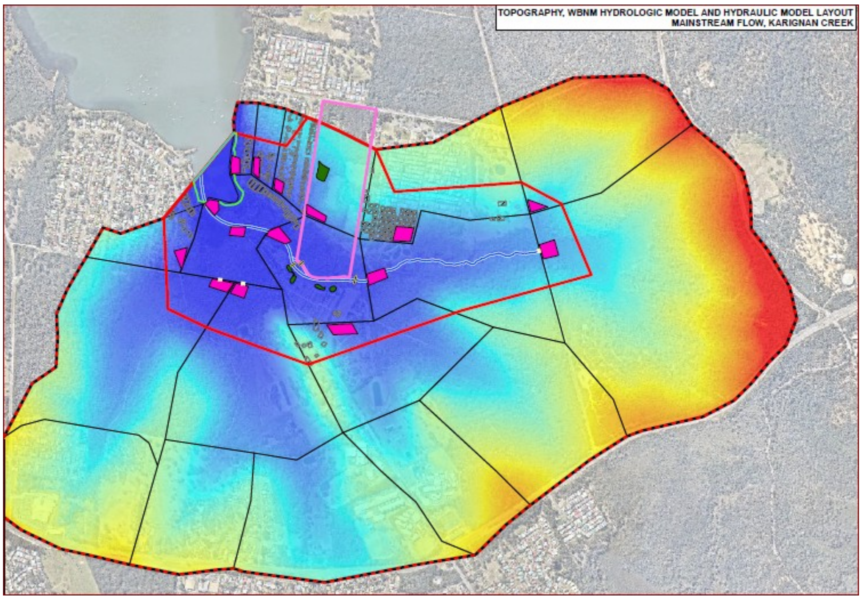
OPTIMA DEVELOPMENTS PTY LTD

Karignan Creek Flood Study & Impact Assessment



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MARCH, 2018

Project **Karignan Creek Flood Study & Impact Assessment**	**Project Number** **117099**
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Date 23 March 2018	**Verified by**

Revision	Description	Distribution	Date
1	1st Draft	Chris Oliver	March 2018
2	2ndt Draft	Chris Oliver	March 2018
3	Final	Chris Oliver	23 March 2018

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LIST OF ACRONYMS

AEP	Annual Exceedance Probability
AHD	Australian Height Datum
AR&R	Australian Rainfall and Runoff
ALS	Airborne Laser Scanning sometimes known as LiDAR
BoM	Bureau of Meteorology
CCC	Central Coast Council
DEM	Digital Elevation Model
DRM	Direct Rainfall Method
EY	Exceedances per Year
GPS	Global Positioning System
GSDM	Generalised Short Duration Method
IFD	Intensity, Frequency and Duration of Rainfall
IPCC	Intergovernmental Panel on Climate Change
m	metre
m^3/s	cubic metres per second (flow measurement)
m/s	metres per second (velocity measurement)
OEH	Office of Environment and Heritage
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
SOBEK	one-dimensional (1D) and two-dimensional (2D) flood and tide simulation software program (hydraulic computer model)
TIN	Triangular Integrated Network
TUFLOW	one-dimensional (1D) and two-dimensional (2D) flood and tide simulation software program (hydraulic computer model)
WBNM	Watershed Bounded Network Model (hydrologic computer model)
1D	One dimensional hydraulic computer model
2D	Two dimensional hydraulic computer model

EXECUTIVE SUMMARY

Optima Developments Pty Ltd is preparing reports for the rezoning of land at Lot 273 DP 755266 (15 Mulloway Road), Chain Valley Bay from E2 Environmental Conservation and E3 Environmental Management to E2 Environmental Conservation and R2 Low Density Residential. The subject site (Figure 1) is located in the Central Coast Council Local Government Area on the northern side of Karignan Creek which is a minor tributary of Lake Macquarie waterway.

The site has an area of approximately 16.6 hectares and the proposal is to subdivide the land into residential lots (the final amount is to be determined, however envisaged to exceed 100 lots) with associated infrastructure. Currently the site is heavily vegetated and occupied by a single residential development and a shed.

In June 2017 the NSW Planning & Environment provided a Gateway determination under Section 56 of the Environmental Planning and Assessment Act 1979 to allow residential development subject to various conditions. One of the conditions is to provide a Flood Study and Flood Impact Assessment in accordance with the requirements issued by the Central Coast Council. This report addresses those flood related requirements.

A flood study is required to determine the design flood levels which are used to determine the flood related controls and to simulate the proposed development and ensure that the proposed works will not adversely affect surrounding properties (i.e raise flood levels or redirect flows). Concept plans of the proposed development options are provided on Figure 2.

Karignan Creek drains into Lake Macquarie waterway which ultimately drains to the Pacific Ocean by the narrow and shallow 6 kilometre long Swansea Channel. All information on historical and design flood levels on Lake Macquarie waterway are provided in the *2012 Lake Macquarie Waterway Flood Study* (Reference 1) prepared for Lake Macquarie City Council by WMAwater.

However flood levels in Karignan Creek are also affected by runoff from the 5 km^2 upstream catchment. This current study considers flooding from:

- Lake Macquarie waterway;
- Karignan Creek;
- overland flow across the site.

The effects of the proposed development can only be assessed once detailed plans are available. Peak flows and potentially peak flood levels in Karignan Creek may be affected if the development occurs without suitable provision for on site detention basins or other suitable mitigation measures to ensure the runoff from the site does not increase as a result of the development. These should be designed in conjunction with appropriate water quality improvement structures.

Within the site itself the existing runoff is not confined to distinct channels and thus occurs as shallow depth overland flow. The only exception is where there is an existing dam. In the absence of distinct channels it is not possible to define a flood planning area within the site but a flood planning area (1% AEP + 0.5m) has been defined along Karignan Creek.

1. INTRODUCTION

1.1. Background

The subject site (Figure 1) has an area of 16.6 hectares is occupied by a single dwelling plus shed and is located south of Mulloway Road, Chain Valley Bay. The site is bounded to the south by Karignan Creek, which flows into Lake Macquarie waterway. To the west lies the low density residential settlement of Chain Valley Bay which comprises predominantly single dwellings. The site is located in close proximity to two manufactured home estates, being Teraglin Lakeside Village to the north-west of Mulloway Road and Valhalla Village located directly adjacent to the subject site on the eastern site boundary. These two manufactured home estates indicate the changing nature of Chain Valley Bay from its historic development as an agricultural area, including market gardens and grazing to an urban release area that provides varied housing opportunities in the Central Coast. (Photo 1).

Photo 1: Study Area (Source: Central Coast Council meeting of 26 April 2017)

The proposal is to amend the Local Environmental Plan (LEP) to permit subdivision into residential lots with the yield to be finalised upon completion of all relevant environmental structures (proposed development concepts are provided on Figure 2). In June 2017 the NSW Planning & Environment provided a Gateway determination under Section 56 of the Environmental Planning and Assessment Act 1979 to allow residential development subject to various conditions. One of the conditions is to provide a Flood Study and Flood Impact Assessment in accordance with the requirements issued by the Central Coast Council (CCC). This report addresses those flood related requirements.

1.2. Flooding

A flood study is required to determine the design flood levels which are used to determine the flood related controls as well as to simulate the proposed development and ensure that the proposed works will not adversely affect surrounding properties (i.e raise flood levels or redirect flows).

Karignan Creek (Figure 3) drains into Lake Macquarie waterway which ultimately drains to the Pacific Ocean by the narrow and shallow 6 kilometre long Swansea Channel. The lake level is normally at 0.1 m AHD and tidal fluctuations are generally only ± 0.05m. Elevated ocean levels due to high tides and storm surge, as well as intense rainfall over the catchment, cause the lake level to rise and thus elevate the lower parts of Karignan Creek. In February 1990, June 2007 and April 2015 the peak lake level reached approximately 1.0 m AHD due to heavy rainfall over the Lake Macquarie waterway catchment. All information on historical and design flood levels in the Lake Macquarie waterway are provided in the *2012 Lake Macquarie Waterway Flood Study* (Reference 1) prepared for Lake Macquarie City Council by WMAwater.

However, flood levels in Karignan Creek are also affected by runoff from the 5.0 km^2 upstream catchment as well as runoff from within the site itself. This current study therefore considers flooding from Lake Macquarie waterway, from Karignan Creek as well as overland flow across the 16.6 hectares site. Since publication of the *2012 Lake Macquarie Waterway Flood Study* (Reference 1) the guidelines for undertaking design flood assessment, as provided in Australian Rainfall and Runoff (AR&R), have been updated. Thus there is a new approach for determining design flood levels. This new approach has been adopted for the investigation of flooding in Karignan Creek but relies on the design flood levels in Lake Macquarie waterway taken from the *2012 Lake Macquarie Waterway Flood Study* (Reference 1).

1.3. Proposed Development

It is proposed to re-develop the site for predominantly residential usage and a flood study, including hydraulic modelling is required to:

1. determine the design flood levels to be adopted for development control purposes, and
2. ensure that the development proposal will not increase flood levels or flows on surrounding properties.

Concept plans of the proposed development are provided on Figure 2.

1.4. Objectives

CCC advised that the flood study and flood impact assessment must:

1. Be based on recently acquired (less than 2 years) ground survey data acquired via traditional ground survey or GPS;
2. Be produced from a two-dimensional (2D) flood model (such as TUFLOW, SOBEK or MIKE-21);

3. Assess various flood sizes, including at least 10% Annual Exceedance probability (AEP), 1% AEP, 0.5% AEP and Probable Maximum Flood (PMF);
4. Assess various flood durations to determine critical duration for flooding at various locations; include longer duration flood events as part of the consideration of any retarding basins;
5. Be prepared consistent with the most recent NSW Office of Environment & Heritage (OEH) Consultant Flood Study Brief, the 2005 *Floodplain Development Manual* (Reference 2) and related Guidelines, the 2016 version of Australian Rainfall and Runoff (AR&R) (Reference 3), and Council's Civil Works Design Guidelines (specifically Part 10);
6. Be inclusive of a written report with mapping, plans and figures detailing:
    - all data, parameters, and any assumptions;
    - hydrologic results from at least two methods;
    - figures and tables of flood extents, velocities, depths, and hazards for each sized flood, both for pre-development and post-development, and for the relative differences, both on the site and beyond;
    - flood planning area (1% AEP + 0.5m freeboard) both pre-development and post-development;
    - all mapping to be also provided for Council's ongoing use in GIS Shp file format for inclusion on Council's GIS.
7. Address the following for pre and post development scenarios:
    - Pre development:
        - evaluation of site conditions: natural water courses, constructed channels, soil type, groundwater, vegetation, stormwater quality;
        - assessment of flood hazard, access & evacuation, and consideration of constraints and opportunities for development;
        - discussion of the hydrology of the site: flow patterns, velocity distribution, sedimentation and erosion potential, flood storage areas, points of discharge from the site, including peak flows and discharge volumes.
    - Post Development:
        - evaluation of changes to site conditions: natural water courses, constructed channels, soil type, groundwater, vegetation, stormwater quality;
        - assessment of changes to flood hazard, access & evacuation, and the compatibility of various types of development to the flood hazard at specific locations, including impacts at properties beyond the site;
        - discussion of changes to the hydrology of the site: flow patterns, velocity distribution, sedimentation and erosion potential, flood storage areas, points of discharge from the site, including peak flows and discharge volumes.

1.5. Limitations of the Present Study

CCC also provided requirements for a drainage and stormwater management study. However the drainage and stormwater management study will be carried out by others.

The present study only considers the flood related issues pertaining to inundation from Lake

Macquarie waterway and by Karignan Creek as well as overland flow within the site. As the design of the site has not been defined it is not possible to accurately determine the impacts of the development. Therefore these have only been considered in general terms and guidelines provided for a more detailed assessment at the design stage.

1.6. Terminology

This report has adopted the approach of the Engineers Australia AR&R terminology guidelines and uses % AEP for all events greater than the 1 EY and EY for all events smaller and more frequent than this.

All levels in this report are in metres to Australian Height Datum (AHD). 0 m AHD approximates mean sea level. Appendix A provides a glossary of commonly used terms. If more explanation of terms or a better understanding of the approach is required, type "*NSW Government Floodplain Development Manual*" into an internet search engine and you will be directed to the NSW Government web site which provides a copy of this manual (Reference 2) and further explanation.

1.7. Accuracy of Model Results

The accuracy of all model results provided in this report is dependent on the accuracy of the input data sets and the ability of the modelling approach to accurately replicate recorded historical flood data. As modelling approaches improve over time and additional flood data becomes available from future flood events the accuracy of the results will improve. Due to the absence of historical flood data and the inability to calibrate the hydrologic / hydraulic model the estimated accuracy of the 1% AEP design flood level at the site is ± 0.3m.

1.8. The Flood Problem

Flooding in Lake Macquarie waterway has occurred in the past and all records are documented in the *2012 Lake Macquarie Waterway Flood Study* (Reference 1). The dates and approximate peak lake levels of all known significant floods in Lake Macquarie waterway are shown in Table 1.

According to the *2012 Lake Macquarie Waterway Flood Study* (Reference 1) the February 1990, June 2007 long weekend and April 2015 events were all smaller than a 5% (1 in 20 year level of 1.23m AHD) AEP event in Lake Macquarie waterway. It should be noted that the design magnitude of a historical flood will vary across a region. For example, near Newcastle the June 2007 long weekend event exceeded a 1% (1 in 100 year) AEP event whereupon at Swansea and south of the Swansea channel it was of much smaller magnitude.

Table 1: Significant Flood Events on Lake Macquarie Waterway

Date (in order of severity)	Approximate Peak Lake Level (m AHD)
18 June 1949	1.25
April 1946	1.20
11 June 1930	1.10
9 June 2007	1.05
22 April 2015	1.01
2 May 1964	1.00
4 February 1990	1.00
1953	0.90
1926/27	0.80
25 February 1981	0.80
May 1974	0.80
4 March 1977	0.70

Notes: Data obtained from the 2012 Lake Macquarie Flood Study - Reference 1.
Levels are an average of several recorded heights.
It is likely that several floods prior to 1970 may not have been recorded.

1.9. Lake Macquarie Waterway Flood Study, June 2012 (Reference 1)

The *2012 Lake Macquarie Waterway Flood Study* was initiated by Council to research and update the prior 1998 *Lake Macquarie Flood Study*, to incorporate predicted impacts of climate change. The study included modelling of the June 2007 long weekend event and incorporated recent detailed bathymetric survey within the Swansea Channel. The study established a hydrologic model (WBNM) and hydraulic model (TUFLOW), which were calibrated and validated to the February 1990 and June 2007 long weekend events. The following conditions were adopted for the design flood analysis:

- 0.1m AHD initial water level in the Lake Macquarie waterway (average lake level);
- 48 hour critical rainfall storm duration inflows (for all design events except the PMF) in conjunction with the respective ocean tides;
- design ocean levels based on the design levels in Fort Denison/Sydney Harbour plus a wave setup component (0.2m assumed for the 1% (1 in 100 year) AEP event);
- all design tides assume the “shape” of the tidal hydrograph of the May 1974 east coast low event as recorded at Fort Denison in Sydney Harbour. This tidal hydrograph approximates the 1% (1 in 100 year) AEP design ocean event;
- the wave setup component was assumed to increase linearly to peak at the same time as the ocean peak;
- the peak ocean level was coincided with the peak rainfall burst in the 48 hour duration event;
- the AR&R 1987 methodology was adopted as the study was undertaken prior to release of the AR&R 2016 methodology. Thus if the study was redone today the peak levels may change.

Design flood levels in Lake Macquarie waterway from the *2012 Lake Macquarie Waterway*

Flood Study (Reference 1) are reproduced in Table 2. Climate change scenarios were analysed for the 20% (1 in 5 year), 5% (1 in 20 year) and 1% (1 in 100 year) AEP events and summarised also in Table 2. The flood levels shown in Table 2 exclude wave runup on the foreshore areas within the lake.

Table 2: Summary of Design Flood Levels in the 2012 Lake Macquarie Waterway Flood Study (Reference 1)

		Peak Lake Level (m AHD)				
		Sea Level Rise		Rainfall Increase		
Event (AEP)	**Existing**	**+ 0.4m**	**+ 0.9m**	**10%**	**20%**	**30%**
50% (1 in 2 year)	0.65	1.04	1.54	0.71	0.77	0.83
20% (1 in 5 year)	0.82	1.21	1.71	0.88	0.94	1.00
10% (1 in 10 year)	0.94	1.32	1.81	1.03	1.11	1.19
5% (1 in 20 year)	1.23	1.61	2.10	1.32	1.40	1.49
2% (1 in 50 year)	1.38	1.74	2.20	1.50	1.61	1.72
1% (1 in 100 year)	1.50	1.86	2.32	1.62	1.73	1.84
0.5% (1 in 200 year)	1.69	2.05	2.51	1.81	1.92	2.03
0.2% (1 in 500 year)	1.87	2.23	2.69	1.99	2.10	2.21
PMF	2.45	2.81	3.27	2.57	2.68	2.79

Note: Underlined levels have been derived by interpolation from model results rather than actual modelling

1.10. Description of Study Area

1.10.1. Site

An inspection of the 16.6 hectare site was undertaken in February 2018 to identify whether any creeks or drainage channels exist in the site. This is important as these would have to be considered in the drainage design of the subdivision. In addition, typical photographs of the site were taken to illustrate the topography.

The study area comprises an approximate 16.6 hectare site, predominately covered by dense vegetation as well as cleared areas (Photo 2), and a dam (Photo 3). As shown in Figure 3 A and B the 16.6 hectare site slopes gently to the south-west and there is no evidence of creeks or defined drainage channels evident within the site. The slope reaches the floodplain at the zone boundary, where the topography flattens. The dam has been designed to allow flow to spill to the northwest (Photo 3) before being diverted to a cleared access road parallel to the western edge of the property (Photo 3).

Due to the absence of defined open channels the drainage of the site is what is generally termed as overland flow i.e runoff is not confined to a path and flows at shallow depth in no defined path. The hydrologic and hydraulic modelling of runoff in this manner can be best represented using a 2 Dimensional (2D) modelling approach termed "rainfall on the grid" or the "direct rainfall method" known as DRM. Further details are provided in Section 2.4.

Photo 2: Typical vegetation at the site and cleared area within the site

Photo 3: Dam and spillway and western cleared access road

1.10.2. Karignan Creek

Karignan Creek is approximately 10 to 20m wide at the upstream limit of the site and up to 30m wide at the mouth. Flow from the 5.0 km^2 catchment is channelled to the southernmost edge of Lake Macquarie waterway via a number of hydraulic structures. These were investigated in order to determine the potential impact on flood levels and how they should be modelled.

The headwaters of Karignan Creek converge at the low-point of Chain Valley Bay Road, where a culvert consisting of four 0.9m diameter pipes (Photo 4) cross under the road. Approximately 40m upstream of the site property boundary, flow is affected by a concrete weir at a level of 1.4m AHD (Photo 4). Adjacent to the property, the creek diverges into two channels. At the left fork of the divergence a concrete weir impacts flow to a level of 0.7m AHD (Photo 5), and at the right fork a land weir has been built to a level of 1.25m AHD (Photo 5). Downstream of the site, the creek channels converge before flowing under a footbridge (Photo 6) into Lake Macquarie waterway.


Photo 4: Chain Valley Bay Road culvert and concrete weir upstream of the site boundary


Photo 5: Concrete weir adjacent to the site and earthen weir opposite the site

Photo 6: Karignan Creek Footbridge

2. MODELLING APPROACH

2.1. Outline

The approach adopted in flood studies to determine design flood levels and investigate stormwater issues largely depends upon the objectives of the study and the quantity and quality of the data (survey, flood, rainfall, flow etc.). In the absence of an extensive historical flood record a flood frequency approach cannot be undertaken for the study area and must rely on the use of design rainfalls and establishment of a hydrologic/hydraulic modelling system. A diagrammatic representation of the flood study process undertaken in this manner is shown in Diagram 1.

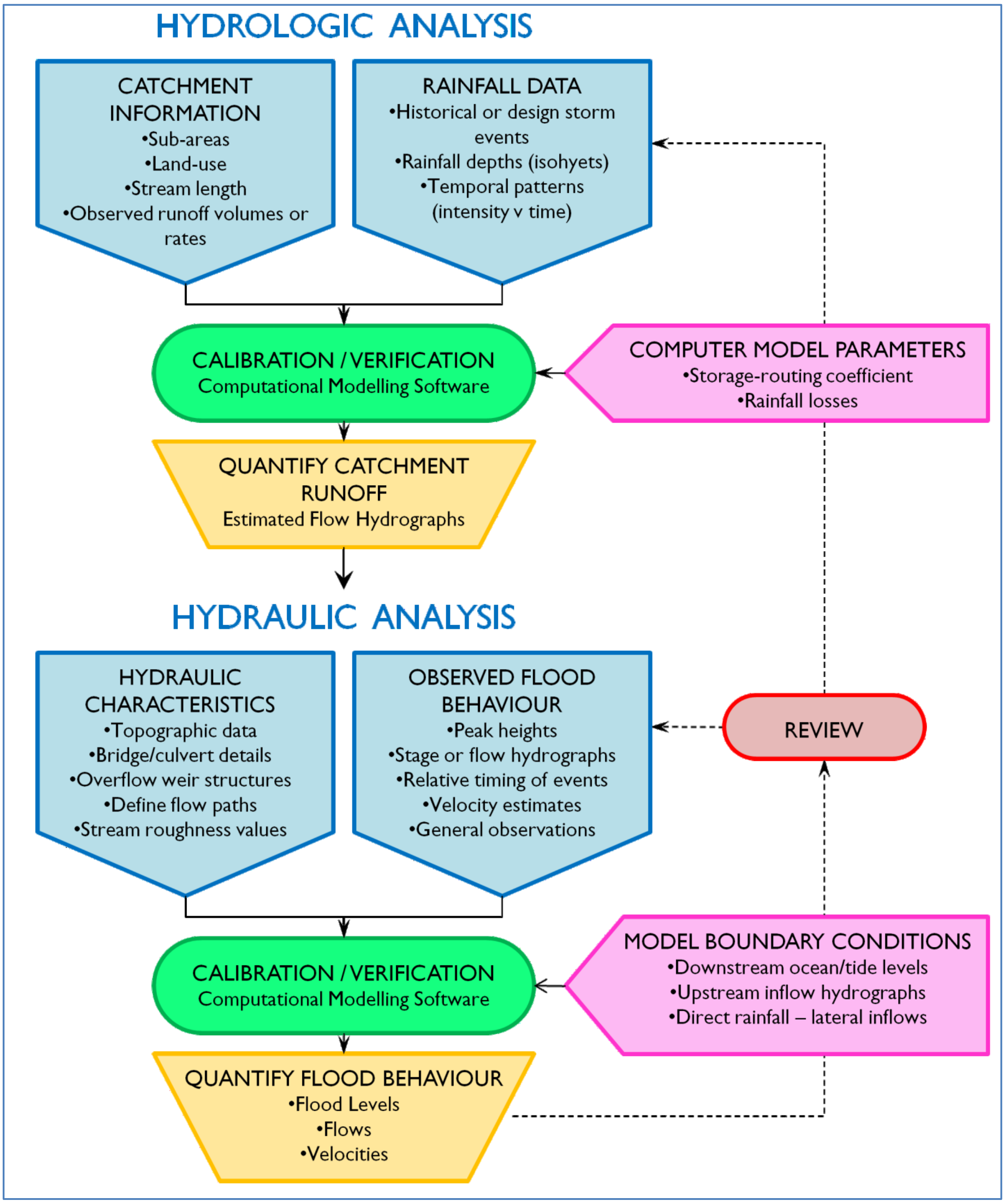


Diagram 1: Flood Study Process

2.2. Data

2.2.1. Survey

Airborne Laser Scanning (ALS) survey data used for the study was collected on 30/09/2014 by the Foundation Spatial Data Framework and obtained by WMAwater on 11/01/2018. The 1m Digital Elevation Model (DEM) used in the study has been derived by applying the Triangular Irregular Network (TIN) method to the ALS point cloud data. The data has a vertical accuracy of 0.3m and a horizontal accuracy of 0.8m (95% confidence interval). Survey data collected by CBH Surveyors in October and November 2017 was not considered suitable for the study due to the small number of actual survey points taken within the site as a result of the dense nature of the vegetation.

2.2.2. Rainfall

AR&R 2016 Intensity Frequency Duration (IFD) curves are available on the BoM website and Table 3 shows the 2016 IFD data at the centroid of the catchment.

Table 3: AR&R 2016 Rainfall Depths (mm)

Duration (min)	Annual Exceedance Probability (AEP)						
	50%	20%	10%	5%	2%	1%	0.5%
30	24.0	34.1	41.9	50.1	62.3	72.7	82.6
60	31.5	44.7	54.8	65.7	81.4	94.8	107.7
120	40.4	57.4	70.2	83.8	103.0	120.0	136.4
180	46.9	66.4	81.0	96.5	119.0	138.0	156.4
360	61.0	86.0	105.0	124.0	153.0	176.0	200.0

Further details on the rainfall data and temporal patterns are provided in Appendix B.

2.2.3. Derivation of PMF

The catchment in which the study area is located has a total area of less than 1,000 km^2. Probable Maximum Precipitation (PMP) rainfall depths for such catchments are calculated using the Generalised Short Duration Method (GSDM) (Reference 4). The PMP rainfall was applied uniformly across the study area using the GSDM ellipsoid A. Table 4 presents the PMP rainfall depths allocated to the study area for each storm duration. The 1 hour PMP rainfall depth is approximately 5 times the 1% AEP rainfall depth.

Table 4: GSDM PMP Rainfall Depths (mm)

Duration (min)	PMP Rainfall Depth (mm)
30	336
60	493
90	563
120	628

2.3. Adopted Modelling Approach for Karignan Creek

Two modelling approaches have been undertaken. One is for flooding from Karignan Creek in combination with any influence from Lake Macquarie waterway and the other is for overland flow across the 16.6 hectare site.

2.3.1. Hydrologic Model - WBNM

There are several suitable hydrologic models for use in this type of study and these are described in AR&R (Reference 3). However as the *2012 Lake Macquarie Waterway Flood Study* (Reference 1) used the WBNM hydrologic model it was decided to adopt the same model. The sub catchment layout is shown as Figure 3. As no flow data are available for calibration of the WBNM model the same C value of 2.4 was adopted, however different design losses were assumed as advised in AR&R (Reference 3).

2.3.2. Hydraulic Model - TUFLOW

A 2D hydraulic model is required to incorporate the hydrologic inflows and determine flood levels, velocities and extents. The TUFLOW model (Reference 5) was adopted as it is widely used and again was the adopted model in the *2012 Lake Macquarie Waterway Flood Study* (Reference 1). It was established using a 2m grid and including the available ALS (Section 2.2.1). Houses in the vicinity of the study area were "blocked out" from the grid to ensure that the flow paths in the local area were accurately reflected.

The speed at which runoff crosses a surface will depend upon the nature (grass, road, dense bush, sand etc.) and grade of the surface. The grade is accounted for by the ground levels of each grid cell obtained from the ALS and the nature of the surface is accounted for by a Manning's "n' factor (refer Reference 3). A listing of the adopted Manning's "n' factors based on judgement, recommended texts and past studies is shown on Table 5.

Table 5: Adopted Manning's "n" values – TUFLOW model

Material	Manning's "n"
Default	0.04
Urban	0.05
Residential	0.03
Roads	0.02
Light Vegetation	0.03
Medium Vegetation	0.06
Heavy Vegetation	0.08
Concrete-lined Channel	0.015
Channel with Light Vegetation	0.04
Channel with Heavy Vegetation	0.07
Bridge	0.1
Building	Null Cell

The TUFLOW model was established to account for flow in Karignan Creek which affects the southern part of the 16.6 hectare site as well as within the site itself. Hydrologic inputs within Karignan Creek itself were obtained from the WBNM model (Section 2.3.1).

2.3.3. Model Verification

The verification of any modelling approach is an important step in the process. This is undertaken by comparing peak water levels recorded in past flood events to those from the hydraulic model input with the historical rainfall for that event. For a major river system there may be many recorded levels along the length of the study area and considerable effort is required to adjust the model to replicate the recorded levels for all historical calibration events.

The choice of events for model verification depends on the availability of peak height and rainfall data for the event. If there is no peak height or rainfall (pluviometer - continuously recording rain gauge) data available for an event it cannot be used for verification.

Whilst the modelling undertaken in the *2012 Lake Macquarie Waterway Flood Study* (Reference 1) was verified against historical peak height data there is no suitable historical peak height data within Karignan Creek to calibrate a model simulating the runoff from the local catchment. Thus similar hydrologic and hydraulic parameters were adopted in the present study to those in the *2012 Lake Macquarie Waterway Flood Study* (Reference 1).

2.3.4. Tailwater Levels in Lake Macquarie Waterway

A tailwater level in Lake Macquarie waterway is required as the outflow boundary from Karignan Creek. In all simulations except the PMF, the TUFLOW model included a constant water level boundary in Lake Macquarie waterway of 1.23 m AHD which represents the 5% AEP flood level of Lake Macquarie waterway (Table 2). For the PMF event a tailwater level of 2.45 m AHD was adopted which represents the PMF flood level of Lake Macquarie waterway (Table 2).

2.3.5. Assessment of Critical Storm Duration

AR&R 2016 requires a more complex investigation to determine the critical storm duration compared to AR&R 1987. This process is described in Appendix B and concluded that the 6 hour storm was the critical storm duration for the 1% AEP event in Karignan Creek.

Consideration of a catchment wide rainfall reduction factor was undertaken but as this indicated a reduction of only approximately 4% it was decided to not adopt any reduction.

For the PMF the critical duration was determined as the 1 hour event based on the peak flows from the WBNM model.

2.3.6. Summary

Following establishment of the TUFLOW model the following steps were undertaken:

- Design inflows using the AR&R 2016 design rainfall methodology (Reference 3) were included in the TUFLOW model;
- Assessment of the events causing the maximum water levels which is termed the critical storm duration;
- Derivation of the design flood levels, contours, depths and velocities as well as preliminary hazard and hydraulic categorisation;
- Assessment of impacts of proposed development;
- Assessment of possible effects of climate change induced sea level rise on design flood levels and extents.

2.4. Adopted Modelling Approach for Overland Flow across the Site

2.4.1. Direct Rainfall Method

The direct rainfall method or DRM was introduced approximately 10 years ago with the use of 2D hydraulic models and the availability of ALS survey data. With a 2D model such as TUFLOW inflows are traditionally incorporated from a "lumped" hydrologic model as undertaken for the modelling of Karignan Creek (refer Section 2.3). With the DRM approach TUFLOW generates the runoff directly onto each grid cell based on the same rainfall IFD, temporal and loss rate parameters as for the traditional hydrologic model. Rain falling on each grid cell is then routed to the next downstream grid cell using the 2D modelling approach.

The DRM approach was adopted in this study to model the overland flow across the site as there are no defined channel systems within the site (refer Section 1.10.1), thus the use of a rainfall runoff model such as WBNM with point inflows cannot be applied.

It should be noted that the TUFLOW model used to define flooding within Karignan Creek adopts inflows from the site using the WBNM model. However the DRM approach is adopted for defining flood levels within the site and upstream from the influence of Karignan Creek.

For the DRM modelling a static tailwater level of 2.0 m AHD within Karignan Creek was adopted for all design events apart from the PMF which adopted a level of 3.0 m AHD. These levels were adopted as they are approximately the 1% AEP flood level and the PMF level at the upstream boundary of the site within the floodplain of Karignan Creek.

No model calibration or verification was possible within the site as there is no historical flood data available. A listing of the adopted Manning's "n' factors based on judgement, recommended texts and past studies is shown on Table 5.

AR&R 2016 requires a more complex investigation to determine the critical storm duration compared to AR&R 1987. This process is described in Appendix B and concluded that the 45 minute storm was the critical storm duration for the 1% AEP event. Details of the approach are provided in Appendix B.

For the PMF the critical duration was determined by modelling each storm durations for the PMF event. A source grid was created to show the durations contributing to the peak flow within the property and that duration was selected as critical

For the PMF the critical duration was determined as the 0.5 hour event based on the peak flows from the overland flow model.

3. RESULTS

3.1. Figures

Note: The a series in the figures relates to Karignan Creek while the b series relates to the actual site itself.

Figure 4 to Figure 11 show the design flood depths, contours and velocities for the 10% AEP, 1% AEP, 0.5% AEP and PMF events. The Flood Planning Area extent based on the 1% AEP + 0.5m is also shown on Figure 5a along Karignan Creek. However within the site the Flood Planning Area extent has not been shown as using the 1% AEP + 0.5m extent within the site is unrealistic as in nearly all places it would exceed the PMF extent.

The risk to life and potential damages to buildings during floods varies both in time and place across the floodplain. In order to provide an understanding of the effects of a proposed development on flood behavior and the effects of flooding on development and people the floodplain can be sub-divided into hydraulic and hazard categories. This categorization should not be used for the assessment of development proposals on an isolated basis, rather they should be used for assessing the suitability of future types of land use and development in the formulation of a floodplain risk management plan.

Hazard classification plays an important role in informing floodplain risk management in an area. Previously, hazard classifications were binary – either Low or High Hazard as described in the Floodplain Development Manual (Reference 2). However, in recent years there have been a number of developments in the classification of hazard. *Managing the floodplain: a guide to best practice in flood risk management in Australia* (Reference 6) provides revised hazard classifications which add clarity to the hazard categories and what they mean in practice. The classification is divided into 6 categories, listed in Table 6, which indicate the restrictions on people, buildings and vehicles. The velocity/depth relationship for each of these categories is depicted in Diagram 2.

Table 6: Hazard Categories

Category	Constraint to people/vehicles	Building Constraints
H1	Generally safe	*No constraints*
H2	Unsafe for small vehicles	*No constraints*
H3	Unsafe for all vehicles, children and the elderly	*No constraints*
H4	Unsafe for all people and all vehicles	*No constraints*
H5	Unsafe for all people and all vehicles	Buildings require special engineering design and construction
H6	Unsafe for people and vehicles	All building types considered vulnerable to failure

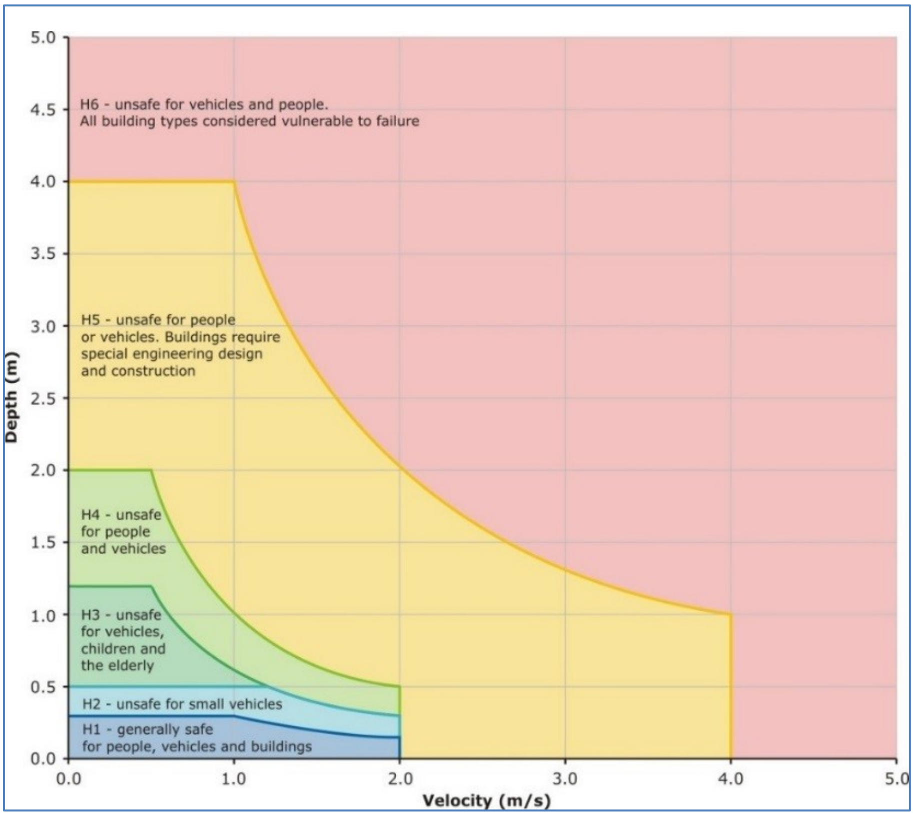


Diagram 2: Hazard Classifications

The provisional hydraulic hazard categorisation based on Table 6 and Diagram 2 is shown on Figure 12 to Figure 15. The hazards are provisional because they only consider the hydraulic aspects of flood hazard. Other factors should be considered in determining the “true” hazard such as size of flood, effective warning time, flood readiness, rate of rise of floodwaters, depth and velocity of flood waters, duration of flooding, evacuation problems, effective flood access, type of development within the floodplain, complexity of the stream network and the inter-relationship between flows.

The 2005 NSW Government’s Floodplain Development Manual (Reference 2) defines three hydraulic categories which can be applied to different areas of the floodplain; namely floodway, flood storage or flood fringe. Floodway describes areas of significant discharge during floods, which, if partially blocked, would cause a significant redistribution of flood flow. Flood storage areas are used for temporary storage of floodwaters during a flood, while flood fringe is all other flood prone land.

There is no single definition of these three categories or a prescribed method to delineate the flood prone land into them. Rather, their categorisation is based on knowledge of the study area, hydraulic modelling and previous experiences.

Please check that this is what has been applied.

For this study, hydraulic categories were defined by the following criteria on Figure 16 to Figure 19, which correspond in part with the criteria adopted by WMAwater and other consultants:

Floodway:	***OR***	**Velocity x Depth > 0.25m^2/s AND Velocity > 0.25m/s** **Velocity > 1.0m/s AND Depth > 0.15m**
Flood Storage:		Land outside the floodway where Depth > 0.5m
Flood Fringe		Land outside the floodway where Depth < 0.5m

3.2. Climate Change

Anthropomorphic induced climate change has the potential to increase sea levels and also design rainfall intensities. A history of the NSW Government's response to climate change and the potential consequences for flood investigations is provided in Reference 7 to 10. A comprehensive assessment of climate change was undertaken in the *2012 Lake Macquarie Waterway Flood Study* (Reference 1).

The changes in peak flood depths have been provided for the 1% AEP event on Figure 20 and Figure 21 for the following climate change scenarios;

- 0.9m rise in Lake Macquarie waterway adopted tailwater level;
- 30% increase in rainfall intensity.

3.3. Effect of Proposed Development

The effect of the proposed development on peak flows and peak flood levels will depend on the nature of the development including the percentage of impervious surfaces, the creation of overland (lined and unlined) flow paths, the extent of a pit and pipe system, the incorporation of water sensitive urban design principles and the extent of flow mitigation devices (on site detention and / or retarding basins).

The key flood related objectives for the design of the development are to ensure that:

1. all buildings, car parking areas and other structures comply with Council's flood related planning controls and
2. the magnitude of the existing peak flows from the site into Karignan Creek are not increased as a result of the development.

As there are no defined channels within the actual site (apart from the dam) and runoff crosses the site as overland flow, it is not possible to define a flood planning area extent within the site. However a flood planning area extent line for flooding along Karignan Creek has been provided on Figure 5 a.

4. REFERENCES

1. Lake Macquarie City Council
   Lake Macquarie Waterway Flood Study
   WMAwater, June 2012

2. **Floodplain Development Manual**
   NSW Government, April 2005

3. **Australian Rainfall and Runoff – A Guide to Flood Estimation, Commonwealth of Australia**
   Ball J, Babister M, Nathan R, Weeks W, Weinmann E, Retallick M, Testoni I, (Editors), 2016

4. Bureau of Meteorology
   The Estimation of Probable Maximum Precipitation in Australia: Generalised Short-Duration Method
   Bureau of Meteorology, June 2003

5. **TUFLOW User Manual, TUFLOW.2016-03-AE-w64**
   BMT WBM, March 2016

6. Commonwealth of Australia
   Managing the floodplain a guide to best practice in flood risk management in Australia
   Commonwealth of Australia, 2013, 2nd Edition

7. **NSW Sea Level Rise Policy Statement**
   New South Wales Government, October 2009

8. Department of Environment, Climate Change and Water
   Flood Risk Management Guide
   August 2010

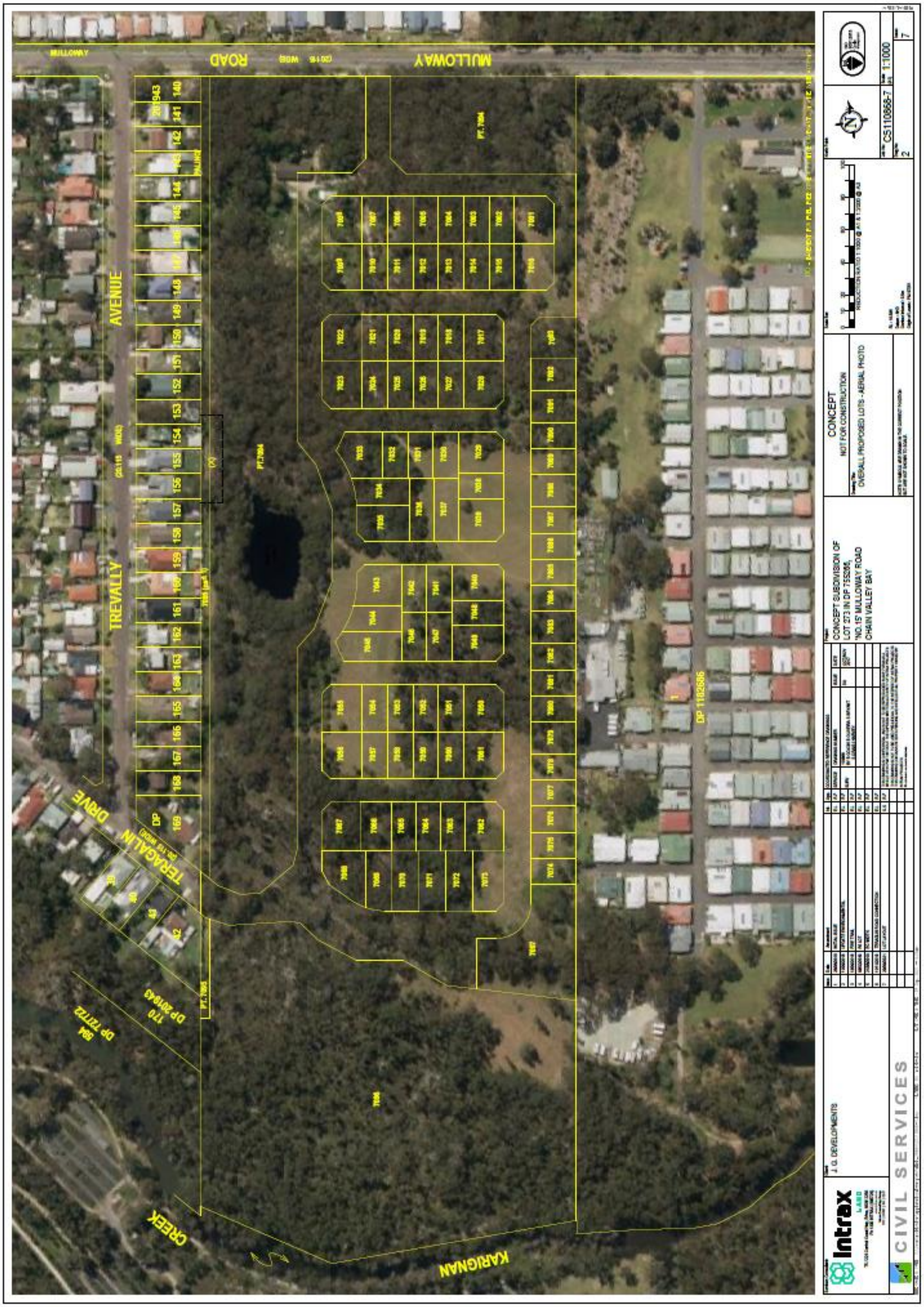
9. Department of Environment, Climate Change and Water
   Derivation of the NSW Government's Sea Level Rise Planning Benchmarks
   October 2009

10. NSW Department of Environment and Climate Change
    Floodplain Risk Management Guidelines – Practical Consideration of Climate Change
    October 2007

Figures

FIGURE 1
STUDY AREA

FIGURE 2
PROPOSED DEVELOPMENT CONCEPTS



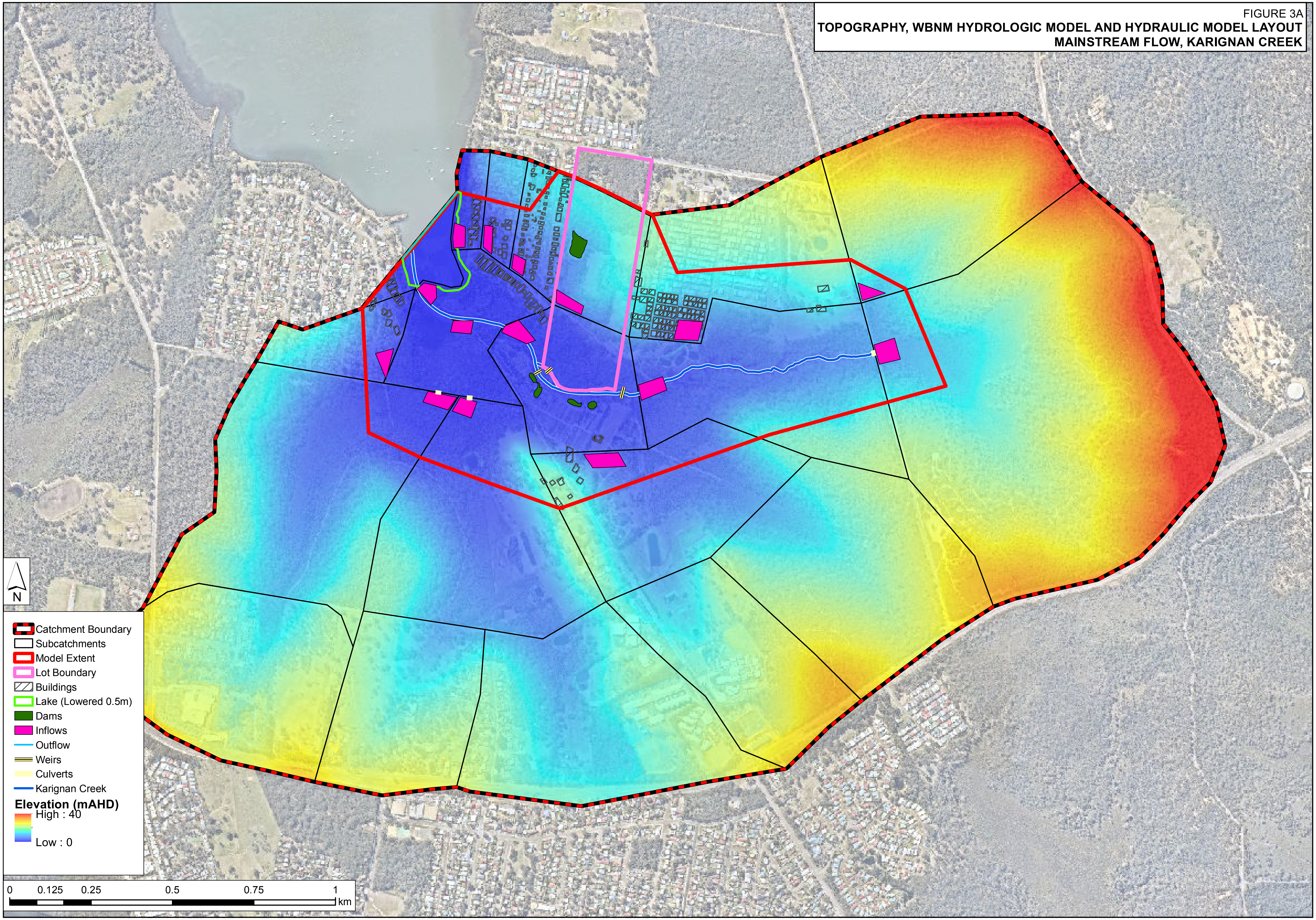


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FIGURE 3B
TOPOGRAPHY, WBNM HYDROLOGIC MODEL AND HYDRAULIC MODEL LAYOUT
KARIGNAN CREEK, OVERLAND FLOW

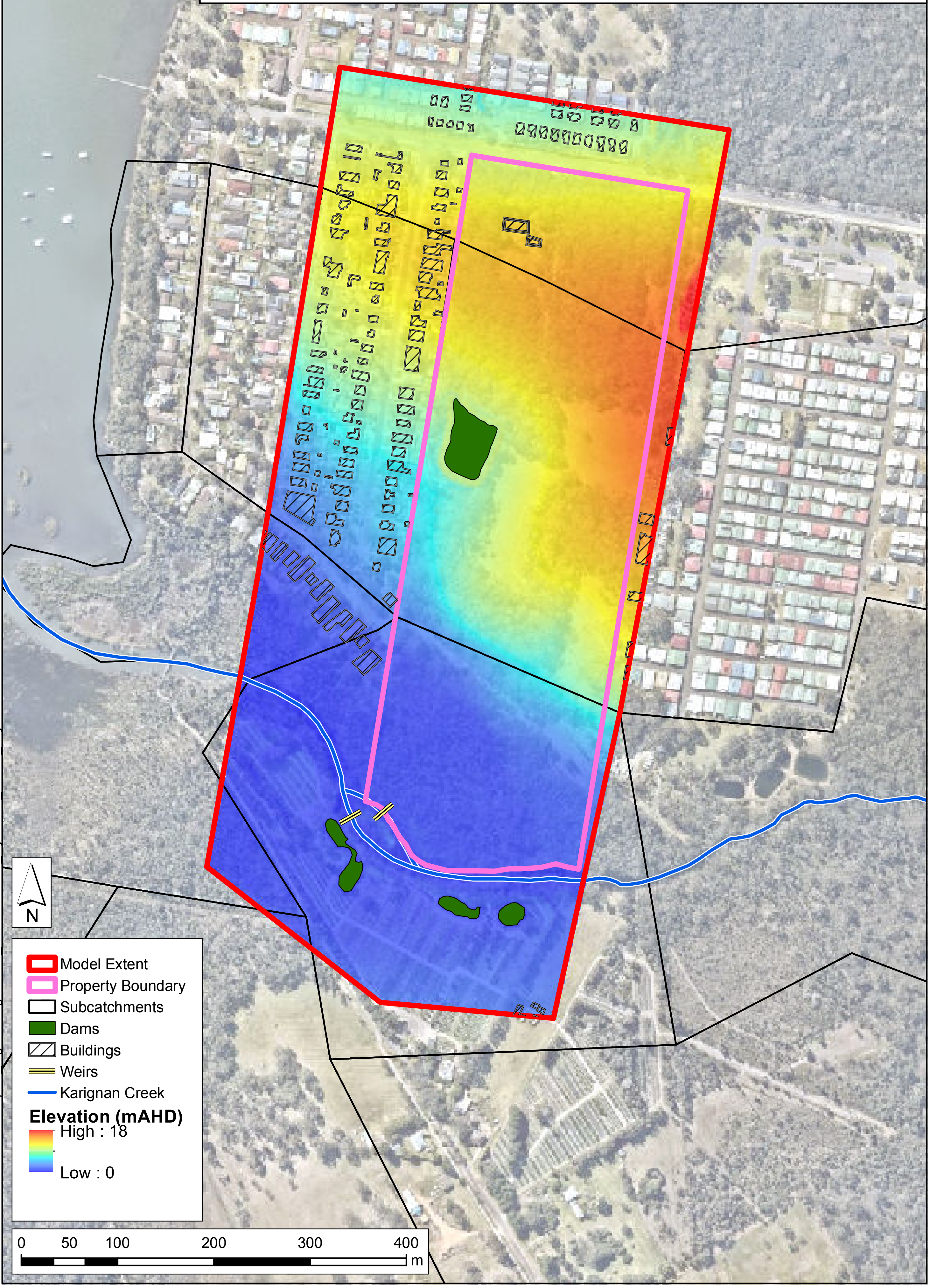

FIGURE 4A

PEAK FLOOD DEPTHS AND CONTOURS, 10% AEP
KARIGNAN CREEK, MAINSTREAM FLOW

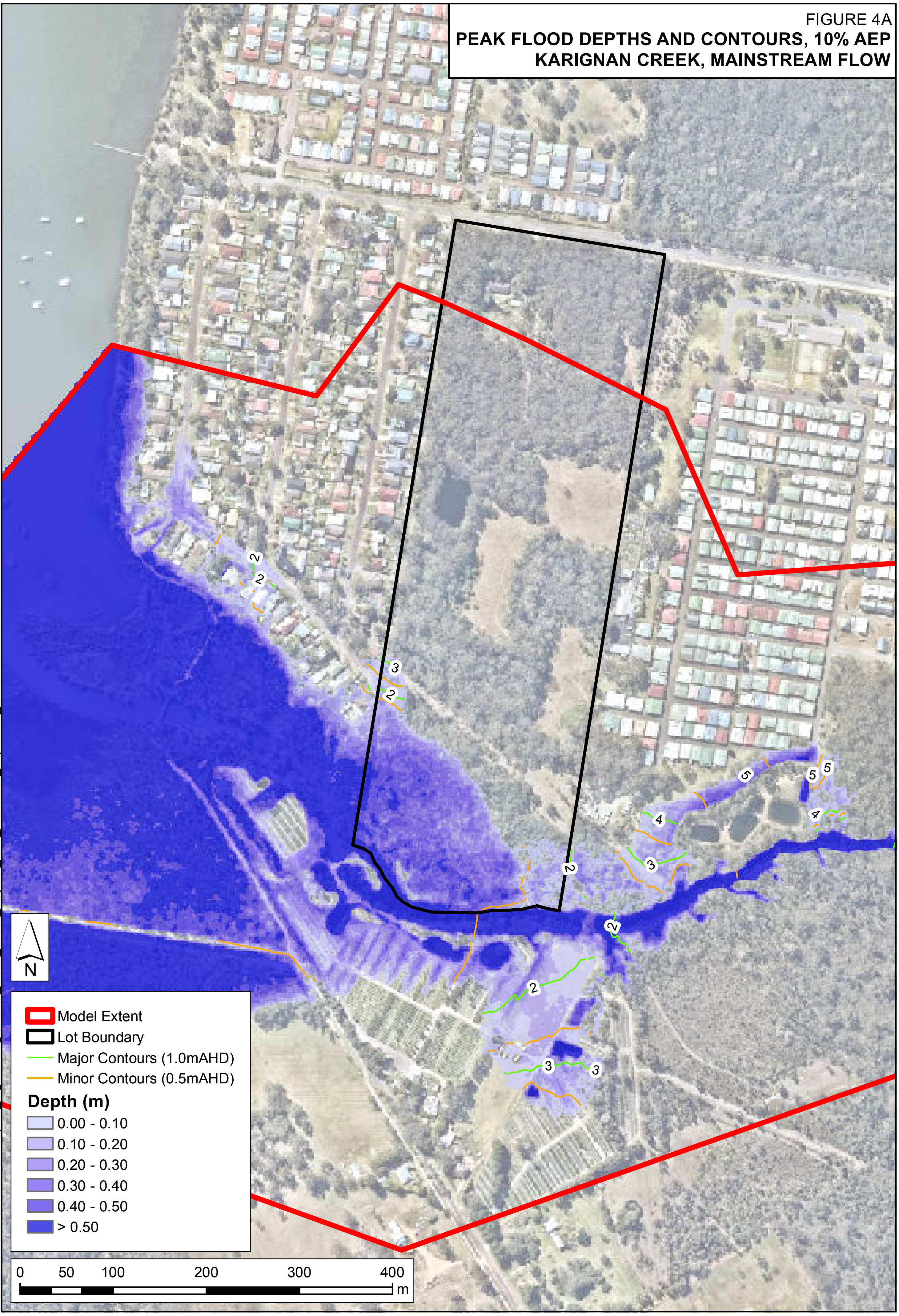

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FIGURE 4B
PEAK FLOOD DEPTHS AND CONTOURS, 10% AEP KARIGNAN CREEK, OVERLAND FLOW

Note: Flood depths less than 50mm are not shown

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FIGURE 5A

PEAK FLOOD DEPTHS AND CONTOURS AND FLOOD PLANNING AREA, 1% AEP
KARIGNAN CREEK, MAINSTREAM FLOW

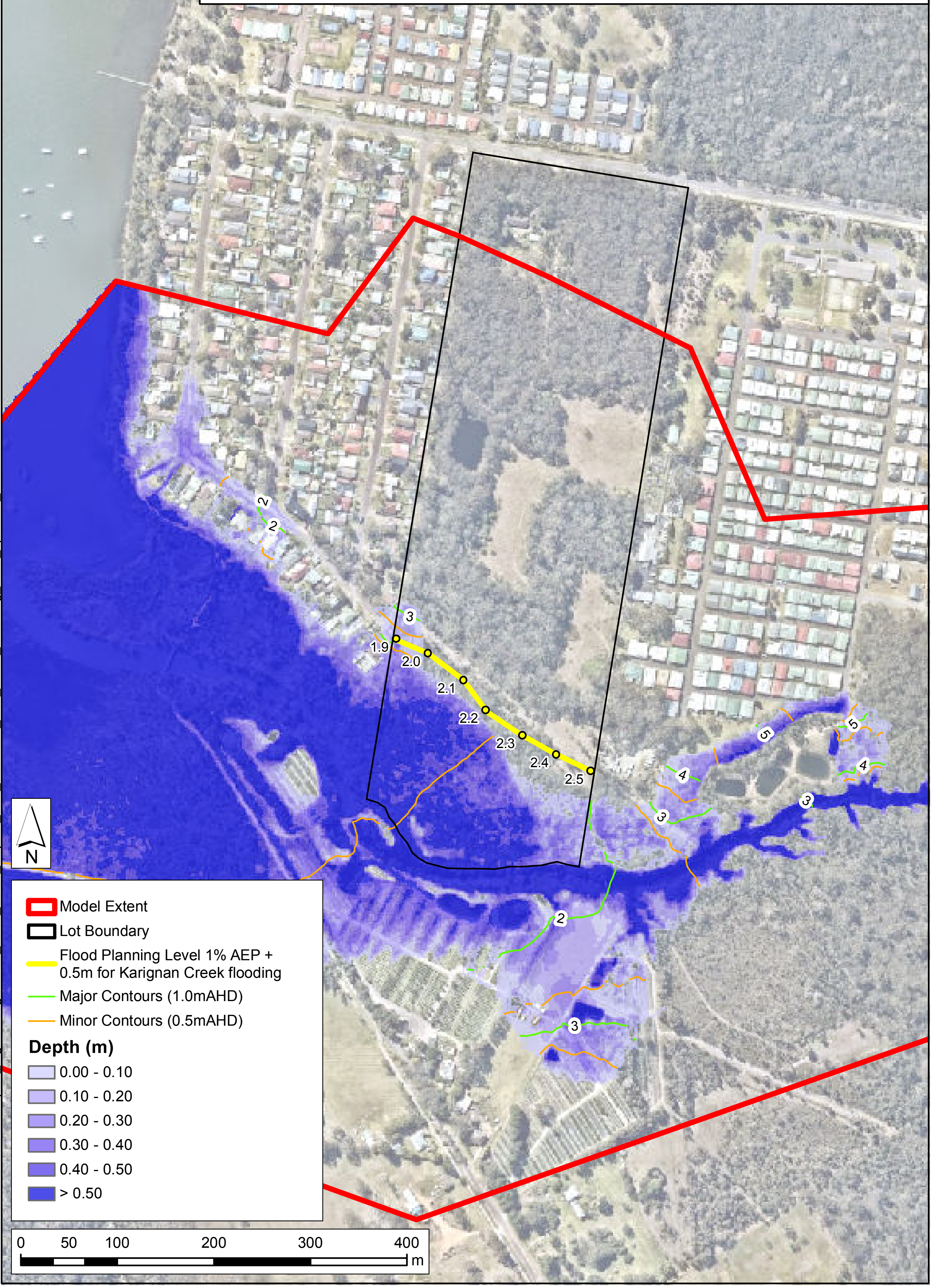

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FIGURE 5B
**PEAK FLOOD DEPTHS AND CONTOURS, 1% AEP
KARIGNAN CREEK, OVERLAND FLOW**

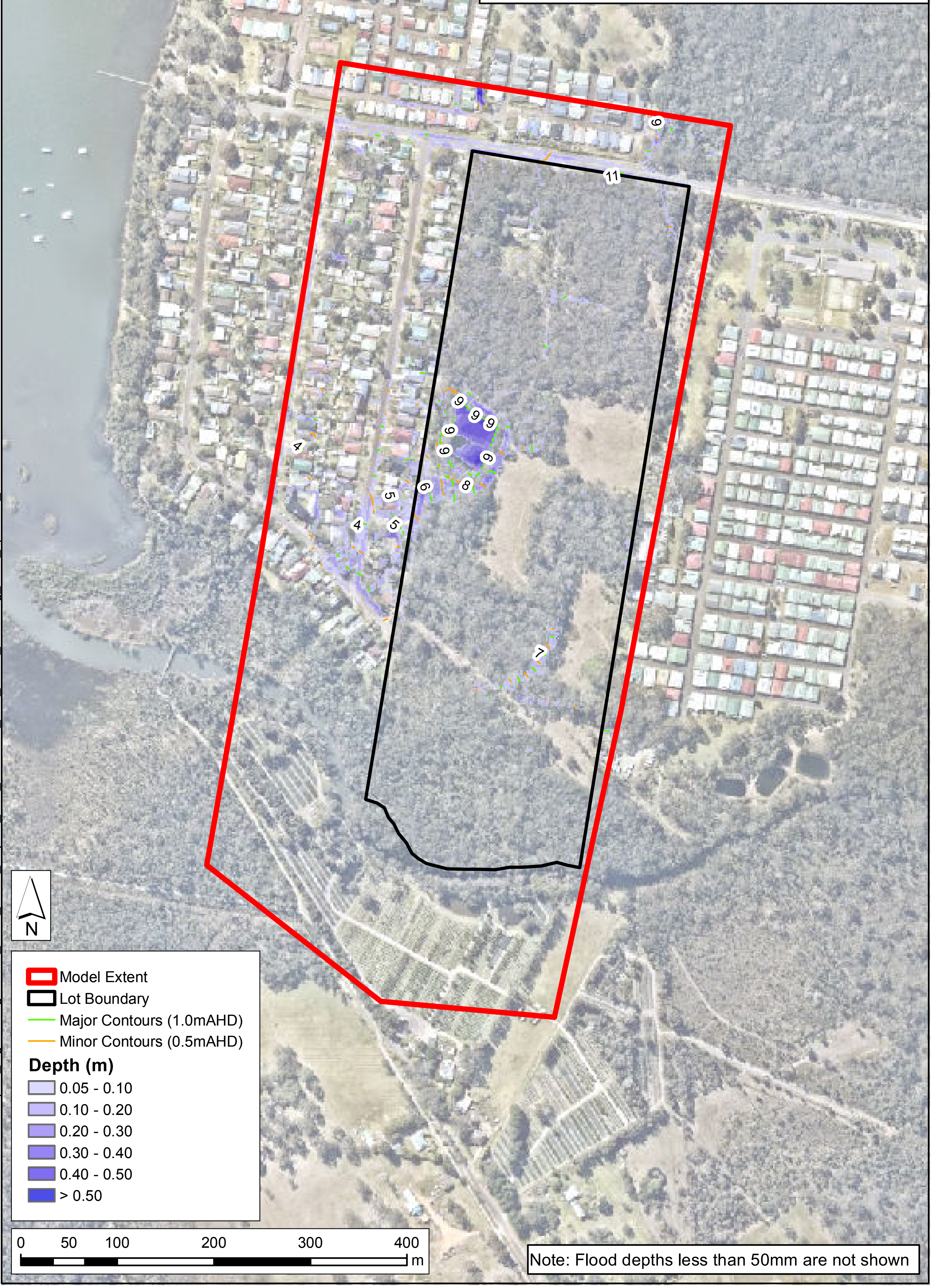

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FIGURE 6A
PEAK FLOOD DEPTHS AND CONTOURS, 0.5% AEP
KARIGNAN CREEK, MAINSTREAM FLOW

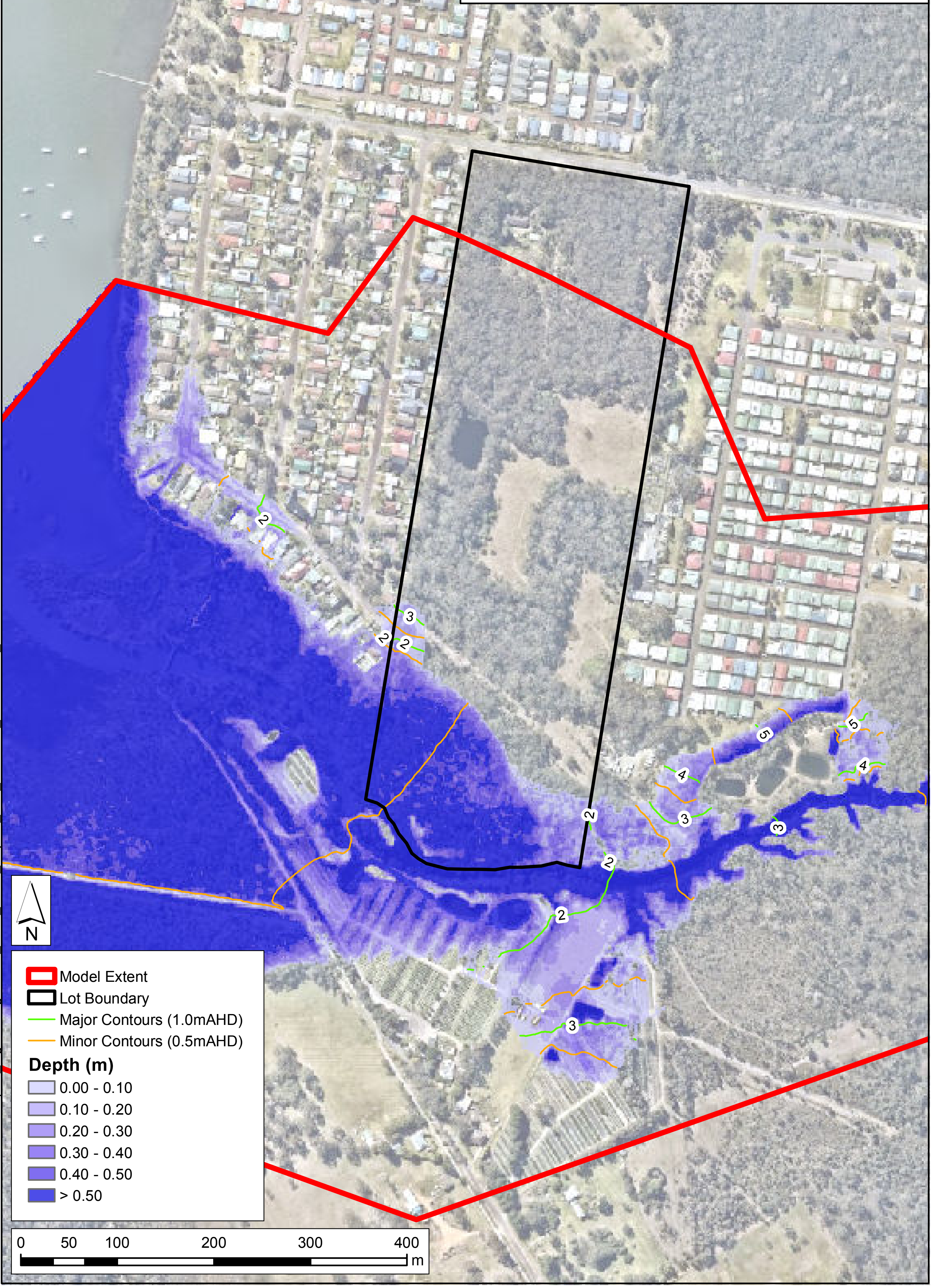
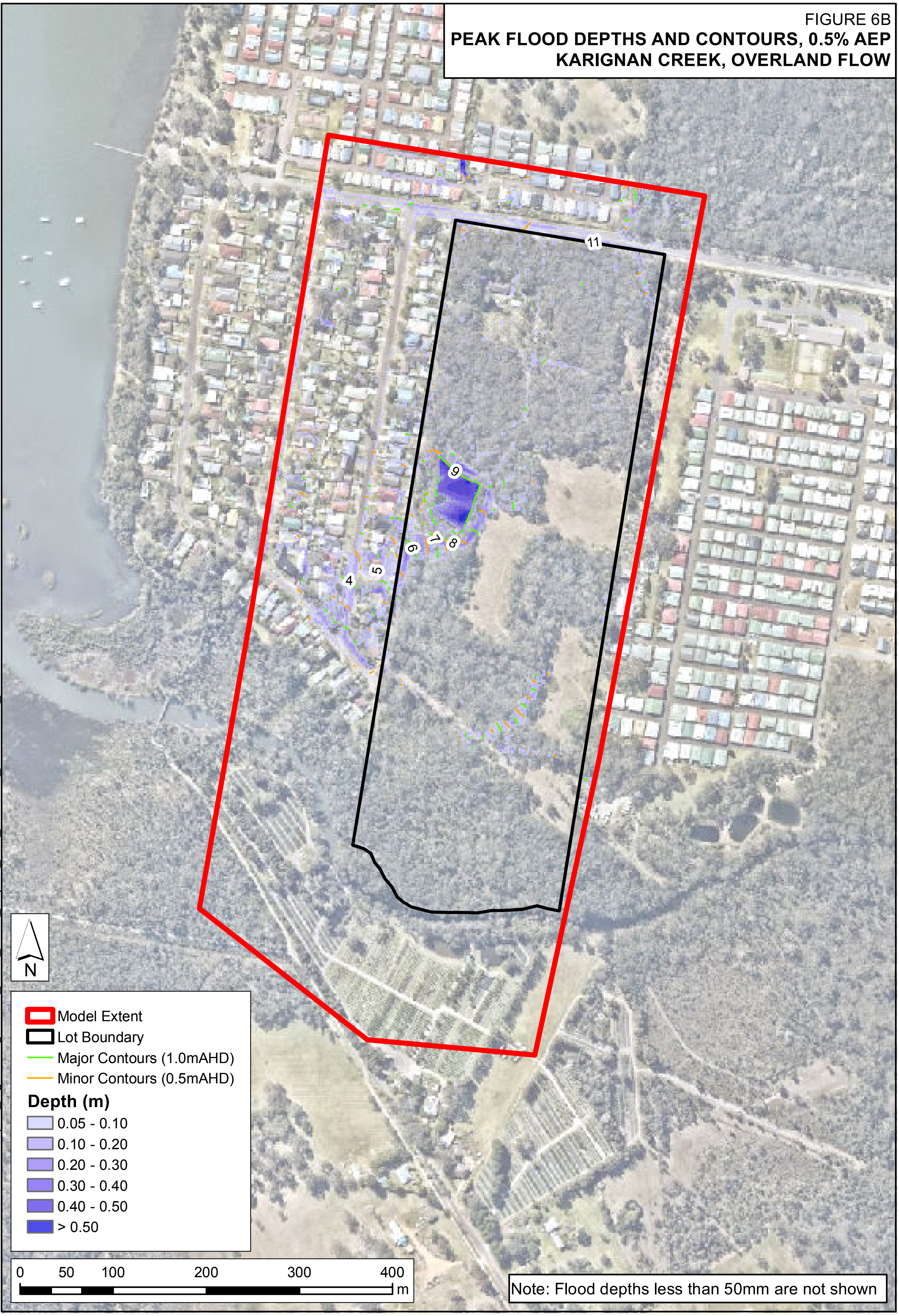


FIGURE 6B

PEAK FLOOD DEPTHS AND CONTOURS, 0.5% AEP
KARIGNAN CREEK, OVERLAND FLOW



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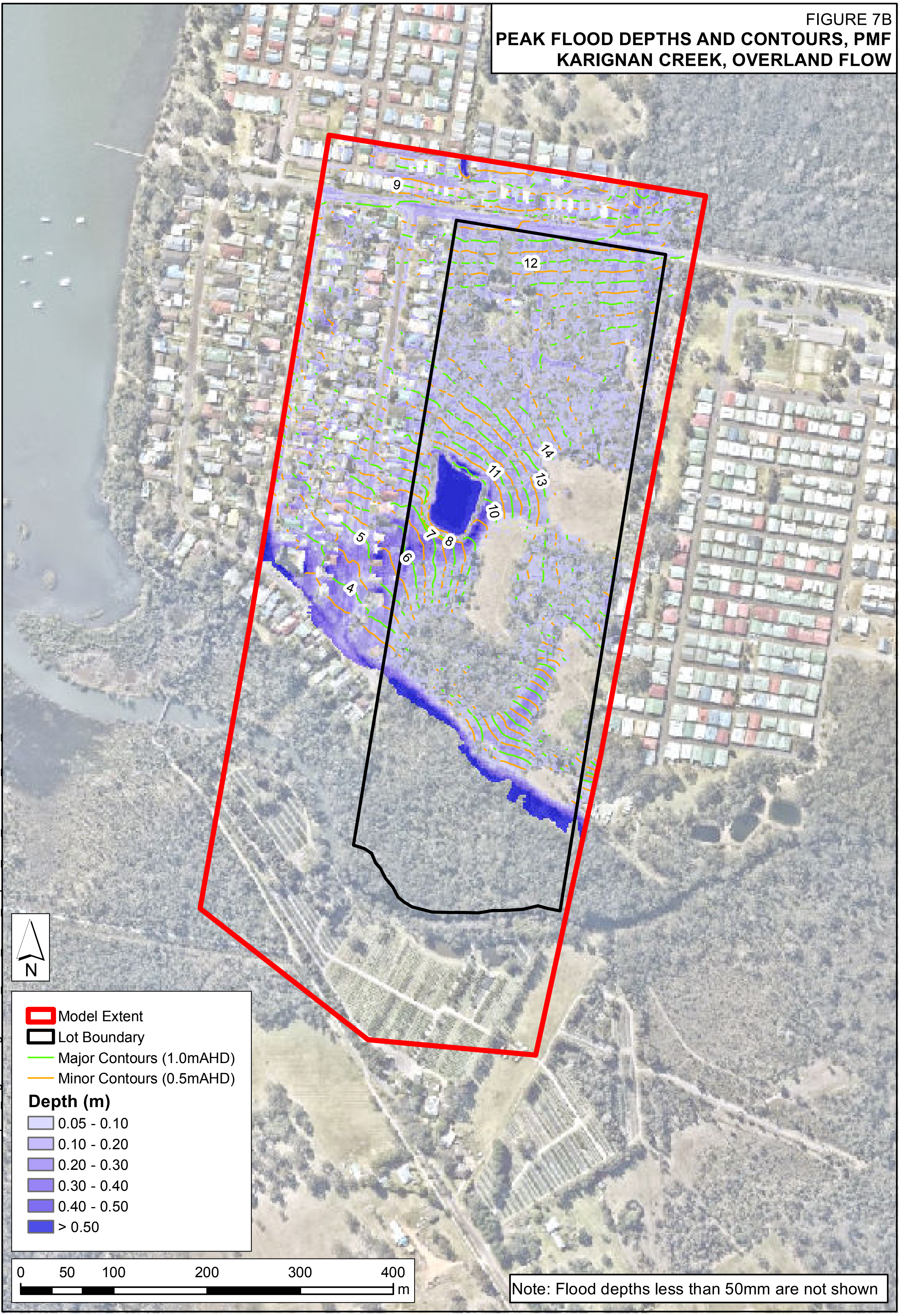

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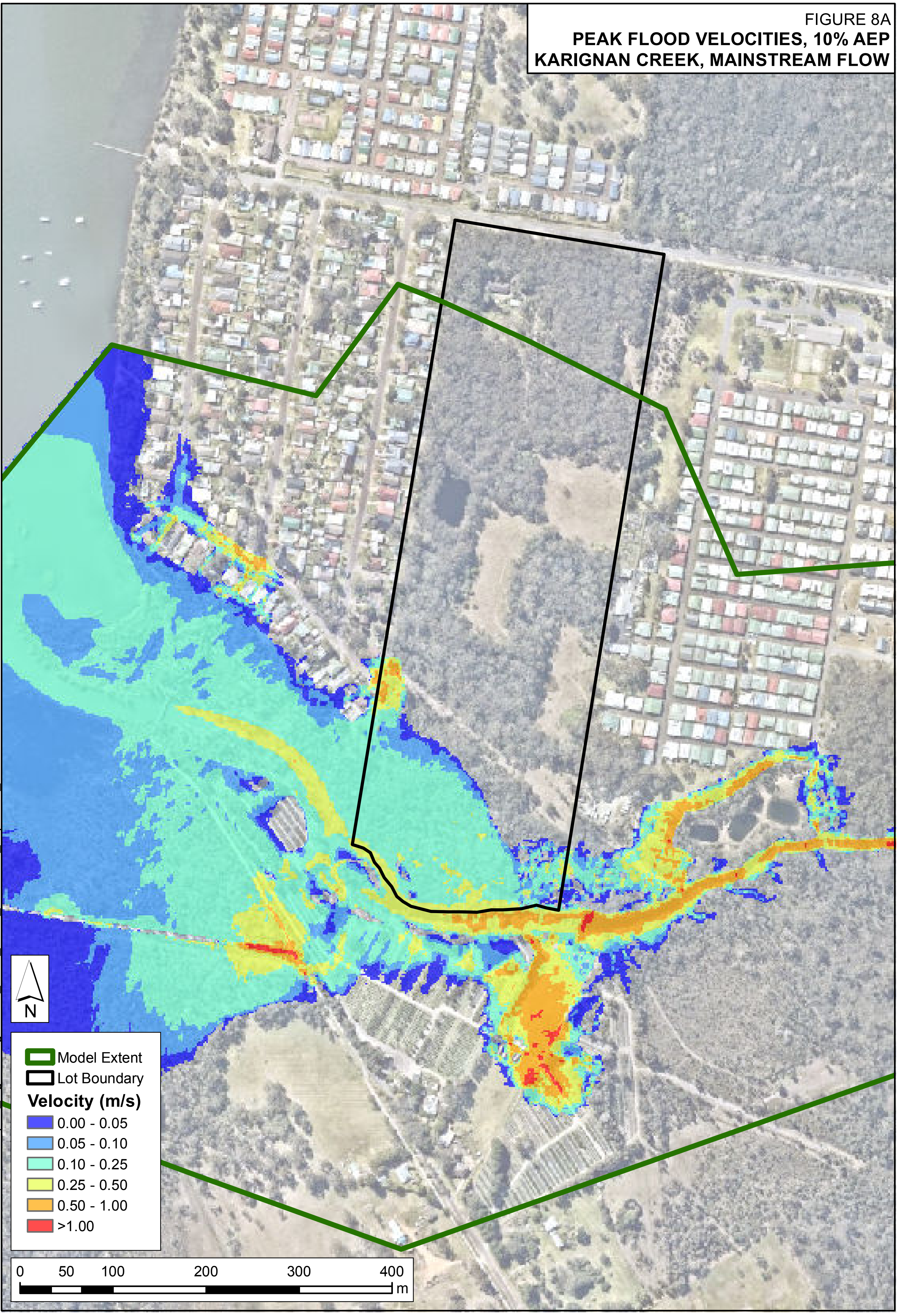
FIGURE 8A
PEAK FLOOD VELOCITIES, 10% AEP
KARIGNAN CREEK, MAINSTREAM FLOW



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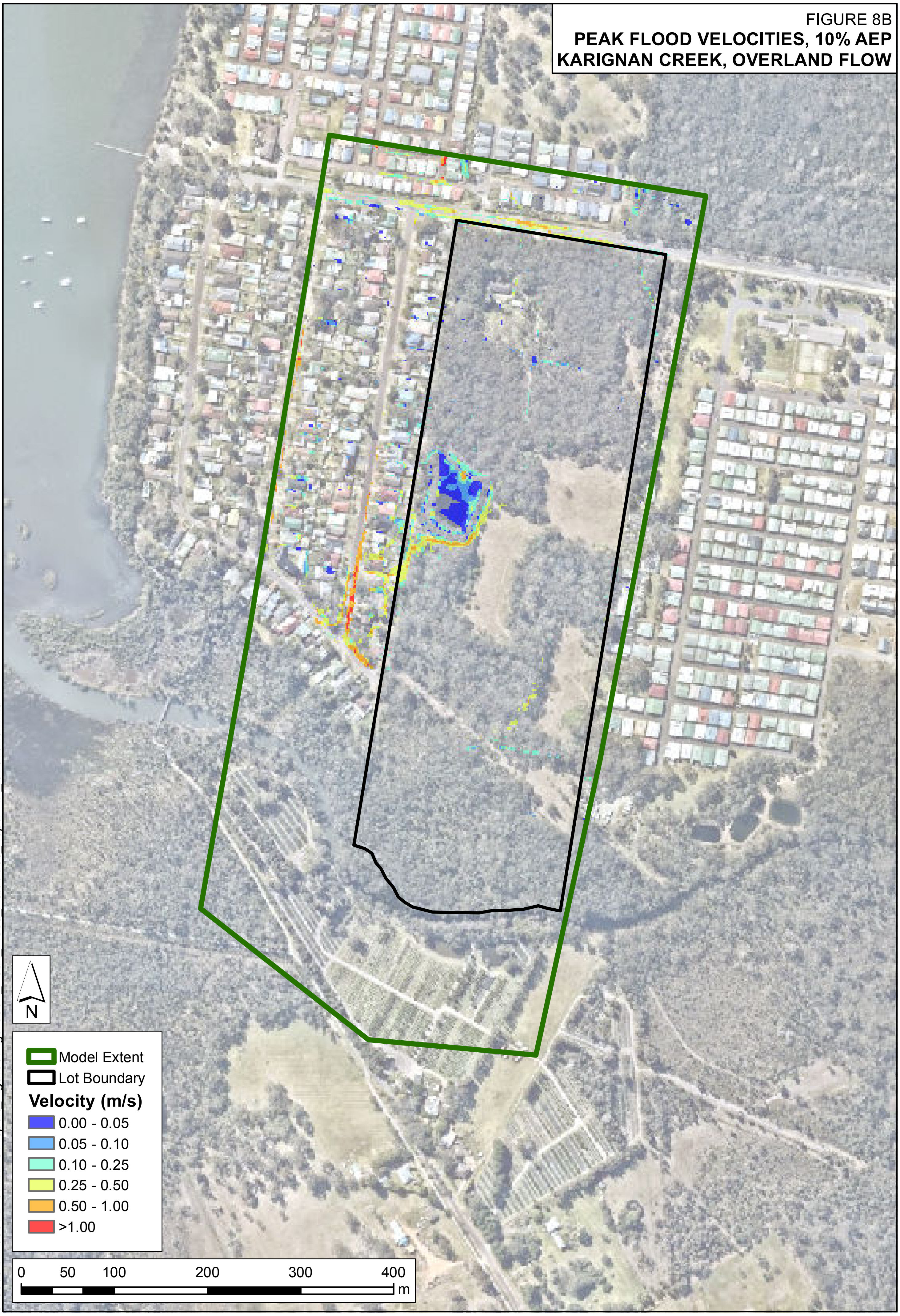

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FIGURE 9A
PEAK FLOOD VELOCITIES, 1% AEP
KARIGNAN CREEK, MAINSTREAM FLOW

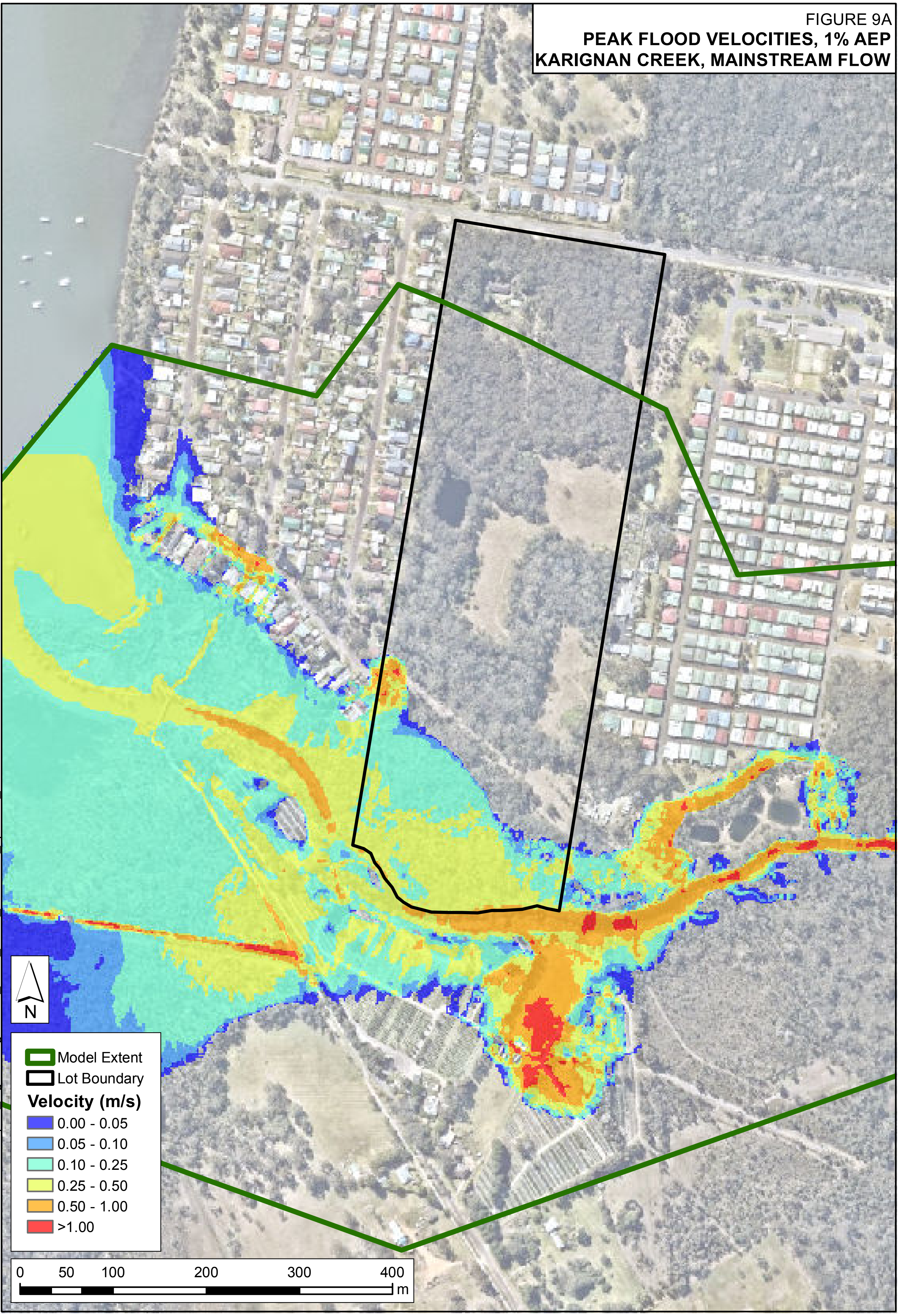

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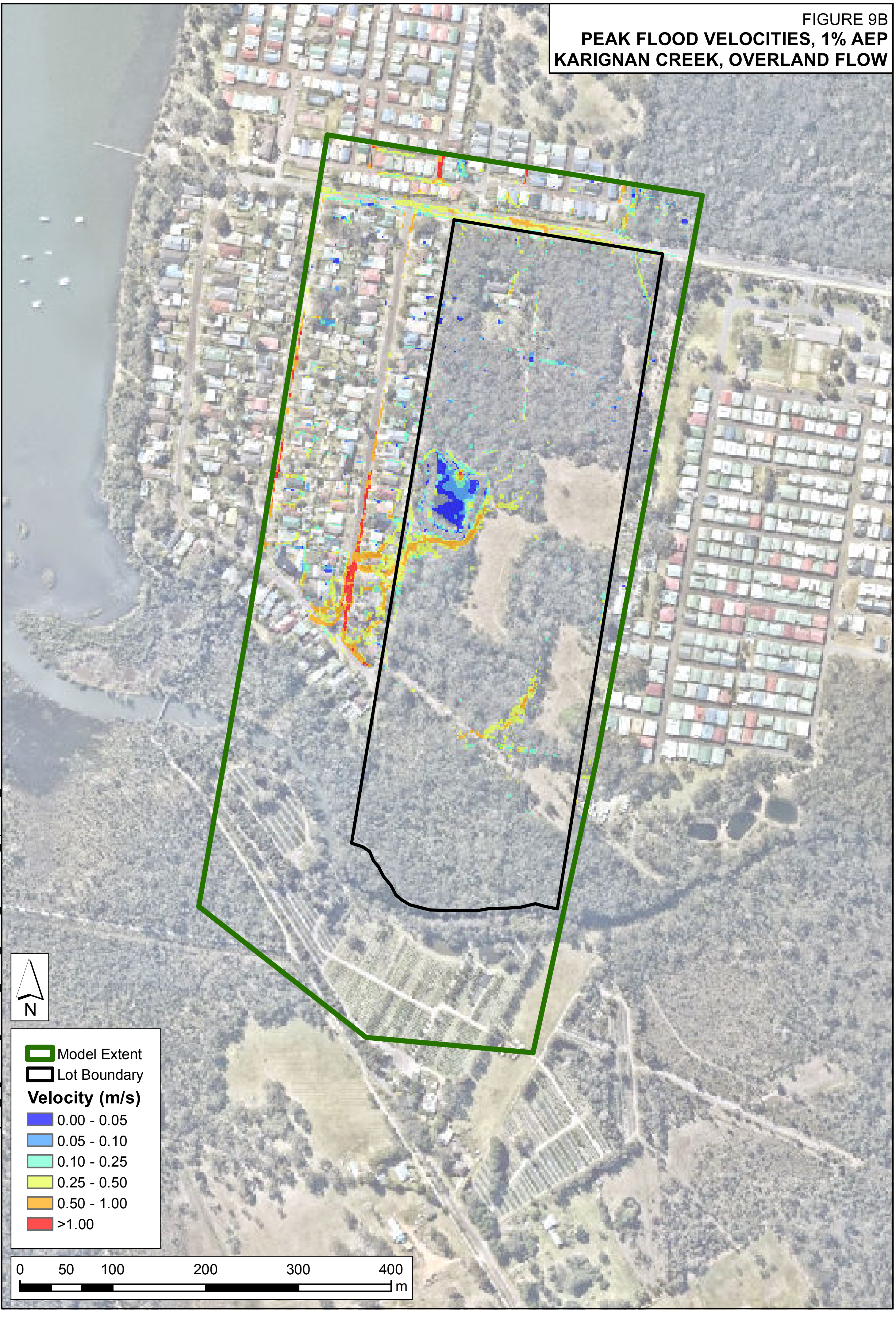
FIGURE 9B
PEAK FLOOD VELOCITIES, 1% AEP
KARIGNAN CREEK, OVERLAND FLOW



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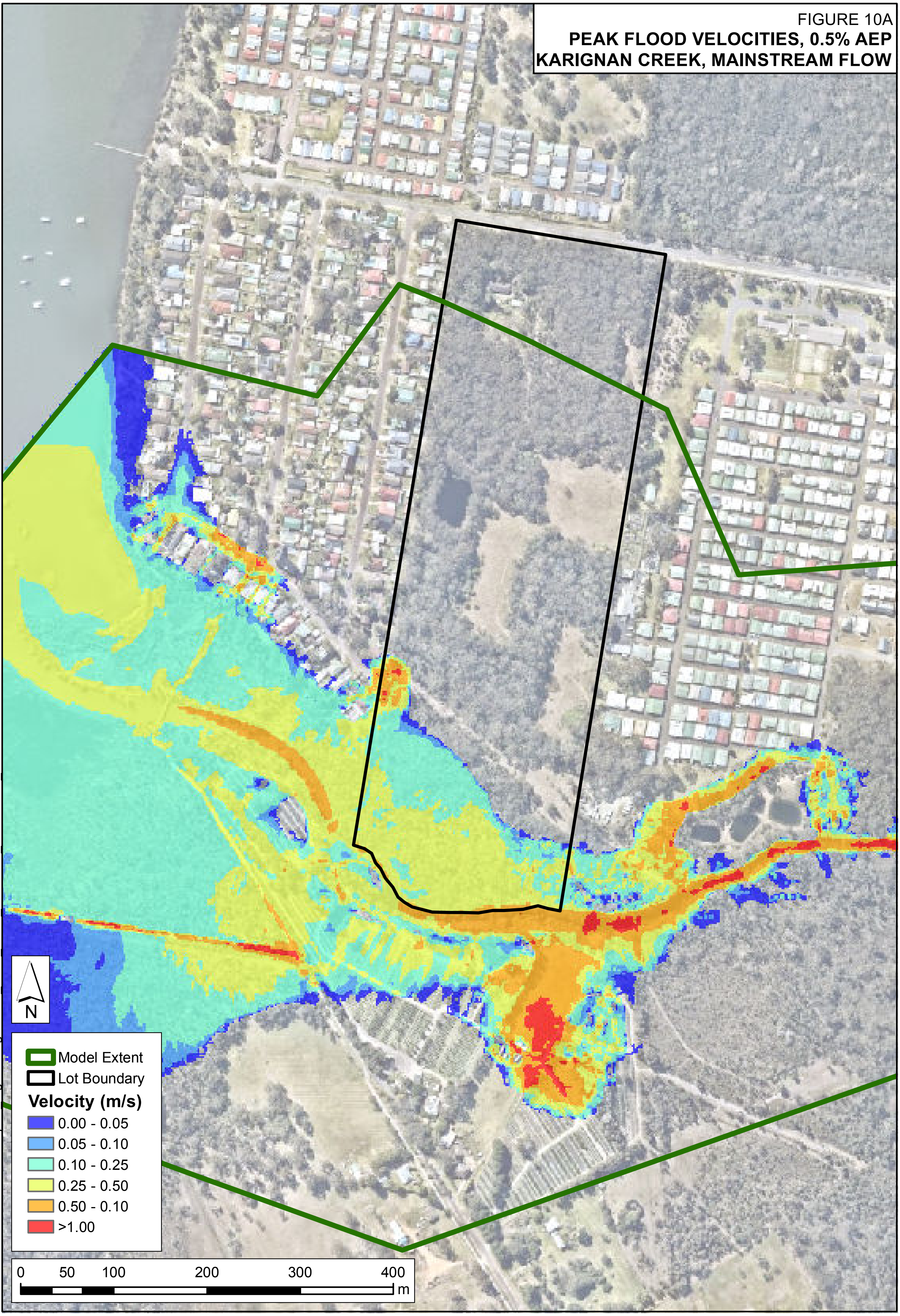

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FIGURE 10B
PEAK FLOOD VELOCITIES, 0.5% AEP KARIGNAN CREEK, OVERLAND FLOW

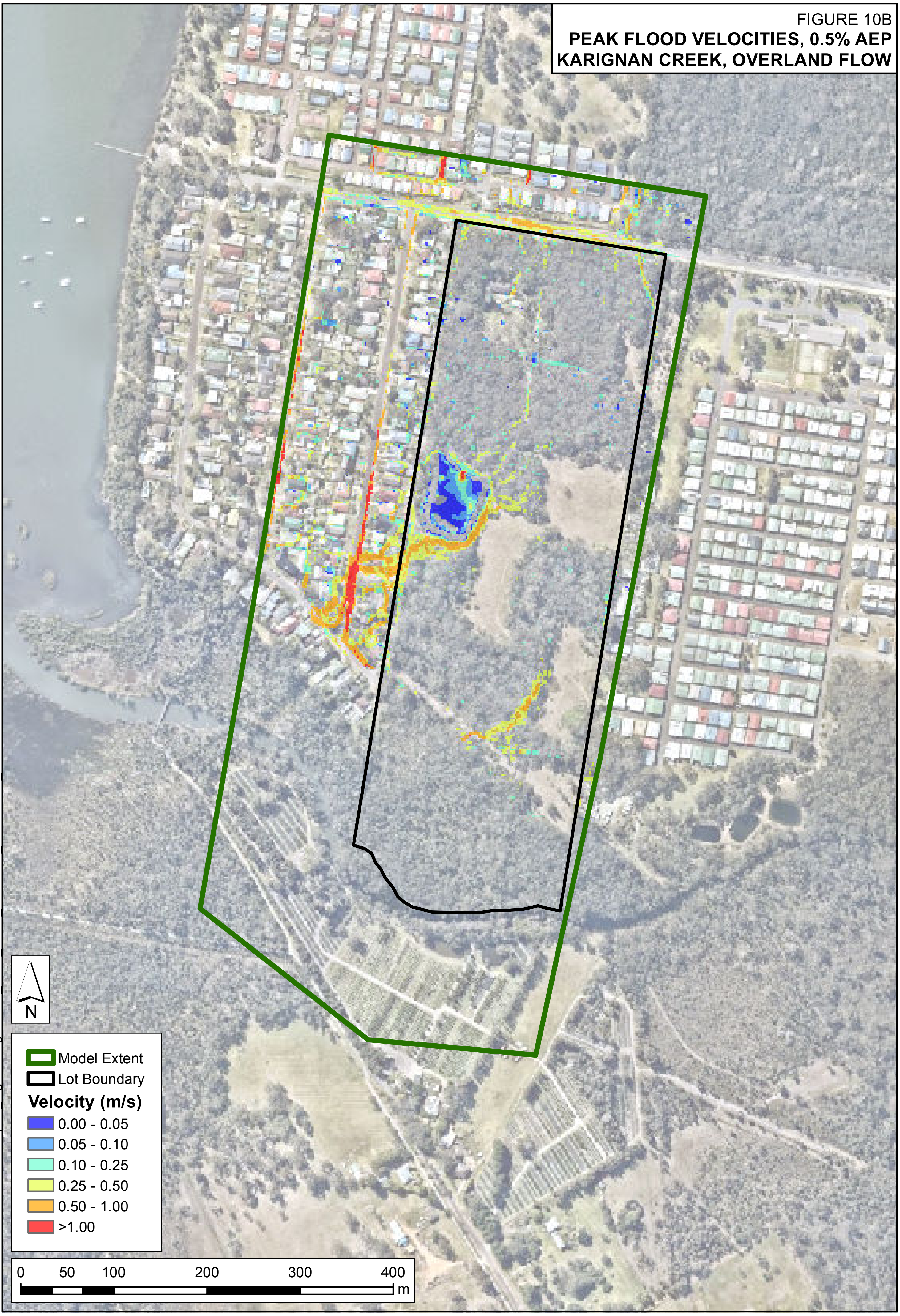

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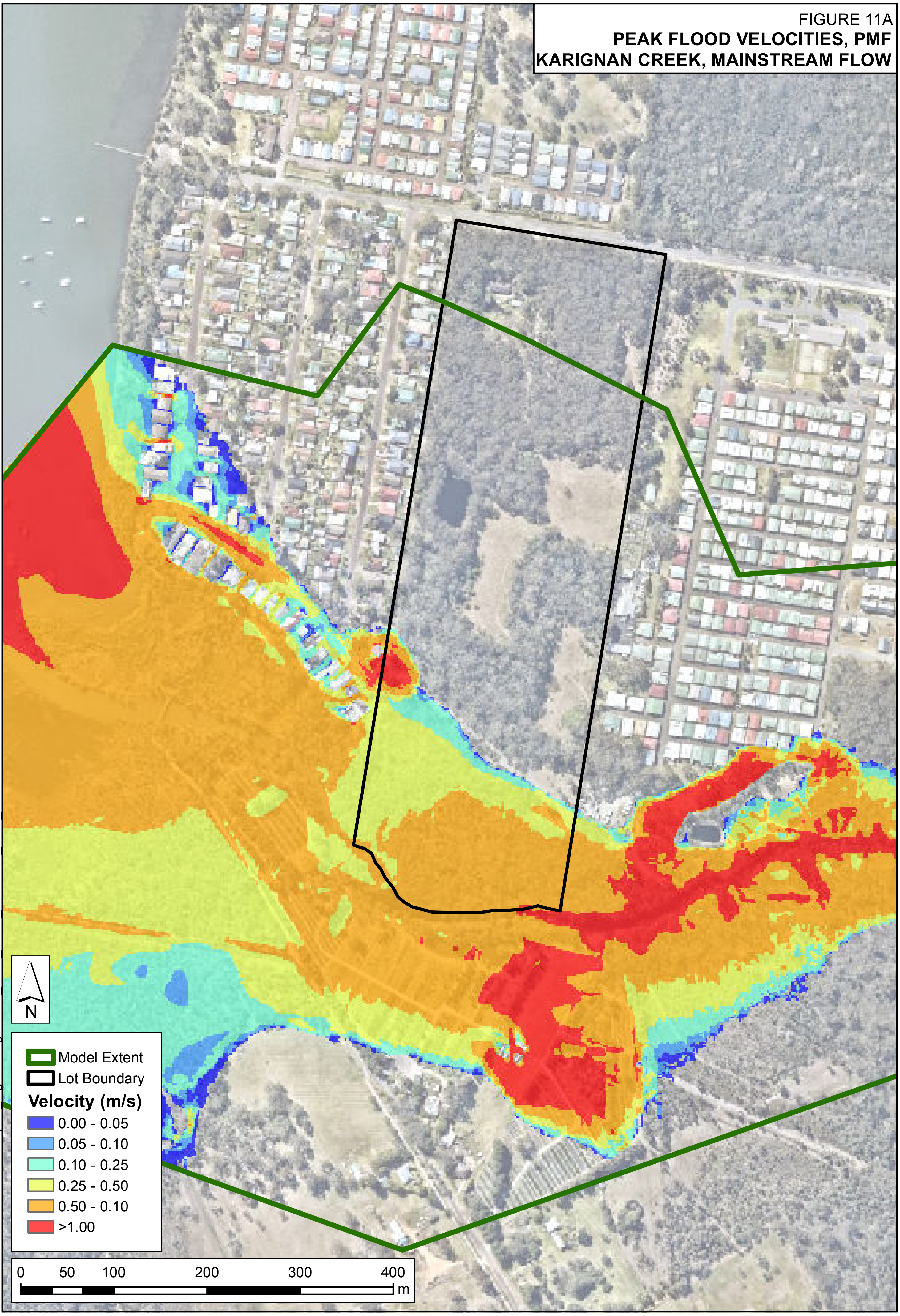
FIGURE 11A
PEAK FLOOD VELOCITIES, PMF
KARIGNAN CREEK, MAINSTREAM FLOW



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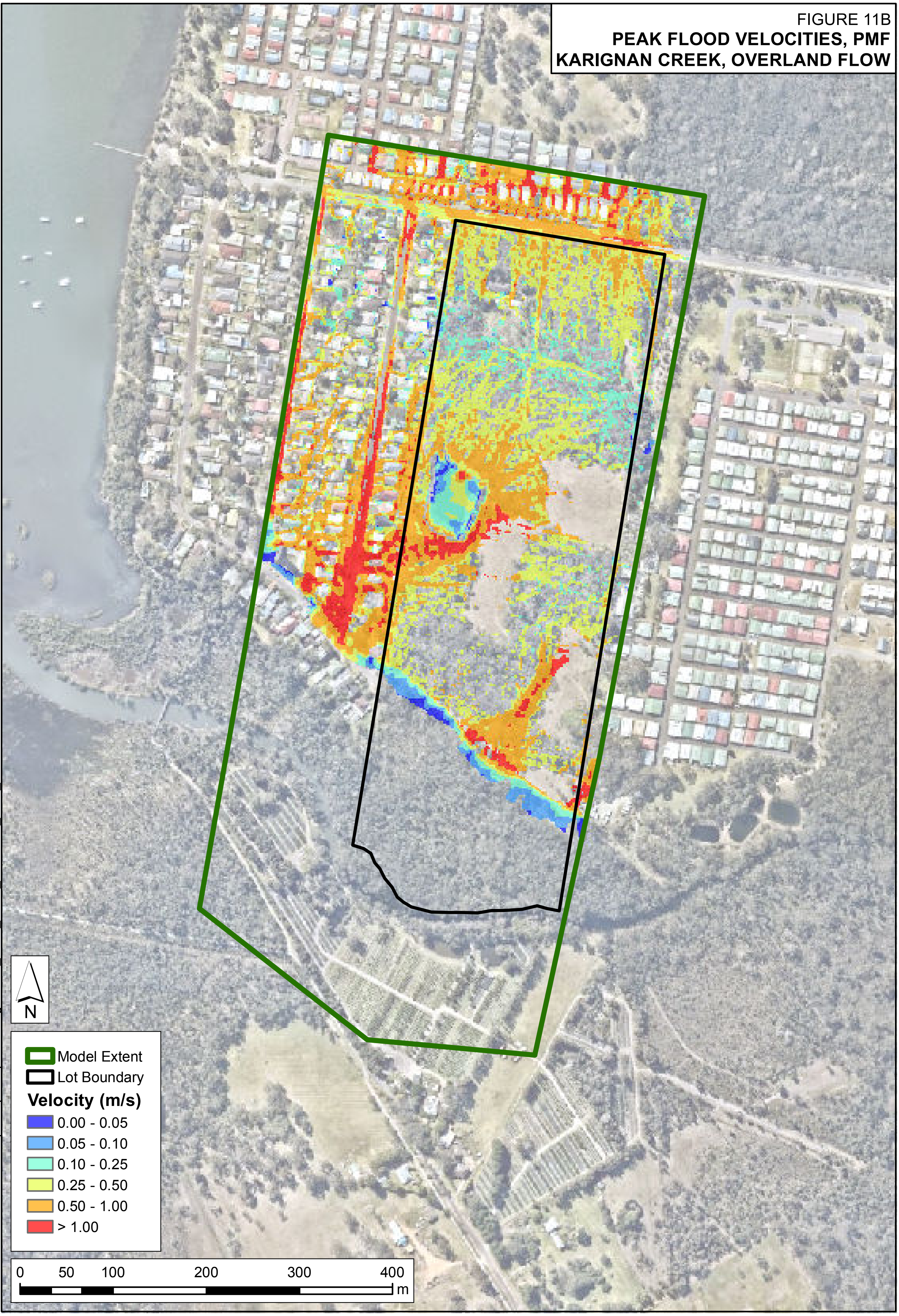

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FIGURE 12A
PROVISIONAL HAZARD CLASSIFICATION, 10% AEP
KARIGNAN CREEK, MAINSTREAM FLOW

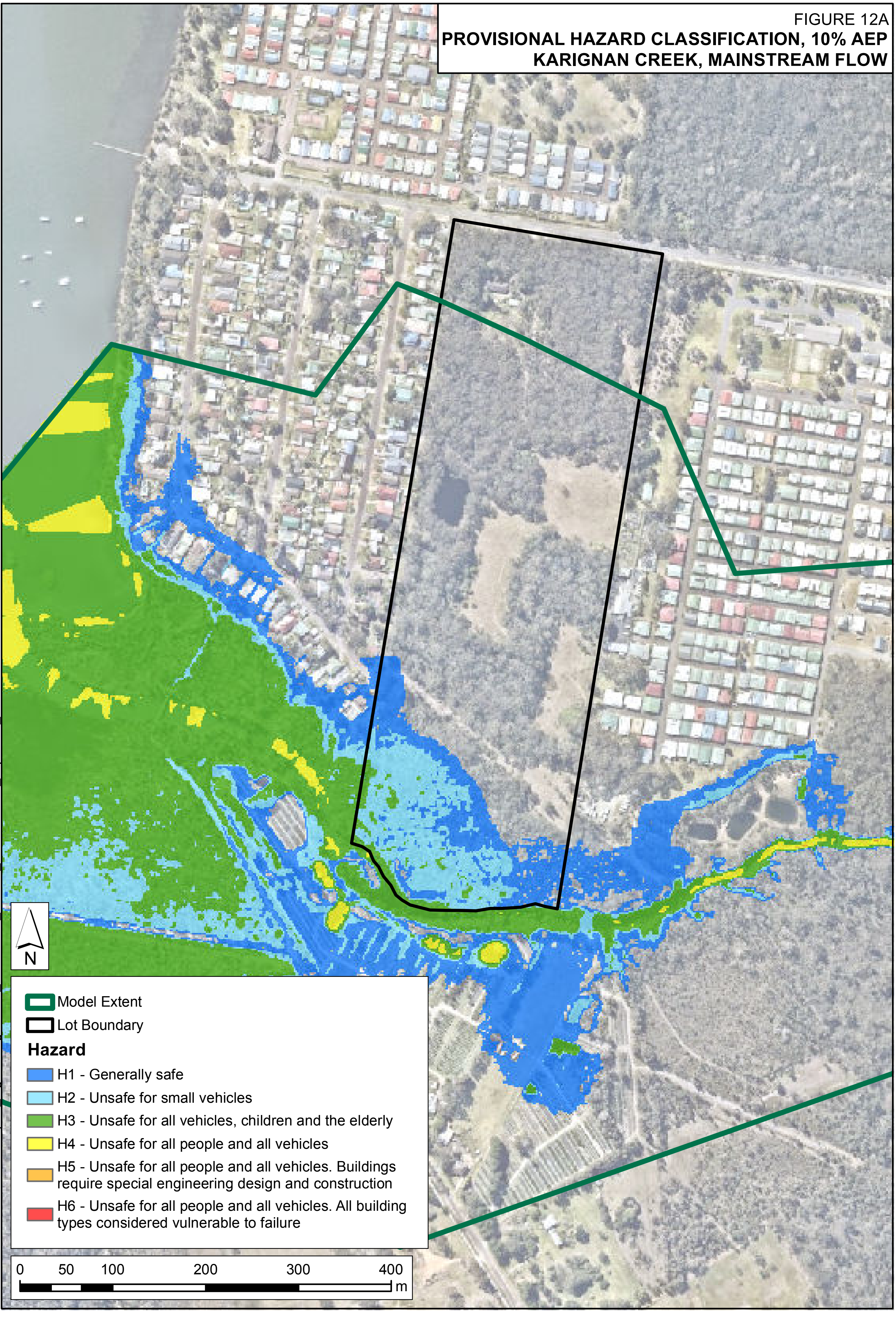

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FIGURE 12B
PROVISIONAL HAZARD CLASSIFICATION, 10% AEP
KARIGNAN CREEK, OVERLAND FLOW

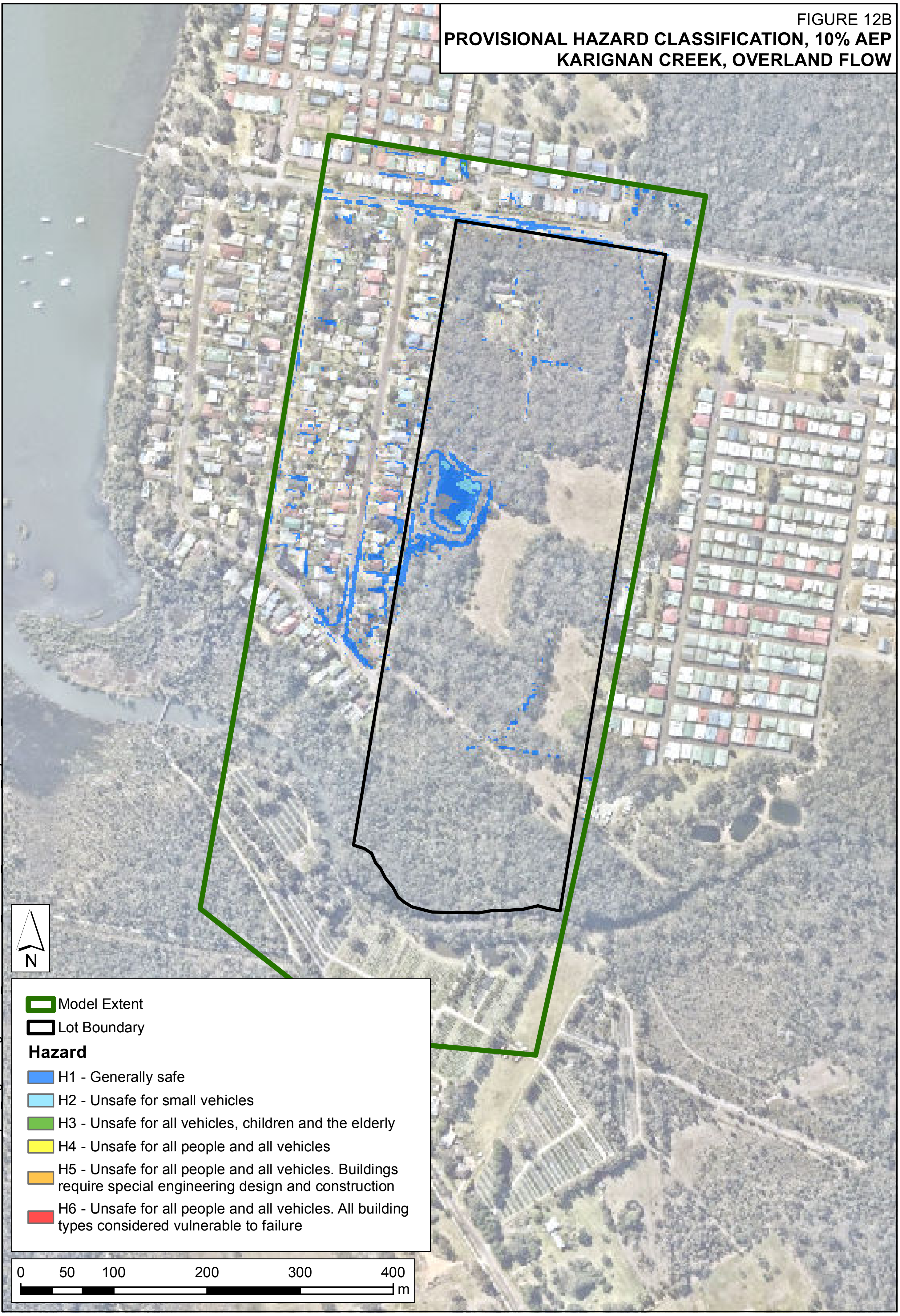

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FIGURE 13A

PROVISIONAL HAZARD CLASSIFICATION, 1% AEP
KARIGNAN CREEK, MAINSTREAM FLOW

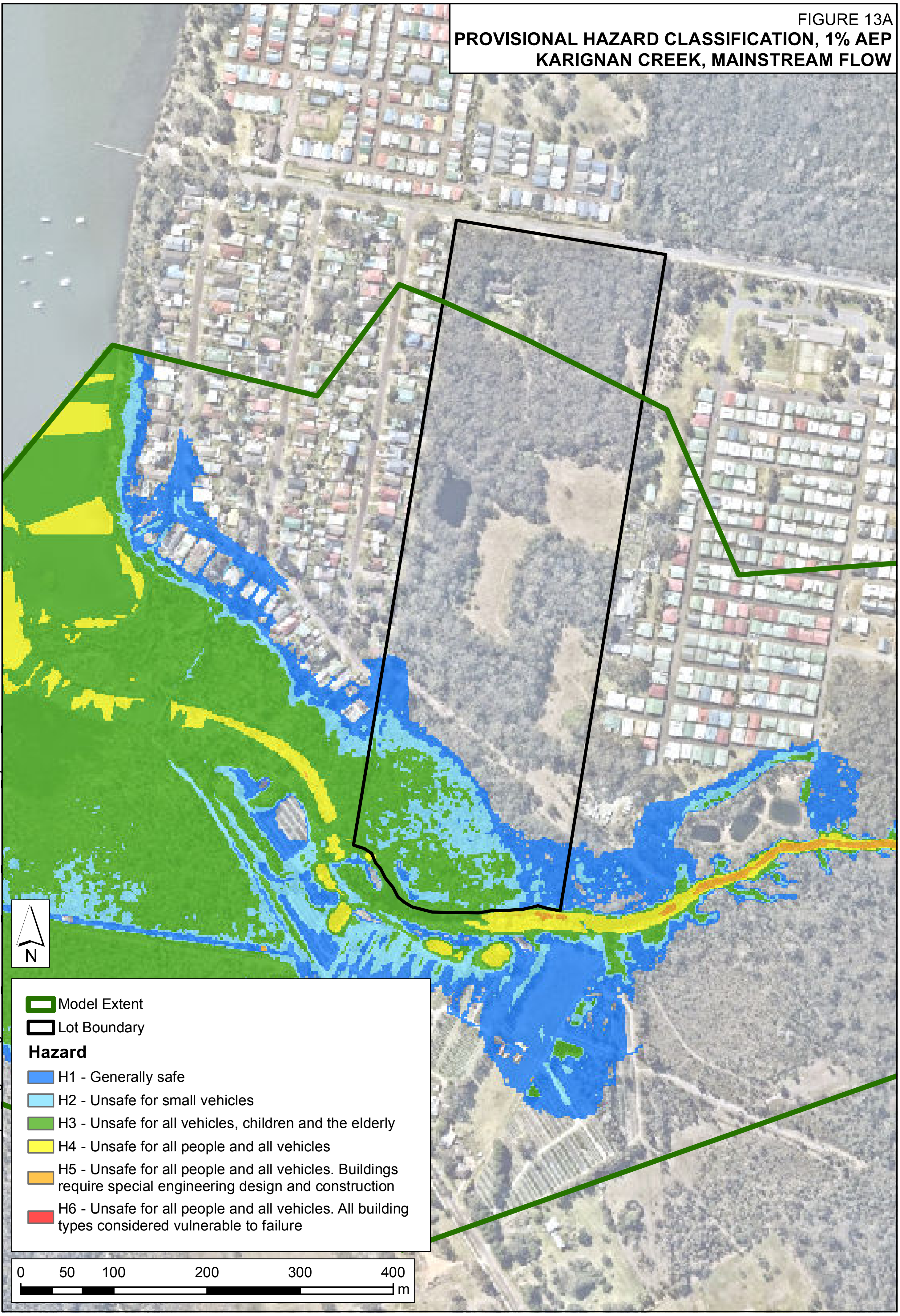

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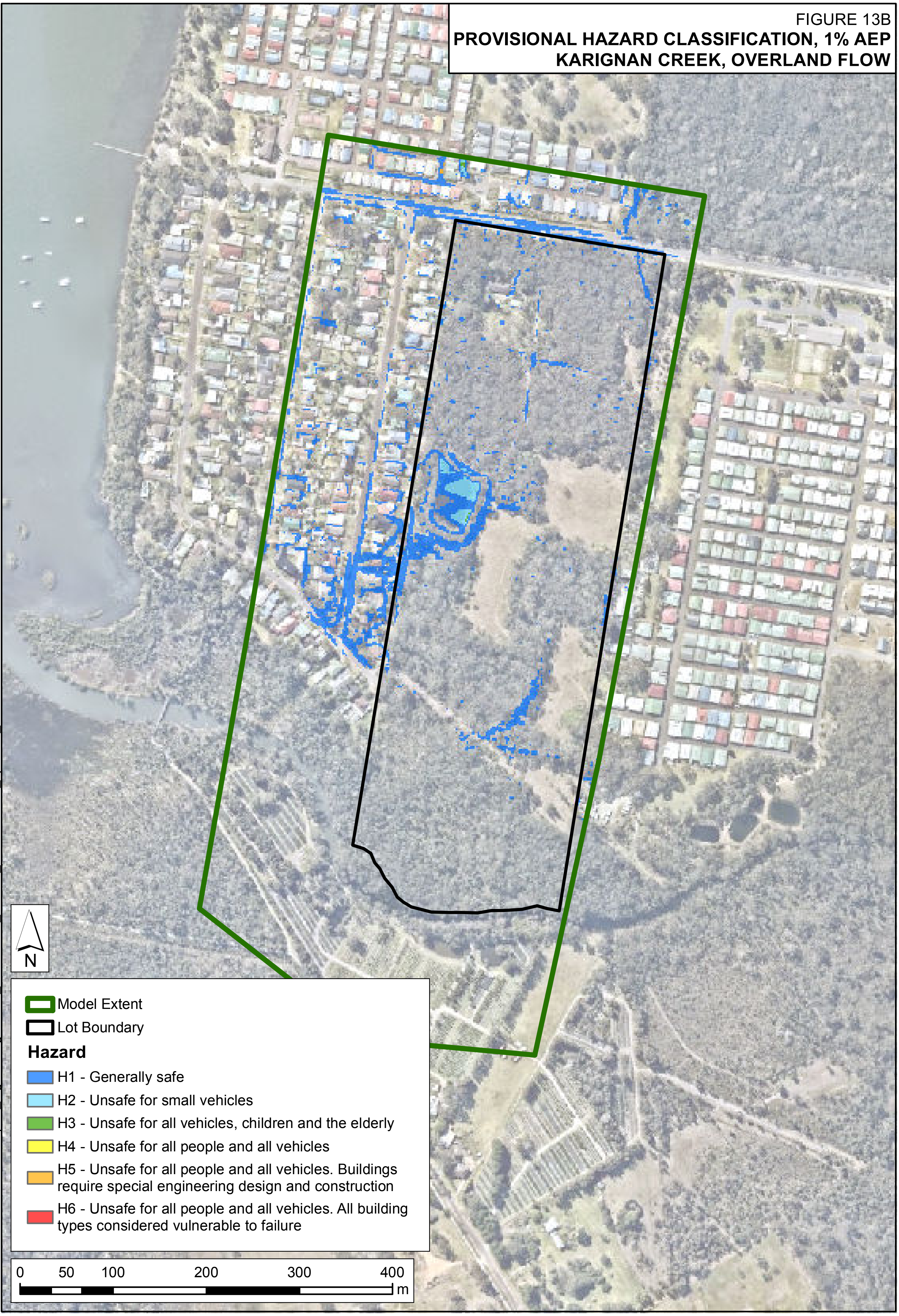
FIGURE 13B

PROVISIONAL HAZARD CLASSIFICATION, 1% AEP
KARIGNAN CREEK, OVERLAND FLOW



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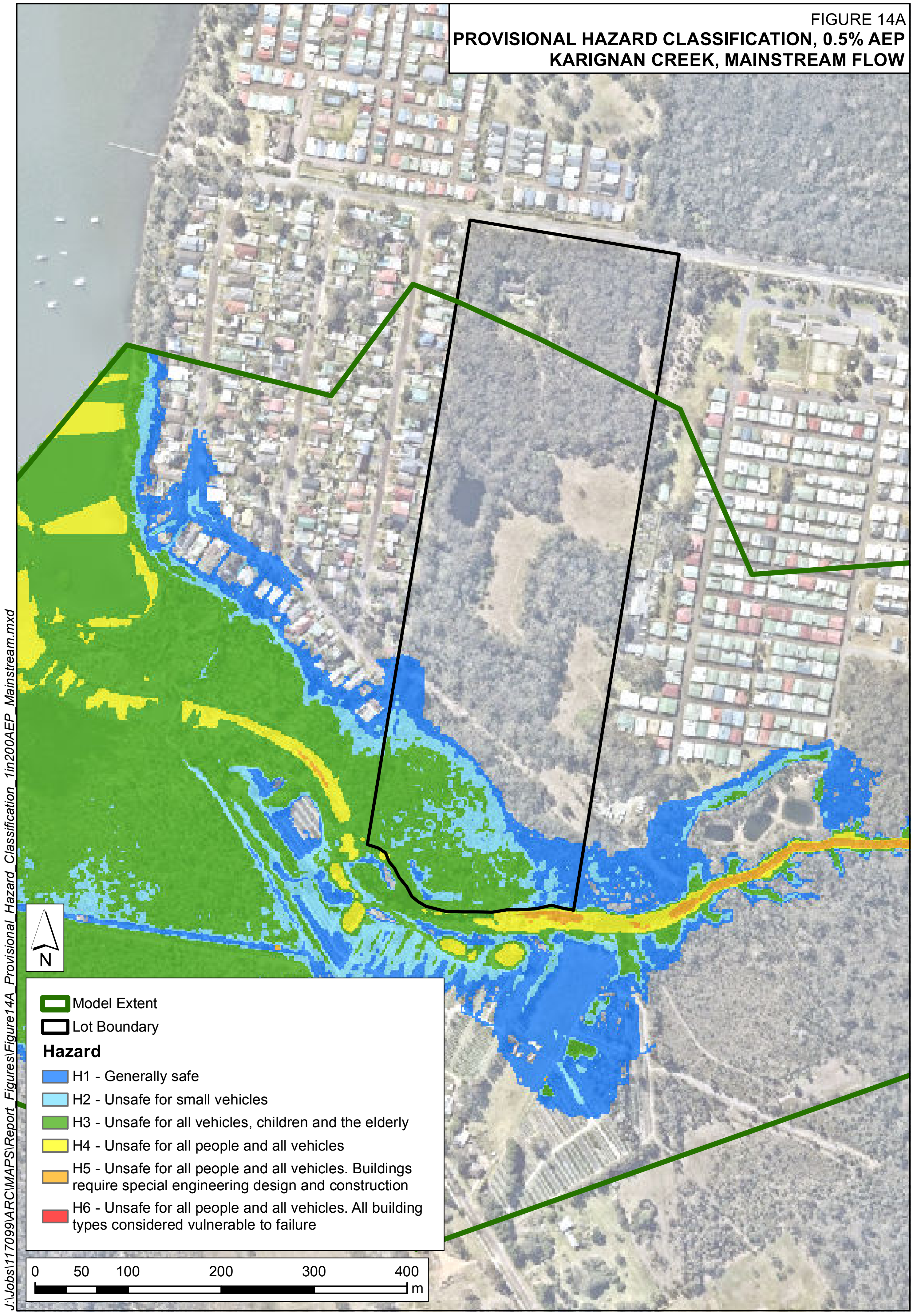
FIGURE 14A
PROVISIONAL HAZARD CLASSIFICATION, 0.5% AEP
KARIGNAN CREEK, MAINSTREAM FLOW
N
Model Extent
Lot Boundary
Hazard
H1 - Generally safe
H2 - Unsafe for small vehicles
H3 - Unsafe for all vehicles, children and the elderly
H4 - Unsafe for all people and all vehicles
H5 - Unsafe for all people and all vehicles. Buildings require special engineering design and construction
H6 - Unsafe for all people and all vehicles. All building types considered vulnerable to failure
0 50 100 200 300 400
m
J:\Jobs\117099\ARC\MAPS\Report_Figures\Figure14A_Provisional_Hazard_Classification_1in200AEP_Mainstream.mxd

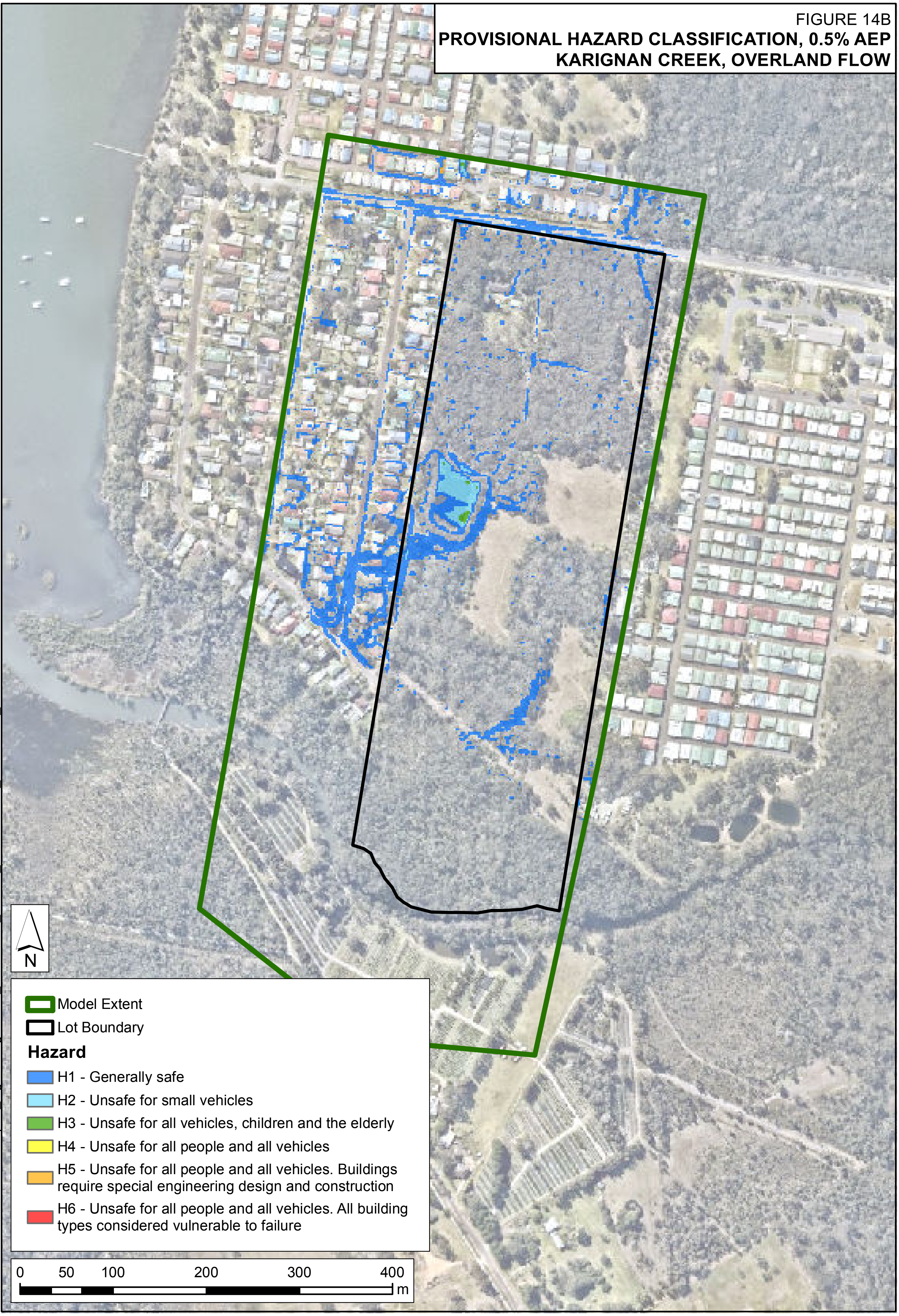

FIGURE 14B
PROVISIONAL HAZARD CLASSIFICATION, 0.5% AEP
KARIGNAN CREEK, OVERLAND FLOW

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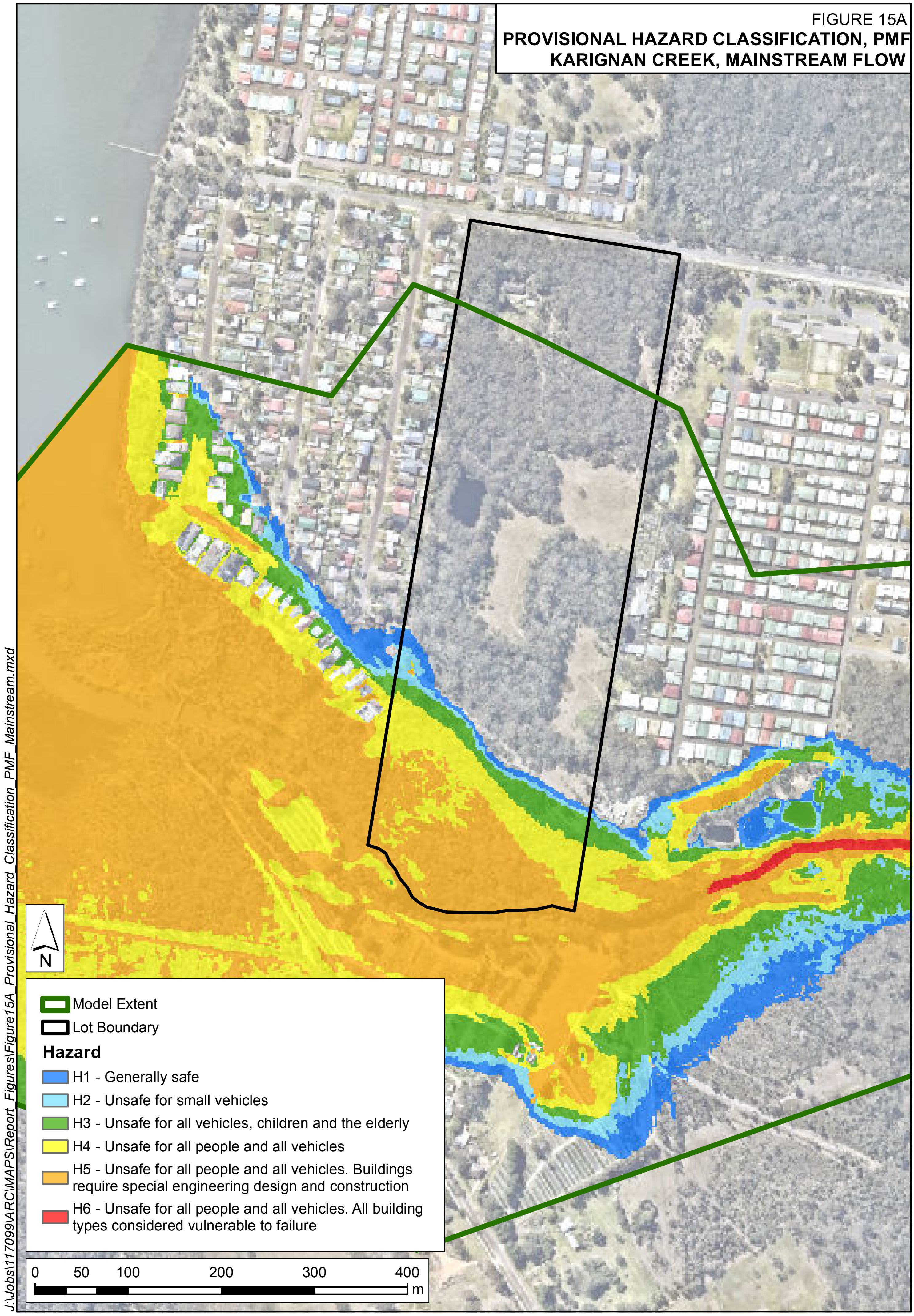
FIGURE 15A
PROVISIONAL HAZARD CLASSIFICATION, PMF
KARIGNAN CREEK, MAINSTREAM FLOW
N
Model Extent
Lot Boundary
Hazard
H1 - Generally safe
H2 - Unsafe for small vehicles
H3 - Unsafe for all vehicles, children and the elderly
H4 - Unsafe for all people and all vehicles
H5 - Unsafe for all people and all vehicles. Buildings require special engineering design and construction
H6 - Unsafe for all people and all vehicles. All building types considered vulnerable to failure
0 50 100 200 300 400
m
J:\Jobs\117099\ARC\MAPS\Report_Figures\Figure15A_Provisional_Hazard_Classification_PMF_Mainstream.mxd

FIGURE 15B

PROVISIONAL HAZARD CLASSIFICATION, PMF
KARIGNAN CREEK, OVERLAND FLOW

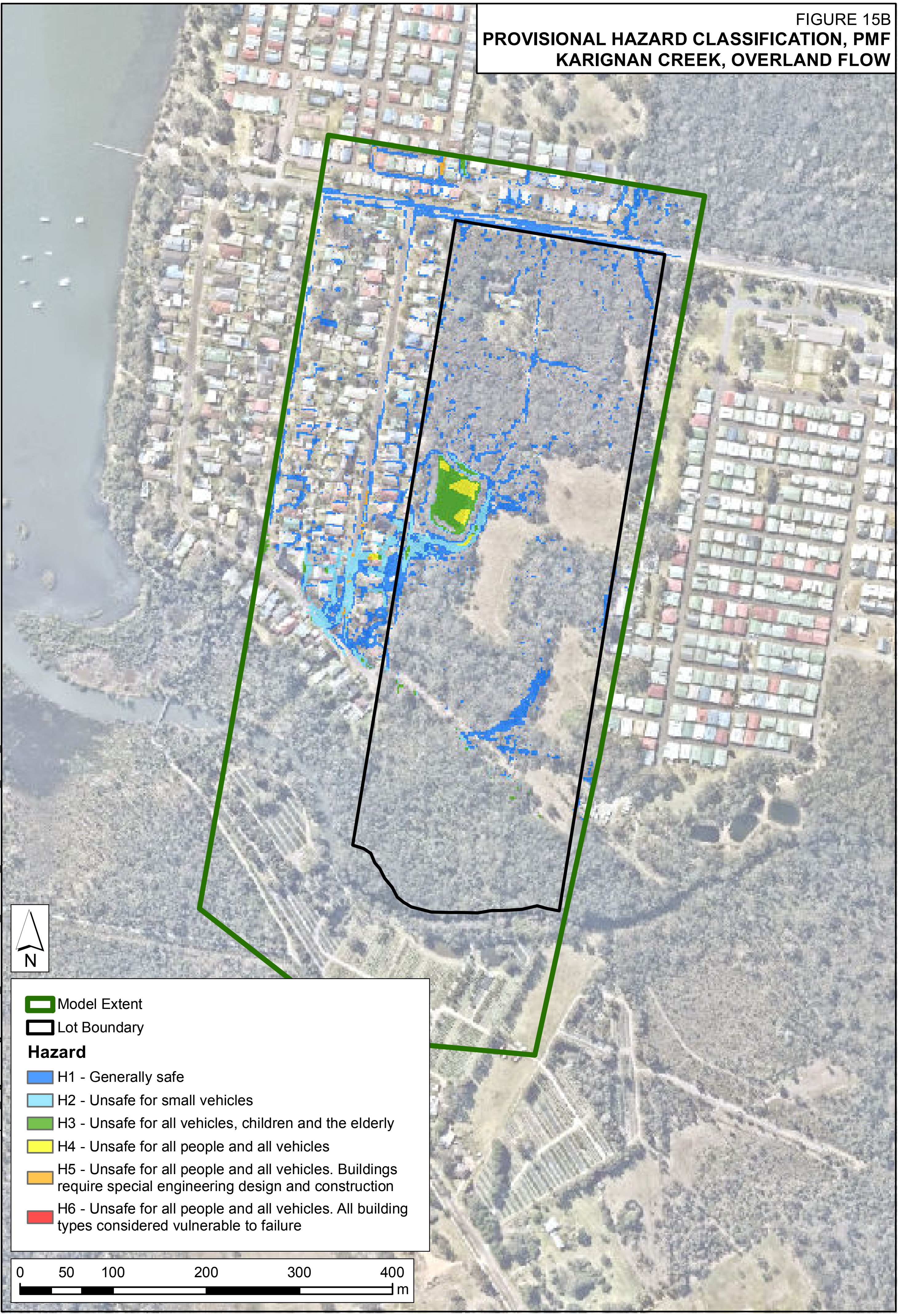

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FIGURE 16A
HYDRAULIC CATEGORISATION, 10% AEP
KARIGNAN CREEK, MAINSTREAM FLOW

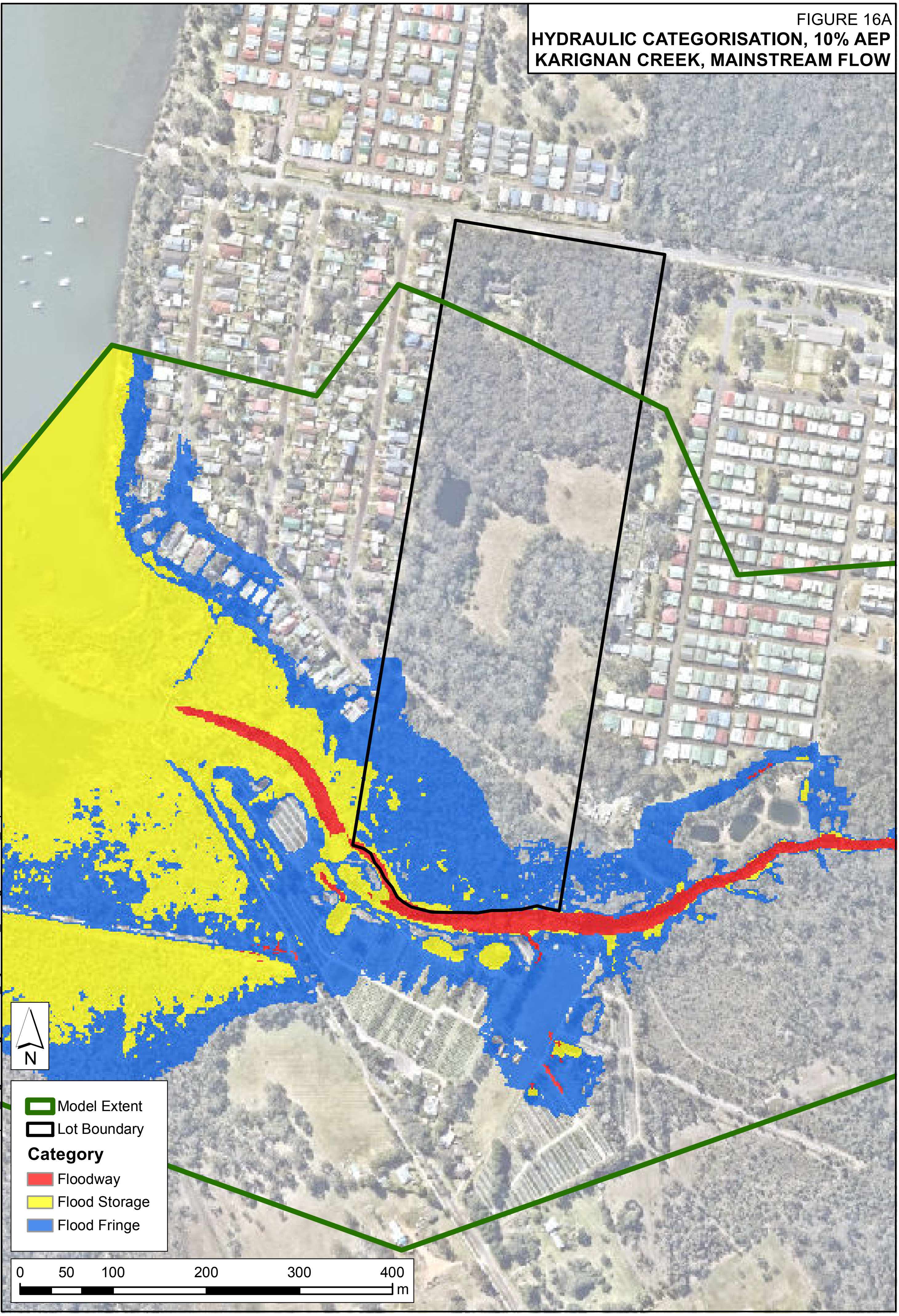

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FIGURE 16B
HYDRAULIC CATEGORISATION, 10% AEP
KARIGNAN CREEK, OVERLAND FLOW

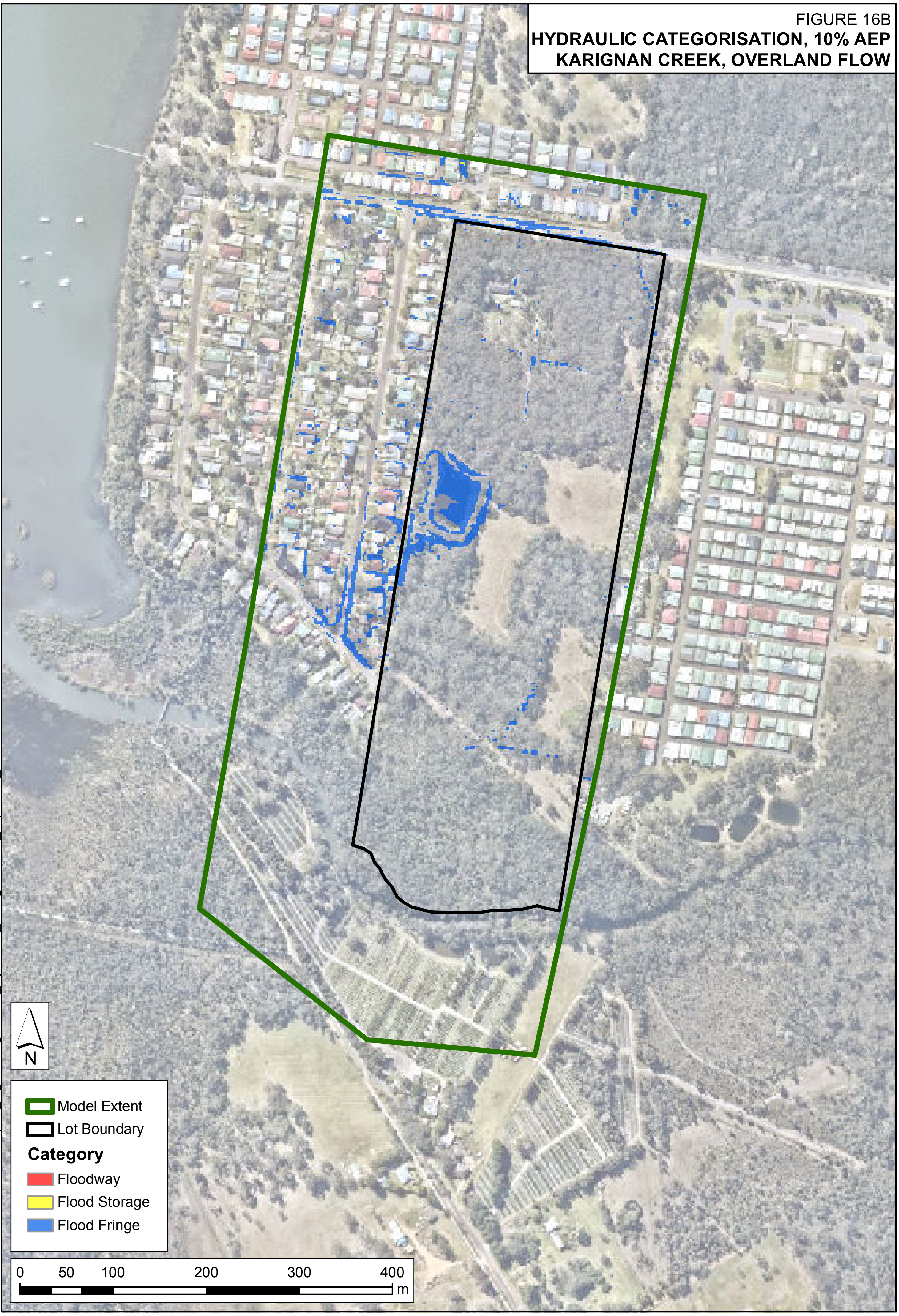

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FIGURE 17A
HYDRAULIC CATEGORISATION, 1% AEP
KARIGNAN CREEK, MAINSTREAM FLOW

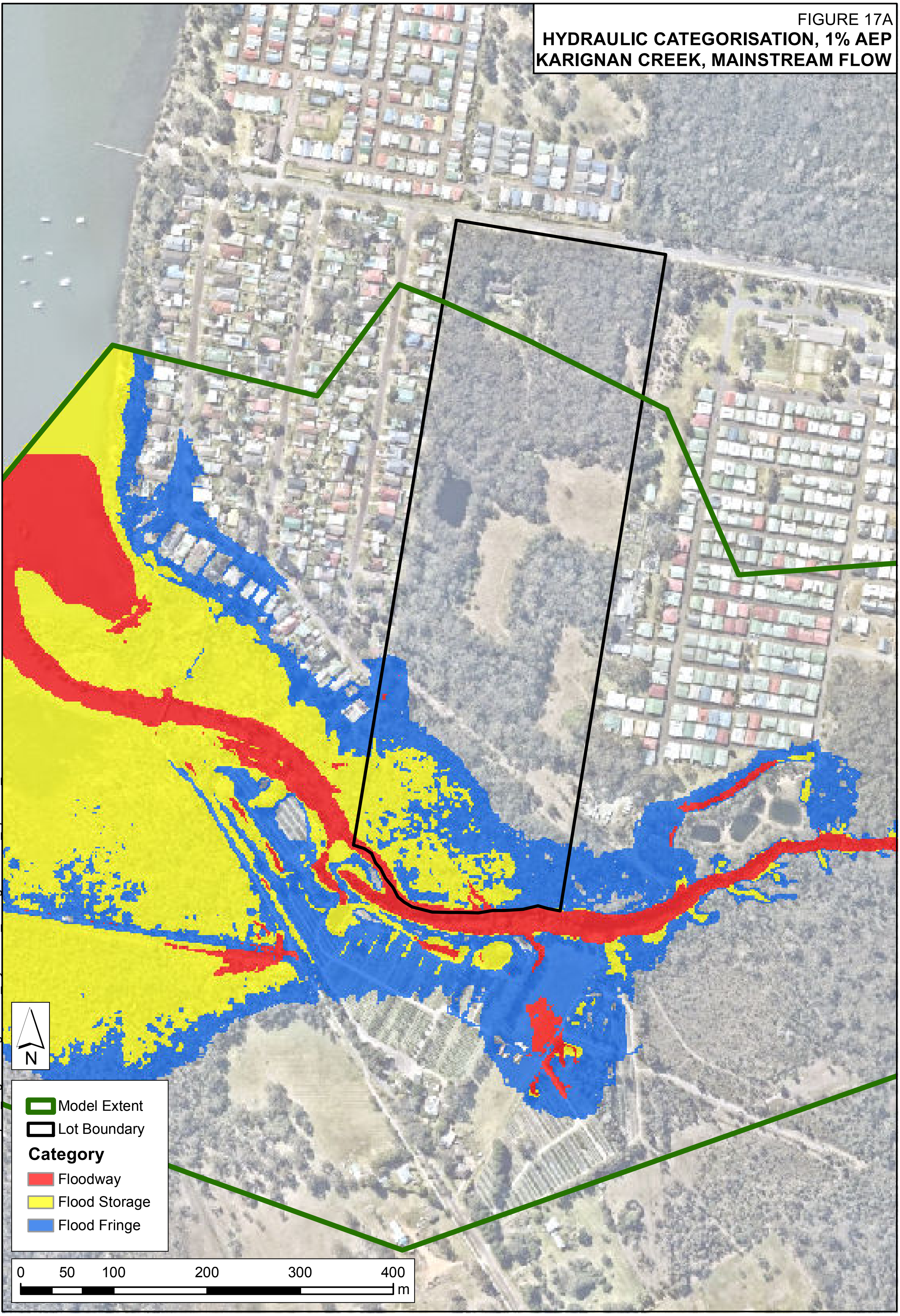


FIGURE 17B
HYDRAULIC CATEGORISATION, 1% AEP
KARIGNAN CREEK, OVERLAND FLOW

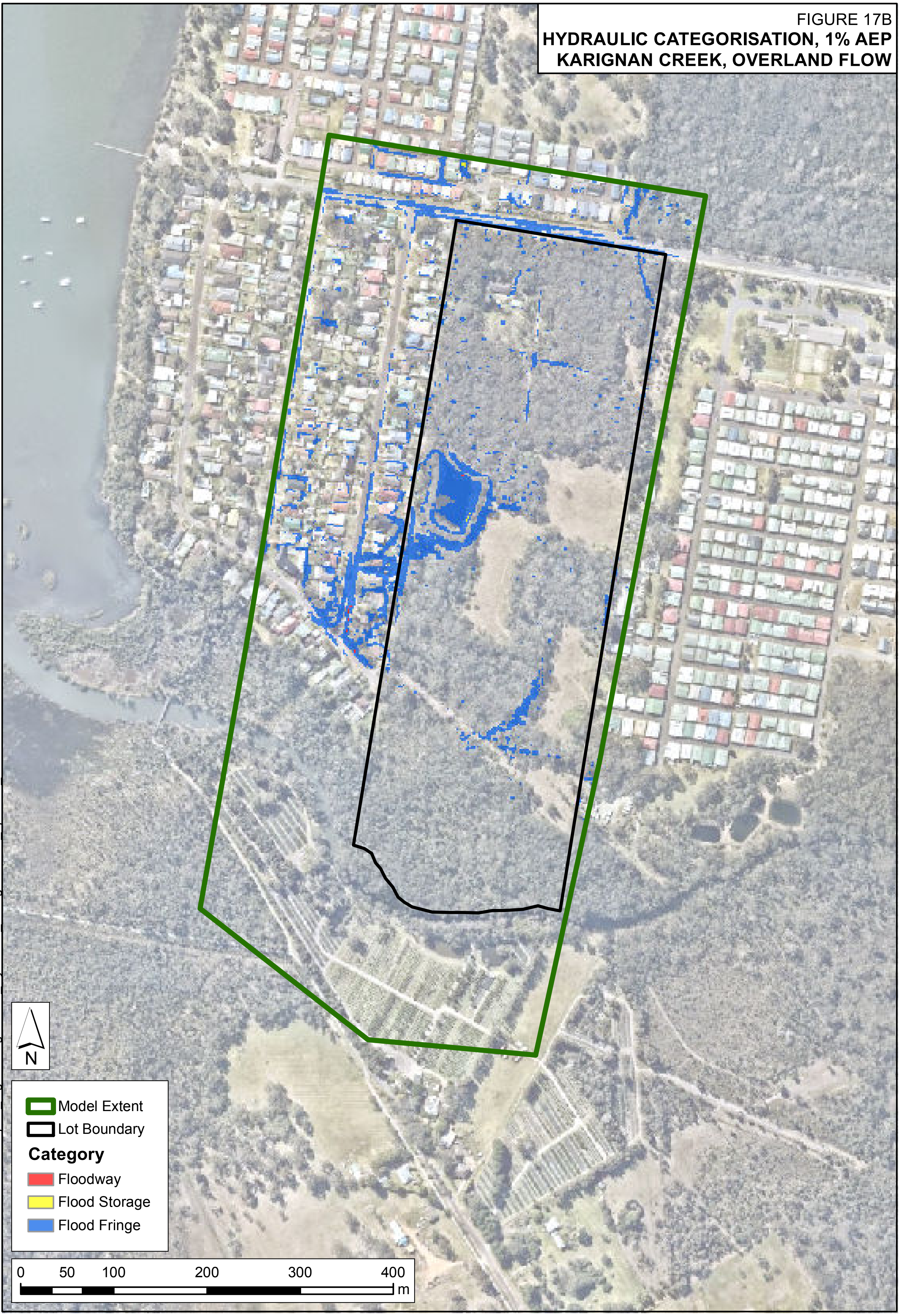


FIGURE 18A
HYDRAULIC CATEGORISATION, 0.5% AEP
KARIGNAN CREEK, MAINSTREAM FLOW

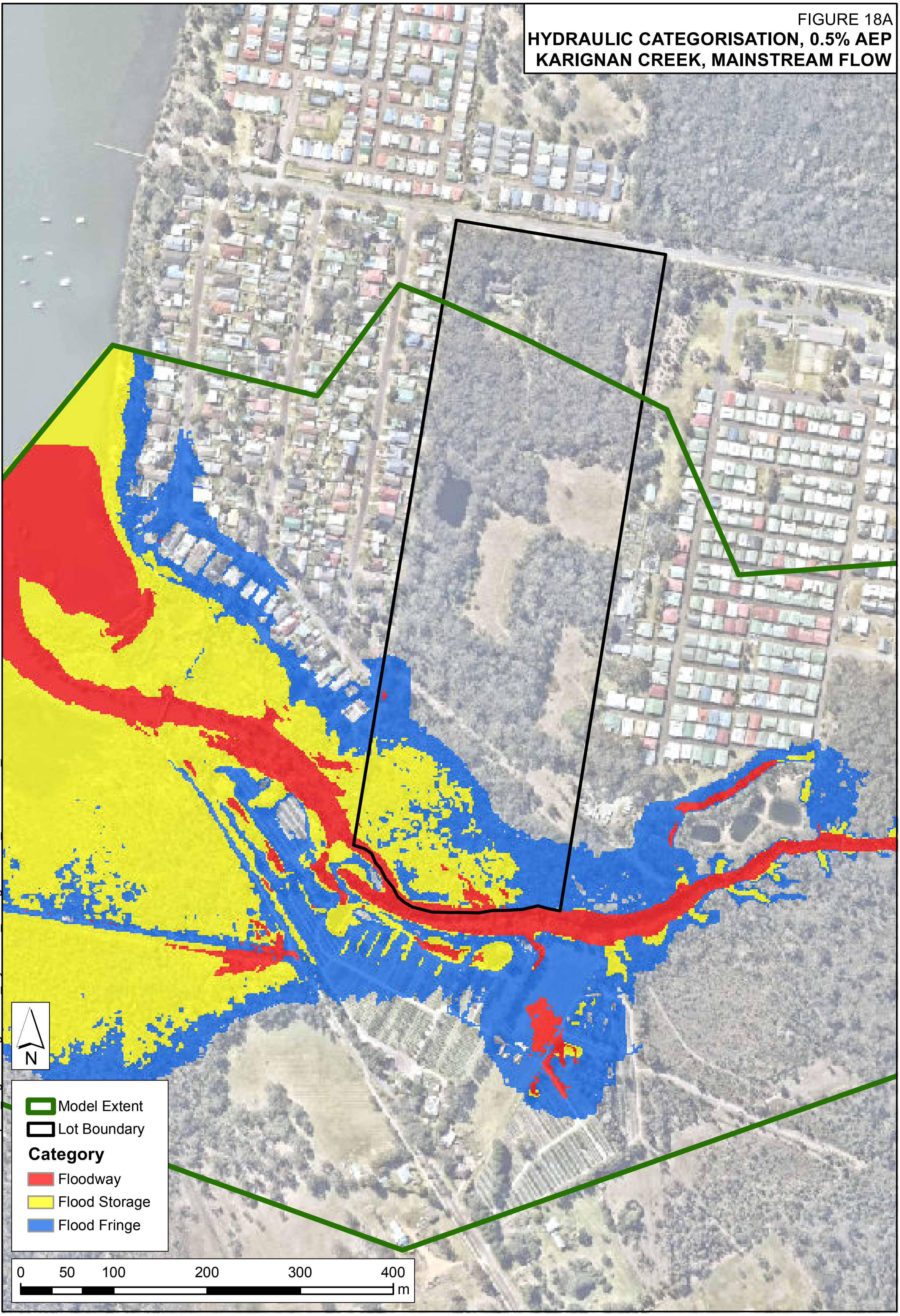
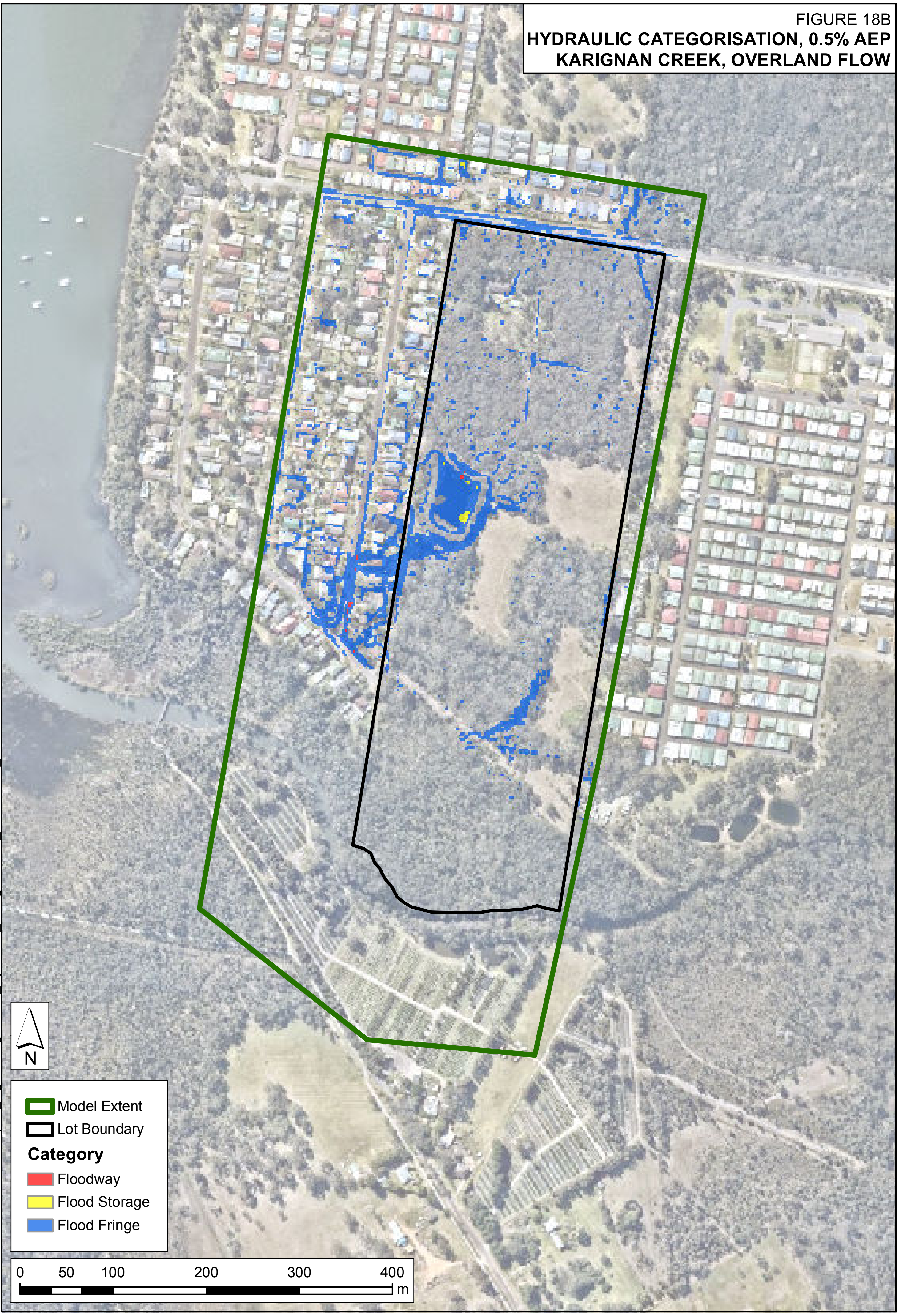


FIGURE 18B
HYDRAULIC CATEGORISATION, 0.5% AEP
KARIGNAN CREEK, OVERLAND FLOW



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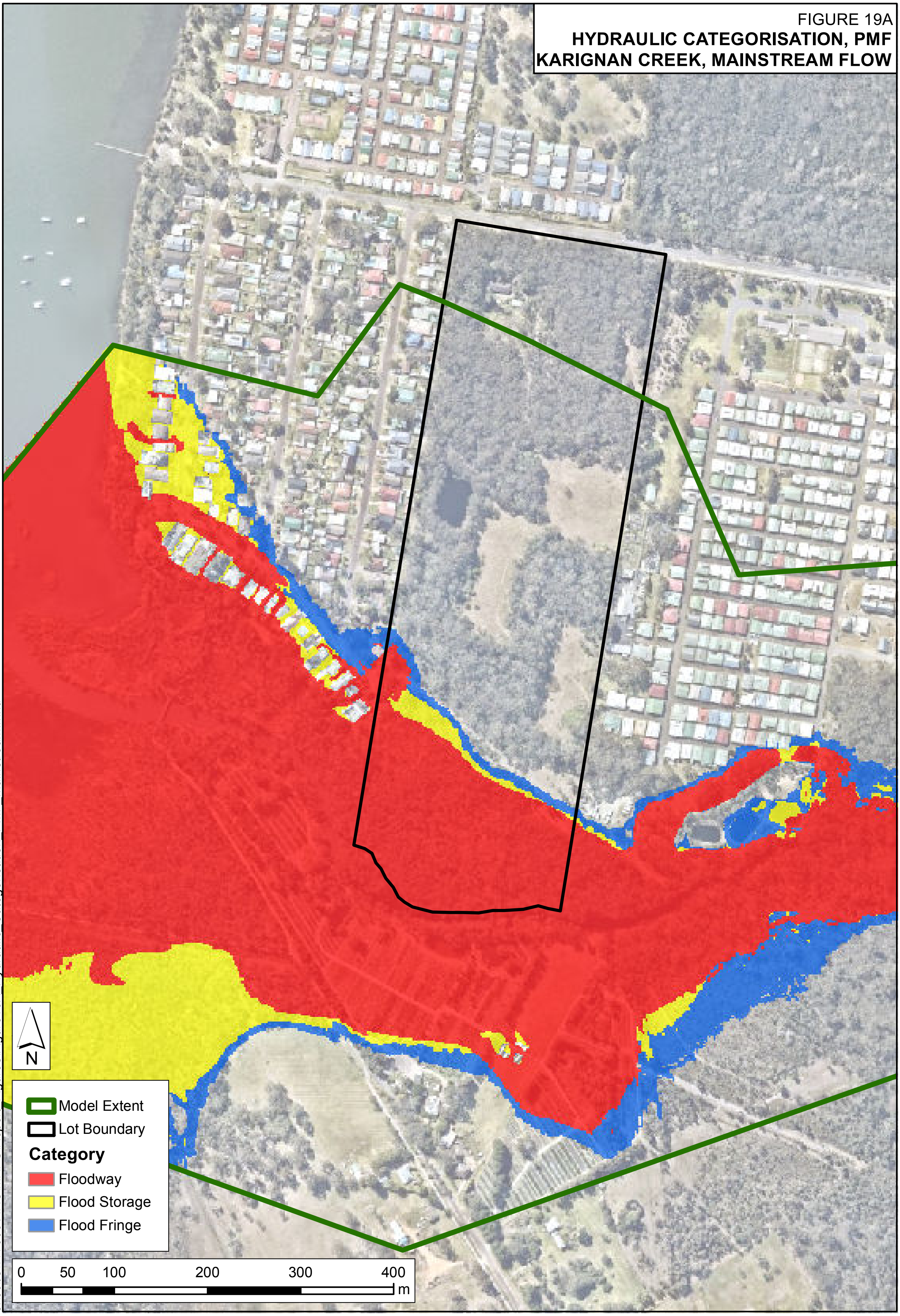
FIGURE 19A
HYDRAULIC CATEGORISATION, PMF
KARIGNAN CREEK, MAINSTREAM FLOW
N
Model Extent
Lot Boundary
Category
Floodway
Flood Storage
Flood Fringe
0
50
100
200
300
400
m
J:\Jobs\117099\ARC\MAPS\Report_Figures\Figure19A_Hydraulic_Categorisation_PMF_Mainstream.mxd

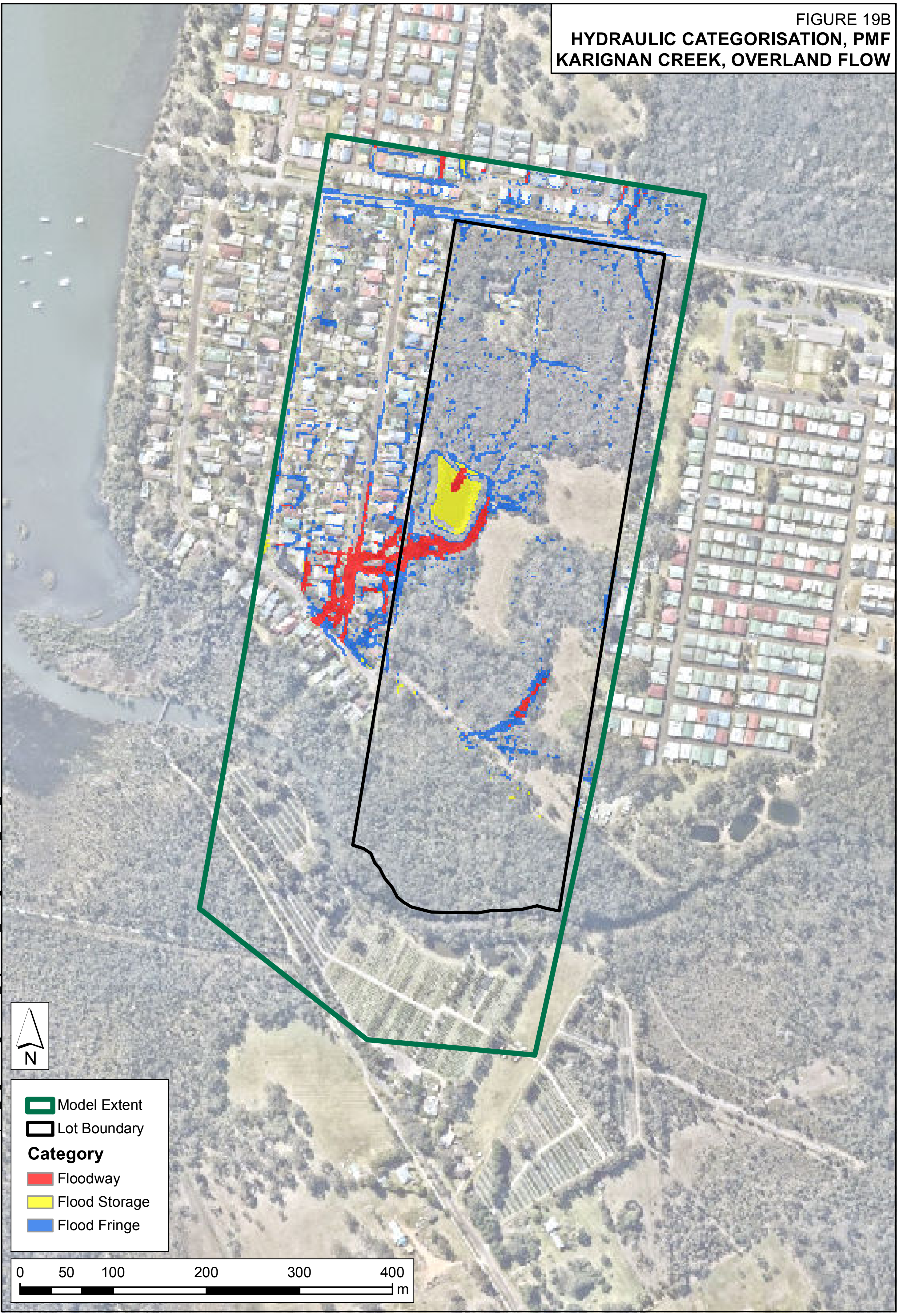

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FIGURE 20A
CHANGE IN PEAK FLOOD DEPTHS, 1% AEP
0.9M RISE IN TAILWATER LEVEL
KARIGNAN CREEK, MAINSTREAM FLOW

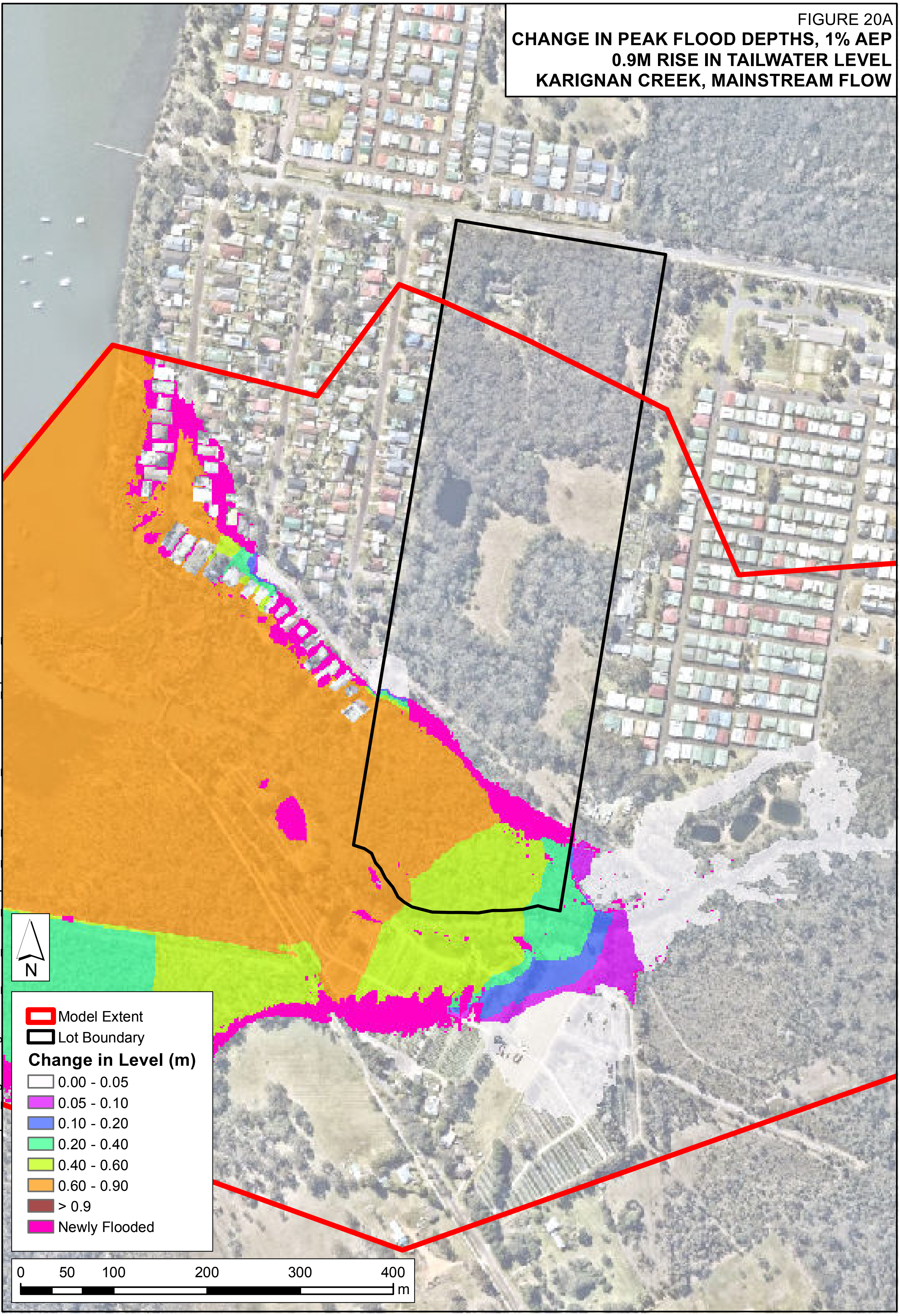
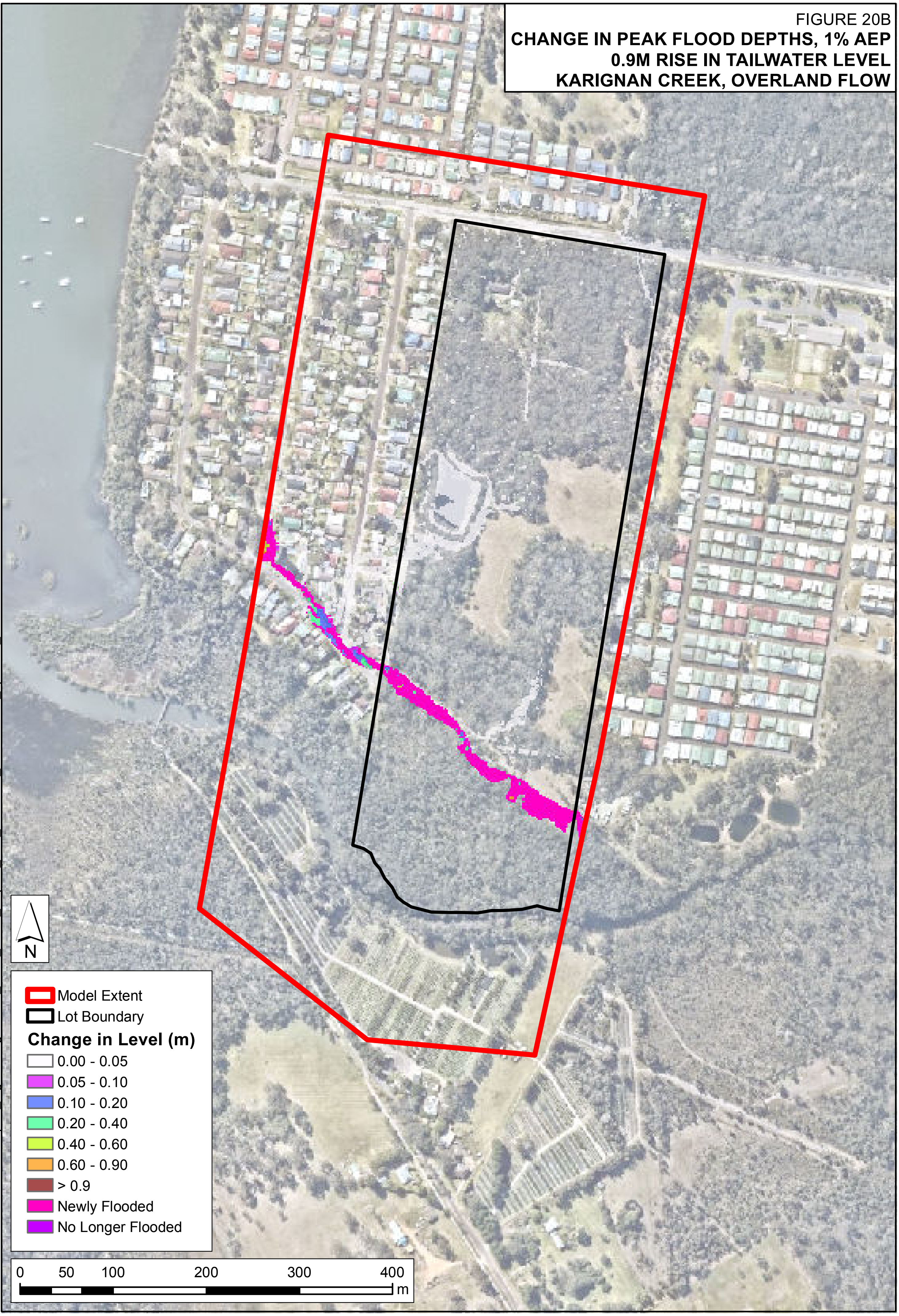


FIGURE 20B
CHANGE IN PEAK FLOOD DEPTHS, 1% AEP
0.9M RISE IN TAILWATER LEVEL
KARIGNAN CREEK, OVERLAND FLOW



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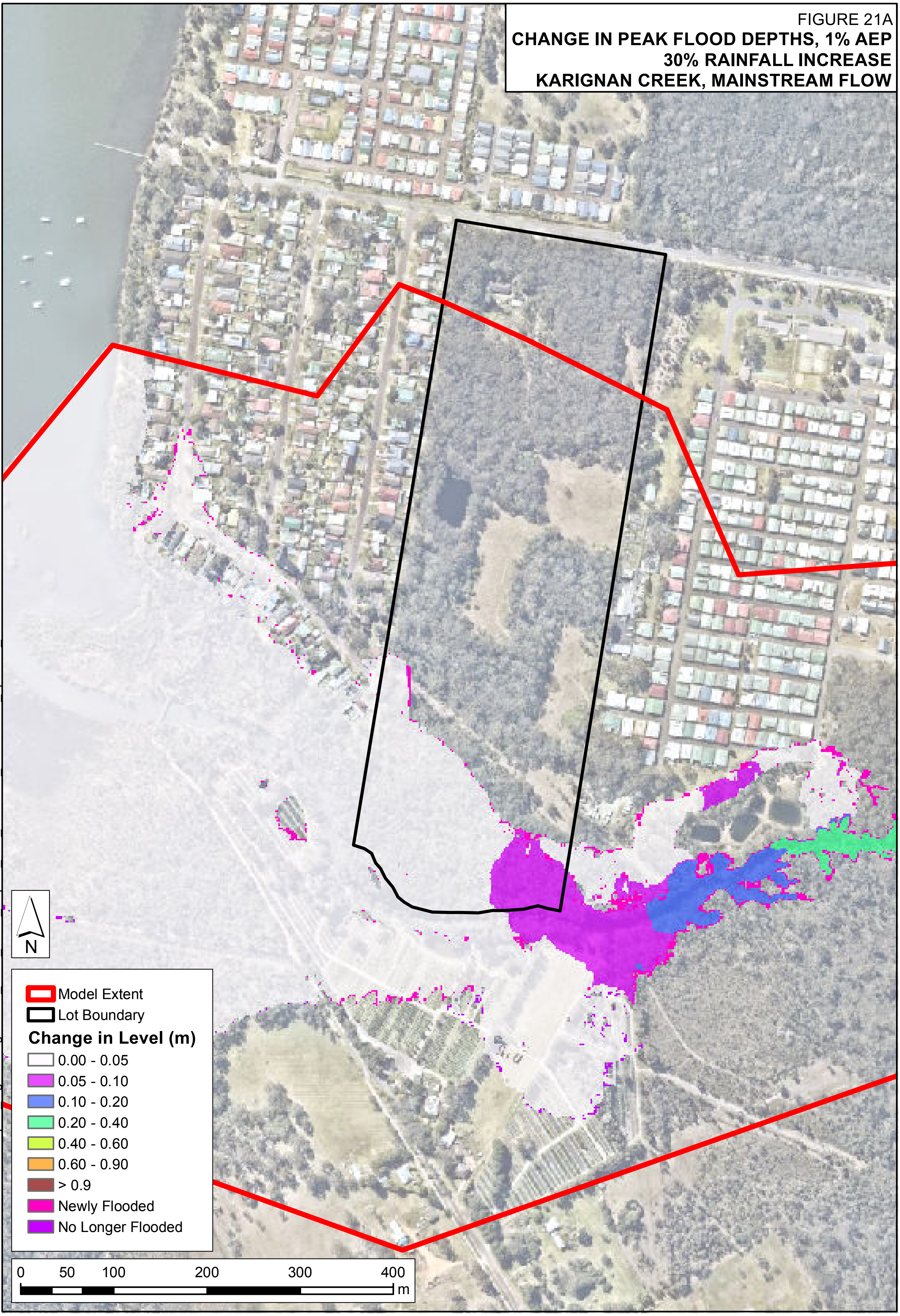

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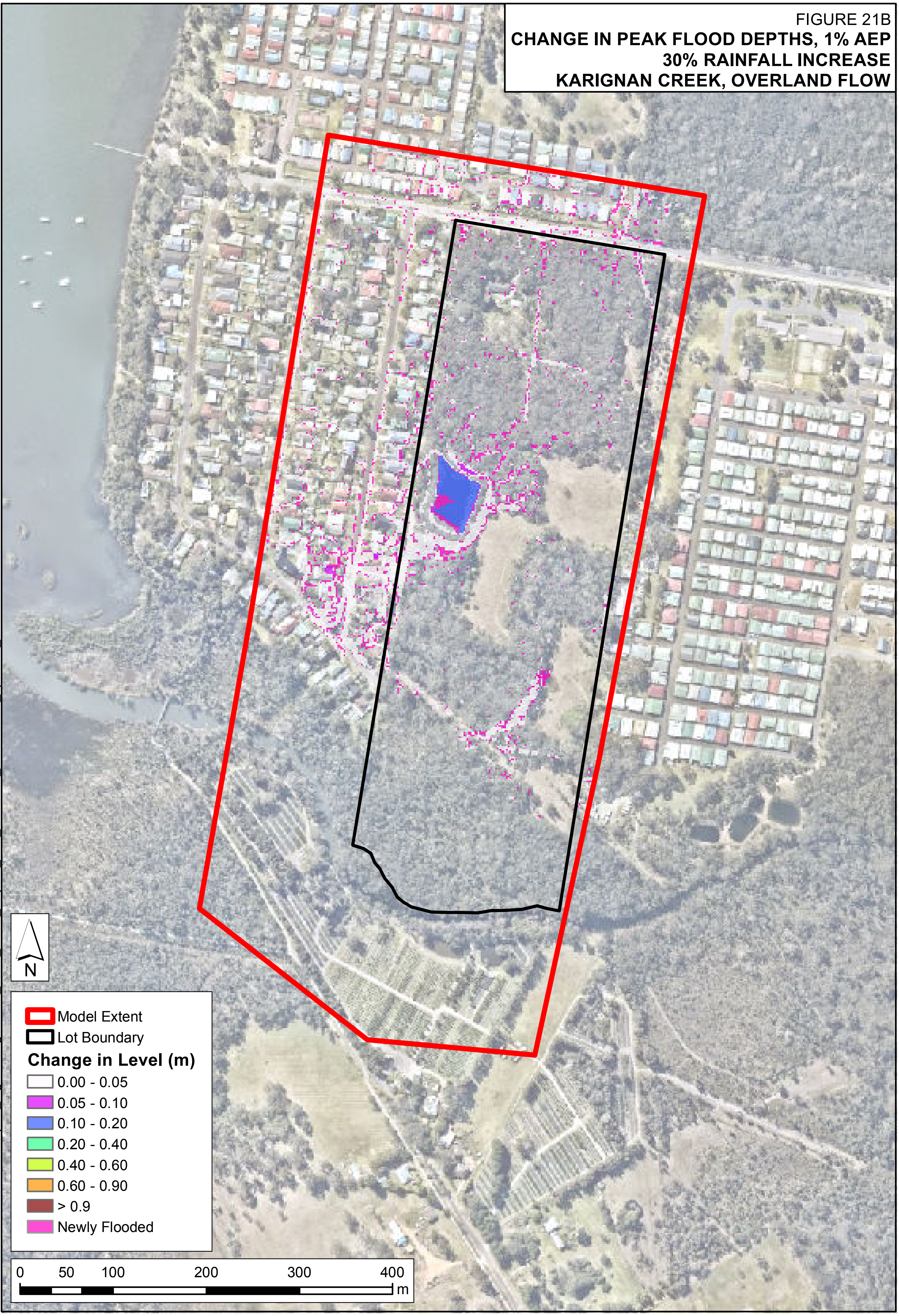
FIGURE 21B
CHANGE IN PEAK FLOOD DEPTHS, 1% AEP
30% RAINFALL INCREASE
KARIGNAN CREEK, OVERLAND FLOW



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Appendix A

APPENDIX A: GLOSSARY of TERMS

Taken from the Floodplain Development Manual (April 2005 edition)

acid sulfate soils	Are sediments which contain sulfidic mineral pyrite which may become extremely acid following disturbance or drainage as sulfur compounds react when exposed to oxygen to form sulfuric acid. More detailed explanation and definition can be found in the NSW Government Acid Sulfate Soil Manual published by Acid Sulfate Soil Management Advisory Committee.
Annual Exceedance Probability (AEP)	The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 m^3/s has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 m^3/s or larger event occurring in any one year (see ARI).
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level.
Average Annual Damage (AAD)	Depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time.
Average Recurrence Interval (ARI)	The long term average number of years between the occurrence of a flood as big as, or larger than, the selected event. For example, floods with a discharge as great as, or greater than, the 20 year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event.
caravan and moveable home parks	Caravans and moveable dwellings are being increasingly used for long-term and permanent accommodation purposes. Standards relating to their siting, design, construction and management can be found in the Regulations under the LG Act.
catchment	The land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location.
consent authority	The Council, Government agency or person having the function to determine a development application for land use under the EP&A Act. The consent authority is most often the Council, however legislation or an EPI may specify a Minister or public authority (other than a Council), or the Director General of DIPNR, as having the function to determine an application.
development	Is defined in Part 4 of the Environmental Planning and Assessment Act (EP&A Act). **infill development:** refers to the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development. **new development:** refers to development of a completely different nature to that associated with the former land use. For example, the urban subdivision of an area previously used for rural purposes. New developments involve rezoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power. **redevelopment:** refers to rebuilding in an area. For example, as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either rezoning or major extensions to urban services.
disaster plan (DISPLAN)	A step by step sequence of previously agreed roles, responsibilities, functions, actions and management arrangements for the conduct of a single or series of connected emergency operations, with the object of ensuring the coordinated

	response by all agencies having responsibilities and functions in emergencies.
discharge	The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second (m^3/s). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s).
ecologically sustainable development (ESD)	Using, conserving and enhancing natural resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be maintained or increased. A more detailed definition is included in the Local Government Act 1993. The use of sustainability and sustainable in this manual relate to ESD.
effective warning time	The time available after receiving advice of an impending flood and before the floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions.
emergency management	A range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding.
flash flooding	Flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain.
flood	Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami.
flood awareness	Flood awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures.
flood education	Flood education seeks to provide information to raise awareness of the flood problem so as to enable individuals to understand how to manage themselves an their property in response to flood warnings and in a flood event. It invokes a state of flood readiness.
flood fringe areas	The remaining area of flood prone land after floodway and flood storage areas have been defined.
flood liable land	Is synonymous with flood prone land (i.e. land susceptible to flooding by the probable maximum flood (PMF) event). Note that the term flood liable land covers the whole of the floodplain, not just that part below the flood planning level (see flood planning area).
flood mitigation standard	The average recurrence interval of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the impacts of flooding.
floodplain	Area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land.
floodplain risk management options	The measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options.
floodplain risk management plan	A management plan developed in accordance with the principles and guidelines in this manual. Usually includes both written and diagrammatic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives.
flood plan (local)	A sub-plan of a disaster plan that deals specifically with flooding. They can exist at State, Division and local levels. Local flood plans are prepared under the

	leadership of the State Emergency Service.
flood planning area	The area of land below the flood planning level and thus subject to flood related development controls. The concept of flood planning area generally supersedes the "flood liable land" concept in the 1986 Manual.
Flood Planning Levels (FPLs)	FPL's are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies and incorporated in management plans. FPLs supersede the "standard flood event" in the 1986 manual.
flood proofing	A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages.
flood prone land	Is land susceptible to flooding by the Probable Maximum Flood (PMF) event. Flood prone land is synonymous with flood liable land.
flood readiness	Flood readiness is an ability to react within the effective warning time.
flood risk	Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below. **existing flood risk:** the risk a community is exposed to as a result of its location on the floodplain. **future flood risk:** the risk a community may be exposed to as a result of new development on the floodplain. **continuing flood risk:** the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure.
flood storage areas	Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas.
floodway areas	Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flows, or a significant increase in flood levels.
freeboard	Freeboard provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level.
habitable room	**in a residential situation:** a living or working area, such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom. **in an industrial or commercial situation:** an area used for offices or to store valuable possessions susceptible to flood damage in the event of a flood.
hazard	A source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community. Definitions of high and low hazard categories are provided in the Manual.
hydraulics	Term given to the study of water flow in waterways; in particular, the evaluation of

	flow parameters such as water level and velocity.
hydrograph	A graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood.
hydrology	Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods.
local overland flooding	Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam.
local drainage	Are smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary.
mainstream flooding	Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam.
major drainage	Councils have discretion in determining whether urban drainage problems are associated with major or local drainage. For the purpose of this manual major drainage involves: • the floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once system capacity is exceeded; and/or • water depths generally in excess of 0.3 m (in the major system design storm as defined in the current version of Australian Rainfall and Runoff). These conditions may result in danger to personal safety and property damage to both premises and vehicles; and/or • major overland flow paths through developed areas outside of defined drainage reserves; and/or • the potential to affect a number of buildings along the major flow path.
mathematical/computer models	The mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run on computers due to the complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain.
merit approach	The merit approach weighs social, economic, ecological and cultural impacts of land use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and well being of the State's rivers and floodplains. The merit approach operates at two levels. At the strategic level it allows for the consideration of social, economic, ecological, cultural and flooding issues to determine strategies for the management of future flood risk which are formulated into Council plans, policy and EPIs. At a site specific level, it involves consideration of the best way of conditioning development allowable under the floodplain risk management plan, local floodplain risk management policy and EPIs.
minor, moderate and major flooding	Both the State Emergency Service and the Bureau of Meteorology use the following definitions in flood warnings to give a general indication of the types of problems expected with a flood: **minor flooding:** causes inconvenience such as closing of minor roads and the submergence of low level bridges. The lower limit of this class of flooding on the reference gauge is the initial flood level at which landholders and townspeople begin to be flooded. **moderate flooding:** low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic routes may be covered. **major flooding:** appreciable urban areas are flooded and/or extensive rural areas are flooded. Properties, villages and towns can be isolated.

modification measures	Measures that modify either the flood, the property or the response to flooding. Examples are indicated in Table 2.1 with further discussion in the Manual.
peak discharge	The maximum discharge occurring during a flood event.
Probable Maximum Flood (PMF)	The PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event should be addressed in a floodplain risk management study.
Probable Maximum Precipitation (PMP)	The PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation.
probability	A statistical measure of the expected chance of flooding (see AEP).
risk	Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment.
runoff	The amount of rainfall which actually ends up as streamflow, also known as rainfall excess.
stage	Equivalent to "water level". Both are measured with reference to a specified datum.
stage hydrograph	A graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum.
survey plan	A plan prepared by a registered surveyor.
water surface profile	A graph showing the flood stage at any given location along a watercourse at a particular time.
wind fetch	The horizontal distance in the direction of wind over which wind waves are generated.

Appendix B

APPENDIX B: AR&R 2016 CRITICAL DURATION ANALYSIS

B1: BACKGROUND

Since the last edition of Australian Rainfall and Runoff (AR&R) in 1987, numerous technological developments and a larger set of data have been used to update the AR&R guideline on design rainfall depths and temporal patterns. This new set of data includes a larger number of rainfall gauges which continuously record rainfall (pluviometers) and a longer record of storms (inclusion of events from approximately 1985 to 2012).

As part of this flood assessment, WMAwater has adopted the AR&R 2016 guidelines and this appendix describes how the critical duration analysis has been undertaken.

B2 AR&R 2016 – DESIGN RAINFALL UPDATE

Three major changes have been made to the approach adopted in AR&R 1987:

1. The Intensity, Frequency and Duration (IFD) rainfall data and the initial and continuing loss values across Australia have been updated;
2. AR&R 2016 recommends using storm initial losses and subtracting pre-burst values from it to get burst initial loss;
3. The approach for adopting design temporal patterns has been significantly revised. AR&R 2016 recommends that 10 temporal patterns are analysed for each duration in order to determine the critical duration. The critical duration is the duration with the temporal pattern set which produces the maximum average peak flow at the location for a given AEP. The temporal pattern adopted for hydraulic modelling, is the temporal pattern which produces the peak flow which is both closest and higher than the average peak flow of the critical duration temporal pattern set.

In a small catchment such as Karignan Creek there is little difference in the design rainfalls across the catchment. Thus the same design IFD data has been adopted across the catchment and no areal rainfall reduction factor has been applied. A comparison of the AR&R 1987 and the 2016 IFD data are shown in Table B1.

Table B1: 1% AEP BoM 2016 and AR&R 1987 Rainfall Depths (mm)

Duration	BoM 2016	AR&R 1987
30 minute	72.7	57.5
1 hour	94.8	79.3
2 hour	120	107.8
3 hour	138	123.9
6 hour	176	162
9 hour	204	190.4
12 hour	230	213.6

B3 PRE BURST RAINFALL AND LOSSES

The pre burst value is the depth of rainfall before the storm burst occurred. It varies for every AEP and duration and is removed from the initial loss value. Therefore all design storms have different initial loss values. The AR&R 2016 data hub provides pre burst values for all storm durations and the median values are shown on Table B2 for the 1% AEP.

Table B2: Median Pre Burst Depth Value 1% AEP (mm)

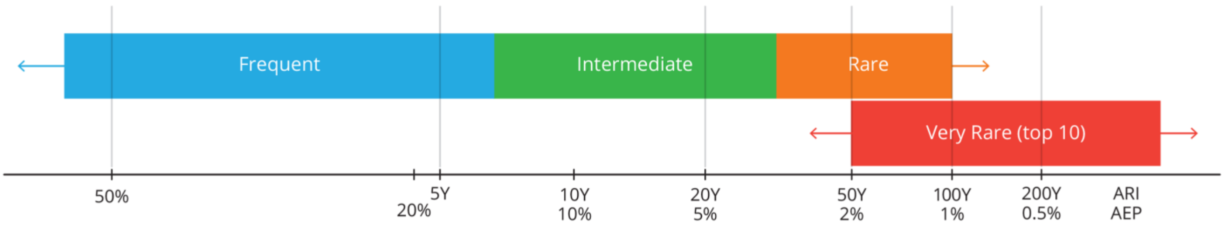
Duration	1% AEP
1 hour	0
2 hour	1.9
3 hour	7.3
6 hour	19.0
9 hour	26.5
12 hour	35.4

Initial and continuous loss values for the catchment from the AR&R 2016 data hub are 49mm and 2.4mm/hr respectively.

B4 STORM TEMPORAL PATTERNS

The most significant change is in the application of storm temporal patterns. AR&R 1987 provided a single temporal pattern for events more and less frequent than a 30 year ARI for each storm duration. AR&R 2016 now provides several patterns for each duration which are divided into four AEP bins.

These temporal patterns are different for each region in Australia and have been extracted from the storms already recorded in each region. The data hub provides a table with all the temporal patterns that could be used at a given location using coordinates. The temporal patterns are grouped in bins based on the intensity of the recorded storms. There are 4 bins ranging from frequent to very rare (Graph B1).



Graph B1: AR&R 2016 Temporal Pattern Bins

The 1% AEP event is part of the rare bin and the 5% AEP event is part of the intermediate bin. AR&R 2016 recommends using 10 temporals patterns for all AEP durations. Note each of the 10 temporal patterns uses the same total rainfall depths and the difference is in how the rainfall is distributed within that storm duration. For example, some storms have the most intense rainfall at the start, some in the middle and some at the end. The different patterns can therefore produce different peak flood levels depending upon the topography of the catchment or storage within the floodplain (such as a lake or lagoon).

The temporal pattern adopted for hydraulic modelling, is the temporal pattern which produces the peak flow which is both closest and higher than the average peak flow of the temporal pattern set.

B5 CRITICAL DURATION ANALYSIS - Karignan Creek

The following process was used for selecting the design temporal patterns for Karignan Creek:

- The peak flows at the end of the upstream and downstream end of the site were selected as comparison points. These corresponded to the inflows and outflow to the TUFLOW 2D model.
- The peak flows were extracted for all 10 temporal patterns at these two locations and the average derived.
- The temporal pattern giving the peak flow value both greater and closest to the average of the 10 patterns was then selected for that duration.
- Each of the two sites can have a different selected temporal pattern for that duration.
- The peak flows from the selected temporal patterns (i.e the average of the 10 patterns) for each duration were compared and the critical duration adopted as the duration providing the greatest peak flow.

Figures B1-B3 are Box Plots of the above analysis. The box defines the first quartile to the third quartile of the results and the extent of the vertical line the maximum and minimum values. The horizontal line within the box represents the median value.

Results from the critical duration analysis are summarised in Table B3.

Table B3: Adopted WBNM Peak Flows Upstream and Downstream of Site

Event	Duration	Upstream Flow (m^3/s)	Downstream Flow (m^3/s)
10% AEP	6hr	10.7	25.5
1% AEP	6hr	19.8	55.5
0.5% AEP	6hr	23.3	65.2

B5 CRITICAL DURATION ANALYSIS - Within the Site

The following process was used for selecting the design temporal patterns within the site.

- The peak flows downstream of the dam and at the edge of the property were selected as comparison points.
- Each temporal pattern was run through the TUFLOW 2D model.
- The peak flows were extracted for all 10 temporal patterns and the average derived.
- The temporal pattern giving the peak flow value both greater and closest to the average of the 10 patterns was then selected for that duration.
- The peak flows from the selected temporal patterns (i.e the average of the 10 patterns) for each duration were compared and the critical duration adopted as the duration providing the greatest peak flow.
- This process concluded that the 45 minute storm was the critical storm duration for the 1% AEP event.

FIGURE B1

BOXPLOTS: 10% AEP

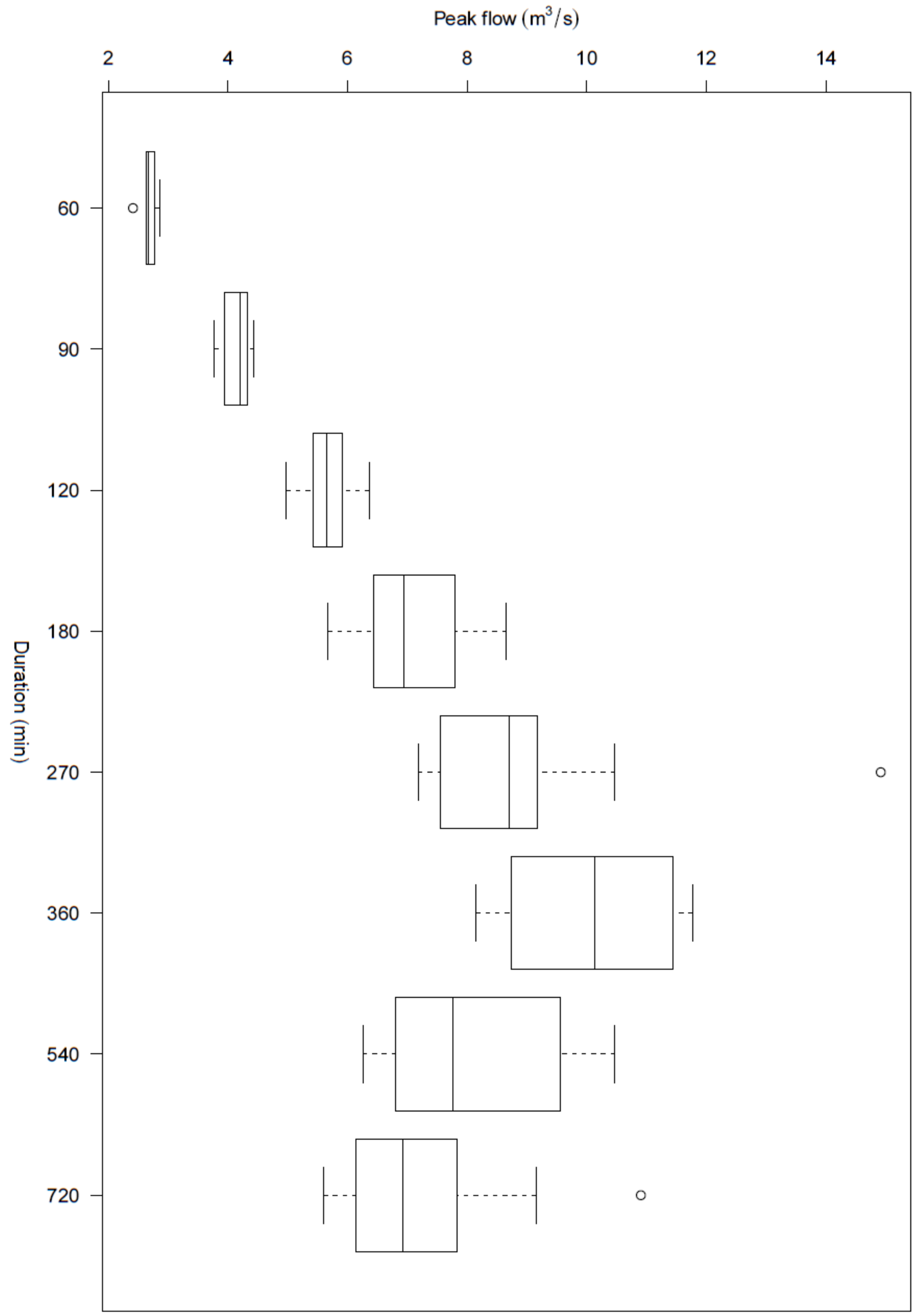


FIGURE B2
BOXPLOTS: 1% AEP

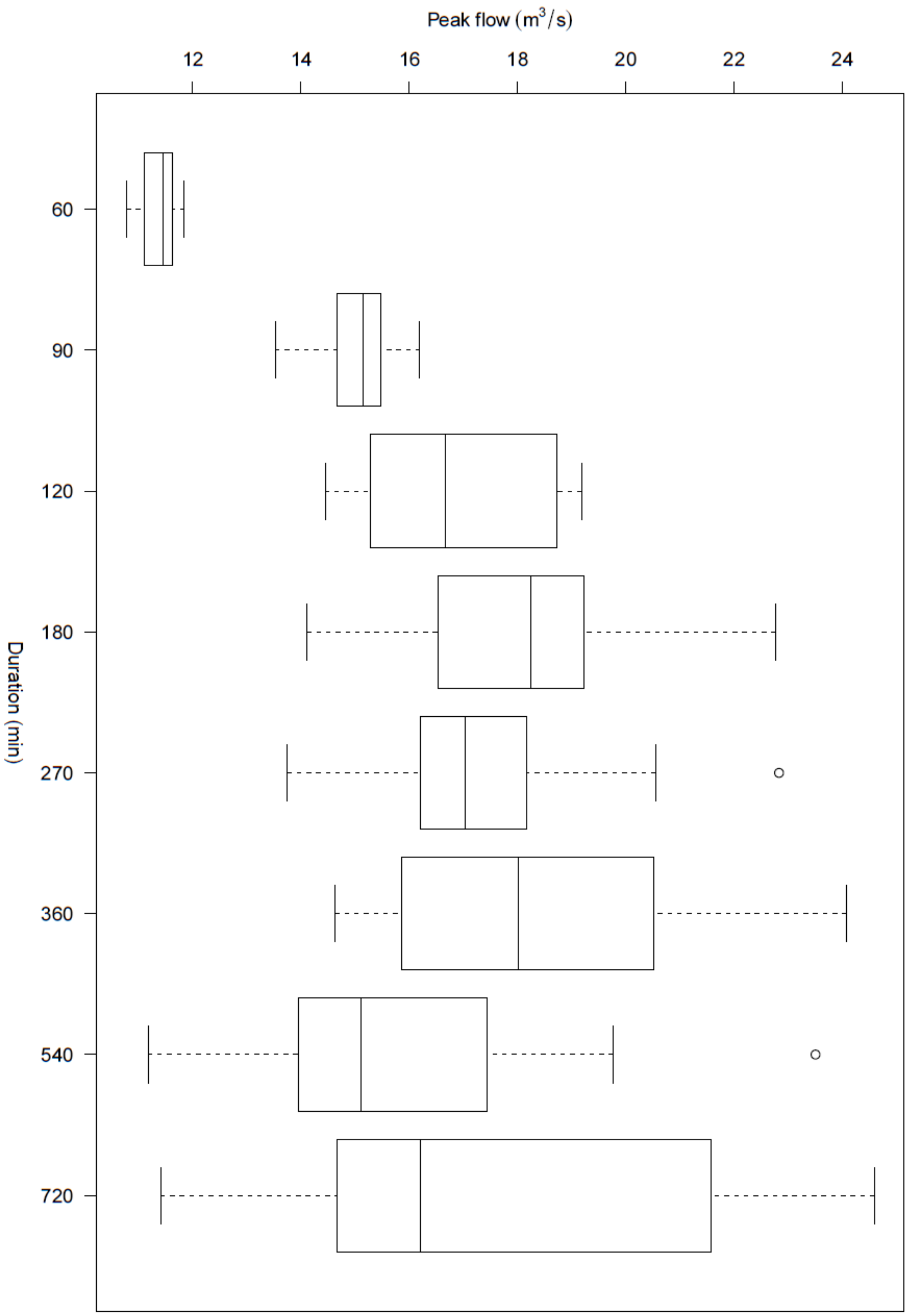


FIGURE B3

BOXPLOTS: 0.5% AEP