GBCMA. Risk to property is as likely of flooding as below from lowest risk to highest;

Category 1 - The property is above the 2% AEP but below the 1% AEP flood level;

Category 2 - The property is above the 5% AEP but below the 2% AEP flood level;

Category 3 - The property is above the 10% AEP but below the 5% AEP flood level;

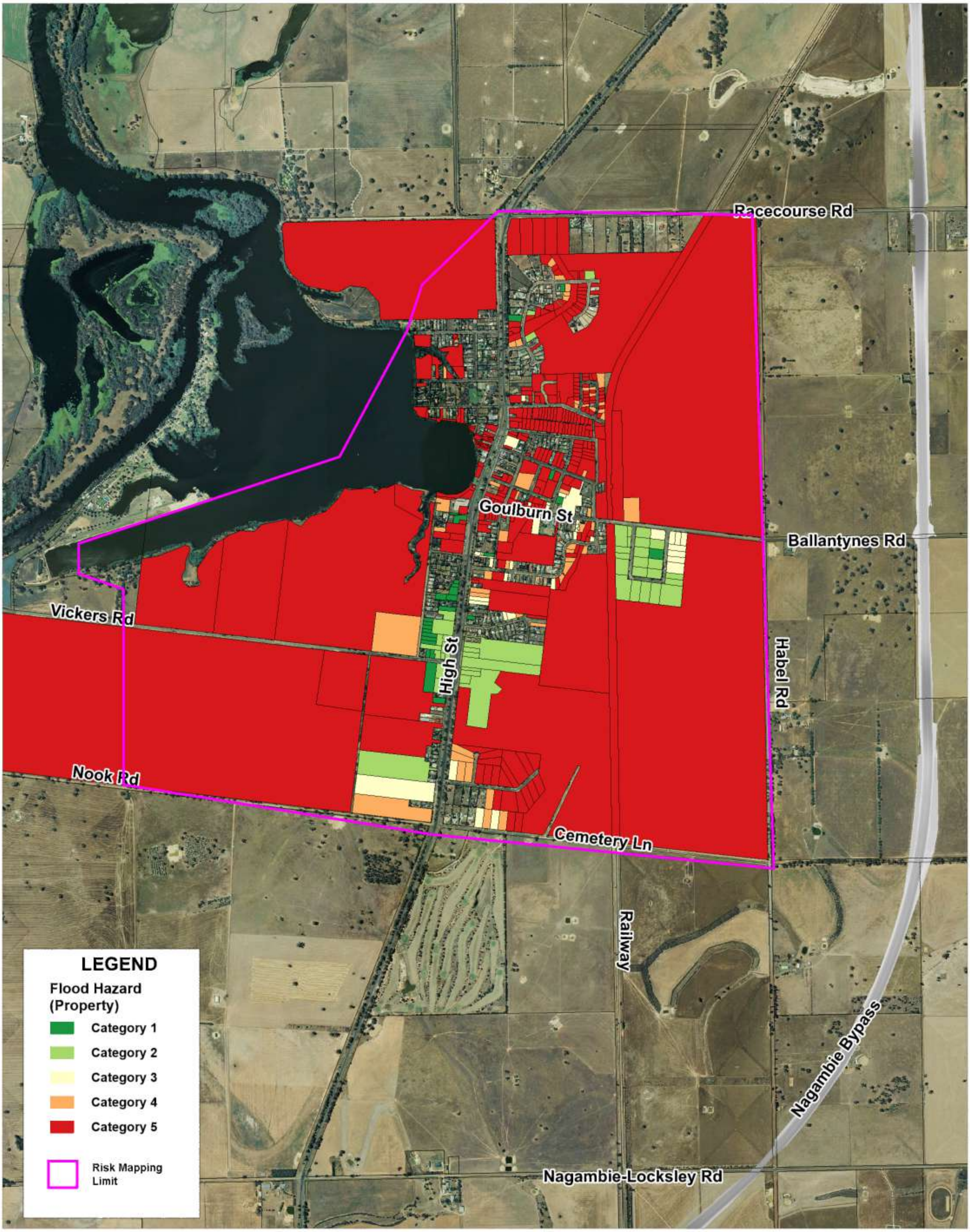
Category 4 - The property is above the 20% AEP but below the 10% AEP flood level; or

Category 5 - The property is below the 20% AEP flood level.

Table 7-1 Properties at Risk

Scenario	Existing
Category 1	30
Category 2	51
Category 3	40
Category 4	59
Category 5	308

Due to the flat nature of the catchment the vast majority of properties are deemed at the highest risk category (Category 5). However, it should be noted that this assessment is based on property boundaries and as such if any water, no matter how shallow or expansive is on the property it is deemed at risk. Properties with less than 5% of the parcel inundated were excluded from analysis as a large number of properties were reported as inundated along the edge due to the resolution of the model. A less conservative approach would be through use of floor levels of dwellings but this information does not exist for each property within the catchment.



Title:

Nagambie Flood Study

Property Flood Risk - Existing Conditions

Figure: 7-12

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8 Flood Damages Assessment

Flood damage assessments are an important component of any floodplain management framework and can be used to guide a mitigation options assessment. This type of analysis enables floodplain managers and decision makers to gain an understanding of the monetary magnitude of assets under threat from flooding. The information determined in the damages assessment is also used to inform the selection of mitigation measures via a cost benefit analysis.

Flood damages can be categorised as either tangible or intangible, depending on whether a monetary value can be assigned to a particular item. Tangible flood damages are those which can readily be assigned a monetary value such as damages to buildings. Tangible flood damages can be further divided into direct or indirect costs. Intangible flood damages are those which cannot be readily assigned a monetary value such as environmental and social costs. Each flood damage category is discussed in more detail below.

Direct tangible damages are the most easily quantifiable damages, as they are the damages that are directly attributable to the floodwater, such as damage to house and business contents. Direct damages can be further divided into:

- Building damages – the internal, external and structural damages caused to property.
- Agricultural damages – the damage to crops, livestock, fences, etc.; and
- Infrastructure damages – the damage to infrastructure such as roads and bridges.

Indirect tangible damages include losses due to the disruption of business, expenses of alternative accommodation, disruption of public services, emergency relief aid and clean-up costs. Thus, indirect damages tend to be more difficult to quantify and are often included as a proportion of direct damages.

Intangible flood damages are not included in standard flood damages assessments as it is difficult to assign monetary value. However, it is important that they are taken into consideration by floodplain managers and decision makers. The intangible damages are often used as a consideration when comparing one flood management measure against another.

The types of flood damages along with their categorisation are shown in Figure 8-1.

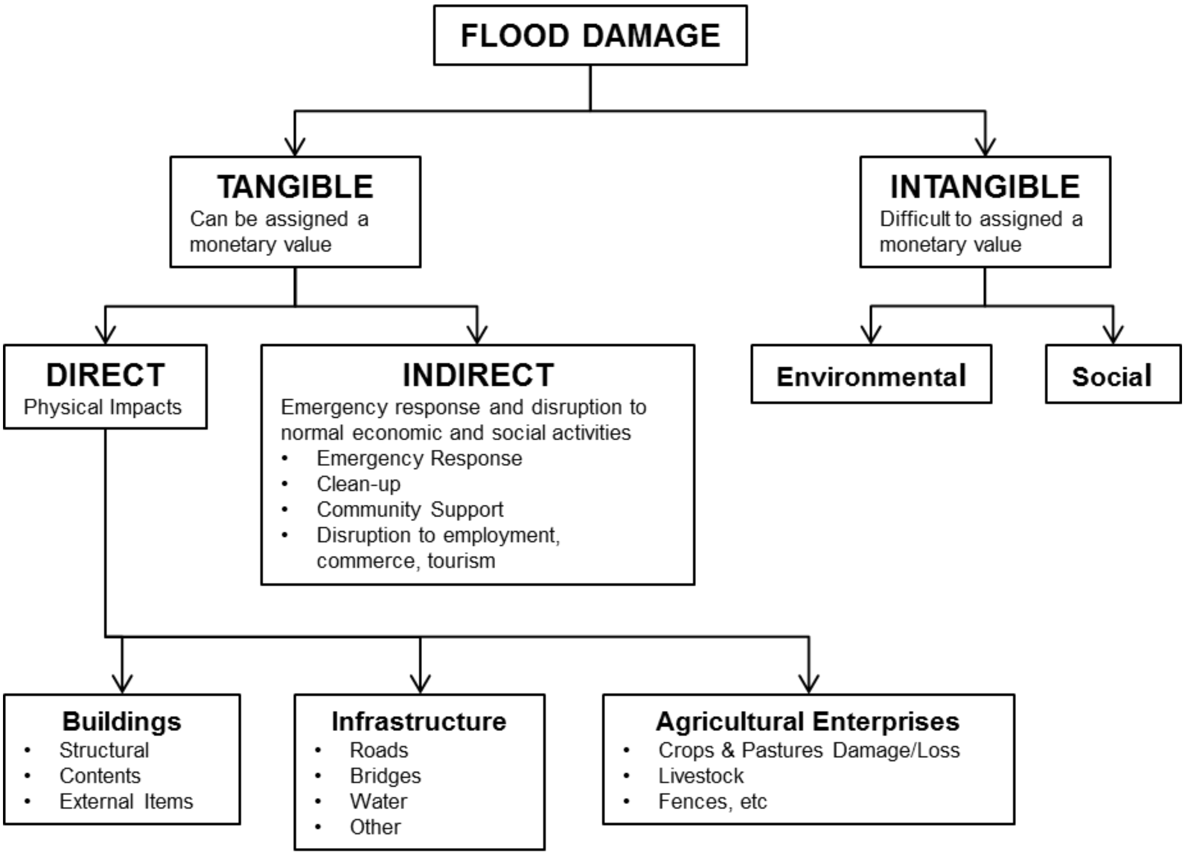


Figure 8-1 Types and Categorisation of Flood Damage Costs - Reproduced from *Rapid Appraisal Method (RAM) For Floodplain Management* (NRE 2000).

Flood damage assessments can either be carried out for an actual flood event or for a potential flood event (a design flood event). An assessment of an actual flood requires an extensive survey and data collection exercise carried out immediately following the flood for best accuracy. Rarely is it feasible to undertake an assessment on an actual flood given the large amount resources that are required. The method adopted for the Study was the Rapid Appraisal Method (RAM), described in more detail in the following Sections.

8.1 Methodology

The basic procedure for calculating monetary flood damages is provided below and is detailed in the following Sections. The basic procedure is:

- Prepare the appropriate relationships between depth of flooding and the assigned monetary value of damages (stage-damage curves).
- Gather the required input information detailing the characteristics of the buildings, agricultural enterprises and infrastructure that will be assessed. This includes data such as floor level, building type, size and condition, agricultural land use type and road type.
- Determine the design flood event impacts on individual buildings, properties, agricultural enterprises and roads. For this assessment, the 20%, 10%, 5%, 2%, 1%, 0.5% and 0.2% AEP design flood events have been used.
- Produce the total estimated potential damages for each design flood event across the study area and present the results in a probability-damage graph.
- Assume indirect damages based on the magnitude of direct damages.
- Determine the average annual damages (AAD).

8.2 Key Assumptions

In order to undertake a damage assessment a number of assumptions are required. The key assumptions for the flood damages assessment for the Study were as follows.

- The damage rates used in the RAM were indexed to a monetary value relative to that at the end of 2016.
- The property boundaries were defined by the cadastral layer provided by GBCMA.
- For commercial properties, the floor area was assumed to be 90% of the cadastral boundary and for industrial properties the floor area was assumed to be 40% of the cadastral boundary.
- To represent floor level inundation in the absence of floor level survey, residential properties were assumed to incur damages when more than 50% of a property is inundated and the depth of flooding is greater than 150 mm.
- To represent inundation in the absence of survey, commercial and industrial properties were assumed to incur damages when more than 33% of a property is inundated and the depth of flooding is greater than 100 mm.
- The damages were based on the provided cadastral layer and planning scheme. This includes a number of lots that are yet to be developed being classified as industrial or residential. This will result in a conservative estimate of damages; this assumption is consistent with the assumptions in the flood mapping.
- The total area of agricultural land and road length were defined in the VICMAP dataset provided by GBCMA and were confined to the flood mapping area.

- There are no damages as a result of flooding in a 2 year ARI design event.
- Velocities experienced within the floodplain were not of a magnitude to destroy a building beyond repair.
- Indirect damages were 30% of direct damages as recommended in the RAM guidelines (NRE 2000).
- The community is inexperienced with flooding and has between 2 and 12 hours warning time before a flood event occurs. This assumption was based on the potentially long time periods between major flood events in the catchment.
- The value of contents for all commercial and industrial buildings is assumed to be low. This assumption was made as there is no data available describing the condition or contents of individual buildings, and given the large floor area of many of the buildings there is likely to be much open floor space.
- All agricultural enterprises are 'dryland broadacre crops'. This assumption was made as there was no data available describing the type of individual agricultural enterprises but the primary land use in the agricultural land surrounding Nagambie township is cropping. There are also vineyards in the catchment, although they are not located within the flood mapping limit.
- There is no agricultural land inundated for longer than one week.

Further assumptions were made for each element of the damages assessment and are outlined in the description provided in the following sections.

8.3 Rapid Appraisal Method (RAM) Damages Assessment

The Rapid Appraisal Method (RAM) was developed for the rapid and consistent determination of flood damages. The RAM methodology can determine building, agricultural and road infrastructure damages, all of which have been determined for this Study.

8.3.1 RAM Building Damages

To determine damages to buildings, the RAM method assumes that if flooding occurs within a property that the maximum building damages will be incurred. The values adopted for this assessment were sourced from the RAM Guidelines (NRE 2000) and are summarised in Table 8-1. In order to convert the potential damages to actual damages the values were also factored by 0.8 to account for an inexperienced community with 2 to 12 hours warning.

For large non-residential buildings (commercial/industrial) with a floor area greater than 1,000m^2 there are three classes defining value of contents:

- low – offices, sporting pavilions, churches, etc.;
- medium – libraries, clothing businesses, caravan parks, etc.; and
- high – electronics, printing, etc.

As discussed above, all buildings were assumed to have a low value of contents. This assumption was made as there is no data available describing the condition or contents of individual buildings within the catchment.

Table 8-1 RAM Building Potential Damage Values

Building Type	Potential Damages
All Buildings other than Large Non-Residential	$25,600
Large Non-Residential – Medium Value of Contents	$56 per m^2

A summary of the RAM building damages for existing conditions is presented in Table 8-2. The summary highlights the number of properties inundated and the associated damages for the range of AEP events. The main drivers of damages within the catchment are from the commercial and industrial areas during the rarer flood events. However, during the more frequent flood events, a larger proportion of the damage is incurred by the residential properties. As discussed above these damages include lots that are yet to be developed so should be considered a conservative estimate on damages within the catchment.

Table 8-2 Existing Conditions RAM Building Damages Summary

Event (AEP)	No. of Properties Inundated	Residential Damages	Commercial and Industrial Damages	Total Building Damages
0.2%	247	$4,889,600	$10,966,384	$15,856,000
0.5%	224	$4,480,000	$6,641,107	$11,121,100
1%	197	$3,968,000	$4,470,648	$8,438,600
2%	186	$3,737,600	$4,288,843	$8,026,400
5%	154	$3,430,400	$1,085,886	$4,516,300
10%	102	$2,406,400	$494,380	$2,900,800
20%	79	$1,817,600	$494,380	$2,312,000

8.3.2 RAM Agricultural Damages

RAM agricultural damages account for damage to crops and clean-up costs. The value of perished stock can also be incorporated; however, the RAM Guidelines (NRE 2000) stipulates that many major flood events do not incur any loss of stock. For this reason, stock losses have not been included in this assessment. Further there is likely to be little to no stock in the Nagambie catchment.

The values adopted for the assessment, Table 8-3 were obtained from the RAM Guidelines (NRE 2000) for dryland broadacre crops. Whilst there are vineyards in the region, there are none present within the flood mapping limit. Clean-up costs are defined by the area of inundation within and outside of floodway areas. As the flood characteristics of the catchment are for relatively shallow and slow moving flood waters it was decided for the purpose of the RAM assessment to designate all flooding as non-floodway damages.

Table 8-3 RAM Agricultural Damage Values

Crop Type	Damages
Dryland Broadacre Crops Inundated for Shorter than 1 week	$131 per hectare
Dryland Broadacre Crops beyond Floodway Area	$225 per hectare

A summary of the RAM agricultural damages for existing conditions is presented in Table 8-4. The summary highlights the area of agricultural land inundated and the associated damages for the range of AEP events.

Table 8-4 Existing Conditions RAM Agricultural Damages Summary

Event (AEP)	Area of Agricultural Land Inundated (hectares)	Crop Damages	Clean Up Costs	Total Agricultural Damages
0.2%	1253	$164,143	$20,048	$184,191
0.5%	1105	$144,755	$17,680	$162,435
1%	986	$129,166	$15,776	$144,942
2%	887	$116,197	$14,192	$130,389
5%	736	$96,416	$11,776	$108,192
10%	607	$79,517	$9,712	$89,229
20%	505	$66,155	$8,080	$74,235

8.3.3 RAM Road Infrastructure Damages

RAM road infrastructure damages are determined by assigning a cost per length of road inundated. The values adopted for this assessment were obtained from the RAM Guidelines (NRE 2000) and are summarised in Table 8-5. The cost values incorporate initial road repair, subsequent accelerated deterioration, initial bridge repair, and subsequent increased maintenance. RAM defines road type in three categories: major sealed roads, minor sealed roads and unsealed roads. Within the study area road types for all roads were defined.

Table 8-5 RAM Road Infrastructure Damage Values

Road Type	Cost per kilometre of Inundation
Major Sealed Roads	$92,242
Minor Sealed Roads	$28,923
Unsealed Roads	$13,055

A summary of the RAM road infrastructure damages for existing conditions is presented in Table 8-6. The summary highlights the total length of road inundated and the associated damages for the range of AEP events.

Table 8-6 Existing Conditions RAM Road Infrastructure Damages Summary

Event (ARI)	Length of Road Inundated (kilometres)	Road Infrastructure Damages
0.2%	13	$457,085
0.5%	11	$411,333
1%	11	$378,759
2%	9	$325,640
5%	7	$251,942
10%	6	$185,410
20%	4	$132,849

8.4 Average Annual Damages

Average annual damages (AAD) are the average damage (in dollars) per year that would occur in a particular area from flooding over a very long period of time. In many years' time there may be no flood damage, in some years there will be minor damage (caused by small, relatively frequent floods) and, in a few years, there will be major flood damage (caused by large, rare flood events). Estimation of AAD provides a basis for comparing the effectiveness of different management measures (i.e. the reduction in the AAD) using benefit cost analysis.

The AAD are calculated as the area under the probability-damage curve. The lower limit on the curve is the 50% AEP design flood event and it is assumed to cause zero damages. The probability-damage curve is extrapolated to account for events with a probability between the 20% and 50% AEP.

Following the calculation of the individual direct damage elements, the total tangible flood damages across the study area can be determined.

The total tangible flood damages, for existing conditions for all modelled events, is presented in Table 8-7 and is illustrated in Figure 8-2. The existing condition AAD for the catchment is $1,666,200.

As discussed above, the damages within the catchment are largely driven by the damage to buildings, particularly commercial and industrial property. This is in part due to the conservative assumption of using the planning scheme rather than individual property assessments but also due to the widespread shallow flooding throughout the catchment which is a limitation of the Rapid Appraisal Method.

Table 8-7 Existing Conditions Damages Summary

Event (ARI)	RAM Building Damages	RAM Agricultural Damages	RAM Road Infrastructure Damages	Indirect Damages	Total Damages	Contribution to AAD
PMP	-	-	-	-	$25,608,600	
0.2%	$15,856,000	$184,191	$457,085	$4,949,200	$21,446,500	$47,055
0.5%	$11,121,100	$162,435	$411,333	$3,508,500	$15,203,400	$54,975
1%	$8,438,600	$144,942	$378,759	$2,688,700	$11,651,000	$67,136
2%	$8,026,400	$130,389	$325,640	$2,544,700	$11,027,100	$113,391
5%	$4,516,300	$110,192	$251,942	$1,463,500	$6,341,900	$260,535
10%	$2,900,800	$89,229	$185,410	$952,600	$4,128,000	$261,748
20%	$2,312,000	$74,235	$132,849	$755,700	$3,274,800	$370,140
50%	$0	$0	$0	$0	$0	$491,220
					Average Annual Damages	**$1,666,200**

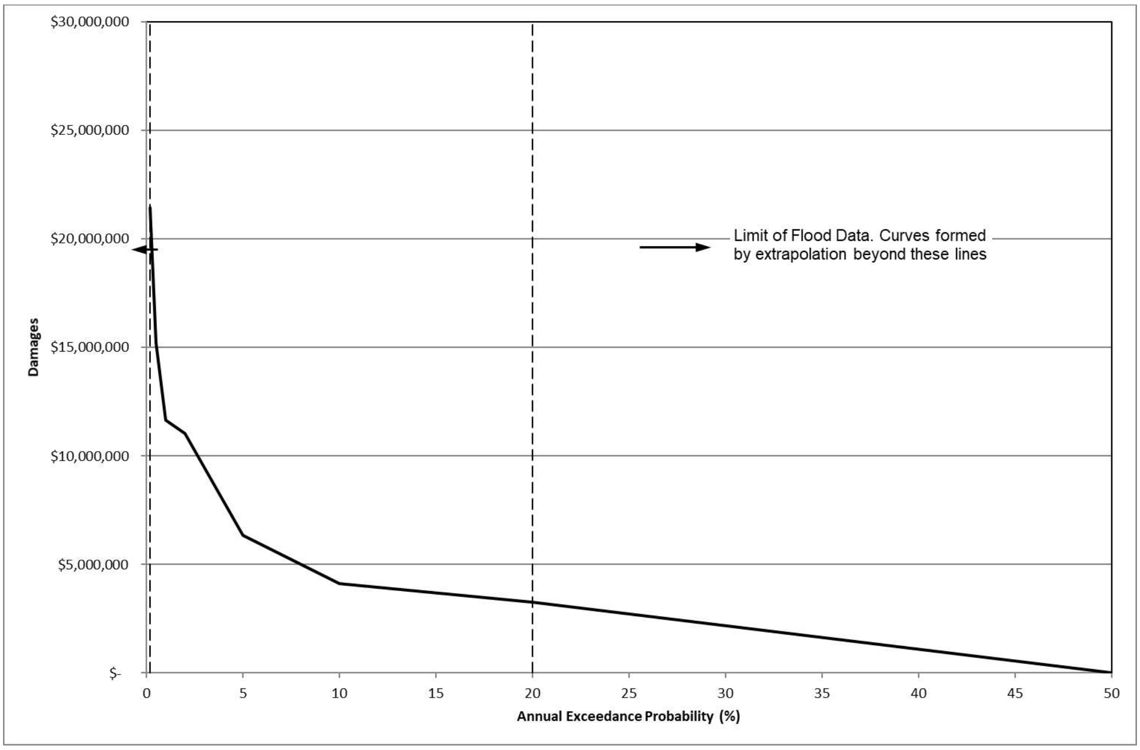


Figure 8-2 Existing Condition Probability-Damages Curve

9 Flood Management

9.1 Background

There are two major categories of floodplain management options that can be used to reduce the risk and consequences of flooding:

(1) Structural Measures – Works that alter the behaviour of flood waters to mitigate the impact of flooding for a certain area.

(2) Non-Structural Measures

  (a) Land Use Planning Controls – Incorporating flooding into land use planning and implementing building control measures; effective in reducing the impact of flooding to future developments.

  (b) Emergency Management and Response – Aimed at reducing the impact of flooding by improving the community's ability to respond to a flood event.

For a floodplain and drainage management plan to be effective it needs to consider and integrate all three of these categories.

9.2 Key Issues

It is important to establish a clear and thorough understanding of the issues to be addressed in order to manage flood risk to Nagambie.

Through flood modelling and mapping undertaken for the Study it is evident that Nagambie is at most risk from widespread slow moving, shallow and frequent flooding. Areas of high hazard are generally restricted to retarding basins and a number of road reserves.

9.3 Structural

Due to the shallow widespread flooding, there are limited opportunities for structural mitigation management options within the catchment. For example, levees and major retarding basins would be largely ineffective as there are few 'choke' points to concentrate flow and store or divert.

9.4 Non-Structural

In the long term, one of the most effective means of flood mitigation is the establishment and enforcement of appropriate planning scheme controls in areas identified as at risk of flooding. Planning controls are effective over time as buildings are renewed they can be built in areas outside the floodplain, or if in an area of low flood risk, can be built above the declared flood level.

9.4.1 Overlays

There exists a number of planning controls that are used within Victoria for ensuring appropriate development in and around flood waters. The most applicable for Nagambie includes:

- Environmental Significance Overlay (ESO);
- Floodway Overlay (FO);

- Land Subject to Inundation Overlay (LSIO);
- Special Building Overlay (SBO); and
- Urban Flood Zone (UFZ).

Consistent with the DELWP's guidelines, it would be recommended to manage the catchment through a combination of Floodway and Land Subject to Inundation Overlays and/or Urban Flood Zones. This method allows development to occur within floodwaters deemed low risk but restricts development in high risk areas.

The proposed planning scheme for the catchment is to assign areas identified as Extreme Hazard to Children (depth greater than 500 mm and/or velocity x depth greater than 0.6 m^2/s) to the more restrictive Floodway Overlay or Urban Flood Zone. Areas identified as lower hazard should be subjected to the less restrictive Land Subject to Inundation Overlay. The proposed planning scheme overlays are presented in Figure 9-1. These overlays are based on existing conditions. Consideration should be given to planning scheme overlays based on developed and/or climate change conditions.

9.4.1.1 Building Controls

Building controls recommended for Nagambie are such that:

- Finished floor levels of all properties within the 1% AEP flood extent are set at a minimum of 300mm above the declared flood levels.
- Finished floor levels of all properties adjacent the 1% AEP flood event extents are set at a minimum of 300mm above the declared flood levels nearest the site.
- There is no development within the UFZ and FO.

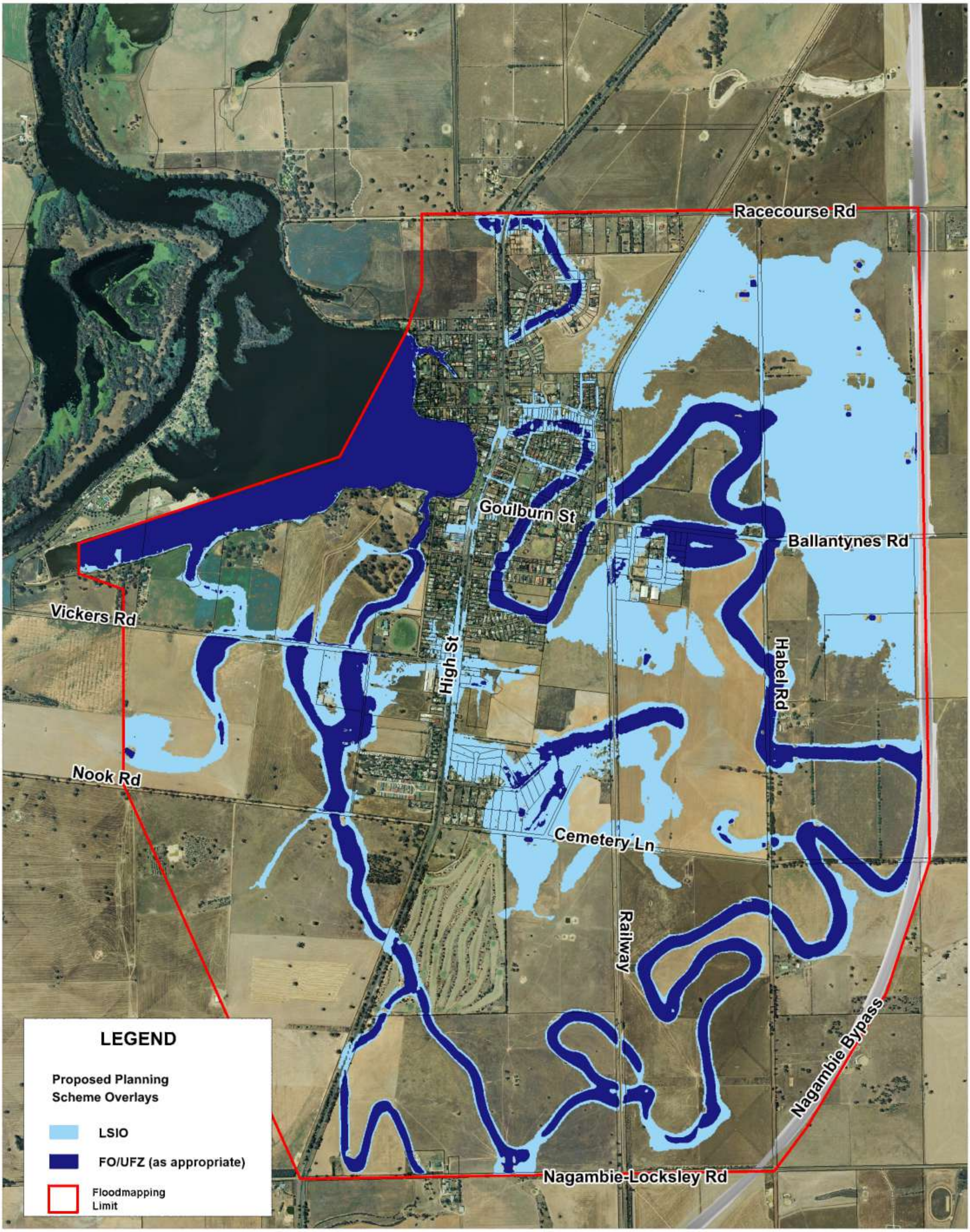
9.4.1.2 Development Controls

Development controls should restrict the runoff generated by future developments to existing or pre-existing levels up to the 1% AEP design event. This could be achieved through water sensitive urban design principals and may include (but not limited to) technologies such as pervious pavement, soak pits, retention basins and so on.

9.4.2 Planning for Climate Change

The DELWP have recommended that the impact of climate change on flooding is assessed by increasing the rainfall intensity of design events. To ascertain the likely impact of climate change, an increased rainfall intensities (and therefore total depth of rainfall) was modelled as described in Section 7.3 The scenario had the rainfall intensity increased by 32% for the design events.

The State climate change adaption plan (2017-2020) states that "new flood studies will more explicitly consider the implications of climate change". Whilst this study has undertaken modelling of a climate change (increased rainfall intensity) scenario, at present, there is no requirement from State Government for the incorporation of the results from this assessment into floodplain management decisions. The incorporation of climate change information into floodplain management decisions is undertaken on a Council by Council basis. These decisions may take the form of setting building controls at the climate change flood levels, for instance.



Title:

Nagambie Flood Study
Proposed Planning Scheme Overlays

Figure: **9-1**

Rev: **A**

N

0 0.5 1km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\Fig9-1_PlanControls_RevA.WOR

10 Summary and Recommendations

This report has documented the methodology and findings of the Nagambie Flood Study. The study has defined the flood behaviour for the catchment through the development of calibrated hydrologic and hydraulics models and the determination of flood behaviour for a range of flood events. These models have been used to determine the flood damages within the catchment. A number of flood management measures have been documented and recommended for adoption within the catchment with the aim of reducing flood risk to Nagambie. These recommendations include:

- Implementation of Planning Scheme Controls (Section 9.4.1)
- Implementation of Building Controls (Section 9.4.1.1)
- Consideration of Planning for Climate Change (Section 9.4.2)

11 References

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Appendix A TIME OF CONCENTRATION CALCULATIONS

BMT WBM	Subject: Rational Method Calculation Sheet	Job No:	M8414	Date:	30/07/2012
		By:	TC	Rev:	1
		Ckd:	JL	Date:	

Catchment	Sub-Catchment	Catchment Type	Tc Method (Adams Rural Method, Mannings Overland Flow, Colebrook-White Pipe Full Flow)	Area (ha)	Impervious Fraction (%)	Tc Adopted (minutes)	Interpolated Intensity (mm/hr)	C10 (From AR&R Vol2 for rural or Calculated for urban)	Fy Rural (Victoria) from AR&RBook4, Table 1.4 or Urban from Book	Runoff Coefficient	Velocity (m/s)	Estimated Flow (m^3/s)
Main Catchment (Illaura Outlet)	Oneils Road	Rural	Adams	987	10%	108.8	34.90	0.15	1.30	0.20	1.0	18.7
	Nagambie Bypass	Rural	Adams	849	8%	102.8	36.45	0.15	1.30	0.20	1.5	16.8
	Golfcourse Confluence	Rural	Adams	2387	9%	152.2	26.90	0.15	1.30	0.20	1.7	34.8
	Vickers Road	Rural	Adams	2570	9%	156.6	26.32	0.15	1.30	0.20	1.7	36.6
	Illaura Development	Urban	Mannings	51	45%	11.6	135.00	0.52	1.20	0.63	1.4	12.1
	Outlet			**2621**	**10%**	**168.2**	**24.86**	**0.16**	**1.30**	**0.20**	**1.6**	**37.0**
Bride Street Catchment	Railway	Rural	Adams	667	9%	93.8	39.09	0.15	1.30	0.20	1.8	14.1
	Bride Street	Urban	Mannings* and Colebrook-White	320	22%	39.6	70.38	0.37	1.20	0.44	1.6	27.4
	Outlet			**987**	**13%**	**133.4**	**29.80**	**0.22**	**1.27**	**0.28**	**1.6**	**22.8**
Western Catchment	Outlet	Rural	Adams	987	6%	108.8	34.91	0.15	1.30	0.20	1.4	18.7
	Outlet			**987**	**6%**	**108.8**	**34.91**	**0.15**	**1.30**	**0.20**	**1.4**	**18.7**
North Catchment	Goulburn Valley Hwy	Rural	Adams	66	10%	39.0	71.00	0.15	1.30	0.20	0.5	2.5
	Nagambie Hospital	Urban	Mannings* and Colebrook-White	93	38%	21.5	98.94	0.47	1.20	0.57	1.3	14.5
	Outlet			**159**	**27%**	**60.5**	**54.69**	**0.34**	**1.24**	**0.42**	**0.8**	**10.2**

*1.0m/s flow velocity adopted instead of Mannings equation

Appendix B IFD Table

Duration		Design Rainfalls for Average Recurrence Intervals (Years)						
		1	2	5	10	20	50	100
(min)	(hr)	(mm/hr)	(mm/hr)	(mm/hr)	(mm/hr)	(mm/hr)	(mm/hr)	(mm/hr)
5	0.083	56.00	73.00	99.00	115.00	137.00	168.00	192.00
5.5	0.092	54.00	71.00	95.00	111.00	132.00	162.00	185.00
6	0.100	52.00	68.00	92.00	108.00	128.00	156.00	179.00
6.5	0.108	50.00	66.00	90.00	104.00	124.00	152.00	174.00
7	0.117	48.90	64.00	87.00	101.00	121.00	147.00	168.00
7.5	0.125	47.60	63.00	85.00	99.00	117.00	143.00	164.00
8	0.133	46.30	61.00	82.00	96.00	114.00	139.00	159.00
8.5	0.142	45.20	60.00	80.00	94.00	111.00	136.00	155.00
9	0.150	44.10	58.00	78.00	91.00	108.00	132.00	151.00
9.5	0.158	43.10	57.00	76.00	89.00	106.00	129.00	148.00
10	0.167	42.20	56.00	75.00	87.00	104.00	126.00	144.00
11	0.183	40.40	53.00	72.00	84.00	99.00	121.00	138.00
12	0.200	38.90	51.00	69.00	80.00	95.00	116.00	133.00
13	0.217	37.50	49.30	66.00	77.00	92.00	112.00	128.00
14	0.233	36.20	47.60	64.00	75.00	89.00	108.00	123.00
15	0.250	35.00	46.10	62.00	72.00	86.00	104.00	119.00
16	0.267	33.90	44.70	60.00	70.00	83.00	101.00	115.00
17	0.283	32.90	43.40	58.00	68.00	80.00	98.00	112.00
18	0.300	32.00	42.10	57.00	66.00	78.00	95.00	109.00
19	0.317	31.20	41.00	55.00	64.00	76.00	92.00	106.00
20	0.333	30.40	39.90	54.00	62.00	74.00	90.00	103.00
21	0.350	29.60	38.90	52.00	61.00	72.00	88.00	100.00
22	0.367	28.90	38.00	51.00	59.00	70.00	86.00	98.00
23	0.383	28.20	37.10	49.80	58.00	69.00	84.00	95.00
24	0.400	27.60	36.30	48.70	57.00	67.00	82.00	93.00
25	0.417	27.00	35.50	47.60	55.00	66.00	80.00	91.00
26	0.433	26.50	34.80	46.60	54.00	64.00	78.00	89.00
27	0.450	25.90	34.10	45.70	53.00	63.00	76.00	87.00
28	0.467	25.40	33.40	44.80	52.00	62.00	75.00	86.00
29	0.483	24.90	32.80	43.90	51.00	60.00	74.00	84.00
30	0.500	24.50	32.20	43.10	50.00	59.00	72.00	82.00
32	0.533	23.60	31.10	41.60	48.30	57.00	70.00	79.00
34	0.567	22.80	30.00	40.20	46.70	55.00	67.00	77.00
36	0.600	22.10	29.10	38.90	45.20	53.00	65.00	74.00
38	0.633	21.50	28.20	37.70	43.80	52.00	63.00	72.00
40	0.667	20.80	27.40	36.60	42.50	50.00	61.00	70.00
45	0.750	19.50	25.60	34.20	39.70	46.90	57.00	65.00
50	0.833	18.30	24.10	32.10	37.30	44.10	53.00	61.00
55	0.917	17.30	22.70	30.30	35.20	41.60	50.00	58.00
60	1.00	16.40	21.60	28.80	33.40	39.50	47.90	55.00
75	1.25	14.20	18.60	24.60	28.50	33.60	40.60	46.20
90	1.50	12.60	16.40	21.70	25.00	29.40	35.40	40.20
105	1.75	11.30	14.80	19.40	22.30	26.20	31.50	35.80

Duration		Design Rainfalls for Average Recurrence Intervals (Years)						
		1	2	5	10	20	50	100
(min)	(hr)	(mm/hr)	(mm/hr)	(mm/hr)	(mm/hr)	(mm/hr)	(mm/hr)	(mm/hr)
120	2.00	10.40	13.50	17.60	20.30	23.70	28.50	32.30
135	2.25	9.56	12.40	16.20	18.60	21.70	26.00	29.50
150	2.50	8.90	11.60	15.00	17.20	20.10	24.00	27.20
165	2.75	8.33	10.80	14.00	16.00	18.70	22.30	25.20
180	3.00	7.85	10.20	13.20	15.00	17.50	20.90	23.60
195	3.25	7.43	9.63	12.40	14.20	16.50	19.60	22.10
210	3.50	7.06	9.14	11.80	13.40	15.60	18.60	20.90
225	3.75	6.74	8.72	11.20	12.70	14.80	17.60	19.80
240	4.00	6.45	8.33	10.70	12.10	14.10	16.70	18.80
270	4.50	5.94	7.67	9.81	11.10	12.90	15.30	17.20
300	5.00	5.53	7.13	9.09	10.30	11.90	14.10	15.80
360	6.00	4.88	6.28	7.97	8.99	10.40	12.30	13.70
420	7.00	4.39	5.64	7.13	8.02	9.25	10.90	12.20
480	8.00	4.01	5.14	6.47	7.27	8.37	9.84	11.00
540	9.00	3.70	4.74	5.94	6.67	7.66	8.99	10.00
600	10	3.44	4.41	5.51	6.17	7.08	8.29	9.24
660	11	3.23	4.13	5.14	5.75	6.59	7.71	8.58
720	12	3.04	3.88	4.83	5.39	6.17	7.21	8.02
840	14	2.71	3.47	4.34	4.85	5.56	6.52	7.26
960	16	2.46	3.15	3.95	4.43	5.08	5.96	6.65
1080	18	2.25	2.89	3.63	4.08	4.69	5.51	6.16
1200	20	2.08	2.67	3.37	3.79	4.37	5.14	5.74
1320	22	1.94	2.49	3.15	3.55	4.09	4.82	5.39
1440	24	1.82	2.34	2.96	3.34	3.85	4.55	5.09
1800	30	1.53	1.98	2.52	2.85	3.30	3.90	4.38
2160	36	1.33	1.72	2.20	2.49	2.89	3.43	3.86
2520	42	1.18	1.52	1.96	2.22	2.59	3.08	3.46
2880	48	1.05	1.37	1.76	2.01	2.34	2.79	3.14
3240	54	0.95	1.24	1.61	1.83	2.14	2.55	2.88
3600	60	0.87	1.13	1.47	1.69	1.97	2.35	2.66
3960	66	0.80	1.04	1.36	1.56	1.82	2.18	2.47
4320	72	0.74	0.97	1.26	1.45	1.70	2.04	2.31

Appendix C PMF Summary Worksheet

GSDM WORKSHEET

LOCATION INFORMATION			
Catchment:	Nagambie	Area:	47.6 km2
State:	VIC	Duration Limit:	3 hours
Latitude:	36.82044° S	Longitude:	145.153° E
Portion of Area Considered:			
Smooth, **S** =	1	Rough, **R** =	0
ELEVATION ADJUSTMENT FACTOR (EAF)			
Mean Elevation:	133.4 mAHD		
Adjustment for Elevation (-0.05 per 300m above 1500m):			0.00
EAF =	1.00		
GSDM MOISTURE ADJUSTMENT FACTOR (MAF)			
GSDM MAF =	0.58		

PMP VALUES (mm)

Duration (hours)	Initial Depth - Smooth (D_S)	Initial Depth - Rough (D_R)	PMP Estimate = (D_SHS + D_RHR) H MAF H EAF	Rounded PMP Estimate (nearest 10 mm)
0.25	183	183	106	**110**
0.5	270	270	157	**160**
0.75	342	342	199	**200**
1	409	409	238	**240**
1.5	468	527	271	**270**
2	527	610	305	**310**
2.5	562	682	326	**330**
3	591	738	343	**340**
4	0	0	0	**0**
5	0	0	0	**0**
6	0	0	0	**0**

Prepared by: TC Date: 21/12/2012
Checked by: JL Date: 21/12/2012

GSAM WORKSHEET

LOCATION INFORMATION				
Catchment:	Nagambie		State:	VIC
GSAM zone:	Inland	Area:	47.6	km^2

CATCHMENTS FACTOR		
Topographical Adjustment Factor TAF =	1.254	(1.0 - 2.0)

Annual Moisture Adjustment Factor

$$MAF = \frac{EPW_{seasonal\_cathcment\_average}}{EPW_{seasonal\_standard}}$$

Season	$EPW_{seasonal\ catchment\ average}$	$EPW_{seasonal\ standard}$	MAF	
Summer (Annual)	60.04	80.80	0.74	(0.60 - 1.05)
Autumn	48.92	71.00	0.69	(0.56 - 0.91)

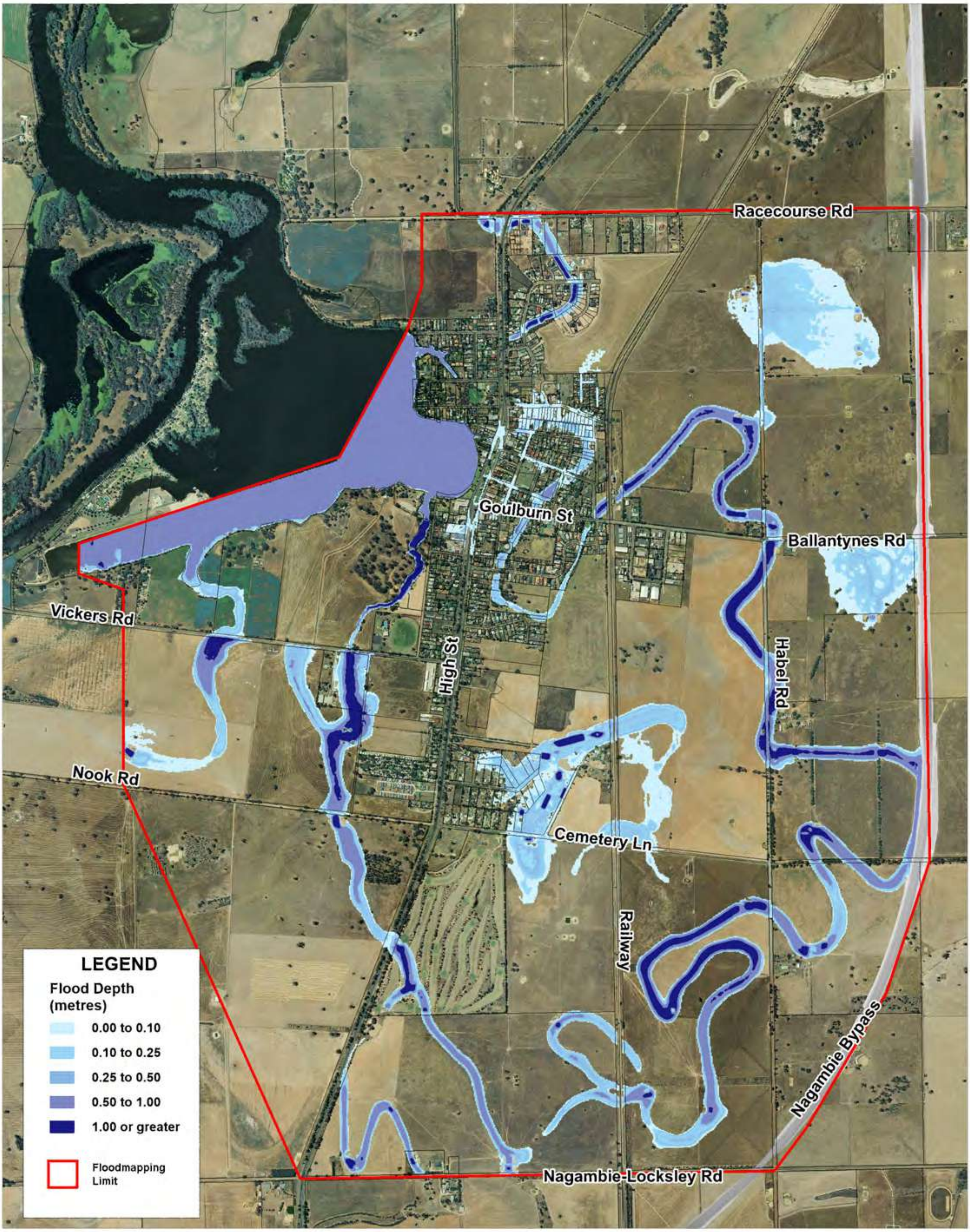
PMP values (mm)	Summer		Autumn	
Duration (hours)	Initial Depth (D_{summer})	PMP Estimate (D_sxTAFxMAF$_s$)	Initial Depth (D_{autumn})	PMP Estimate (D_axTAFxMAF$_a$)
24	463	431	659	569
36	494	461	757	654
48	515	480	810	700
72	557	519	858	741
96	583	543	873	754

FINAL PMP VALUES (mm)

Duration (hours)	Maximum of the Seasonal Depths	Rounded PMP Estimate (nearest 10 mm)	Final PMP Estimate (from envelope)
0.25	Where applicable, calculate GSDM depths (Bureau of Meteorology, 2003)	110	110
0.5		160	160
0.75		200	200
1		240	240
1.5		270	270
2		310	310
2.5		330	330
3		340	340
4		0	0
5		0	0
6		0	0
12	(no preliminary estimates available, read off graph)		
24	569	570	570
36	654	650	650
48	700	700	700
72	741	740	740
96	0	0	0

Prepared by: TC Date: 21/12/2012
Checked by: JL Date: 21/12/2012

Appendix D Peak Flood Depth Maps



Title:

Nagambie Flood Study
5 Year ARI Peak Flood Depth - Existing Conditions

Figure: D-1

Rev: A

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N

0 0.5 1km

Approx. Scale

BMT WBM

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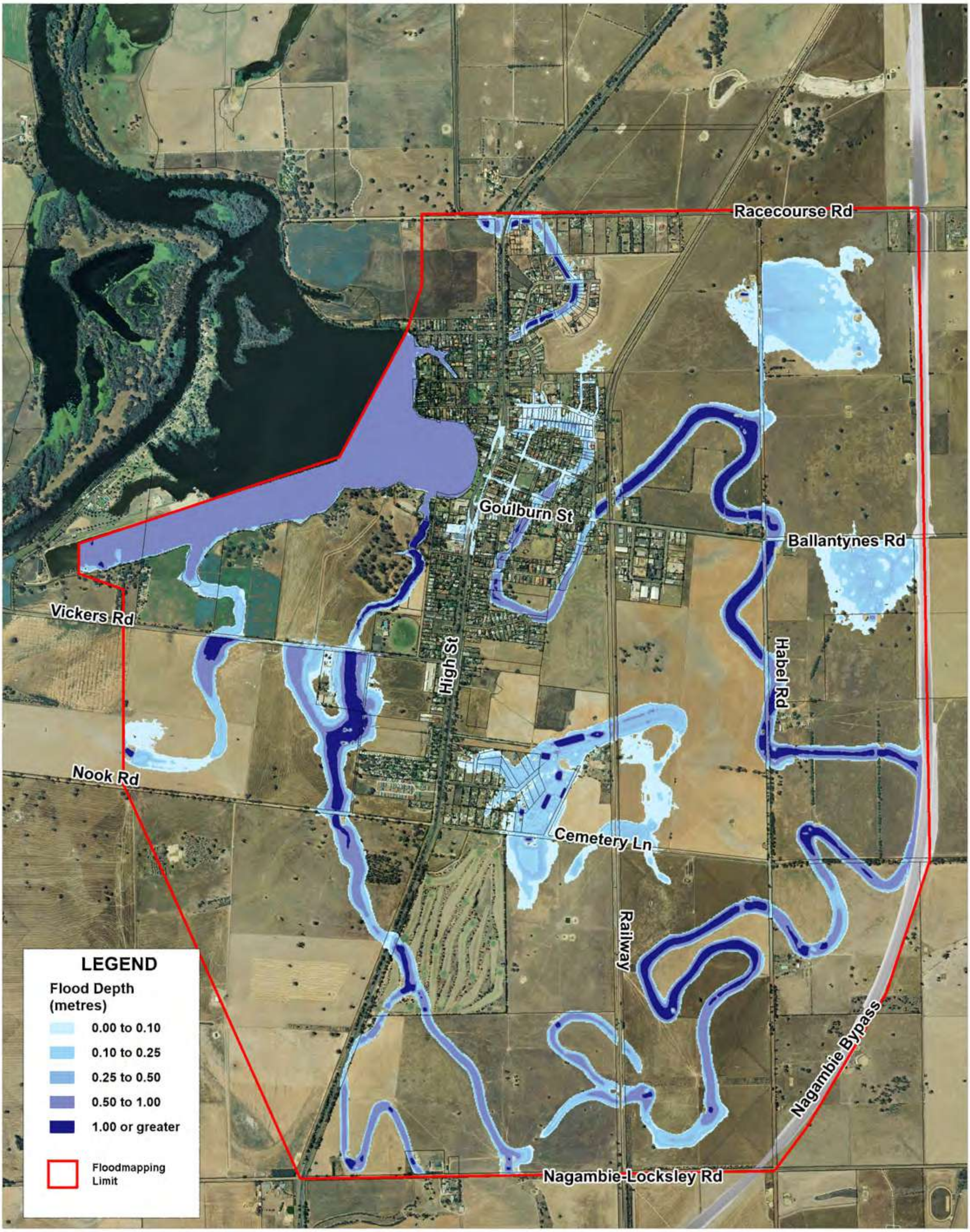

Title:

Nagambie Flood Study
10 Year ARI Peak Flood Depth - Existing Conditions

Figure: **D-2**

Rev: **A**

BMT WBM
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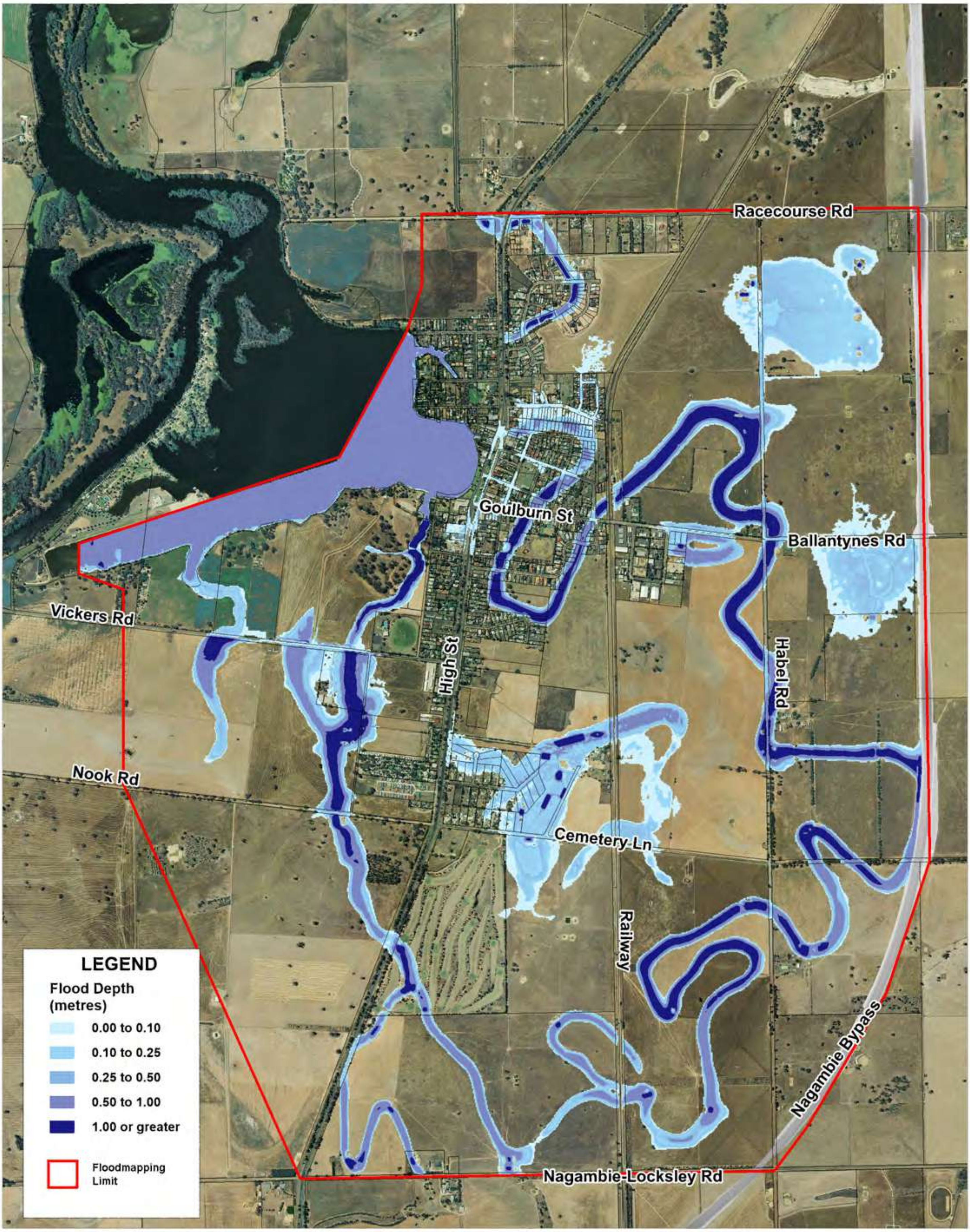

Title:

Nagambie Flood Study
20 Year ARI Peak Flood Depth - Existing Conditions

Figure: **D-3**

Rev: **A**

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N

0 0.5 1km
Approx. Scale

BMT WBM
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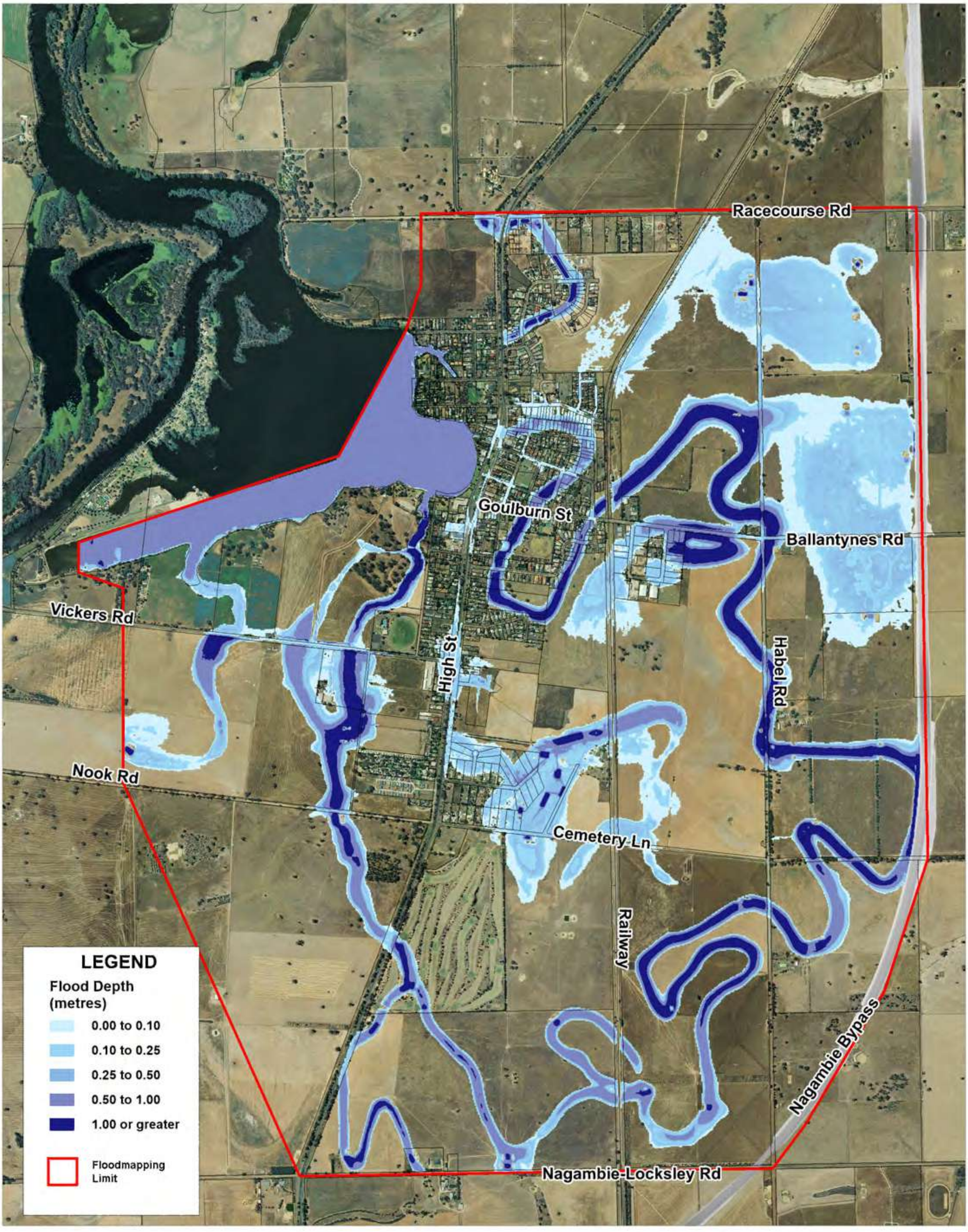
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigD-3_20yrFldDepth_RevA.WOR



Title:

Nagambie Flood Study
50 Year ARI Peak Flood Depth - Existing Conditions

Figure: D-4

Rev: A

N

0 0.5 1km
Approx. Scale

BMT WBM
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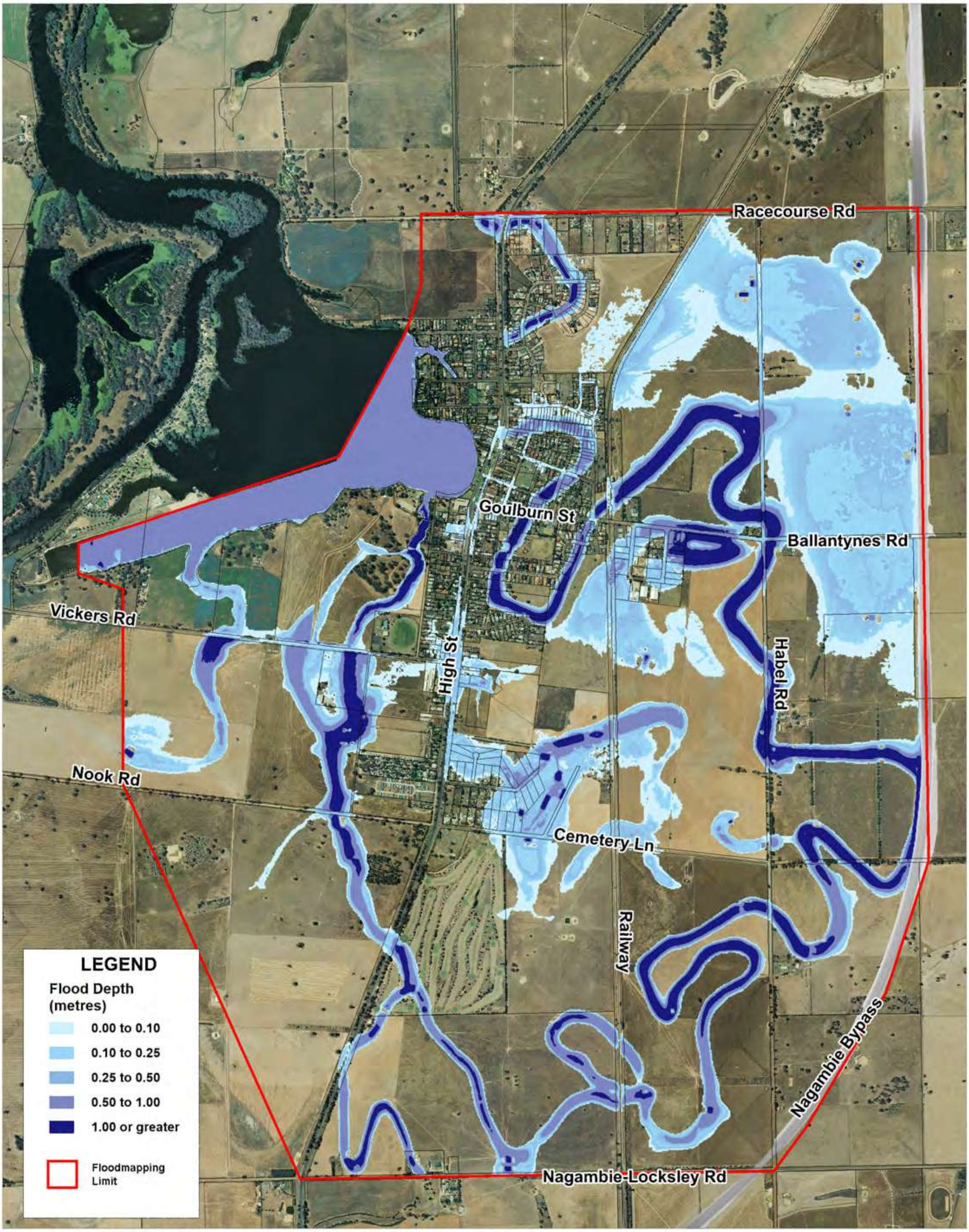
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigD-4_50yrFldDepth_RevA.WOR



Title:

Nagambie Flood Study

100 Year ARI Peak Flood Depth - Existing Conditions

Figure: **D-5**

Rev: **A**

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N

0 0.5 1km

Approx. Scale

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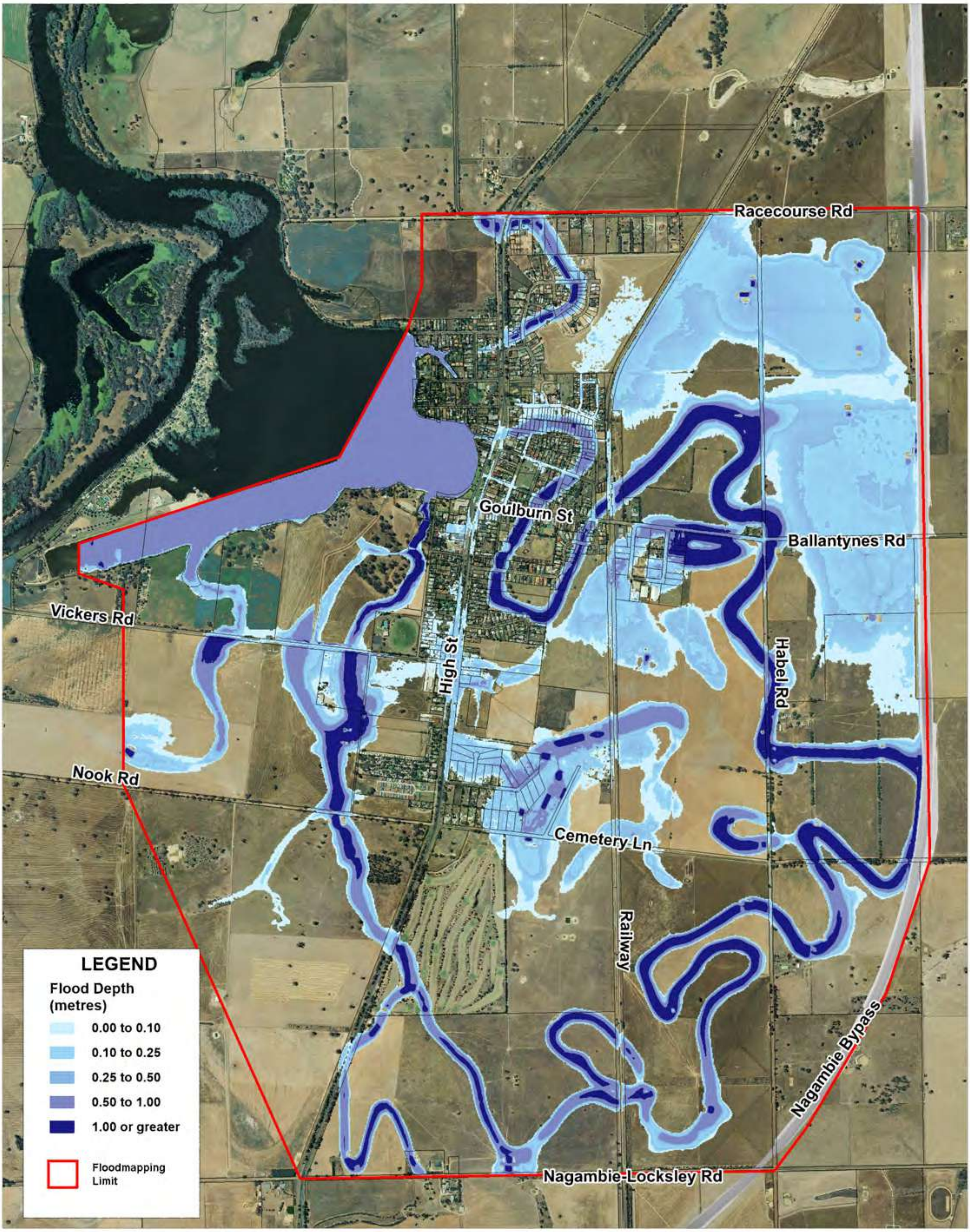
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigD-5_100yrFldDepth_RevA.WOR



Title:

Nagambie Flood Study
200 Year ARI Peak Flood Depth - Existing Conditions

Figure: D-6

Rev: A

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N

0 0.5 1km

Approx. Scale

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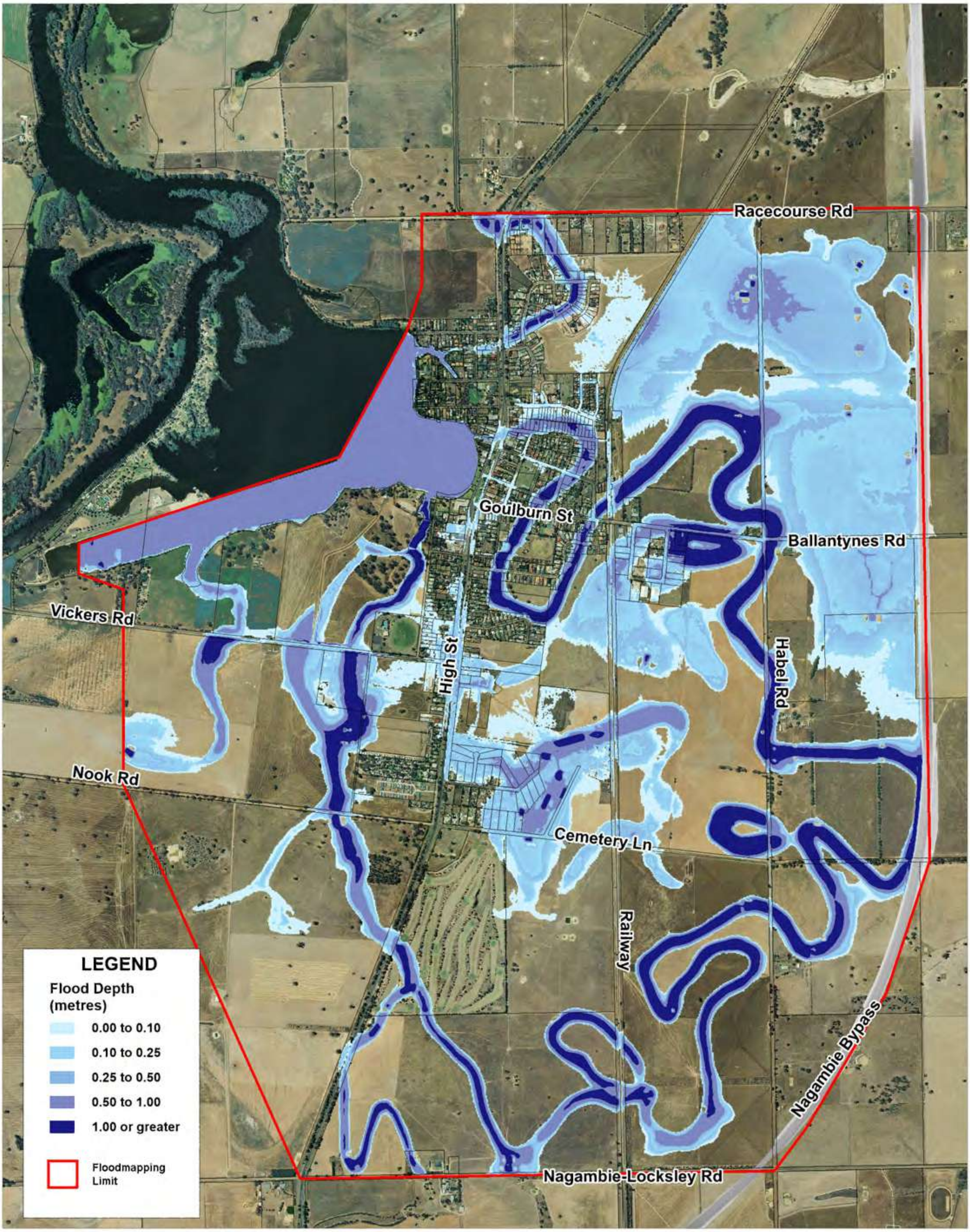
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigD-6_200yrFldDepth_RevA.WOR



Title:

Nagambie Flood Study

500 Year ARI Peak Flood Depth - Existing Conditions

Figure: **D-7**

Rev: **A**

N

0 0.5 1km

Approx. Scale

BMT WBM

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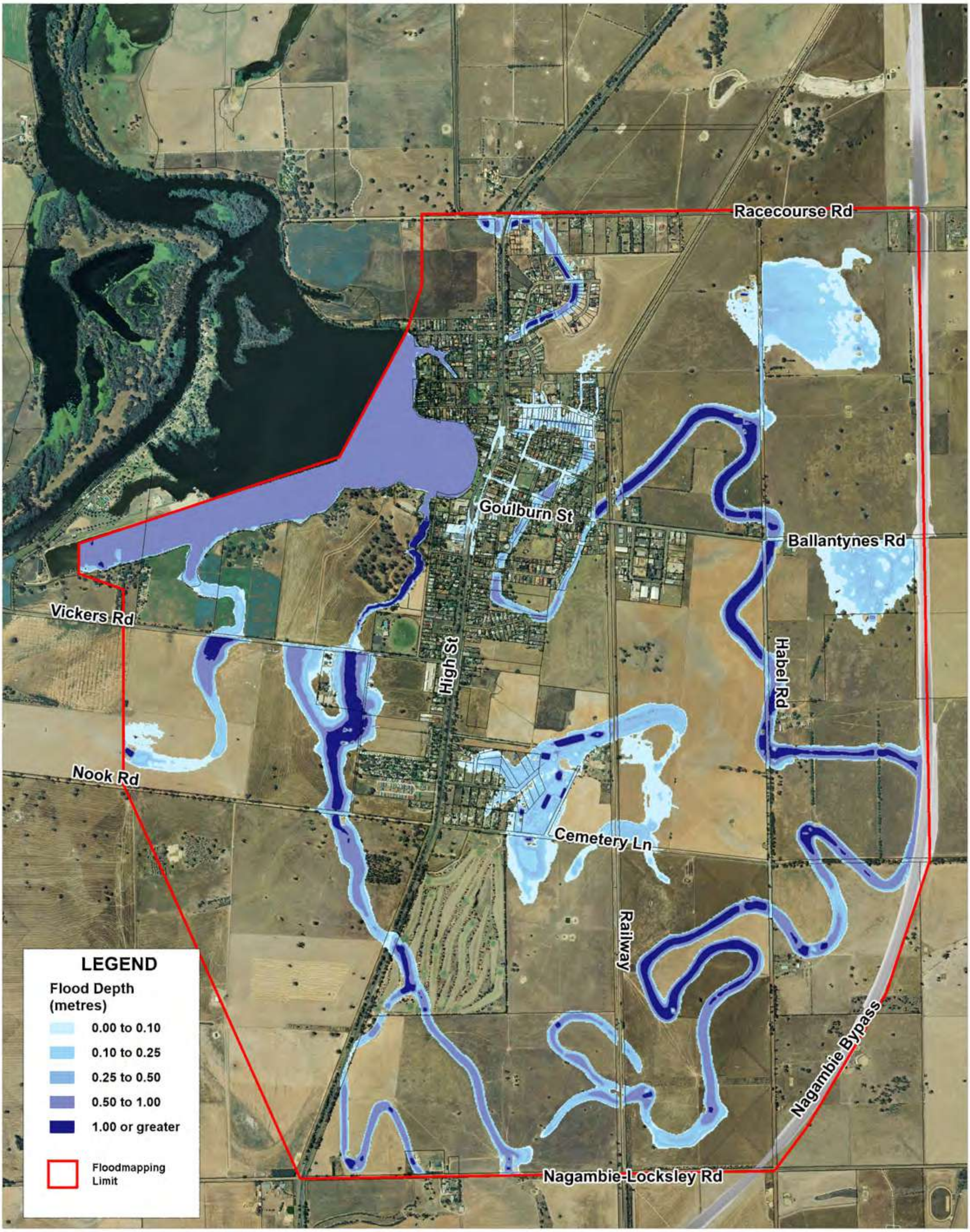
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigD-7_500yrFldDepth_RevA.WOR



Title:

Nagambie Flood Study

5 Year ARI Peak Flood Depth - Developed Conditions

Figure: **D-8**

Rev: **A**

N

0 0.5 1km

Approx. Scale

BMT WBM

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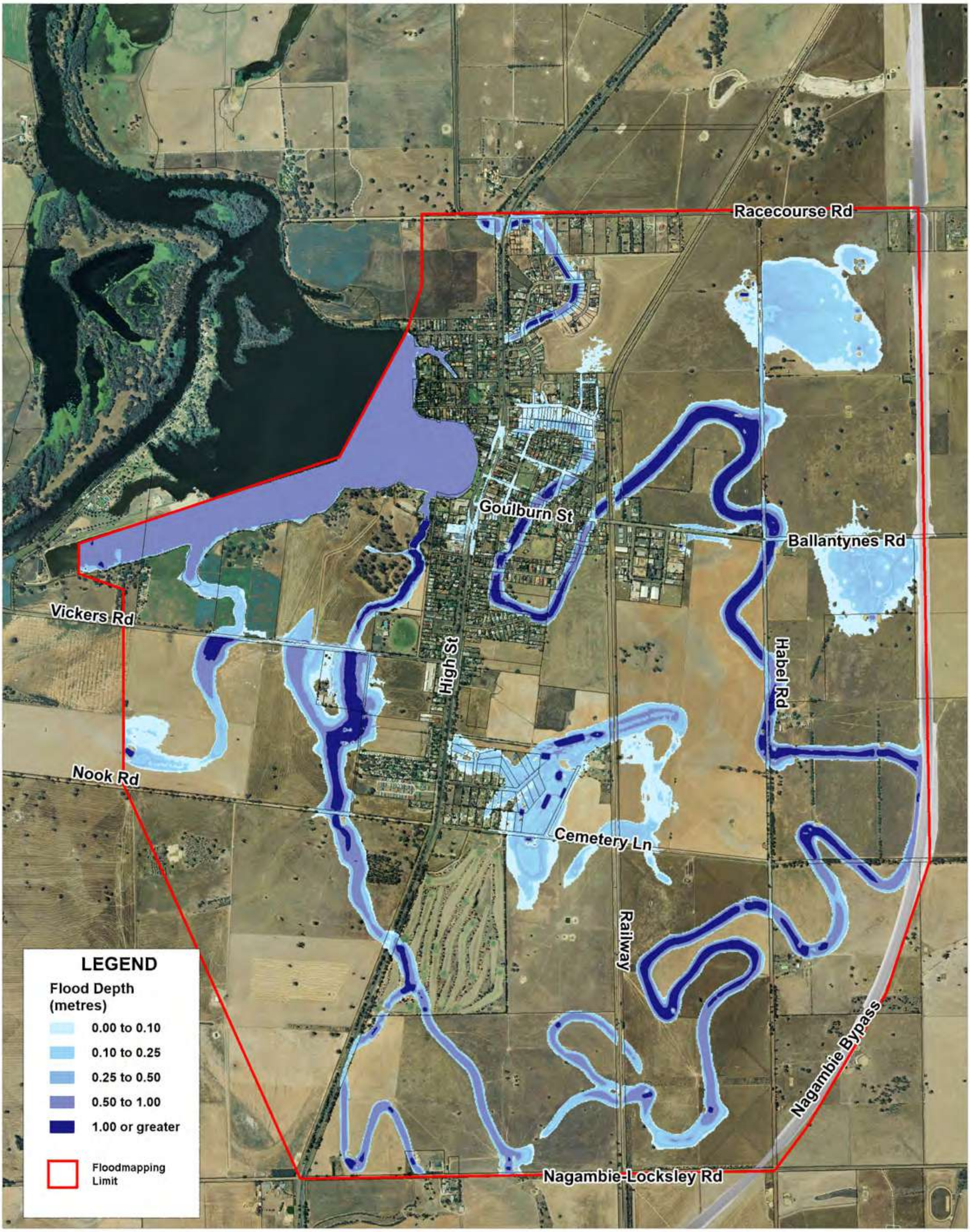
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigD-8_5yrFldDepth_RevA.WOR



Title:

Nagambie Flood Study
10 Year ARI Peak Flood Depth - Developed Conditions

Figure: **D-9**

Rev: **A**

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N

0 0.5 1km

Approx. Scale

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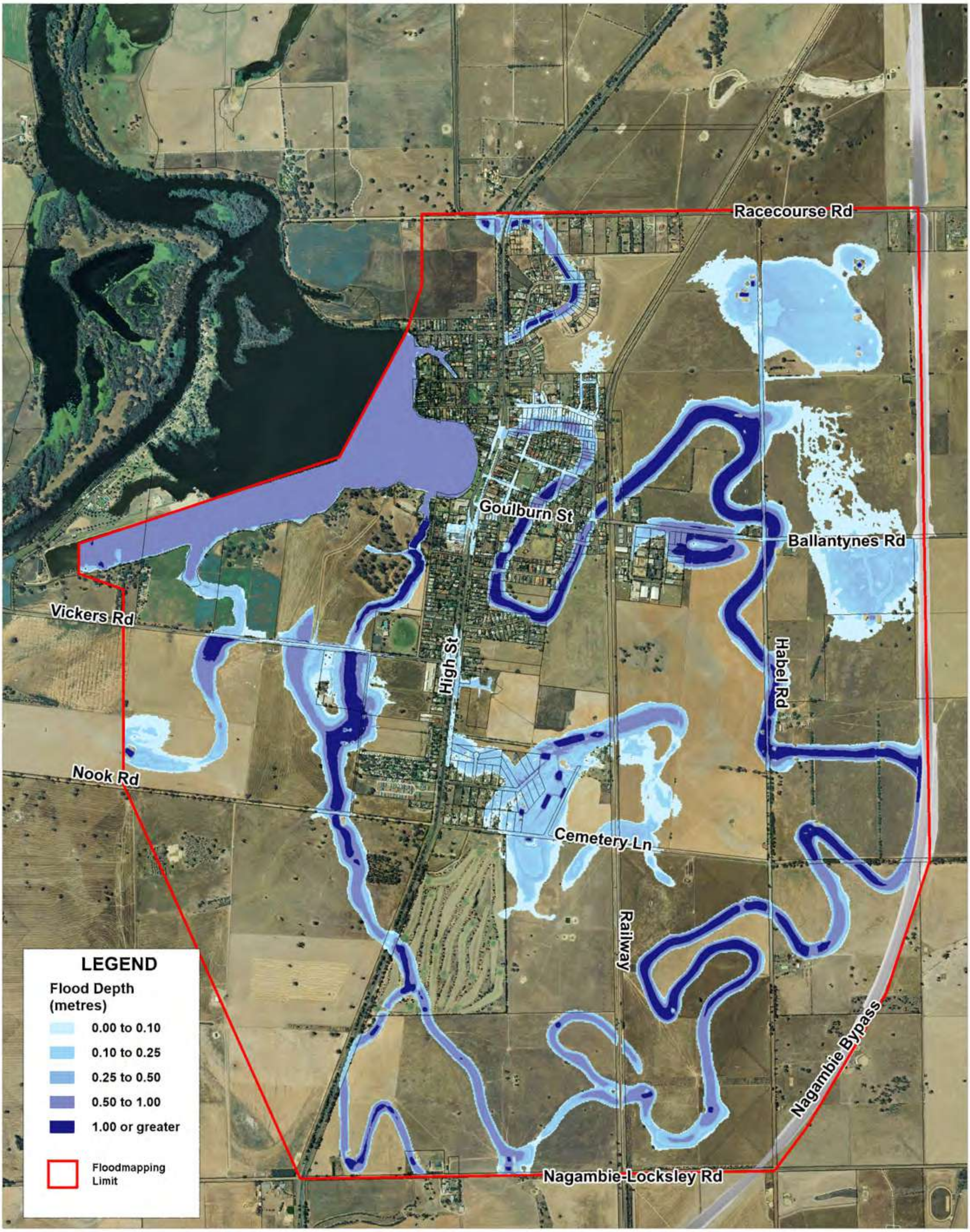
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigD-9_10yrFldDepth_RevA.WOR



Title:

Nagambie Flood Study
20 Year ARI Peak Flood Depth - Developed Conditions

Figure: D-10

Rev: A

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N

0 0.5 1km

Approx. Scale

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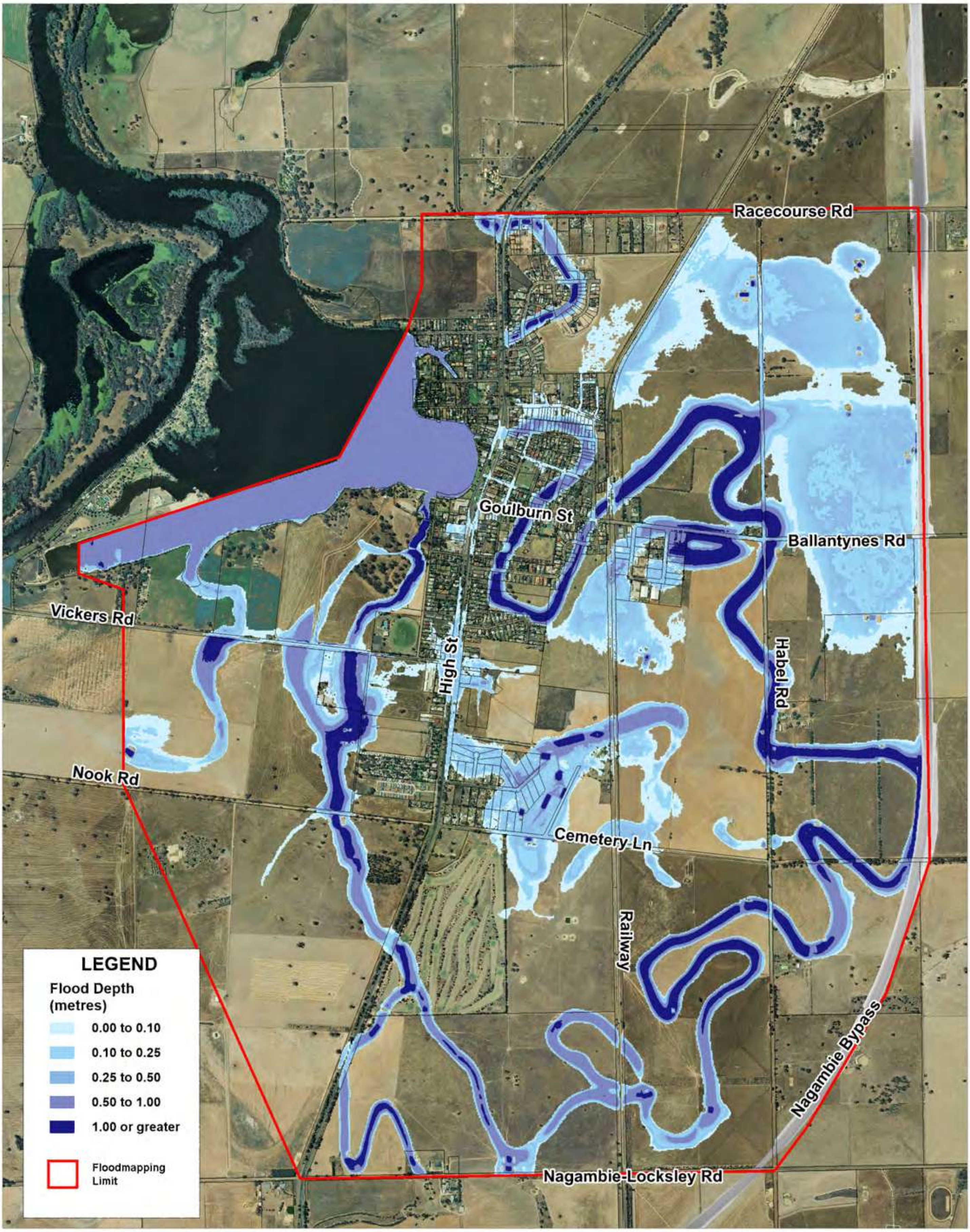

Title:

Nagambie Flood Study
50 Year ARI Peak Flood Depth - Developed Conditions

Figure: **D-11**

Rev: **A**

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N

0 0.5 1km

Approx. Scale

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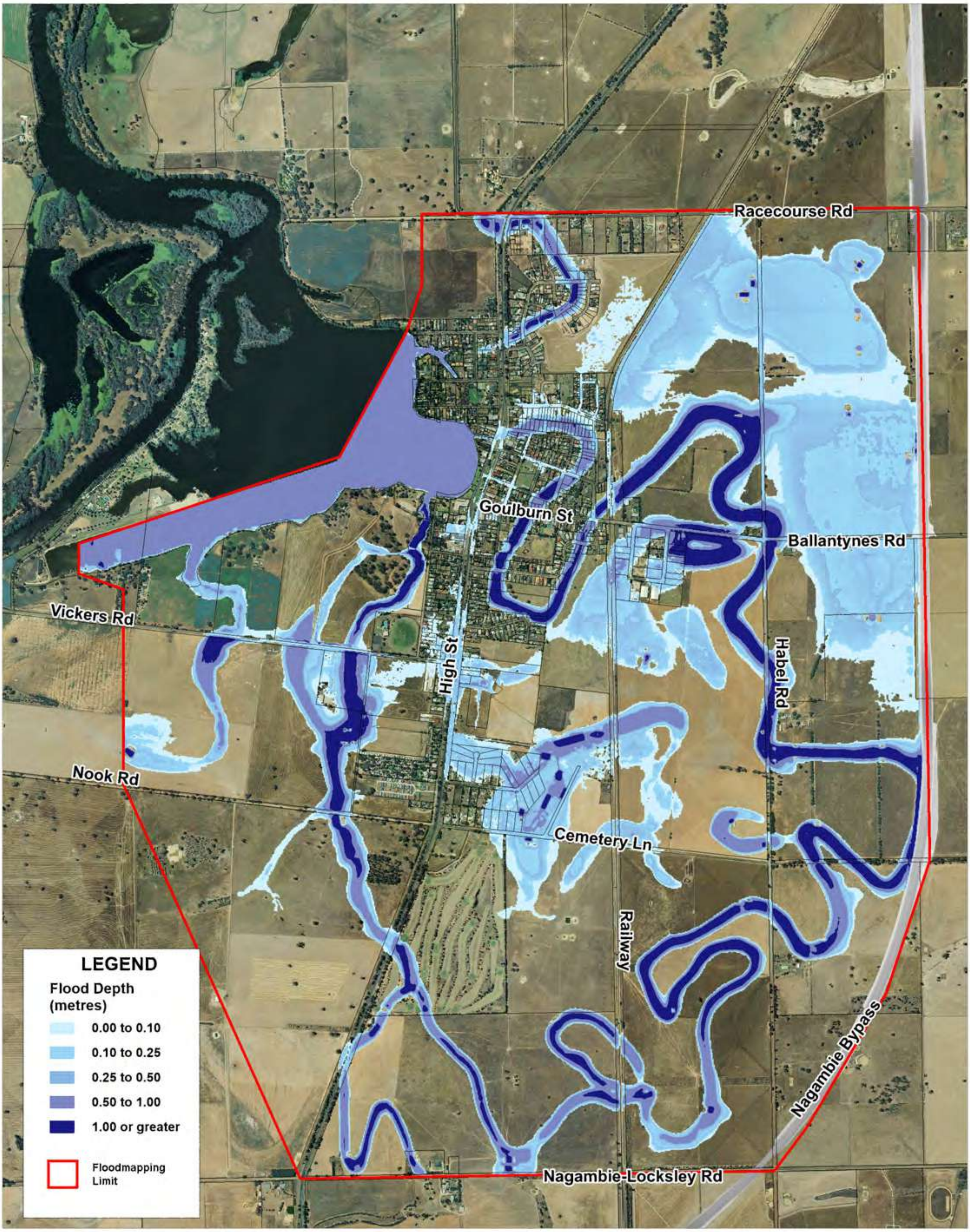

Title:

Nagambie Flood Study
100 Year ARI Peak Flood Depth - Developed Conditions

Figure: **D-12**

Rev: **A**

N

0 0.5 1km

Approx. Scale

BMT WBM

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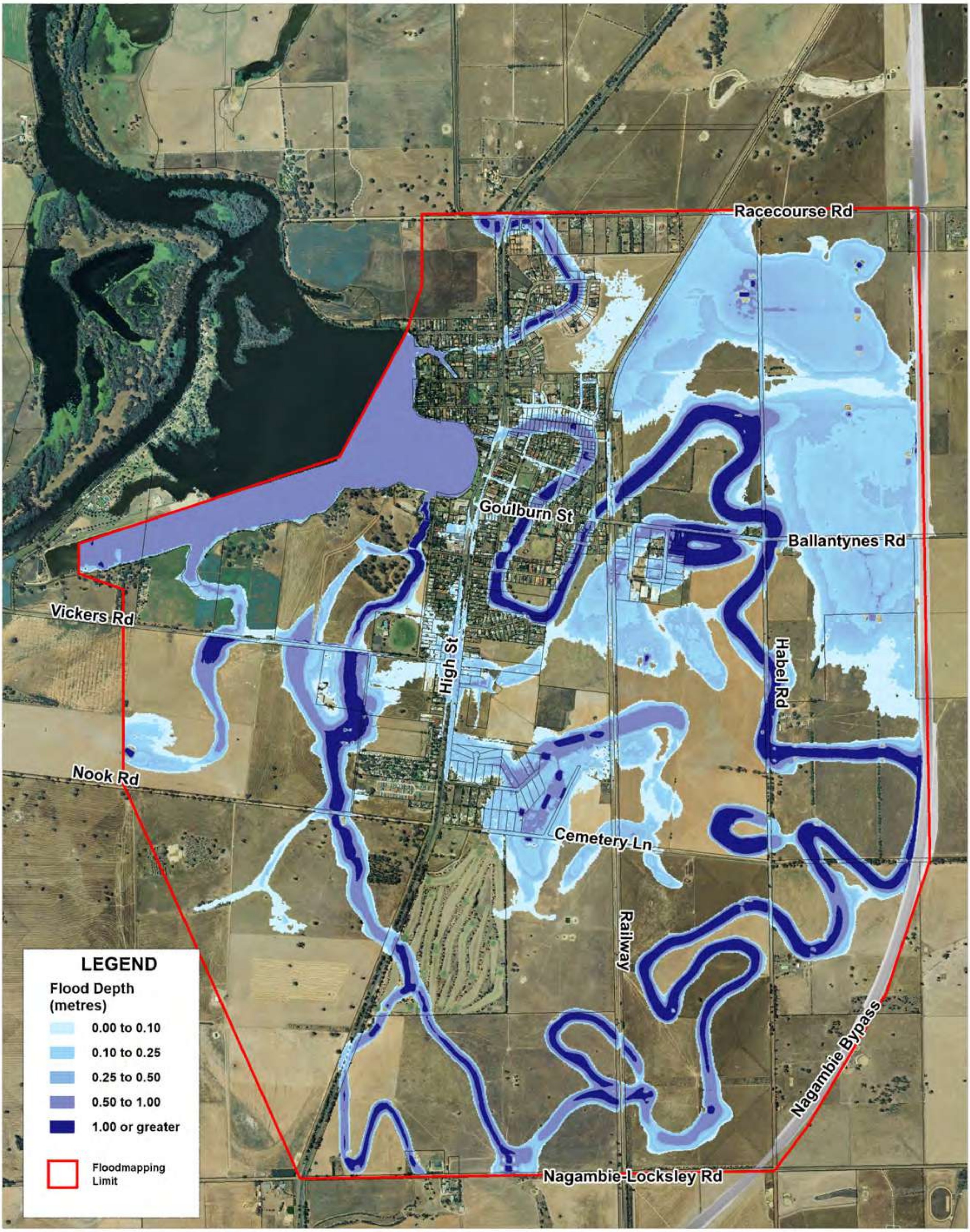
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigD12_100yrFldDepth_RevA.WOR



Title:

Nagambie Flood Study
200 Year ARI Peak Flood Depth - Developed Conditions

Figure: D-13

Rev: A

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N

0 0.5 1km

Approx. Scale

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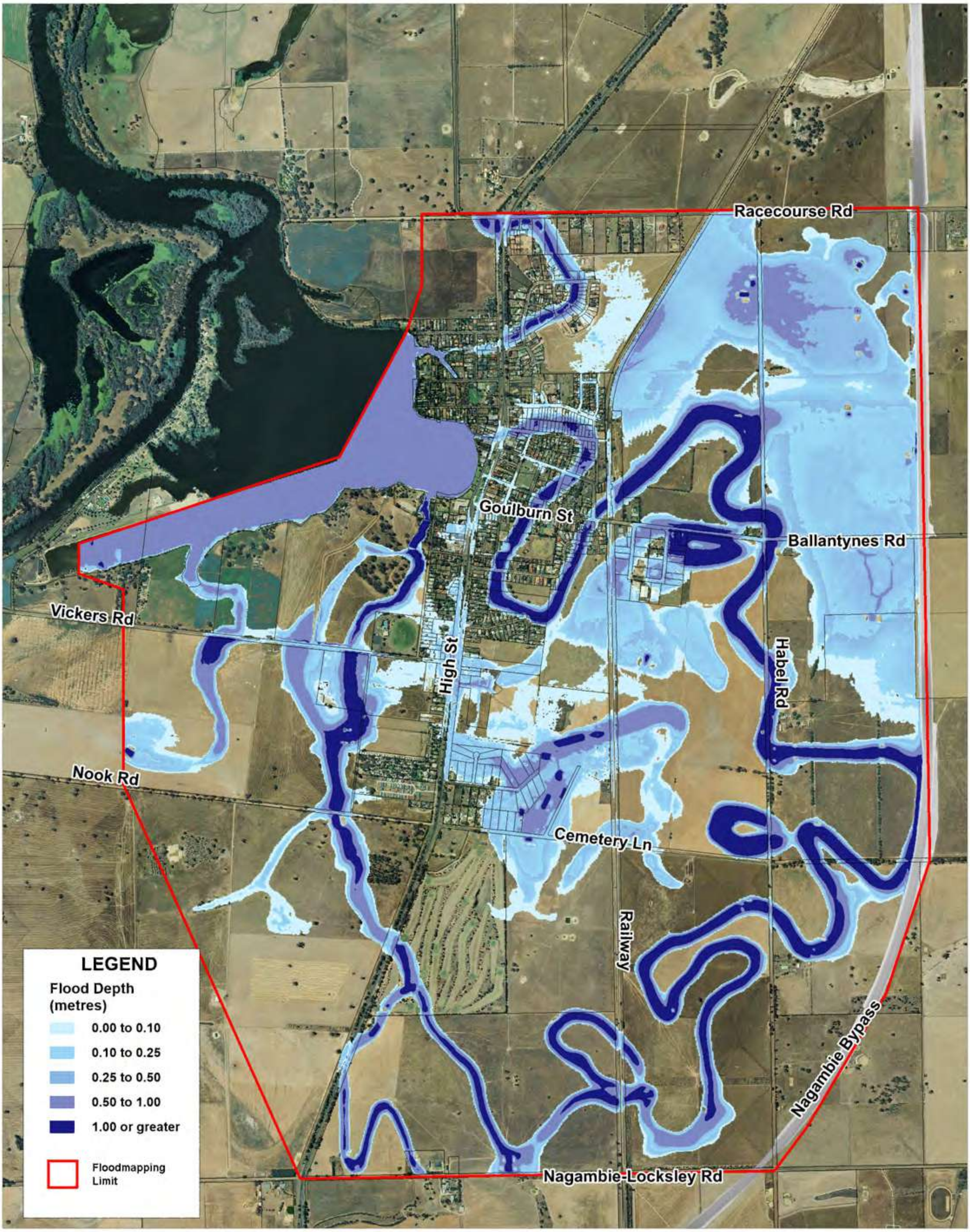

Title:

Nagambie Flood Study

500 Year ARI Peak Flood Depth - Developed Conditions

Figure: **D-14**

Rev: **A**

N

0 0.5 1km

Approx. Scale

BMT WBM

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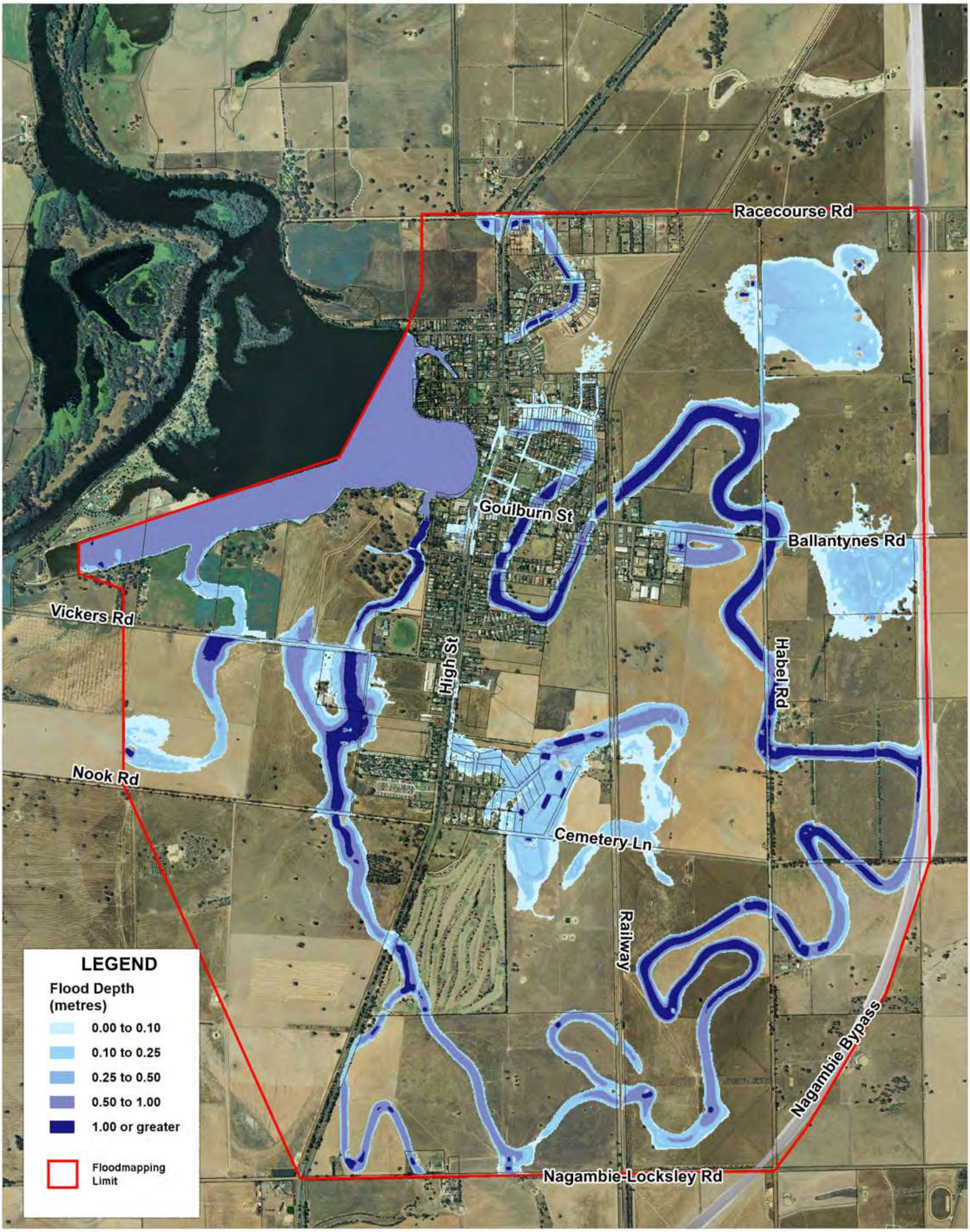

Title:

Nagambie Flood Study
5 Year ARI Peak Flood Depth - Climate Change

Figure: D-15

Rev: A

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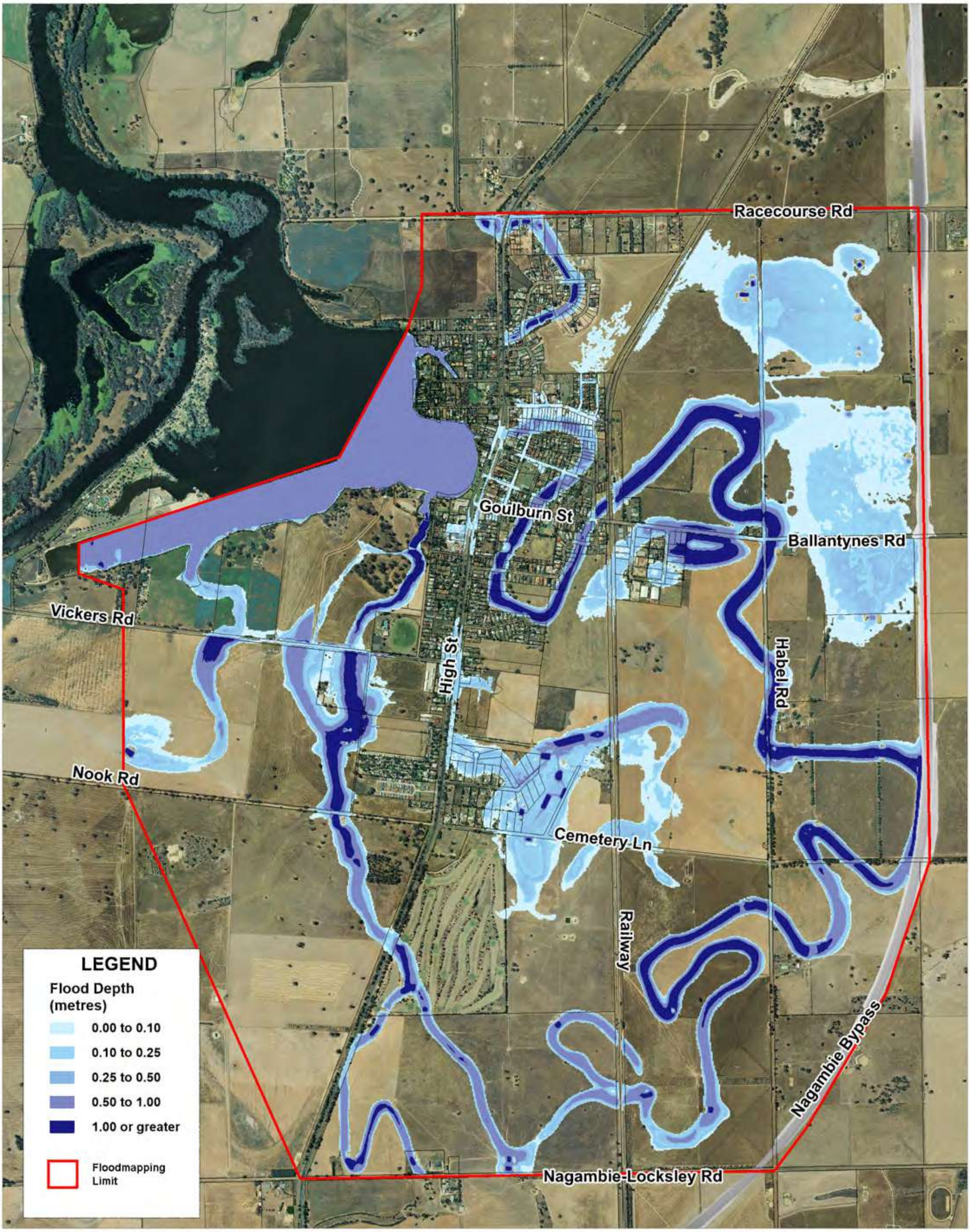

Title:

Nagambie Flood Study
10 Year ARI Peak Flood Depth - Climate Change

Figure: D-16

Rev: A

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

0 0.5 1km

Approx. Scale

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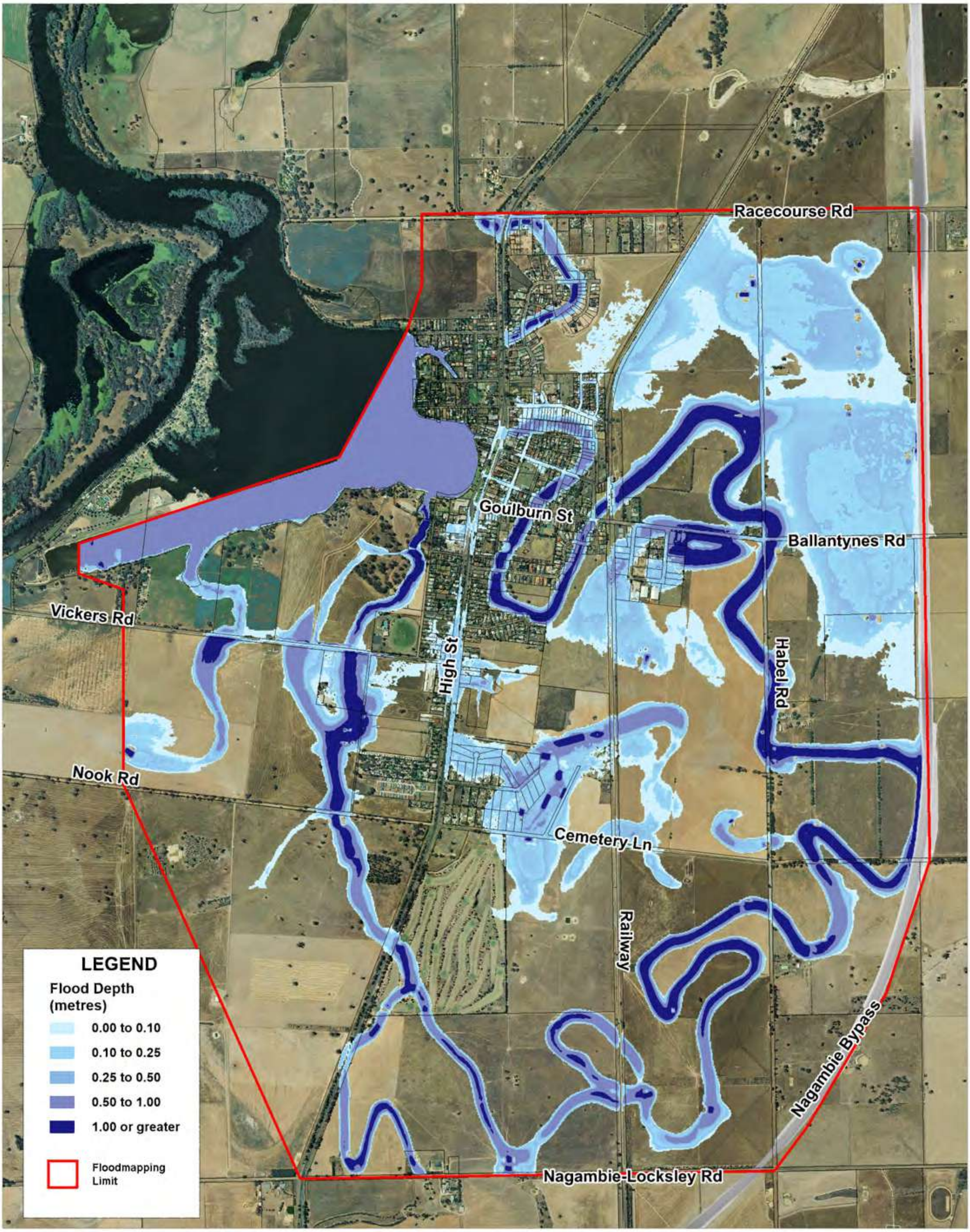

Title:

Nagambie Flood Study
20 Year ARI Peak Flood Depth - Climate Change

Figure: D-17

Rev: A

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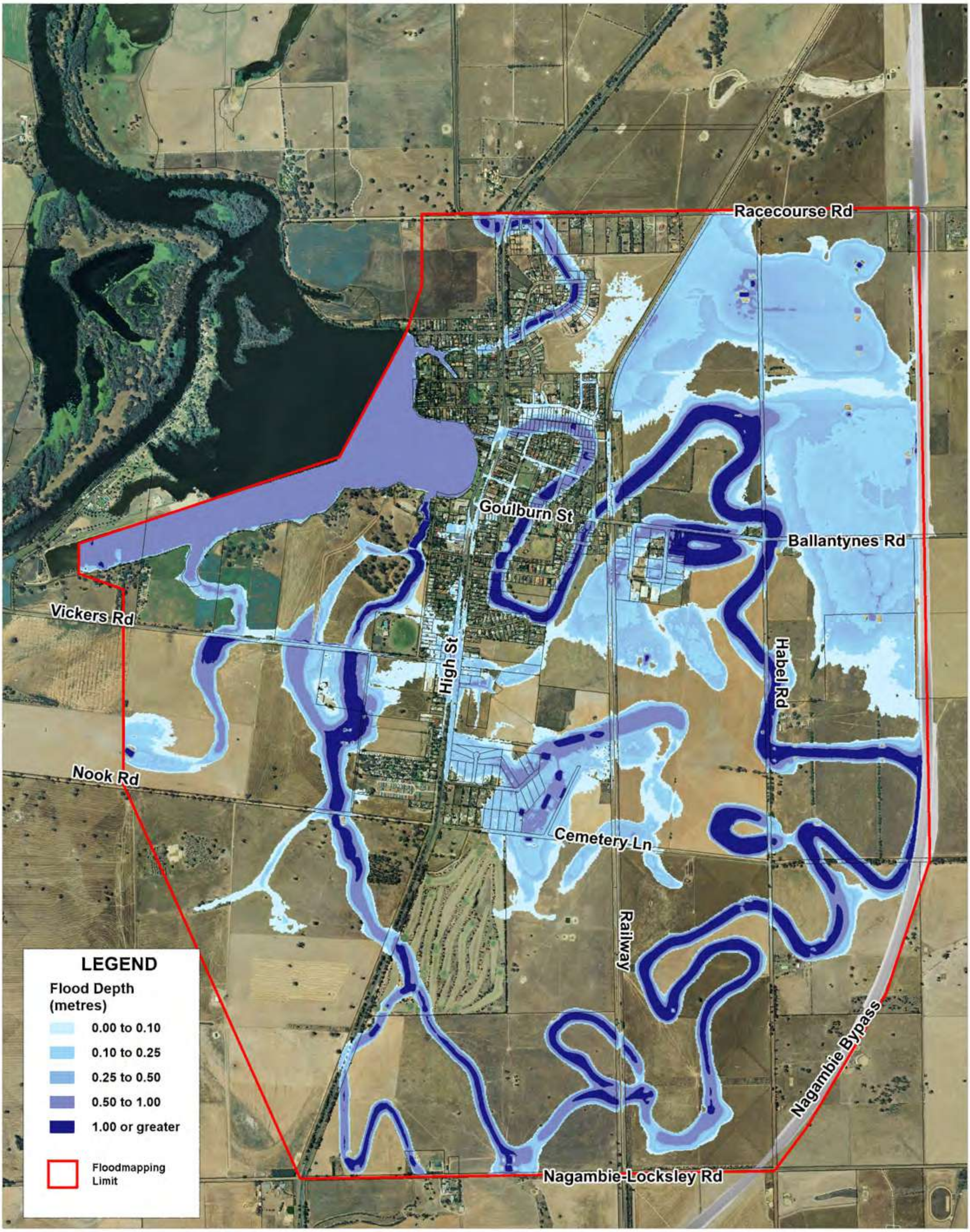

Title:

Nagambie Flood Study
50 Year ARI Peak Flood Depth - Climate Change

Figure: **D-18**

Rev: **A**

N

0 0.5 1km

Approx. Scale

BMT WBM

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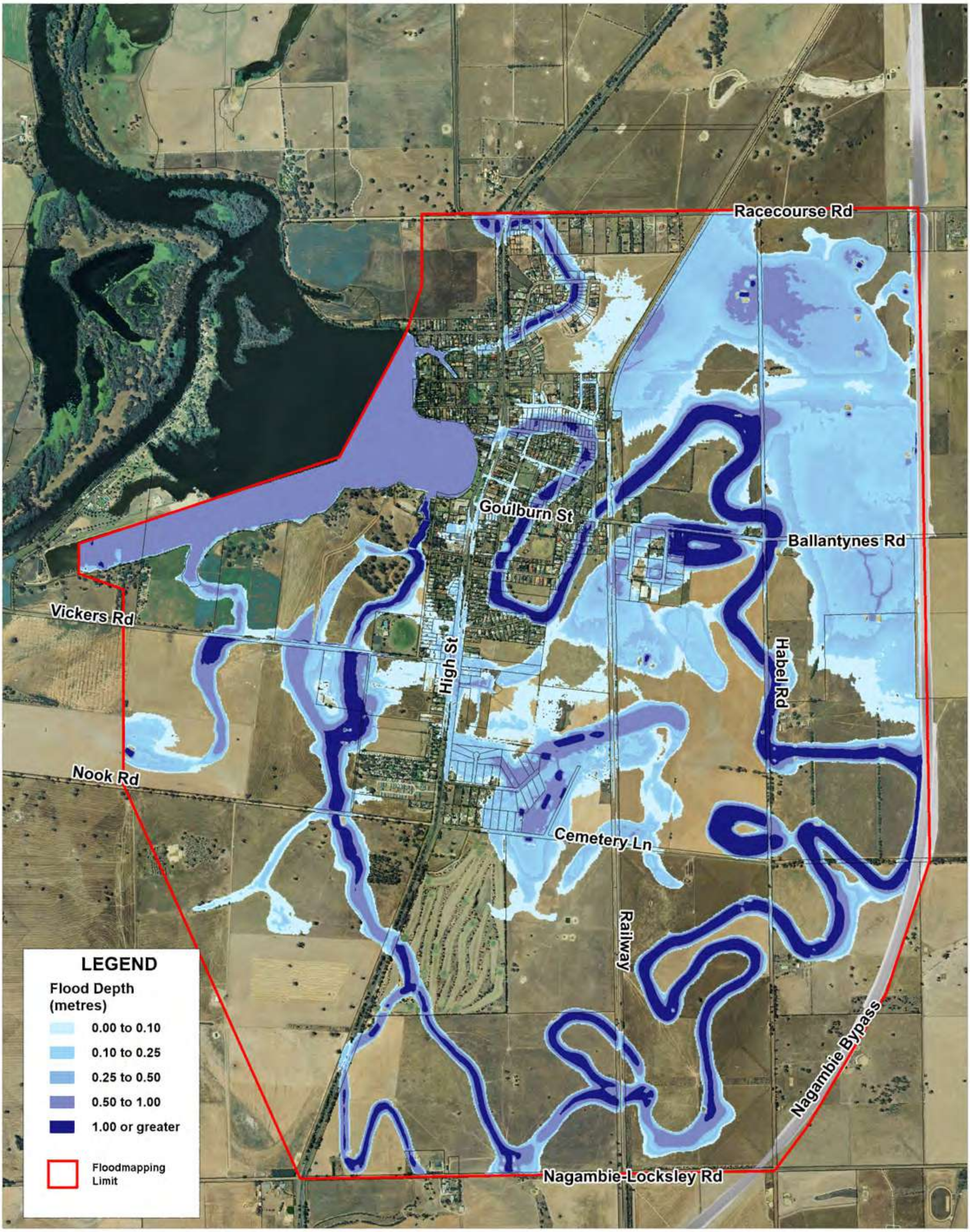
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigD-18_50yrFldDepth_RevA.WOR



Title:

Nagambie Flood Study
100 Year ARI Peak Flood Depth - Climate Change

Figure: **D-19**

Rev: **A**

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N

0 0.5 1km
Approx. Scale

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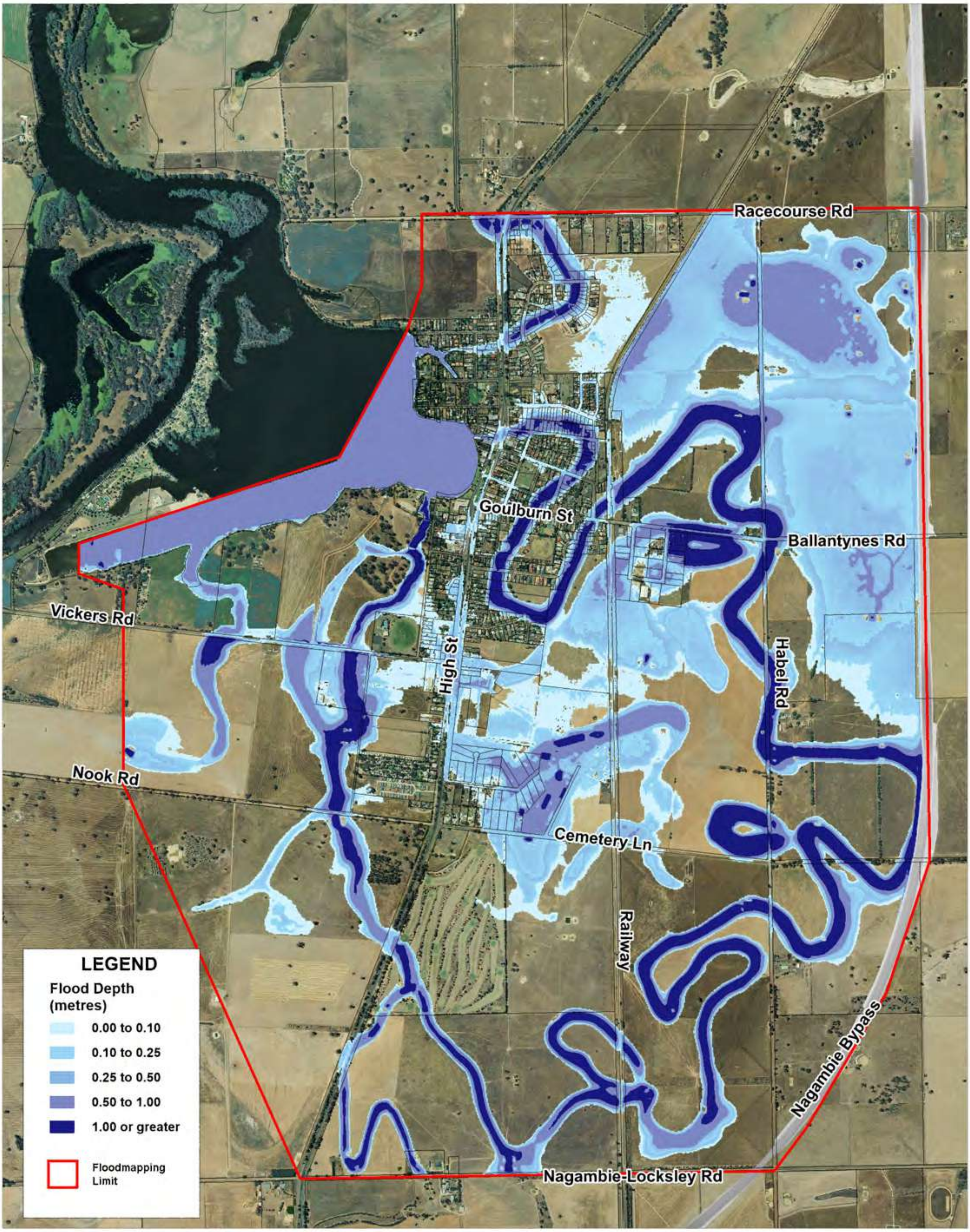
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigD-19_100yrFldDepth_RevA.WOR



Title:

Nagambie Flood Study
200 Year ARI Peak Flood Depth - Climate Change

Figure: D-20

Rev: A

N

0 0.5 1km

Approx. Scale

BMT WBM

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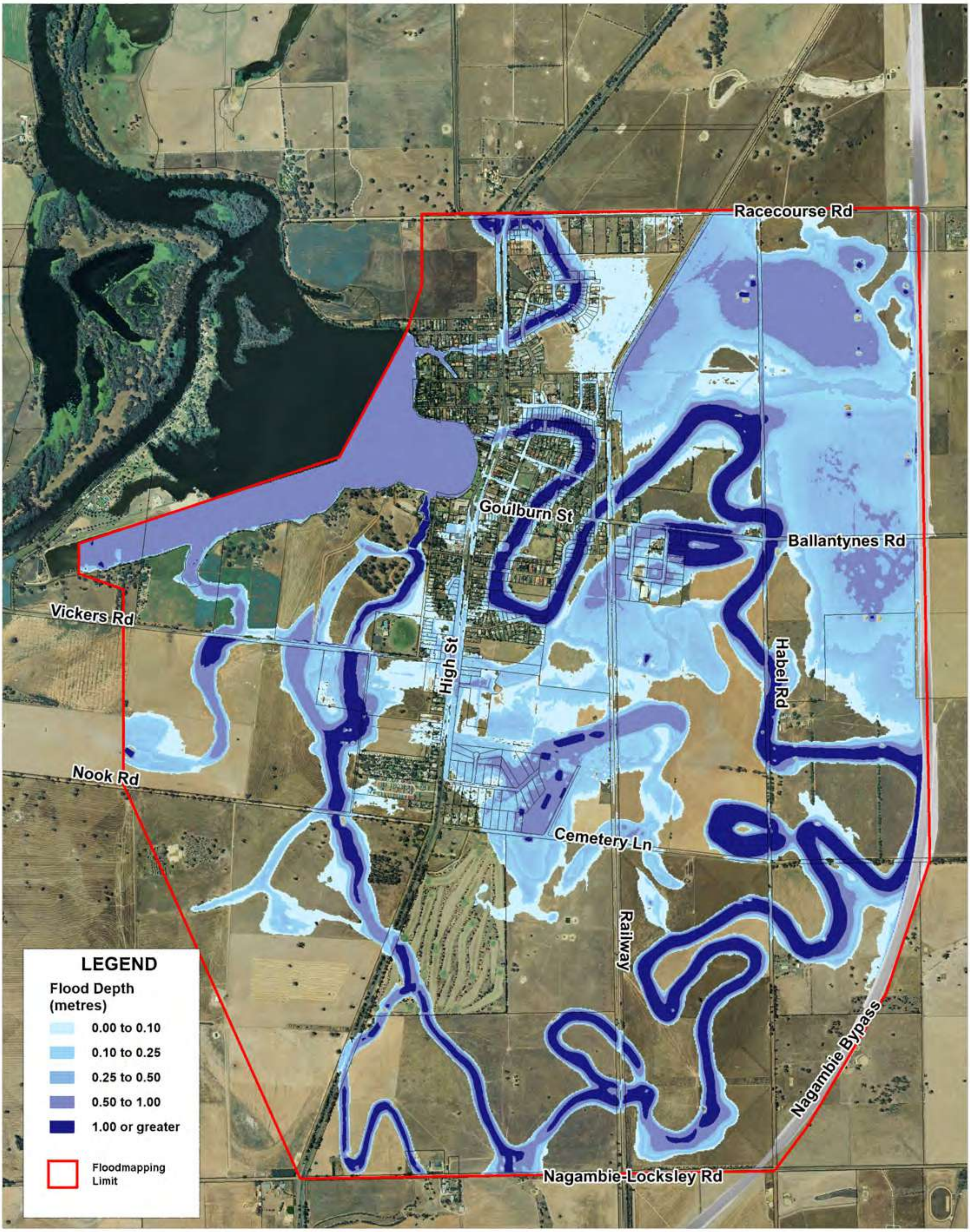

Title:

Nagambie Flood Study
500 Year ARI Peak Flood Depth - Climate Change

Figure: D-21

Rev: A

N

0 0.5 1km
Approx. Scale

BMT WBM
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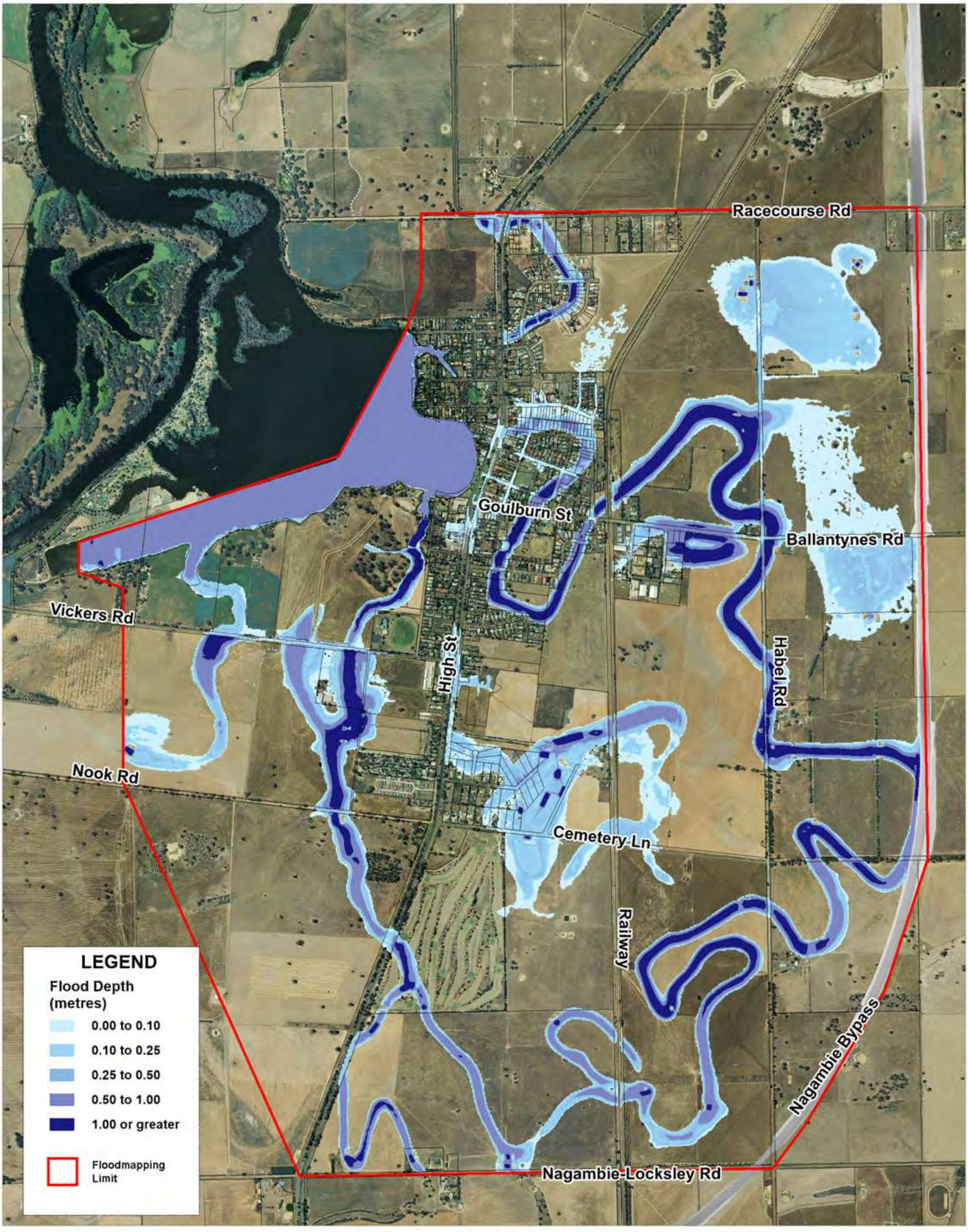
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigD-21_500yrFldDepth_RevA.WOR



Title:
Nagambie Flood Study
5 Year ARI Peak Flood Depth - Developed Climate Change

Figure: **D-22**

Rev: **A**

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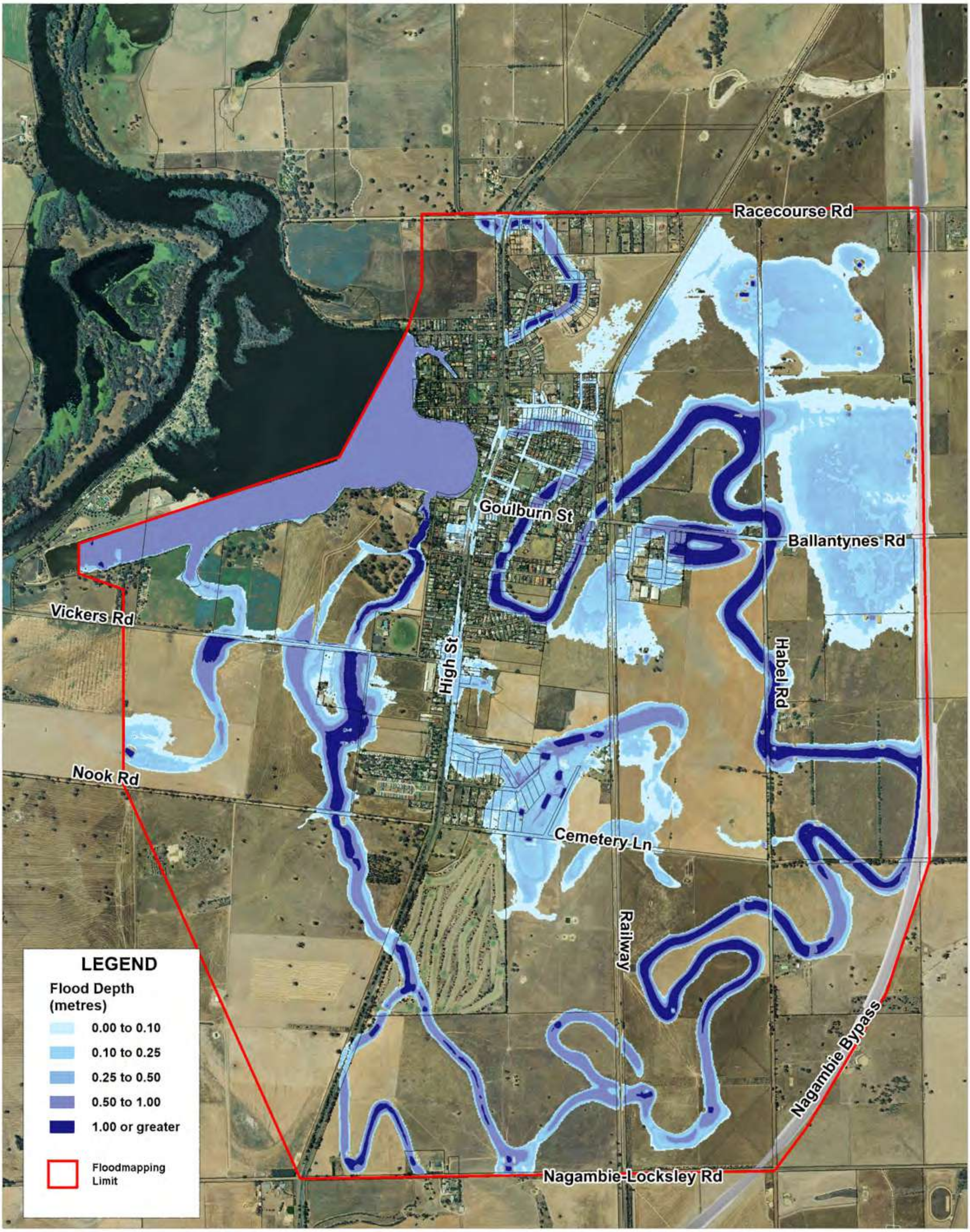
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigD-22_5yrFldDepth_RevA.WOR



Title:

Nagambie Flood Study

10 Year ARI Peak Flood Depth - Developed Climate Change

Figure: **D-23**

Rev: **A**

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N

0 0.5 1km

Approx. Scale

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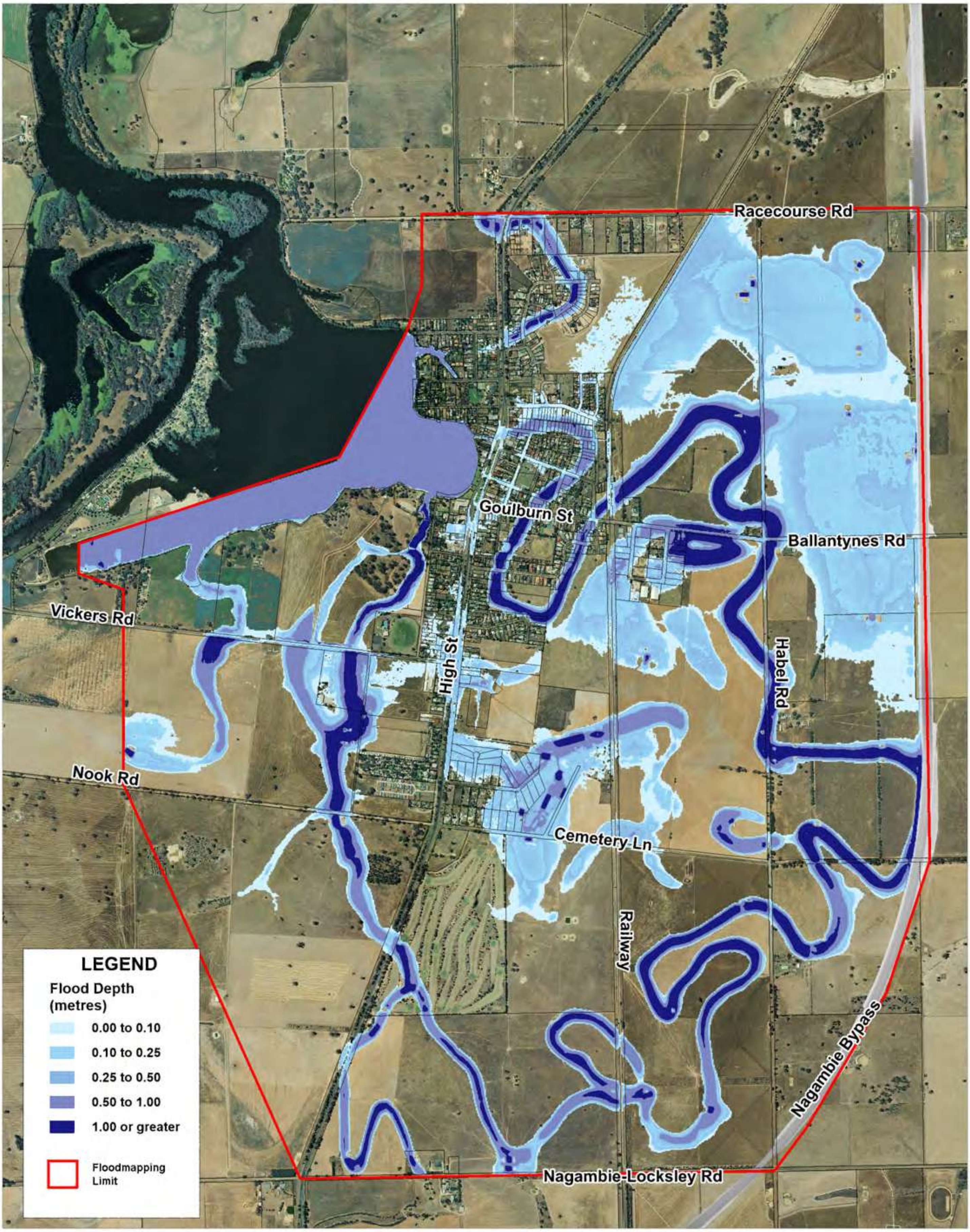
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigD-23_10yrFldDepth_RevA.WOR



Title:

Nagambie Flood Study

20 Year ARI Peak Flood Depth - Developed Climate Change

Figure: **D-24**

Rev: **A**

N

0 0.5 1km

Approx. Scale

BMT WBM

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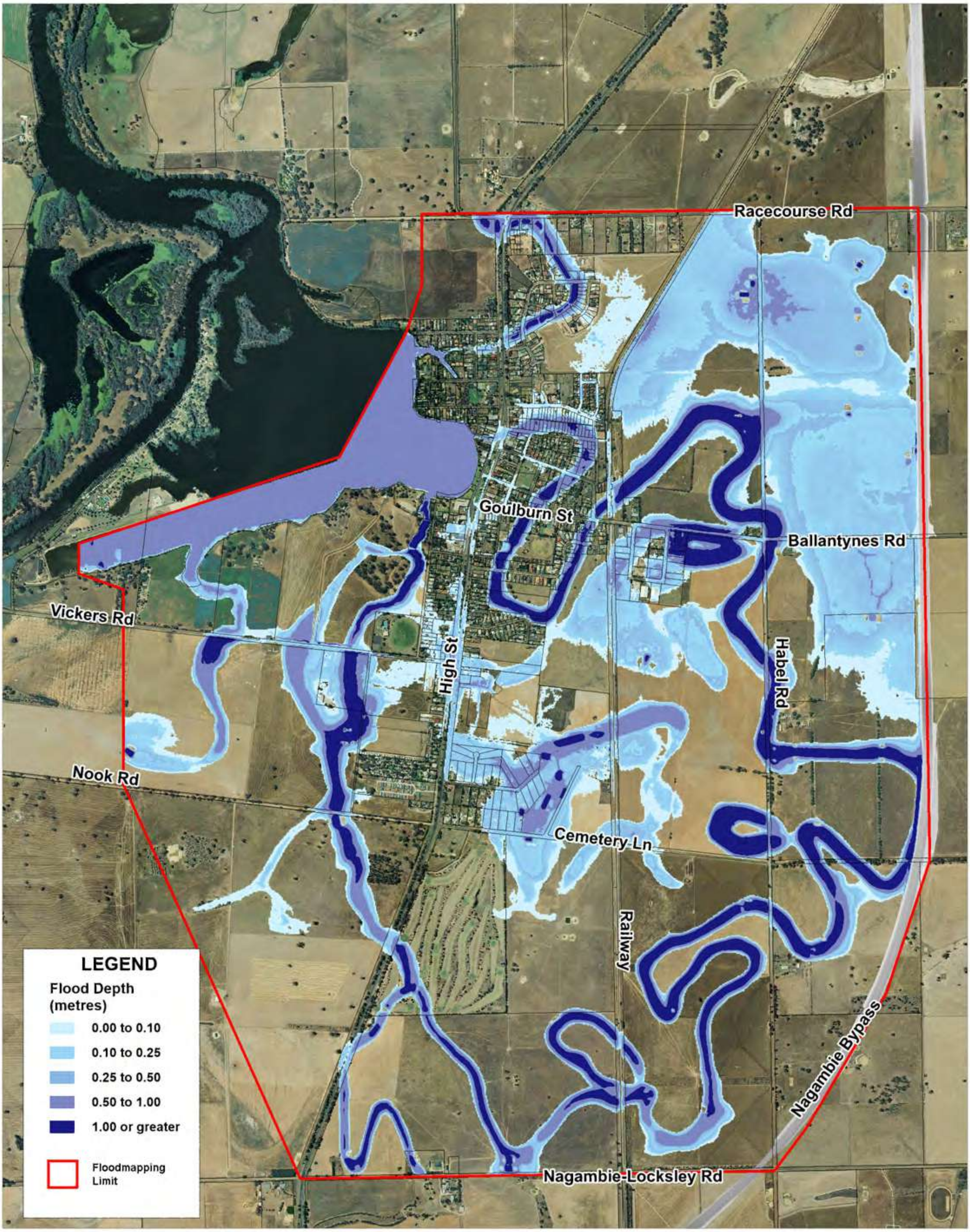
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigD-24_20yrFldDepth_RevA.WOR



Title:

Nagambie Flood Study
50 Year ARI Peak Flood Depth - Developed Climate Change

Figure: **D-25**

Rev: **A**

N

0 0.5 1km

Approx. Scale

BMT WBM

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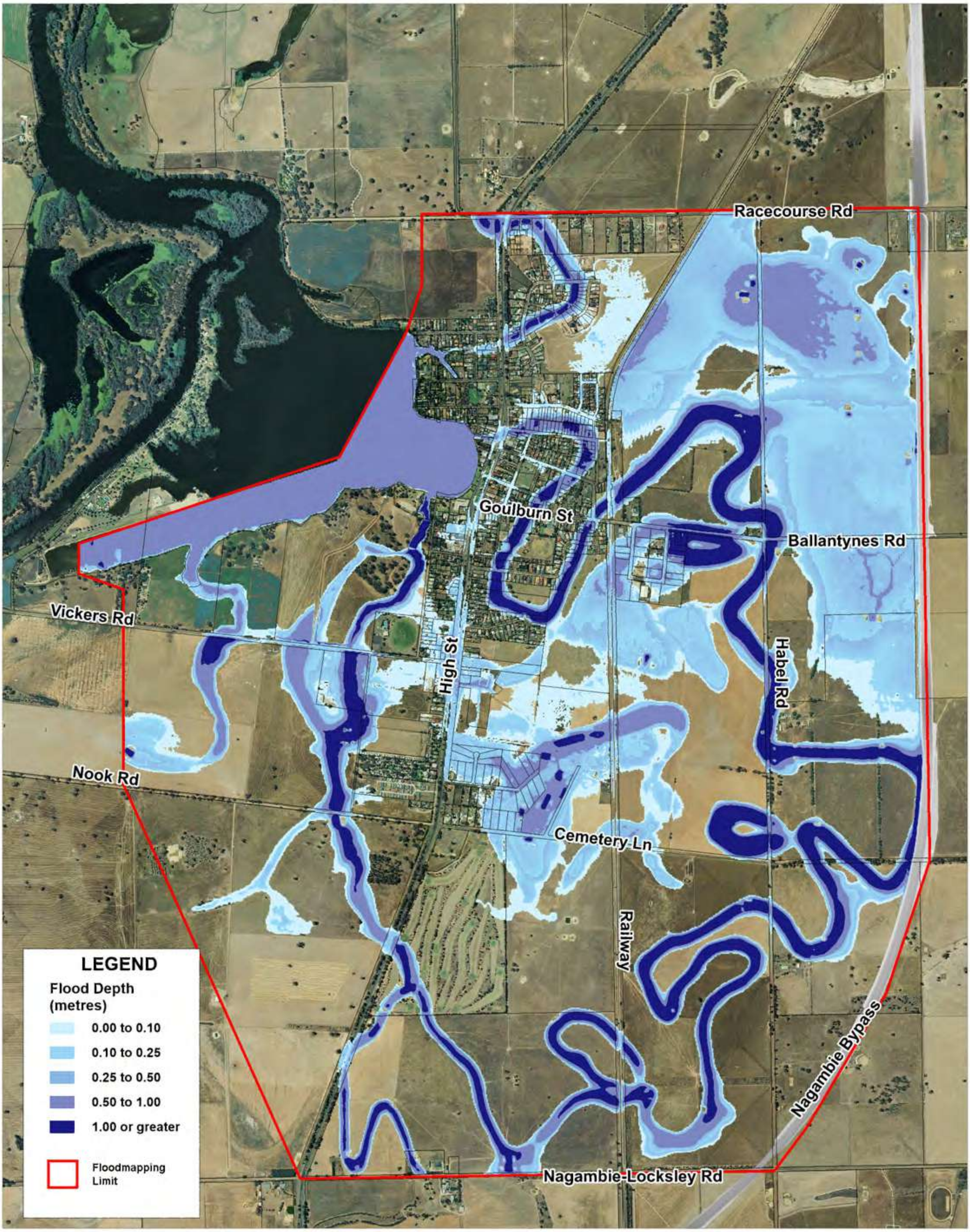
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigD-25_50yrFldDepth_RevA.WOR



Title:

Nagambie Flood Study

100 Year ARI Peak Flood Depth - Developed Climate Change

Figure: **D-26**

Rev: **A**

N

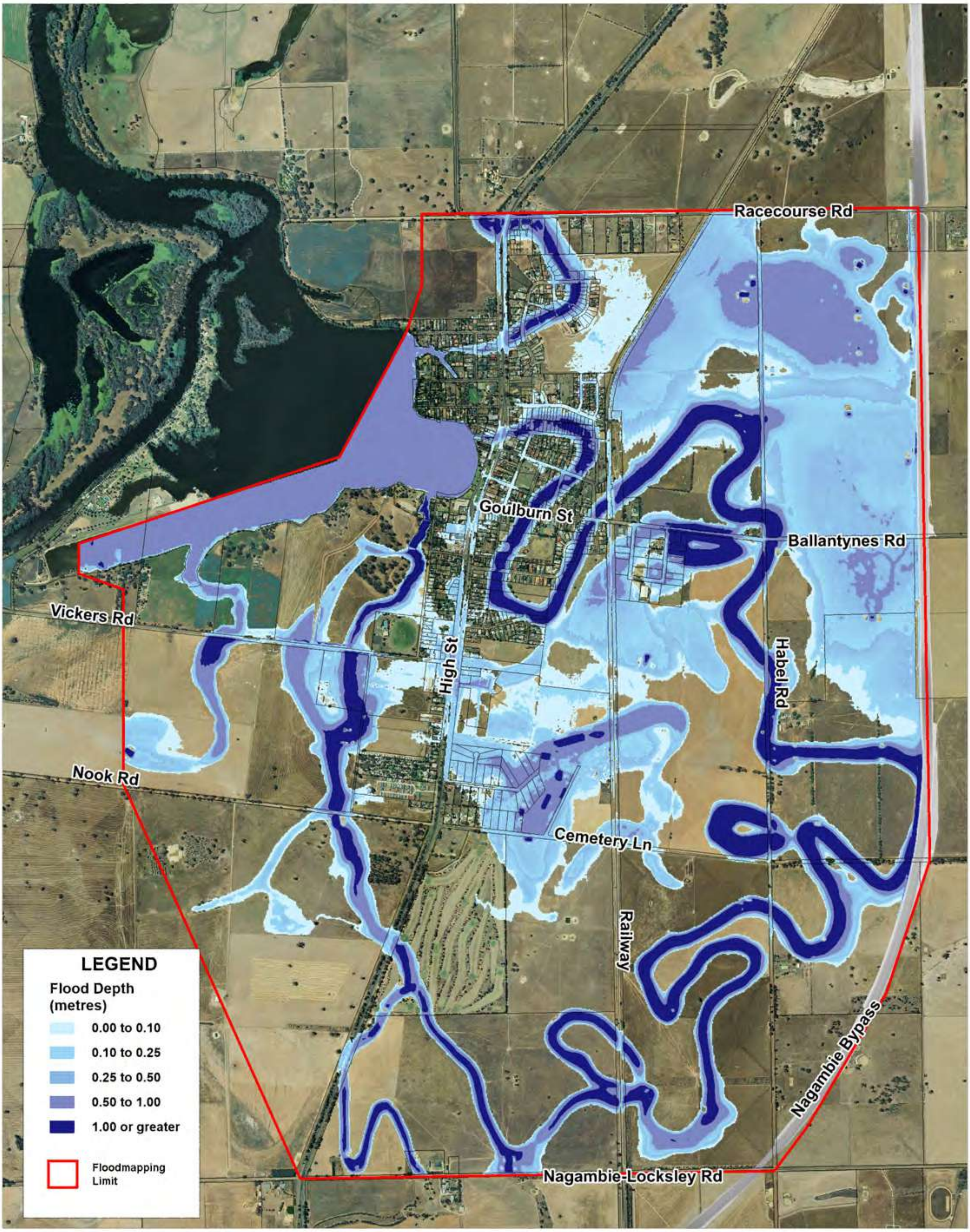
0 0.5 1km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigD-26_100yrFldDepth_RevA.WOR



Title:

Nagambie Flood Study

200 Year ARI Peak Flood Depth - Developed Climate Change

Figure: **D-27**

Rev: **A**

N

0 0.5 1km

Approx. Scale

BMT WBM

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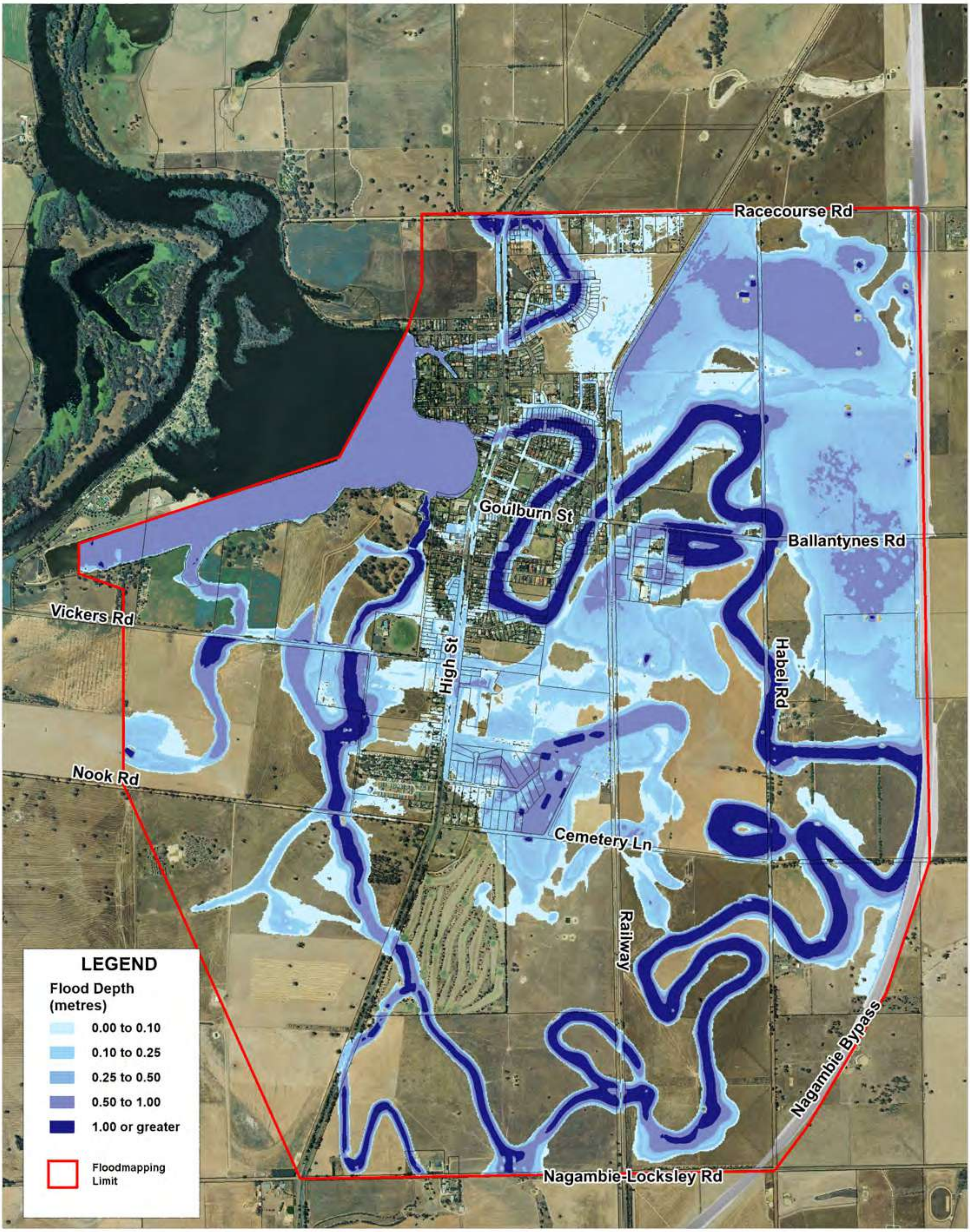
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigD-27_200yrFldDepth_RevA.WOR



Title:

Nagambie Flood Study
500 Year ARI Peak Flood Depth - Developed Climate Change

Figure: D-28

Rev: A

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N

0 0.5 1km

Approx. Scale

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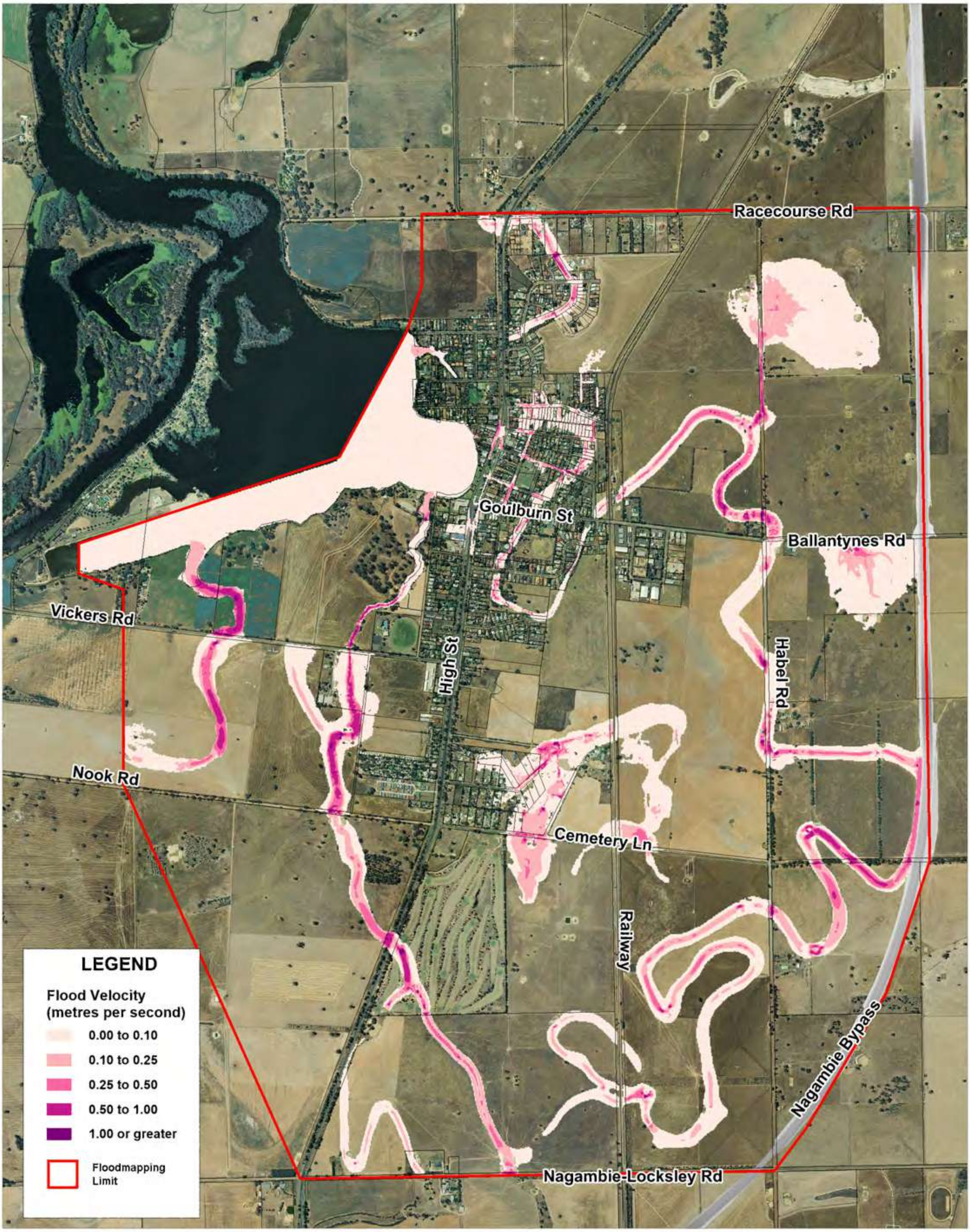
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigD-28_500yrFldDepth_RevA.WOR

Appendix E Peak Flood Velocity Maps



Title:

Nagambie Flood Study

5 Year ARI Peak Flood Velocity - Existing Conditions

Figure: **E-1**

Rev: **A**

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N

0 0.5 1km

Approx. Scale

BMT WBM

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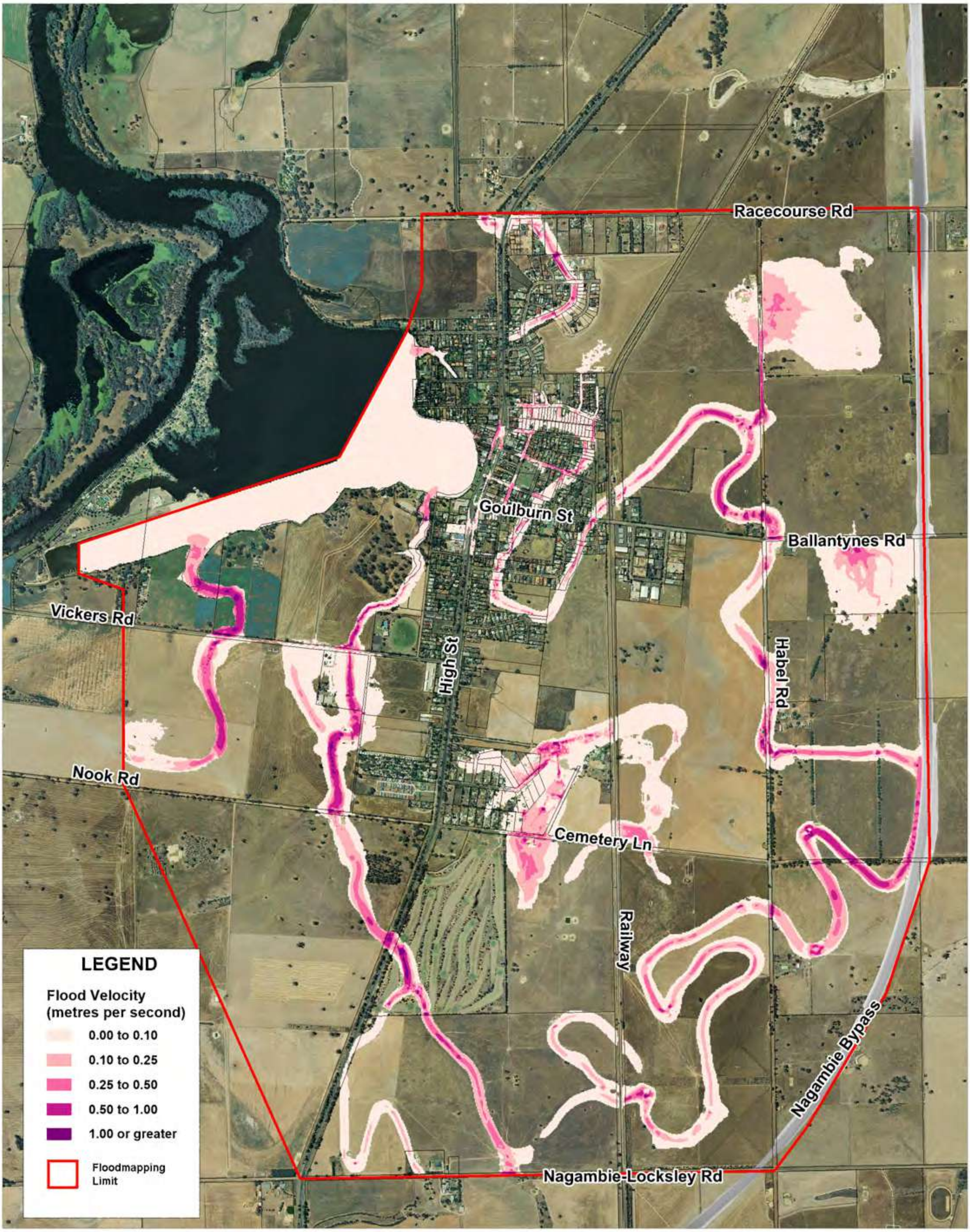
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigE-1_5yrFldVel_RevA.WOR



Title:

Nagambie Flood Study

10 Year ARI Peak Flood Velocity - Existing Conditions

Figure: **E-2**

Rev: **A**

N

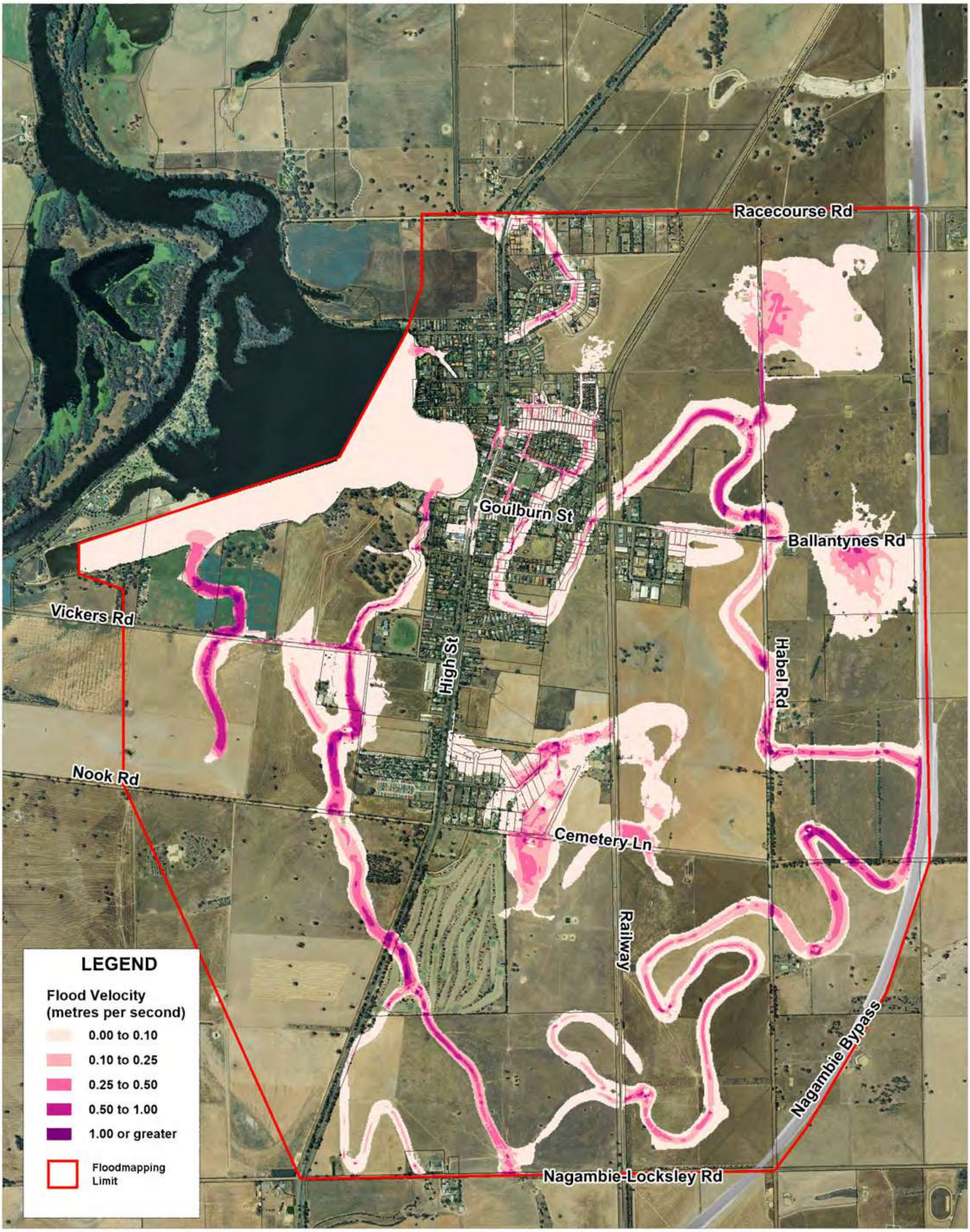
0 0.5 1km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigE-2_10yrFldVel_RevA.WOR



Title:

Nagambie Flood Study

20 Year ARI Peak Flood Velocity - Existing Conditions

Figure: **E-3**

Rev: **A**

N

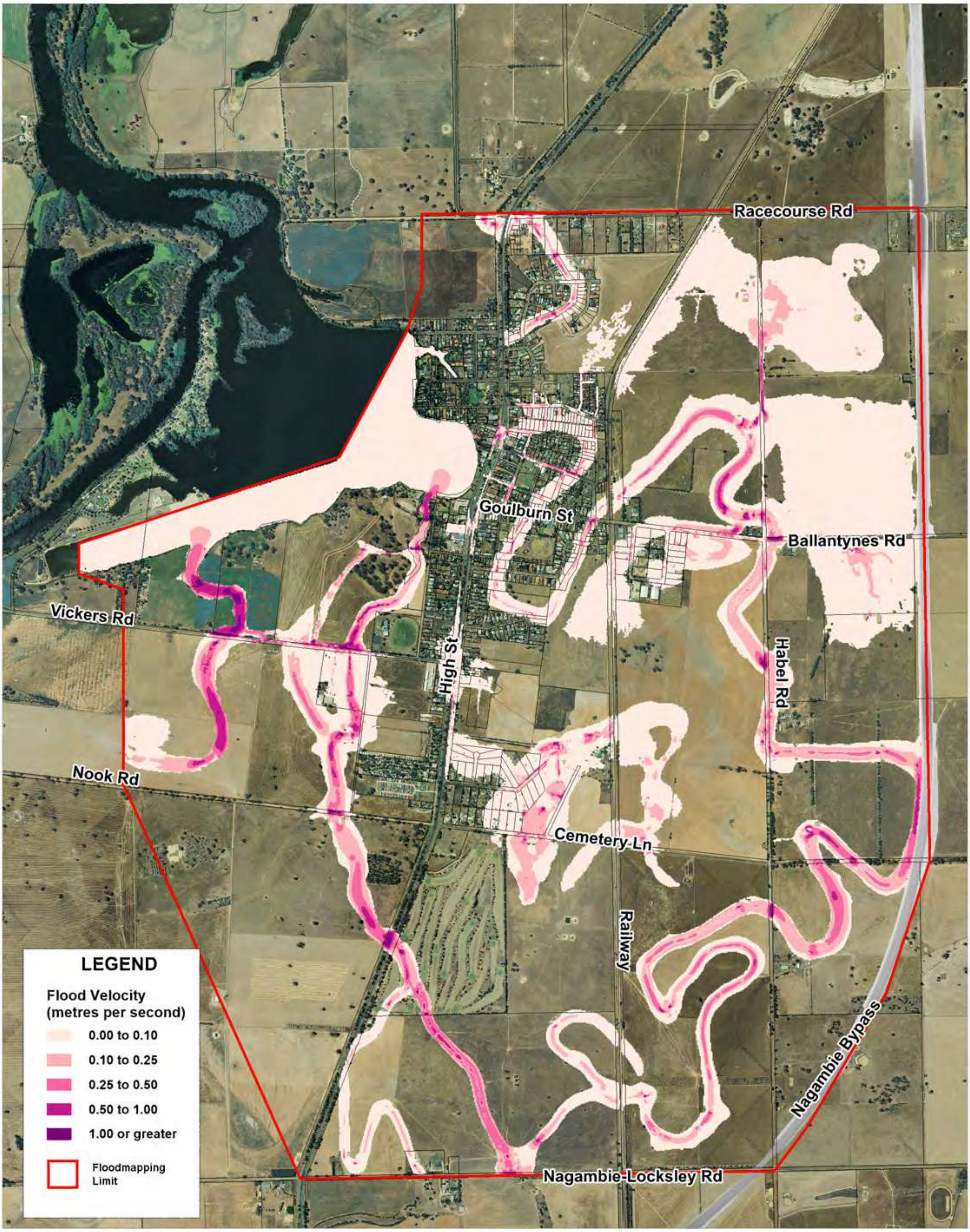
0 0.5 1km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigE-3_20yrFldVel_RevA.WOR



Title:

Nagambie Flood Study
50 Year ARI Peak Flood Velocity - Existing Conditions

Figure: E-4

Rev: A

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N

0 0.5 1km

Approx. Scale

BMT WBM

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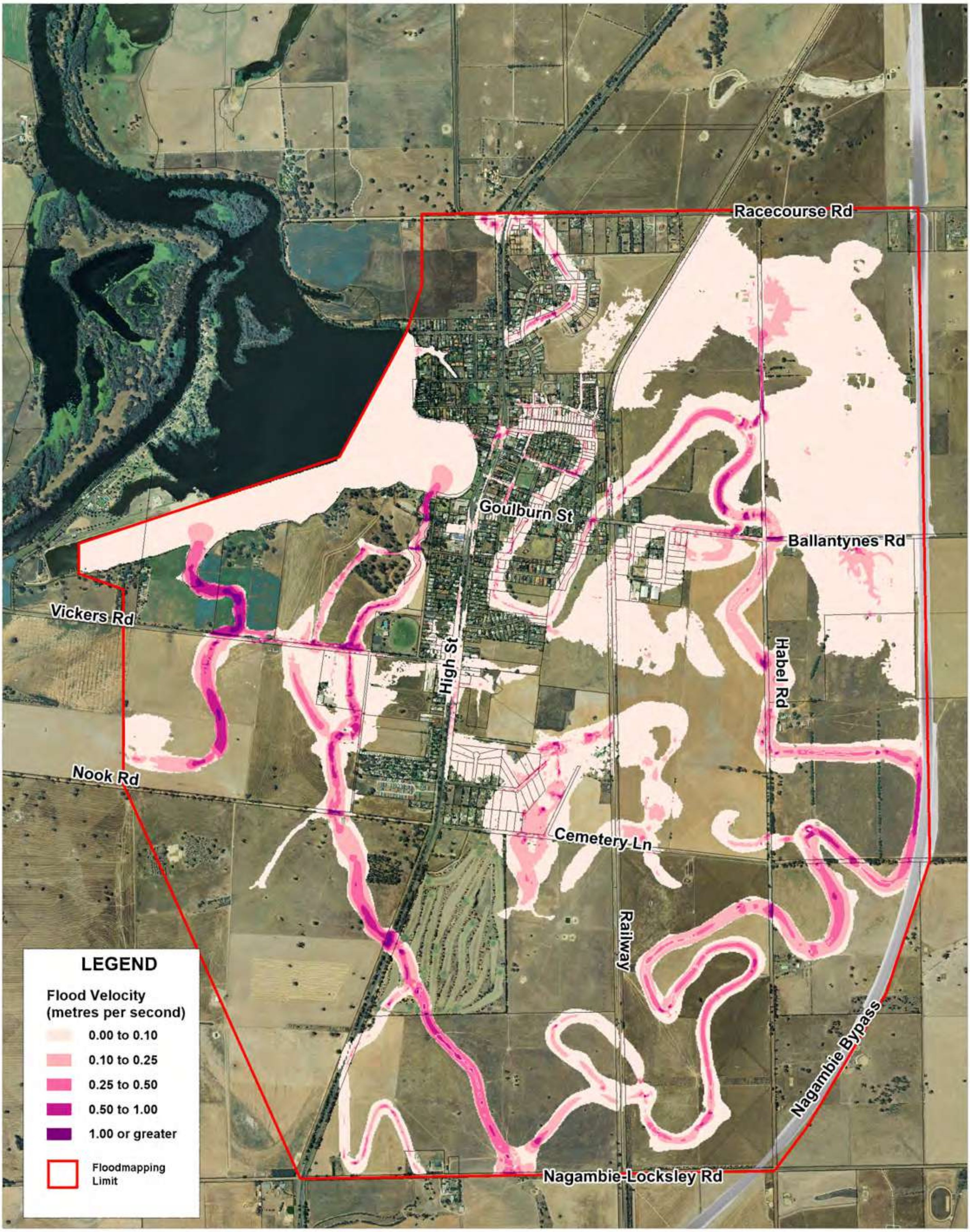


Title:

Nagambie Flood Study
100 Year ARI Peak Flood Velocity - Existing Conditions

Figure: E-5

Rev: A

N

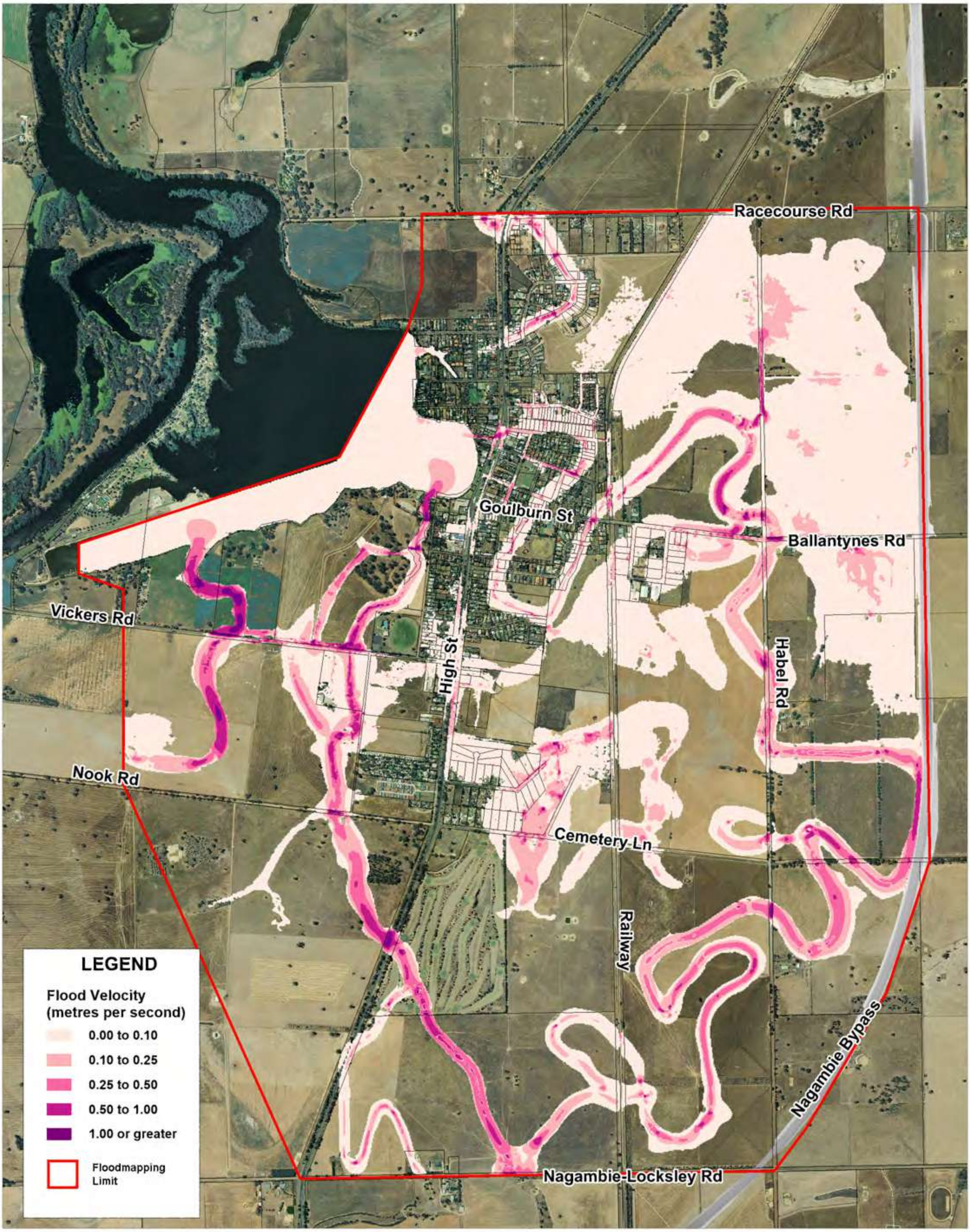
0 0.5 1km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigE-5_100yrFldVel_RevA.WOR



Title:

Nagambie Flood Study
200 Year ARI Peak Flood Velocity - Existing Conditions

Figure: **E-6**

Rev: **A**

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N

0 0.5 1km
Approx. Scale

BMT WBM
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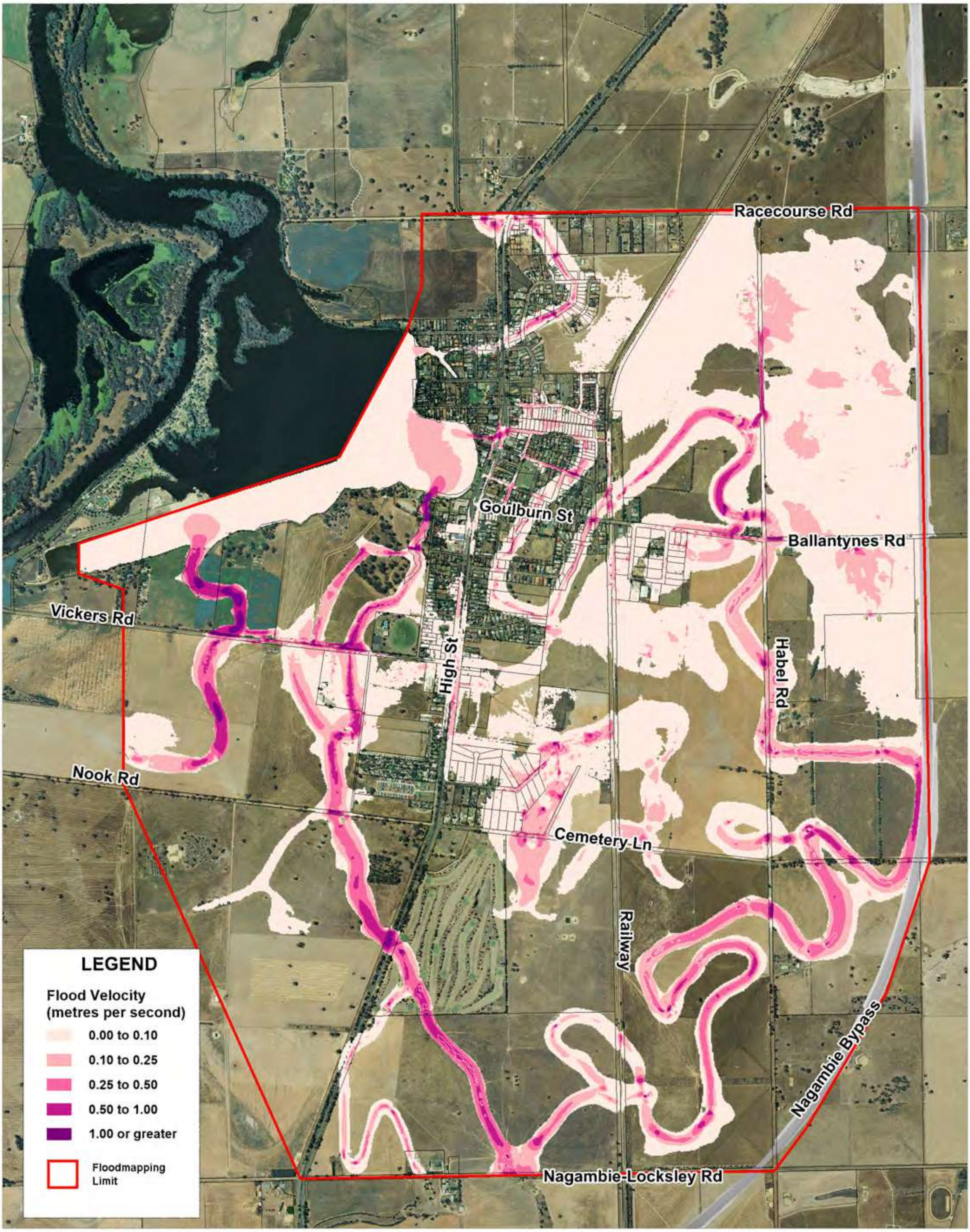
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigE-6_200yrFldVel_RevA.WOR



Title:

Nagambie Flood Study
500 Year ARI Peak Flood Velocity - Existing Conditions

Figure: **E-7**

Rev: **A**

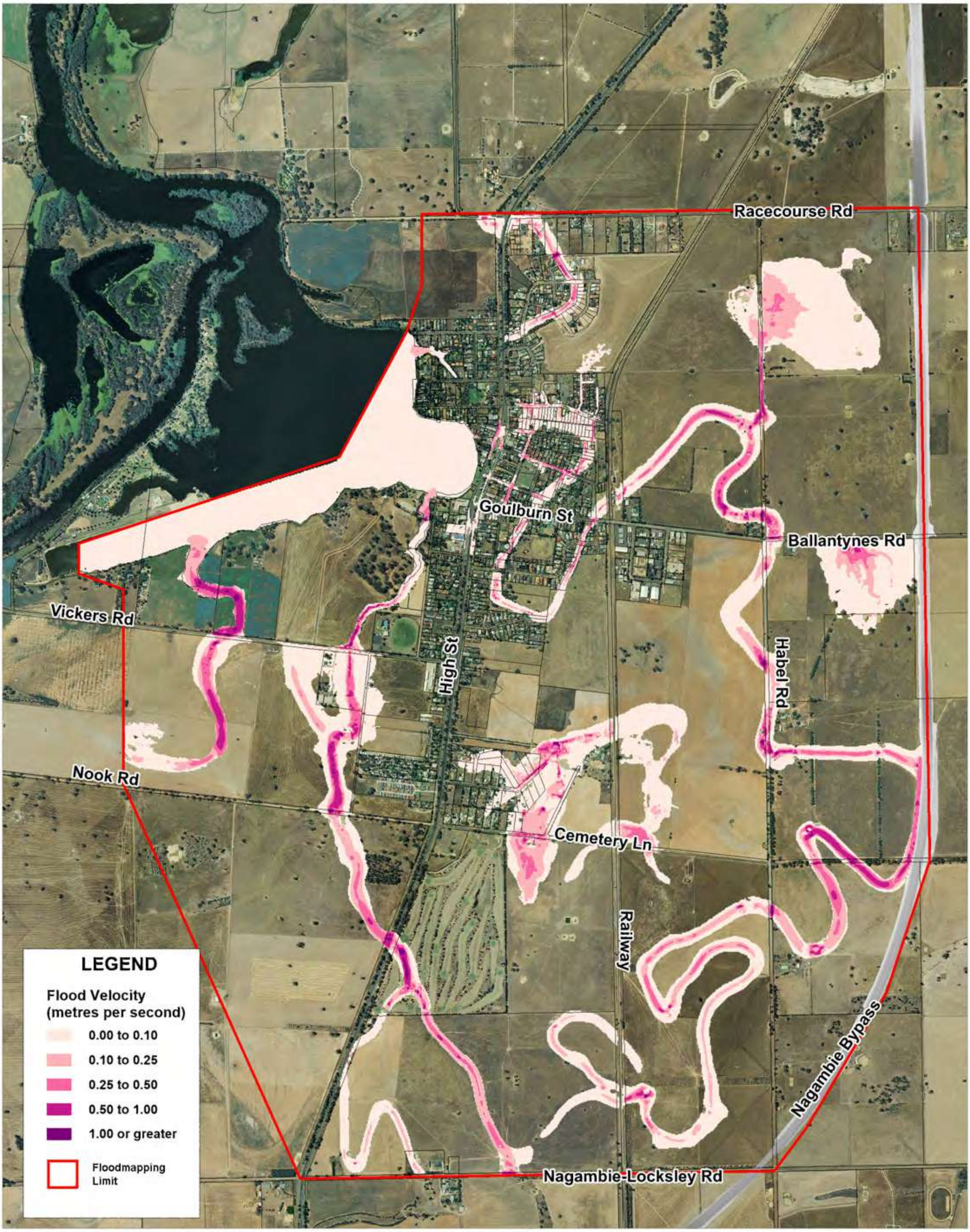
N

0 0.5 1km

Approx. Scale

BMT WBM
www.bmtwbm.com.au

Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigE-7_500yrFldVel_RevA.WOR



Title:

Nagambie Flood Study

5 Year ARI Peak Flood Velocity - Developed Conditions

Figure: **E-8**

Rev: **A**

N

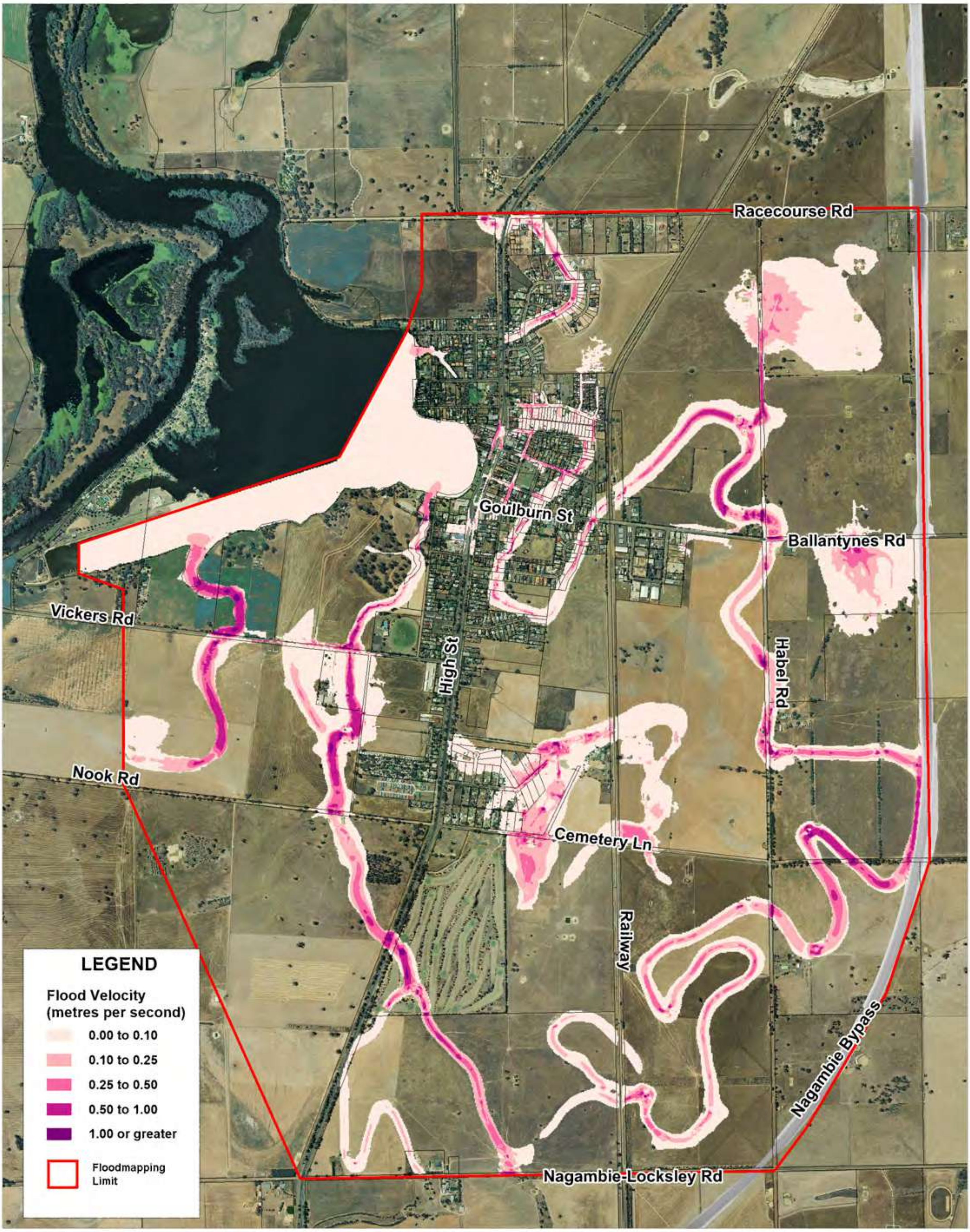
0 0.5 1km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigE-8_5yrFldVel_RevA.WOR



Title:

Nagambie Flood Study
10 Year ARI Peak Flood Velocity - Developed Conditions

Figure: E-9

Rev: A

N

0 0.5 1km

Approx. Scale

BMT WBM

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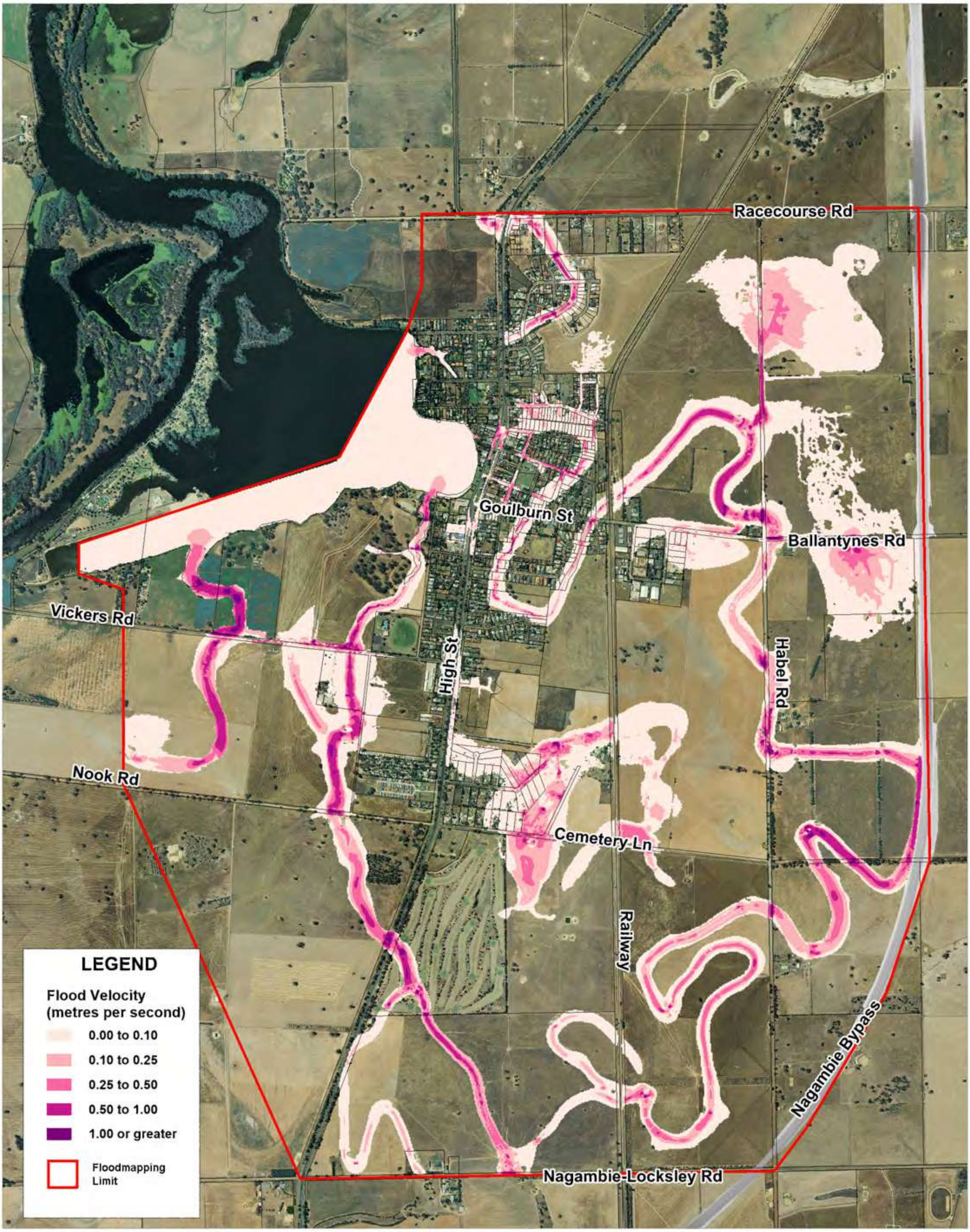
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigE-9_10yrFldVel_RevA.WOR



Title:

Nagambie Flood Study

20 Year ARI Peak Flood Velocity - Developed Conditions

Figure: **E-10**

Rev: **A**

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N

0 0.5 1km

Approx. Scale

BMT WBM

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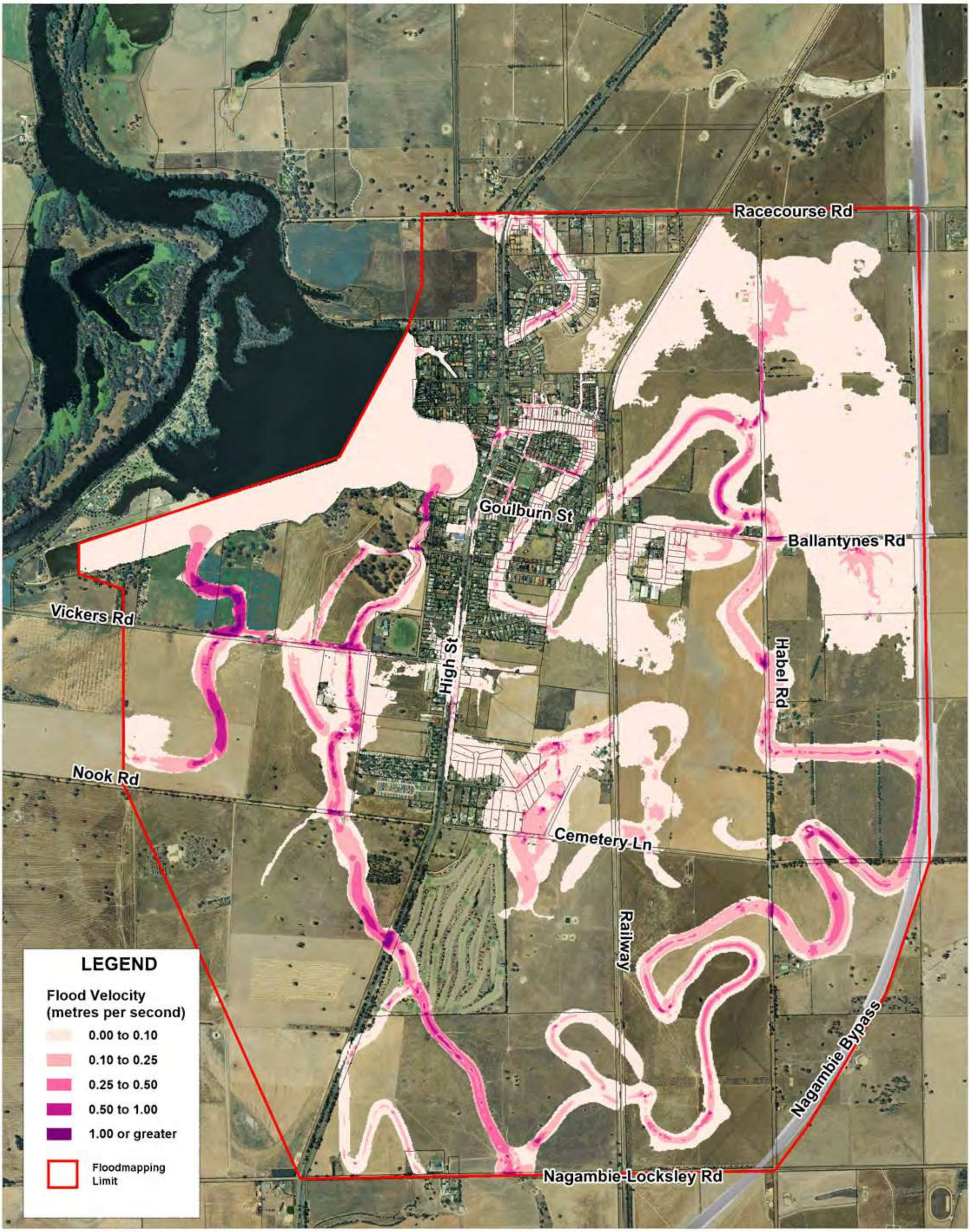
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigE-10_20yrFldVel_RevA.WOR



Title:

Nagambie Flood Study

50 Year ARI Peak Flood Velocity - Developed Conditions

Figure: **E-11**

Rev: **A**

N

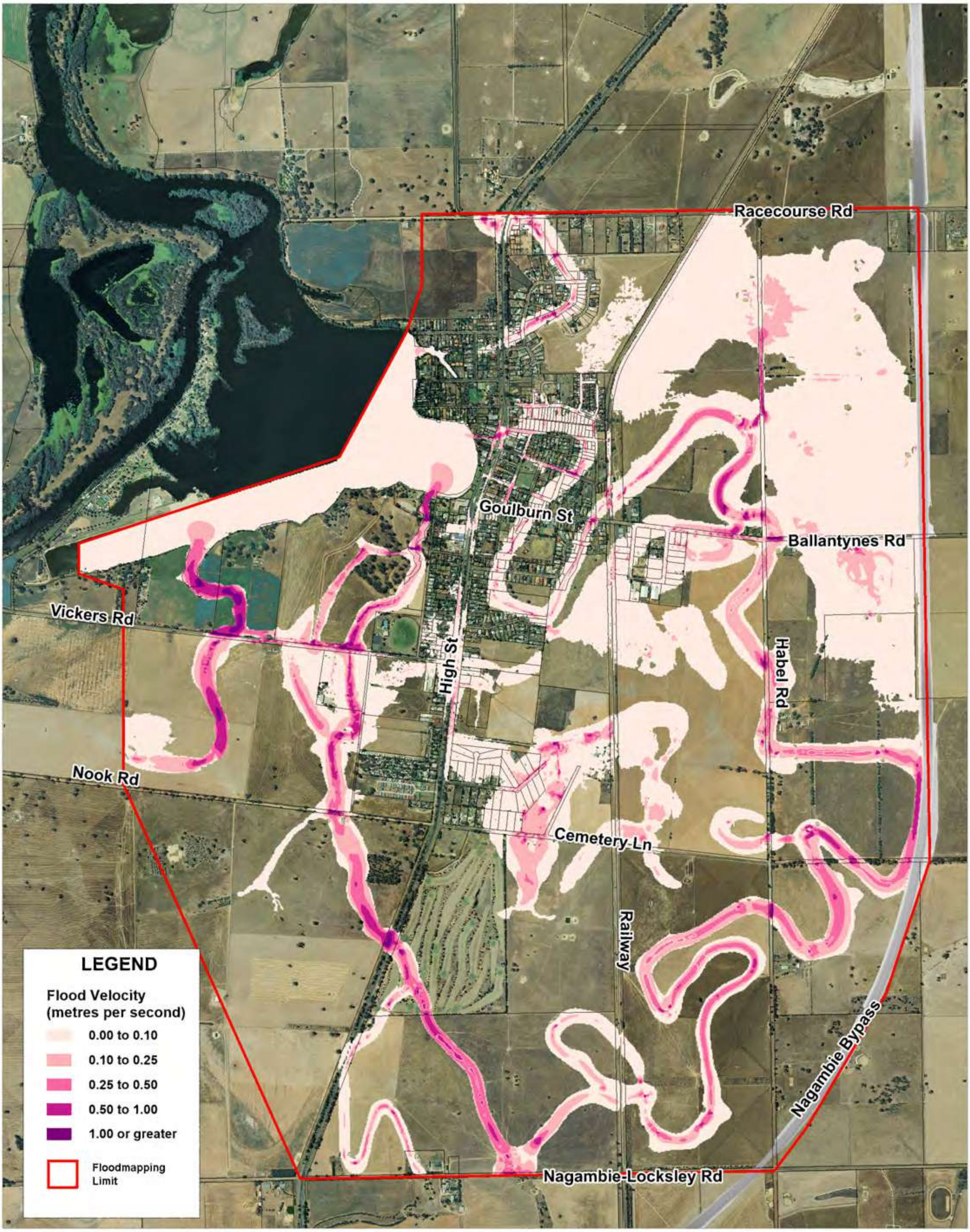
0 0.5 1km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigE-11_50yrFldVel_RevA.WOR



Title:

Nagambie Flood Study
100 Year ARI Peak Flood Velocity - Developed Conditions

Figure: **E-12**

Rev: **A**

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N

0 0.5 1km

Approx. Scale

BMT WBM

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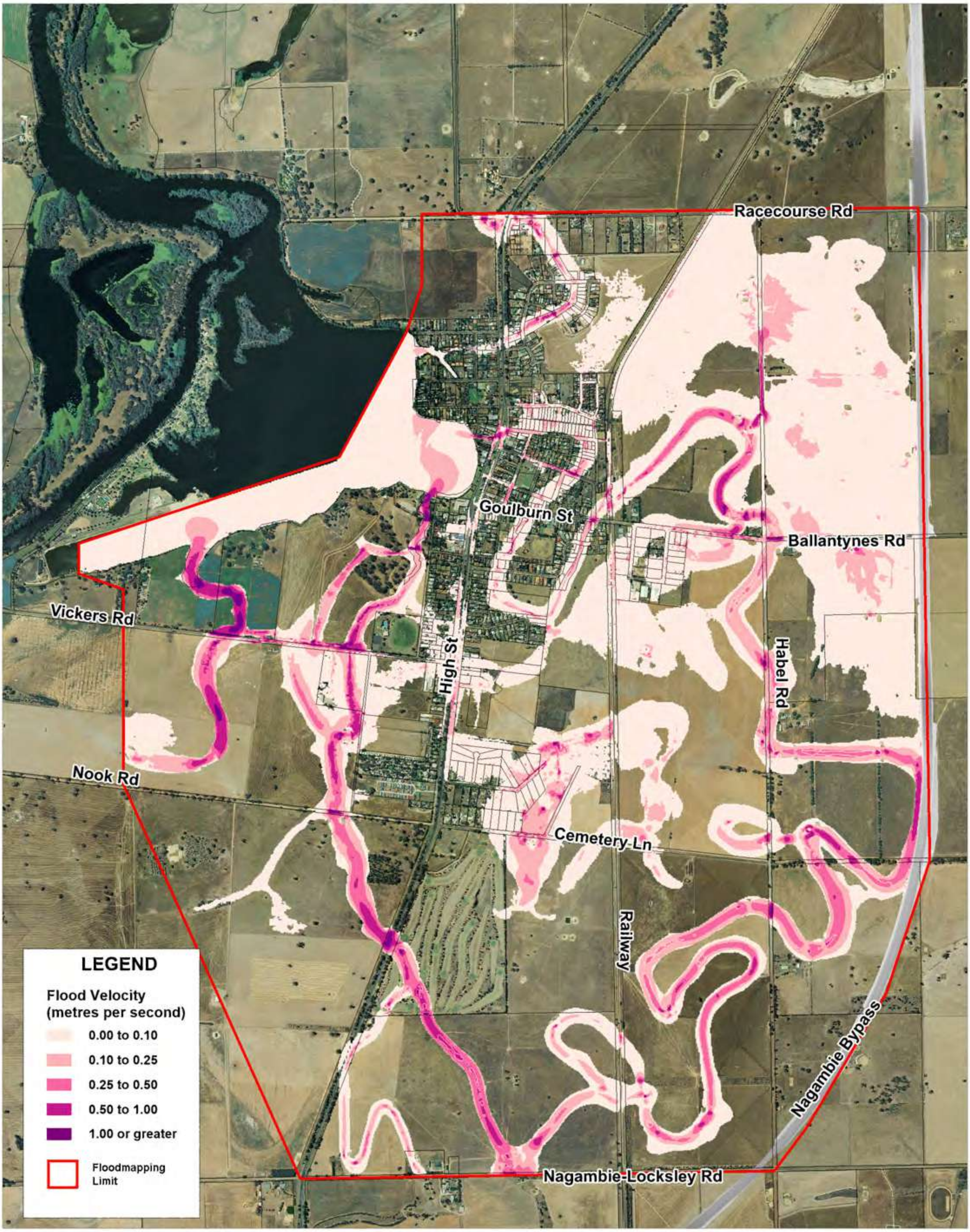
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigE-12_100yrFldVel_RevA.WOR



Title:

Nagambie Flood Study
200 Year ARI Peak Flood Velocity - Developed Conditions

Figure: **E-13**

Rev: **A**

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N

0 0.5 1km

Approx. Scale

BMT WBM

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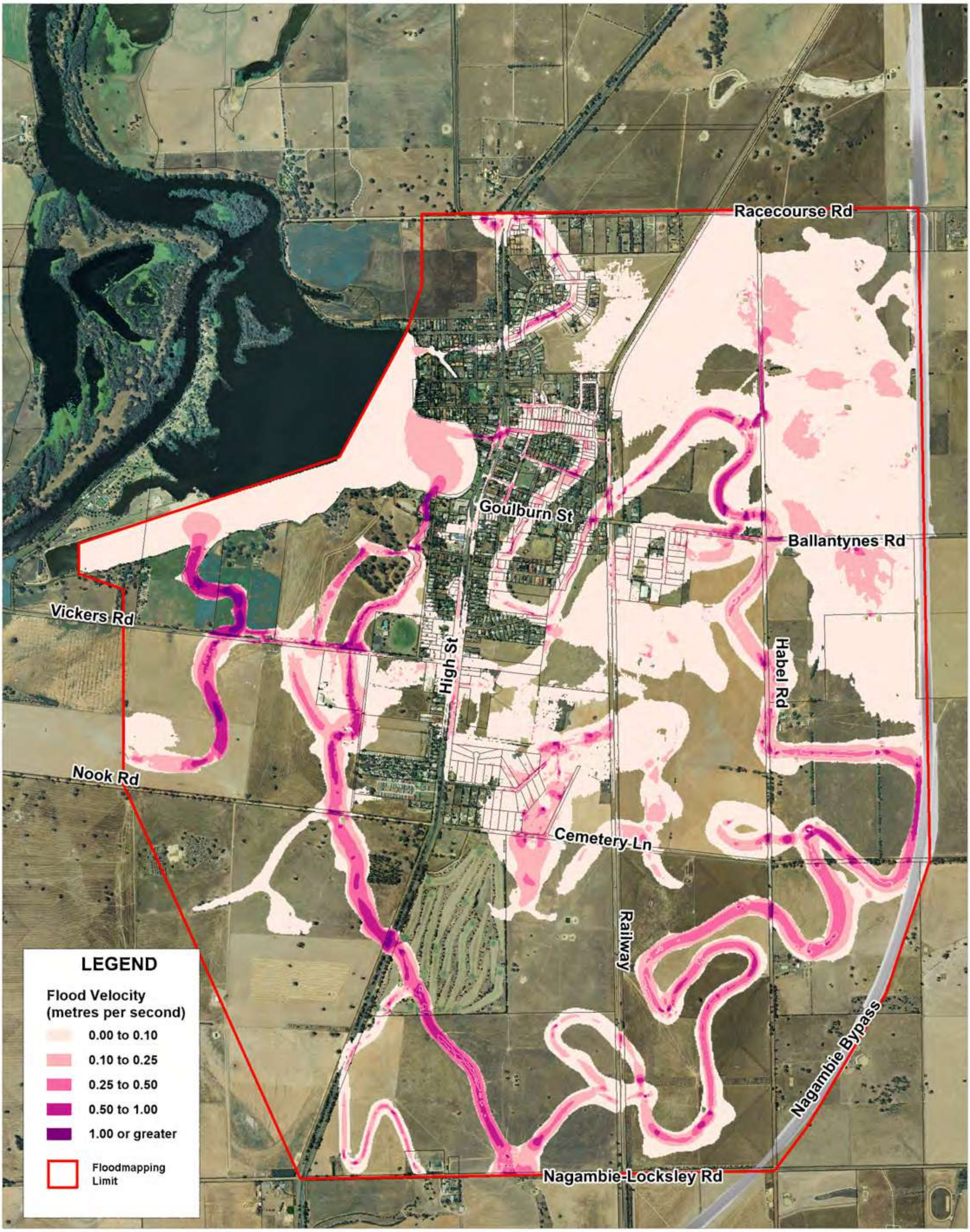
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigE-13_200yrFldVel_RevA.WOR



Title:

Nagambie Flood Study

500 Year ARI Peak Flood Velocity - Developed Conditions

Figure: **E-14**

Rev: **A**

N

0 0.5 1km

Approx. Scale

BMT WBM

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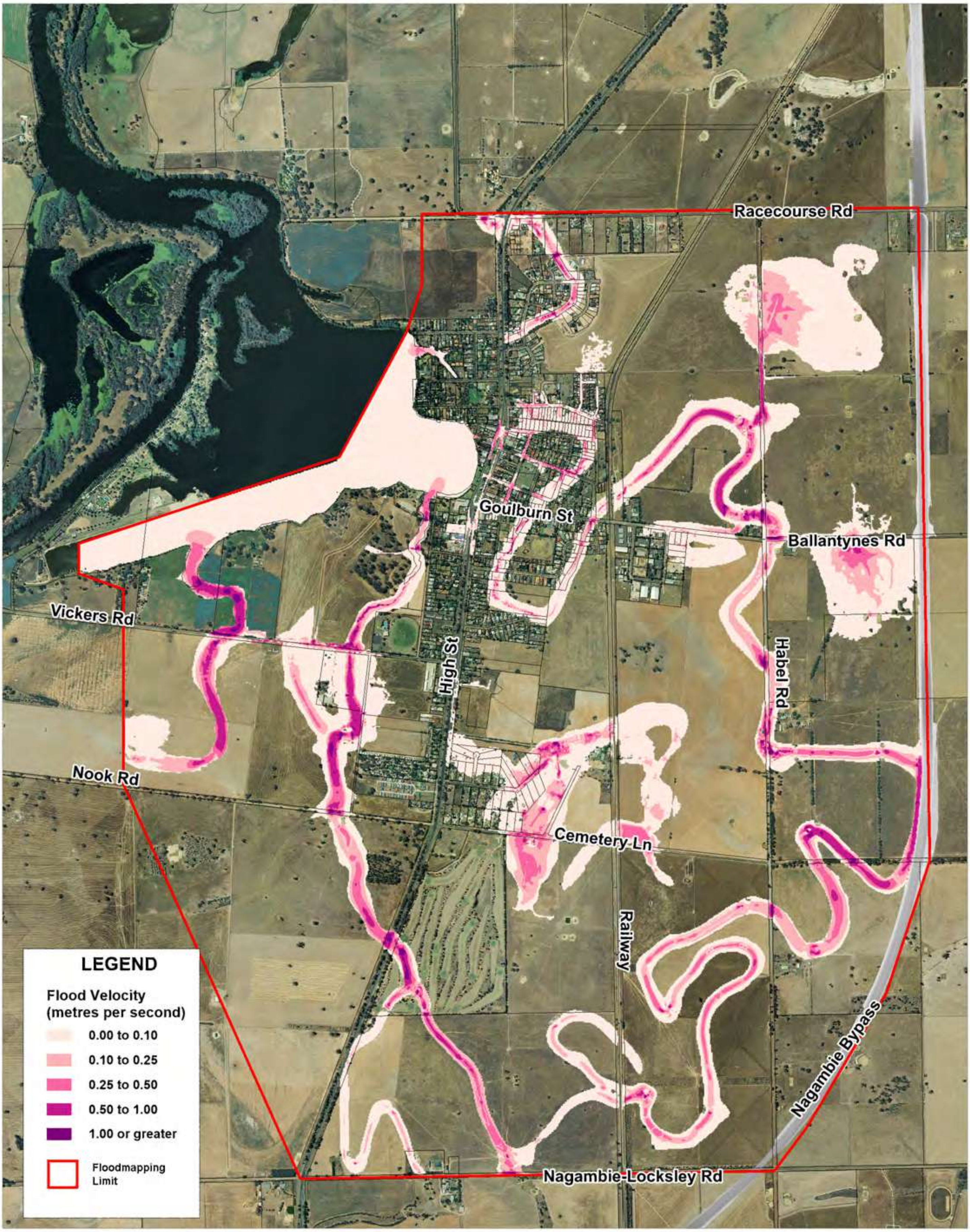
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigE-14_500yrFldVel_RevA.WOR



Title:

Nagambie Flood Study
5 Year ARI Peak Flood Velocity - Climate Change

Figure: **E-15**

Rev: **A**

BMT WBM
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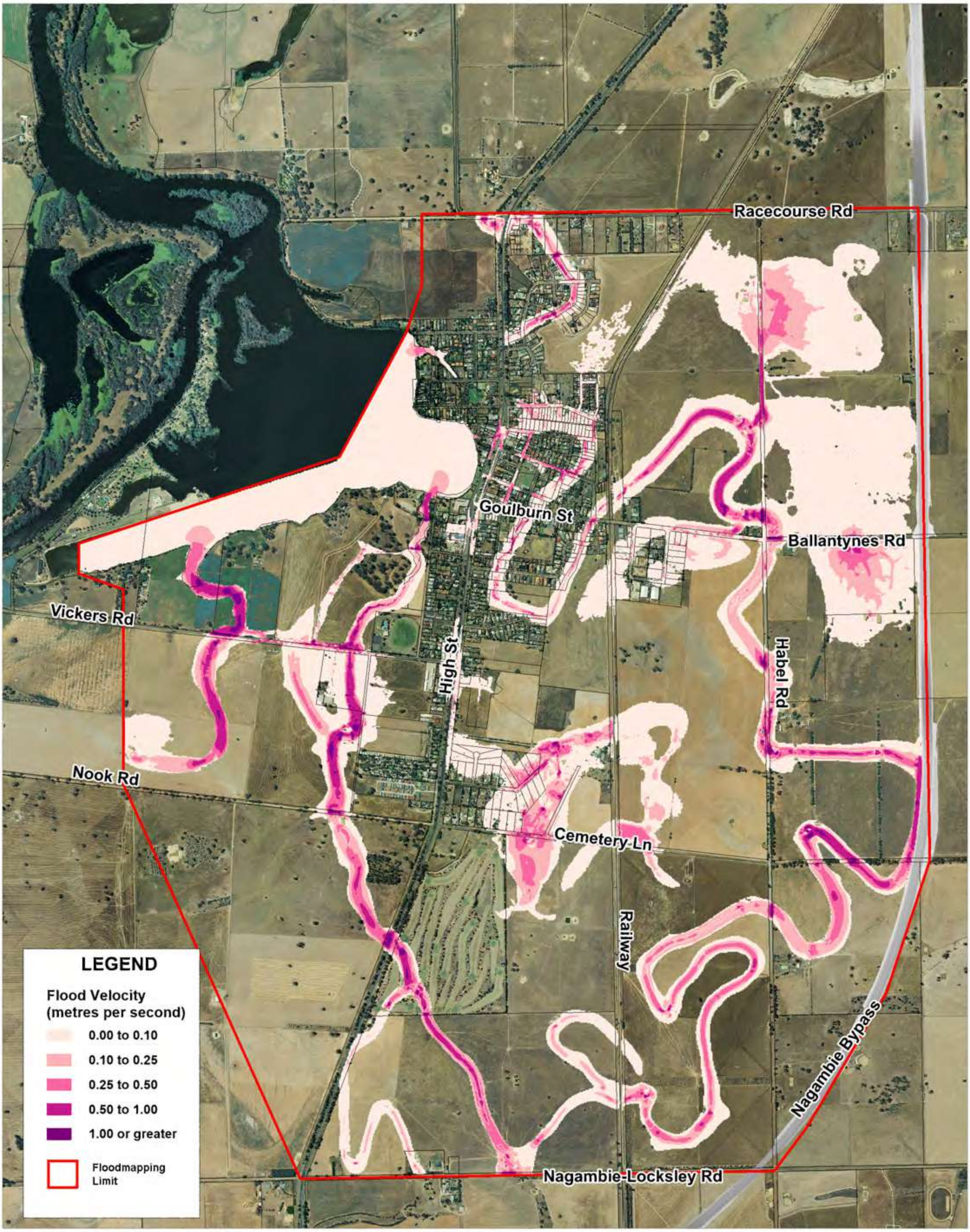
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigE-15_5yrFldVel_RevA.WOR



Title:

Nagambie Flood Study
10 Year ARI Peak Flood Velocity - Climate Change

Figure: **E-16**

Rev: **A**

N

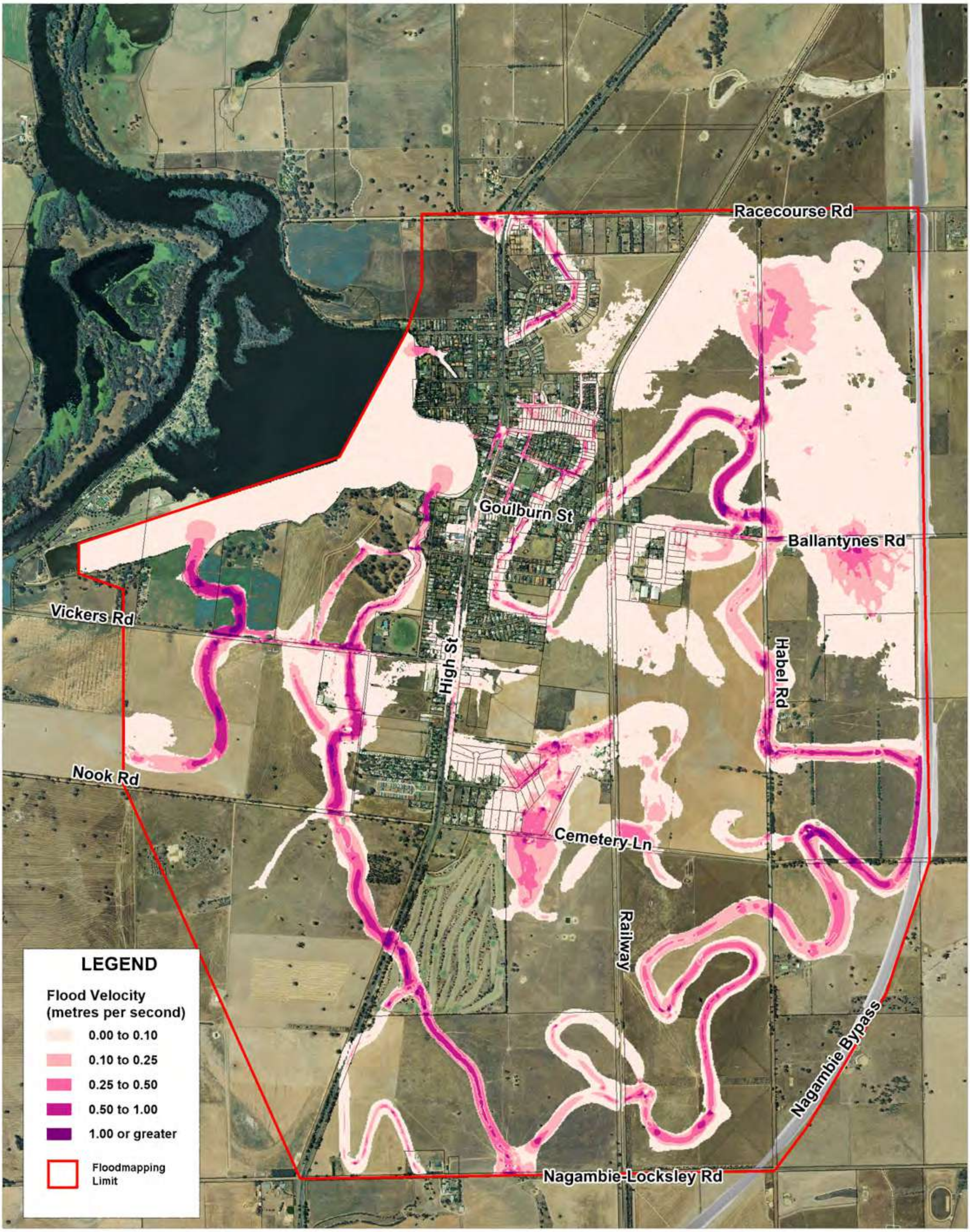
0 0.5 1km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigE-16_10yrFldVel_RevA.WOR



Title:

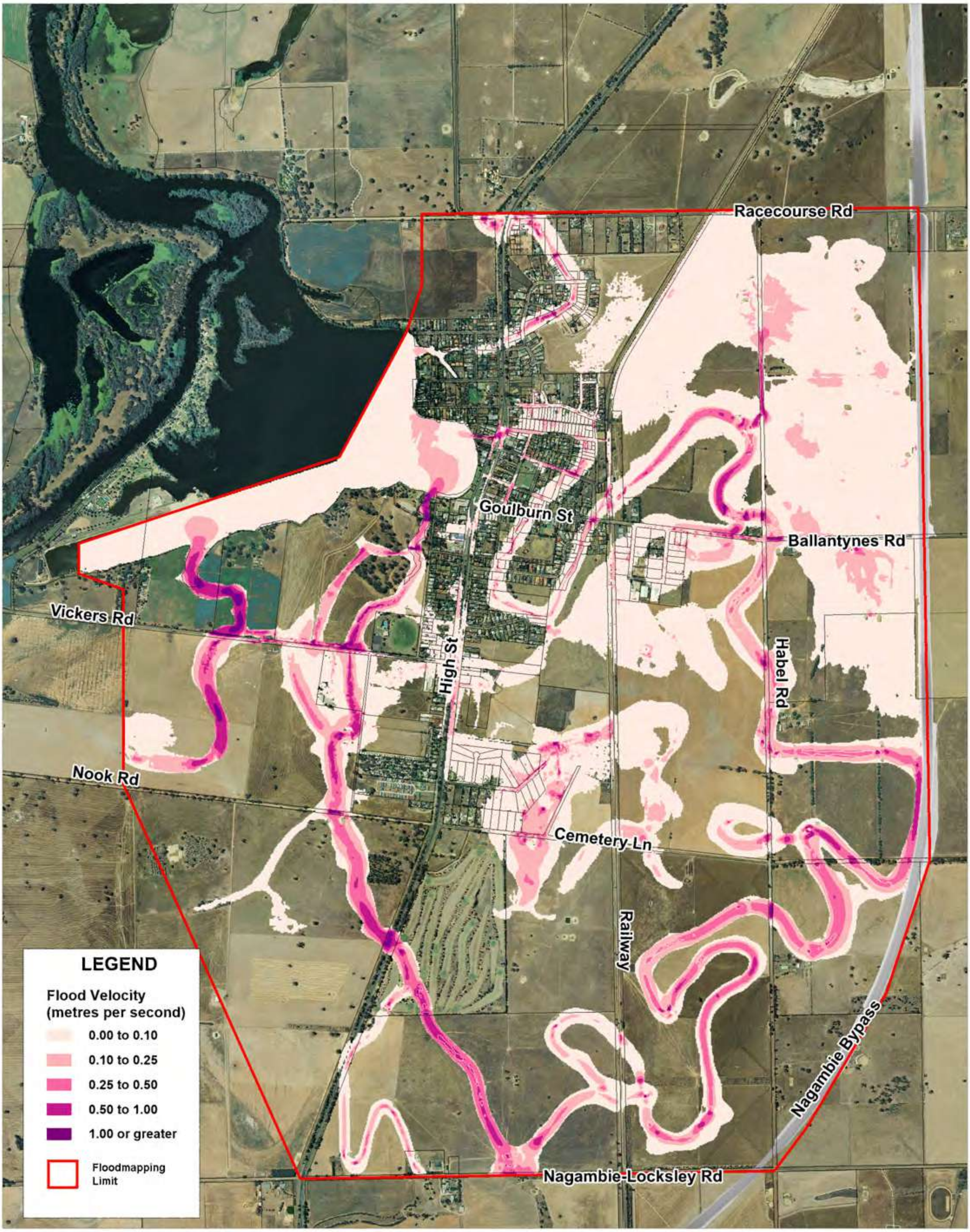
Nagambie Flood Study
20 Year ARI Peak Flood Velocity - Climate Change

Figure: **E-17**

Rev: **A**

BMT WBM
www.bmtwbm.com.au

Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigE-17_20yrFldVel_RevA.WOR



Title:

Nagambie Flood Study
50 Year ARI Peak Flood Velocity - Climate Change

Figure: **E-18**

Rev: **A**

N

0 0.5 1km

Approx. Scale

BMT WBM

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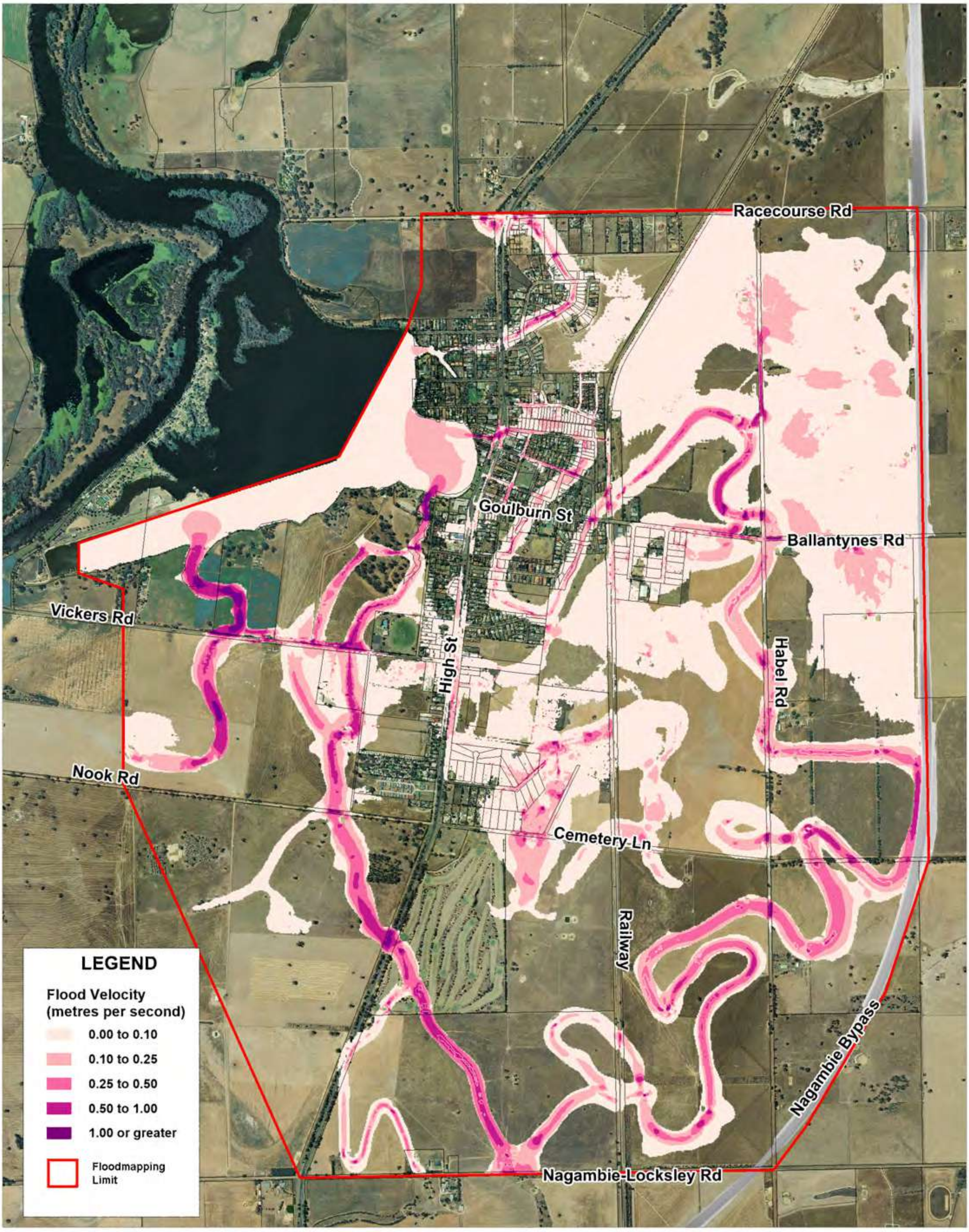
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigE-18_50yrFldVel_RevA.WOR



Title:

Nagambie Flood Study
100 Year ARI Peak Flood Velocity - Climate Change

Figure: **E-19**

Rev: **A**

BMT WBM
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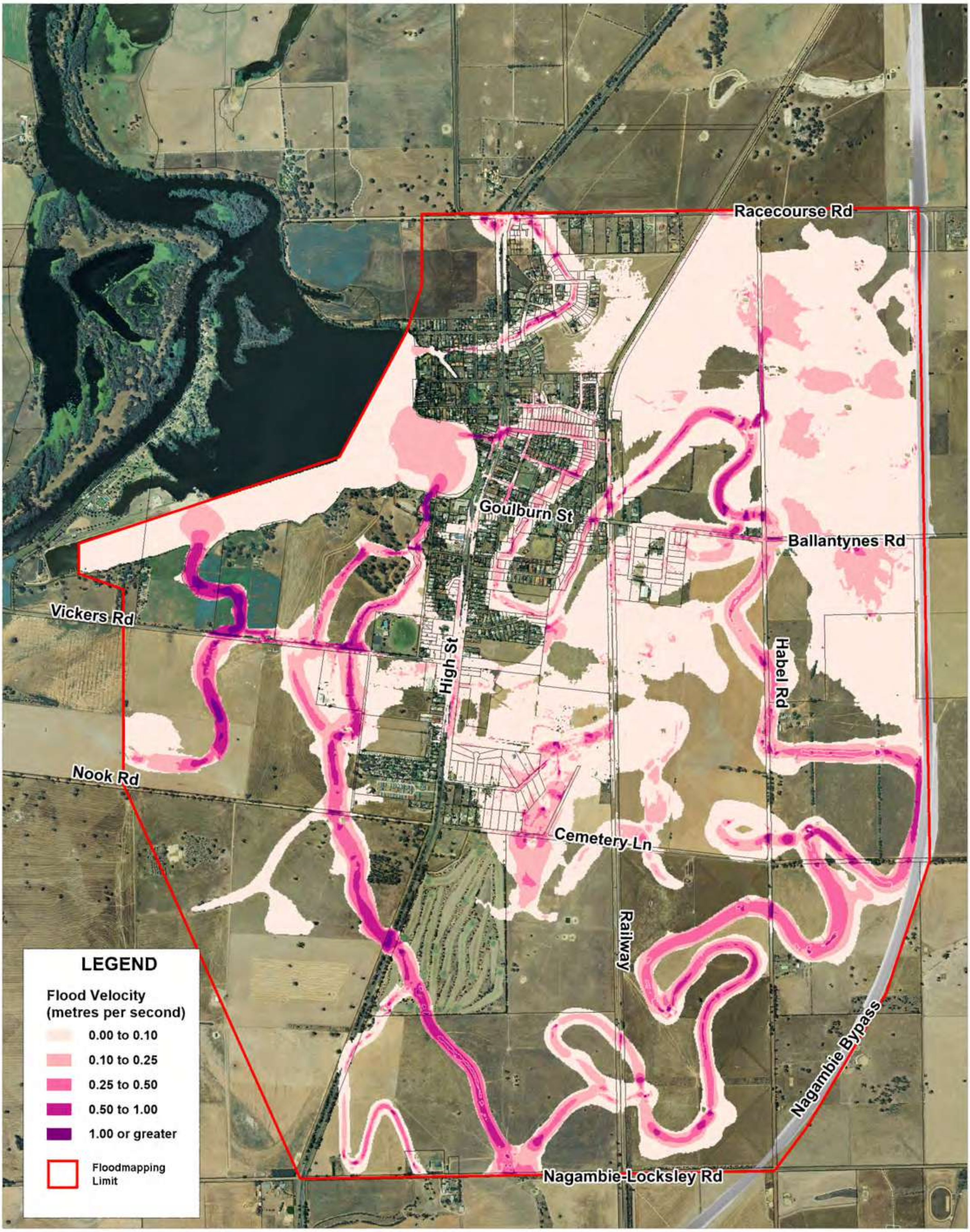
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigE-19_100yrFldVel_RevA.WOR



Title:

Nagambie Flood Study
200 Year ARI Peak Flood Velocity - Climate Change

Figure: **E-20**

Rev: **A**

N

0 0.5 1km
Approx. Scale

BMT WBM
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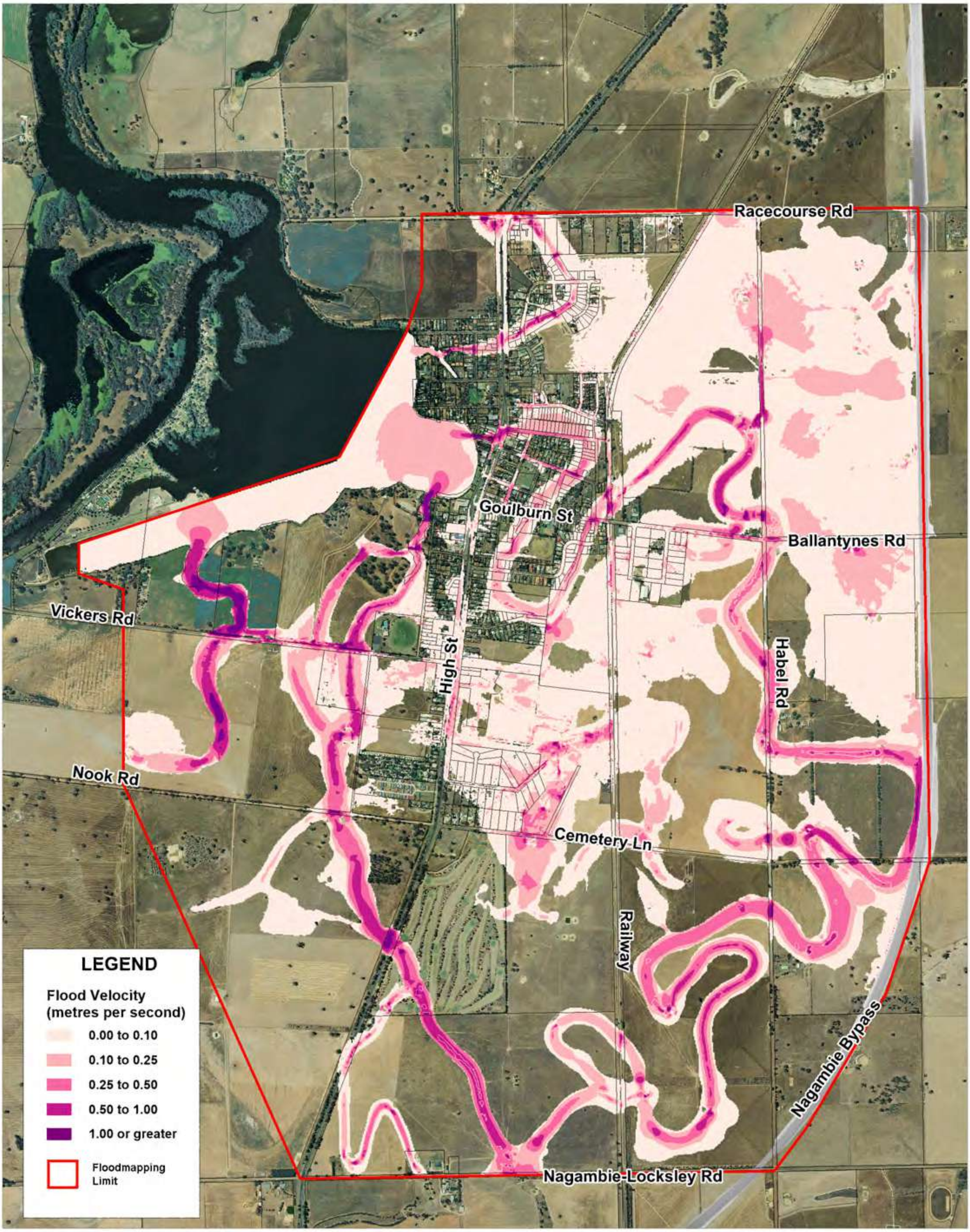
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigE-20_200yrFldVel_RevA.WOR



Title:

Nagambie Flood Study
500 Year ARI Peak Flood Velocity - Climate Change

Figure: **E-21**

Rev: **A**

N

0 0.5 1km
Approx. Scale

BMT WBM
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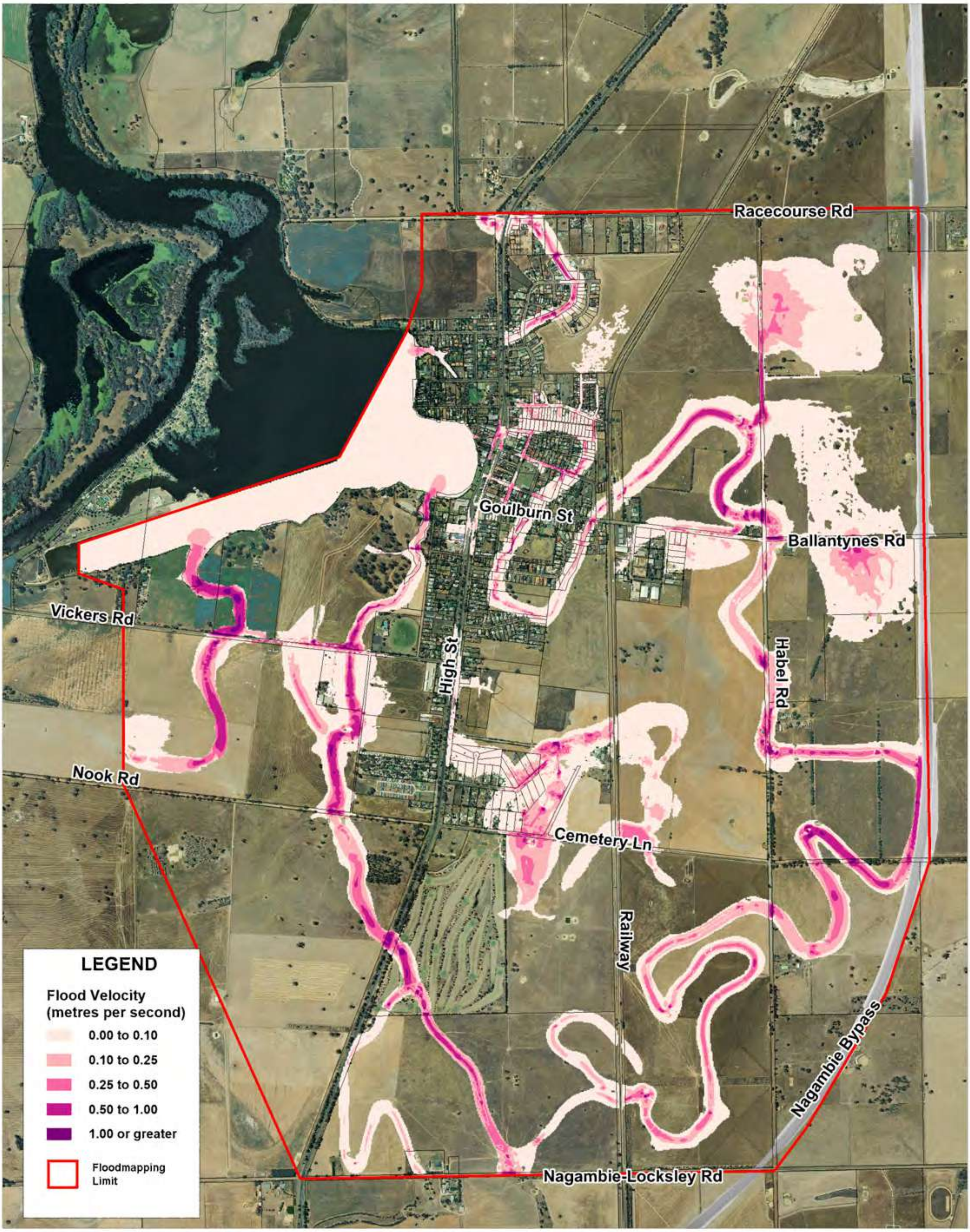
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigE-21_500yrFldVel_RevA.WOR



Title:

Nagambie Flood Study
5 Year ARI Peak Flood Velocity - Developed Climate Change

Figure: E-22

Rev: A

N

0 0.5 1km

Approx. Scale

BMT WBM

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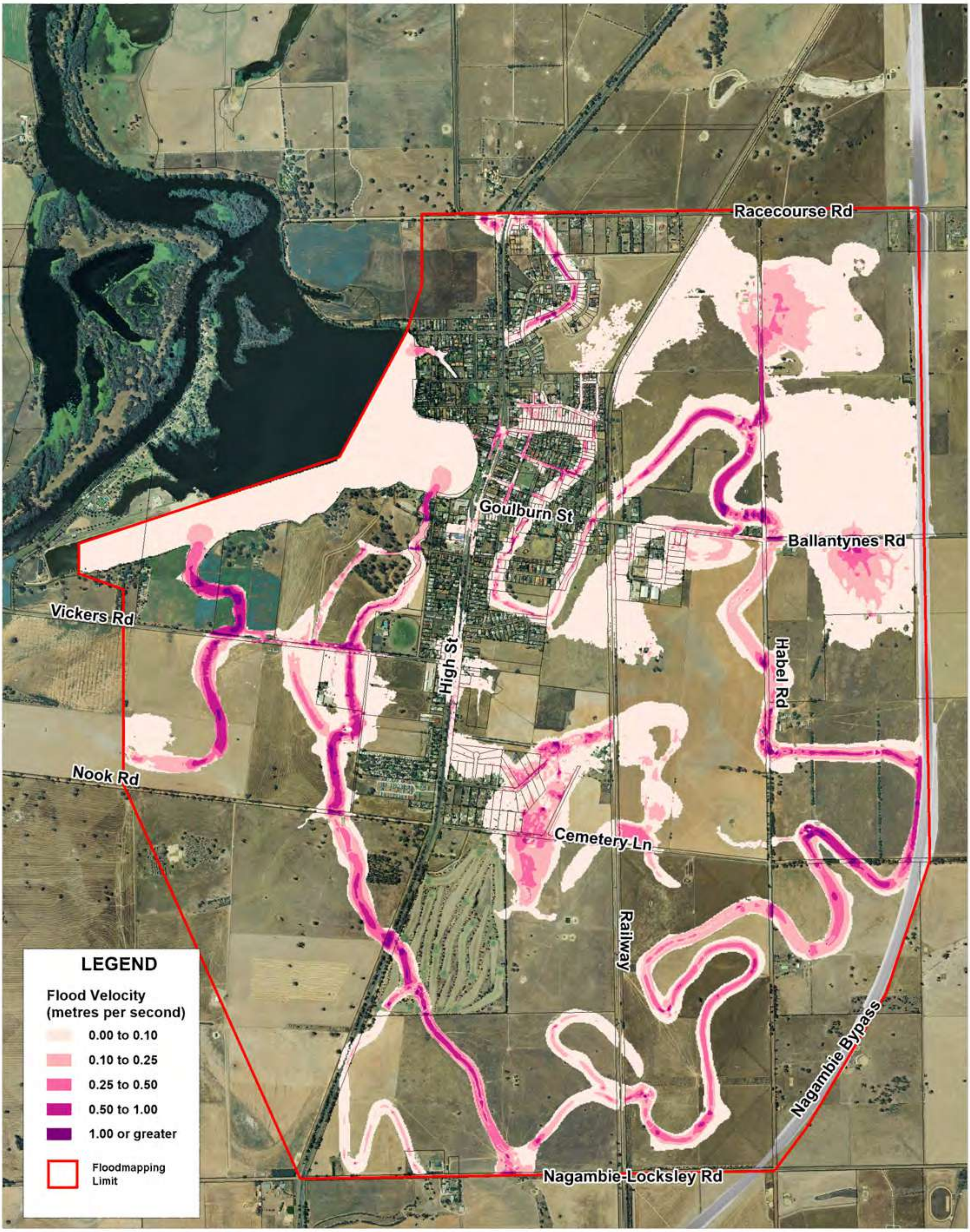
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigE-22_5yrFldVel_RevA.WOR



Title:

Nagambie Flood Study
10 Year ARI Peak Flood Velocity - Developed Climate Change

Figure: **E-23**

Rev: **A**

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N

0 0.5 1km
Approx. Scale

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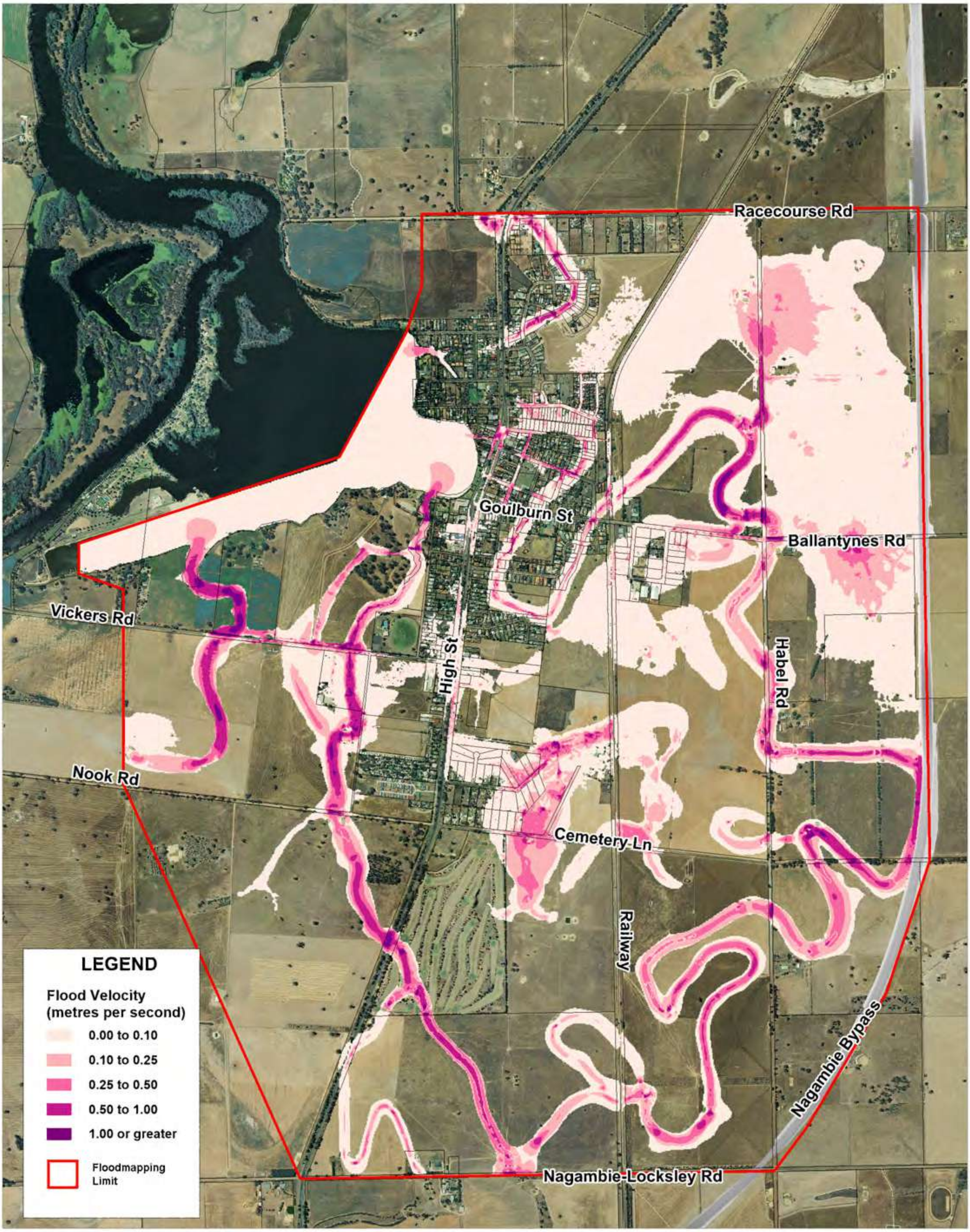

Title:

Nagambie Flood Study
20 Year ARI Peak Flood Velocity - Developed Climate Change

Figure: **E-24**

Rev: **A**

N

0 0.5 1km

Approx. Scale

BMT WBM

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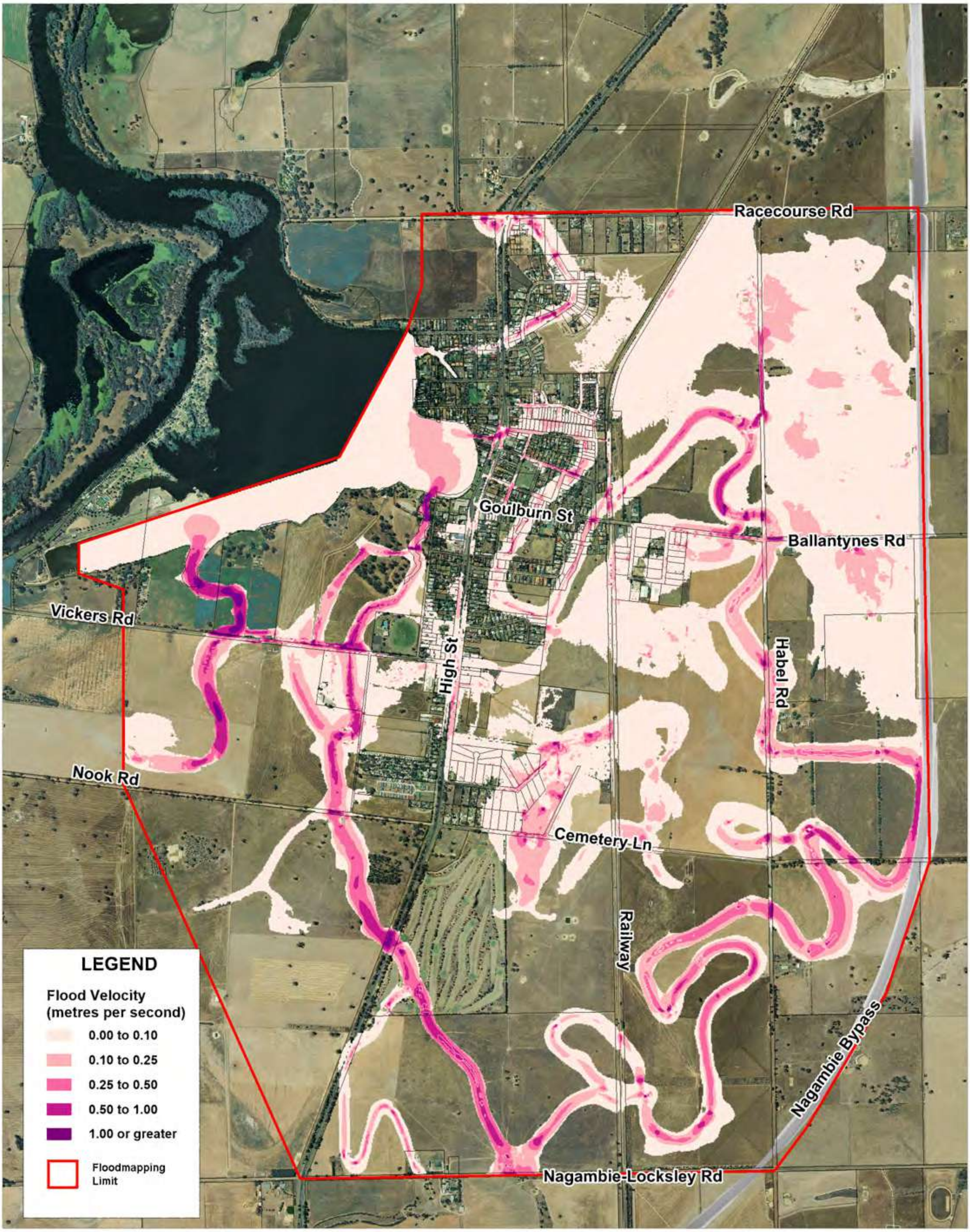
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigE-24_20yrFldVel_RevA.WOR



Title:

Nagambie Flood Study
50 Year ARI Peak Flood Velocity - Developed Climate Change

Figure: **E-25**

Rev: **A**

N

0 0.5 1km

Approx. Scale

BMT WBM
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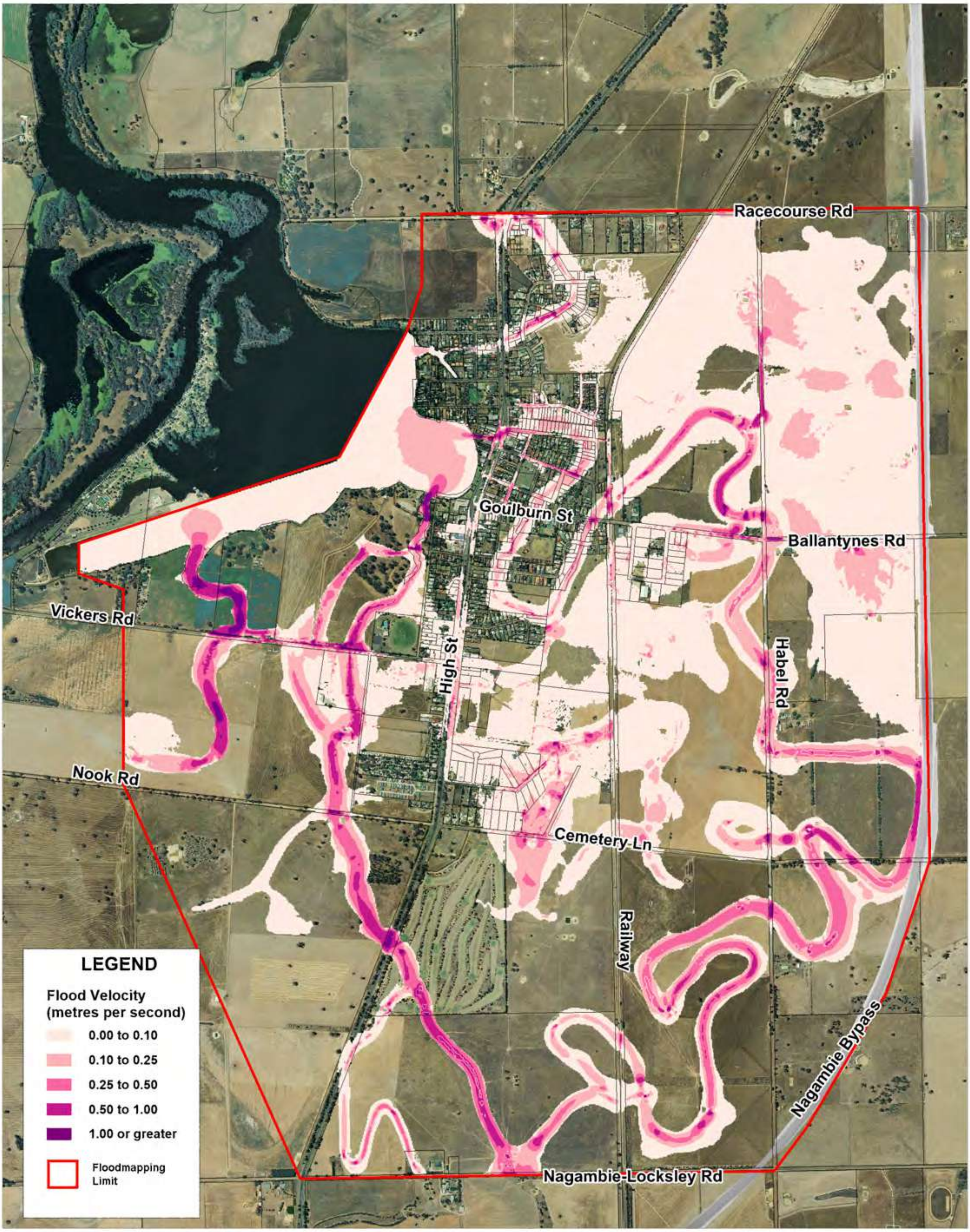

Title:

Nagambie Flood Study
100 Year ARI Peak Flood Velocity - Developed Climate Change

Figure: **E-26**

Rev: **A**

N

0 0.5 1km

Approx. Scale

BMT WBM
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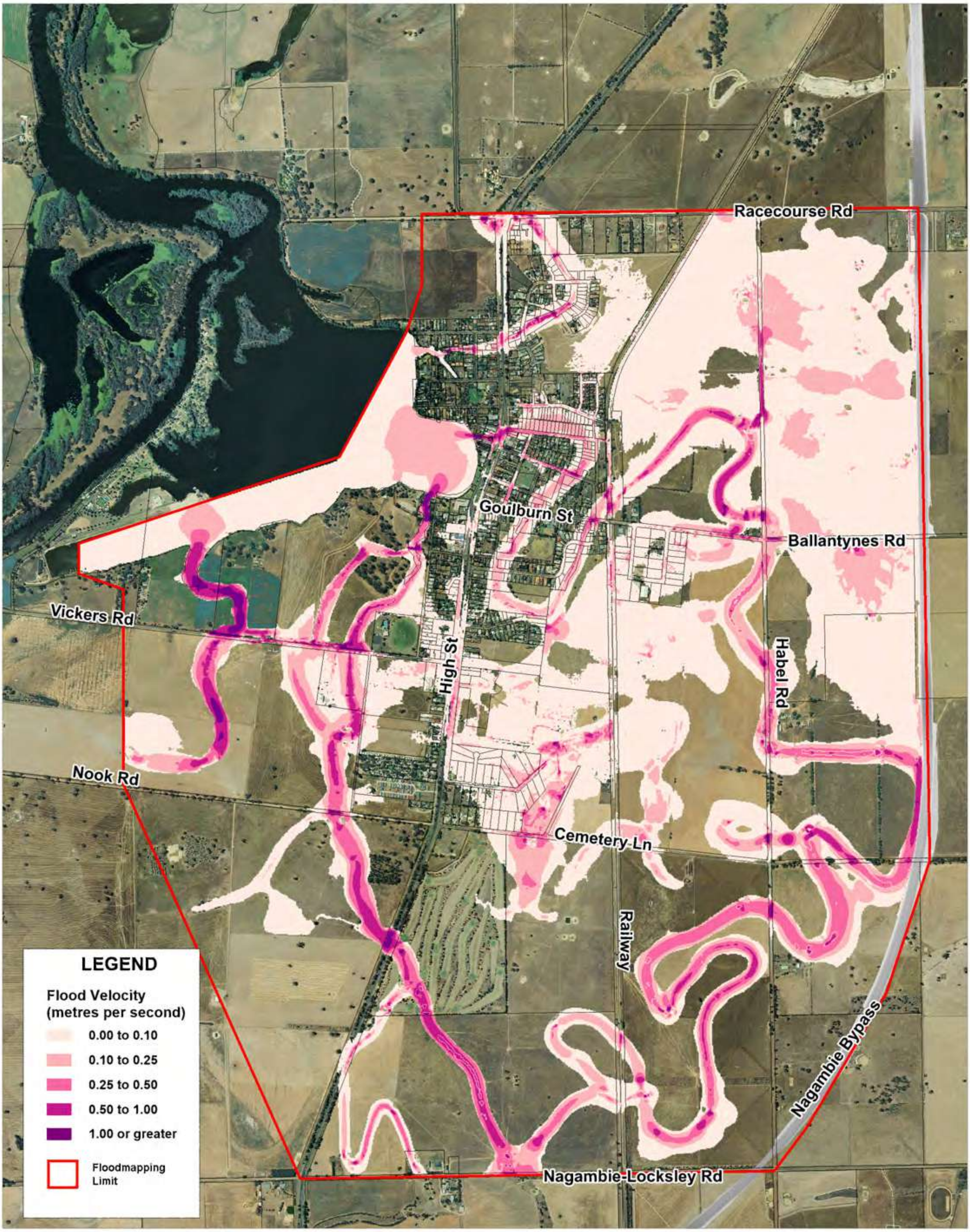
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigE-26_100yrFldVel_RevA.WOR



Title:

Nagambie Flood Study

200 Year ARI Peak Flood Velocity - Developed Climate Change

Figure: **E-27**

Rev: **A**

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N

0 0.5 1km

Approx. Scale

BMT WBM

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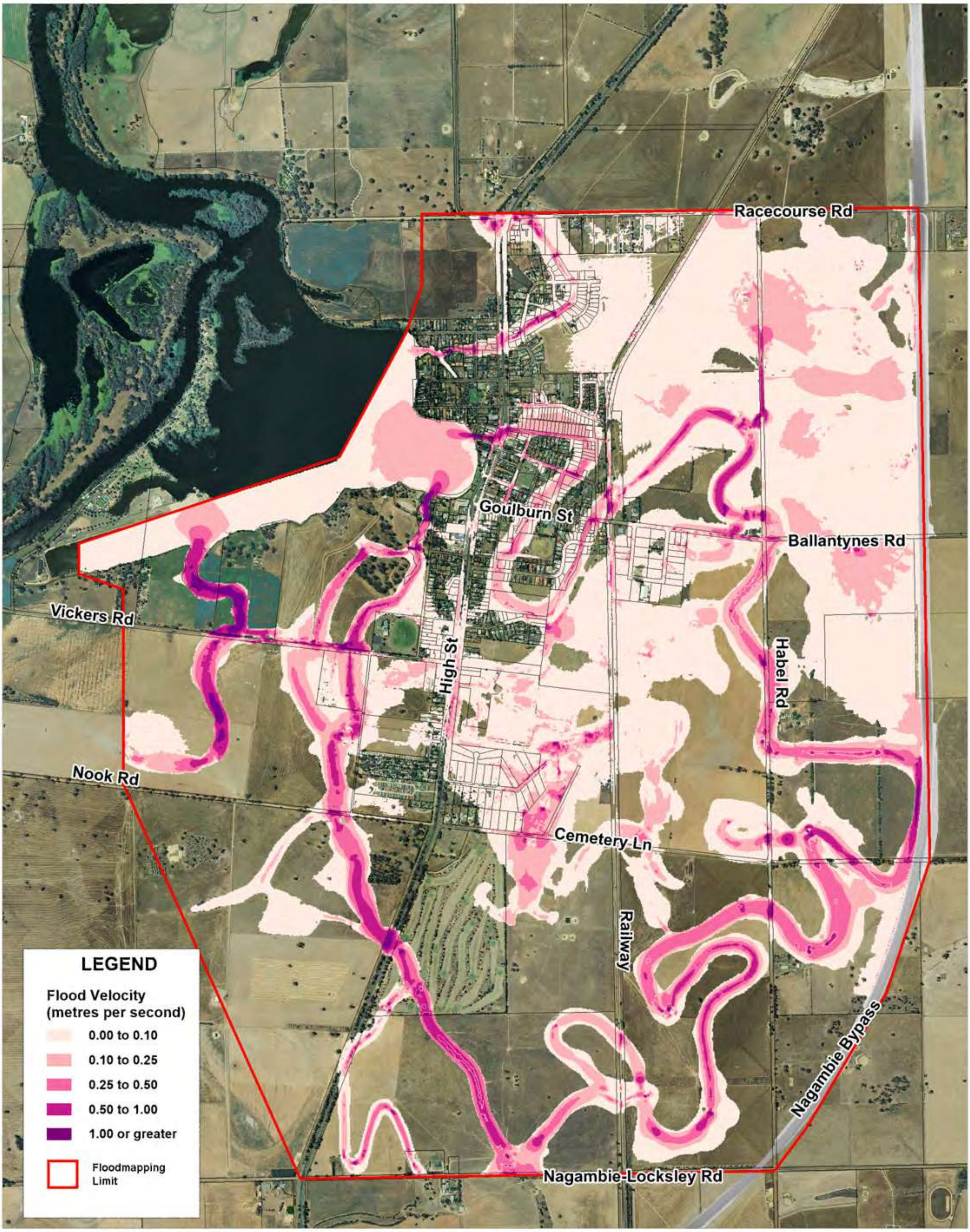
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigE-27_200yrFldVel_RevA.WOR



Title:
Nagambie Flood Study
500 Year ARI Peak Flood Velocity - Developed Climate Change

Figure: **E-28**

Rev: **A**

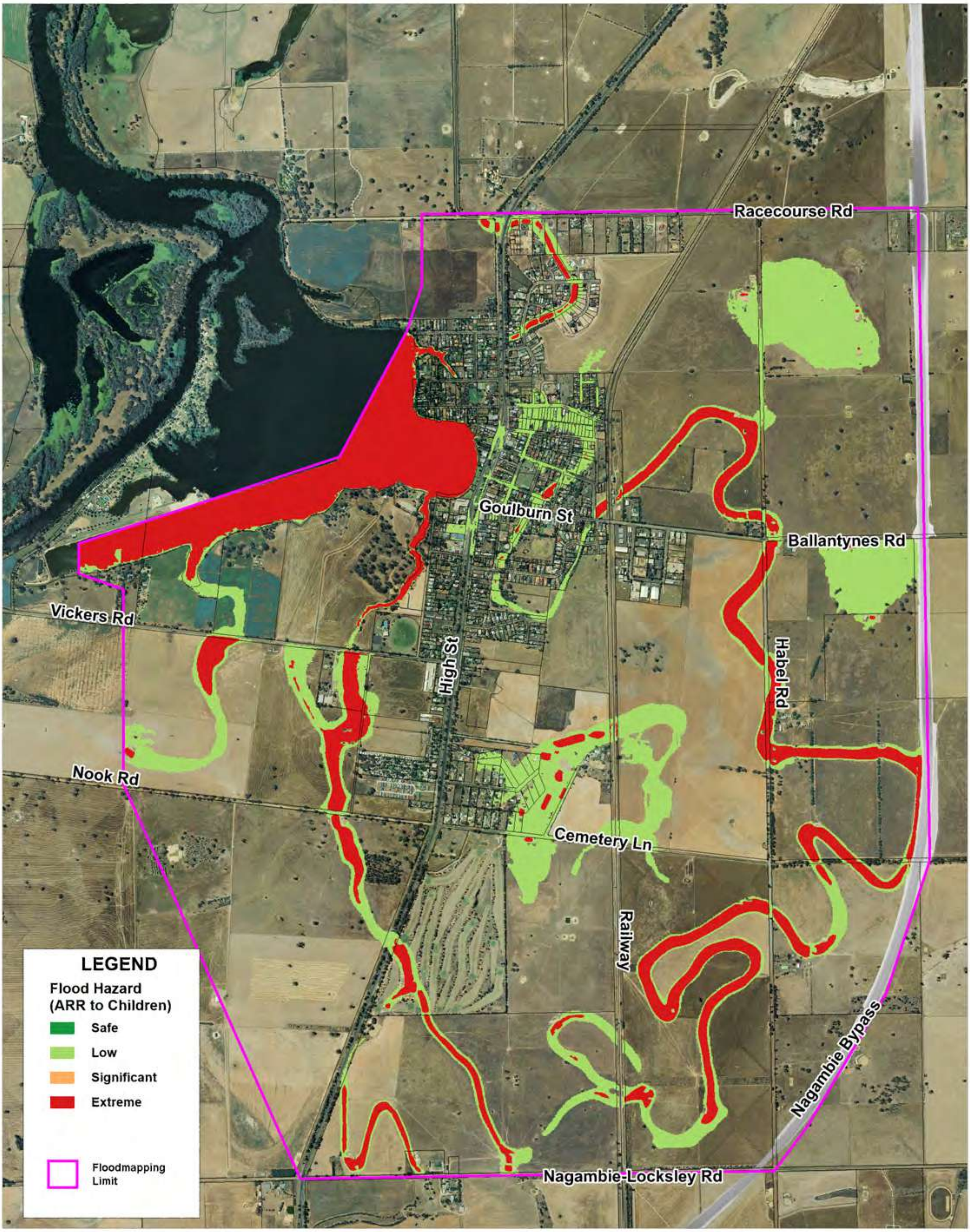
N

0 0.5 1km
Approx. Scale

BMT WBM
www.bmtwbm.com.au

Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigE-28_500yrFldVel_RevA.WOR

Appendix F Peak Flood Hazard



Title:

Nagambie Flood Study

5 Year ARI Peak Flood Hazard - Existing Conditions

Figure: **F-1**

Rev: **A**

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N

0 0.5 1km

Approx. Scale

BMT WBM

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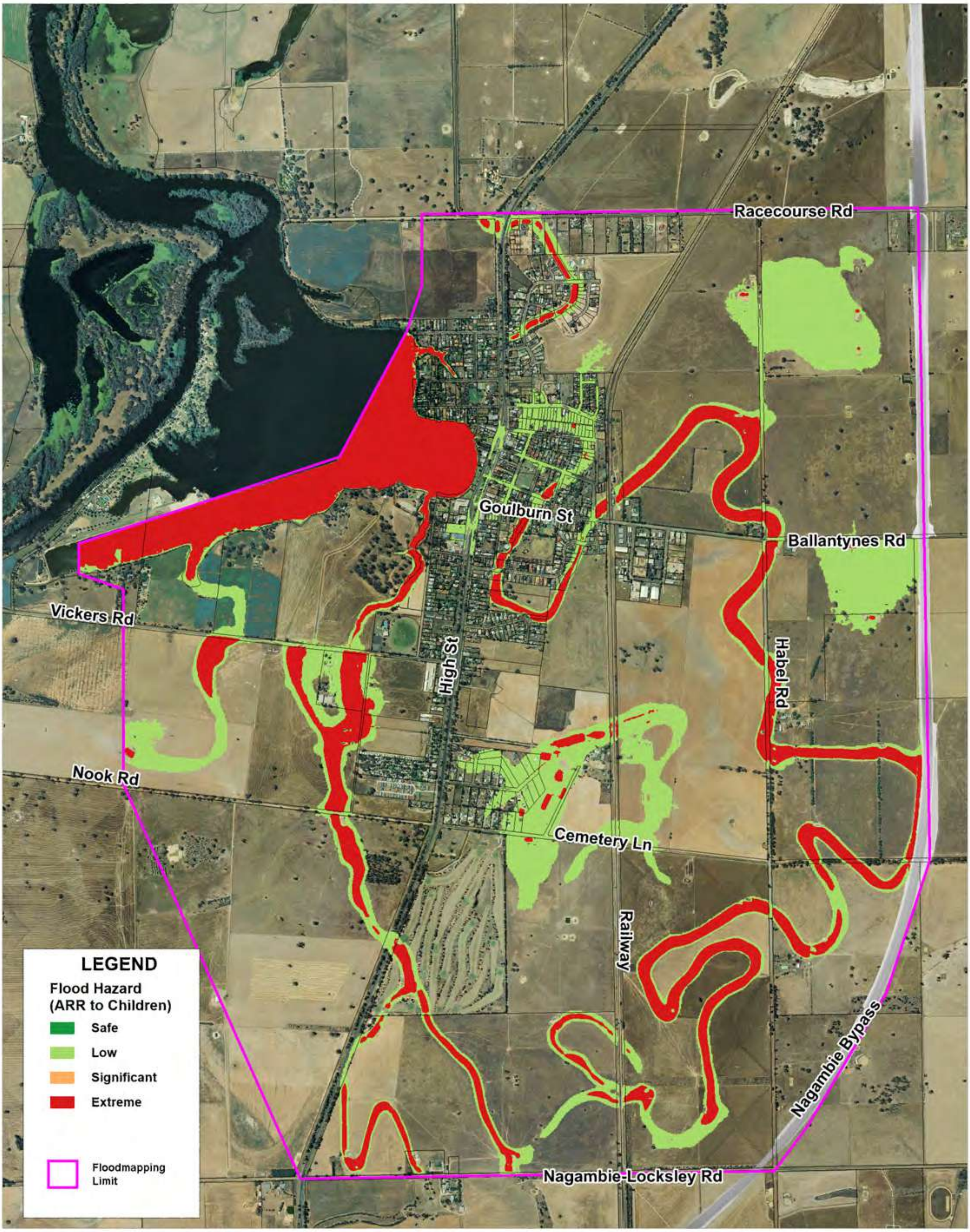
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigF-1_5yr _E01_FldHaz_RevA.WOR



Title:

Nagambie Flood Study

10 Year ARI Peak Flood Hazard - Existing Conditions

Figure: **F-2**

Rev: **A**

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N

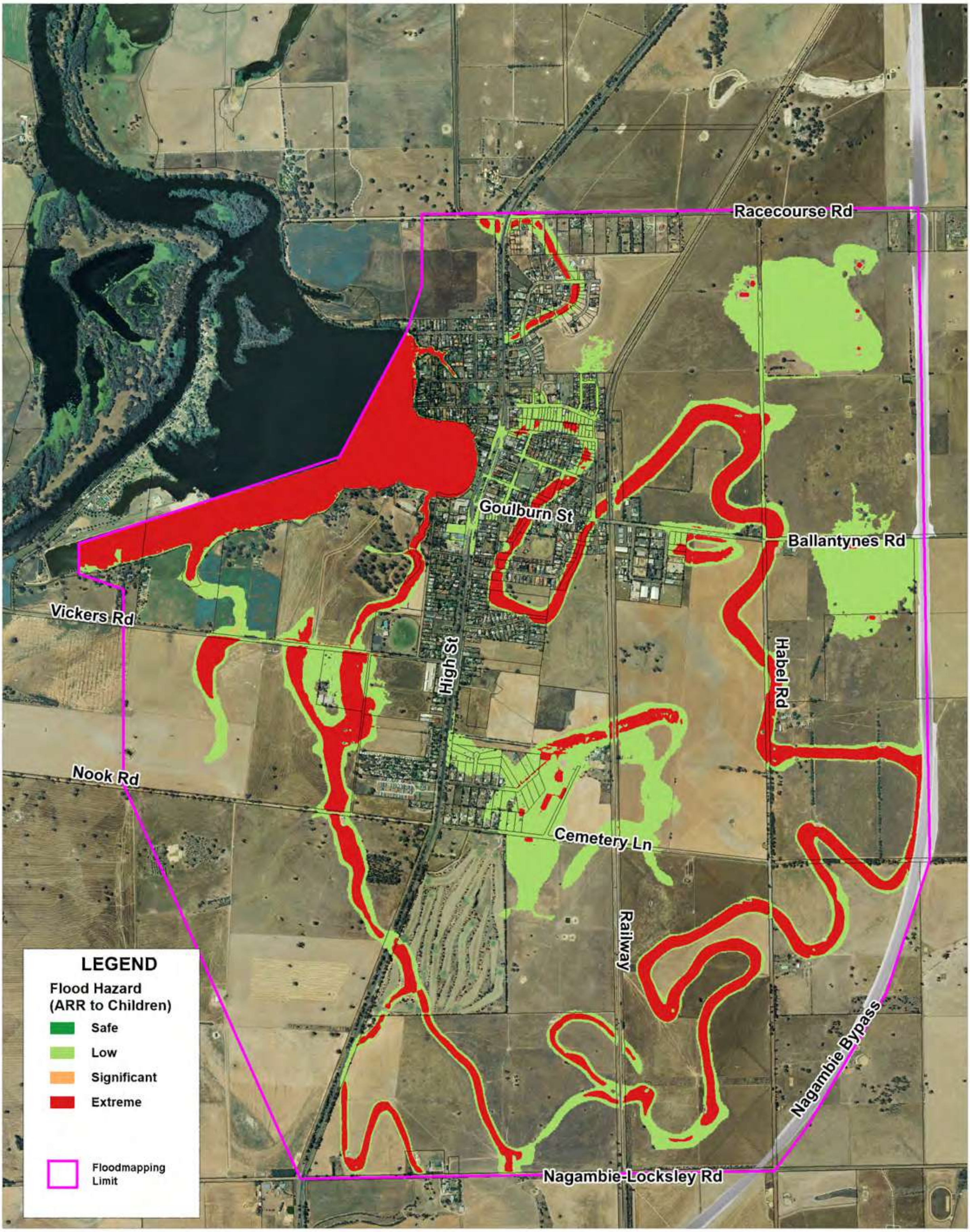
0 0.5 1km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigF-2_10yr _E01_FldHaz_RevA.WOR



Title:

Nagambie Flood Study
20 Year ARI Peak Flood Hazard - Existing Conditions

Figure:
F-3

Rev:
A

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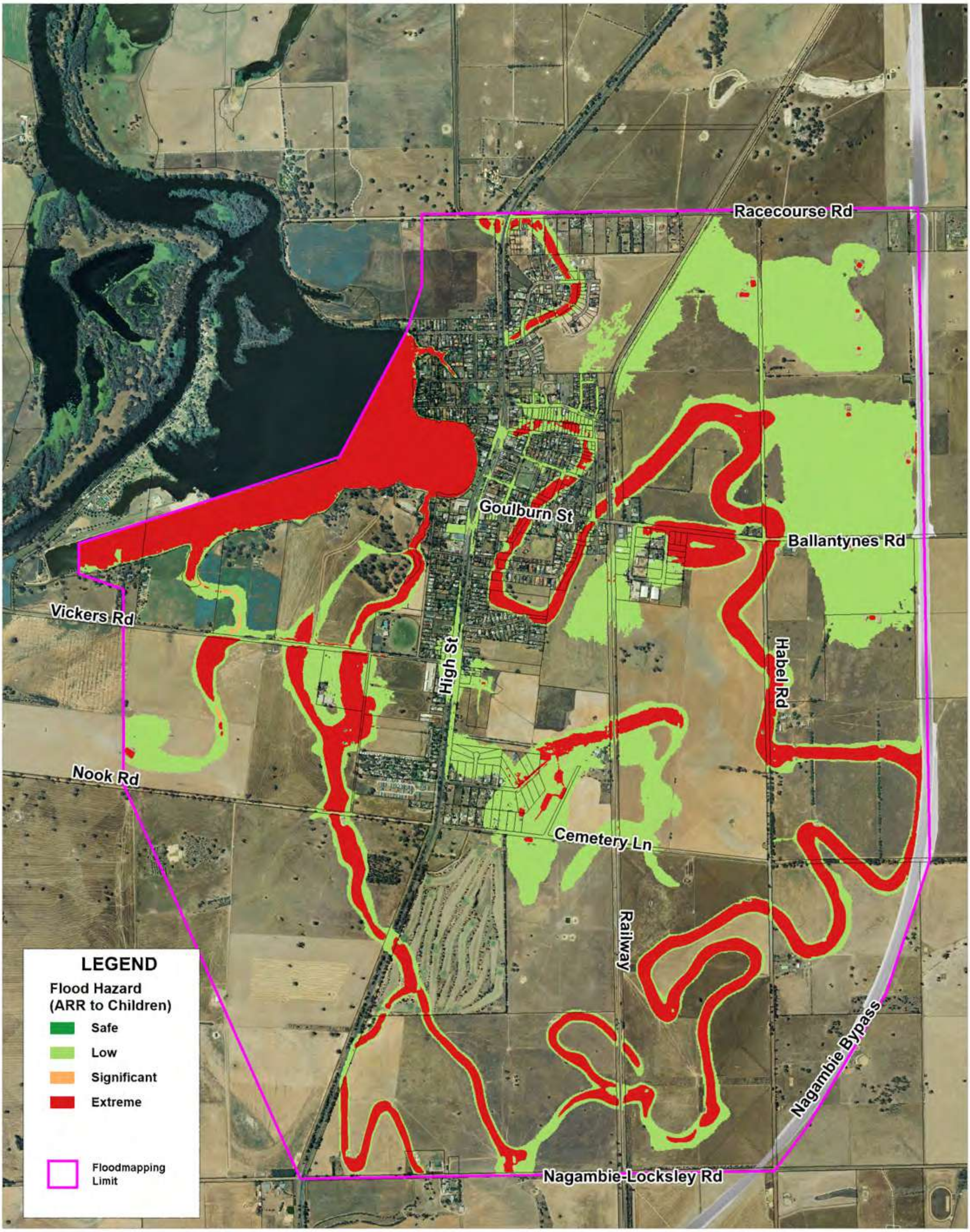
N

0 0.5 1km
Approx. Scale

BMT WBM
www.bmtwbm.com.au

Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigF-3_20yr _E01_FldHaz_RevA.WOR



Title:

Nagambie Flood Study
50 Year ARI Peak Flood Hazard - Existing Conditions

Figure: **F-4**

Rev: **A**

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N

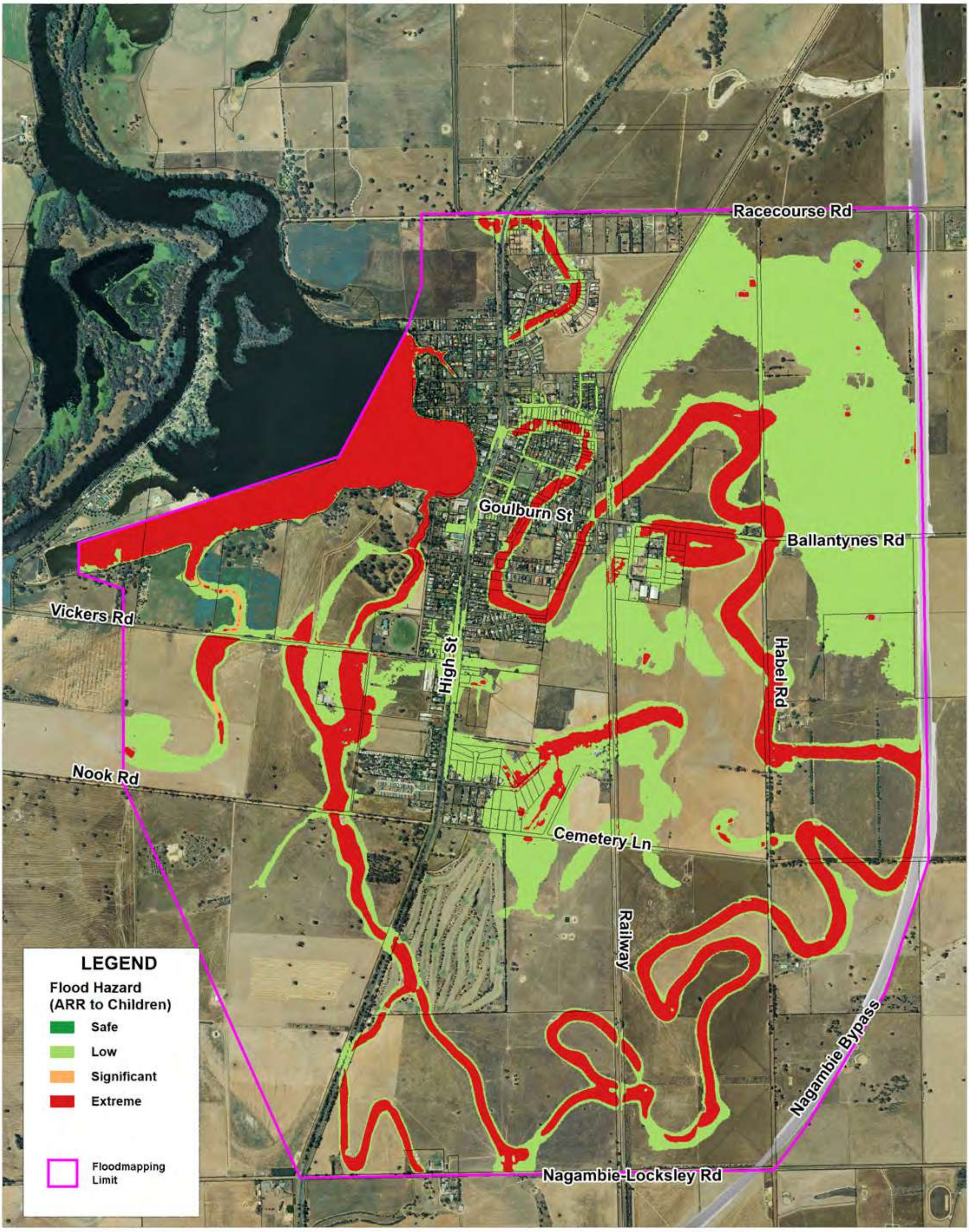
0 0.5 1km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigF-4_50yr _E01_FldHaz_RevA.WOR



Title:

Nagambie Flood Study

100 Year ARI Peak Flood Hazard - Existing Conditions

Figure: **F-5**

Rev: **A**

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

0 0.5 1km

Approx. Scale

BMT WBM

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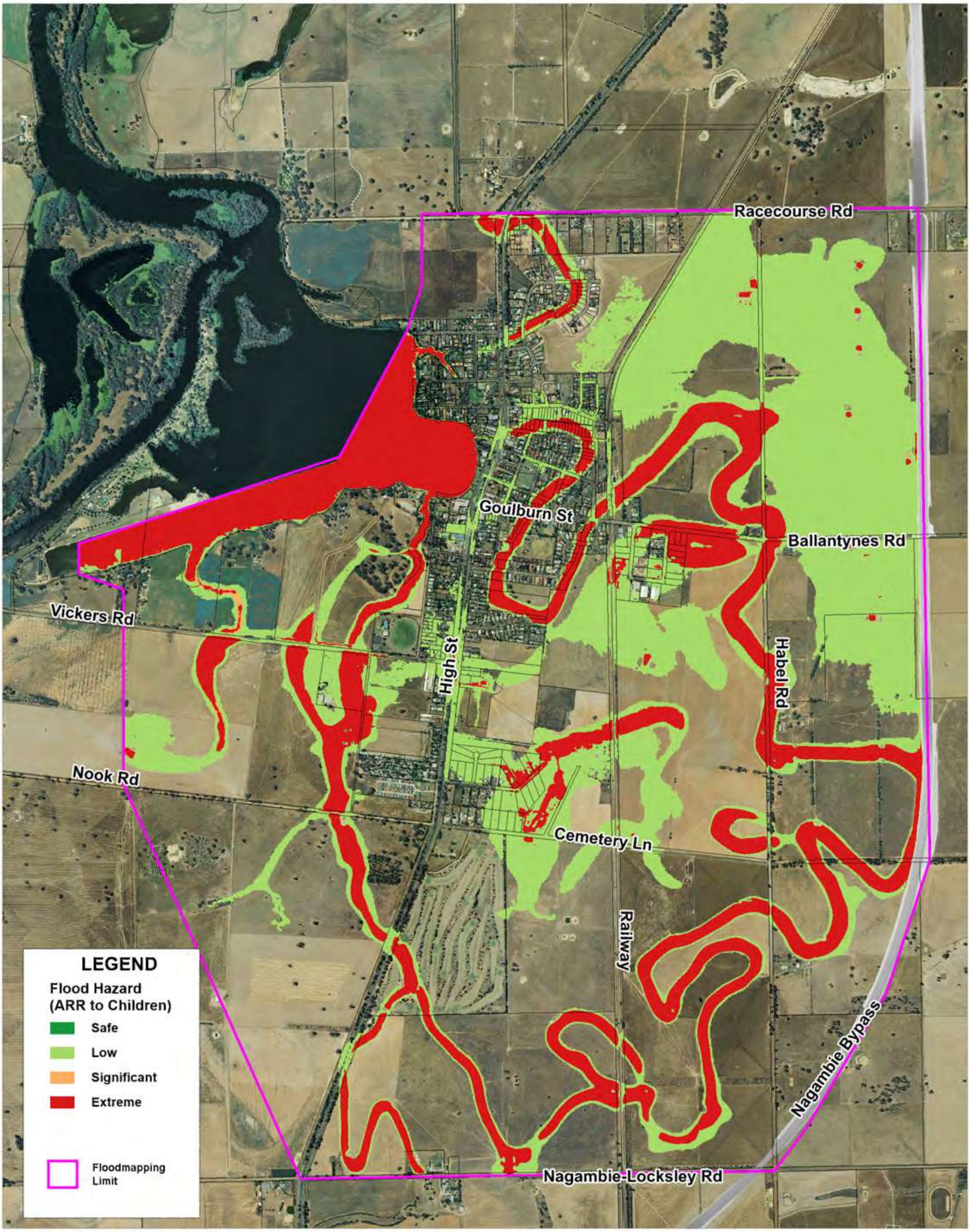
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigF-5_100yr _E01_FldHaz_RevA.WOR



Title:

Nagambie Flood Study
200 Year ARI Peak Flood Hazard - Existing Conditions

Figure: **F-6**

Rev: **A**

BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

N

0 0.5 1km

Approx. Scale

BMT WBM

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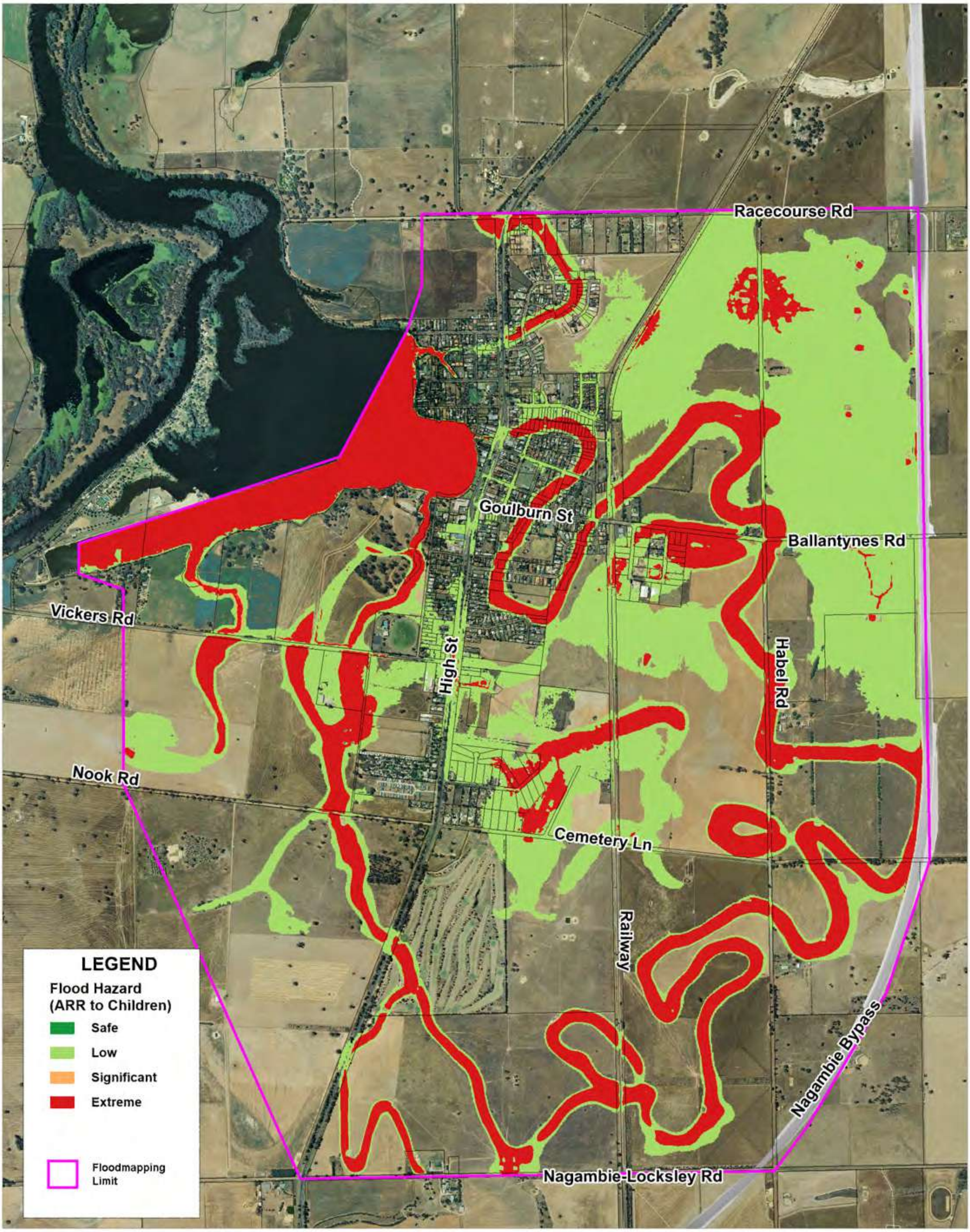
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigF-6_200yr _E01_FldHaz_RevA.WOR



Title:

Nagambie Flood Study
500 Year ARI Peak Flood Hazard - Existing Conditions

Figure: F-7

Rev: A

N

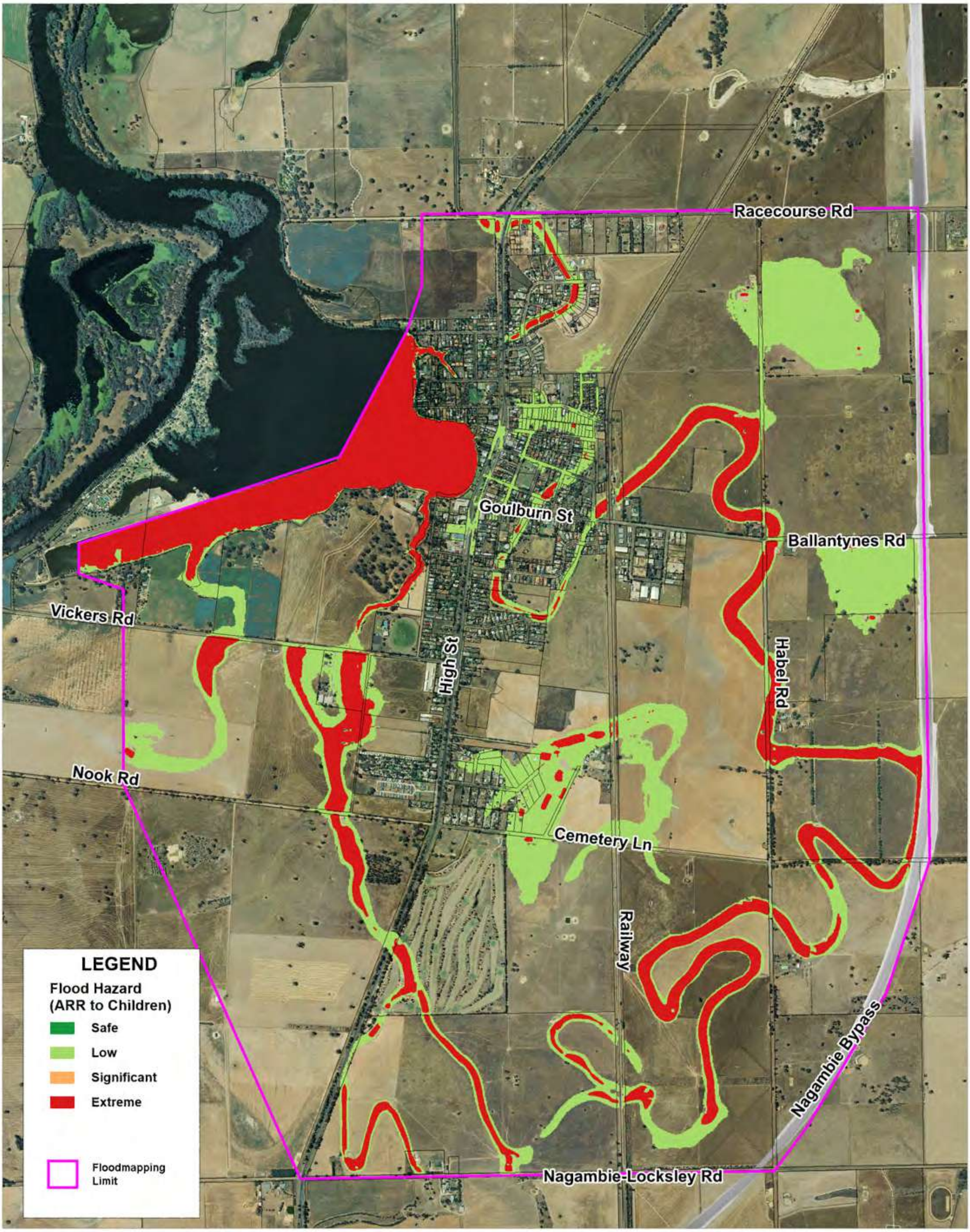
0 0.5 1km

Approx. Scale

BMT WBM

www.bmtwbm.com.au

Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigF-7_500yr _E01_FldHaz_RevA.WOR



Title:

Nagambie Flood Study
5 Year ARI Peak Flood Hazard - Developed Conditions

Figure: F-8

Rev: A

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N

0 0.5 1km

Approx. Scale

BMT WBM

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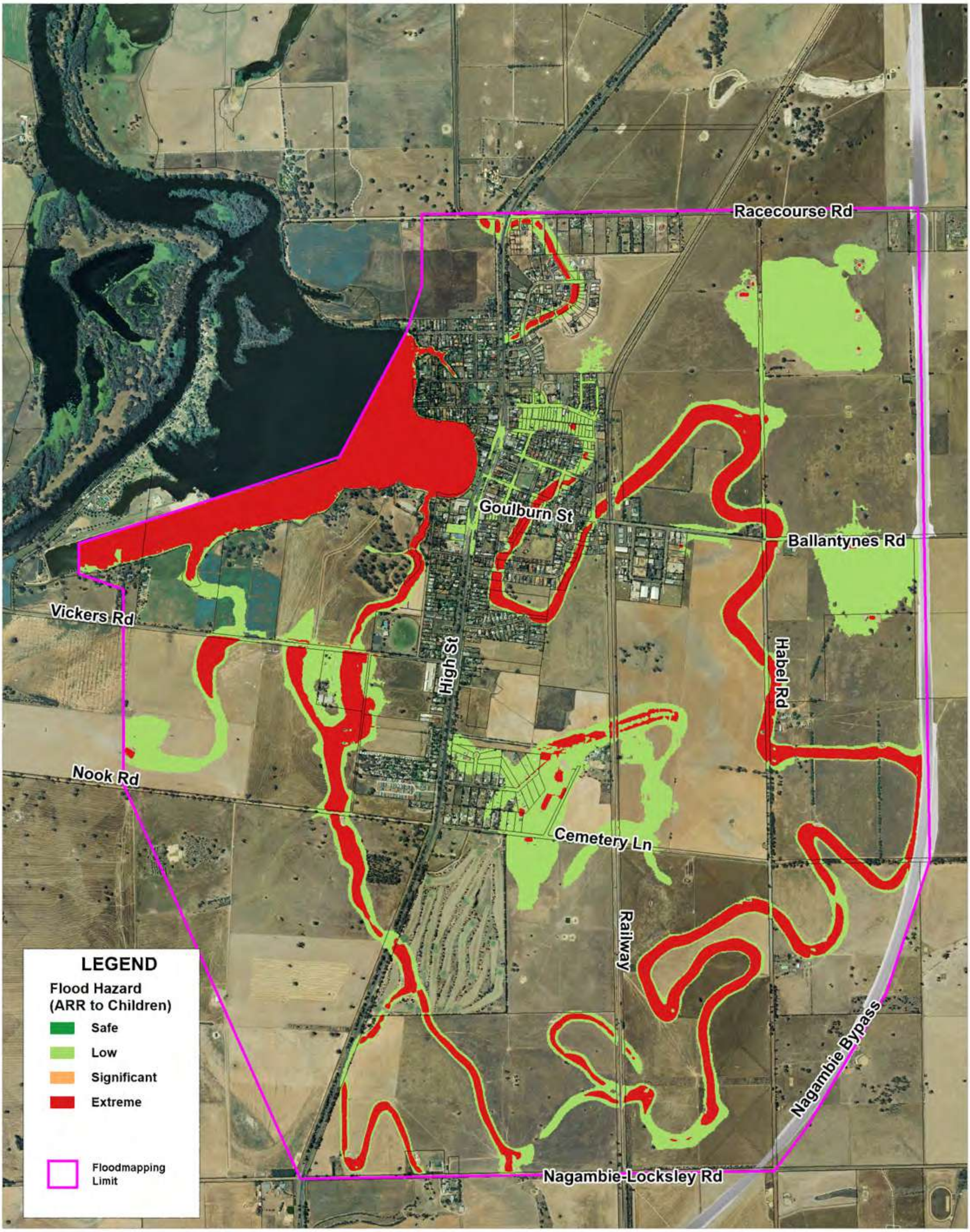
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigF-8_5yr _E01_FldHaz_RevA.WOR



Title:

Nagambie Flood Study

10 Year ARI Peak Flood Hazard - Developed Conditions

Figure: **F-9**

Rev: **A**

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N

0 0.5 1km

Approx. Scale

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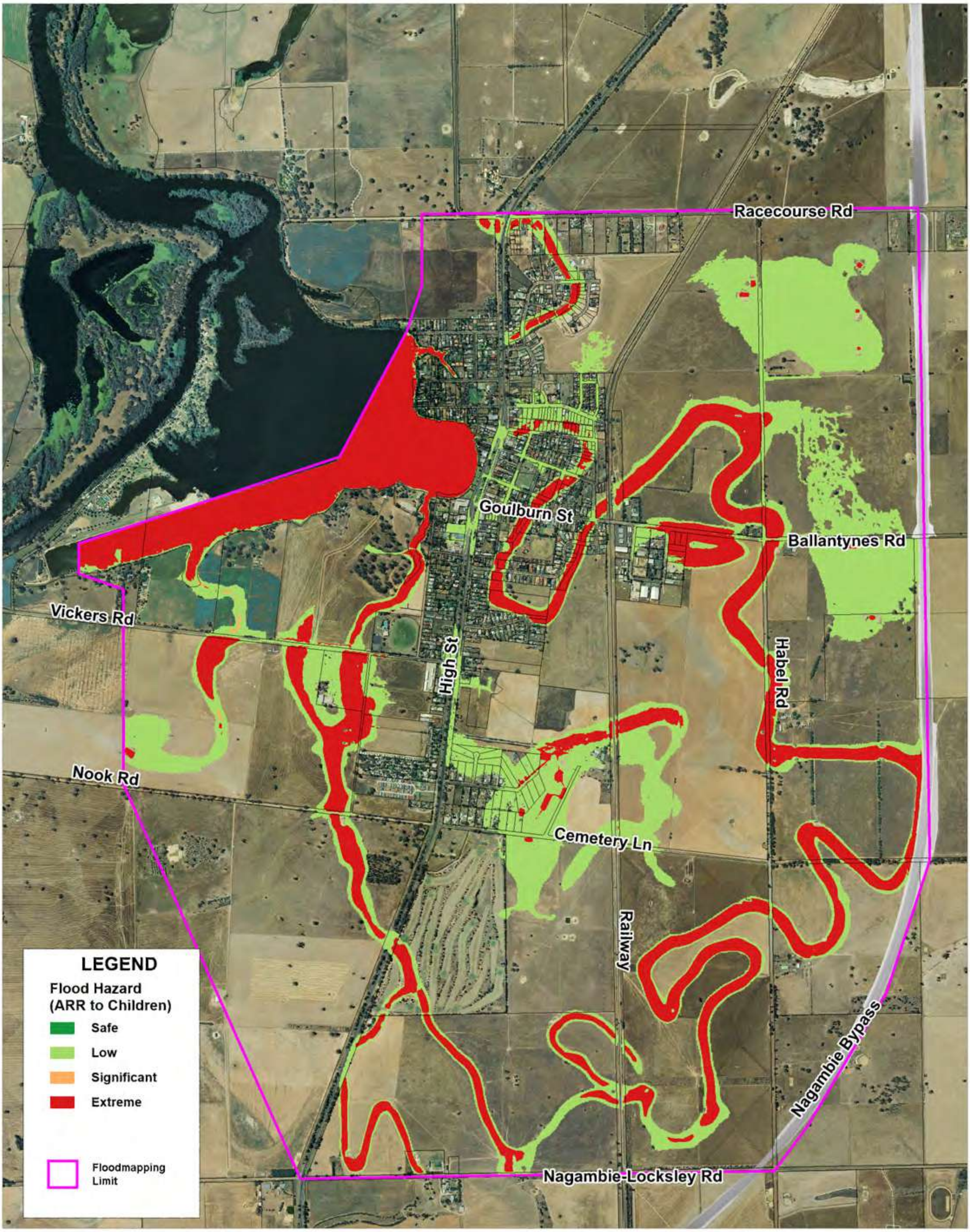

Title:

Nagambie Flood Study
20 Year ARI Peak Flood Hazard - Developed Conditions

Figure: **F-10**

Rev: **A**

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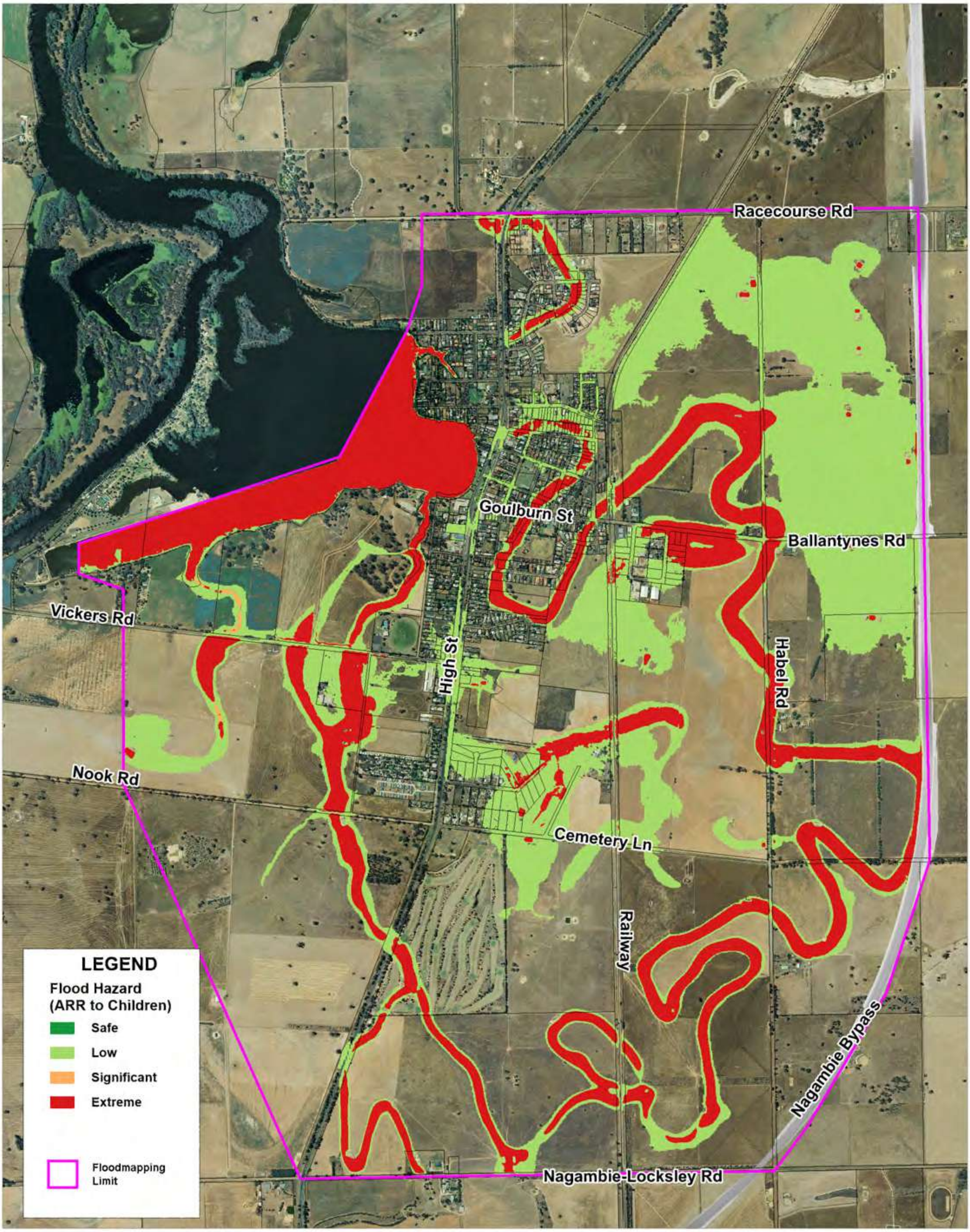

Title:

Nagambie Flood Study
50 Year ARI Peak Flood Hazard - Developed Conditions

Figure: **F-11**

Rev: **A**

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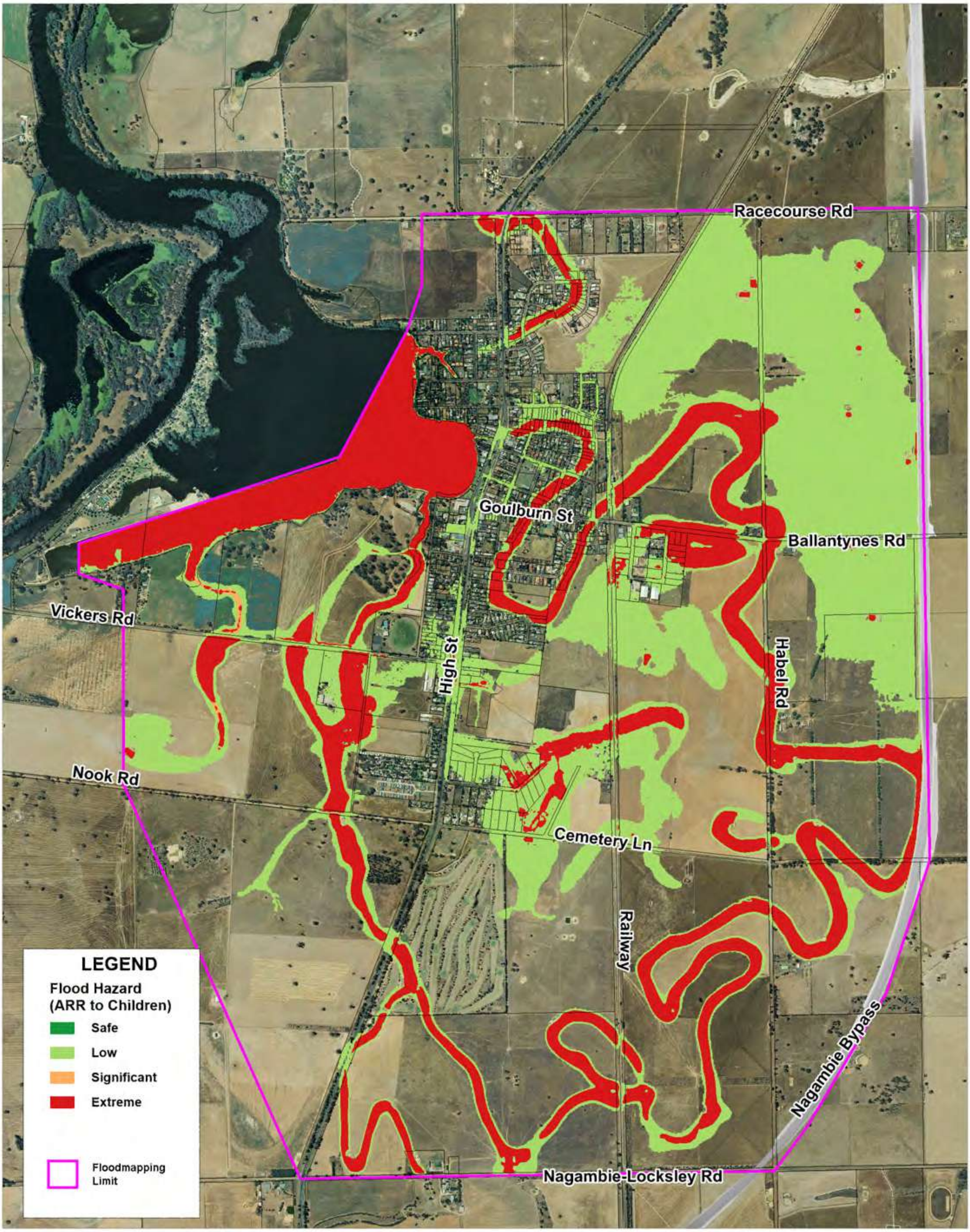

Title:

Nagambie Flood Study
100 Year ARI Peak Flood Hazard - Developed Conditions

Figure: **F-12**

Rev: **A**

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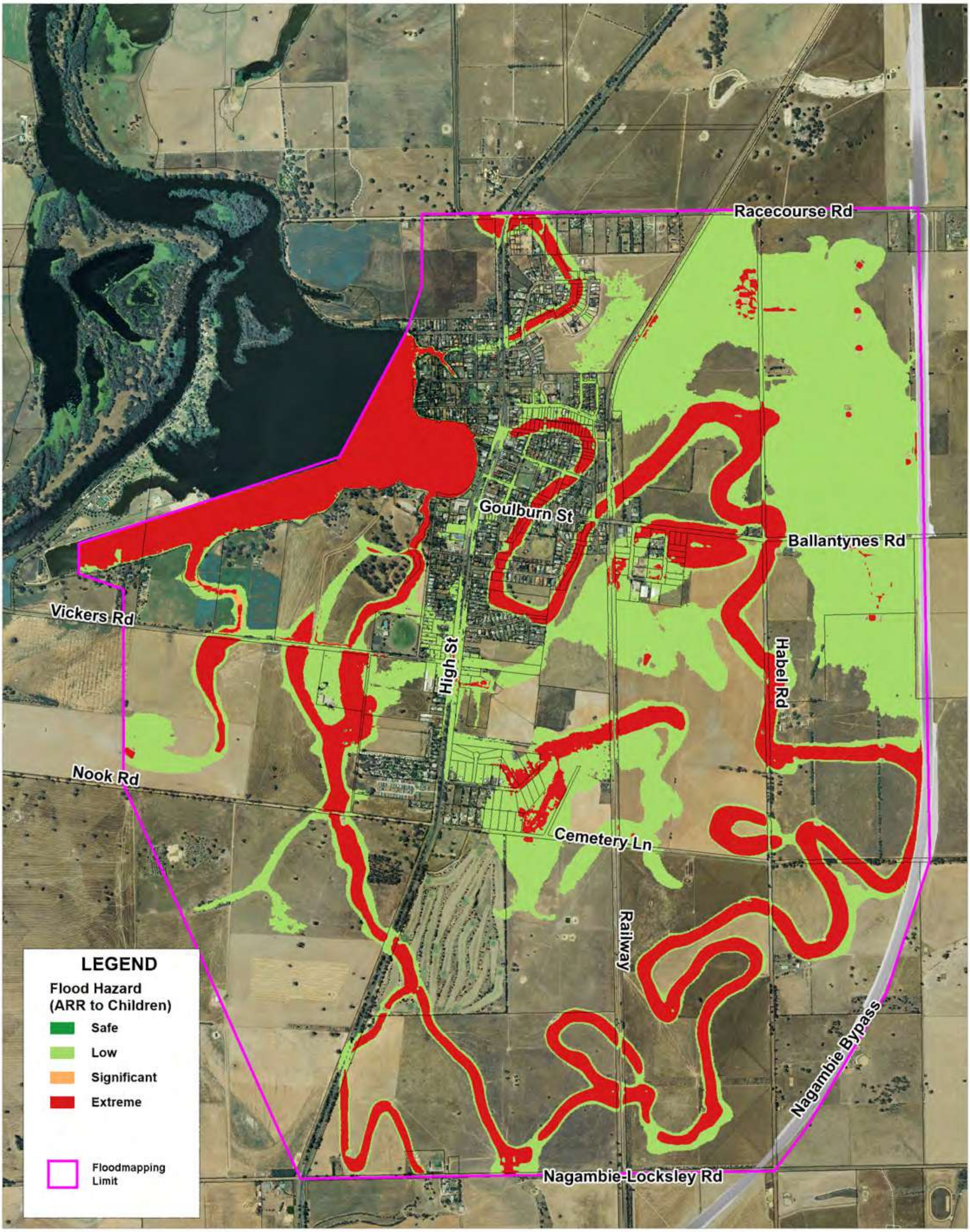
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigF-12_100yr _E01_FldHaz_RevA.WOR



Title:

Nagambie Flood Study
200 Year ARI Peak Flood Hazard - Developed Conditions

Figure: **F-13**

Rev: **A**

N

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Approx. Scale

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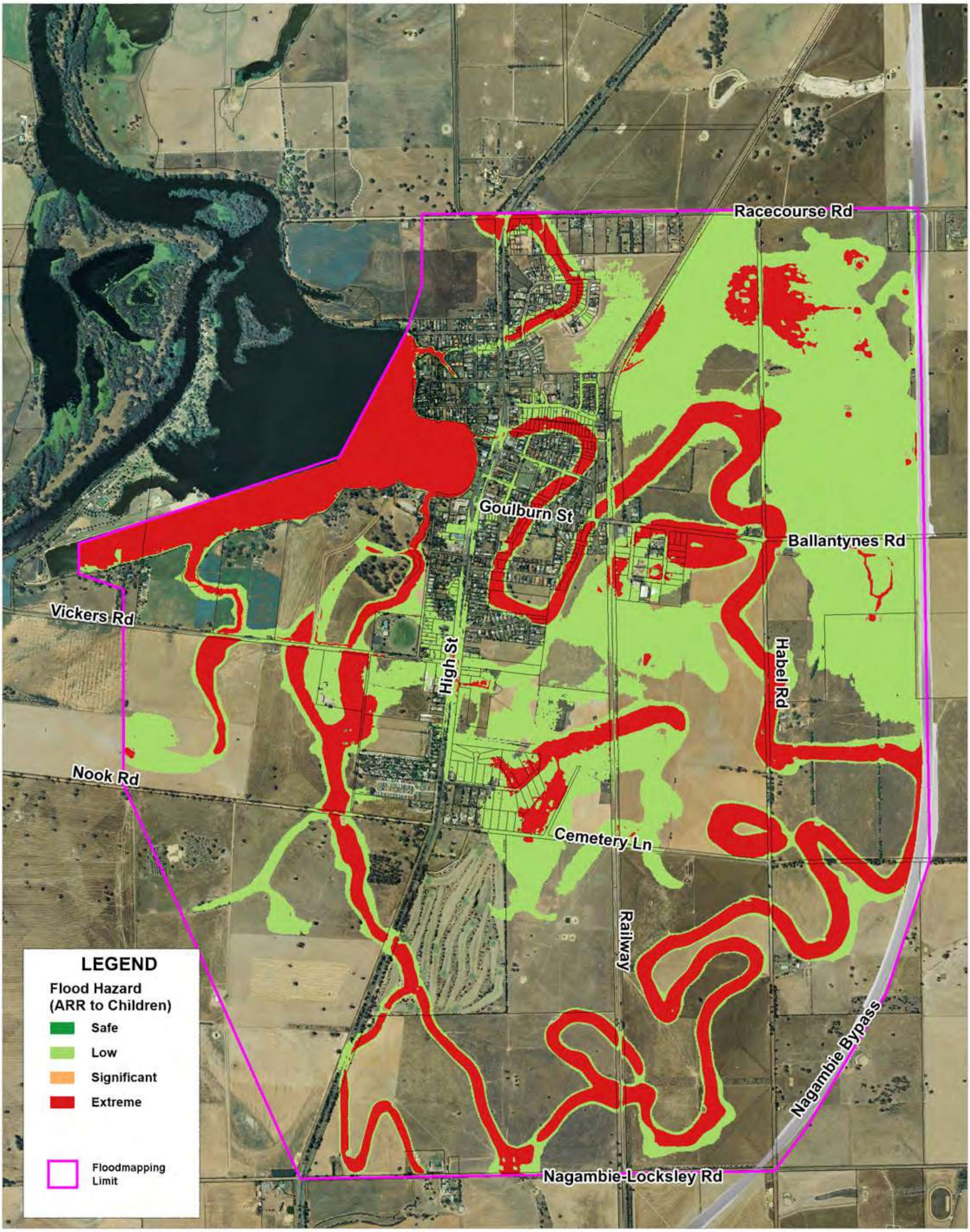
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigF-13_200yr _E01_FldHaz_RevA.WOR



Title:
Nagambie Flood Study
500 Year ARI Peak Flood Hazard - Developed Conditions

Figure: **F-14**

Rev: **A**

N

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Approx. Scale

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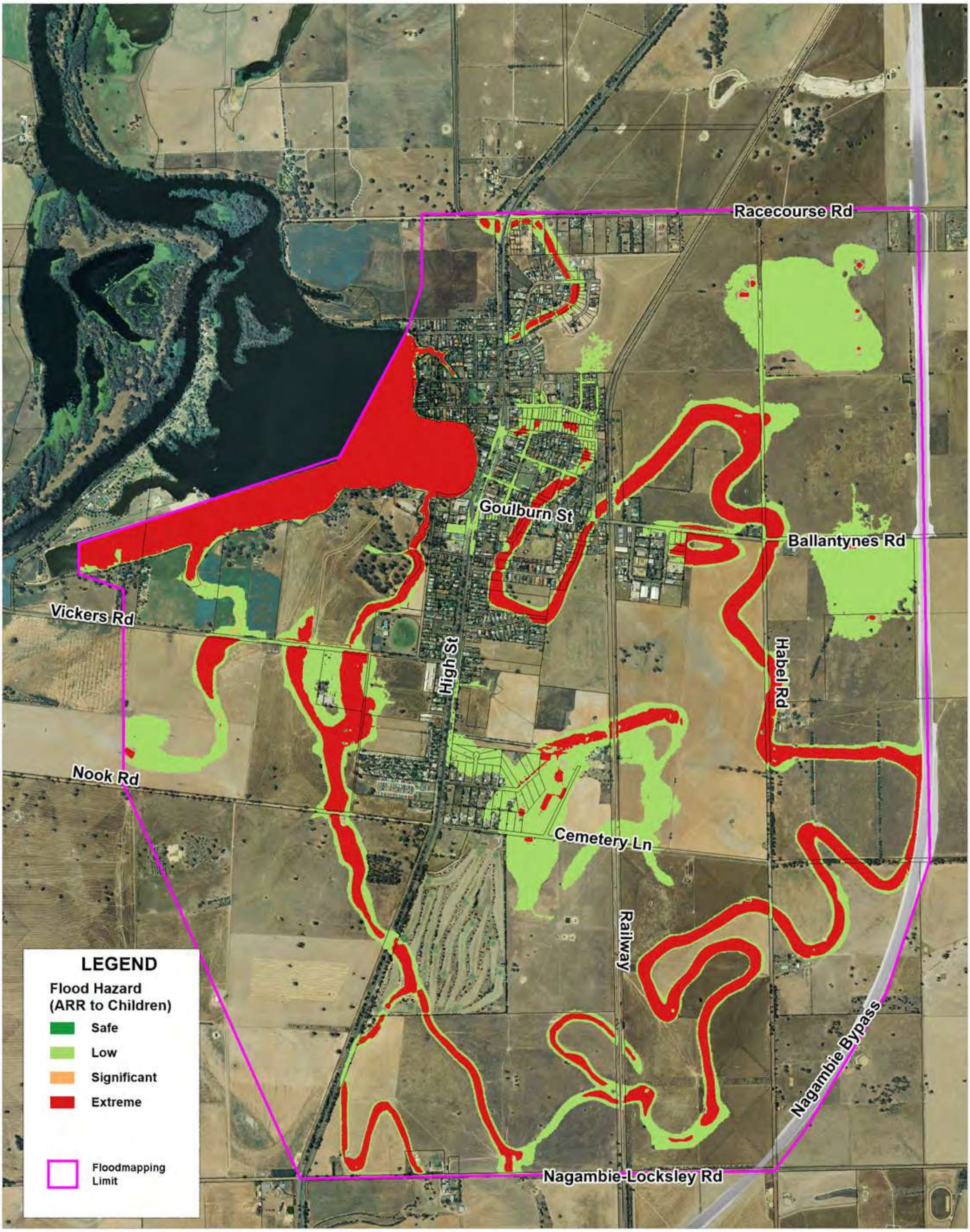
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigF-14_500yr _E01_FldHaz_RevA.WOR



Title:

Nagambie Flood Study
5 Year ARI Peak Flood Hazard - Climate Change

Figure: **F-15**

Rev: **A**

N

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Approx. Scale

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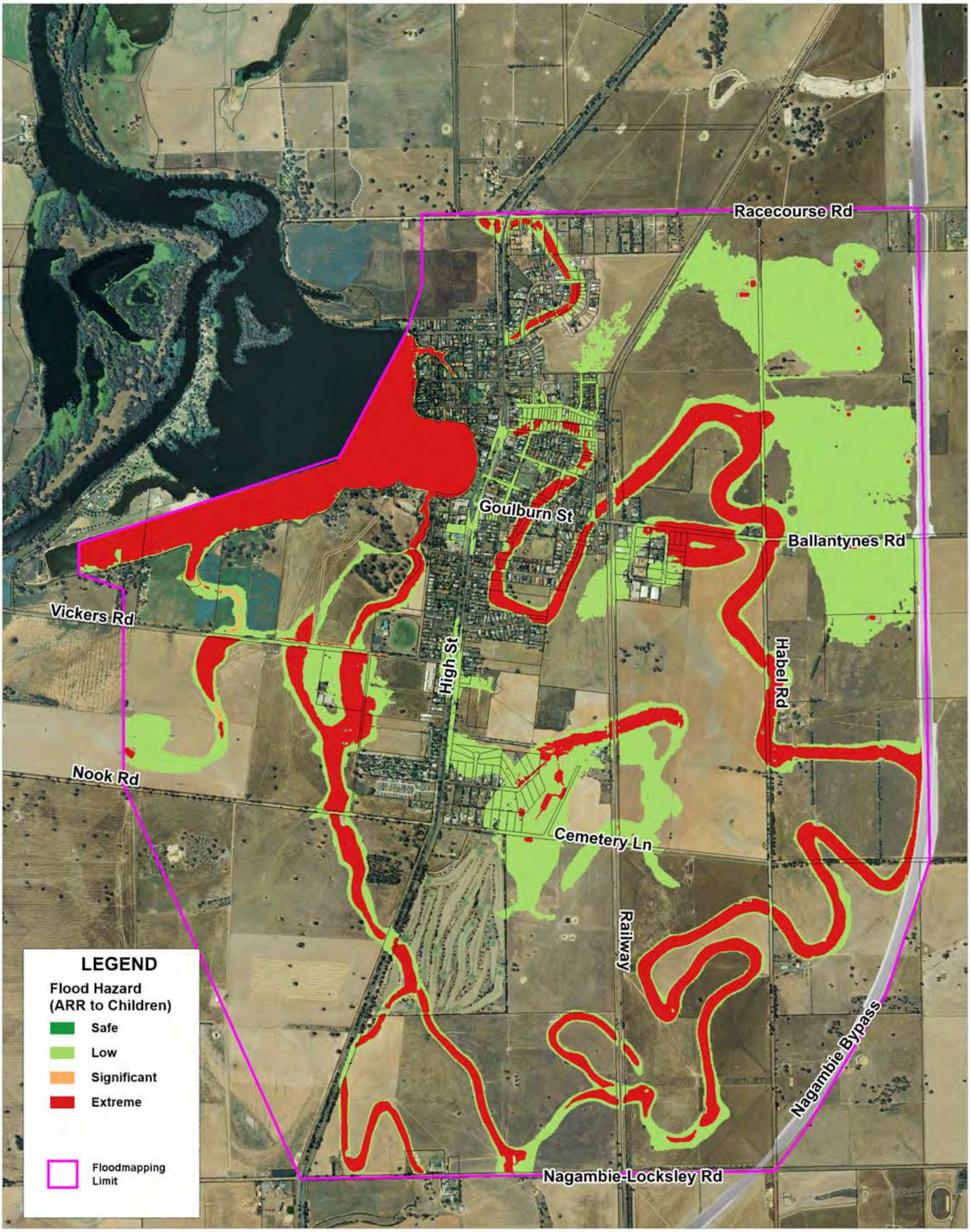
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigF-15_5yr _E01_FldHaz_RevA.WOR



Title:

Nagambie Flood Study
10 Year ARI Peak Flood Hazard - Climate Change

Figure: **F-16**

Rev: **A**

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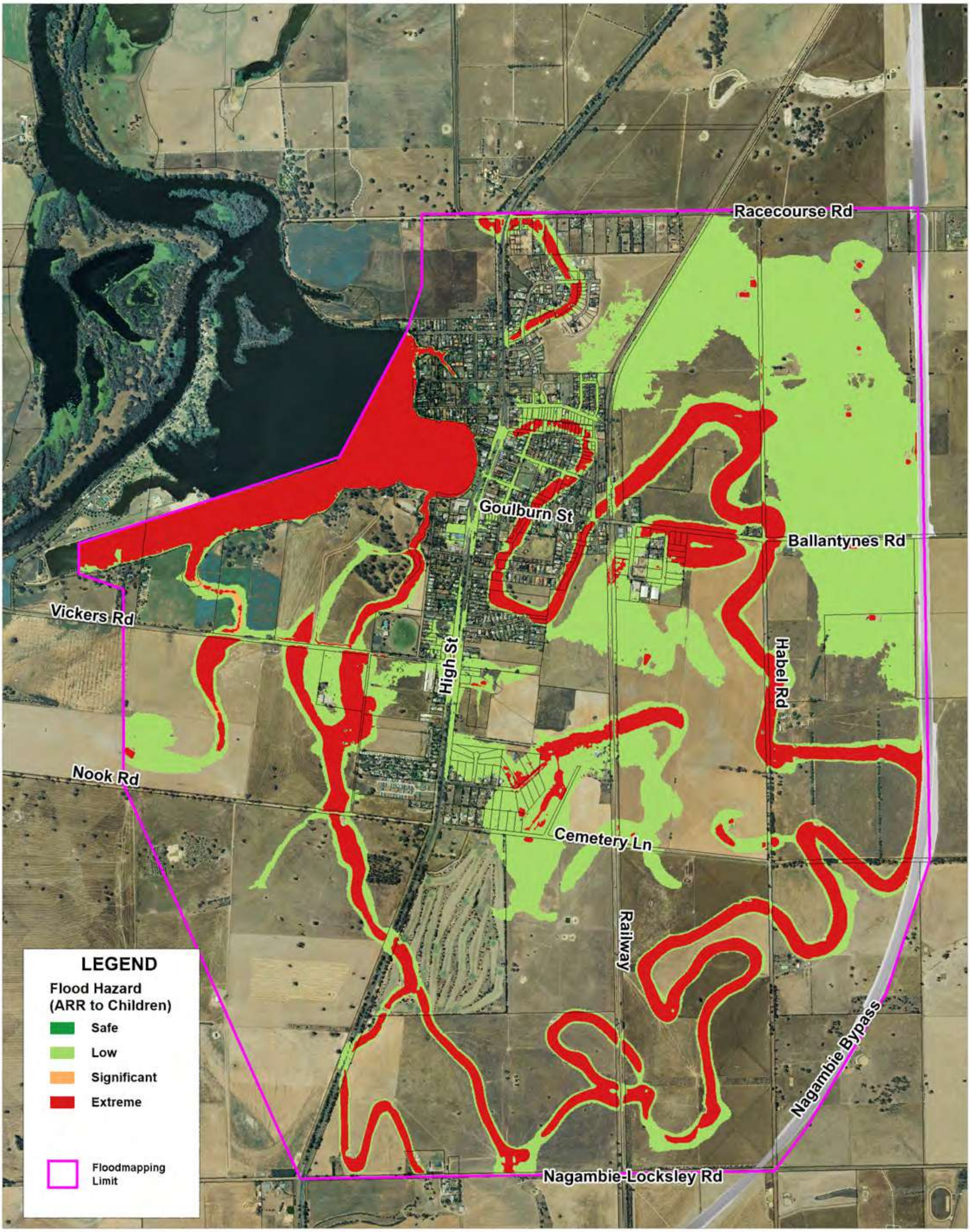

Title:

Nagambie Flood Study
20 Year ARI Peak Flood Hazard - Climate Change

Figure: **F-17**

Rev: **A**

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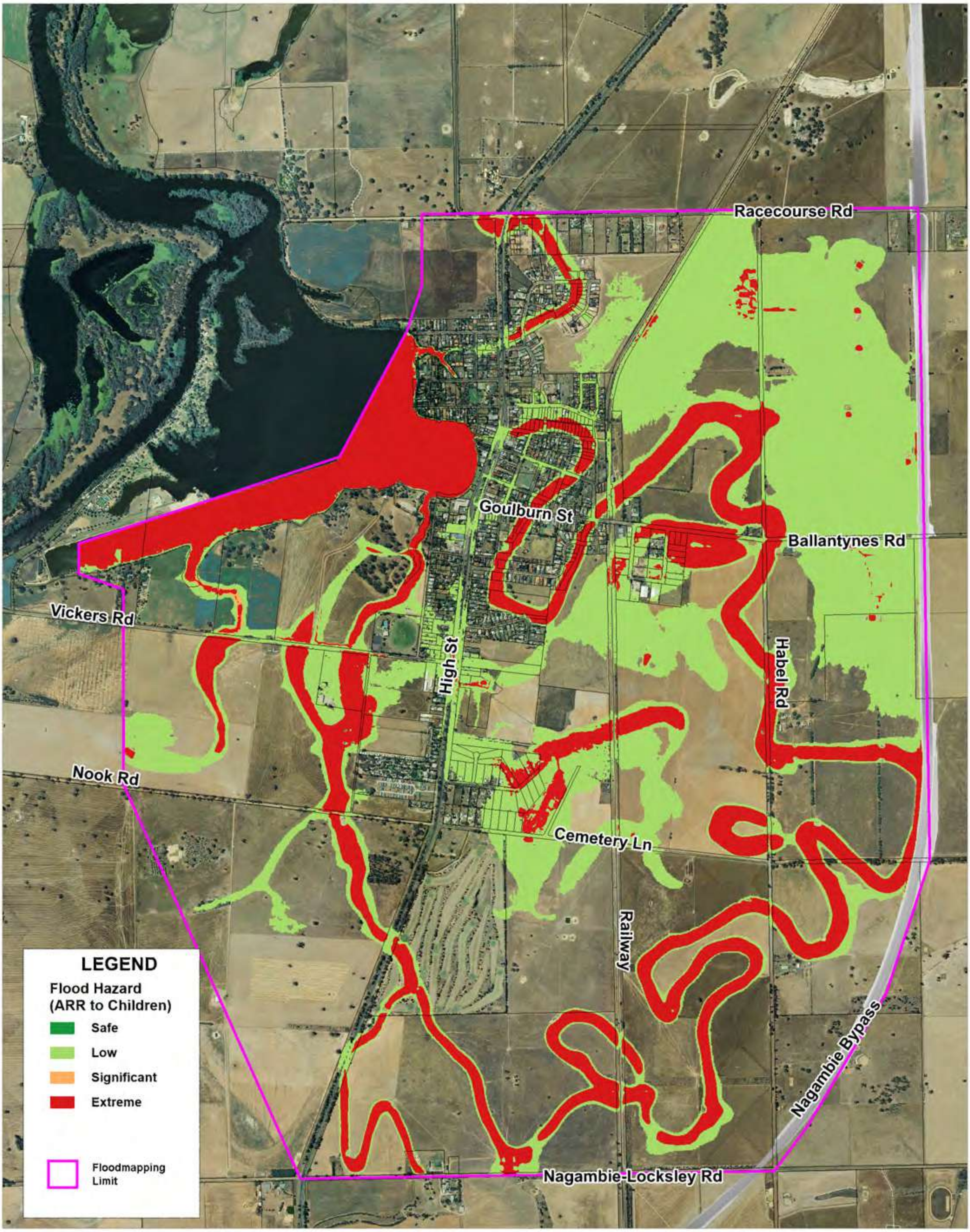
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigF-17_20yr _E01_FldHaz_RevA.WOR



Title:	Figure:	Rev:
Nagambie Flood Study **50 Year ARI Peak Flood Hazard - Climate Change**	**F-18**	**A**

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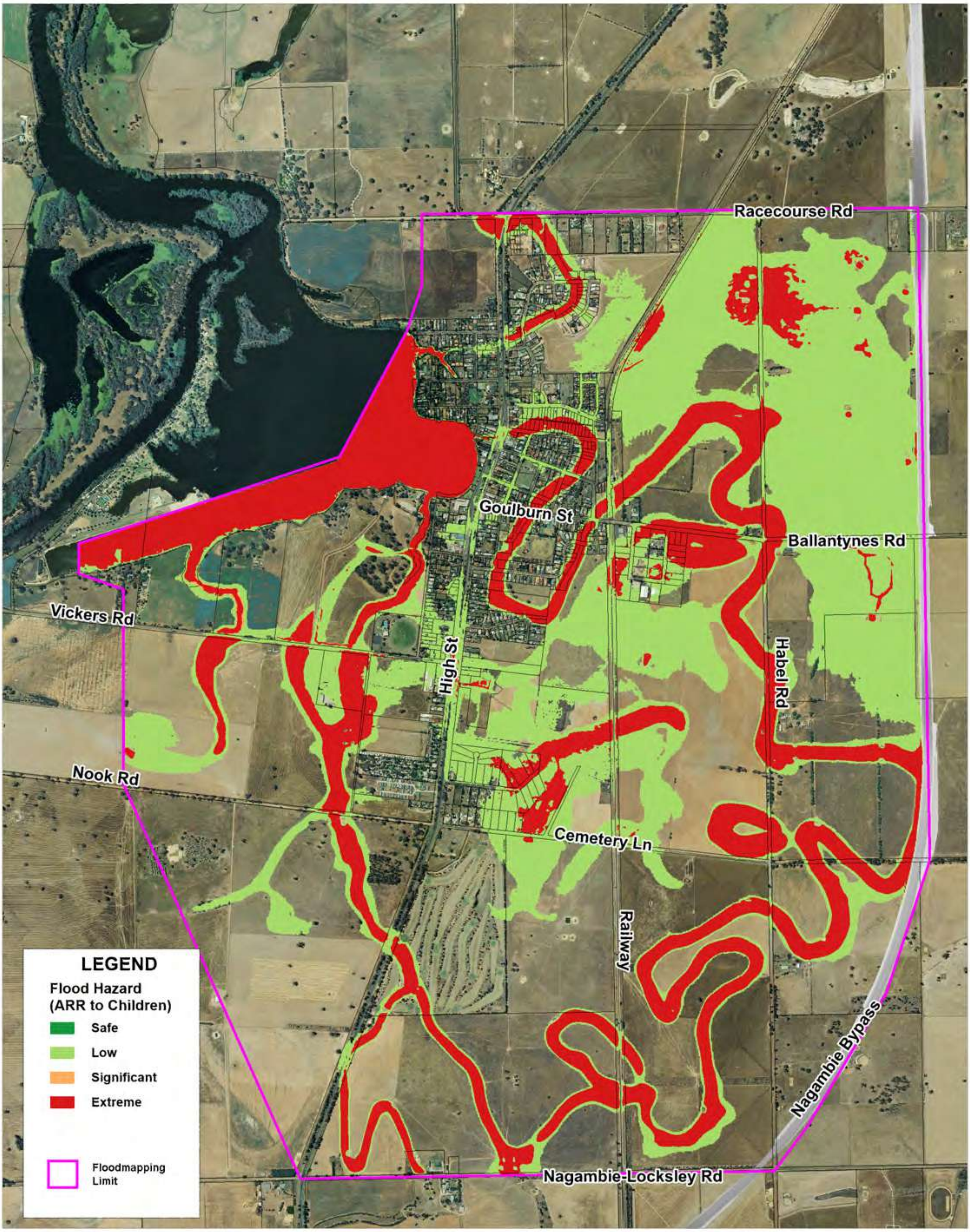
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigF-18_50yr _E01_FldHaz_RevA.WOR



Title:

Nagambie Flood Study
100 Year ARI Peak Flood Hazard - Climate Change

Figure: **F-19**

Rev: **A**

N

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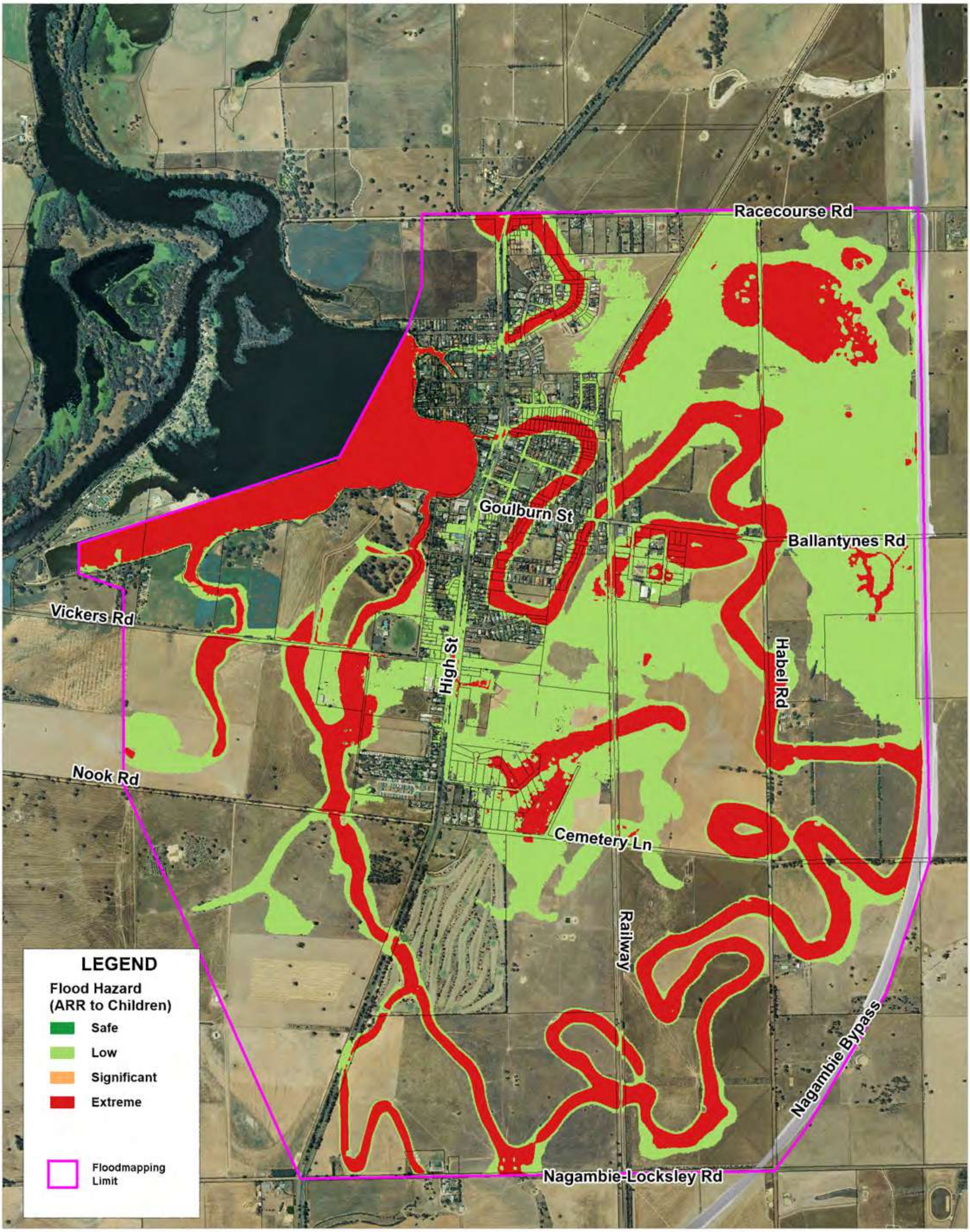
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigF-19_100yr _E01_FldHaz_RevA.WOR



Title:

Nagambie Flood Study
200 Year ARI Peak Flood Hazard - Climate Change

Figure: **F-20**

Rev: **A**

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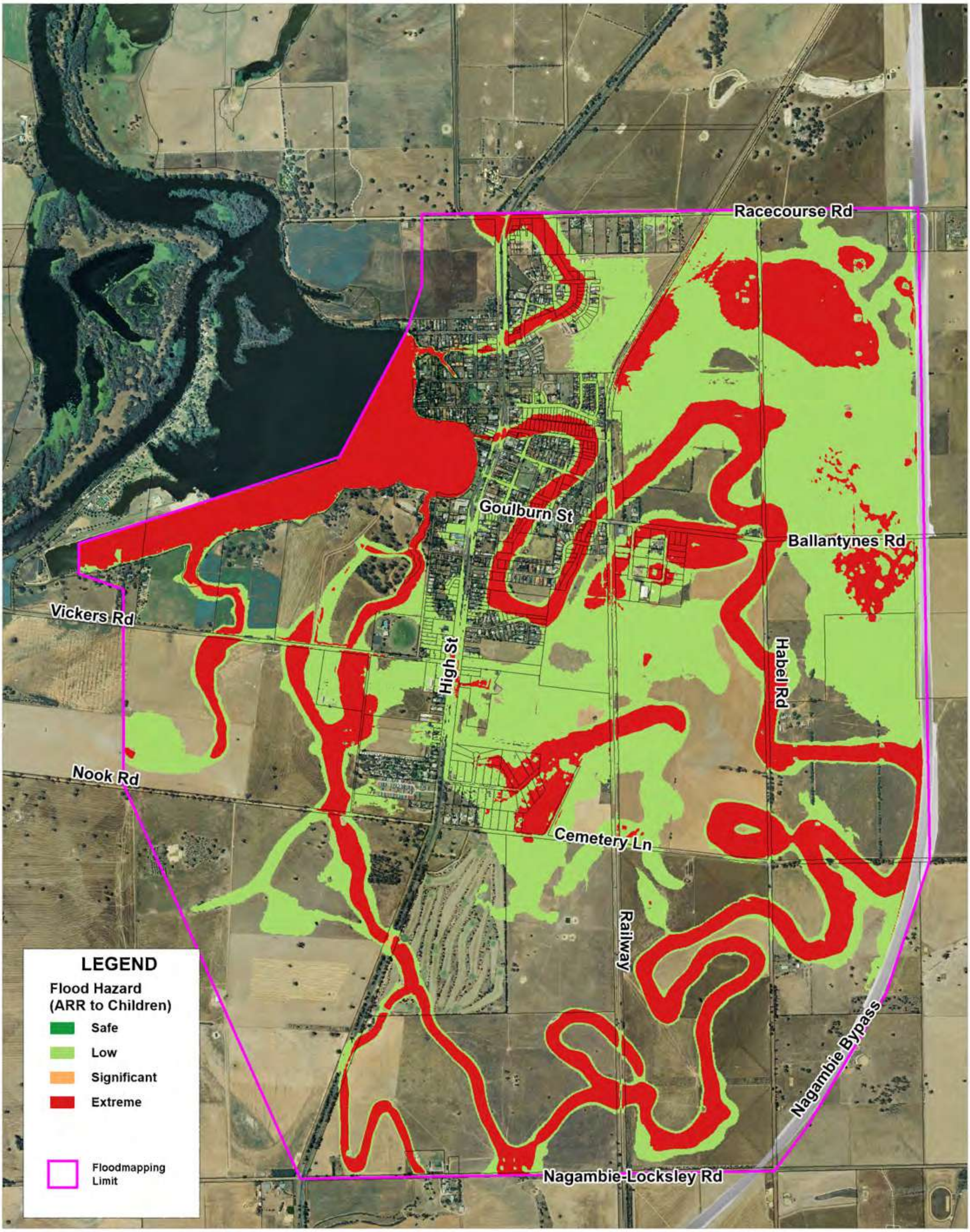

Title:
Nagambie Flood Study
500 Year ARI Peak Flood Hazard - Climate Change

Figure: **F-21**

Rev: **A**

N

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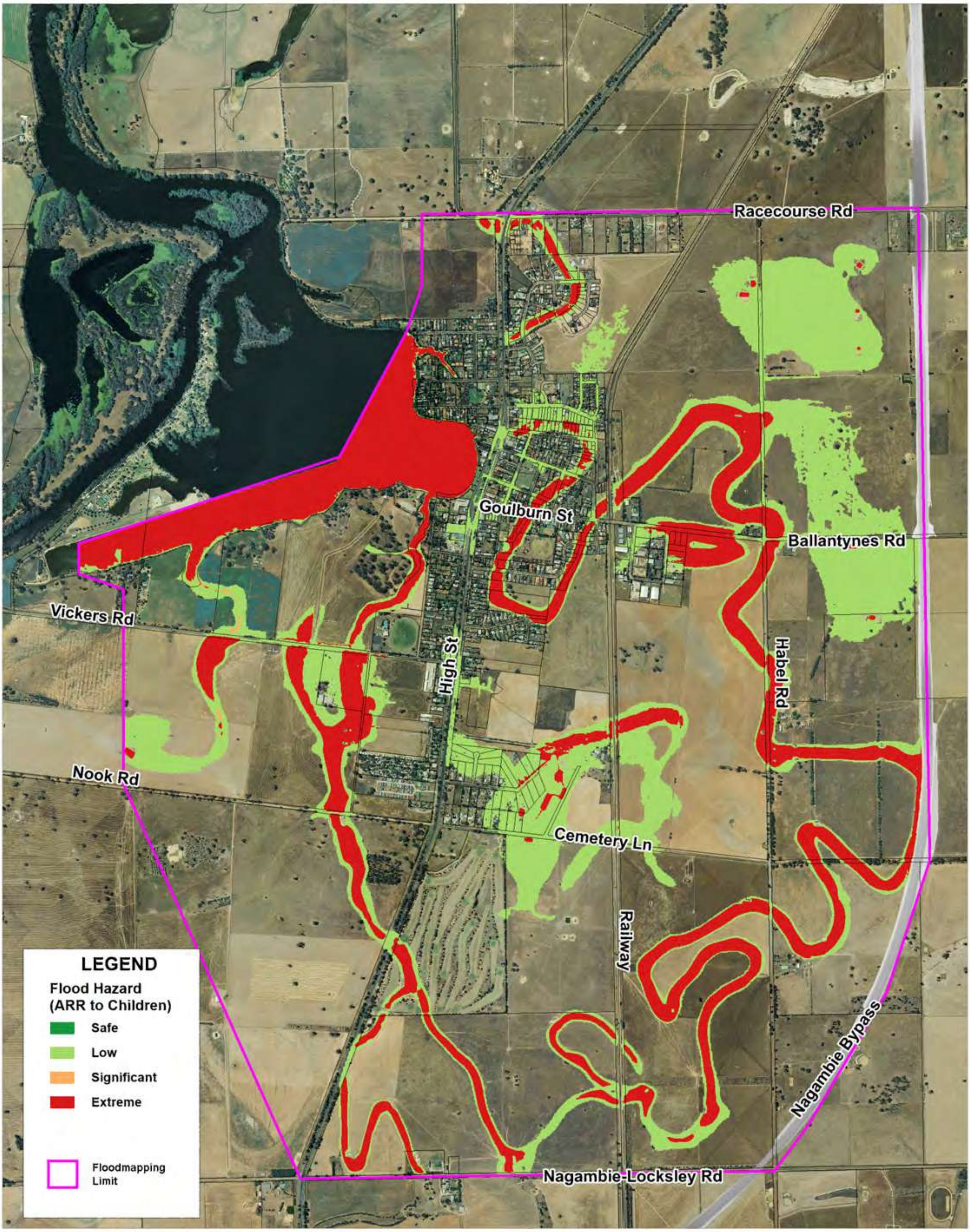
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigF-21_500yr _E01_FldHaz_RevA.WOR



Title:

Nagambie Flood Study
5 Year ARI Peak Flood Hazard - Developed Climate Change

Figure: F-22

Rev: A

N

0 0.5 1km

Approx. Scale

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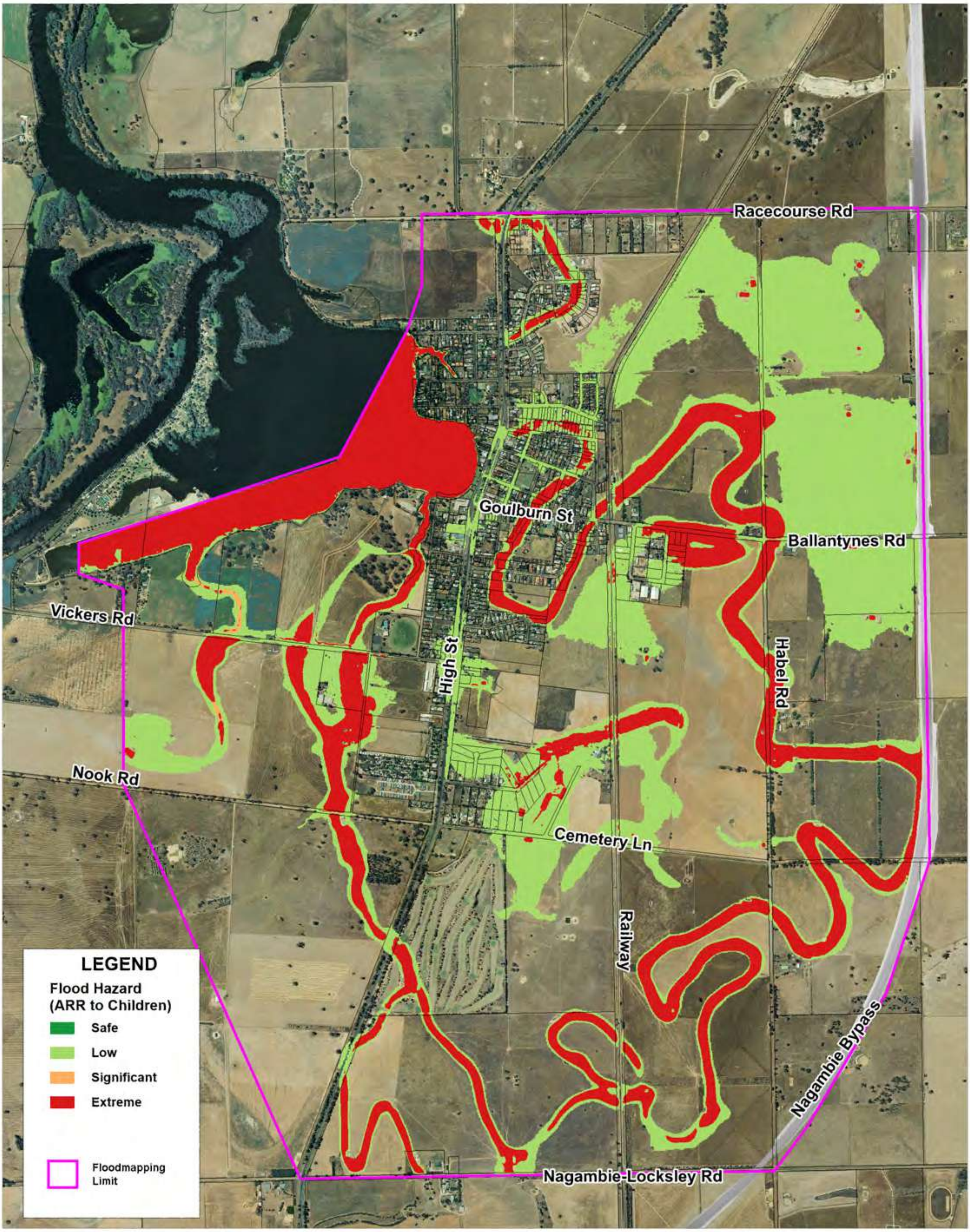
Filepath : T:\M8414.JL.Nagambie_FS\MapInfo\Drawings\R.M8414.003.01.Final\FigF-22_5yr _E01_FldHaz_RevA.WOR



Title:

Nagambie Flood Study
10 Year ARI Peak Flood Hazard - Developed Climate Change

Figure: **F-23**

Rev: **A**

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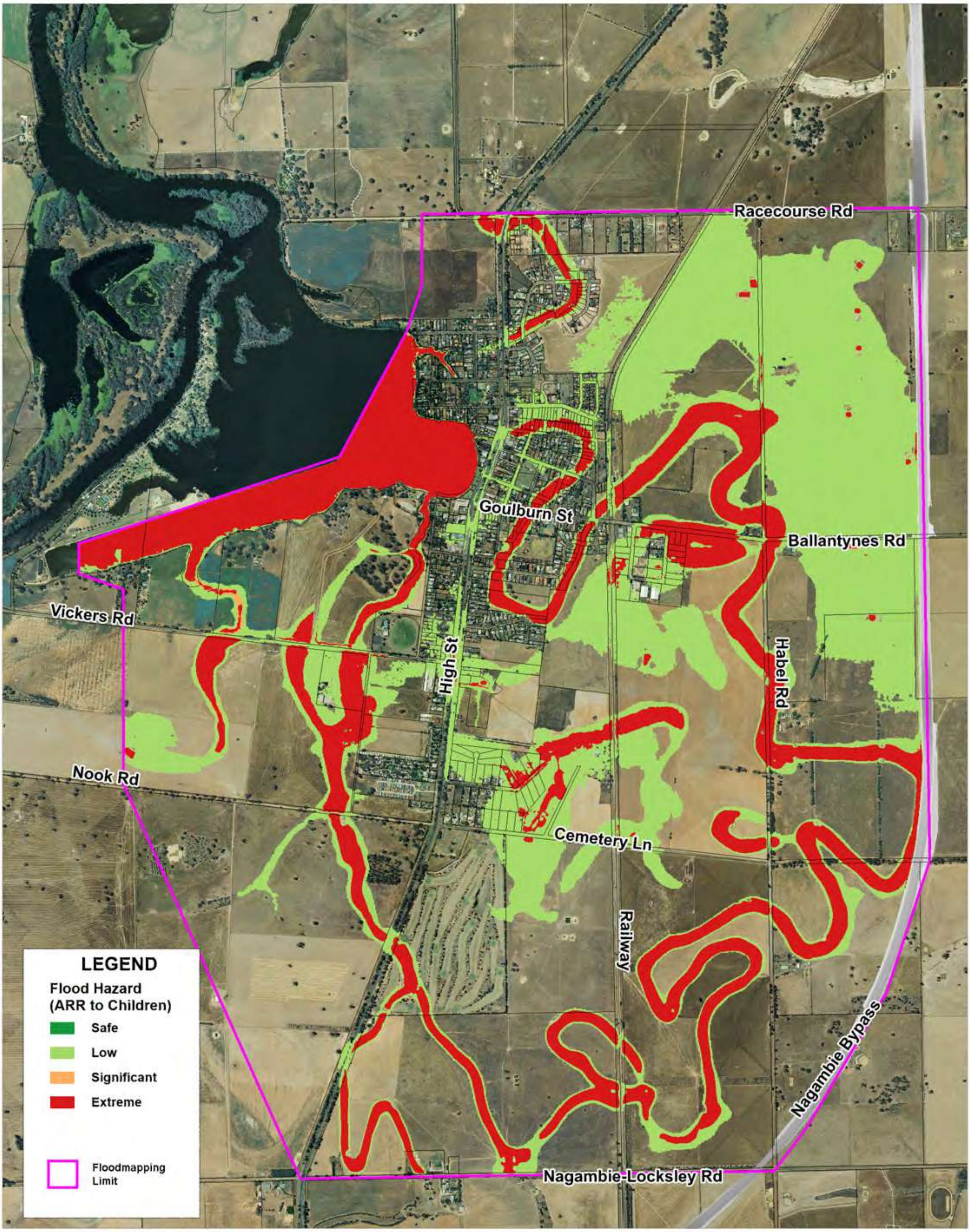

Title:

Nagambie Flood Study

20 Year ARI Peak Flood Hazard - Developed Climate Change

Figure: **F-24**

Rev: **A**

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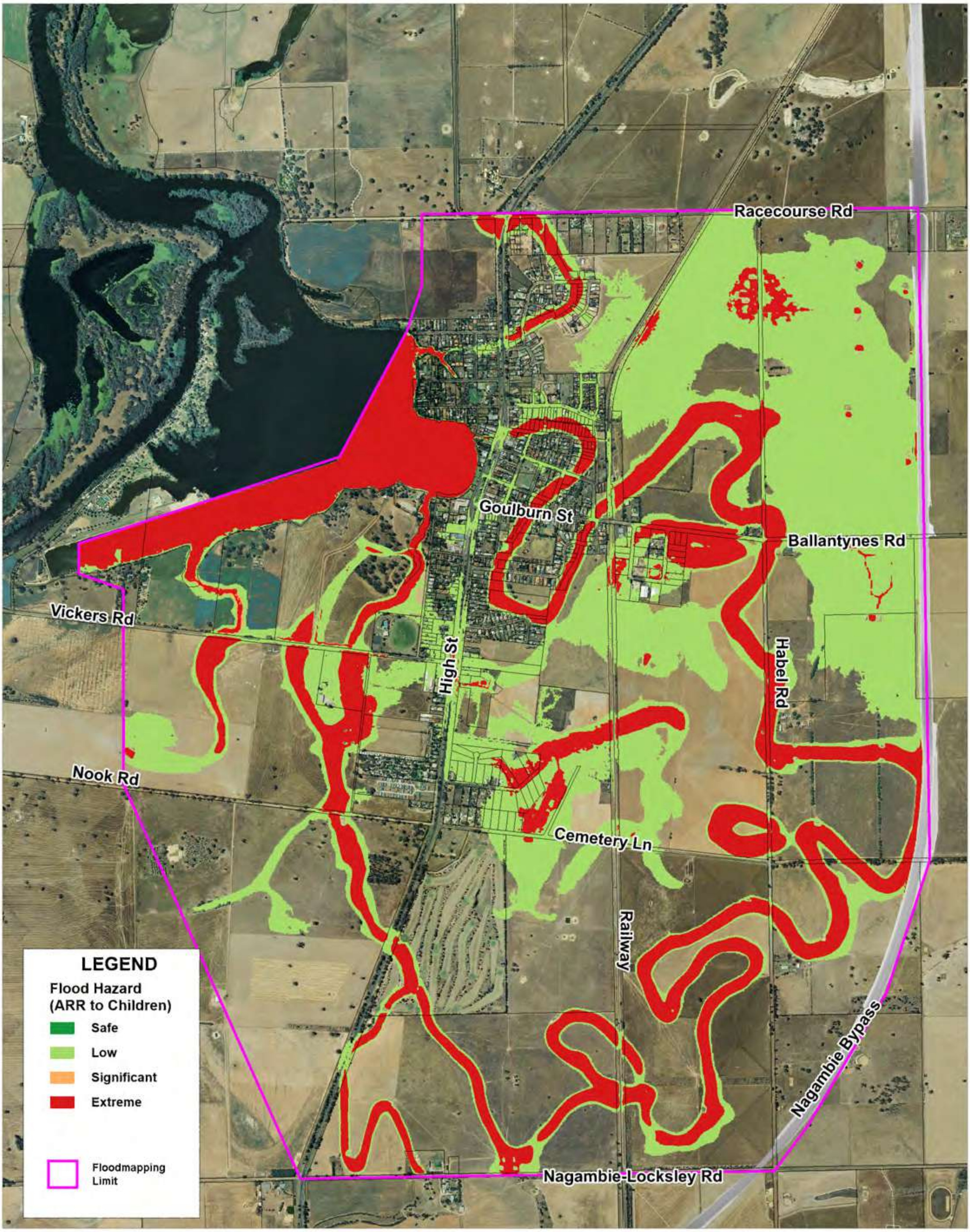

Title:

Nagambie Flood Study
50 Year ARI Peak Flood Hazard - Developed Climate Change

Figure: **F-25**

Rev: **A**

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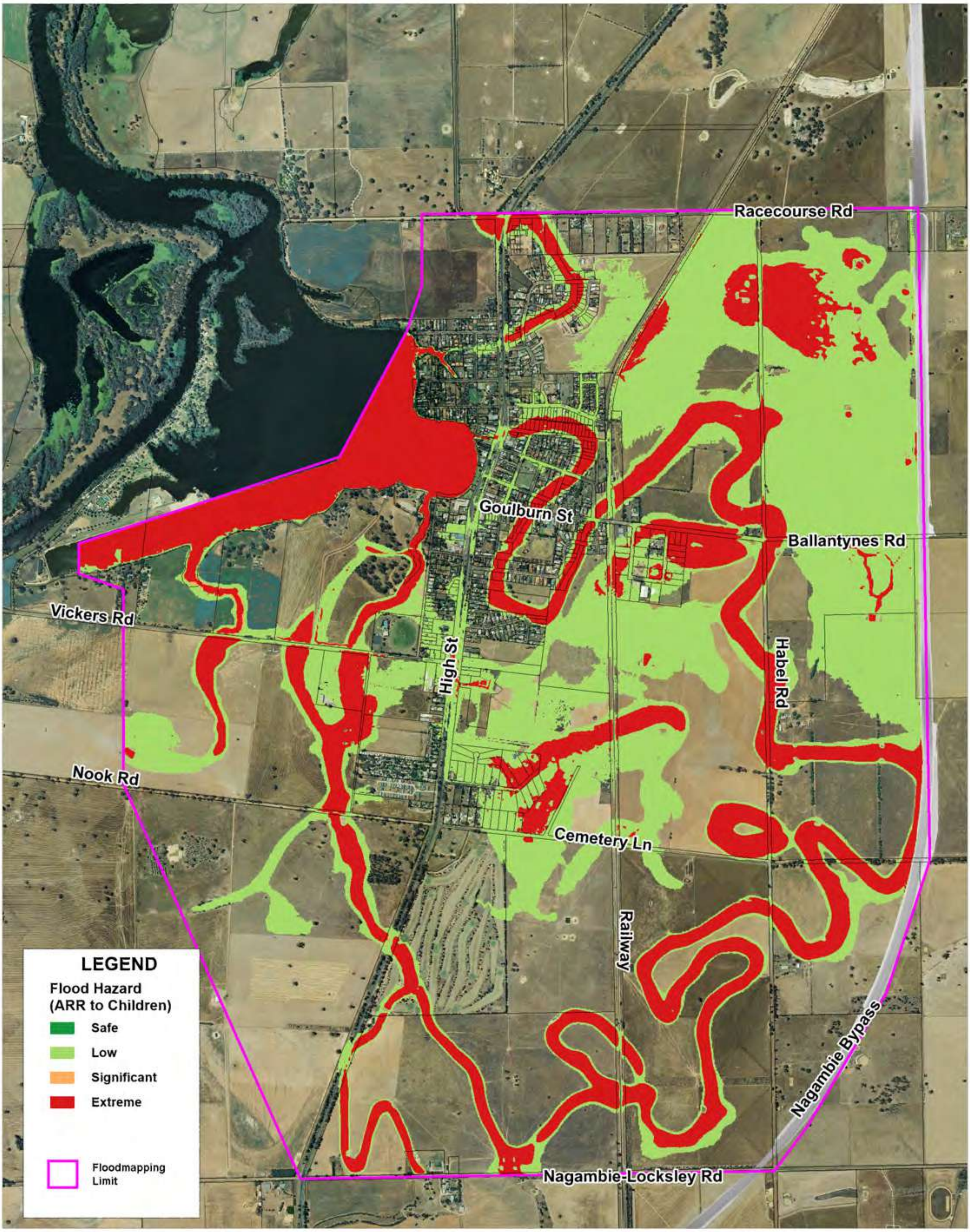

Title:

Nagambie Flood Study

100 Year ARI Peak Flood Hazard - Developed Climate Change

Figure: **F-26**

Rev: **A**

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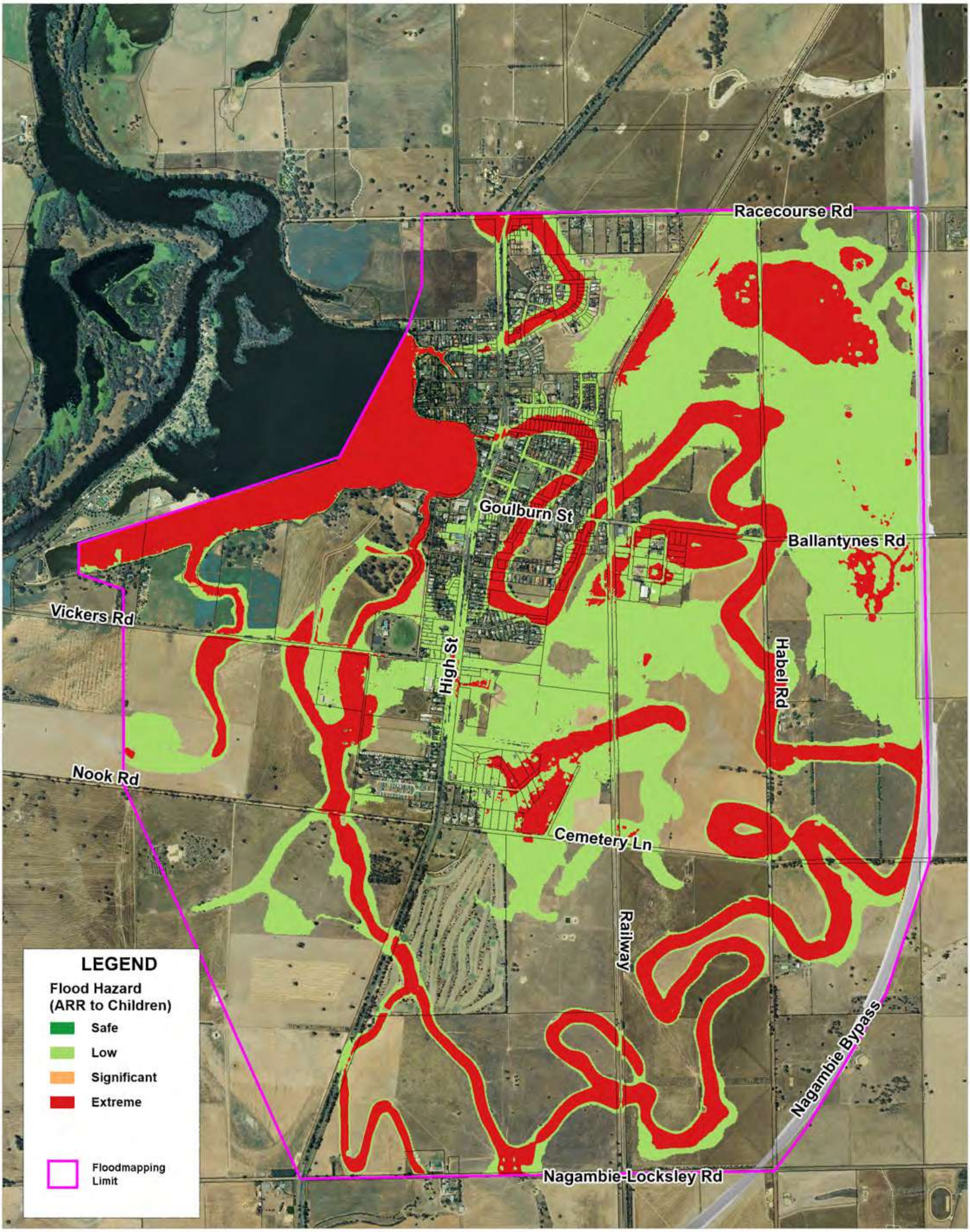

Title:

Nagambie Flood Study
200 Year ARI Peak Flood Hazard - Developed Climate Change

Figure: F-27

Rev: A

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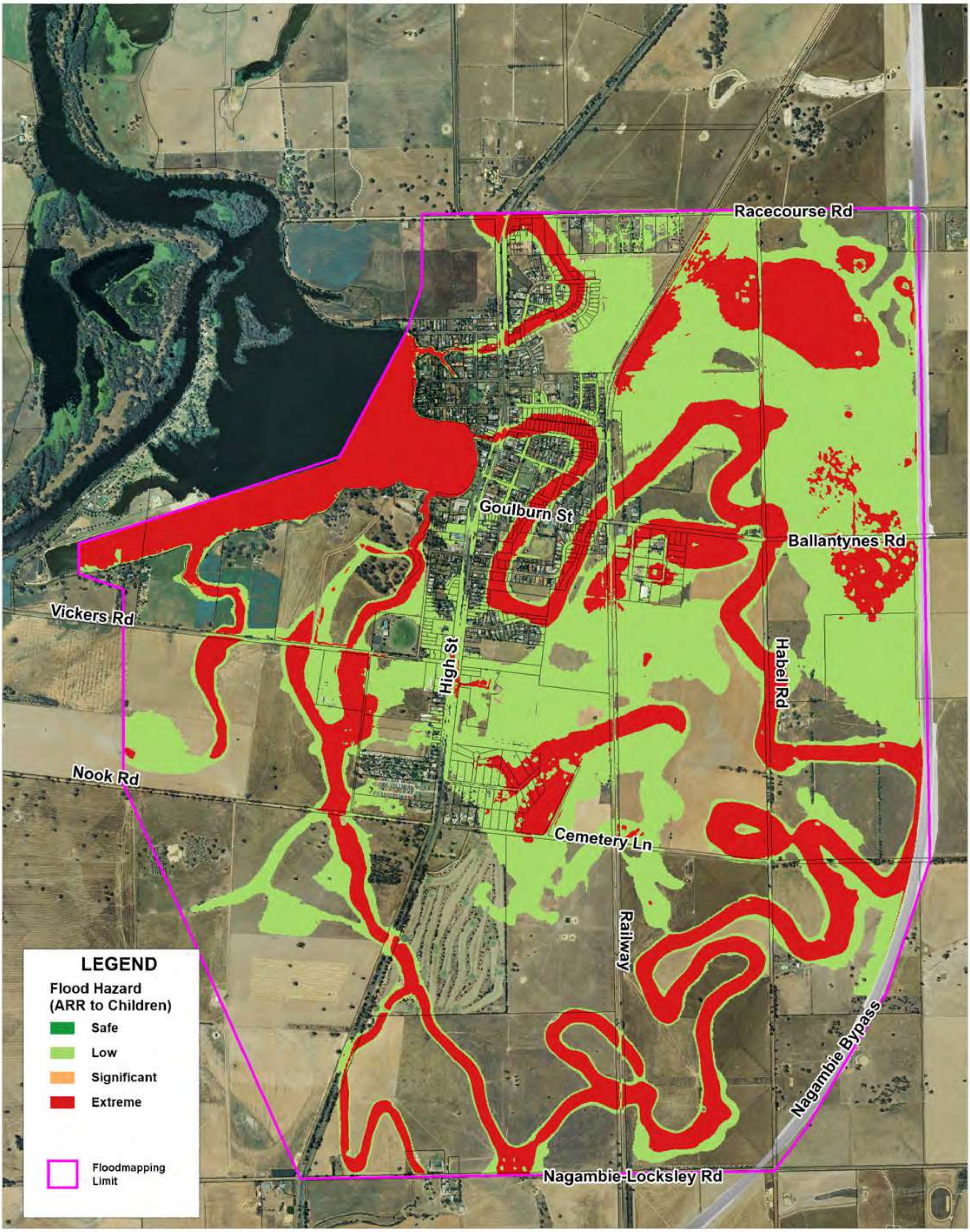

Title:

Nagambie Flood Study
500 Year ARI Peak Flood Hazard - Developed Climate Change

Figure: **F-28**

Rev: **A**

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