Bayside Gardens Lifestyle Village, Empire Bay

Probable Maximum Flood Assessment

Revision 1
December 2021

Catchment Simulation Solutions

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1 Introduction

Progressive Property Solutions, acting on behalf of Barnes Property Investments Pty Ltd, has prepared a Planning Proposal for a property located at 437 Wards Hills Road, Empire Bay (Lot 1 DP 610629) which currently serves as a caravan park. The location of the site is shown in **Figure 1**, which is enclosed in **Appendix A**.

The Planning Proposal seeks to rezone the existing site from 7(c2) to E3 (Environmental Management). As the E3 zoning does not permit caravan parks it is also proposed to apply an Additional Permitted Use of "caravan park" to the site. This Proposal would seek to ultimately enable future development of a long-term caravan park/manufactured home estate on the site.

The Planning Proposal is currently progressing through Central Coast Council. A Council assessment of the Planning Proposal dated 14 September provided in principle support for the Proposal but noted that parts of the site are potentially at risk of inundation during large floods. As noted in the extract from the Council report below, a flood study was prepared to support the Planning Proposal. However, concern was raised regarding existing caravan sites being in high hazard areas during the probable maximum flood (PMF), which was not included in the flood study.

> The Flood Study has been assessed and is considered to contain information satisfactory for the assessment of the Planning Proposal.
>
> Generally, the majority of the site is what could be considered low hazard (H1 - H3) in the PMF however, the areas of higher hazard (H4 - H6) are currently in locations where there is risk to people and light structures.
>
> This is not optimal. A redesign of the site flow paths, may lead to a dispersing of hazard, reducing the overall hazard plume.
>
> Indeed, designing to accommodate the flow with reduced hazard, is in the interest of the site development.
>
> It is understood that this may be an iterative process. Minor reshaping of terrain, roadway levels and structure locations can all aid in the reduction of hazard.
>
> It is recommended that:
>
> - a rain on grid analysis with the inclusion of all buildings as obstacles be undertaken for PMF hazard analysis.
> - the hazard should be mapped H1-H6.
> - intensification of use of the caravan park in areas of high hazard should not be supported.
> - the site should be planned to account for the flow path and minimise its impact through the site.
>
> The intent is to ensure that no dwellings are to remain in High Hazard areas, and no new structures of any type be placed in the High Hazard areas.
>
> The Planning Proposal will stipulate that no new dwellings or associated structures are to be placed in high hazard areas and that existing structures in high hazard areas are to be relocated.

Accordingly, Progressive Property Solutions, acting on behalf of Barnes Property Investments Pty Ltd engaged Catchment Simulation Solutions to undertake a PMF hazard assessment for the site. The outcomes of the assessment are presented in the following report. It describes the development of a new computer flood model that was used to simulate the PMF for existing development conditions and understand where the existing sites may be incompatible with the PMF flood hazard. It also describes measures that could be potentially implemented as part of the future development of the site to remove existing sites from high hazard areas and/or mitigations measures that could be implemented to reduce the flood hazard to acceptable levels in line with Council's recommendations.

2 Flood Assessment for Existing Conditions

2.1 Introduction

A review of available flood information was completed at the outset of the project. This identified two previous studies that contain flooding information for the site:

- 'Empire Bay Catchment Flood Study' (Cardno Lawson Treloar, 2010): Provides flood information for a range of design floods including the PMF. However, due to the broad-scale nature of the study, the flood model was not sufficiently detailed to represent local flood behaviour across the site (particularly with regard to representing the impediment to flow afforded by individual buildings across the existing site and the potential high velocity/hazard flow paths between sites/buildings).
- 'Flooding Assessment Report for Planning Proposal' (NGH Consulting Group, 2020): This assessment was prepared specifically to support the Planning Proposal. This included a more detailed flood assessment targeting the site. However, the analysis was restricted to the 1% AEP flood (i.e., the PMF was not assessed) and the impediment to flow afforded by sites/buildings was not explicitly represented.

In recognition of the limitations identified above and the requirements detailed by Central Coast Council (as summarised in Chapter 1), a new flood model was developed specifically to simulate the PMF. The following sections describe the development of the flood model as well as the PMF hazard outputs for existing site conditions.

2.2 Flood Model

2.2.1 Model Development

As discussed, development of a new hydraulic model was considered necessary as part of the current study to provide the best description of flood behaviour across the site. The new flood model was developed using the TUFLOW HPC software (version 2020-10-AA). In accordance with the instruction from Council, a "direct rainfall" TUFLOW model was developed which permits application of rainfall directly to the hydraulic model (i.e., hydrologic and hydraulic processes are represented in the same model rather than having separate hydrologic and hydraulic models).

The TUFLOW model that was developed for the study incorporated the following features:

- <u>Model Domain</u>: the TUFLOW model area extended across the full catchment area draining downstream of Empire Bay Road. Although the model domain extends well beyond the site itself, this was completed to ensure any potential interaction of flow from nearby watercourses was captured. The extent of the model is shown on **Figure 2.1**.
- <u>Grid Size</u>: a 1 metre grid size was used to represent the variation in terrain and hydraulic properties (e.g., Manning's n roughness) across the model area. Sub-grid sampling was also employed to enable a more detailed storage and conveyance representation at the sub-grid level. A 0.5 metre sub sampling interval was adopted.

- Topography: the elevations that were assigned to each grid cell in the model were based upon a Digital Elevation Model (DEM) developed from LiDAR data that was captured in 2020 by the NSW Government's Department of Spatial Services. The LiDAR DEM was compared with plans of detailed ground survey that was collected across the site in 2017 (a copy of the survey is enclosed in **Appendix B**). This comparison showed that the LiDAR provided a good representation of existing ground elevations across most of the site. However, the LiDAR failed to pick up some finer scale features such as a solid wall located along the eastern property boundary as well as the drainage gullies extending across site. Therefore, the survey information was used to incorporate additional detail in the terrain model in the form of "z lines".

- Manning's "n" Roughness: Roughness coefficients, which describe the resistance to flow afforded by different types of materials, were assigned based upon visual inspection of contemporary aerial imagery. The extent of each material type is shown in **Figures 2.1** and **2.2**. Since rainfall is being applied directly in the model, the effective roughness of materials will vary with respect to water depth for some materials (most notably grass). Therefore, depth varying roughness coefficients were adopted for some of the land use types. The roughness values assigned to each material/land use are provided in **Table 1** (the adopted roughness values are based on another direct rainfall model developed for Central Coast Council as documented in the 'Killarney Vale/Long Jetty Catchment Flood Study', 2014). As shown in **Table 1**, buildings were assigned a very high roughness values to reflect the significant impediment to flow afforded by these structures.

Table 1 Roughness Values

Material Description	Depth Varying Manning's 'n' Values							
	$Depth_1$ *(metres)*	n_1	$Depth_2$ *(metres)*	n_2	$Depth_3$ *(metres)*	n_3	$Depth_4$ *(metres)*	n_4
Grass	<0.03	0.050	0.05	0.045	0.070	0.040	>0.1	0.030
Sparse Trees	<1	0.035	>2	0.070				
Dense Trees	<1	0.050	>2	0.100				
Watercourses	-	0.045						
Roadway	<0.04	0.021	0.1	0.018	>0.15	0.016		
Buildings	<0.09	0.030	>0.1	1.000				

- Pipes/Culverts: Details of pipes and culverts in the vicinity of the site were included in the model based upon information contained in the survey plans and was supplemented with the LiDAR information, aerial imagery, and Google Street View. The locations of each pipe/culvert included in the model are shown in **Figure 2.2.**

- Downstream Boundary Condition: The downstream boundary for the model was defined using a normal depth (i.e., Manning's) calculation based upon a bed slope of 1%. As shown in **Figure 2.1**, The downstream boundary was located approximately 300 metres downstream of Empire Bay Drive, which is considered a sufficient distance downstream to not impact results that are the focus of the current study (i.e., upstream of Empire Bay Drive).

- Upstream/Inflow Boundary Conditions: Inflows to the TUFLOW model were defined by applying PMP rainfall to every cell within the model based on PMP rainfall hyetographs. Further details on how the PMP rainfall was derived is provided below.

2.2.2 Design Rainfall

As noted in previous sections, the primary objective of the study was to understand flood hazard conditions during the probable maximum flood (PMF). The PMF is considered to be the largest flood that could conceivably occur across a particular area. The PMF is estimated by routing the probable maximum precipitation (PMP) through the computer model.

PMP rainfall depths were derived for a range of storm durations up to and including the 6-hour event based on procedures set out in the Bureau of Meteorology's *'Generalised Short Duration Method'* (GSDM) (Bureau of Meteorology, 2003). The GSDM PMP calculations for the study area are included in **Appendix C**. The temporal distribution of the rainfall was also defined based upon the GSDM PMP guideline.

2.2.3 Rainfall Losses

An initial rainfall loss of 10mm and a continuing loss rate of 2.5mm/hr was adopted for pervious land use types (e.g., grass, trees). For impervious surfaces (e.g., buildings, roads) an initial loss of 1 mm and a continuing loss rate of 0mm/hr was adopted.

2.2.4 Results

The full range of PMP storm durations documented in **Appendix C** were applied to the TUFLOW model and the model was used to simulate the movement of floodwaters across the model area for the probable maximum flood (PMF). The critical PMF duration (i.e., the storm duration that produced the highest flood levels/depths) across the site was determined to be 30 minutes.

Peak depth and velocity vector results were extracted from the PMF simulation and are provided in **Figure 3**. The velocity vectors show the direction and magnitude of flow velocities.

The peak depth and velocity results were also used to prepare flood hazard mapping for the PMF. The hazard mapping was prepared based upon flood hazard vulnerability curves presented in Chapter 7 of Book 6 of 'Australian Rainfall & Runoff' (Ball et al, 2019). The hazard curves are reproduced in Plate 1. As shown in Plate 1, the flood hazard mapping provides an understanding of the potential impact of floodwaters on vehicles, buildings, and people. The flood hazard map is provided in **Figure 4**.

As discussed, the adopted modelling approach for the study involves applying rainfall directly to each cell in the computer model and routing the rainfall excess based on the physical characteristics of the catchment. Once the rain falling on each grid cell exceeds the rainfall losses, each cell will be "wet". However, water depths across the majority of the catchment will likely be very shallow and would not present a significant flooding problem. Therefore, it was necessary for the results of the computer simulations to be "filtered" to distinguish between areas of significant inundation depth / flood hazard and those areas subject to negligible inundation. In this regard, a minimum depth threshold of 0.15 metres was adopted.

That is, only areas exposed to inundation depths of more than 0.15 metres are displayed in **Figure 3** and **Figure 4**.

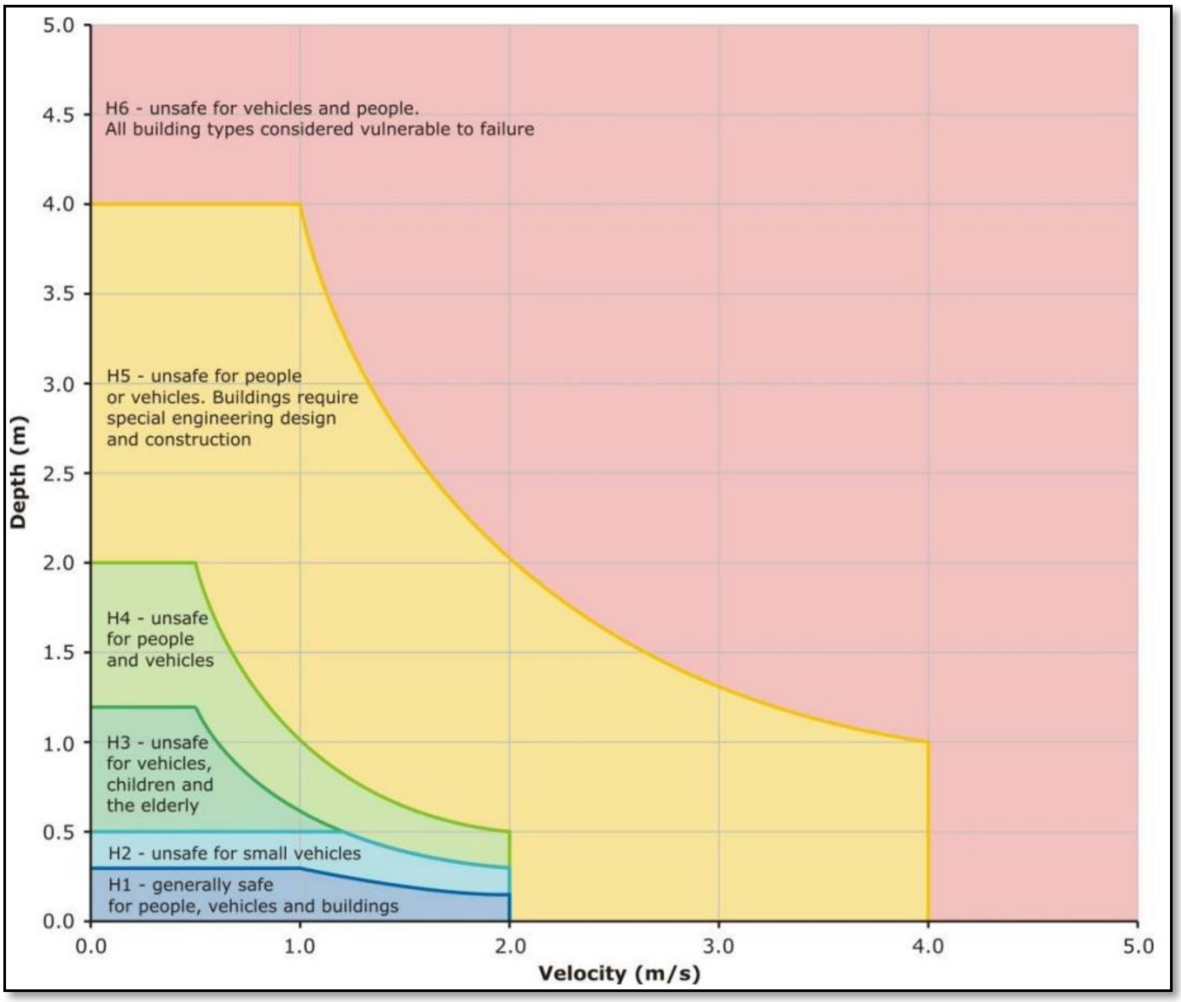

Plate 1 Flood hazard vulnerability curves (Ball et al, 2019)

Figure 3 shows that the wall located along the eastern boundary of the site serves as a barrier to flow approaching the site, with a significant proportion of flow being redirected north. However, the depths of water immediately east of the site are sufficient to overtop the wall and spill in a north-westerly direction through the site. Significant depths and velocities are predicted along a small drainage gully located immediately south of the southernmost existing sites. Peak depths of over 1 metre and peak velocities of up to 2 m/s are predicted in this area. Across the balance of the site, peak water depths are generally predicted be between 0.5 and 0.75 metres. The velocity vectors in **Figure 3** also demonstrate the significant impact that buildings have on the direction of flow with much of the higher velocity flows being directed down roadways. Peak velocities along internal roadways are commonly predicted to reach 1.5 m/s while velocities in the immediately vicinity of buildings are generally less than 1 m/s.

Figure 4 shows that much of the site would be exposed to either negligible or low hazard conditions (i.e., <H4). This includes much of the southern part of the site where potential future development is proposed as well are localised areas within the north-eastern section of the existing sites.

However, **Figure 4** also shows that parts of the site are likely to experience high hazard (i.e., >H3) conditions during the PMF. This includes part sections of some roads as well as some existing buildings. Most notably, the southern most existing buildings would be party exposed to H5 hazard which has the potential to cause structural damage to light structures.

Therefore, the outcomes of the existing PMF hazard modelling have demonstrated that most of the site and buildings would likely be exposed to low hazard conditions. However, some buildings would experience high hazard conditions and are considered incompatible with the hazard. Therefore, it is evident that modifications will need to be completed around these buildings to reduce the hazard to more tolerable levels. Further details on the potential modifications that could be completed as part of the potential future development of the site to better manage the PMF hazard is provided in the following chapter.

3 FLOOD ASSESSMENT FOR POTENTIAL FUTURE CONDITIONS

3.1 Introduction

One of the main objectives of the current study that was stipulated by Central Coast Council was to ensure no new development occurs in high hazard areas while removing existing sites from high hazard areas and/or otherwise reducing the flood hazard across existing sites to ensure they were not exposed to high hazard conditions.

Therefore, the model that was used to quantify PMF flood behaviour for existing conditions was iteratively updated to reflect potential future development options. This included a combination of removing some existing sites, terrain modifications (i.e., filling and regrading) and realignment of the main drainage gully that extends through the site. The suggested mitigation measures are described in the following sections along with the revised flood hazard with the mitigation options in place.

It should be noted that the measures are suggestions on potential mitigation measures only. They are intended to demonstrate that the PMF hazard can be appropriately managed as part of the future development of the site for the purposes of the Planning Proposal. Further refinement of the options (as well as the potential for other mitigations options) will need to be completed and modelled as part of the future Development Application for the site.

3.2 Model Updates

The TUFLOW hydraulic model that was used to define existing flood behaviour was updated to include a representation of the suggested mitigation measures, which are shown in **Figure 5**. As shown in **Figure 5**, this involved the following modifications to the TUFLOW model:

- Removing some existing buildings from high hazard areas (refer black hatching in **Figure 5**).
- Relocate existing drainage gully (refer green hatching in **Figure 5**) further south into an existing drainage easement (refer aqua hatching in **Figure 5**). Regrading will also be completed to direct flows that overtop the eastern site wall towards this new channel (refer magenta hatching in **Figure 5** as well as typical cross-section).
- Install new wall/levee along southern side of existing southern buildings to deflect PMF flows back towards new drainage gully.
- Installation of a new junction pit and 0.5 metre diameter pipe to redirect piped flows that currently pass under the eastern wall into the new drainage gully.
- Minor filling (i.e., maximum of 0.5 metres) of a small section of the potential future development footprint (refer red hatching in **Figure 5**).
- Updating of some materials polygons to reflect the alignment of future roads.

3.3 Results

3.3.1 Hydraulics

The updated hydraulic model was used to re-simulate the PMF with the suggested mitigation measures in place. Peak floodwater depth and velocity vectors were extracted from the results of the modelling and are presented in **Figure 6** in **Appendix A**. Flood hazard mapping was also prepared and is presented in **Figure 7**.

Figure 6 shows that the PMF depths and velocities across the northern and southern sections of the site are broadly consistent with existing conditions. However, the mitigations measures have altered depth and velocities through the central section of the site. This includes deeper and faster moving water through the central sections of the site. However, depths and velocity across the existing southern sites are significantly reduced due to the protection afforded by the wall.

Figure 7 also confirms that the existing sites that are suggested for retention would be exposed to a maximum of H3 hazard (i.e., low hazard) during the PMF if the suggested mitigation measures are implemented. It also shows that the potential future development areas would be exposed to a maximum of H2 hazard which is also considered low hazard. H5 hazard (high hazard) is predicted through the central sections of the site, however, no existing or potential future habitable development is currently proposed in this area.

Figure 7 also shows that the southern sections of the potential future development areas as well as localised areas within the north-western section of the existing site would be elevated above the peak level of the PMF. Therefore, there would be opportunities for residents in lower sections of the site to temporarily relocate/seek refuge to these more elevated areas during a PMF should the need arise.

Overall, the outcomes of the PMF assessment for potential future development conditions shows that existing and future development can likely proceed in a manner that is consistent with the flood hazard provided supplementary mitigation measures are also implemented. It is recommended that further refinement of the existing and future development layouts is completed in conjunction with the potential mitigation measures as the design progresses and the effectiveness of any design modifications are supported by appropriate flood modelling to demonstrate the PMF hazard is still being appropriately managed.

4 SUMMARY

This report has summarised the outcomes of a probable maximum flood (PMF) assessment that was completed to support a Planning Proposal for a site located at 437 Wards Hills Road, Empire Bay. The assessment follows on from a request by Central Coast Council to ensure that no existing or potential future buildings are located in high hazard areas during the PMF.

The assessment was completed using a newly developed, direct rainfall TUFLOW model. The TUFLOW model was first used to simulate flood behaviour across the local catchment for existing conditions. The outcomes of this assessment confirmed that some existing sites would likely to exposed to high flood hazard conditions (i.e., >H3 hazard).

Therefore, the TUFLOW model was updated to include a range of potential mitigation measures that aimed to reduce the exposure of existing and potential future development areas to high hazard conditions. This included a combination of removing some existing sites, terrain modifications (i.e., filling and regrading) and realignment of the main drainage gully that extends through the site.

The outcomes of the revised modelling with the mitigation measures in place showed that the hazard can be managed during the PMF. More specifically it demonstrated that no existing or potential future development areas would be exposed to high hazard conditions during the PMF if the suggested mitigation measures are implemented.

It should be noted that the mitigation measures are suggestions for the purpose of assessing the feasibility of the Planning Proposal. There are opportunities for the design of the future site and any associated mitigation measures to be refined at a later stage (e.g., during the future Development Application). However, it is recommended that the performance of any future designs is supported by PMF modelling to confirm that the flood hazard is suitably managed.

5 REFERENCES

- BMT WBM (2018). TUFLOW User Manual. Version 2020-01-AA.
- Bureau of Meteorology. (2003). The Estimation of Probable Maximum Precipitation in Australia: Generalised Short Duration Method.
- Cardno (2010), Empire Bay Catchment Flood Study. Prepared for Gosford City Council.
- Catchment Simulation Solutions (2014), Killarney Vale/Long Jetty Catchments Flood Study. Prepared for Wyong Shire Council
- NGH Consulting Group (2010), Flooding Assessment Report for Planning Proposal. Prepared for Barnes Property Investments Pty Ltd

APPENDIX A
FIGURES

Figure 1: Study Area

Aerial photograph : NSW SixMaps 2021

Site Boundary

N

0 200 400 m

Scale: 1:10000 (at A3)

Prepared by:

Catchment Simulation Solutions

Suite 1, Level 10, 70 Phillip St
Sydney, NSW, 2000

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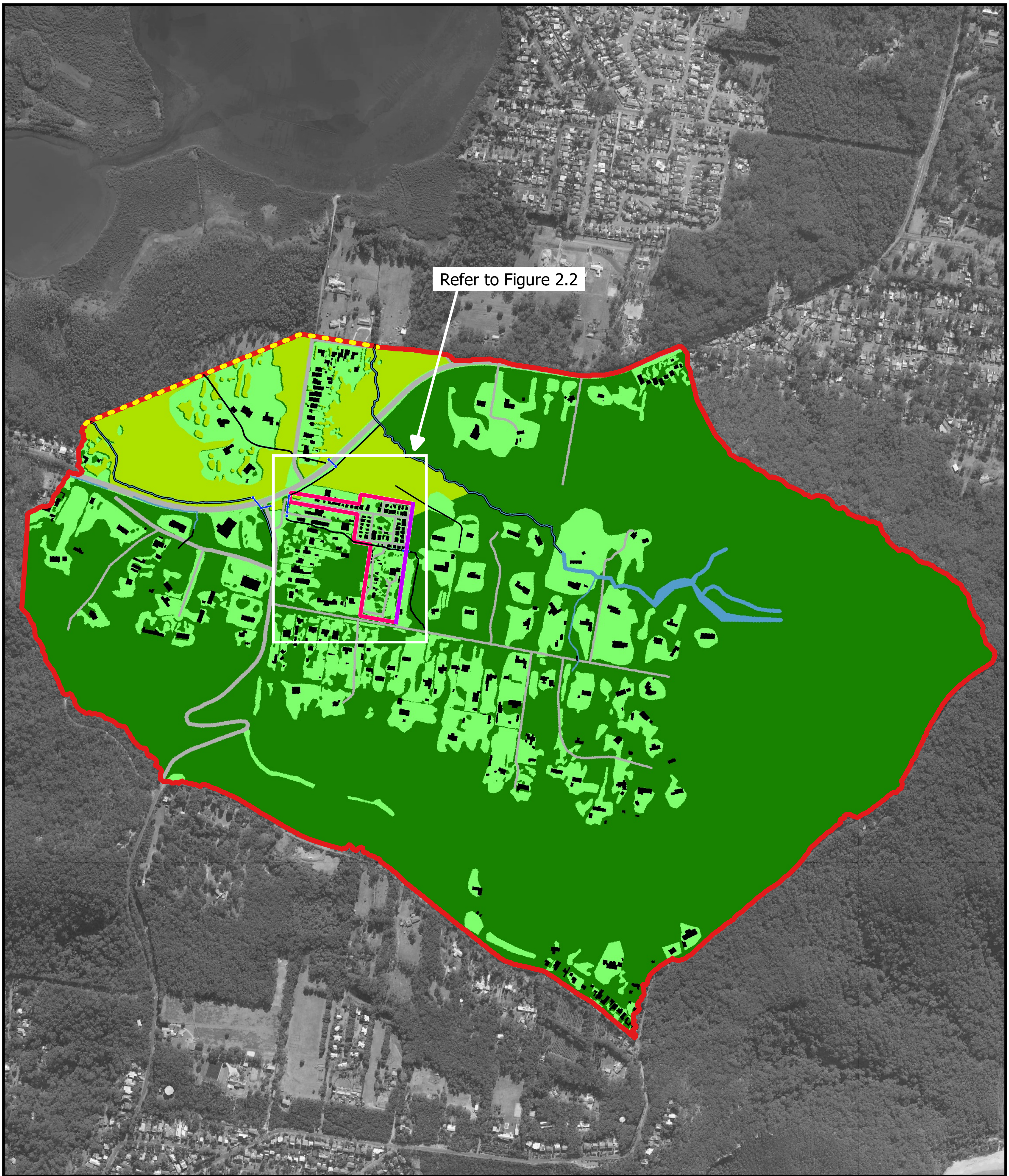

Figure 2.1: TUFLOW Model Layout

Aerial photograph : NSW SixMaps 2021

Site Boundary
Model Extent
Gully/Creek
Stormwater Pit/Node
Stormwater Pipe
Stage-Discharge Downstream Boundary
Eastern Wall

Materials
Grass
Sparse Trees
Dense Trees
Watercourses
Roadway
Buildings

N

0 300 600 m

Scale: 1:13000 (at A3)

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Figure 2.2: TUFLOW Model Layout

Aerial photograph : NSW SixMaps 2021

Site Boundary
Model Extent
Gully/Creek
Stormwater Pit/Node
Stormwater Pipe
Stage-Discharge Downstream Boundary
Eastern Wall

Materials

Grass
Sparse Trees
Dense Trees
Watercourses
Roadway
Buildings

N

0 50 100 m

Scale: 1:2000 (at A3)

Prepared by:
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Suite 1, Level 10, 70 Phillip St
Sydney, NSW, 2000

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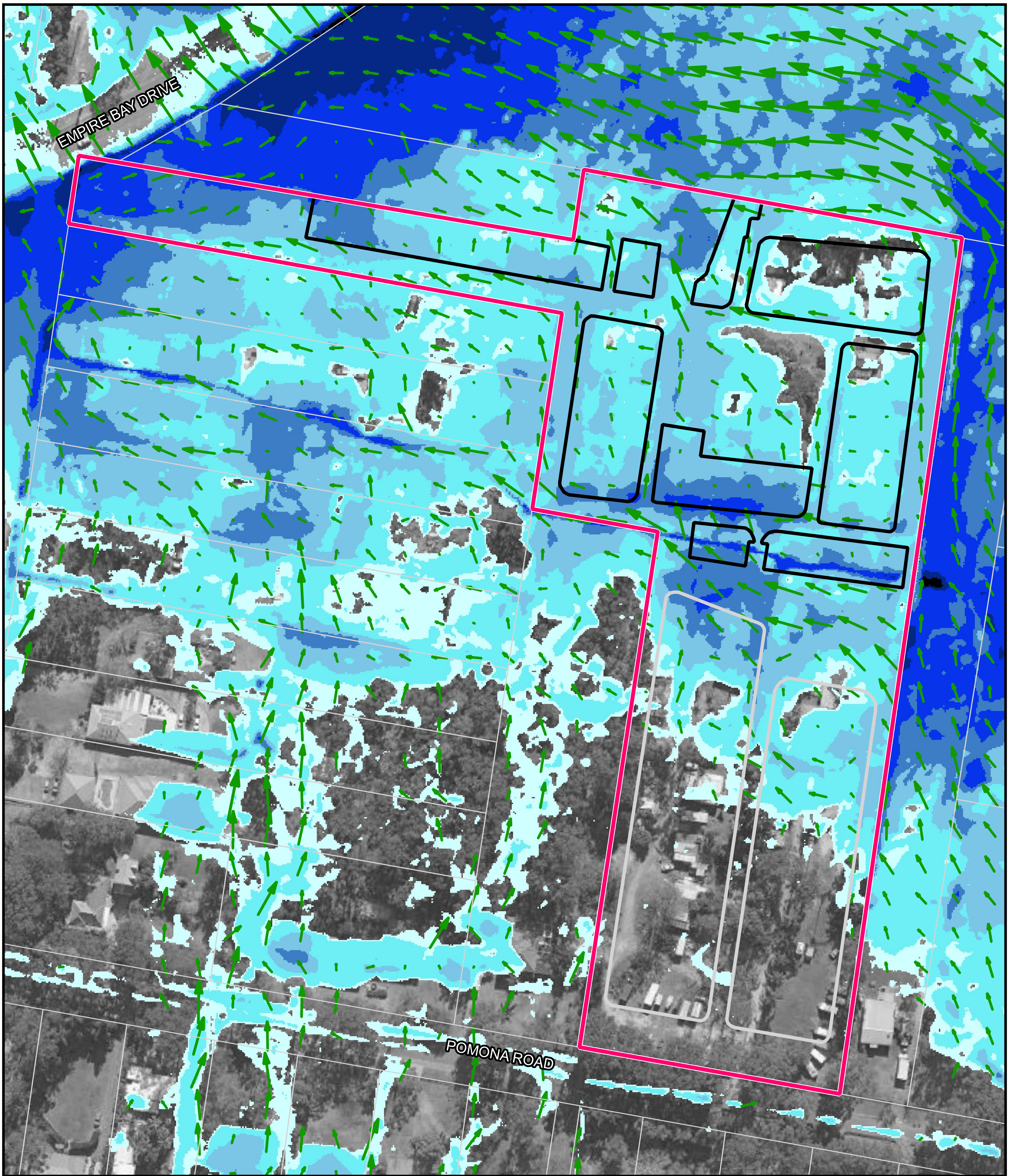

Figure 3: Peak PMF Floodwater Depths & Velocities for Existing Conditions

Aerial photograph : NSW SixMaps 2021

- Existing Development Area
- Future Development Area
- Velocity Vector (2m/s)

Depth (m)

- 0.15 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00

N

0 40 80 m

Scale: 1:2000 (at A3)

Prepared by:
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Suite 1, Level 10, 70 Phillip St
Sydney, NSW, 2000

Note: Only areas subject to inundation depths greater than 0.15 metres are displayed.

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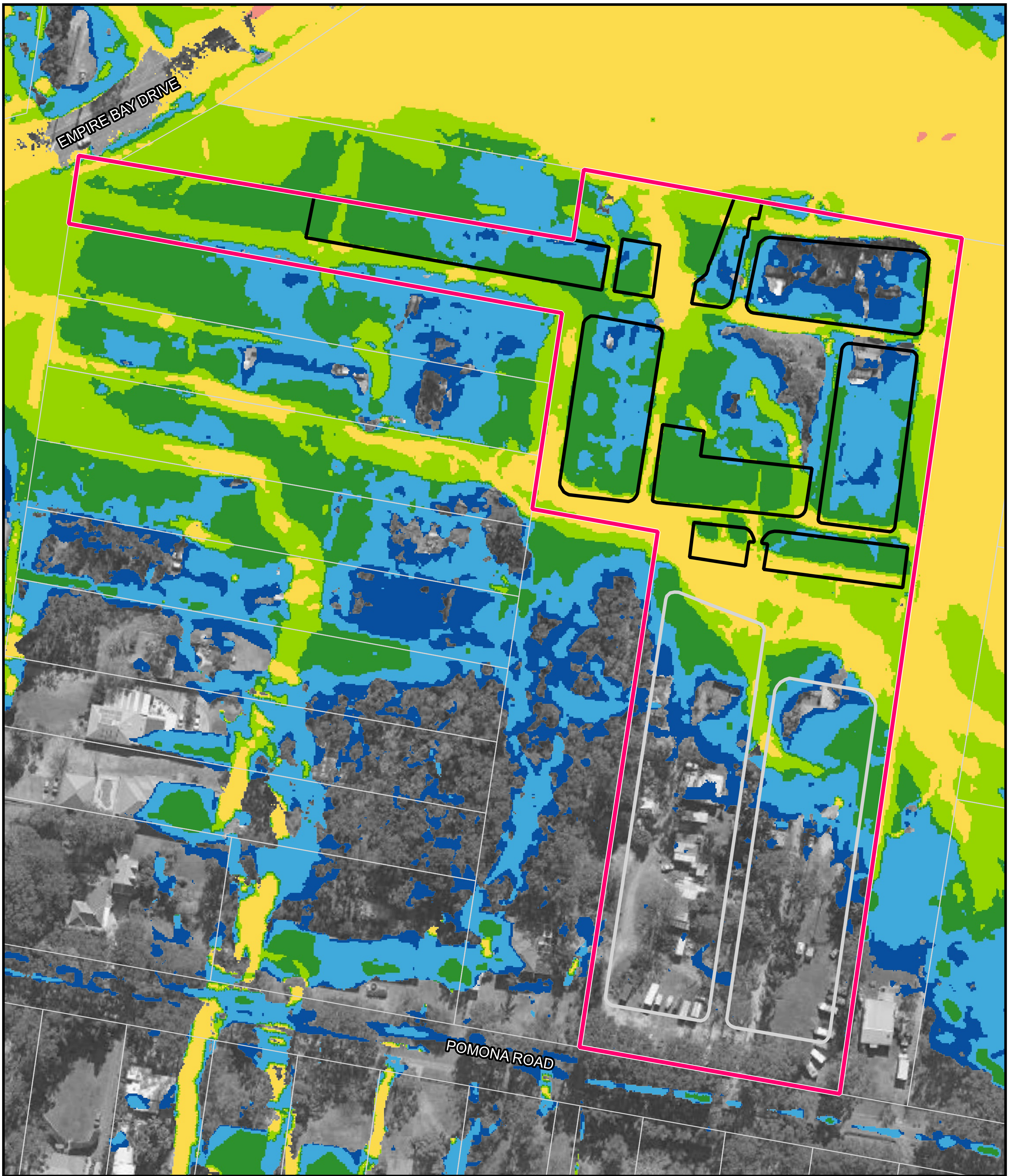

Figure 4: Peak PMF Flood Hazard for Existing Conditions

Aerial photograph : NSW SixMaps 2021

Existing Development Area
Future Development Area

Hazard Category

- H1 - Generally safe
- H2 - Unsafe for small vehicles
- H3 - Unsafe for vehicles, children and elderly
- H4 - Unsafe for people and vehicles
- H5 - Unsafe for people and vehicles; Buildings require special design
- H6 - Unsafe for people and vehicles; All buildings vulnerable to failure

N

0 40 80 m

Scale: 1:2000 (at A3)

Prepared by:
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Suite 1, Level 10, 70 Phillip St
Sydney, NSW, 2000

Note: Only areas subject to inundation depths greater than 0.15 metres are displayed.

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Figure 5: Potential Development Mitigation Concept

Aerial photograph : NSW SixMaps 2021

- Site Boundary

Existing Development Area

- To remain
- To remove

Proposed Development Area

- To remain unchanged
- To raise

- Existing gully to fill
- New gully
- Terrain to re-grade
- Proposed wall
- New stormwater junction pit
- New stormwater pipe
- Existing stormwater pipe

N

0 20 40 m

Scale: 1:1000 (at A3)

Prepared by:
Catchment Simulation Solutions
Suite 1, Level 10, 70 Phillip St
Sydney, NSW, 2000

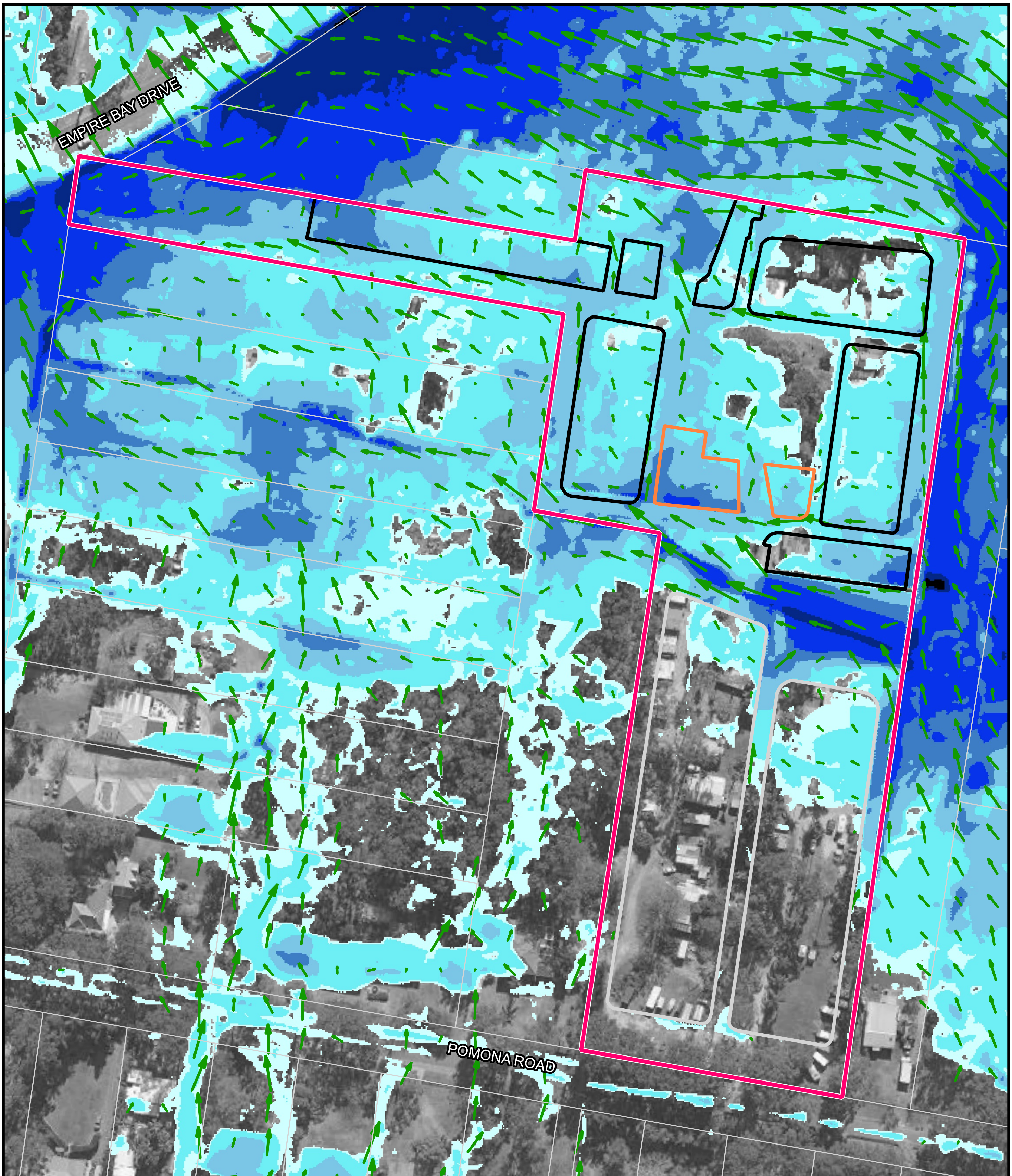

Figure 6: Peak PMF Floodwater Depths & Velocities for Potential Future Conditions

Aerial photograph : NSW SixMaps 2021

- Existing Development Area
- Modified Existing Development Area
- Future Development Area
- Velocity Vector (2m/s)

Depth (m)

- 0.15 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00

N

0 40 80 m

Scale: 1:2000 (at A3)

Prepared by:

Catchment Simulation Solutions

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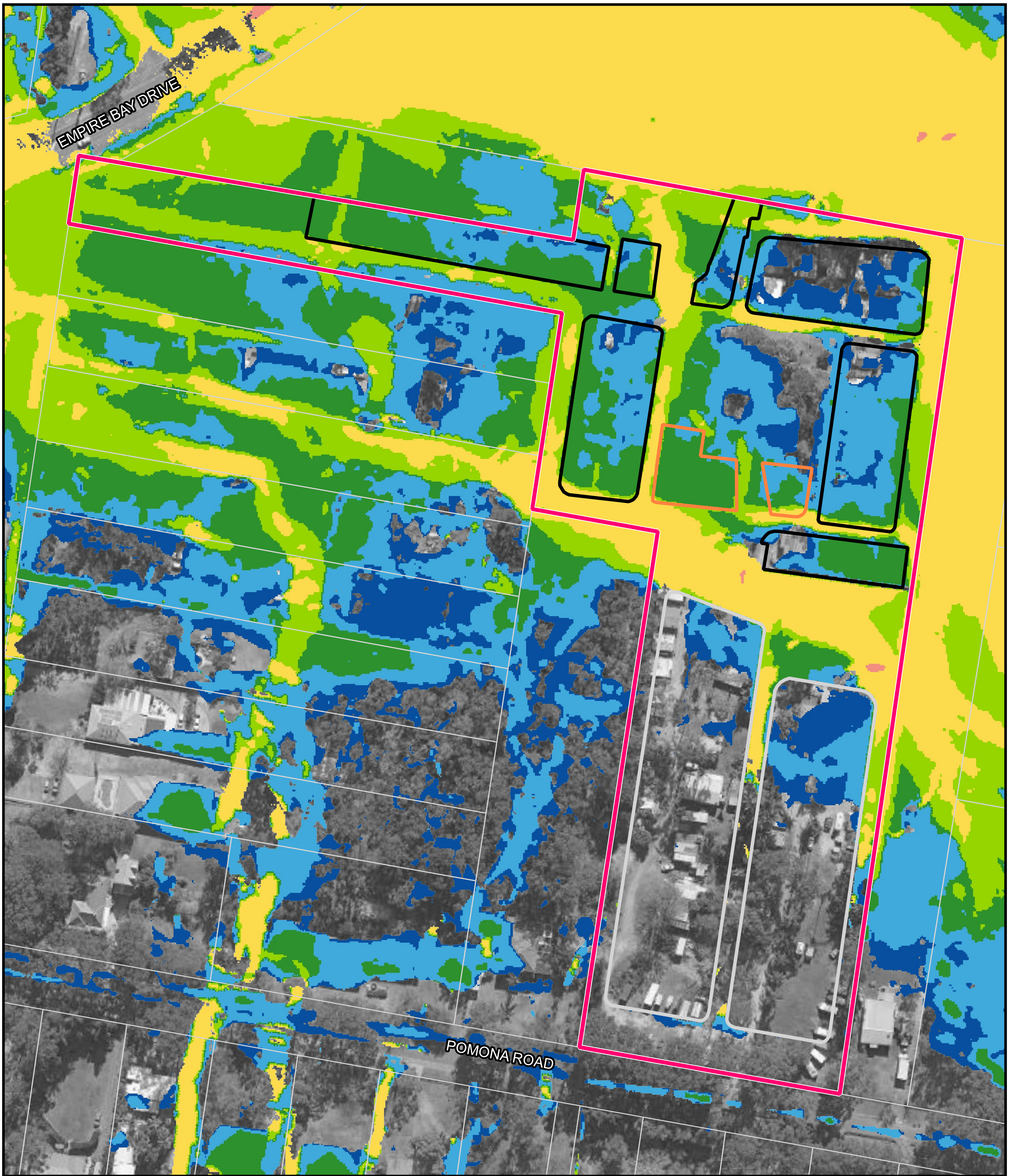

Figure 7: Peak PMF Flood Hazard for Potential Future Conditions

Aerial photograph : NSW SixMaps 2021

- Existing Development Area
- Modified Existing Development Area
- Future Development Area

Hazard Category

- H1 - Generally safe
- H2 - Unsafe for small vehicles
- H3 - Unsafe for vehicles, children and elderly
- H4 - Unsafe for people and vehicles
- H5 - Unsafe for people and vehicles; Buildings require special design
- H6 - Unsafe for people and vehicles; All buildings vulnerable to failure

Note: Only areas subject to inundation depths greater than 0.15 metres are displayed.

N

0 40 80 m

Scale: 1:2000 (at A3)

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APPENDIX B
SITE SURVEY

BAYSIDE VILLAGE

Empire Bay

(E) - EASEMENT FOR DRAINAGE 1.83 WIDE (C429802)

Clarke Dowdle & Associates
Development Consultants
surveyors - planners - ecologists - bushfire consultants

#1 OSCAR STREET UMINA BEACH NSW 2257
ph (02)43443553 fax (02)43446636
email admin@cdasurveys.com.au
Po Box 3122 Umina NSW 2257

client: BAYSIDE VILLAGE

reference #Go: 13018(1) number in set:

project: #7 POMONA ROAD, EMPIRE BAY.

details: Lot 1 in DP 610629

drawing: PLAN SHOWING PARK LOT LAYOUT

red. ratio: 1:1200	datum: A.H.D.	job date: 16/02/07	
L.G.A.: GOSFORD		Parish: KINCUMBER	
contour interval: 1m		County: NORTHUMBERLAND	

Origin of Levels : SSM 74944
Location : Wards Hill Road, Empire Bay.
R.L. : 15.30m A.H.D.

approved: Registered Surveyor

assessed: A.W.C.
drawn: P.M.D.
surveyed: D.G.

amendments:

no.	description:	date:
D	New Buildings Added and Lots Reviewed	19/07/17
C	Retaining Wall Detail Added	16/05/16
B	Tree Detail Added	11/01/16
A	some lots reviewed	17/06/11

notes:
all dimensions are in metres unless otherwise shown.
check and confirm all areas & dimensions on site prior to the commencement of any works. do not scale from face of plan.
preliminary boundary fixation has been undertaken only.
if any construction is planned on or close to the boundaries further survey work will be required.
a complete investigation of services has not been undertaken for this survey.

1 : 100
1 : 600

APPENDIX C
PMP CALCULATIONS

GSDM CALCULATION SHEET

LOCATION INFORMATION

Catchment Bayside Gardens | Area 1.68 km^2

State New South Wales | Duration Limit 6.0 hrs

Latitude 33.5121^{0}S | Longitude 151.3822^{0}E

Portion of Area Considered:

Smooth, **S** = 0.00 (0.0 - 1.0) | Rough, **R** = 1.00 (0.0 - 1.0)

ELEVATION ADJUSTMENT FACTOR (EAF)

Mean Elevation 63 m

Adjustment for Elevation (-0.05 per 300m above 1500m) 0.00

EAF = **1.00** (0.85 – 1.00)

MOISTURE ADJUSTMENT FACTOR (MAF)

MAF = **0.70** (0.40-1.00)

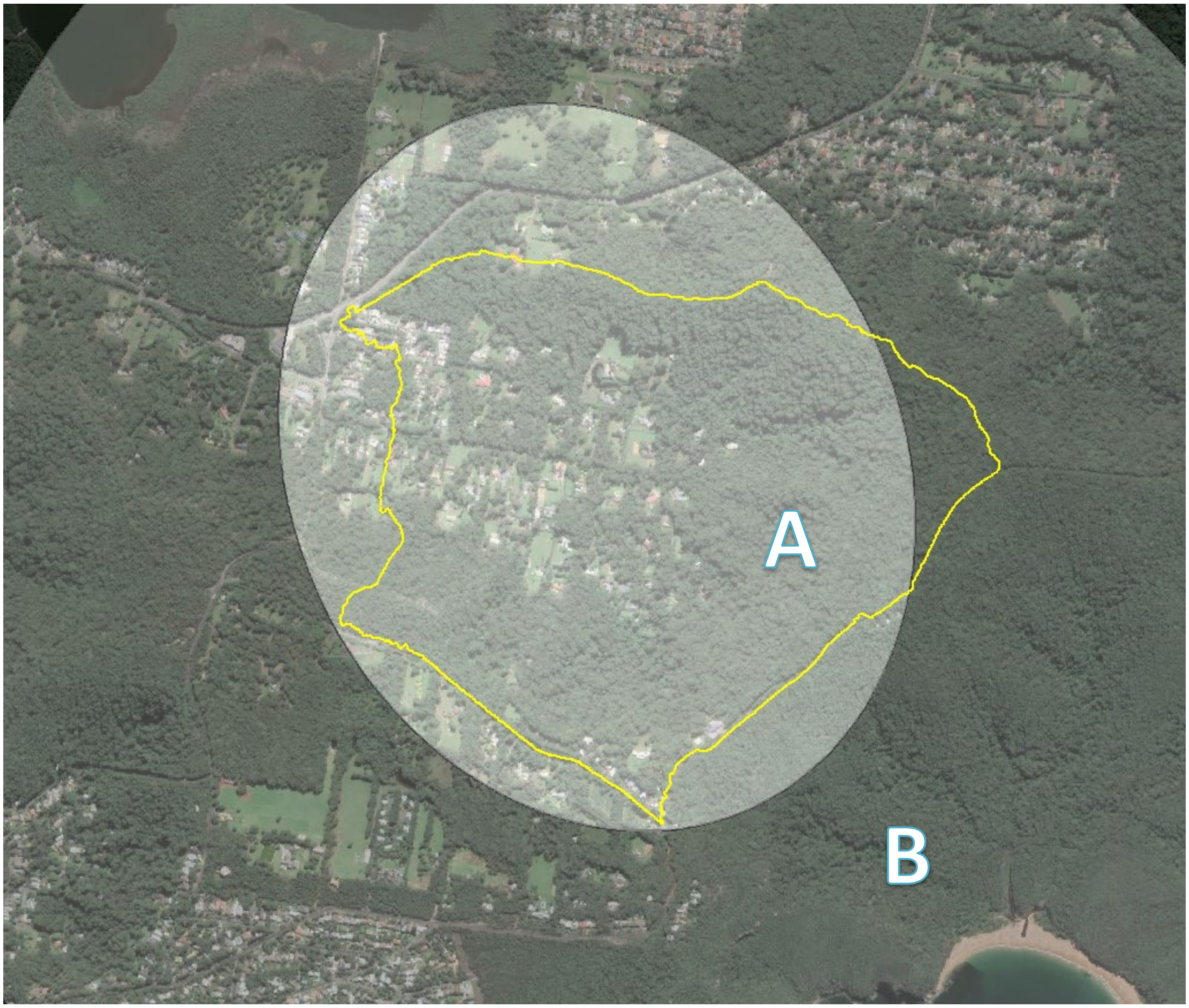
PMP VALUES (mm)

Duration (hours)	Initial Depth -Smooth (D_S)	Initial Depth -Rough (D_R)	PMP Estimate = (D_SxS + D_RxR) x MAF x EAF	Rounded PMP Estimate (nearest 10 mm)
0.25	238	238	167	170
0.50	343	343	240	240
0.75	433	433	303	300
1.00	502	502	351	350
1.50	573	647	453	450
2.00	638	757	530	530
2.50	680	837	586	590
3.00	717	920	644	640
4.00	781	1048	733	730
5.00	844	1158	810	810
6.00	890	1222	856	860

Prepared By S. See | Date 28/10/2021

Checked By D. Tetley | Date 28/10/2021

GSDM SPATIAL DISTRIBUTION



GSDM SPATIAL DISTRIBUTION

DURATION = 0.25 Hours							
Ellipse	Catchment Area Between Ellipse (km^2)	Catchment Area Enclosed by Ellipse (km^2)	Initial Mean Rainfall Depth (mm)	Adjusted Mean Rainfall Depth (mm)	Rainfall Volume enclosed by Ellipse ($mm.km^2$)	Rainfall Volume between Ellipses ($mm.km^2$)	Mean Rainfall Depth between ellipses (mm)
A	1.60	1.60	239	167	267	267	167
B	0.08	1.68	238	167	280	13	156
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

DURATION = 0.50 Hours							
Ellipse	Catchment Area Between Ellipse (km^2)	Catchment Area Enclosed by Ellipse (km^2)	Initial Mean Rainfall Depth (mm)	Adjusted Mean Rainfall Depth (mm)	Rainfall Volume enclosed by Ellipse ($mm.km^2$)	Rainfall Volume between Ellipses ($mm.km^2$)	Mean Rainfall Depth between ellipses (mm)
A	1.60	1.60	344	241	385	385	241
B	0.08	1.68	343	240	404	19	229
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

GSDM SPATIAL DISTRIBUTION (continued)

DURATION = 0.75 Hours							
Ellipse	Catchment Area Between Ellipse (km^2)	Catchment Area Enclosed by Ellipse (km^2)	Initial Mean Rainfall Depth (mm)	Adjusted Mean Rainfall Depth (mm)	Rainfall Volume enclosed by Ellipse ($mm.km^2$)	Rainfall Volume between Ellipses ($mm.km^2$)	Mean Rainfall Depth between ellipses (mm)
A	1.60	1.60	433	303	485	485	303
B	0.08	1.68	433	303	509	24	290
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

DURATION = 1.0 Hours							
Ellipse	Catchment Area Between Ellipse (km^2)	Catchment Area Enclosed by Ellipse (km^2)	Initial Mean Rainfall Depth (mm)	Adjusted Mean Rainfall Depth (mm)	Rainfall Volume enclosed by Ellipse ($mm.km^2$)	Rainfall Volume between Ellipses ($mm.km^2$)	Mean Rainfall Depth between ellipses (mm)
A	1.60	1.60	503	352	562	562	352
B	0.08	1.68	502	351	591	28	338
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

GSDM SPATIAL DISTRIBUTION (continued)

DURATION = 1.5 Hours

Ellipse	Catchment Area Between Ellipse (km^2)	Catchment Area Enclosed by Ellipse (km^2)	Initial Mean Rainfall Depth (mm)	Adjusted Mean Rainfall Depth (mm)	Rainfall Volume enclosed by Ellipse ($mm.km^2$)	Rainfall Volume between Ellipses ($mm.km^2$)	Mean Rainfall Depth between ellipses (mm)
A	1.60	1.60	648	453	725	725	453
B	0.08	1.68	647	453	761	37	439
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

DURATION = 2.0 Hours

Ellipse	Catchment Area Between Ellipse (km^2)	Catchment Area Enclosed by Ellipse (km^2)	Initial Mean Rainfall Depth (mm)	Adjusted Mean Rainfall Depth (mm)	Rainfall Volume enclosed by Ellipse ($mm.km^2$)	Rainfall Volume between Ellipses ($mm.km^2$)	Mean Rainfall Depth between ellipses (mm)
A	1.60	1.60	759	531	849	849	531
B	0.08	1.68	757	530	891	43	511
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

GSDM SPATIAL DISTRIBUTION (continued)

DURATION = 2.5 Hours							
Ellipse	Catchment Area Between Ellipse (km^2)	Catchment Area Enclosed by Ellipse (km^2)	Initial Mean Rainfall Depth (mm)	Adjusted Mean Rainfall Depth (mm)	Rainfall Volume enclosed by Ellipse (mm.km^2)	Rainfall Volume between Ellipses (mm.km^2)	Mean Rainfall Depth between ellipses (mm)
A	1.60	1.60	839	587	939	939	587
B	0.08	1.68	837	586	986	47	564
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

DURATION = 3.0 Hours							
Ellipse	Catchment Area Between Ellipse (km^2)	Catchment Area Enclosed by Ellipse (km^2)	Initial Mean Rainfall Depth (mm)	Adjusted Mean Rainfall Depth (mm)	Rainfall Volume enclosed by Ellipse (mm.km^2)	Rainfall Volume between Ellipses (mm.km^2)	Mean Rainfall Depth between ellipses (mm)
A	1.60	1.60	922	645	1031	1031	645
B	0.08	1.68	920	644	1082	51	614
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

GSDM SPATIAL DISTRIBUTION (continued)

DURATION = 4.0 Hours							
Ellipse	Catchment Area Between Ellipse (km^2)	Catchment Area Enclosed by Ellipse (km^2)	Initial Mean Rainfall Depth (mm)	Adjusted Mean Rainfall Depth (mm)	Rainfall Volume enclosed by Ellipse ($mm.km^2$)	Rainfall Volume between Ellipses ($mm.km^2$)	Mean Rainfall Depth between ellipses (mm)
A	1.60	1.60	1050	735	1174	1174	735
B	0.08	1.68	1048	733	1233	59	707
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

DURATION = 5.0 Hours							
Ellipse	Catchment Area Between Ellipse (km^2)	Catchment Area Enclosed by Ellipse (km^2)	Initial Mean Rainfall Depth (mm)	Adjusted Mean Rainfall Depth (mm)	Rainfall Volume enclosed by Ellipse ($mm.km^2$)	Rainfall Volume between Ellipses ($mm.km^2$)	Mean Rainfall Depth between ellipses (mm)
A	1.60	1.60	1160	812	1298	1298	812
B	0.08	1.68	1158	810	1362	65	777
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A

GSDM SPATIAL DISTRIBUTION (continued)

DURATION = 6.0 Hours							
Ellipse	Catchment Area Between Ellipse (km^2)	Catchment Area Enclosed by Ellipse (km^2)	Initial Mean Rainfall Depth (mm)	Adjusted Mean Rainfall Depth (mm)	Rainfall Volume enclosed by Ellipse ($mm.km^2$)	Rainfall Volume between Ellipses ($mm.km^2$)	Mean Rainfall Depth between ellipses (mm)
A	1.60	1.60	1225	857	1370	1370	857
B	0.08	1.68	1222	856	1438	69	823
C	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D	N/A	N/A	N/A	N/A	N/A	N/A	N/A
E	N/A	N/A	N/A	N/A	N/A	N/A	N/A
F	N/A	N/A	N/A	N/A	N/A	N/A	N/A
G	N/A	N/A	N/A	N/A	N/A	N/A	N/A
H	N/A	N/A	N/A	N/A	N/A	N/A	N/A
I	N/A	N/A	N/A	N/A	N/A	N/A	N/A
J	N/A	N/A	N/A	N/A	N/A	N/A	N/A