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Date:	27 November 2019	Contact name:	Rohan Hudson
Your reference:	N/A	Telephone:	0404918794
Our reference:	PA2211-RHDHV-North Byron Flood Advice Memo-Rev1e	Email:	Rohan.Hudson@rhdhv.com
Classification:	Confidential		

North Byron Beach Resort Development - Flood Assessment – Initial Flood Modelling

Dear Sir,

Royal HaskoningDHV (RHDHV) has been commissioned to provide flood advice to support a planning proposal for "infill" of nine (9) E4 zoned lots along Bayshore Drive on the former golf course adjacent to Elements of Byron.

Our understanding is that the North Byron Beach Resort is proposing to Byron Shire Council to lodge a planning proposal to rezone 9 lots to the north of their existing development for the purposes of an E4 Environmental Living (Residential). It is our understanding that each of the lots would contain a single dwelling (possibly with detached garage).

The site is subject to flooding in a range of flood events from the Belongil Catchment, which is heavily influenced by tailwater levels in Belongil creek, including tidal and storm surge influence, and as such, the planning proposal will be supported by an submission by RHDHV as a qualified flood engineer.

This memo provides advice on:

- A review of previous flood studies relating to the study site and Belongil Creek.
- A review of the TUFLOW model made available by BSC that was developed as part of the SMEC (2009) Belongil Creek Flood Study and used in the subsequent Floodplain Risk Management Study and Plan (BMT WBM, 2015).
- Updates to the TUFLOW model including:
    - Improvements to the applied hydrology
    - Improvements to the ground elevation data (DEM)
- An initial assessment of the potential flood impact of raising 9 building pads above the required flood planning level.

1 Review of Previous Flood Studies

A range of literature containing information relevant to flooding at the study site (Belongil Creek) was reviewed. A list of key documents is presented below.

- Belongil Creek Flood Study - PWD (1986)
- North Beach Byron Flooding and Drainage – Maunsell (2005)
- Belongil Creek Flood Study – SMEC (2009)
- Belongil Creek TUFLOW Model Review - BMT WBM (2011)
- Belongil Creek Floodplain Risk Management Study - BMT WBM (2014)
- Belongil Creek Floodplain Risk Management Plan - BMT WBM (2014)
- Belongil Estuary Protection Works Investigations – Numerical Modelling of Entrance Behaviour- Royal HaskoningDHV (2015)

2 Review of Council Flood Study Model

A review of the TUFLOW model provided by BSC for use in the flood assessment found:

- The model extent was limited by the model domain (likely required due to computation limitation when the model was originally developed). This limited model domain is presented in **Figure 1**.
- Because of the limited model extent, the hydrological inflows were incorrectly applied in the subject site which significantly influence flood conditions in the study area. The method used to apply the hydrological inflows does not correctly consider important hydrological processes and significantly over-predicts the likely sub-catchment routing that would occur in the Byron hind-dune system, that flows southward toward the study area. It also meant that hydraulic controls such as the Black Rock Road were ignored. Flows from sub-catchments 1 (area north of Black Rock Road) and 2 (area between Black Rock Road and sub-catchment 3 divider (refer **Figure 1**)) were originally introduced in the small area defined at location 2 in **Figure 1**. This previous error resulted in three times the expected flow being introduced to the site in the 100 year ARI. This error has now been corrected.
- Model elevation data was based on limited photogrammetry and 2m contour data and was not based on LiDAR data (LiDAR was only flown in 2010 so not available when the model was originally developed). The DEM used in the SMEC (2009) Flood Study model is presented in **Figure 2**, while the DEM used in the current flood assessment is presented in **Figure 3**.
- The model used a combined 100yr ARI tidal and fluvial event to simulate the 100yr ARI flood event. The peak tidal water level in the 100yr ARI model was 2.413 m AHD, which is higher than the 2.29 m AHD which is presented in BMT WBM (2011) as the current 100yr ARI tidal water level.

Figure 1: SMEC (2009) Flood Study Model Setup and Catchments

Notes:
- Red Line – Catchment Boundary
- Green Lines – Sub-catchment inflow areas
- Black Line – Model domain boundary / extent

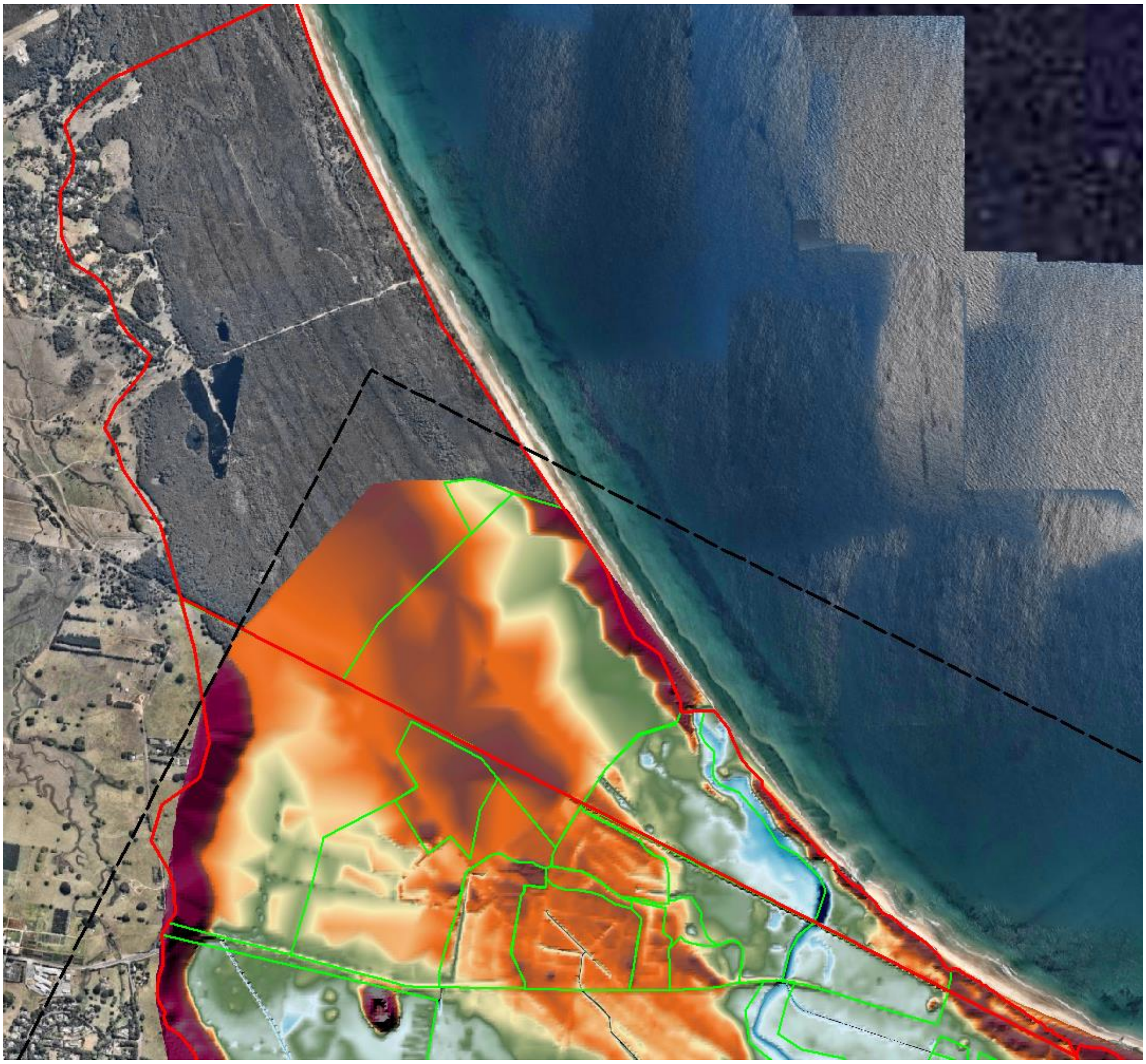

Figure 2: SMEC (2009) Flood Study Model Elevation data

3 Updates to Flood Model

Updates and improvements to the TUFLOW flood are outlined below.

3.1 Model Elevation Data

A number of sources of bathymetry/elevation data were used to create the final model including:

- Detailed ground model based on survey of the study site from Bennett & Bennett surveyors (September 2019);
- Floodplain and ground levels based on 2010 LPI LiDAR data;
- Nearshore and downstream channel bathymetry based on August 2015 survey (Bennett & Bennett);
- Belongil Creek channel and upstream bathymetry based on NSW Govt. (DPWS/OEH) survey from July 1994;

The resultant DEM used in the current flood assessment in presented in **Figure 3**.

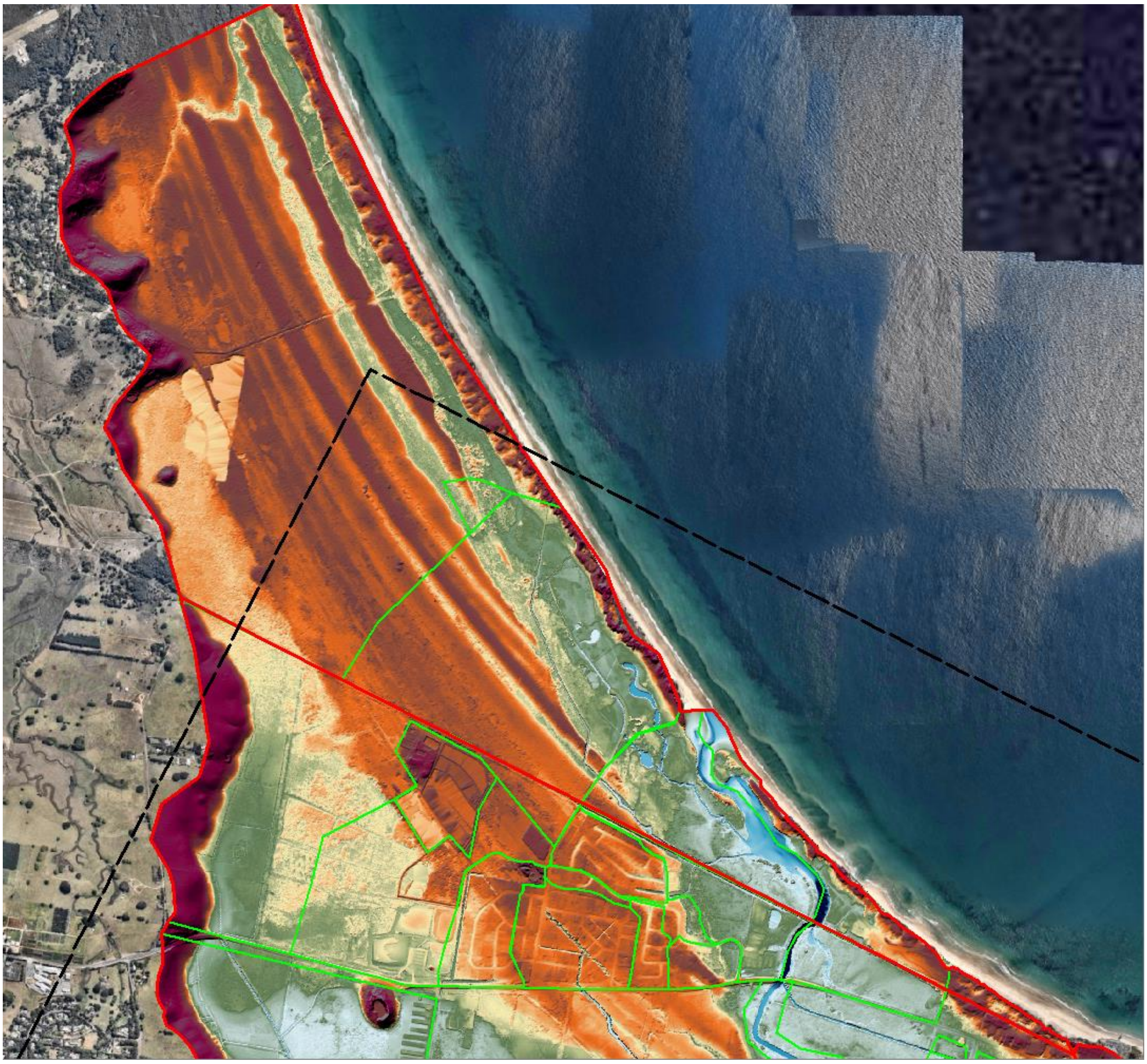

Figure 3: Updated Flood Assessment Model Elevation data

3.2 Model Structures

A number of drains and culverts specific to the study site were added to the model. Culvert inverts and sizes were based on information from BMT WBM (2013) as presented in **Figure 4** as well as data provided in the Bennett & Bennett survey files. The figure also shows the location of a number of drainage lines that were appropriately defined using z-shape model elements which ensure a continuous flow path and provide better resolution than the available LiDAR data.

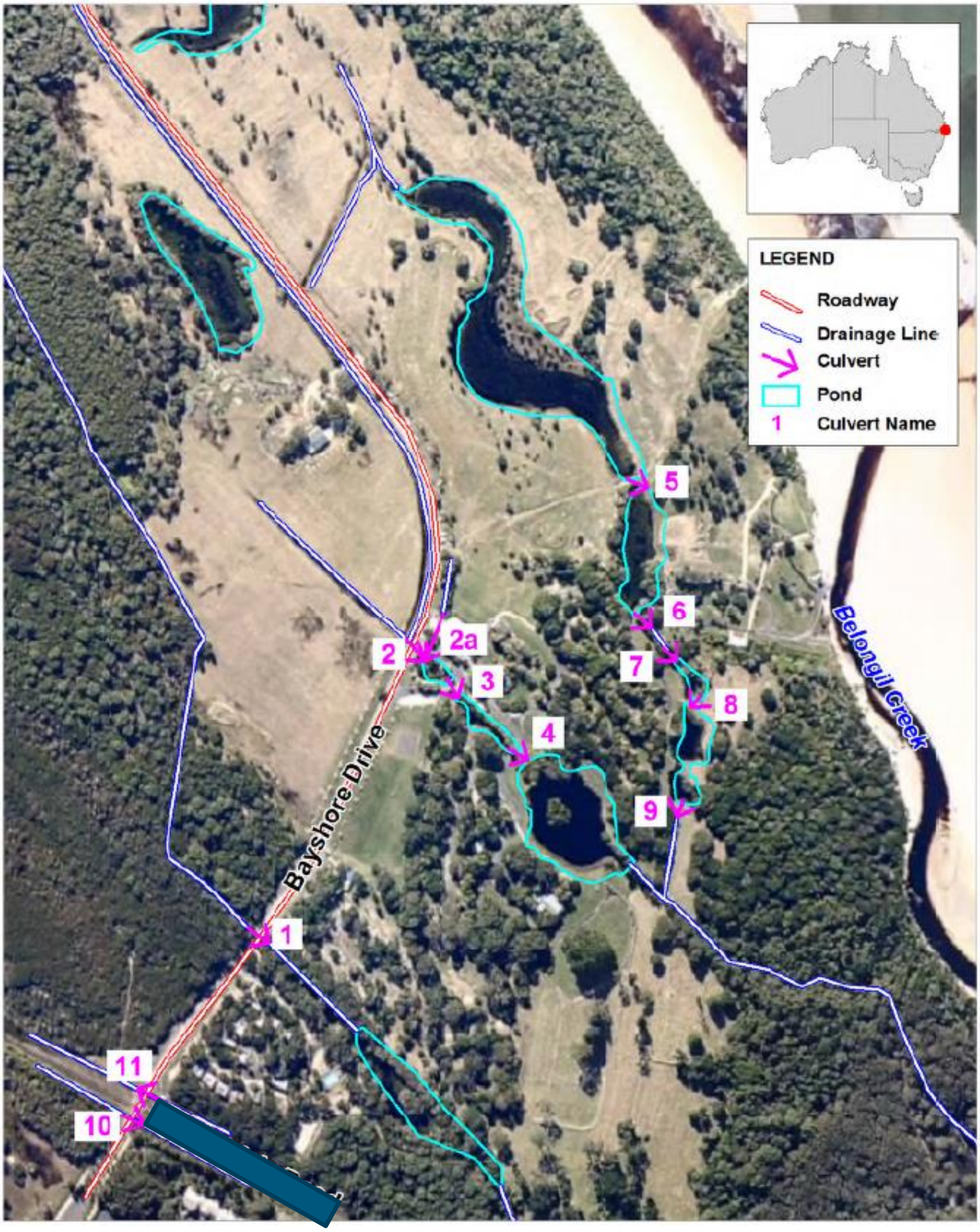

Figure 4: Location of Culverts (from BMT WBM (2013))

3.3 Model Extents and Application of Hydrologic Inflows

The model was extended to cover the full catchment extent (including the area north of Black Rock Road) as presented in **Figure 3**. While the hydrological model and provided inflows were unchanged, the method of applying the inflows was updated to provide a more realistic hydrologic input. For the two catchments north of the study site, the model was updated from the “standard SA inputs” (which inputs flow at the lowest point in the catchment), to an “SA all input” (which spreads inflow over the entire sub-catchment and is similar to a “direct rainfall” input). This is appropriate for the two sub-catchments which have a very complicated internal structure and should not be considered a single sub-catchment. The use of this hydrological input allows the hydraulic model (which includes an updated DEM) to define where the flow in these areas should go and allows the ground elevation definition to provide catchment storage.

4 Initial Flood Model Results

4.1 Peak Site Flood Levels

Peak flood levels at the site for a range of model configurations and design events are presented in **Table 1**.

Table 1: Predicted Peak Flood Levels

Model Run / Scenario / Design Event	Peak Flood Level (m AHD) *
Existing Flood Model - Base - 100yr Event (Q100 & T100)	2.62
Updated Flood Model - Base - 100yr Event (Q100 & T100)	2.35
Updated Flood Model - Base - 100yr Fluvial Only (Q100 & 0.5m Tide)	2.29
Updated Flood Model - Base - 100yr Tide Only (T100)	1.92
Updated Flood Model - 2050 - 100yr Tide Only (T100 + 0.4mSLR and 0.2m SS)	2.53
Updated Flood Model - 2100 - 100yr Tide Only (T100 + 0.9mSLR and 0.3m SS)	3.25
Updated Flood Model - Base - PMF Event (Q PMF & T100)	2.99

Notes:
- Q100 is 100yr ARI fluvial deign event
- T100 is 100yr ARI tidal deign event
- SLR – sea level rise, SS – additional storm surge (wind & wave setup)

* Please note that these results are preliminary in nature and may be subject to change following review.

4.2 Predicted Post Development Flood Impact

The model was updated to include 9 large (30x30m) building pads that were conservatively raised to 5 m AHD to allow preliminary assessment of flood impact. The assumed location of the included building pads and the predicted change in peak flood levels is presented in **Figure 5**. It should be noted that the actual location and size of the buildings will be determined at a later date, after consideration of coastal hazard and other design considerations. As the impact is caused by loss of flood storage, the actual location of the pads will have limited influence on the magnitude of the flood impact. The model predicts that the inclusion of the 9 large building pads would locally increase the peak flood levels a by maximum of 3-5 cm, and that the impact away from the proposed rezoning area the impact is less than 1 cm.

Figure 5: Location of Building Pads and Predicted Flood Impact (100yr ARI)

Notes: - black hatched areas are nine, 30 x 30m raised pads (location of the pads is preliminary with the actual location and size of the buildings to be determined at a later date after consideration of coastal hazard and other design considerations).
- orange to red is increased flood levels between 1-5 cm

4.3 Existing & Predicted Post Development Flood Hazard

The existing and predicted post development flood hazard has been assessed using the flood hazard curves proposed by Smith et al. (2014) and recommended by the Australian Emergency Management Institute (AEMI). This approach provides a range of hazard classifications which increase in severity based on the safety threat posed to vehicles, people and buildings. These classifications and the corresponding flood hazard curves are shown in **Figure 6**.

The existing 100yr ARI flood hazard is presented in **Figure 7**and shows that the proposed development area is defined as an H3 hazard area. The predicted post development flood hazard is presented in **Figure 8** and shows that the proposed building pads would not results in a noticeable change to the hazard classification. The existing flood hazard for the PMF event is presented in **Figure 9** and shows that the proposed development area is now an H4 hazard area, however, given the PMF level is only 3.00 m AHD and the likely flood planning level is ~3.1 m AHD floor level will be above the PMF level which should reduce any potential issues associated with flood evacuation.

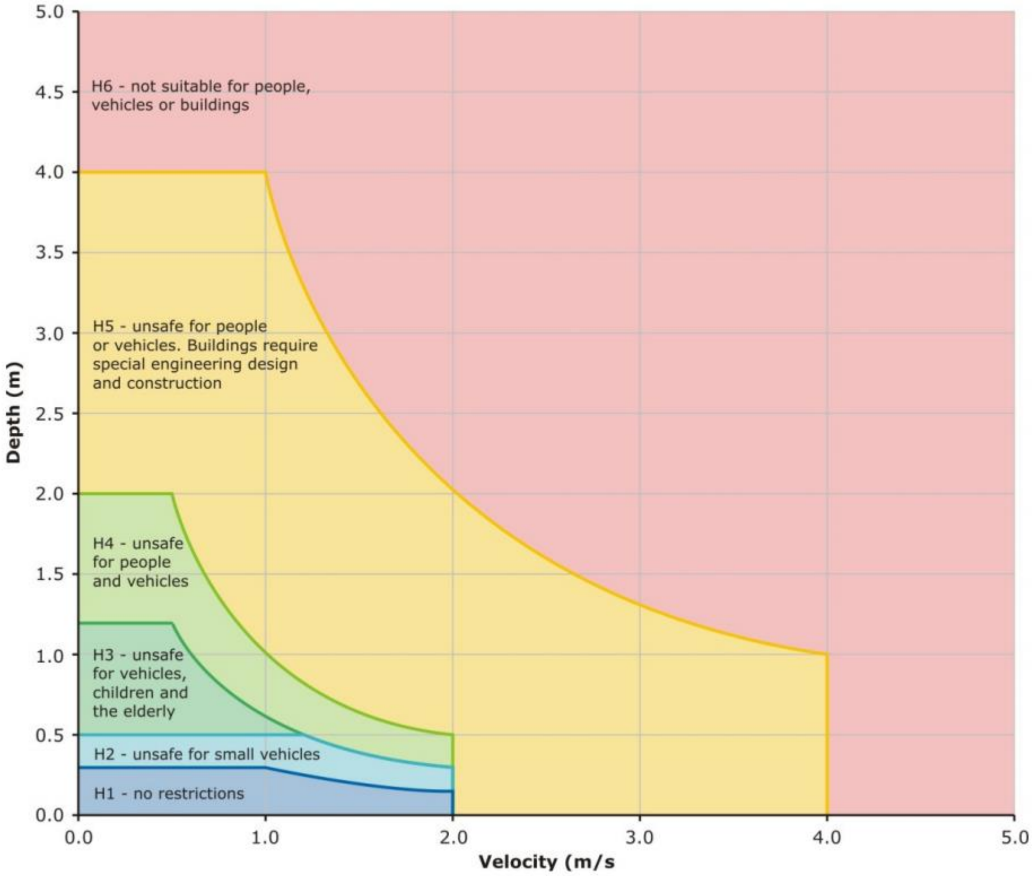

Figure 6: *Combined Flood Hazard Curves*

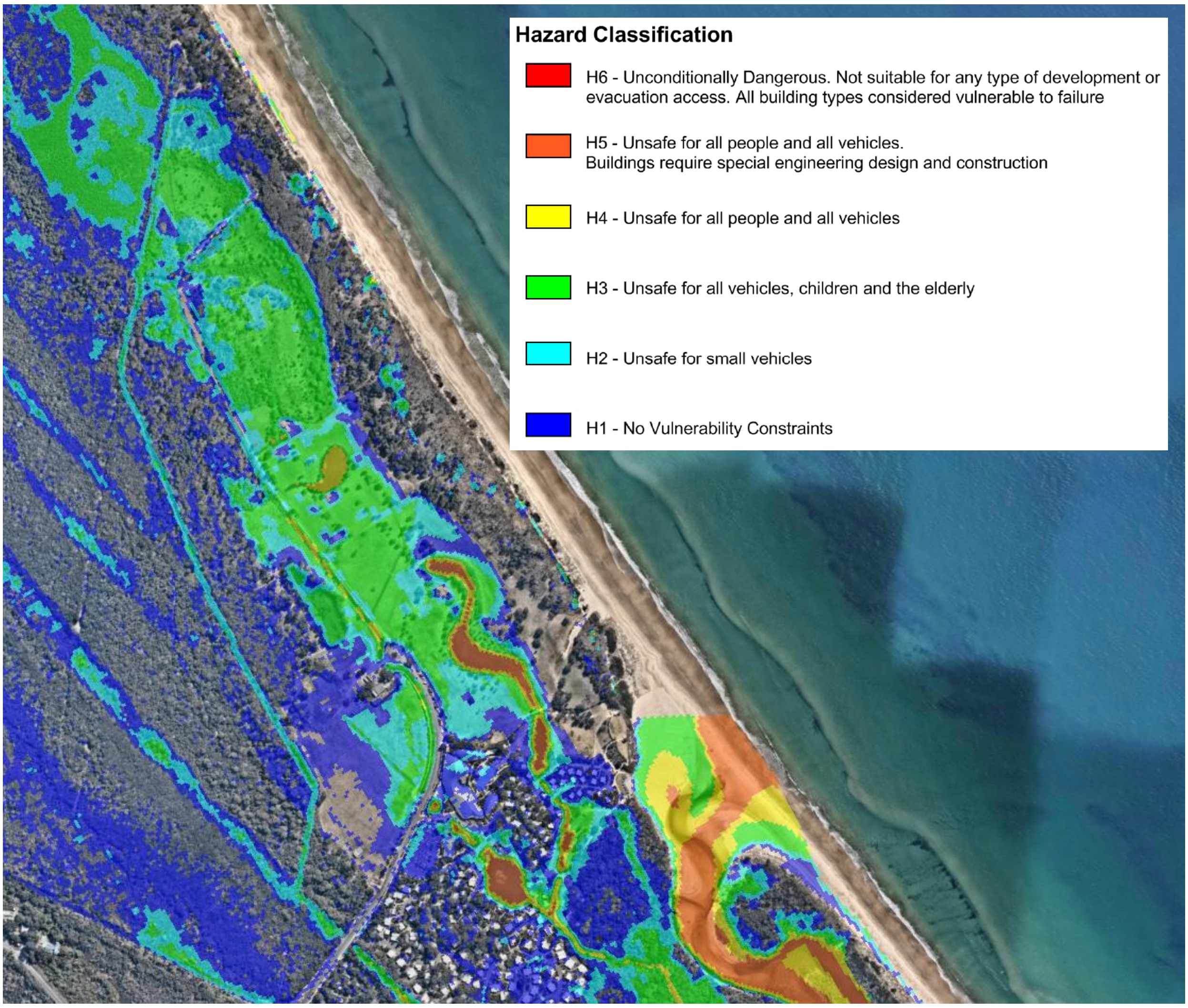

Figure 7: *Existing 100yr ARI Flood Hazard*

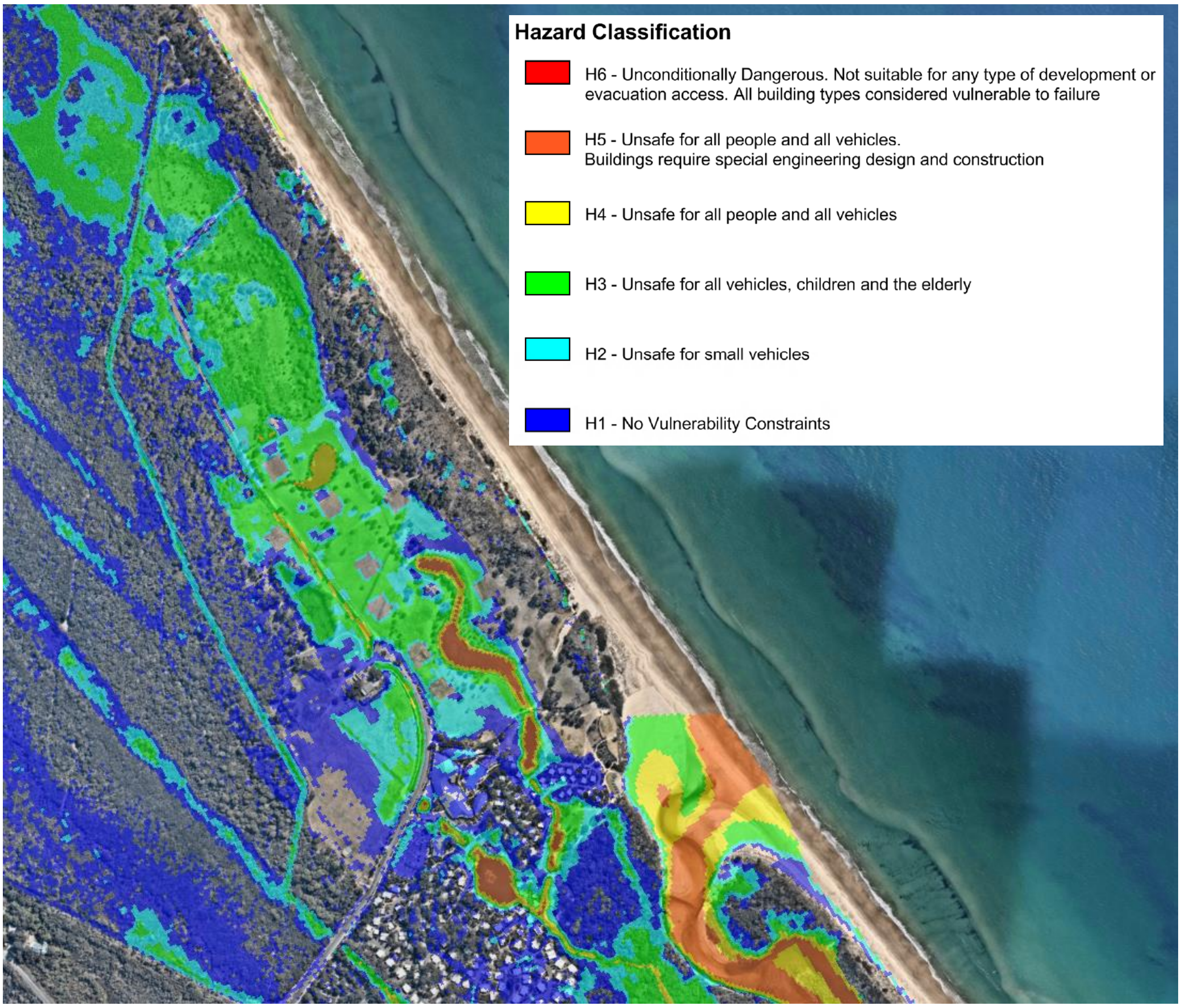

Figure 8: *Predicted Post Development 100yr ARI Flood Hazard*

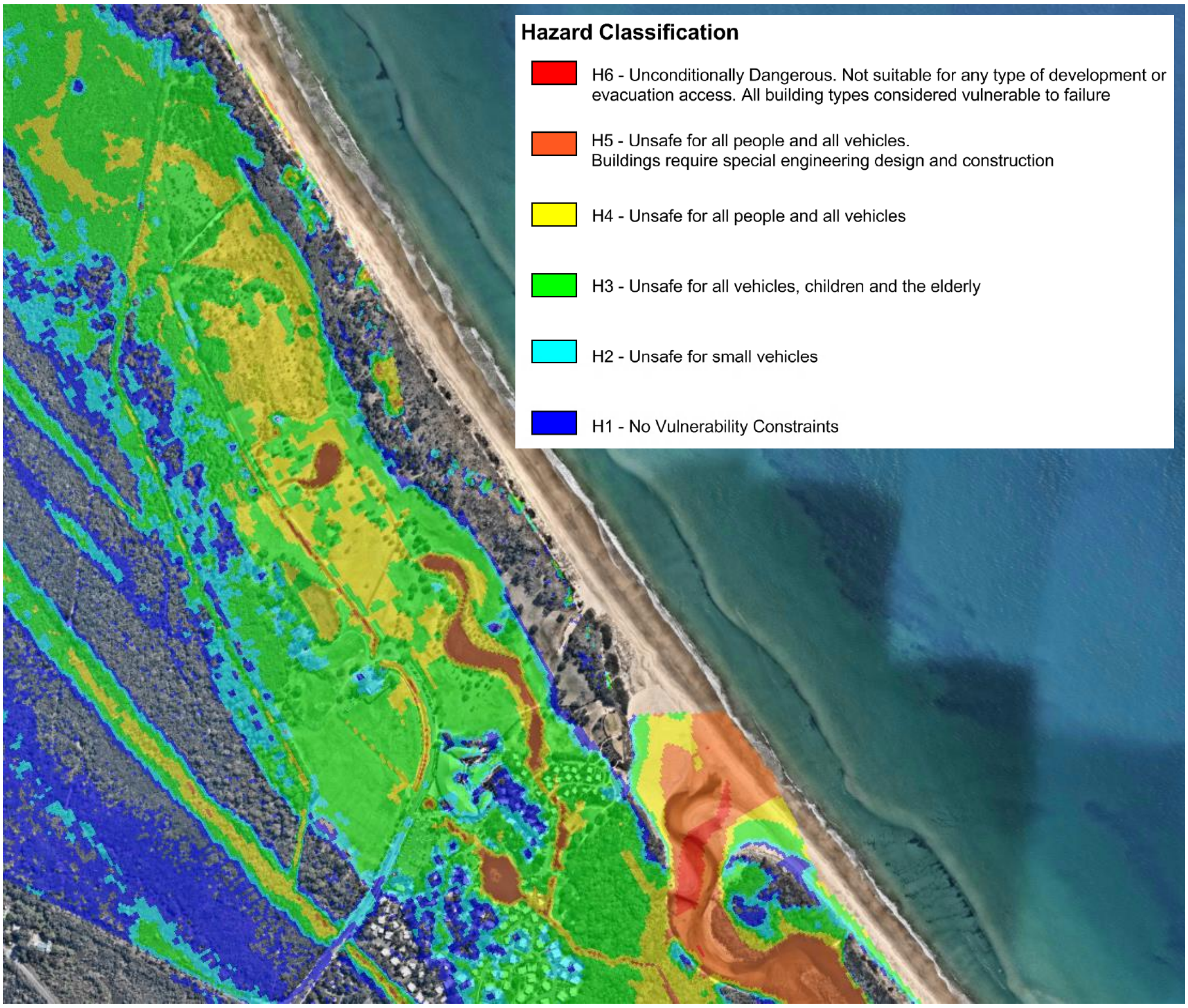

Figure 9: *Existing PMF Flood Hazard*

5 References

BMT WBM (2011) 'Belongil Creek Floodplain Risk Management Study and Plan, TUFLOW Model Review', October 2011.

BMT WBM (2013) 'North Beach Byron Flood Impact Assessment', Attachment 5 of Appendix G of DA for the establishment of resort Central Facilities at the North Byron Beach Resort, September 2013.

BMT WBM (2014a) 'Belongil Creek Floodplain Risk Management Study', Draft, August 2014.

BMT WBM (2014b) 'Belongil Creek Floodplain Risk Management Plan', Draft, August 2014.

BMT WBM (2015) 'Belongil Creek Floodplain Risk Management Study', Summary, March 2015.

DHI (2002) 'Design Ocean Levels Analysis – Belongil Creek, Byron Bay, Report of Maunsell Pty Ltd, December 2002.

Maunsell (2005) 'North Beach Byron Flooding and Drainage'

PWD (1986) 'Belongil Creek flood study', Report No. L.I.107

Royal HaskoningDHV (2015) 'Belongil Estuary Protection Works Investigations – Numerical Modelling' Report for North Byron Beach Resort, October 2015.

SMEC (2009) 'Belongil Creek Flood Study', Final Report, for Byron Shire Council, November 2009.

Should you have any queries regarding this technical memo, please do not hesitate to contact Rohan Hudson on 4926 9506 or Ben Patterson on 4926 9503.

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Classification:	Confidential		

North Byron Beach Resort Development - Flood Assessment

Dear Sir,

Royal HaskoningDHV (RHDHV) has been commissioned to provide a review of recent changes to flood planning guidance and to advise h

ow the new planning guidelines may impact previous flood advice to support a planning proposal. The planning proposal is to rezone land on Bayshore Drive from a number of current zones to E4 “Environmental Living”. A future subdivision will the be lodged to create 9 lots from the existing 4.

The previous flood advice was provided the on the 5th November 2019.

The previous planning proposal received Gateway Determination of 8/3/2021. It should be noted that the new planning guidance described in this memo will not apply to proposals that have already received Gateway Determination.

This memo provides advice on:

- A review of change to planning guidelines regarding flood planning levels
- How potential changes to Byron Shire Councils adopted flood planning level could impact the proposed development of the sites located along Bayshore Drive.

1 Review of Recent Changes to Flood Planning Levels

The Department of Planning, Industry and Environment has updated a package of materials relating to the management of flood-prone land. The materials are:

- a new planning circular: Considering flooding in land use planning: guidance and statutory requirements (and revoking the existing planning circular PS 07-003),
- a new guideline: Considering Flooding in Land Use Planning (2021) (and revoking the Guideline on Development Controls on Low Flood Risk Areas),

- an amendment to clause 7A of Schedule 4 to the Environmental Planning and Assessment Regulation 2000. The changes will simplify the notation to advise of flood-related development controls up to the flood planning area (clause 7A(1)) or between the flood planning area and the PMF (clause 7A(2)),
- two standard instrument local environmental plan (LEP) clauses which introduce flood- related development controls (one mandatory, one optional),
- a SEPP amendment to replace councils existing flood planning clause with the new mandatory standard instrument clause, and
- a revised local planning direction regarding flooding issued under section 9.1 of the Environmental Planning and Assessment Act 1979 (the Act).

The flood-prone land package will come into effect on 14 July 2021, but as previously noted it does not apply to land with Gateway Approval.

The updated flood-prone land package will allow councils to apply appropriate controls for flood risk as assessed through the floodplain management process outlined in the Floodplain Development Manual.

The new package will ensure both existing and future community are more resilient to flooding through addressing flood risk appropriately, as not all flood risk is the same for the same probability flood event and this needs to be taken into consideration when undertaking land-use planning.

The 2007 Planning Circular for Flood-Prone Land no longer aligns with the NSW Government's approach to flood risk management. The 2007 Planning Circular provided advice to councils on the Guideline on Development Controls on Low Flood Risk Areas, Ministerial Direction No. 4.3, and the Environmental Planning and Assessment Regulation 2000 clauses relating to notations on planning certificates.

The 2007 package has restricted councils in NSW from applying residential development controls on land between the 1% Annual Exceedance Probability (AEP) and the Probable Maximum Flood (PMF). As a result, development has occurred in floodplains, above the 1% AEP but below the PMF, with limited or no flood-related development controls to manage the risk or build flood resilience into communities. This poses a risk to the physical and economic safety of communities, results in less resilient communities and creates an increasing risk to the NSW Government when extreme floods occur.

The revised flood-prone land package allows a more contemporary approach to better manage flood risk beyond the 1% AEP, including building greater resilience to the effects of climate change. The update package addresses the key concerns over the safety of people, the management of potential damage to property and infrastructure, and the management of the cumulative impacts of development, particularly on evacuation capacity.

The below points detail where the flood planning clause applies:

- The flood planning clause applies to land within the Flood Planning Area (FPA), being land below the Flood Planning Level (FPL). The FPL is generally a combination of the Defined Flood Event (DFE) plus a freeboard.
- The DFE is selected by council, (through the FRM process outlined in the Floodplain Development Manual) as the basis for limiting the likelihood of exposure to flooding and associated risks to life and property damage.
- The manual identifies the 1% AEP flood event, or an equivalent historic flood, as an appropriate starting point for determining the FPL.

- The manual allows councils to select a rarer (i.e. more extreme) DFE to address broad scale flood impacts in consideration of the social, economic, environmental and cultural consequences associated with floods of different probabilities.
- Special flood considerations apply to land located above the FPA to the probable maximum flood (PMF).

2 Flood Planning Level Considerations for the Proposed Development

The potential impact on the proposed development, due to flood planning level (FPL) changes that Byron Shire Council (BSC) may adopt due to the NSW Department of Planning changes to the flood-prone land package (described above) is described in this Section.

2.1 Peak Site Flood Levels

Peak flood levels (as presented in Royal HaskoningDHV (2019)) at the site for a range of model configurations and design events are presented in **Table 1**.

Table 1: Predicted Peak Flood Levels

Model Run / Scenario / Design Event	Peak Flood Level (m AHD)
Updated Flood Model - Base - 100yr Event Combined (Q100 & T100)	2.38
Updated Flood Model - Base - 100yr Event Envelope (Q100 & T020)	2.28
Updated Flood Model - Base - 100yr Event Envelope (Q020 & T100)	2.29
Updated Flood Model - Base - 100yr Fluvial Only (Q100 & 0.5mAHD fixed tailwater)	2.28
Updated Flood Model - Base - 100yr Tide Only (T100)	2.04
Updated Flood Model - 2050 - 100yr Tide Only (T100 + 0.4mSLR and 0.2m SS)	2.68
Updated Flood Model - 2050 - 100yr Event Combined (Q100 & T100 + 0.4mSLR and 0.2m SS)	2.81
Updated Flood Model - 2050 - 100yr Event Envelope (Q020 & T100 + 0.4mSLR and 0.2m SS)	2.77
Updated Flood Model - 2100 - 100yr Tide Only (T100 + 0.9mSLR and 0.3m SS)	3.36
Updated Flood Model - 2100 - 100yr Fluvial & Tide (Q100 with T100 + 0.9mSLR and 0.3m SS)	3.40
Updated Flood Model – 2100 with 30% increase in rain - 100yr Fluvial+30% & Tide (Q100(+30%) with T100 + 0.9mSLR and 0.3m SS)	3.41
Updated Flood Model - Base - PMF Event (Q PMF & T100)	2.98

Notes: - Q100 is 100yr ARI (1% AEP) fluvial deign event
- T100 is 100yr ARI (1% AEP) tidal deign event
- SLR – sea level rise, SS – additional storm surge (wind & wave setup)

2.2 Existing Flood Planning Levels (2019)

The definition of the Flood Planning Levels (FPL) are Specified in the Byron LEP (2014) (which was accessed on 25/10/2019 at - https://www.legislation.nsw.gov.au/#/view/EPI/2014/297/part6/cl6.3) as below.

- **flood planning level** means the level of a 1:100 ARI (average recurrent interval) flood event plus 0.5 metre freeboard.
- ***future flood planning level*** means the level of a 1:100 ARI (average recurrent interval) flood event plus 0.5 metre freeboard, plus allowances for projected climate change to the year 2100.

The BSC DCP (2014) also states that a 2050 FPL should be applied to new dwellings in an existing residential development.

Based on the model results and the applicable freeboards, the relevant flood planning levels for the site are:

- Flood planning level (100yr ARI envelope) – 2.29 + 0.5 m = 2.79 m AHD
- Future (2100) planning level – 3.41 + 0.5 m = 3.91 m AHD
- FPL (2050) for new dwellings in an existing residential development – 2.77 + 0.5 m = 3.27 m AHD

2.3 Potential Flood Planning Levels (2021)

Potential flood planning levels adopted by BSC due to the NSW Department of Planning changes to the flood-prone land package (described above) mean that events greater than the 1% AEP, and potentially up to the PMF require consideration. It should be noted that while the new flood-prone land package indicates that a Defined Flood Event (DFE) larger than the 1% AEP may be adopted by Council, it does not provide definitive guidance on what freeboard Councils should adopt. Traditionally the 0.5 m freeboard was applied to account for a range of factors such as: model accuracy, the impact of wind or vehicle waves on flood levels and event, and the potential impact of climate changes. If a higher DFE is adopted, Councils may choose to apply a lower free board. However, to provide a conservative FPL, a 0.5m freeboard has been adopted in the below calculations.

In addition to consideration of events up to the PMF, the new flood-prone land package allows Councils to adopt a FPL that takes into consideration the impact of Climate Change (including sea level rise and increased intensity flood events). This means that BSC may also set a FPL based on the future (2100) flood planning level (that includes sea level rise and other considerations).

The three potential FPL for the study site include:

- Flood planning level (100yr ARI envelope) – 2.29 + 0.5 m = 2.79 m AHD
- PMF flood planning level (PMF flood & 1% AEP tide) – 2.98 + 0.5 m = 3.48 m AHD
- Future (2100) 1% AEP planning level – 3.41 + 0.5 m = 3.91 m AHD

From the above we can see that the Future (2100) 1% AEP planning level (1% AEP (+30%) Fluvial with 1% AEP Tide (+ 0.9m sea level rise and 0.3m storm surge) is 1.12m higher than the current FPL, while the PMF base FPL is 0.69m higher than the current FPL.

Given typical existing ground levels for the 9 development site is 2.0mAHD, the finished floor level (FFL) would range between ~0.8m for the current FPL up to ~1.9 m above the existing ground level. While there would be an increased fill cost associated with adopting the higher FPL and increased design requirement for accessibility (stairs, ramps & driveways), adopting the higher FPL at the study site would not prevent the proposed development of the site.

2.4 Existing & Predicted Post Development Flood Hazard

The predicted post development flood hazard has been assessed using the flood hazard curves proposed by Smith et al. (2014) and recommended by the Australian Emergency Management Institute (AEMI). This approach provides a range of hazard classifications which increase in severity based on the safety threat posed to vehicles, people and buildings. These classifications and the corresponding flood hazard curves are shown in **Figure 1**.

The predicted post development flood hazard is presented in **Figure 2** and shows that the proposed building pads would not results in a noticeable change to the hazard classification. The existing flood hazard for the PMF event is presented in **Figure 3** and shows that the proposed development area is now an H4 hazard area, however, given the PMF level is only 3.00 m AHD and the applicable flood planning level is potentially 3.91 m AHD, floor levels will be above the existing PMF level which should reduce any issues associated with flood evacuation as refuge in place can be adopted.

The predicted post development flood hazard for the 2100 climate change conditions (2100 SLR with 30% increase in rainfall) is presented in **Figure 4**. While the pads raise the buildings out of the floodplain, if pads were not used, the area is subject to H4 hazard which does not require specialist building engineering design consideration for flooding conditions.

The predicted post development 100yr ARI flood hazard for the 2050 climate change conditions (2050 SLR) is presented in **Figure 5**. While the pads raise the buildings out of the floodplain, if pads were not used the area is subject to H3 hazard which does not require specialist engineering design consideration and while considered unsafe for elderly people or children is considered safe for adults to wade through.

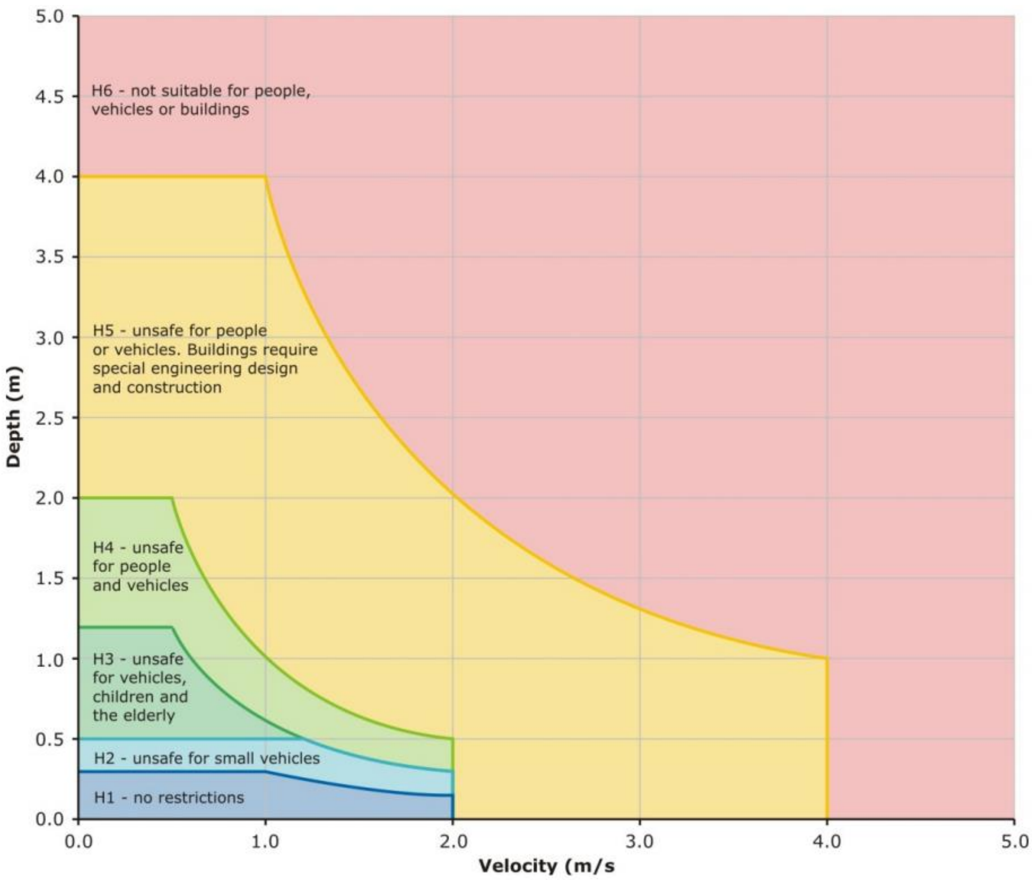

Figure 1: *Combined Flood Hazard Curves*

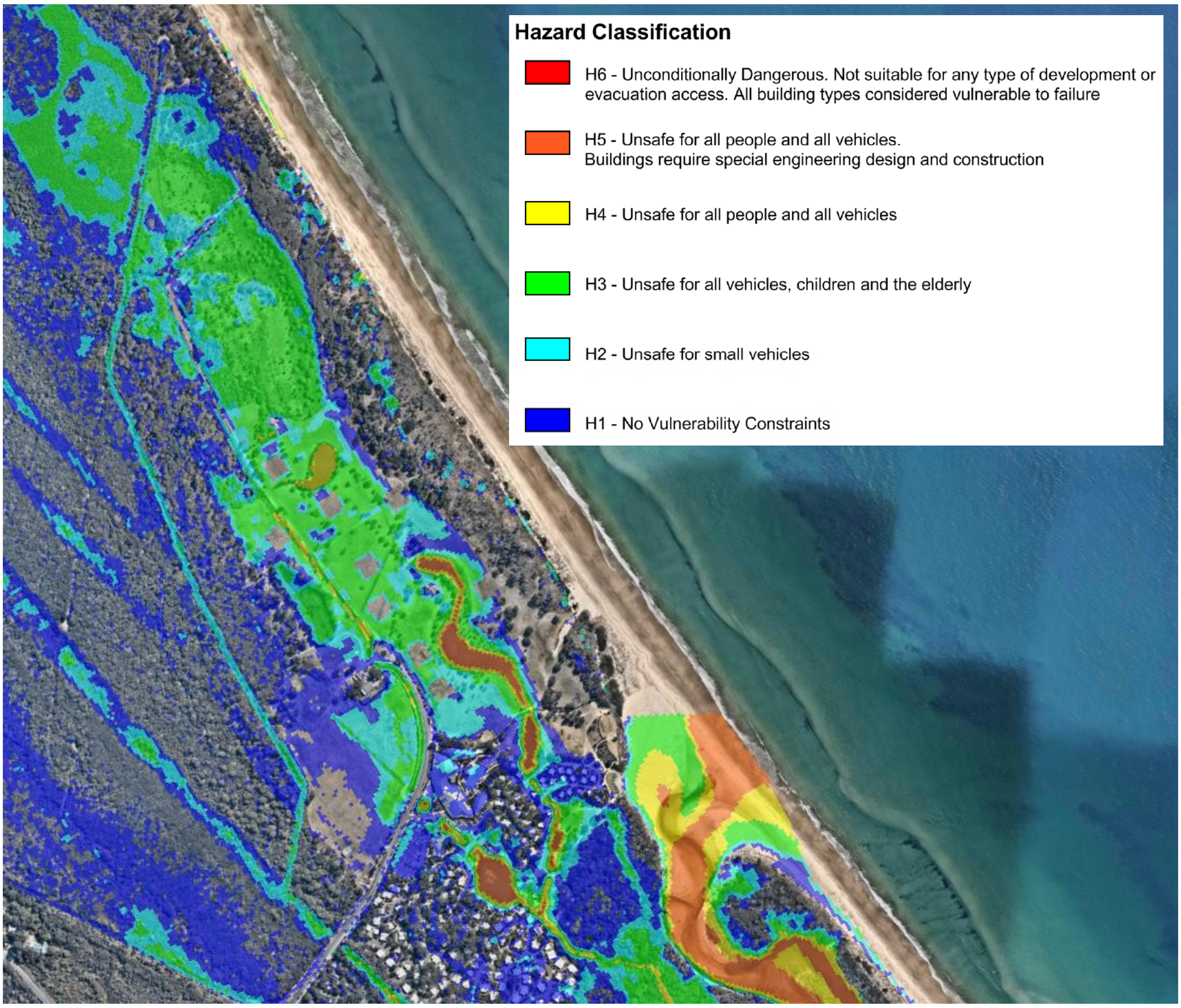

Figure 2: *Predicted Post Development 100yr ARI Flood Hazard*

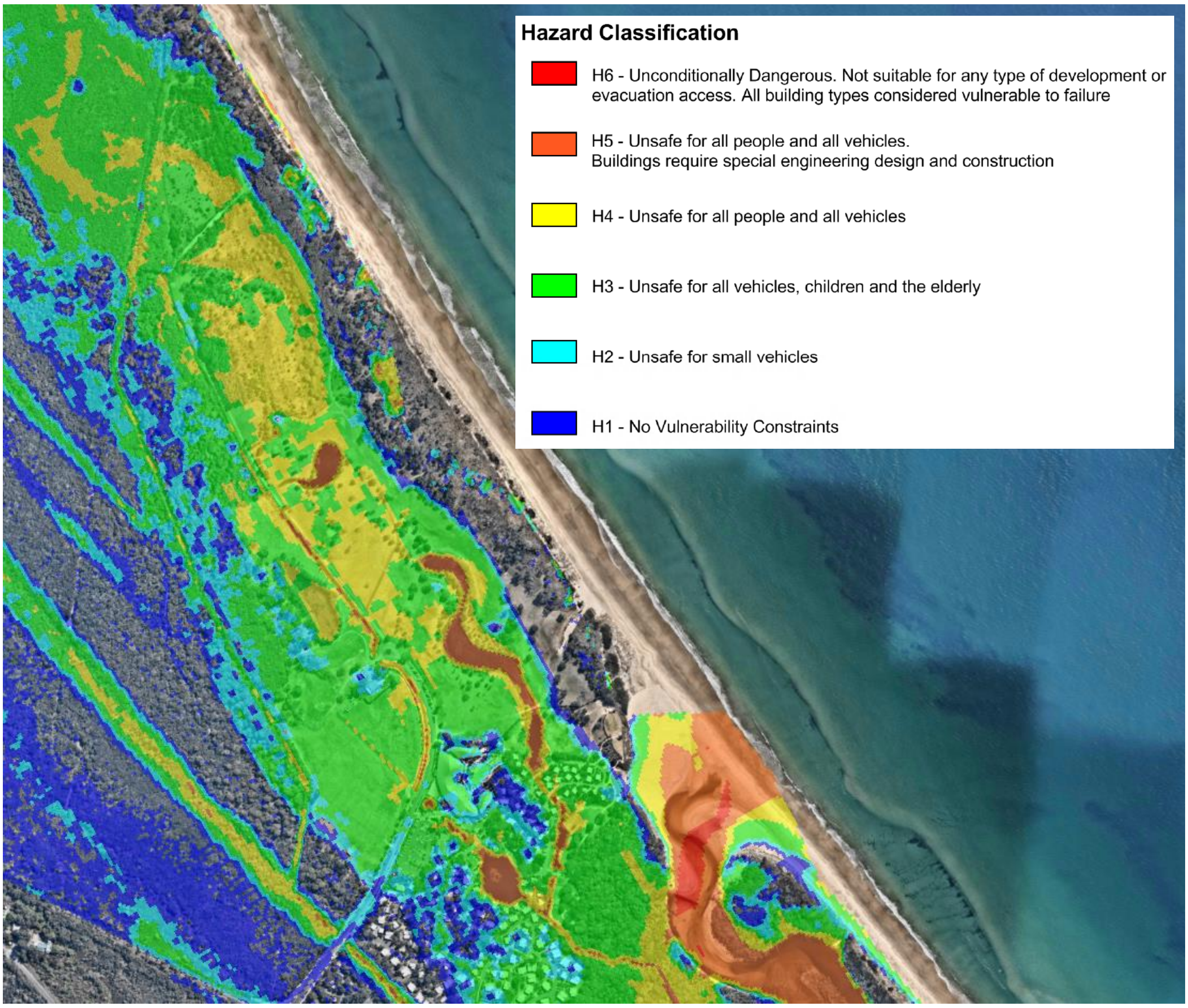

Figure 3: *Existing PMF Flood Hazard*

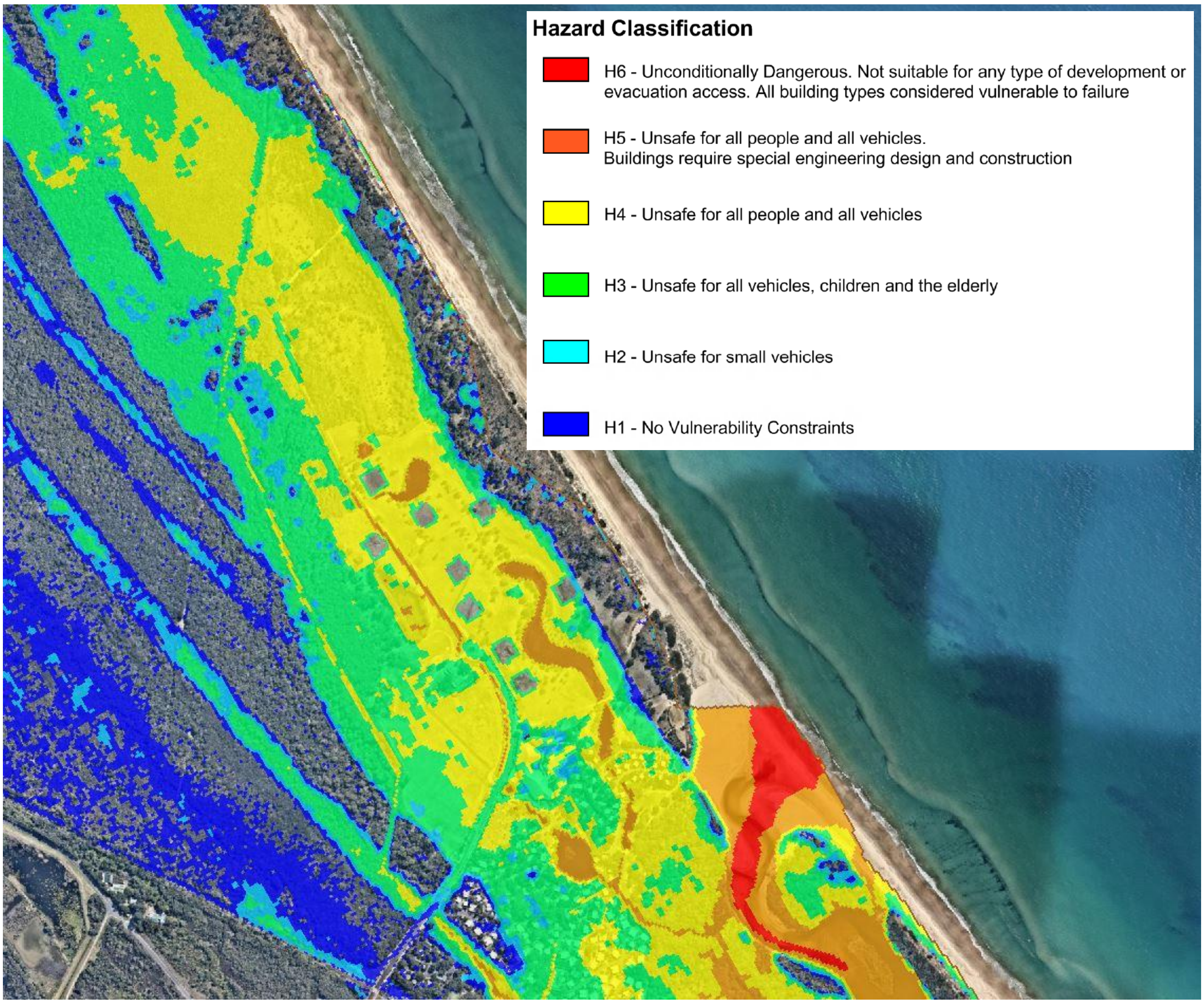

Figure 4: *100yr ARI with 30% rainfall and 2100 SLR - Flood Hazard*

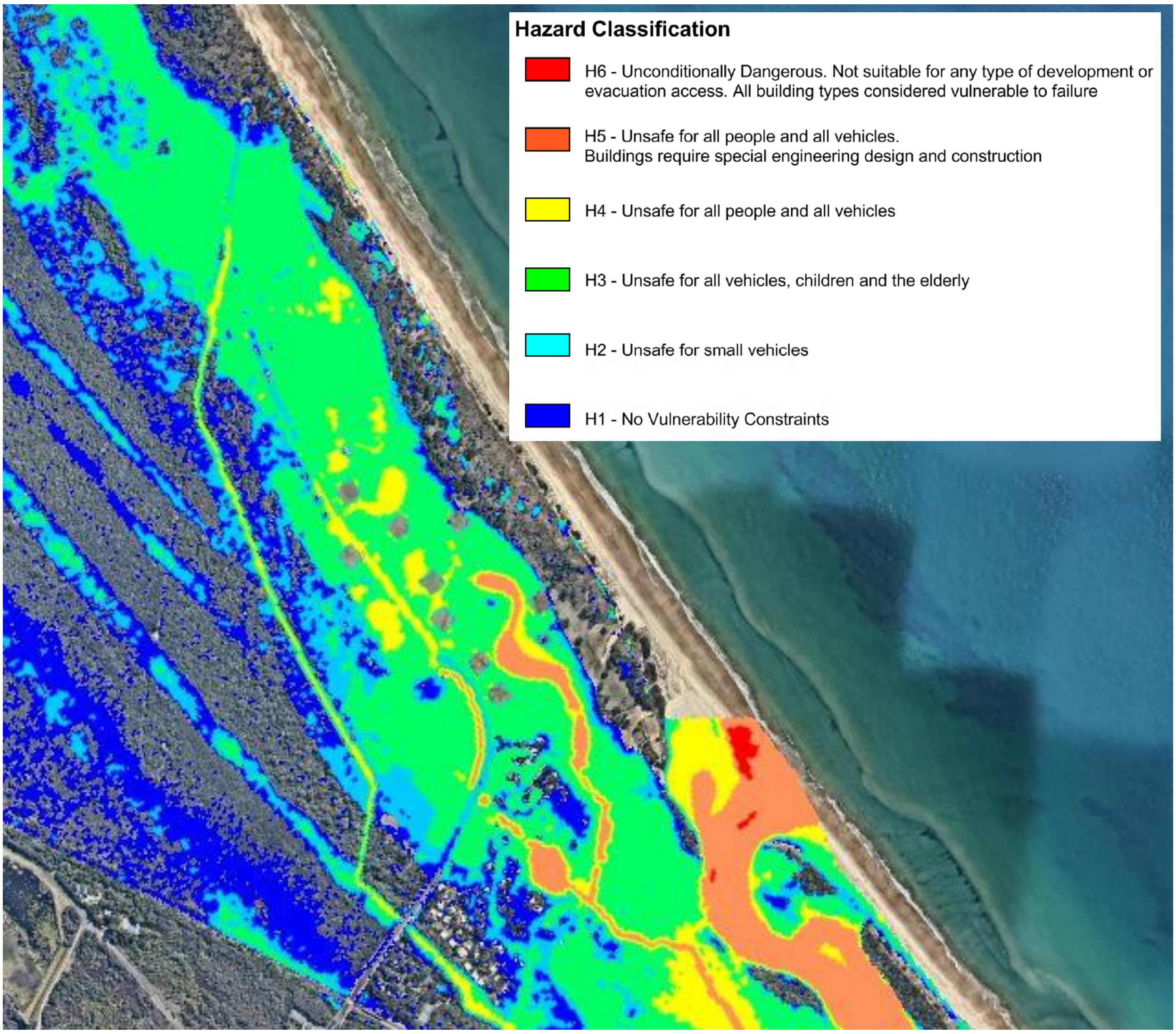

Figure 5: *100yr ARI (Q020 & T100) and 2050 SLR - Flood Hazard*

2.5 Structural Soundness and Building Components

The proposed development sites would sit above the PMF level and above the 100yr, cc2100 level. Therefore, no special flood related structural conditions are required. Even if a large fill pad was not used, because the area is a backwater, peak current speeds are very low (max 0.3 m/s) and therefore even in the future 100yr ARI 2100 conditions, Flood Hazard is only H4 (refer **Figure 6**), so no specialist engineering design for flood loadings would be required.

2.6 Evacuation Considerations

Water level versus time plots for the existing 100yr ARI combined event and the future 2100 climate change (SLR and 30% increase rainfall) are presented in **Figure 6**. The graph shows that in the proposed development area, water would rise with the tide, however, the drop in water level is limited by the downstream ground level that sits at approximately 2.2mAHD and creates a sill that reduces the rate of drainage. Below a flood level of approximately 2.2mAHD, the area is drained by the network of drainage lines and culverts. Because these culverts are quite small (typically twin 0.6 or 0.9m pipes) and the flood volume is relatively large, it may take up to a day to fully drain the last 0.3 to 0.5m of depth from the area (typically ground levels are 1.8 to 2.0 m AHD).

Given that proposed sites would sit higher than the PMF level and above the 100yr, cc2100 level, shelter in place is possible, with maximum isolation times of 4-8 hours being likely. Because the flooded area is a backwater, current speeds are very low (max 0.3 m/s) and boat rescue would be possible, if required.

The extension of Bayshore Drive northward at an elevation of approximately 2.4mAHD and the provision of slightly raised driveways (say 2.4 m AHD) could be considered to assist evacuation.

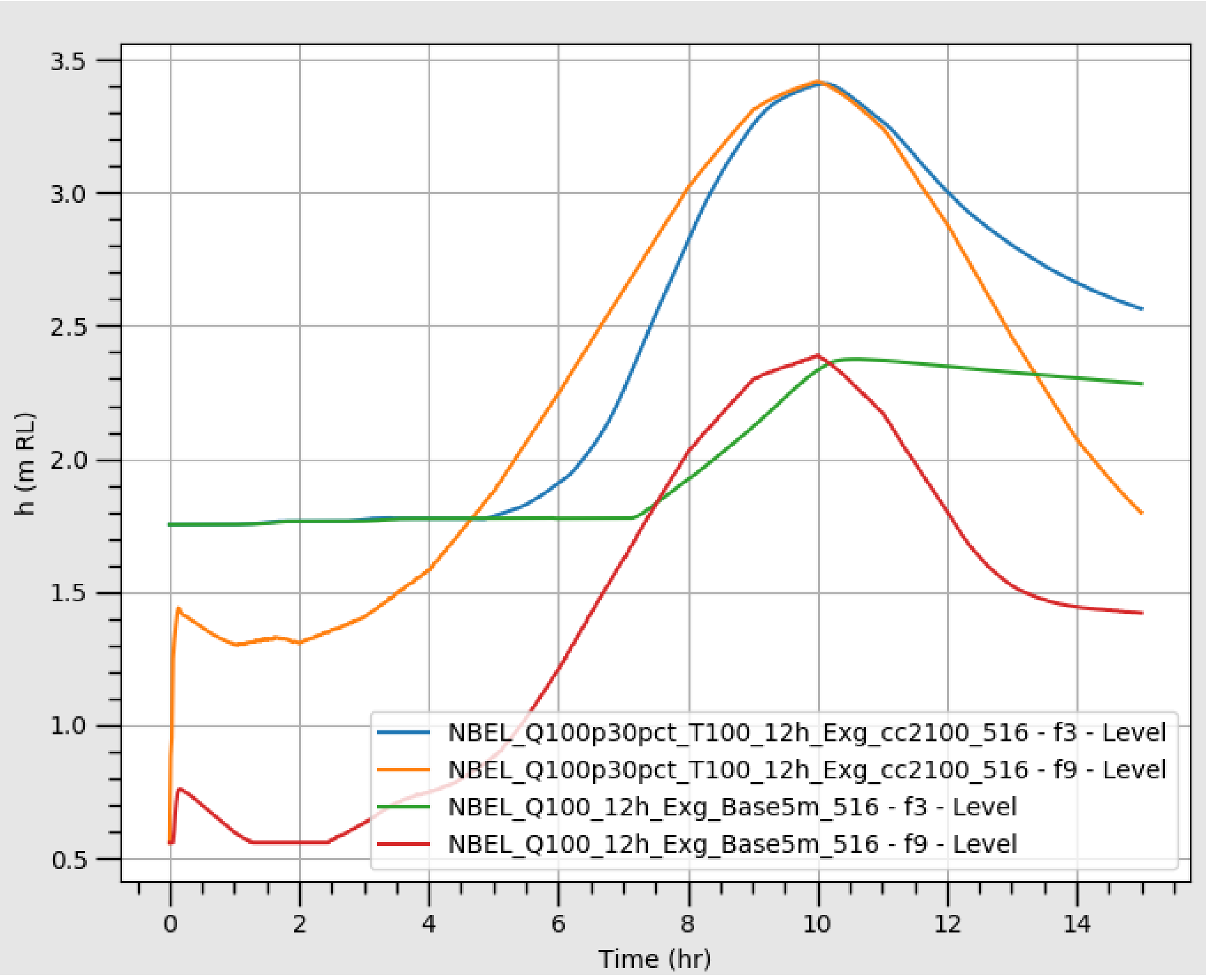

Figure 6: Water Level vs Time Plot (100yr ARI & 100yr CC2100)

Notes: - Location f3 is proposed development area, f9 is Belongil Creek entrance (i.e. tidal conditions)
- NBEL_Q100_12h (is combined Q100 & T100 existing conditions)
- NBEL_Q10030pct_T100…..cc2100 (is combined Q100 & T100 is climate change 2100 SLR with +30% rainfall)

Royal HaskoningDHV

3 Summary and Conclusions

The Department of Planning, Industry and Environment has updated a package of materials relating to the management of flood-prone land. The flood-prone land package will come into effect on 14 July 2021, but will not be applicable to planning proposals that have already received Gateway Determination.

The updated flood-prone land package will allow councils to apply appropriate controls for flood risk as assessed through the floodplain management process outlined in the Floodplain Development Manual.

Potential flood planning levels adopted by BSC due to the NSW Department of Planning changes to the flood-prone land package (described above) mean that events up to the PMF now require consideration.

It should be noted that while the new flood-prone land package indicates that a defined flood event (DFE) larger than the 1% AEP may be adopted by Council, it does not provide definitive guidance on what freeboard Councils should adopt. To provide a conservative FPL, a 0.5m freeboard has been adopted in the below calculations.

In addition to consideration of events up to the PMF, the new flood-prone land package allows Councils to adopt a FPL that takes into consideration the impact of Climate Change (including sea level rise and increased intensity flood events). This means that BSC may also set an FPL based on the future (2100) flood planning level.

The three potential FPL for the study site include:

- Flood planning level (100yr ARI envelope) – 2.29 + 0.5 m = 2.79 m AHD
- PMF flood planning level (PMF flood & 1% AEP tide) – 2.98 + 0.5 m = 3.48 m AHD
- Future (2100)1% AEP planning level – 3.41 + 0.5 m = 3.91 m AHD

From the above we can see that the Future (2100) planning level (1% AEP (+30%) Fluvial with 1% AEP Tide (+ 0.9m sea level rise and 0.3m storm surge) is 1.12m higher than the current FPL, while the PMF base FPL is 0.69m higher than the current FPL.

Given typical existing ground levels for the development site is 2.0mAHD, the finished floor level (FFL) of potential future houses would range between ~0.8m for the current FPL up to ~1.9 m above the existing ground level. While there would be an increased fill cost associated with adopting the higher FPL and increased design requirement for accessibility (stairs, ramps & driveways), adopting the higher FPL at the study site would not prevent the proposed development of the site.

If Council were to adopt a lower freeboard in conjunction with the higher defined flood event a lower finished floor level would be possible.

Flood hazard, structural and evacuation considerations have also been investigated against a higher design flood event and indicate the development is still considered feasible under these conditions.

Should you have any queries regarding this technical memo, please do not hesitate to contact Rohan Hudson on 4926 9506 or Ben Patterson on 4926 9503.

Ben Patterson
Technical Director
Rivers and Water Management – Australia

4 References

Royal HaskoningDHV (2019) ‘North Byron Beach Resort Development - Flood Assessment‘, Report for North Byron Beach Resort, November 2019.

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Classification:	Confidential		

North Byron Beach Resort Development - Flood Assessment – Hydraulic Categorisation

Dear Sir,

Royal HaskoningDHV (RHDHV) has been commissioned to provide a response to a number of flood related questions regarding the proposed North Byron Beach Resort Development on Bayshore Drive.

This memo provides information relating to the hydraulic categorisation that resulted in the site being considered a "No Development" area, in the Belongil Creek FRMS&P. The investigation presented in this memo shows that if the FRMS&P model used accurate ground elevation data and hydrology, the study site would not be considered a floodway. The updated FRMS&P model also shows that the site is considered low hazard, so using the FRMS&P criteria would be considered potentially suitable for development.

This memo should be read in conjunction with the previous flood advice that was provided the on the 5th November 2019.

A companion memo describing further sensitivity testing and validation of the updated FRMS&P model used to assess the North Byron Beach Resort development is currently being prepared.

1 Requirement to Review Hydraulic Categorisation

The NSW Department of Planning, Industry & Environment (DPIE) originally provided comment to Byron Shire Council (BSC) in a letter dated 14th February 2020, stating that according to the Belongil FRMS&P, the site sits in a "No Development" categorisation.

Byron Shire Council also raised the issue of a "No Development" categorisation for the site in an email dated 13th August 2021.

The flood assessment should specifically address Council's adopted Belongil Creek Floodplain Risk Management Study and Plan (BMT WBM, 2015). In particular, Figure 9-1 of the adopted Plan specifies the site as "No Development". Further information should be provided addressing the basis of that designation and providing justification for not following that recommendation.

The same email raised that cumulative impact also be considered.

2 Summary of Belongil FRMS&P Future Development Zones

Figure 9.1 of Belongil Creek Floodplain Risk Management Study and Plan (FRMS&P) Summary (BMT WBM, 2015) is presented below. The text states that the "No Development" area is based on either a Floodway Hydraulic Categorisation or a High hazard categorisation. Further detail is provided in Appendix H (Future Development Assessment) of the Discussion Paper Addendum, this is Discussion Paper 9 and is dated April 2013.

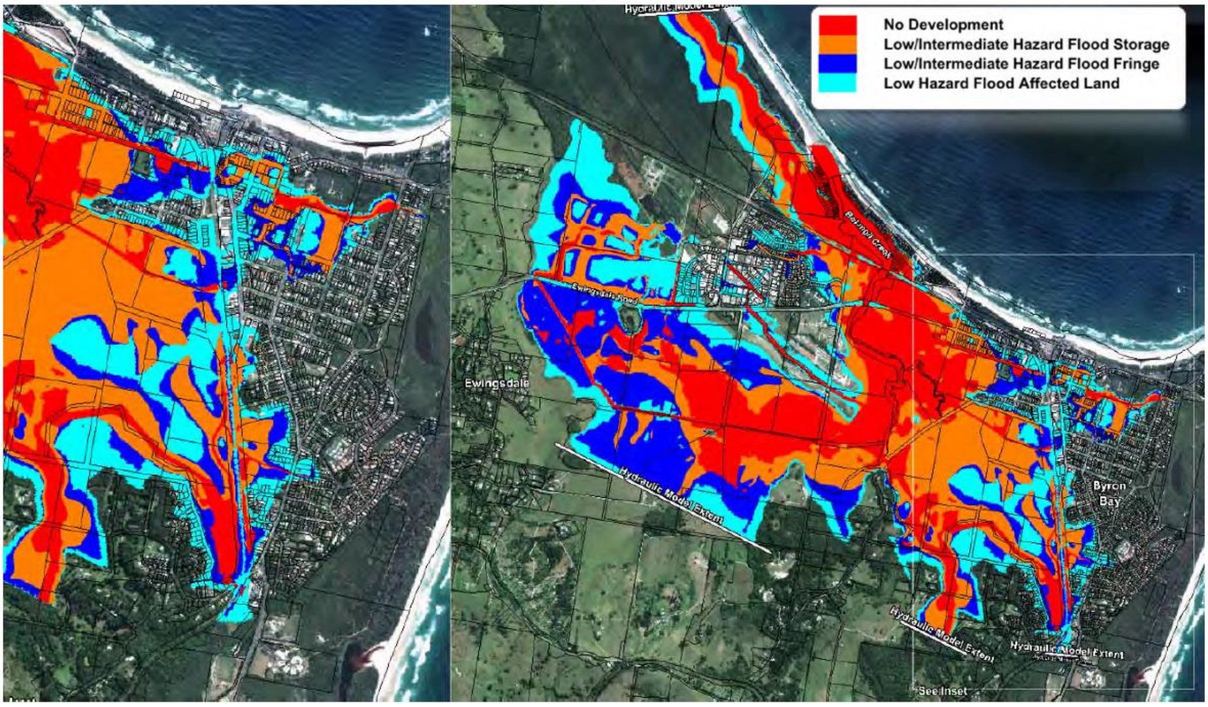

Figure 9-1 Future Development Zones

BMT WBM

Figure 1: *Future Development Zone (BMT WBM, 2015)*

The Future Development Assessment Discussion Paper (BMT WBM, 2013) provides more detail on the derivation of the "No Development" zone presented in the above figure. From the below figure we can see that the No Development zone is a combination of Floodway and High Hazard classifications, though in the area of interest, it the Floodway classification is the cause of the resulting "no development" criteria.

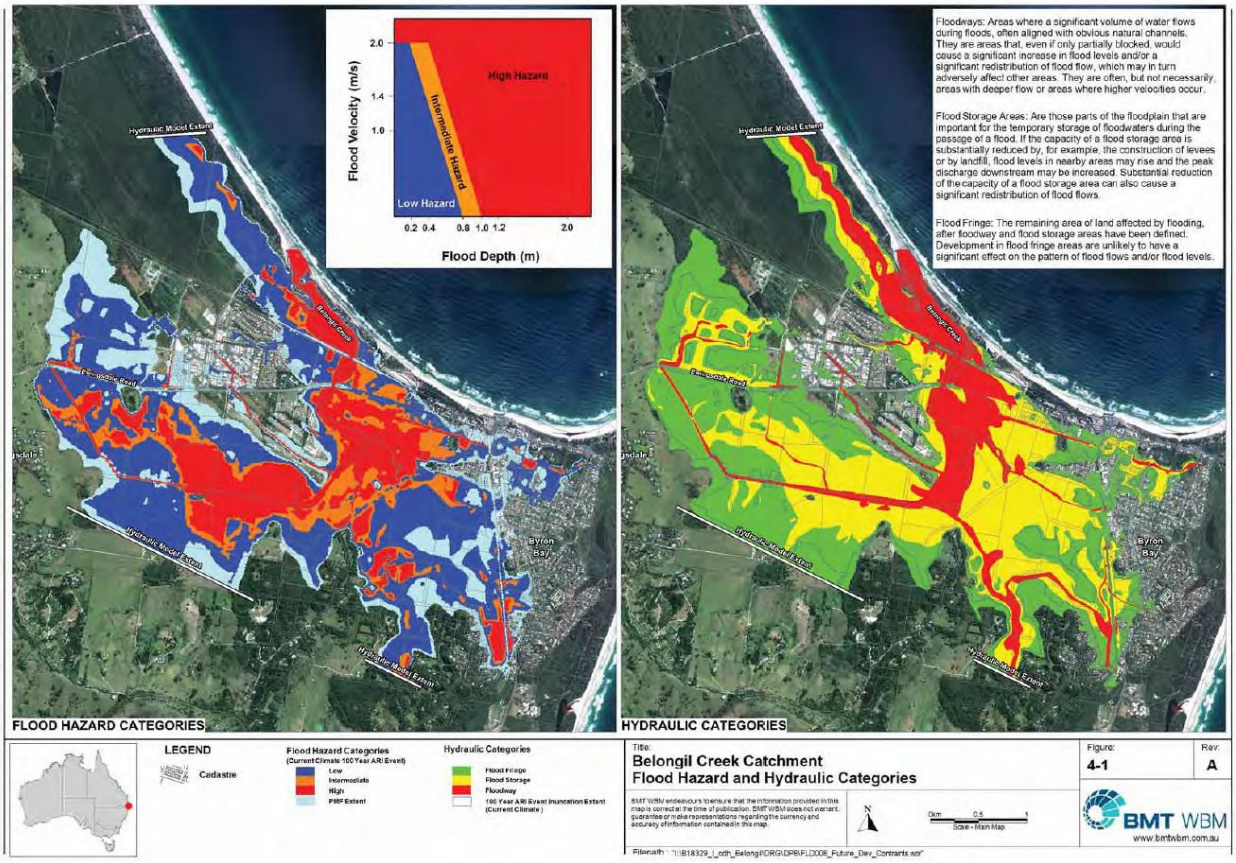

Figure 2: *Flood Hazard and Hydraulic Categories (BMT WBM, 2013)*

3 Investigation into Adopted FRMS&P Floodway Criteria

3.1 Hydraulic Categorisation

There are no prescriptive methods for determining what parts of the floodplain constitute floodways, flood storages and flood fringes. Descriptions of these terms within the Floodplain Development Manual (FDM) (NSW Government, 2005) are essentially qualitative in nature. Of particular difficulty is the fact that a definition of flood behaviour and associated impacts is likely to vary from one floodplain to another depending on the circumstances and nature of flooding within the catchment.

The hydraulic categories as defined in the Floodplain Development Manual are:

- **Floodway -** Areas that convey a significant portion of the flow. These are areas that, even if partially blocked, would cause a significant increase in flood levels or a significant redistribution of flood flows, which may adversely affect other areas.
- **Flood Storage -** Areas that are important in the temporary storage of the floodwater during the passage of the flood. If the area is substantially removed by levees or fill it will result in elevated water levels and/or elevated discharges. Flood Storage areas, if completely blocked would cause peak flood levels to increase by 0.1m and/or would cause the peak discharge to increase by more than 10%.
- **Flood Fringe -** Remaining area of flood prone land, after Floodway and Flood Storage areas have been defined. Blockage or filling of this area will not have any significant effect on the flood pattern or flood levels.

Given it can be hard to assess the above in a 2D flood model a number of simpler approaches to define flood impact categories are often used. Approaches to define hydraulic categories that are often considered include partitioning the floodplain based on:

- Peak flood velocity (m/s);
- Peak flood depth (m);
- Peak velocity * depth (sometimes referred to as discharge per unit width (m^2/s)), and;
- Combinations of the above.

3.2 Belongil FRMS&P Floodway Criteria

BMT WBM (2013) did not specify, what criteria they adopted to define the floodway. By trialling a number of different velocity depth product (v x d) criteria with the FRMS&P 100yr ARI results in GIS, it appears that a 0.15 criteria was used to define the floodway (refer **Figure 3**).

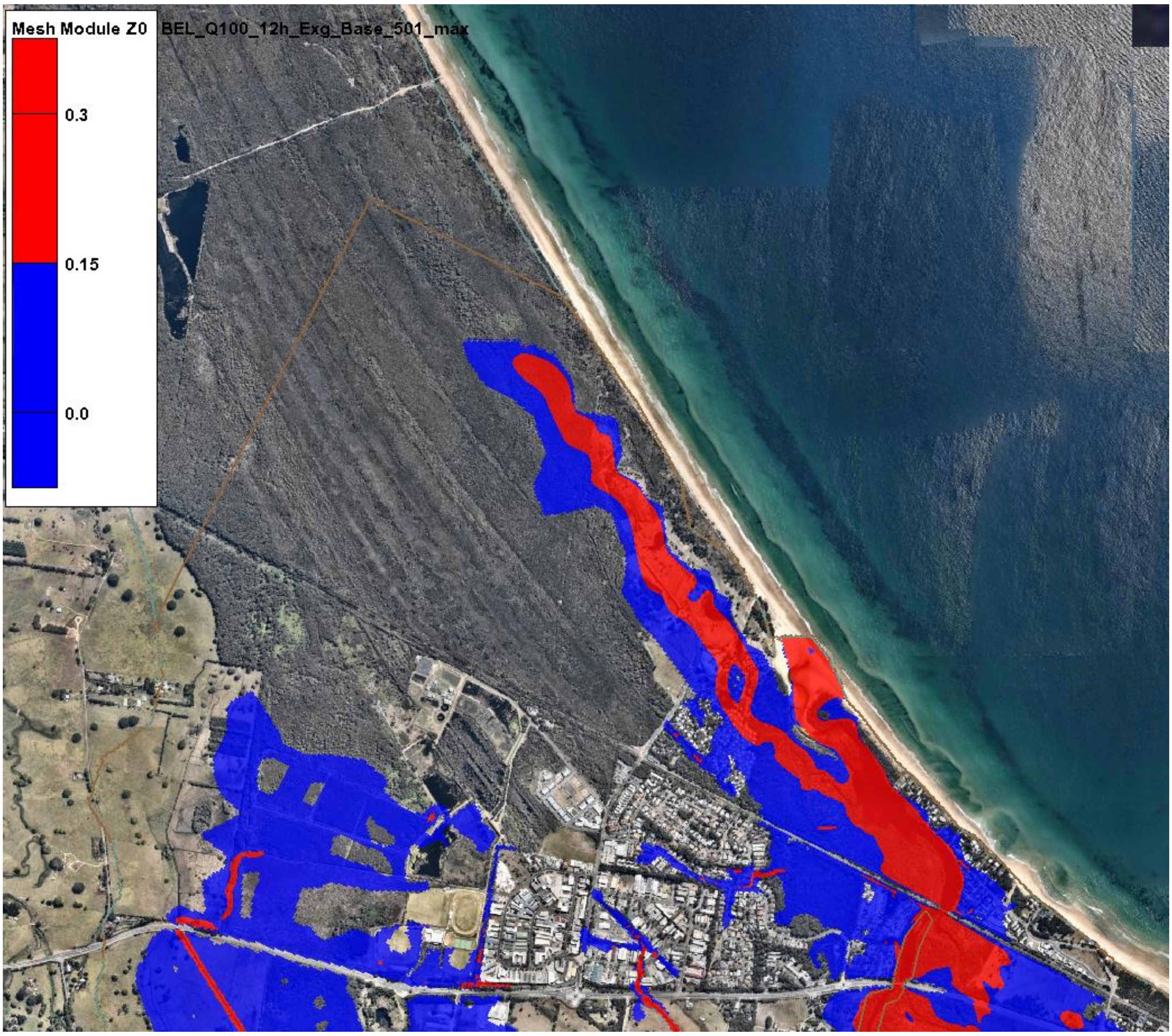

Figure 3: *Flood Way Definition using 0.15 V x D criteria and FRMS&P Model Results for Q100*

Notes: - Red area is floodway defined as areas with V x D > 0.15 m^2/s
- Blue areas are flood storage or flood fringe V x D < 0.15 m^2/s

3.3 Belongil FRMS&P Floodway Criteria with Updated Model

Applying the V x D 0.15 criteria used to define the floodway to the results from the updated model produces the results presented in **Figure 4**, which shows that the proposed development site should not be considered a floodway. The main reasons for the change in V x D product at the site is due to the use of accurate ground elevation data in the updated model and also a more appropriate hydrologic boundary. Differences between the ground elevation data used in the FRMS&P model and the updated model are apparent by comparing **Figure 5** and **Figure 6**. Differences in the models are further described in RHDHV (2019) which outline the shortcomings with the adopted FRMS&P hydrology.

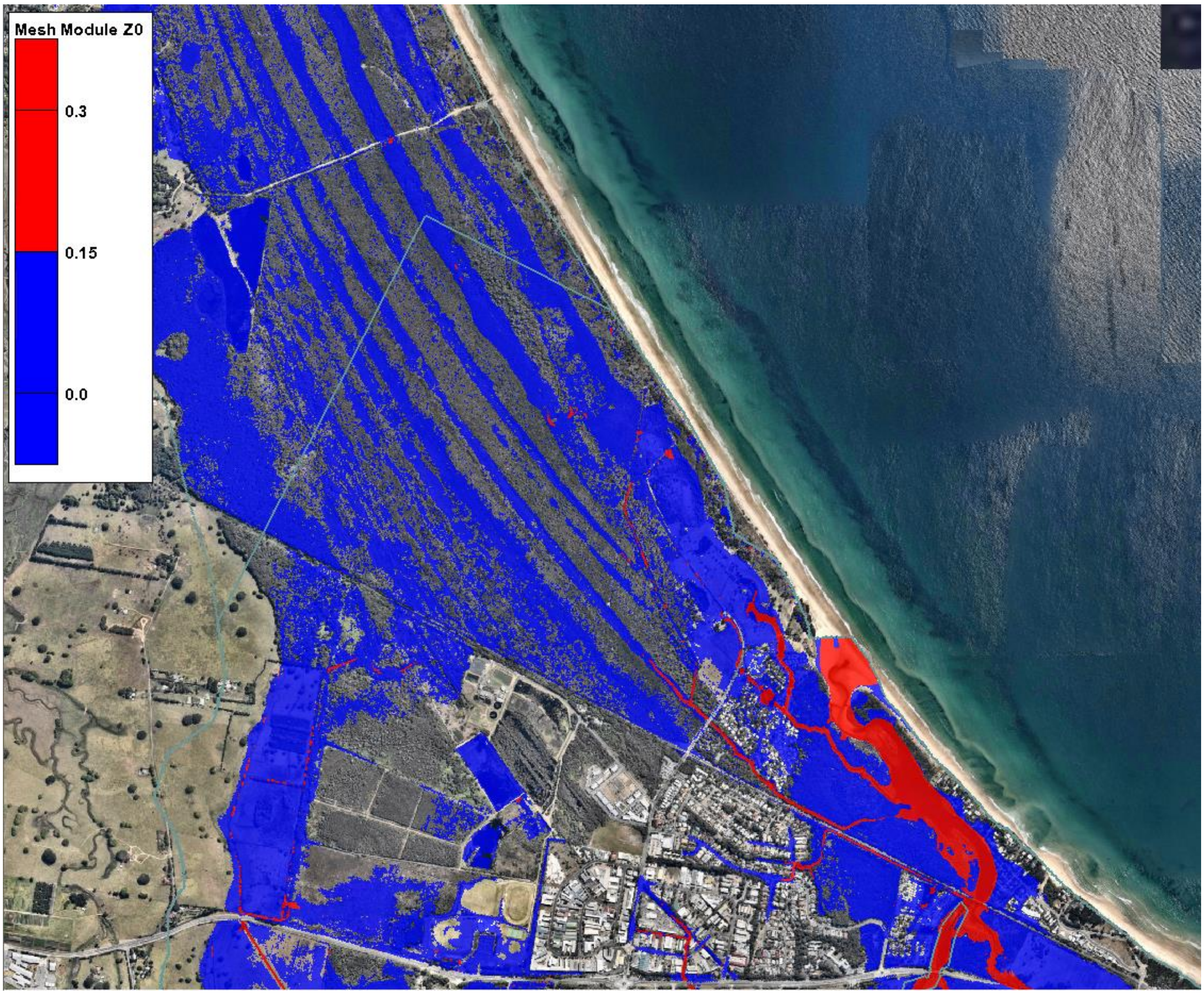

Figure 4: *Flood Way Definition using 0.15 V x D criteria and Updated FRMS&P Model Results for Q100*

Notes: - Red area is floodway defined as areas with V x D > 0.15 m^2/s
- Blue areas are flood storage or flood fringe V x D < 0.15 m^2/s

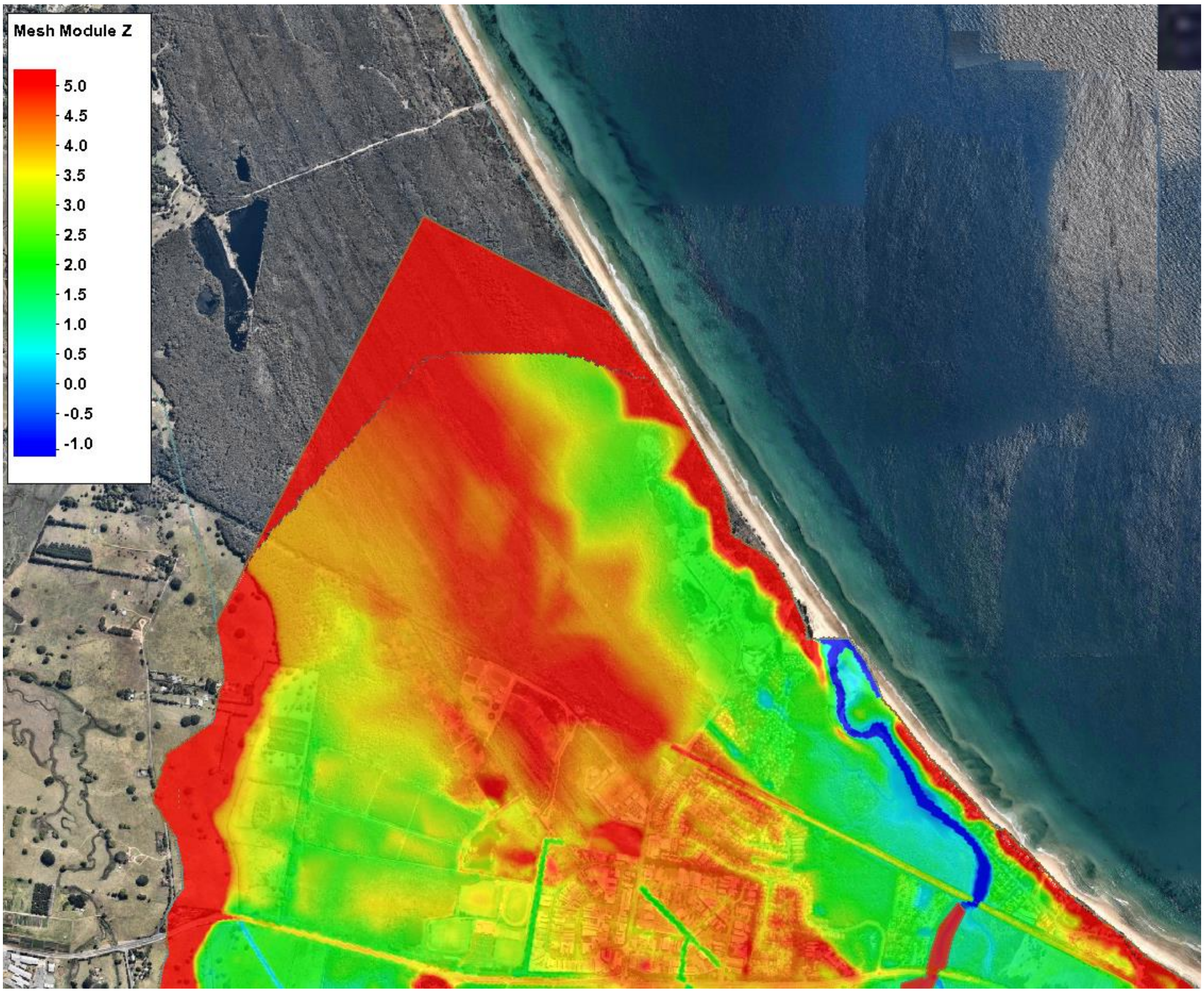

Figure 5: FRMS&P Model Elevation data

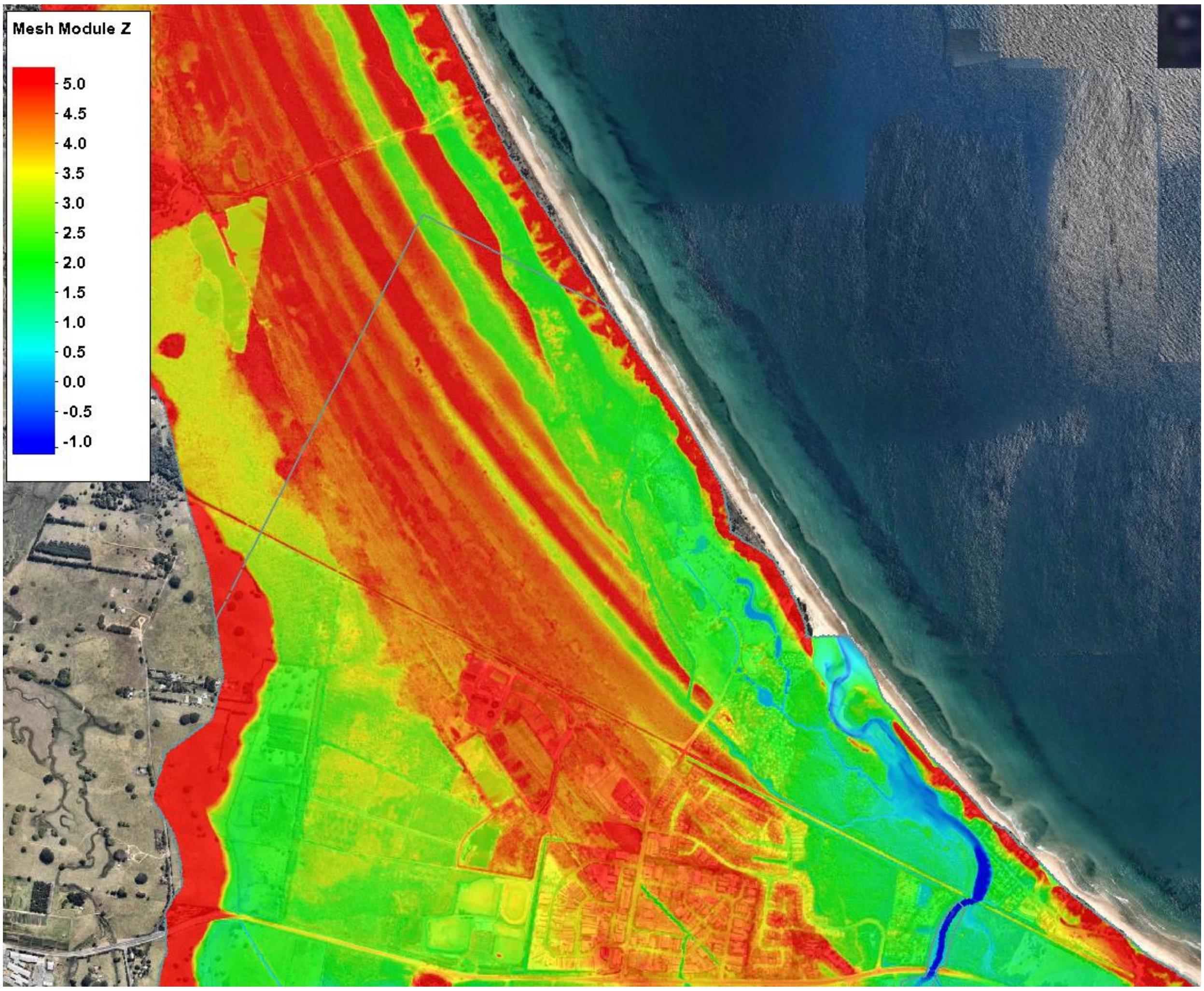

Figure 6: Updated FRMS&P Model Elevation data

4 Flood Hazard Consideration

Flood Hazard using the NSW FDM definition as adopted in the FRMS&P is presented in **Figure 7** for the FRMS&P model **Figure 8** or the updated FRMS&P model. For the updated model we can see that the only high hazard areas coincide with the existing pond areas or drainage line alongside Bayshore Drive.

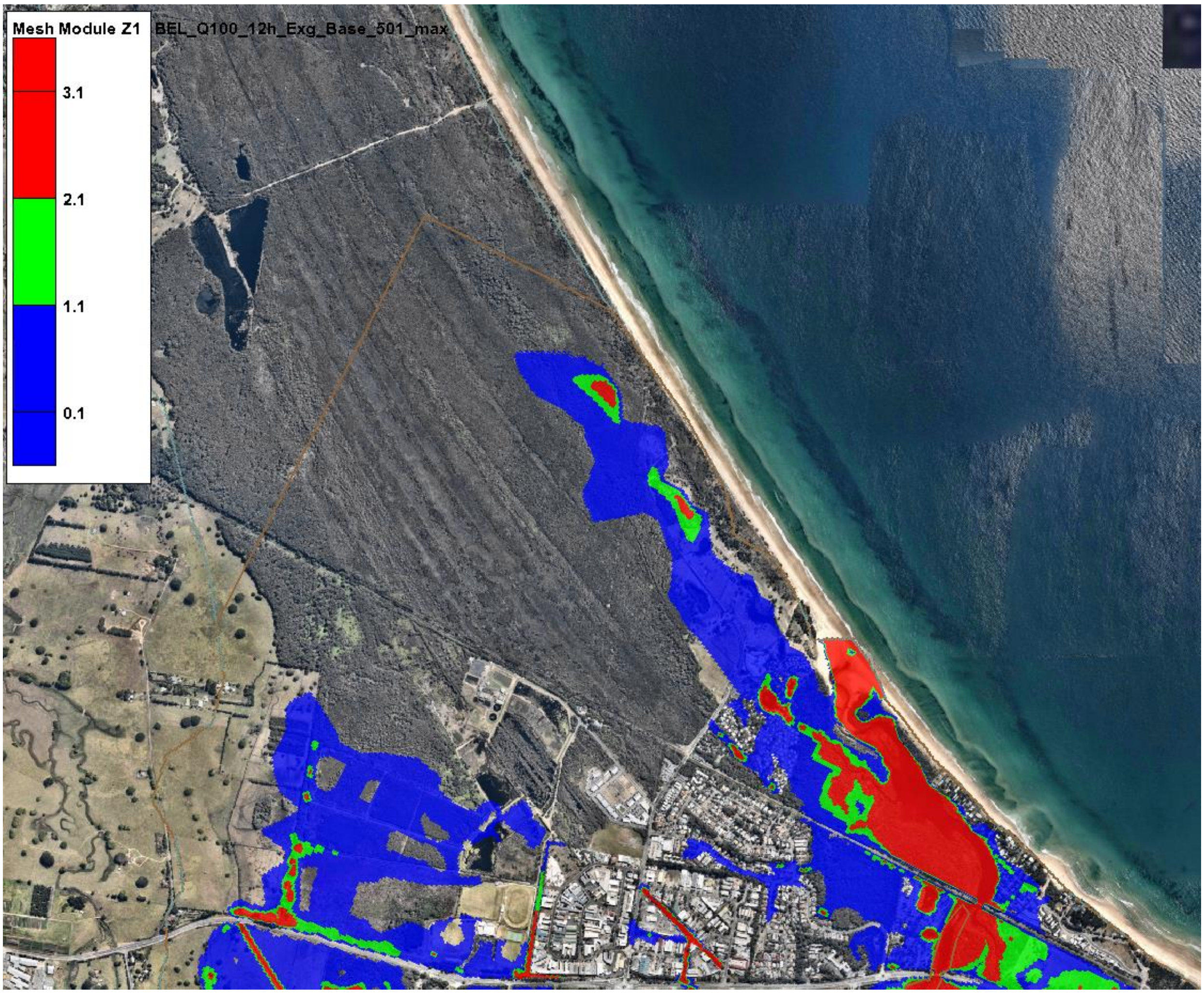

Figure 7: *NSW Flood Hazard Definition - FRMS&P Model Results for Q100*

Notes:
- Red area is high hazard
- Green area is intermediate hazard
- Blue area is low hazard

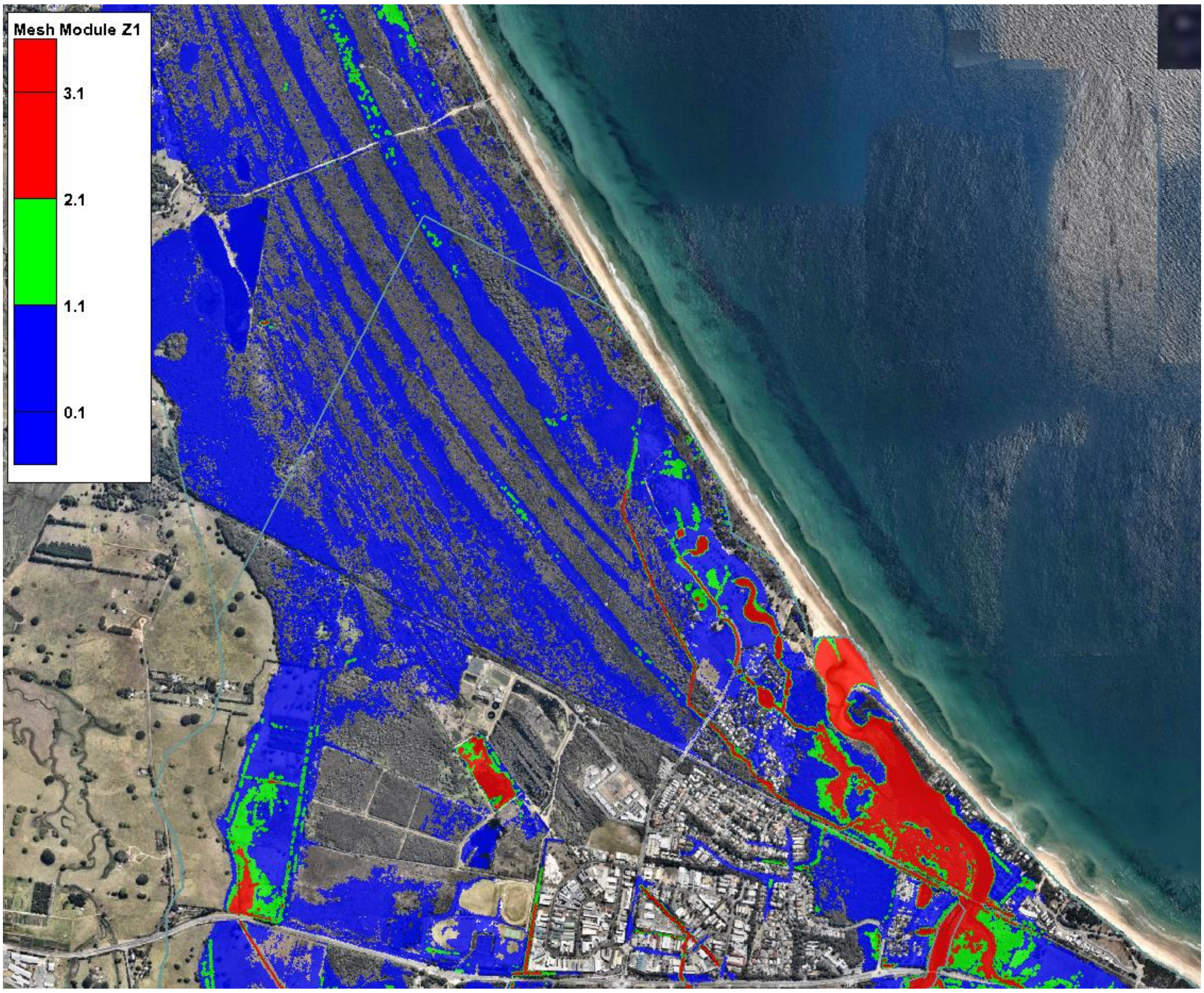

Figure 8: *NSW Flood Hazard Definition – Updated FRMS&P Model Results for Q100*

Notes:
- Red area is high hazard
- Green area is intermediate hazard
- Blue area is low hazard

5 Cumulative Impact Consideration

BMT WBM (2013) also investigated the flood impact of potential future development areas. Any impacts seem to be restricted to areas upstream of the railway line so will not affect the proposed North Belongil development.

6 Impact of Proposed Development

The impact of the proposed development was assessed in RHDHV (2021b) and was shown to create only a localised impact of up to a few centimetres (refer **Figure 9**). From the figure it can be seen that the development does not contribute to off site impact and the area cannot be a floodway, as the definition of a floodway (refer Section 3.1) is that any blockage of a floodway will result in significant increase in flood levels or a significant redistribution of flood flows, which may adversely affect other areas.

Figure 9: Location of Large (2000m²) Building Pads and Predicted Flood Impact (100yr ARI)

Notes: - black hatched areas are nine, 45 x 45m raised pads (location of the pads is preliminary with the actual location and size of the buildings to be determined at a later date after consideration of coastal hazard and other design considerations).
- orange to red is increased flood levels between 1-5 cm

7 Summary and Conclusions

This memo provides information relating to the hydraulic categorisation that resulted in the North Byron proposed development site being considered a “No Development” area, in the Belongil Creek FRMS&P. The investigation presented in this memo shows that if the FRMS&P model had used accurate ground elevation data and hydrology, the study site would not be considered a floodway. Our investigation found that a velocity depth product of 0.15 was used to define floodway areas in BMT WBM (2013 & 2015). It should be noted that the more recent North Byron FRMS&P (WMAwater, 2020) proposed a V x D criteria of 0.25 (Capricornia Canal at South Golden Beach) or 0.35 (Brunswick River Simpsons Creek).

Using this 0.15 criteria, the updated FRMS&P model (using accurate ground level data and hydrological inputs) does not consider that the site is a floodway. The updated FRMS&P model also shows that the site is considered low hazard, so using the FRMS&P criteria would be considered potentially suitable for development.

An investigation shows that the site would not be impacted by the cumulative impact assessment provided in BMT WBM (2013). The impact of the development was also presented and found to be minor and localised. The minimal site impact provides further qualification that the site is not consider a “floodway”.

Should you have any queries regarding this technical memo, please do not hesitate to contact Rohan Hudson on 4926 9506 or Ben Patterson on 4926 9503.

Ben Patterson
Technical Director
Rivers and Water Management – Australia

8 References

BMT WBM (2013), ‘Belongil Creek Floodplain Risk Management Study and Plan Discussion Paper 8: Future Development Assessment’, April 2013

BMT WBM (2015), ‘Belongil Creek Floodplain Risk Management Study and Plan Summary’, March 2015

Royal HaskoningDHV (2019) ‘North Byron Beach Resort Development - Flood Assessment ‘, Report for North Byron Beach Resort, November 2019.

Royal HaskoningDHV (2021a) ‘North Byron Beach Resort Development - Flood Assessment – Flood Planning Level Advice ‘, Report for North Byron Beach Resort, 14 July 2021.

Royal HaskoningDHV (2021b) ‘North Byron Beach Resort Development - Flood Assessment – Double Pad Size ‘, Report for North Byron Beach Resort, 3 August 2021.

WMAwater (2020) ‘North Byron Floodplain Risk Management Study and Draft Plan’, April 2020.

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Classification:	Confidential		

North Byron Beach Resort Development - Flood Assessment – Hydraulic Model Setup and Verification

Dear Sir,

Royal HaskoningDHV (RHDHV) has been commissioned to provide a response to a number of flood related questions regarding the proposed North Byron Beach Resort Development on Bayshore Drive.

This memo provides information relating to the hydraulic model setup used to investigate the study area. The investigation presented in this memo shows that the model used is based on the FRMS&P model though has been significantly improved in the area of interest to more accurately represent important flood mechanisms. Key model updates / improvements include:

a) Refinement in model resolution (from 10m to 5m)

b) The use of more accurate (LiDAR) ground elevation data

c) Improved hydrological representation of the hind (Pleistocene) dune system

d) Improved hydraulic representation of local waterways and structures (culverts and channels)

This memo should be read in conjunction with the previous flood advice that was provided the on 5th November 2019.

A companion memo describing a review and update of the hydraulic classification was provided to Council on the 3rd September 2021.

This memo provides:

- A summary of previous studies – Section 2
- A review of the Council Flood Study / FRMS&P model – Section 3
- A description of the model updates undertaken to improve the model – Section 4
- A description of the important flood mechanisms – Section 5
- A comparison of the updated model results to those of the FRMS&P model – Section 6
- A summary of available calibration data and a new model verification event – Section 7
- A summary of model sensitivity testing undertaken – Section 8

1 Requirement to Provide Additional Model Setup and Validation Information

The NSW Department of Planning, Industry & Environment (DPIE) originally provided comment to Byron Shire Council (BSC/Council) in a letter dated 14th February 2020 regarding the proposed development. In addition to providing responses to question raised by DPIE, Council also asked whether the updated model had been calibrated/verified against an event.

Byron Shire Council also raised the issue of model calibration and accuracy in an email dated 13th August 2021 which stated:

"the updated flood model …. should be calibrated to a known event, to demonstrate the accuracy of predicted flood levels"

On the 23rd August, 2021 RHDHV and Council staff reviewed available information. Council was unable to provide any additional calibration data. On the 27th August, RHDHV provided Council with a proposed approach to sensitivity testing that could be done to improve confidence in the model considering no additional calibration data could be identified. Council agreed to this approach on the 1st September 2021.

2 Available Previous Flood Studies

A range of literature containing information relevant to flooding at the study site (Belongil Creek) is available. A list of key documents is presented below.

- Belongil Creek Flood Study - PWD (1986)
- North Beach Byron Flooding and Drainage – Maunsell (2005)
- Belongil Creek Flood Study – SMEC (2009)
- Belongil Creek TUFLOW Model Review - BMT WBM (2011)
- North Beach Byron Flood Impact Assessment - BMT WBM (2013)
- Belongil Creek Floodplain Risk Management Study - BMT WBM (2014)
- Belongil Creek Floodplain Risk Management Plan - BMT WBM (2014)
- Belongil Estuary Protection Works Investigations – Numerical Modelling of Entrance Behaviour - Royal HaskoningDHV (2015)
- North Byron Beach Resort Development - Flood Assessment – Initial Flood Modelling - Royal HaskoningDHV (2019)
- North Byron Beach Resort Development - Flood Assessment – Flood Planning Level Advice - Royal HaskoningDHV (2021a)
- North Byron Beach Resort Development - Flood Assessment – Double Pad Size - Royal HaskoningDHV (2021b)
- North Byron Beach Resort Development - Flood Assessment – Hydraulic Categorisation - Royal HaskoningDHV (2021c)

3 Review of Council Flood Study / FRMS&P Model

3.1 Review of Council FRMS&P TUFLOW Model

Available models for use in the flood impact assessment were purchased from Council. Council provided two models:

a) The Belongil Creek FRMS&P TUFLOW model (BMT WBM, 2011, 2014, 2015)

b) The Belongil Creek STP Upgrade model (BMT WBM, 2019)

A review of the FRMS&P TUFLOW model provided by BSC for use in the flood assessment found:

- The model extent was limited by the model domain (likely required due to computation limitation when the model was originally developed). This limited model domain is presented in **Figure 1**.
- Model resolution is 10m.
- Because of the limited model extent, the hydrological inflows were incorrectly applied in the subject site which significantly influences flood conditions in the study area. The method used to apply the hydrological inflows does not correctly consider important hydrological processes and significantly over-predicts the likely sub-catchment routing that would occur in the Byron hind-dune system, that flows southward toward the study area. It also meant that hydraulic controls such as the Black Rock Road were ignored. Flows from sub-catchments 1 (area north of Black Rock Road) and 2 (area between Black Rock Road and sub-catchment 3 divider (refer **Figure 1**)) were originally introduced in the small area defined at location 2 in **Figure 1**. This previous error resulted in three times the expected flow being introduced to the site in the 100 year ARI. This error has now been corrected.
- Model elevation data was based on limited photogrammetry and 2m contour data and was not based on LiDAR data (LiDAR was only flown in 2010, so it was not available when the model was originally developed). The DEM used in the SMEC (2009) Flood Study model is presented in **Figure 2**, while the DEM used in the current flood assessment is presented in **Figure 3**. The ground elevation data in the vicinity of the study area used in Flood Study and subsequent FMRS&P appears to be very coarse with large triangulations evident in the DEM. The low resolution / low quality ground data used in this part of the model means that a high degree of uncertainty would be associated with any flood results in this part of the model. Higher resolution data is used in other parts of the model but does not cover the current area of interest.
- The model used a combined 100yr ARI tidal and fluvial event to simulate the 100yr ARI flood event. The peak tidal water level in the 100yr ARI model was 2.413 m AHD, which is higher than the 2.29 m AHD which is presented in BMT WBM (2011) as the current 100yr ARI tidal water level.

Figure 1: SMEC (2009) Flood Study Model Setup and Catchments

Notes: - Red Line – Catchment Boundary
- Green Lines – Sub-catchment inflow areas
- Black Line – Model domain boundary / extent

A review of the STP TUFLOW model provided by BSC for use in the flood assessment found:

- The model extent was only for a small extent and did not cover the North Byron Resort area.
- The model used a 1m resolution and was based on LiDAR data.
- The model does not appear to have been calibrated.

Overall, apart from the updated LiDAR data and a few other model refinements, because of the limited model extent, it could not be used for the North Byron flood impact assessment.

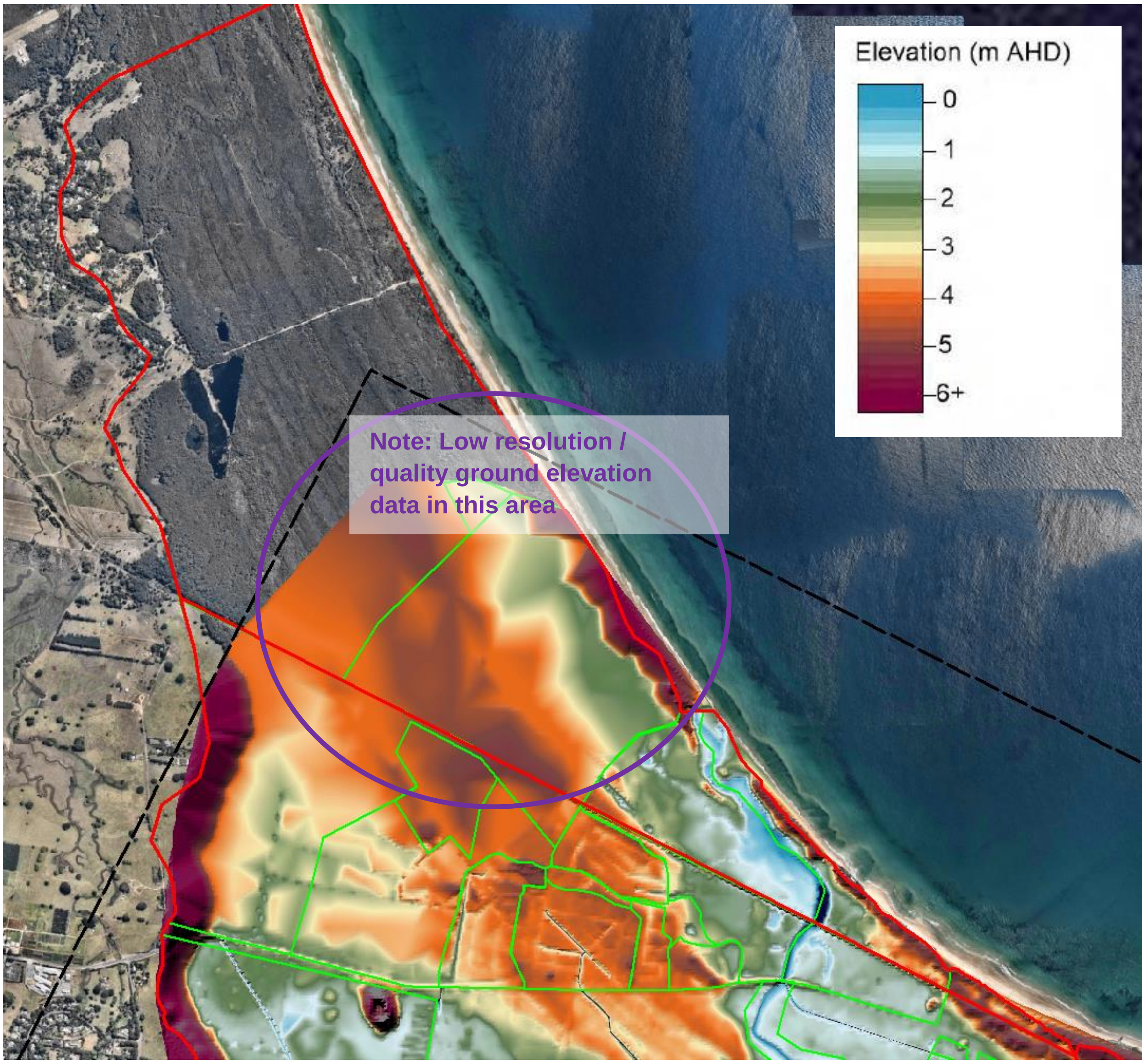

Figure 2: SMEC (2009) Flood Study Model Elevation data

3.2 Review of Council FRMS&P Design Flood Data (Hydrology & Tides)

Council provided hydrological inflows from the Belongil FRMS&P study (BMT WBM, 2014 & 2015) which were originally defined during the Belongil Flood Study (SMEC, 2009). They are based on a RAFTS, hydrological model which was not provided. SMEC (2009) reports that a range of duration were simulated with the 12 hour duration found to be critical (i.e. produced the highest flood levels).

Given that the model was calibrated to three observed events (1974, 1984 and 2003), it was assumed that the design hydrological inflows are appropriate for the study. The hydrological inflows for the three calibration events were not provided.

A summary of the design tide / storm surge levels is provided in **Table 1**. The 100yr ARI tidal tailwater conditions are described in Attachment 1 of BMT WBM (2011). They match the values Council provided in the FRMS&P TUFLOW model for all but the 100yr ARI (current) conditions. The table shows that the level should be 2.29 m AHD, but the values used in the model and that matches the FRMS&P model results is 2.41 m AHD. The reason for the additional 0.13m level is unknown but was adopted in this study to ensure consistency with the FRMS&P results.

The design tide levels used in the FRMS&P study seem quite high. The 100yr ARI tidal level of 2.29 m AHD is calculated based on a 0.94 m AHD high tide (which is approximately a king tide level (i.e. only occurs a few times a year)), 0.9 m of storm surge and 0.45m of wave setup. The 5yr tide level of 2.03 m AHD would appear to also be quite high, considering there are no observed tidal flood events in the flood study calibration record. Due to the relatively frequent nature of the 5 yr ARI tide event, it would appear likely that if it was a realistic estimate of design tidal flooding, it would have been observed on the flood record. The estimate of design storm tide are considered quite high and hence likely to produce a very conservative estimate of tidal flooding.

For the 2050 prediction of the 100yr ARI storm tide, 0.6m was added to the current 100yr ARI estimate of the design tide. This includes an estimate of 0.4m sea level rise and an additional 0.2m in surge to account for potential increases in storm severity associate with predicted climate changes impacts. For the 2100 prediction of the 100yr ARI storm tide, 1.2m was added to the current 100yr ARI estimate of the design tide. This includes an estimate of 0.9m sea level rise and an additional 0.3m in surge to account for potential increases in storm severity associate with predicted climate changes impacts.

Given the study site is so close to the Belongil Creek entrance, it is significantly influenced by the tidal flood mechanism. The uncertainty regarding the accuracy of these design tide conditions should be considered when considered flood risk at the site.

Table 1: Peak Tidal Water Levels used in FRMS&P and Flood Study

Model Run / Scenario / Design Event	Peak Flood Level (m AHD)
100yr ARI Tide including Storm Surge and 0.4m SLR – SMEC (2009)	2.82
5yr ARI Tide including Storm Surge (no SLR) – BMT WBM (2011)	2.03
20yr ARI Tide including Storm Surge (no SLR) – BMT WBM (2011)	2.18
100yr ARI Tide including Storm Surge (no SLR) – BMT WBM (2015)	2.41*
100yr ARI Tide including Storm Surge, 0.2m addition storm surge (increased storm intensity due to climate change) and 0.4m SLR (2050) – BMT WBM (2011)	2.89
100yr ARI Tide including Storm Surge, 0.3m addition storm surge (increased storm intensity due to climate change) and 0.9m SLR (2050) – BMT WBM (2011)	3.49

* BMT WBM (2011/2015) provides a 100yr ARI tide with storm surge peak level 2.29mAHD, the reasoning for the additional 0.13m used in the FRMS&P model is not provided. The value of 2.41mAHD was adopted in this study to ensure consistency with the provided model results.

4 Updates to Flood Model

The FRMS&P model was updated to use the best available data and to fix errors in the older model. The updates and improvements to the TUFLOW flood are outlined below.

4.1 Model Elevation Data and Resolution

A number of sources of bathymetry/elevation data were used to create the final model including:

- Detailed ground model based on survey of the study site from Bennett & Bennett surveyors (September 2019);
- Floodplain and ground levels based on 2010 LPI LiDAR data;
- Nearshore and downstream channel bathymetry based on August 2015 survey (Bennett & Bennett);
- Belongil Creek channel and upstream bathymetry based on NSW Govt. (DPWS/OEH) survey from July 1994;

The resultant DEM used in the current flood assessment in presented in **Figure 3**.

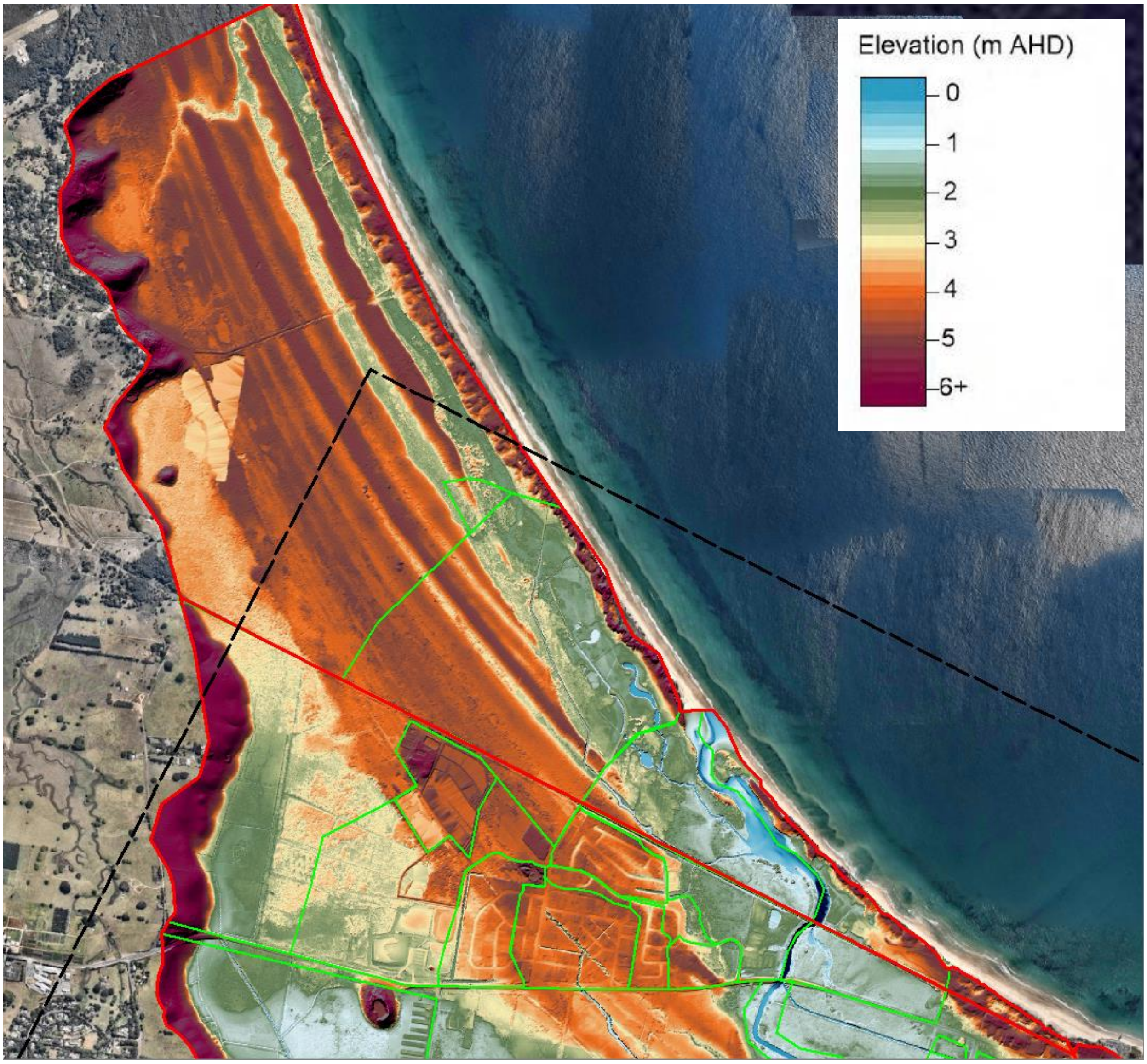

Figure 3: Updated Flood Assessment Model Elevation data

4.2 Model Structures

A number of drains and culverts specific to the study site were added to the model. Culvert inverts and sizes were based on information from BMT WBM (2013) as presented in **Figure 4** as well as data provided in the Bennett & Bennett survey files. The figure also shows the location of a number of drainage lines that were appropriately defined using z-shape model elements which ensure a continuous flow path and provide better representation than the available LiDAR data.

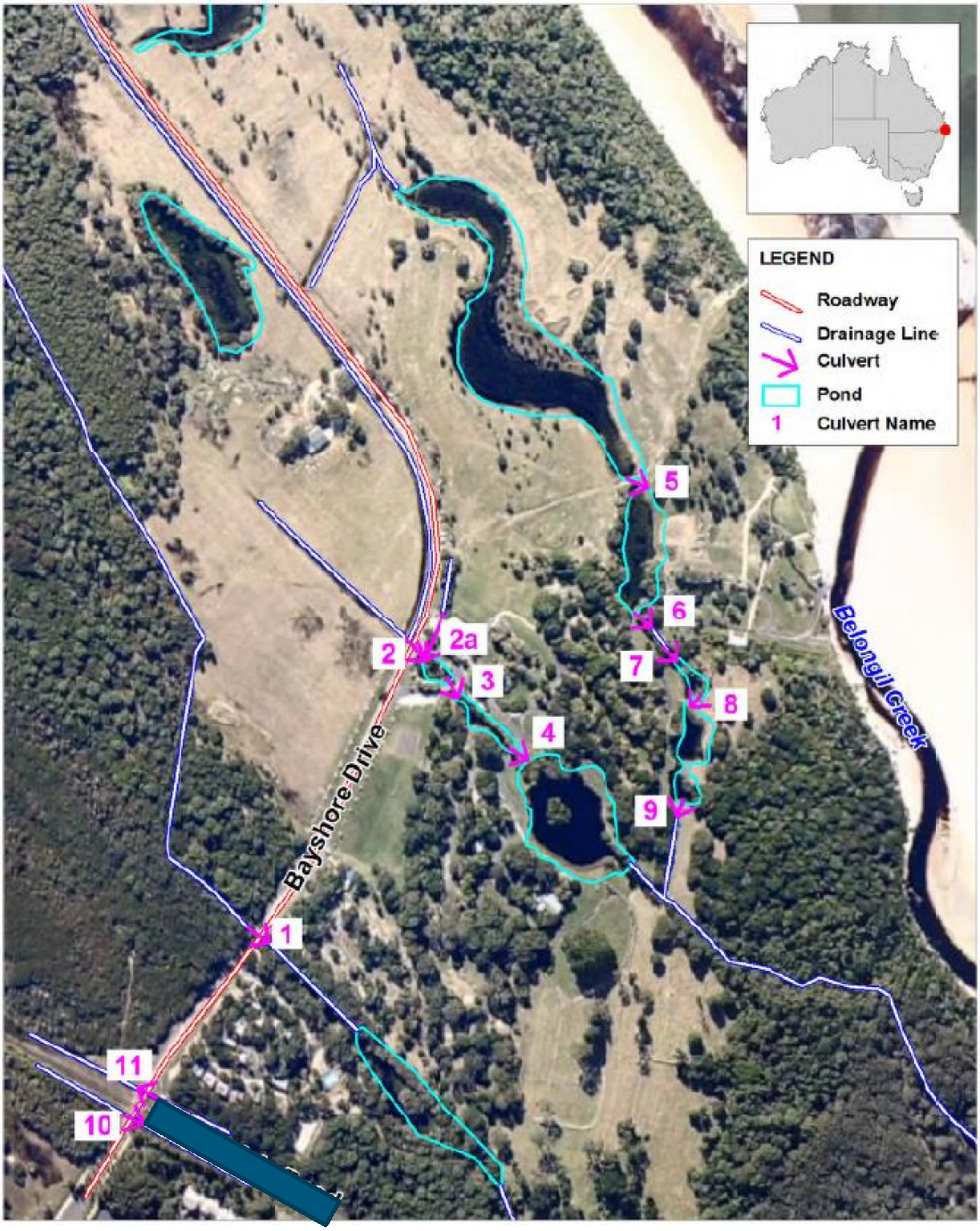

Figure 4: Location of Culverts (from BMT WBM (2013))

4.3 Model Extents, Resolution and Application of Hydrologic Inflows

The model was extended to cover the full catchment extent (including the area north of Black Rock Road) as presented in **Figure 3**. The model resolution was also increased from 10m to 5m, allowing for better definition of features such as channels and rail/road crests.

While the hydrological model and provided inflows were unchanged, the method of applying the inflows was updated to provide a more realistic hydrologic input. For the two catchments north of the study site, the model was updated from the "standard SA inputs" (which inputs flow at the lowest point in the catchment), to an "SA all input" (which spreads inflow over the entire sub-catchment and is similar to a "direct rainfall" input). This is appropriate for the two sub-catchments which have a very complicated internal structure (refer **Figure 3** (ground elevation data)) and should not be considered a single sub-catchment that drains to a traditional single catchment outlet. The use of the updated hydrological input method allows the hydraulic model (which includes an updated DEM) to define where the flow in these areas should go and allows the ground elevation definition to provide catchment storage. **Figure 5** presents the 100yr fluvial flood levels in the updated model showing the complicated drainage network and significant level of flood storage that occurs due to hydraulic controls such as the raised Black Rock Road and the two levee bank structures located immediately upstream of the study area.

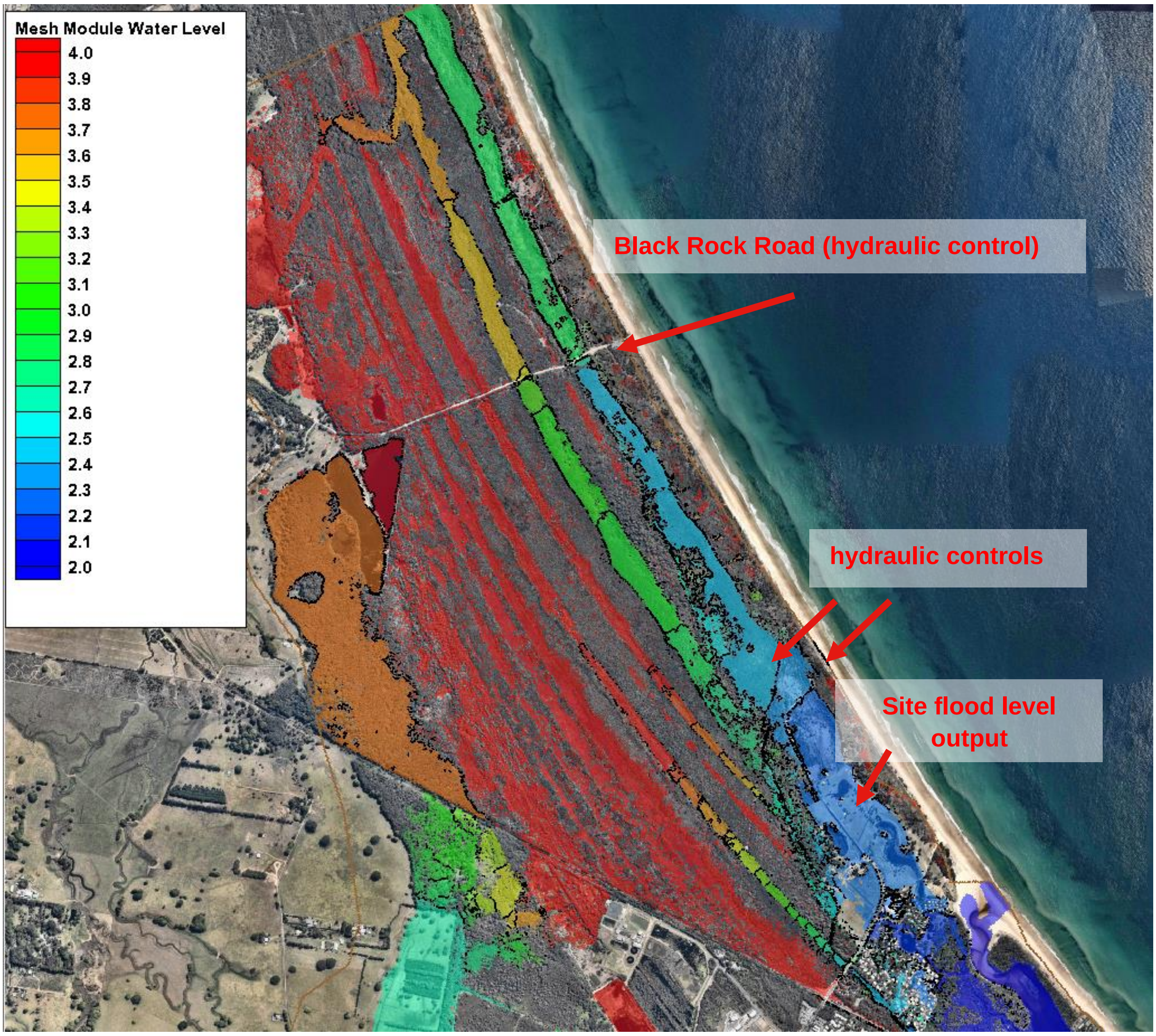

Figure 5: Predicted Flood Levels – Updated Model (100yr ARI Fluvial, no storm surge or SLR)

5 Key Flood Mechanisms and Design Events

The FRMS&P design events ran both 100yr ARI rainfall/fluvial and tidal design events in the one simulation. This makes evaluating the significance of each individual flood mechanism difficult. In order to better judge both the performance of the model and also the influence of individual flood mechanisms additional simulations have been undertaken.

5.1 Fluvial Flooding

Predicted flooding from the 100yr ARI fluvial (i.e. rain) event is presented in **Figure 5**, **Figure 6** and **Figure 7**.

Figure 5 shows how flood waters fill the low valley like features between the Pleistocene dune ridges with water flowing in a southerly direction across the site before discharging into Belongil Creek downstream of the railway line. **Figure 6** presents zoomed in flood levels of the site for the 100yr ARI fluvial event, where flood levels are observed to be fairly flat across the site which can be represented by a single flood level as provided in **Table 2**, which shows the peak 100yr ARI fluvial design level as being 2.27 m AHD. The influence of the two hydraulic controls immediately upstream of the site and the key control downstream of the site is apparent in **Figure 6**.

Figure 7 provides further detail of the flood levels at the downstream hydraulic control. Ground elevation in the vicinity of the hydraulic constriction is presented in **Figure 8** where the high ground (that constricts the flood flows) is associated with the row of accommodation that was constructed between the channel and the dune beside the mouth of Belongil Creek.

Fluvial flooding in the North Byron Resort area is considered independent of fluvial flooding in Belongil Creek as the railway line significantly constricts flow from the Belongil Creek wetland area.

A summary of peak flood levels or the site for six different magnitude fluvial only design flood events is presented in **Table 2**. The model predicts that flood depths in the 5yr and 10yr ARI are less than 15cm and discharge across the site is less than 2.3 m^3/s. This is because the upstream dune system is able to provide significant flood storage such that only a small amount of discharge is predicted through this site. In the 20yr ARI event at peak level of 2.08 m AHD is predicted and is associated with a 0.35 m flood depth and a discharge of 4 m^3/s.

Peak flood levels for the probable maximum flood (PMF) are presented in **Figure 9**, which for the site produces a peak flood level of 2.97 m AHD which produces a site depth of 1.24 m. Timeseries of water levels at the site are provided in **Figure 10** and show the rate of rise of the PMF, which rises 1.24 m over less than 5 hours. A half PMF discharge event was also simulated and produced a peak flood level of 2.62 m AHD. The half PM event only produced a peak discharge of 30.3 m^3/s, which further highlights the influence of available flood storage in the upstream catchment area. A sensitivity test of 30% increase in 100yr ARI discharge was also run and produced a peak flood level of 2.38 m AHD and a discharge of 11.9 m^3/s.

A 100yr ARI tide only event is also presented in **Table 2** and **Figure 10**, and shows a 100yr ARI tide is predicted to produce a peak flood level of 2.04 m AHD. If a 100yr ARI tide coincided with a 100yr fluvial event it would produce a peak flood level of 2.38 m AHD with flood depth rising to ~0.6 m over 3 hours.

Table 2: Peak Discharge, Water Levels and Depths for Fluvial Only Design Events (Updated Model)

Model Run / Scenario / Design Event	Peak Flow (m^3/s)*	Peak Flood Level (m AHD)	Peak Flood Depth* (m)
PMF	82.6	2.97	1.24
Half PMF	30.3	2.62	0.89
100yr ARI Fluvial (0.5m TWL)	7.2	2.27	0.54
20yr ARI Fluvial (0.5m TWL)	4.0	2.08	0.35
10yr ARI Fluvial (0.5m TWL)	2.3	1.88	0.15
5yr ARI Fluvial (0.5m TWL)	1.8	1.85	0.12
100yr ARI Tidal, no rain	0	2.04	0.31
Combined 100yr ARI Fluvial & 100yr Tidal	7.2	2.38	0.65
100yr ARI Fluvial +30% discharge (0.5m TWL)	11.9	2.38	0.65

Note * TWL – Tail Water Level. Peak flow is provided for a location immediately downstream of the upstream onsite hydraulic control, the location of the water level point is provided in **Figure 5**. Ground Level is 1.73m AHD.

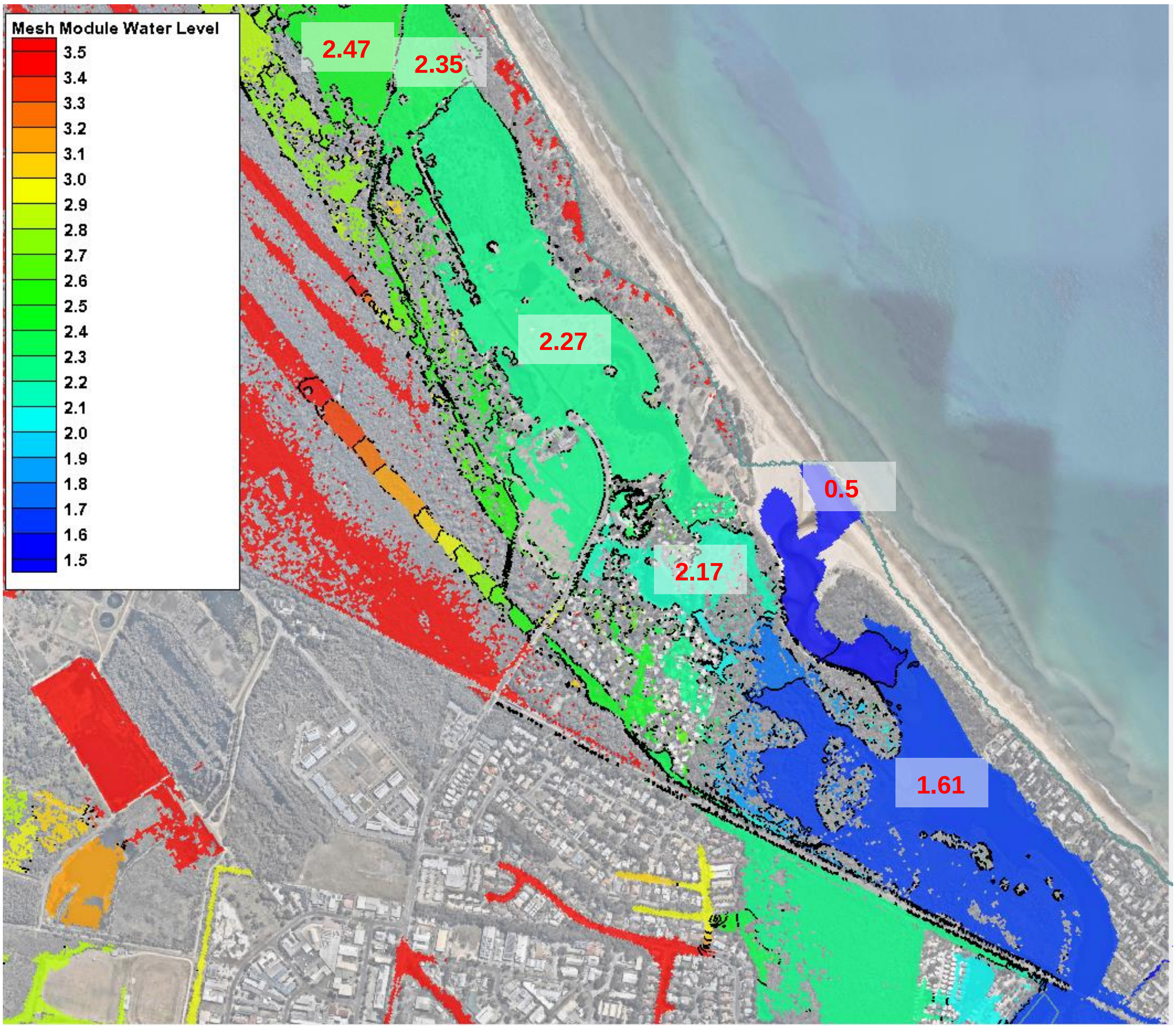

Figure 6: Predicted Flood Levels (m AHD) – Updated Model (100yr ARI Fluvial, no storm surge or SLR)

Figure 7: Predicted Flood Levels – Updated Model (100yr ARI Fluvial, no storm surge or SLR) – Zoomed to Constriction

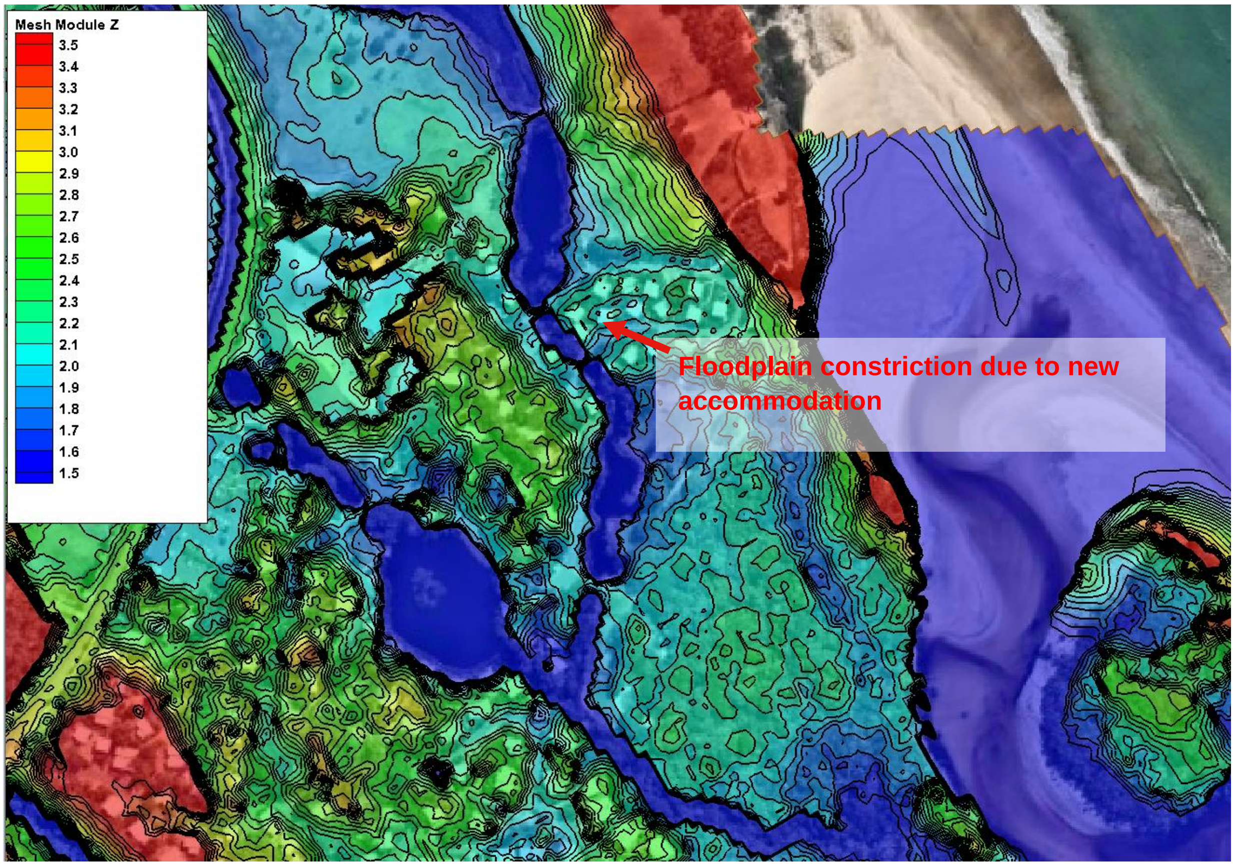

Figure 8: Ground Elevation Data – Zoomed (Raised Ground for New Accommodation has restricted the Flow Path)

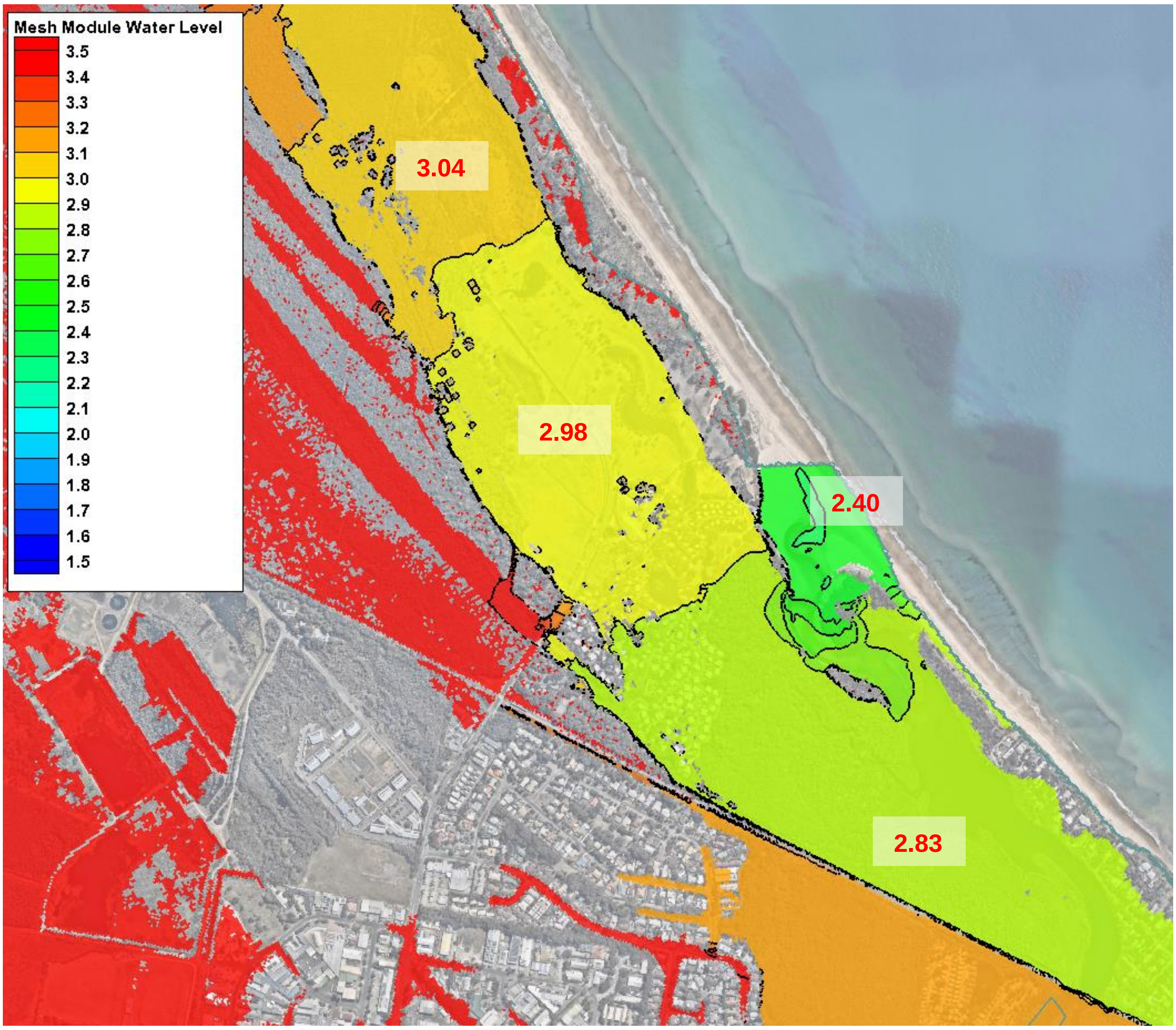

Figure 9: Predicted Flood Levels – Updated Model (PMF Event, 2.4mAHD storm surge, no SLR)

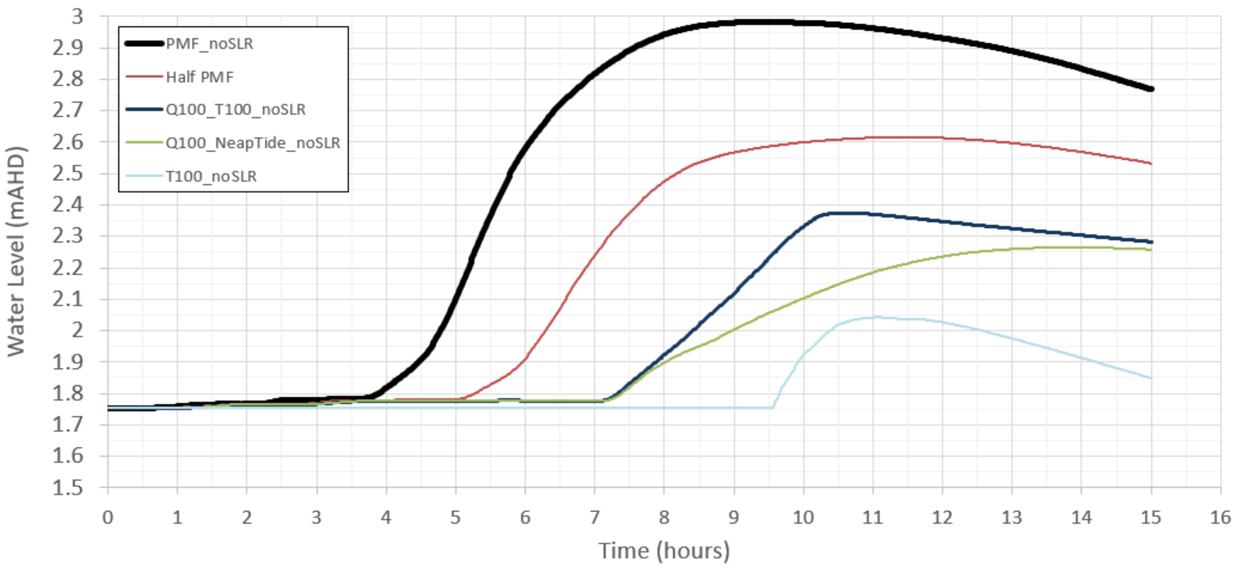

Figure 10: Time Series for a Range of Design Flood Events – Updated Model (no SLR)

5.2 Tidal Flooding and Climate Change / SLR

Predicted flooding from the 100yr ARI tide only event is presented in **Figure 11**. From the figure it can be seen that a peak flood level at the site is 2.04 m AHD from a design offshore tide of 2.41 m AHD (refer **Table 1**). The influence of the hydraulic controls is again present though this time the control associated with the constriction of the floodplains helps reduce flood levels due to tidal flooding. The site drain that runs to the south western edge of the site can be clearly seen, though during tidal flooding it allows water to travel upstream.

While current (no SLR) 100yr ARI tidal flooding is lower than the 100yr ARI fluvial flooding, sea level rise and associated climate change impacts (i.e. increased storminess) is predicted to make tidal inundation the critical flood mechanism at the site. **Figure 12** presents predicted flood levels for the 100yr tide for the predicted 2100 conditions (i.e. include 0.3m of additional storm surge and 0.9m of SLR) (refer Section 3.2), which produces a peak flood level of 3.36 m AHD at the site. This level is higher than the current condition predicted PMF. If the 100yr (2100) tide coincided with an 100yr ARI fluvial event the peak flood level would increase by 5cm to 3.41 m AHD (refer **Figure 13**). If the discharge was further increased by 30% the peak flood level would only rise by less than 1cm to 3.42 m AHD.

Timeseries of water levels at the site are provided in **Figure 14** and show the rate of rise of the SLR tidal events, which rises 1.7 m over less than 4 hours. The timeseries further highlight that the fluvial event has less influence on peak water level for the increasing levels of SLR.

The assessment shows that while tidal inundation is not currently a significant threat to the site, the influence of the predicted levels of climate change and associated sea level rise (SLR) mean that tidal inundation could become the critical flood mechanism for the site if the predicted changes eventuate.

It should also be noted that there is a considerable degree of uncertainty with the current prediction of the design tide events (refer Section 3.2). This is in part because they assume storm surge events, coincide not only with high levels of wave setup but also with a king tide event. The reliance on these three mechanisms being coincident means that it is likely there is a considerable over estimation of the design tide. This is partly apparent in that all observed flood events appear to be from a fluvial source and were not associated with a tidal flood mechanism.

Table 3: Peak Water Levels and Depths for Tidal Design Events (Updated Model)

Model Run / Scenario / Design Event	Peak Flood Level (m AHD)	Peak Flood Depth (m)
PMF (no SLR)	2.98	1.25
Combined Q100 (+30%) & T100 (2100 SLR)	3.42	1.69
Combined Q100 & T100 (2100 SLR)	3.41	1.68
T100 (2100 SLR)	3.36	1.63
Combined Q100 & T100 (2050 SLR)	2.81	1.08
T100 (2050 SLR)	2.68	0.95
Combined Q100 & T100 (no SLR)	2.38	0.65
Q100, no tide (no SLR)	2.28	0.55
T100 (no SLR)	2.04	0.31

Note: the location of the water level point is provided in **Figure 5**. Ground Level is 1.73m AHD.

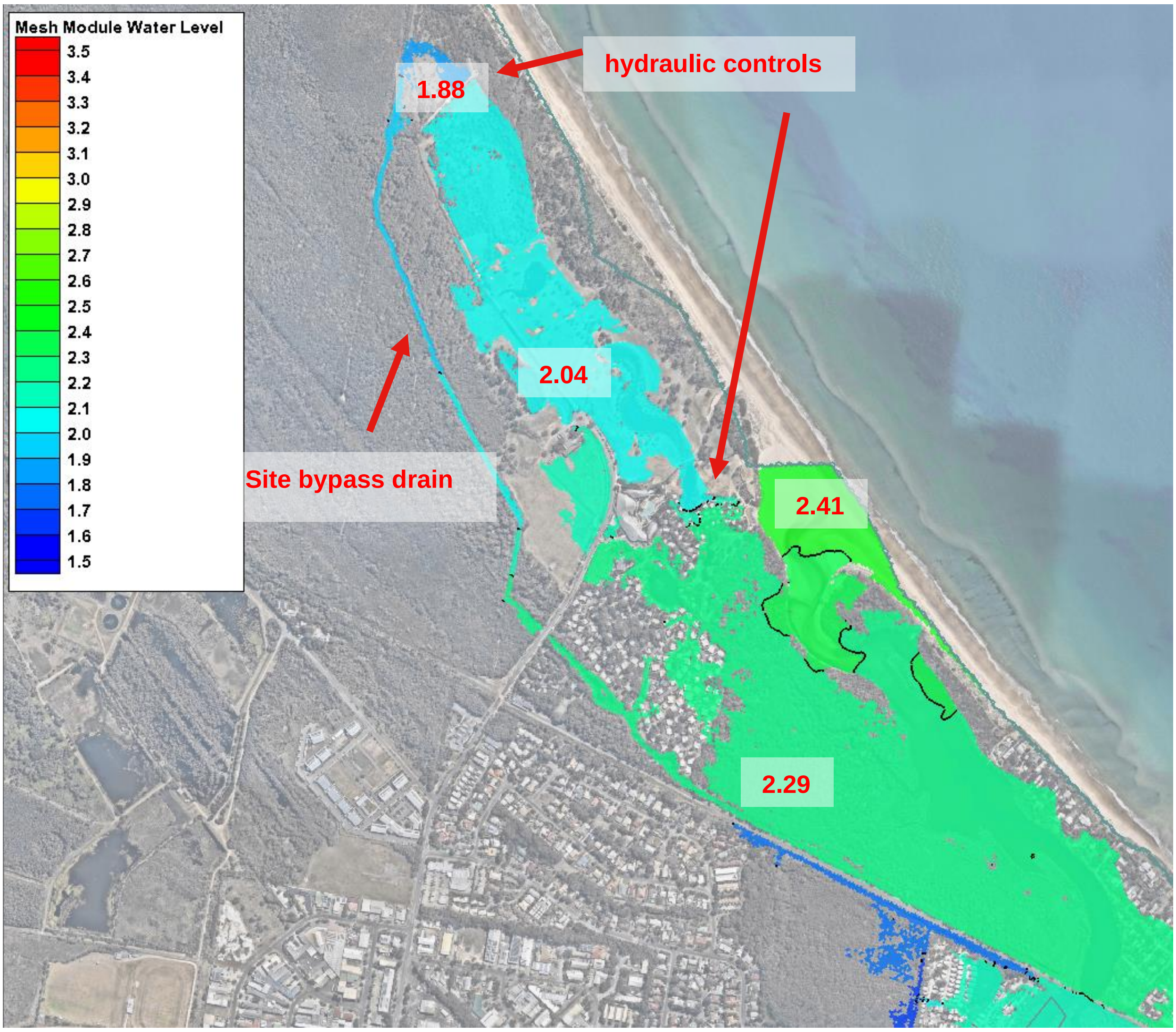

Figure 11: Predicted Flood Levels – Updated Model (100yr ARI Tide / Storm Surge, no CC/SLR)

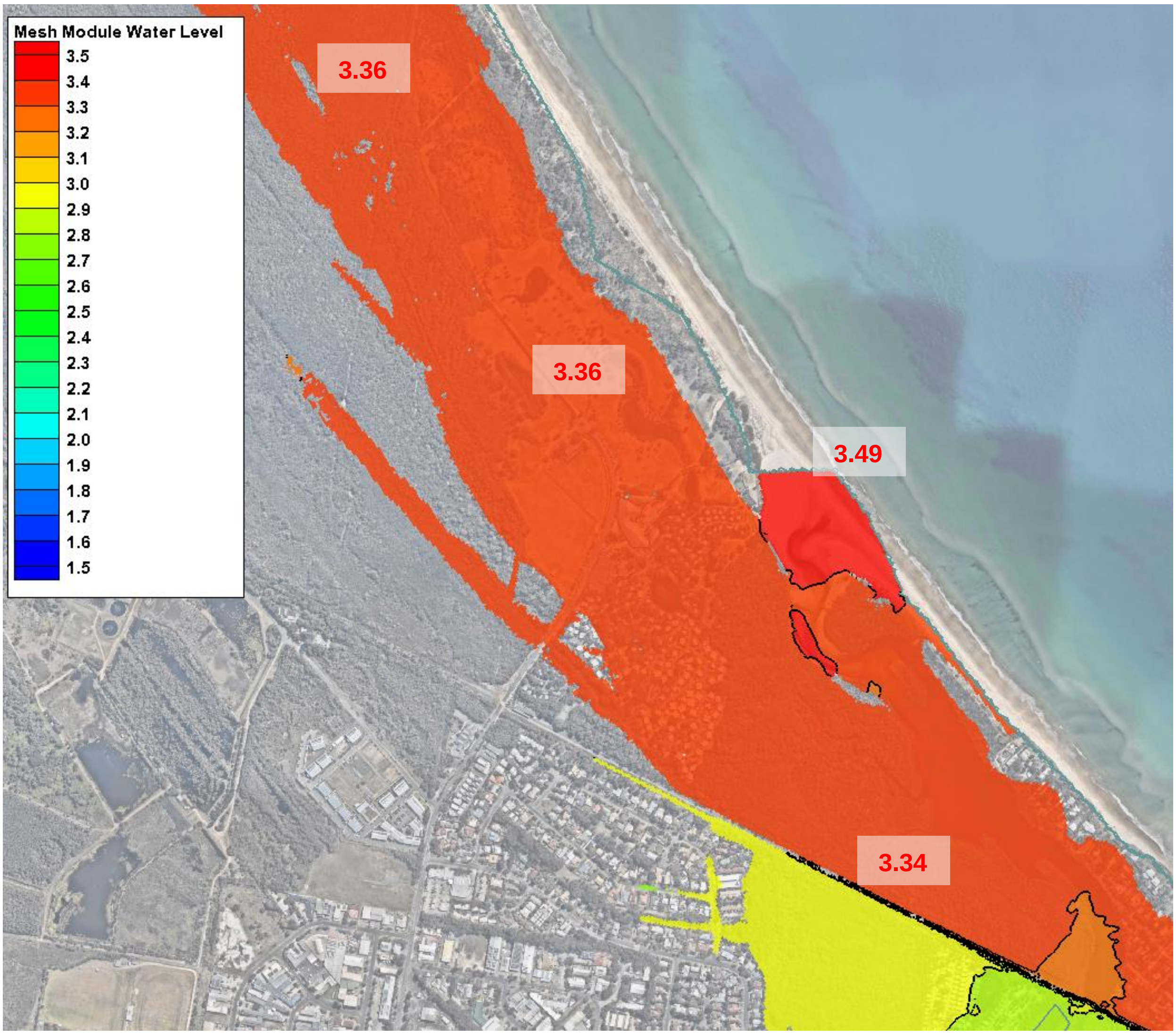

Figure 12: Predicted Flood Levels – Updated Model (100yr ARI Tide / Storm Surge, CC2100)

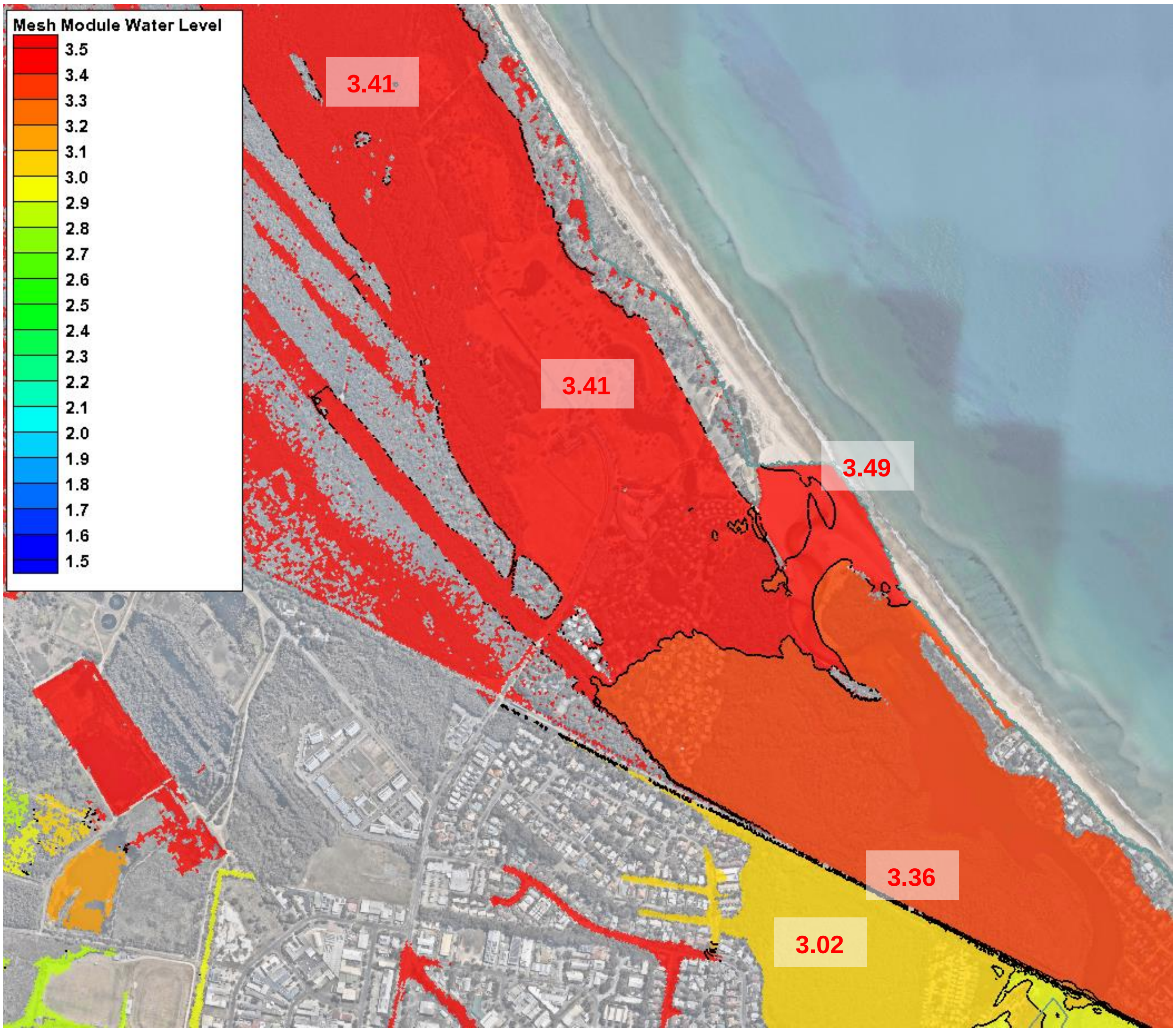

Figure 13: Predicted Flood Levels – Updated Model (100yr ARI Rain & Tide / Storm Surge, CC2100)

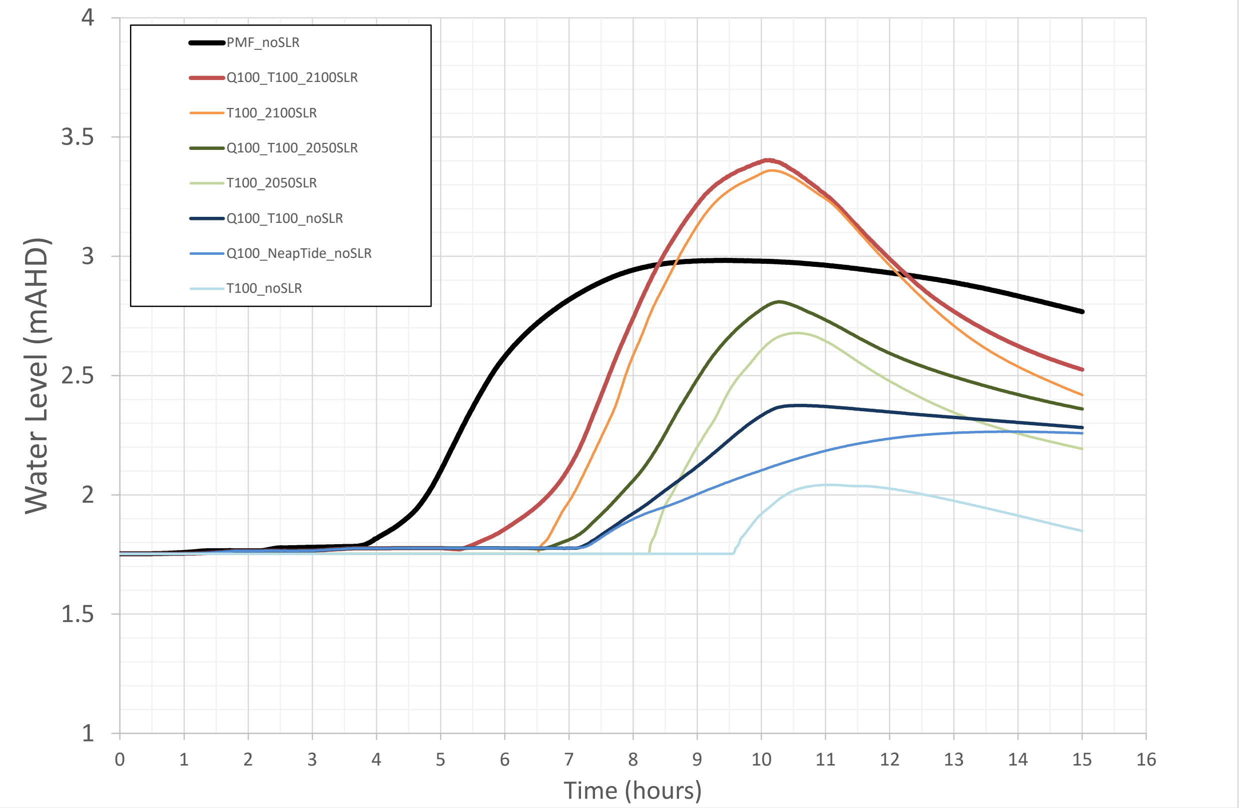

Figure 14: Time Series for a Range of Design Flood Events – Updated Model (including SLR)

5.3 Combined Fluvial and Tidal Flooding

In the FRMS&P results were only provided for combined / coincident fluvial and tidal events of the same magnitude (i.e. 100yr ARI fluvial event with a 100yr ARI tide event). By combining two 100yr ARI events, the probability of occurrence is likely to be significantly more severe than an 100yr ARI event. To account for this the current NSW Government guidelines suggest typically combining an envelope of the: 100yr ARI fluvial event with a 20yr ARI tide event and 100yr ARI tide event with a 20yr ARI fluvial event, which should allow for a degree of coincidence without producing such a rare (high magnitude) outcome.

A figure showing the predicted flood levels for a combined 100yr ARI fluvial event with a 100yr ARI tide event is presented in **Figure 15**, while individual peak site levels from three different events (fluvial only, tide only and combined) are summarised in **Table 4**. The influence of combining the two flood mechanisms can be made by comparing **Figure 15** (combined 100yr ARI Fluvial and Tide) to **Figure 7** (100yr ARI Fluvial only) and **Figure 11** (100yr ARI Tide only). From the three figures and the timeseries data presented in **Figure 14**, it is apparent that the coincident tide prevents the fluvial flood waters from leaving Belongil Creek and increases flood levels by 10cm above the 100yr ARI fluvial only event. The combined event also significantly increases the rate of flood rise (~0.6m in 3 hours) compared to the fluvial only event.

Table 4: Peak Water Levels and Depths for Combined Fluvial and Tidal Design Events (Updated Model)

Model Run / Scenario / Design Event	Peak Flood Level (m AHD)	Peak Flood Depth (m)
Combined Q100 & T100 (no SLR)	2.38	0.65
Q100, no tide (no SLR)	2.28	0.55
T100 (no SLR)	2.04	0.31

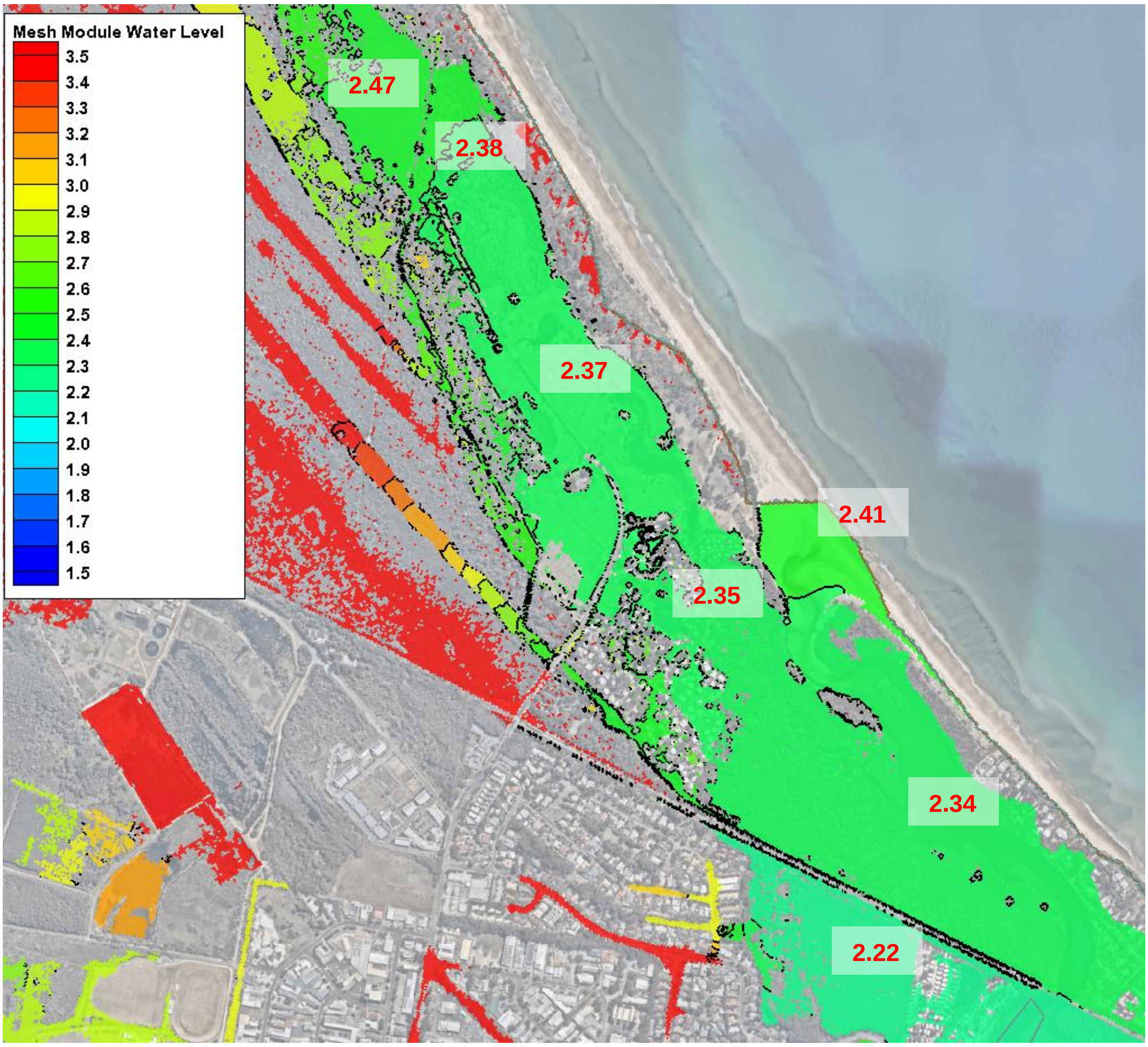

Figure 15: Predicted Flood Levels – Updated Model (Combined 100yr ARI Rain & Tide / Storm Surge, no SLR)

6 Comparison of Updated Model Results to Previous Studies

The updated flood model prediction of the 100yr ARI, 2100 design level is in close agreement with that presented in the Belongil Creek FRMS&P (BMT WBM, 2015) which provided a peak flood level of 3.36 m AHD. Key difference in peak water levels are because the FRMS&P has a less well defined rail embankment which allows more of the tidal flood wave to propagate into the upstream storages as is apparent comparing **Figure 16** to **Figure 13**.

The updated flood model prediction of the 100yr ARI, 2100 design level is in close agreement with that presented in the North Beach Byron Flood Impact Assessment (BMT WBM, 2013) which provided a peak flood level of 3.43 m AHD. A summary of the three peak water levels from the three studies is provided in **Table 5**. The BMT WBM (2013) result closely matches the updated model results because it also used more accurate LiDAR data than what was used in the FRMS&P study.

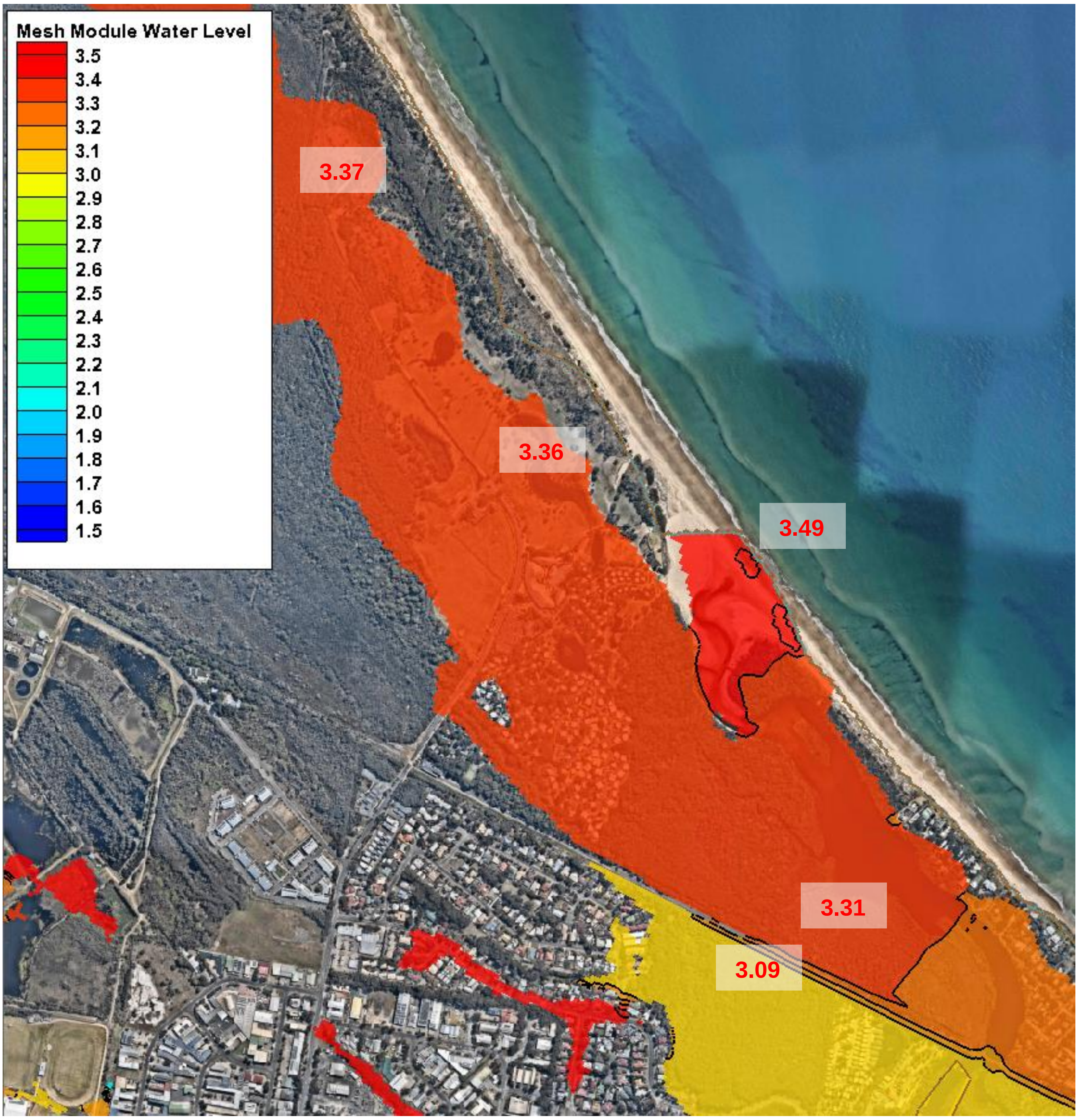

Figure 16: Predicted Flood Levels – FRMS&P Model (100yr ARI Rain & Tide / Storm Surge, CC2100)

Table 5: Peak Water Levels and Depths for Design Events Comparison of Previous Studies

Model Run / Scenario / Design Event	Peak Flood Level (m AHD)
Combined Q100 (+30%) & T100 (2100 SLR) – Updated Model	3.42
Combined Q100 & T100 (2100 SLR) – Updated Model	3.41
Combined Q100 (+30%) & T100 (2100 SLR) – FRMS&P Model	3.36
Combined Q100 (+30%) & T100 (2100 SLR) – BMT WBM (2013)	3.43

7 Available Calibration Data and Model Verification

7.1 Flood Study (SMEC, 2009) Calibration

The FRMS&P model is based on the model produced as part of the SMEC (2009) flood study. The flood study model was calibrated to three events including flood events in 1974, 1984 and 2003. Available flood data points area presented in **Figure 17**. From the figure it can be seen that there are no data points within the North Byron Resort area and only one point (from 1984) is downstream of the railway line. Some key points regarding the three calibration event are:

1974 – Only one point downstream of the Ewingsdale Bridge – 1.38mAHD – this is actually quite a low flood level. The data indicates this event was primarily fluvial in nature due to the difference in water levels either side of Ewingsdale Bridge. No data was available downstream of the railway bridge.

1984 – Only 1 calibration mark – 1.67mAHD – downstream of railway line – in order to calibrate the model a sandbar blocking the lagoon entrance was introduced to the TUFLOW model.

2003 – no data in area of interest.

While the calibration undertaken during the flood study provided useful data for ensuring appropriate performance of the model upstream of the rail line, the lack of observed flood data in the North Byron Resort area means that the Flood Study model and hence the FRMS&P model should not be considered calibrated in the key study area.

7.2 Updated Model 2005 Validation Event

Additional calibration data was requested from Council; however, no additional data was made available. A literature review found that the June 2005 was also severe, so additional qualitative data was sought.

The July 5, 2005 Byron Shire Echo (https://www.echo.net.au/issues/2007/) reported that the flood was sever and there was a flood related fatality in Byron (corner Ewingsdale Road & Kendall Street) when a cyclist riding home from work, was drowned when he was swept from the road in to the floodwaters and became tangled in a fence. Data contained in MHL (2005) indicates that at the Belongil Depot rain gauge, the event was less than a 2yr ARI rain event, however, at Yocum gauge it was a 20yr ARI event, further north it was much a more severe event.

While no surveyed flood levels could be compared to the model, a qualitative validation examining 20yr ARI flood depth in the vicinity of Ewingsdale Road & Kendall Street (**Figure 18**) shows flood depths in the order of 0.2 to 0.5 m which could be hazardous to a cyclist.

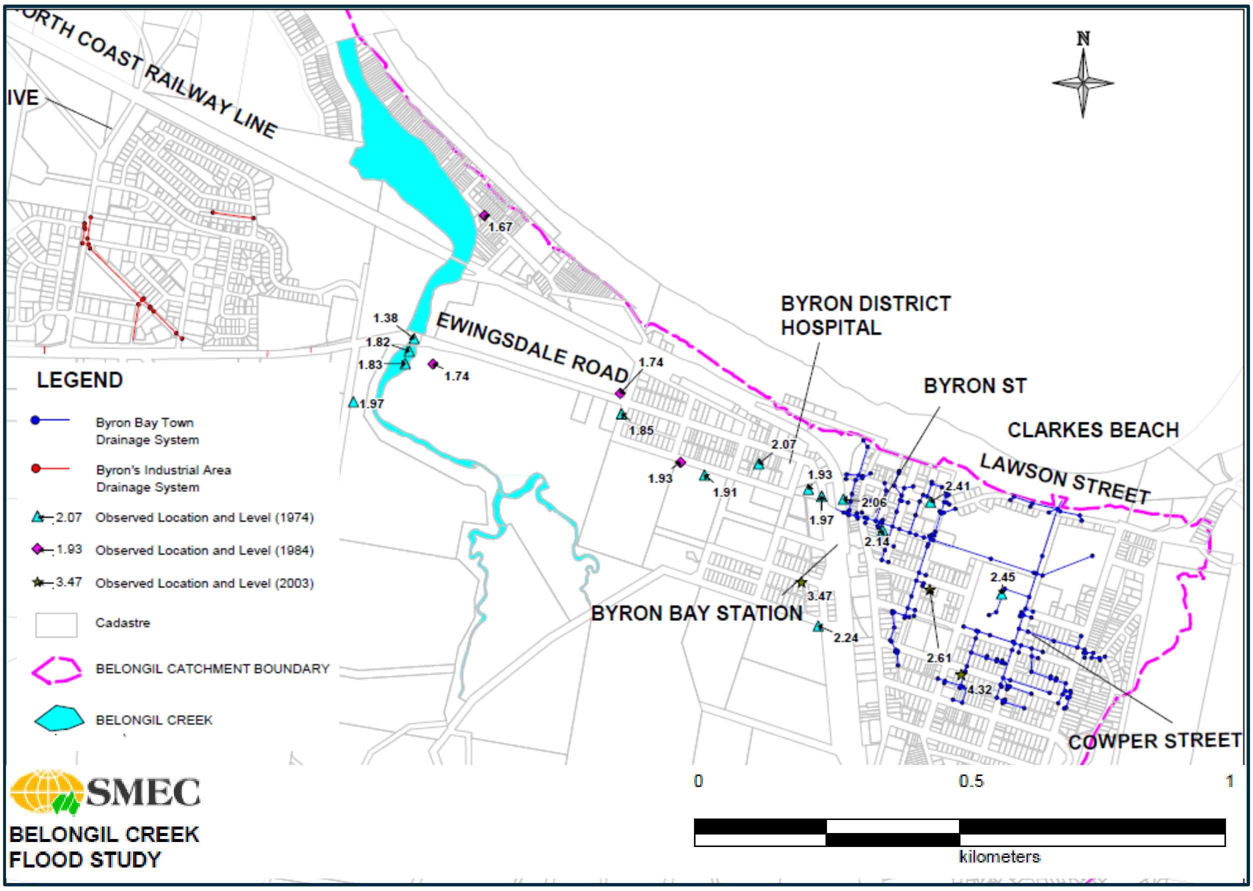

Figure 17: Available Calibration Data (SMEC, 2009)

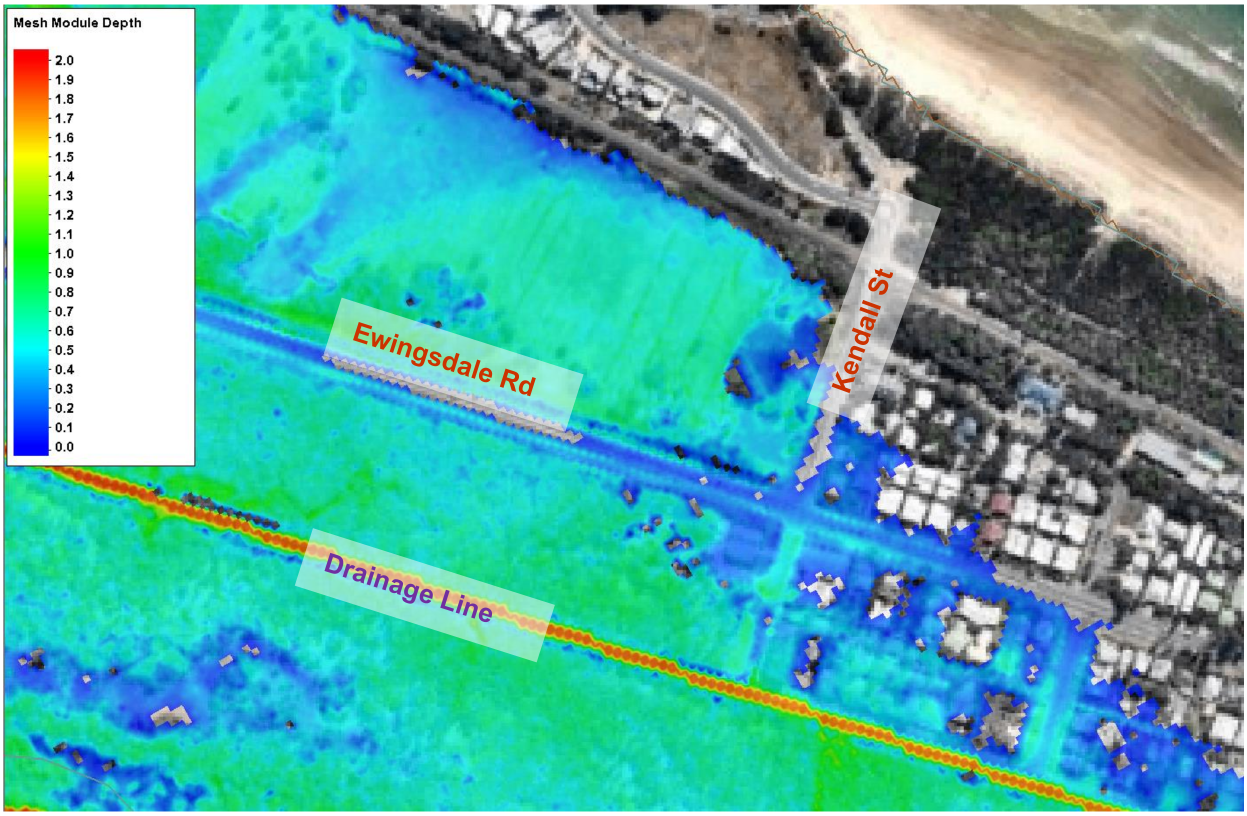

Figure 18: Predicted Flood Depths – Updated Model (20yr ARI Results)

8 Model Sensitivity Testing

Sensitivity testing has been undertaken to further assess the performance of the updated flood study model. Sensitivity testing is often used in model studies where there is not sufficient calibration data to assess the performance of a model. If a model is not sensitive to changes in typical model parameters, a greater level of confidence can be associated with model predictions. Sensitivity testing is usually undertaken on the event used to determine the study outcome. In this case the setting of the flood planning level (FPL) for the site is considered the key study outcome. As the FPL is to be based on the 100yr ARI 2100 event this was adopted as the design event to undertake the sensitivity testing on.

Sensitivity testing included:

a) Roughness change +/- 20%;
b) ICOLL entrance / berm level
c) Discharge +/- 30%

Table 6 presents a summary of the results of the sensitivity results. The results show:

- A 30% increase in fluvial discharge only increases flood levels at the site by 1cm
- Changing the roughness by +/- 20%, changes flood levels by less than 1cm

The above indicates that peak flood levels are insensitive to potential inaccuracies in the setting of roughness values or hydrological parameters. This gives further confidence in the models prediction of this design event.

The impact of a closed Belongil Creek opening (i.e. ICOLL entrance) was assessed with berm crests of 1, 2 and 4 mAHD. Noting that the entrance is mechanically opened if flood levels exceed ~1 m AHD. However, if there was a sudden storm Council may not have time to artificially open the entrance. Because under the 2100 SLR scenario, the key flood mechanism is tidal inundation, a 1 or 2m AHD entrance berm would reduce flood levels upstream of the entrance area (albeit by only a maximum 3cm).

In the case of a 4m AHD berm, because the 100yr ARI 2100 peak storm tide is 3.49 m AHD, a high berm would prevent tidal inundation occurring. However, because a combined tidal and fluvial event was simulated the flood level still rises to 2.29 m AHD. In the area downstream of the railway line this is much lower that the 3.4 m AHD flood level predicted due to tidal inundation.

Table 6: Predicted Peak Flood Levels (Sensitivity Test Results)

Model Run / Scenario / Design Event	Peak Flood Level (m AHD)
Base Case - 2100 - 100yr Fluvial & Tide (Q100 with T100 + 0.9mSLR and 0.3m SS)	3.40
Increase flow by 30% - 2100 - 100yr Fluvial & Tide (Q100 (+30% discharge) with T100 + 0.9mSLR and 0.3m SS)	3.41
Global Increase Roughness by 20% - 2100 - 100yr Fluvial & Tide (Q100 with T100 + 0.9mSLR and 0.3m SS, n plus 20%)	3.40*1
Global Decrease Roughness by 20% - 2100 - 100yr Fluvial & Tide (Q100 with T100 + 0.9mSLR and 0.3m SS, n minus 20%)	3.40*2
ICOLL Berm at 1m AHD - 2100 - 100yr Fluvial & Tide (Q100 with T100 + 0.9mSLR and 0.3m SS, ICOLL Berm = 1mAHD)	3.39*3

ICOLL Berm at 2m AHD - 2100 - 100yr Fluvial & Tide (Q100 with T100 + 0.9mSLR and 0.3m SS, ICOLL Berm = 2mAHD)	3.38*3
ICOLL Berm at 4m AHD - 2100 - 100yr Fluvial & Tide (Q100 with T100 + 0.9mSLR and 0.3m SS, ICOLL Berm = 4mAHD)	2.29*4

Notes:
- Q100 is 100yr ARI (1% AEP) fluvial deign event
- T100 is 100yr ARI (1% AEP) tidal deign event
- SLR – sea level rise, SS – additional storm surge (wind & wave setup)

1) Upstream of Ewingsdale Road there is a ~3cm increase in peak water levels
2) Upstream of Ewingsdale Road there is a ~2cm drop in peak water levels
3) Because this event is tidally dominated, an ICOLL berm restricts sea water entering Belongil Creek and results in reduced flood levels.
4) With the ICOLL berm at 4mAHD, the storm surge cannot enter the creek, though the 100yr ARI discharge cannot leave it either, however, there is sufficient storage in the Belongil wetland system such that in the study area the flood levels do not significantly increase with the ICOLL entrance closed.

9 Summary and Conclusions

This memo provides information relating to the hydraulic model setup used to investigate the North Byron Resort study area. The investigation presented in this memo shows that the model used is based on the FRMS&P model though has been significantly improved in the area of interest to more accurately represent important flood mechanisms. Key model updates / improvements include:

a) Refinement in model resolution (from 10m to 5m)

b) The use of more accurate (LiDAR) ground elevation data

c) Improved hydrological representation of the hind (Pleistocene) dune system

d) Improved hydraulic representation of local waterways and structures (culverts and channels)

This memo provided:

- A review of the Council Flood Study / FRMS&P model – and highlighted a number of required improvements. The review also highlighted that a quite severe/conservative estimate of design tide has been adopted which does not appear to reflect observed flood conditions
- A description of the model updates undertaken to improve the model. These updates make use of the best available data and have greatly increased the potential accuracy of the model (especially in the area of interest.
- A description of the important flood mechanisms. This highlights the relative importance/influence of tidal and fluvial flood mechanisms and also the outcomes of combined/coincident fluvial & tidal events. The change in critical flood mechanism from fluvial to tidal due to the likely impacts of climate change (including increased storm surge and sea level rise).
- A comparison of the updated model results to those of the FRMS&P model – shows that for the adopted design event (combined 100yr ARI Tide and100yr Fluvial), the updated model produces a peak flood level that is 5cm higher than the FRMS&P model. This is due to improved definition of the railway embankment.
- A summary of available calibration data found that there were not any useful calibration data points in the area of interest, and that Council was not able to supply any new useful data. The June 2005 flood event was identified as a new model qualitative verification event, with the 20yr ARI event able to reproduce observed flood behaviour.

- Model sensitivity testing was also undertaken to further improve confidence in the updated models' prediction of the critical design flood event. The model was found to be relatively insensitive to the usual range of adopted parameter values. This further increases confidence in the ability of the model to produce a realistic estimate of flood levels for the adopted design event.

Should you have any queries regarding this technical memo, please do not hesitate to contact Rohan Hudson on 4926 9506 or Ben Patterson on 4926 9503.

Ben Patterson
Technical Director
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10 References

BMT WBM (2011) ‘Belongil Creek Floodplain Risk Management Study and Plan, TUFLOW Model Review’, October 2011.

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Our reference:	PA2821	Email:	Rohan.Hudson@rhdhv.com
Classification:	Confidential		

North Byron Beach Resort Development - Flood Assessment – Assessment of Evacuation Options

Dear Sir,

Royal HaskoningDHV (RHDHV) has been commissioned to provide a response to a number of flood related questions regarding the proposed North Byron Beach Resort Development on Bayshore Drive.

This memo provides information relating to the formulation and assessment of evacuation options for the proposed development.

This memo should be read in conjunction with the previous flood advice that was provided the on 5th November 2019 and the letter data 16th September 2021 which provides further detail of the model setup and verification along with a description of key flood mechanisms.

A memo describing potential flood planning levels for the site was provided to Council on the 19th July 2021.

1 Requirement to Provide Information Regarding Flood Evacuation

Byron Shire Council raised the issue of flood evacuation in an email dated 13th August 2021 which stated:

"Council will not support sheltering in place as the sole evacuation response. The assessment should demonstrate the ability to provide for a safe and effective evacuation option for future residents that does not rely on rescue by boat. If the recommended option involves raising of a section of Bayshore Drive, the flood impacts of such work need to be addressed and information provided demonstrating how the commitment to the works can be guaranteed."

The purpose of this document aims to summarise evacuation issues and available options.

2 Evacuation Considerations

A range of factors need to be appropriately considered to assess the risks associated with development of the study site and the requirement and safety of potential evacuation options.

2.1 Summary of Flood Conditions

2.1.1 Existing Conditions (no Sea Level Rise)

A description of key flood mechanisms and details of design flood results is provided in Royal HaskoningDHV (2021d). Peak flood levels have been summarised in **Table 1**, while a graph presenting timeseries of water levels for a range of design events is presented in **Figure 1**.

These peak water levels and time-series of water levels highlight the relative importance/influence of tidal and fluvial flood mechanisms and also the outcomes of combined/coincident fluvial & tidal events. The change in critical flood mechanism from fluvial to tidal due to the likely impacts of climate change (including increased storm surge and sea level rise) is also apparent.

The current flood risk to the site is quite low, with events less than a 20yr ARI resulting in only minor flood depths. This means that evacuation would likely to only be required for events above the 20yr ARI fluvial level. The existing hazard (using H1-H6 criteria) for the 20yr ARI fluvial event is shown in **Figure 3** and shows that the highest hazard along the likely evacuation route (walking or driving up to 300m to the existing raised Bayshore Drive) is less than H2 (so safe walking or passage in a 4WD would be possible). In the 100yr ARI fluvial event (refer **Figure 4**) it can be seen that there are now some H3 hazard areas, so children or the elderly may require assistance for evacuation. The 100yr ARI tidal event produces inundation lower than the 20yr ARI fluvial event meaning that a similar evacuation response would be relevant. During a combined coincident 100yr fluvial and 100yr tidal event (i.e. Q100/T100) the extent of H3 hazard is slightly larger (refer **Figure 5**). However, it should be noted that the estimate of the T100 level is very severe and is significantly greater than any tidal flood events observed in Belongil Creek. The availability of a new water level gauge in Belongil Creek (which we believe was installed in either 2020 or 2021) will mean that a better understanding of tidal flooding will be available in the future (once a number of flood events can be examined and quantified).

Table 1: Peak Water Levels and Depths for Tidal Design Events (Updated Model)

Model Run / Scenario / Design Event	Peak Flood Level (m AHD)	Peak Flood Depth (m)
PMF (no SLR)	2.98	1.25
Combined Q100 (+30%) & T100 (2100 SLR)	3.42	1.69
Combined Q100 & T100 (2100 SLR)	3.41	1.68
T100 (2100 SLR)	3.36	1.63
Combined Q100 & T100 (2050 SLR)	2.81	1.08
T100 (2050 SLR)	2.68	0.95
Combined Q100 & T100 (no SLR)	2.38	0.65
Q100, no tide (no SLR)	2.28	0.55
T100 (no SLR)	2.04	0.31
Q20, no tide (no SLR)	2.08	0.35
Q10, no tide (no SLR)	1.88	0.15
Q5, no tide (no SLR)	1.85	0.12

Note: the location of the water level point is provided near the middle of the development.
Ground Level is 1.73m AHD. Q100 is the 100yr ARI fluvial design event, while T100 is the 100yr ARI tidal design event.

Royal HaskoningDHV

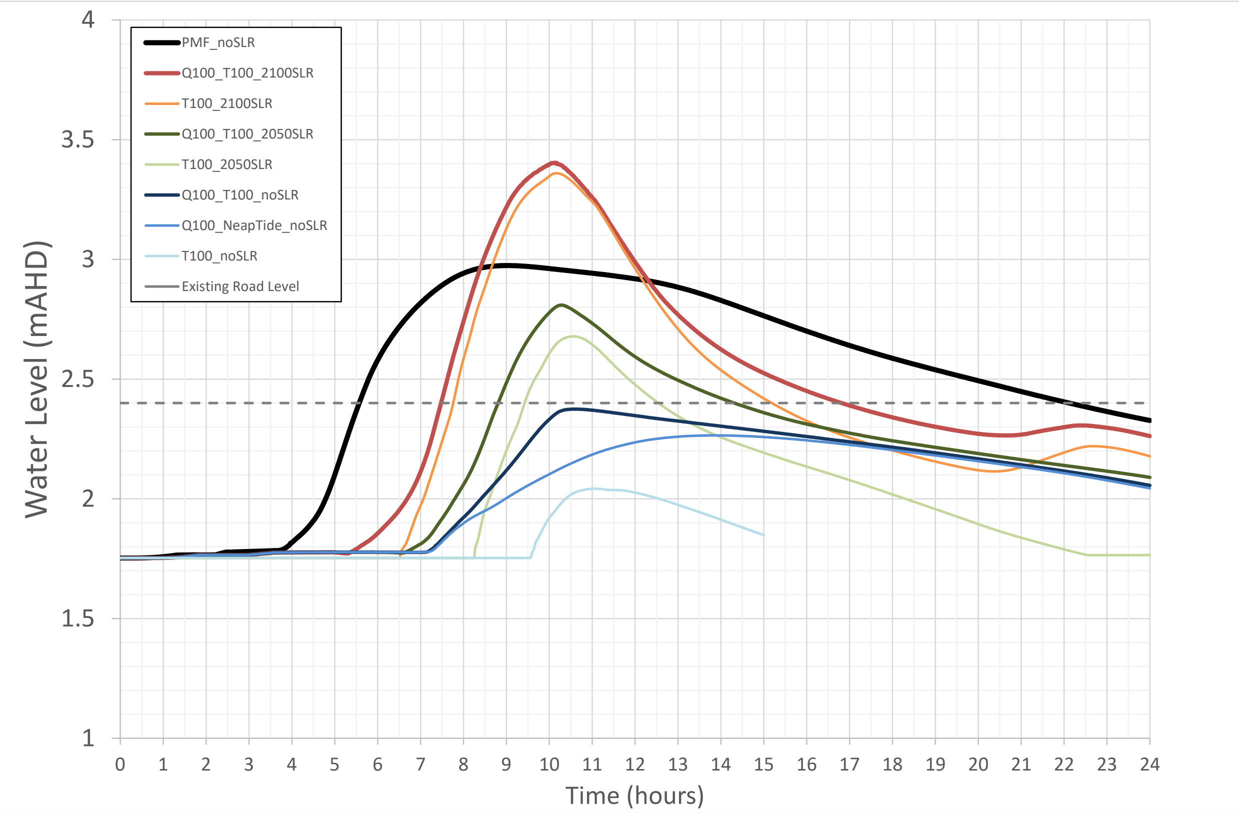


Figure 1: Time Series for a Range of Design Flood Events – Updated Model (including SLR)

Note: the location of the water level point is provided near the middle of the development.
Ground Level is 1.73m AHD. Q100 is the 100yr ARI fluvial design event, while T100 is the 100yr ARI tidal design event.

Examining the flood mechanisms described in Royal HaskoningDHV (2021d), the presence of a flow constriction downstream of the proposed development means that the flood velocities on the site are very low due to the very low water gradient, that is predicted in both fluvial and tidal events.

2.1.2 Future Conditions (Sea Level Rise and Climate Change)

While the current (i.e. no SLR) flood hazard seems low, combining conservative estimate of the 100yr design tide events with 0.4 and 0.9m of sea level rise (SLR) produces flood levels and associated flood hazards in which safe evacuation becomes more of an issue. It is important to note that there exists a significant uncertainty regarding the timing (i.e. rate) and magnitude of future SLR (refer Section 5).

Because a house is likely to have a design life of 50+ years, and is typically difficult to raise once constructed, the adoption of a flood planning level (FPL) that considers future increases in sea level rise important. However, because roads and driveways can more easily be raised in the future, a wait and see approach is considered reasonable for the requirement of a flood evacuation route.

The setting of a high floor level that is above the PMF level, also significantly reduces the requirement for evacuation, in that it eliminates any drowning risk and leaves only the potential risk of a medical emergency. The likelihood of a medical emergency occurring during the 12-16 hour isolation window that could occur during rare flood event, is considered very low. Given that there are only nine properties that are proposed as part of the new development, the risk of medical emergency is further reduced because of the very low population at risk.

Evacuation distances and the rate at which flood water rise should also be considered. Higher (flood free) ground is available along a driveway / road at a maximum distance of 900m. Assuming a vehicle safe low speed of 10 km/h it would take less than 5 minutes to drive to a flood free location along Bayshore Drive. For a slow walking speed of 1 m/s it would take a maximum of 15 minutes to walk to a safe flood free location along Bayshore Drive. Though given evacuation is only required for those who may require medical assistance, shelter in place should be considered appropriate for most future residents. The graphs presenting timeseries of water levels for a range of design events presented in **Figure 1**, show that the maximum rate of water level rise is 0.5 m/hr. Given a maximum evacuation time of 15 minutes, this means that once evacuation commences, the maximum level water would rise is 0.125m. This relatively slow rate-of-rise, coupled with short evacuation distances and low (9) number properties, means that if evacuation is required it is likely to be considered low risk, especially when coupled with an appropriate flood warning system.

2.2 Summary of Evacuation Consideration

A summary of key facts influencing site evacuation includes:

- The existing Bayshore Drive road level is 2.5 m AHD.

- The proposed 100yr ARI, 2100 flood level is 3.4 m AHD. Council DCP states evacuation must be within 0.3 m of this level. This means a road with a 3.1 m AHD crest level may be required.

- If the new road (Bayshore Drive Extension) is higher than the existing Bayshore Drive, then adverse safety conditions could occur if the lower part of the road is flooded. **Figure 2** presents the location of the existing Bayshore Drive road and the proposed Bayshore Drive extension (it is currently a gravel road/track).

- It is important to note that the 100yr ARI 2100 peak tide level (3.49 m AHD), is extremely conservative and is based on a high estimate of the 100yr ARI storm surge (2.29m AHD) with an additional 0.9m sea level rise (SLR) and 0.3m for increased storm surge.

- The current 100yr ARI combined tidal and fluvial peak flood level is 2.4 m AHD, while the PMF level is 3.0 m AHD.

- The adopted flood planning level (FPL) and hence floor level is 3.9 m AHD. This means properties are well above potential flood levels even in the most extreme of conditions. Because of the high floor level, if evacuation is not possible, then low risk shelter in place provides a safe option, provided urgent medical evacuation is not required. A typical isolation time of 6-12 hours (refer **Figure 1**) is likely due to the nature of tidal inundation. However, in the PMF a maximum isolation time of 12-24 hours is possible due to the slow passage of stored upstream flood waters, though it is important to realise frequency of a PMF is considered between a 1 in 10,000 and 1 in 100,000 year ARI event.

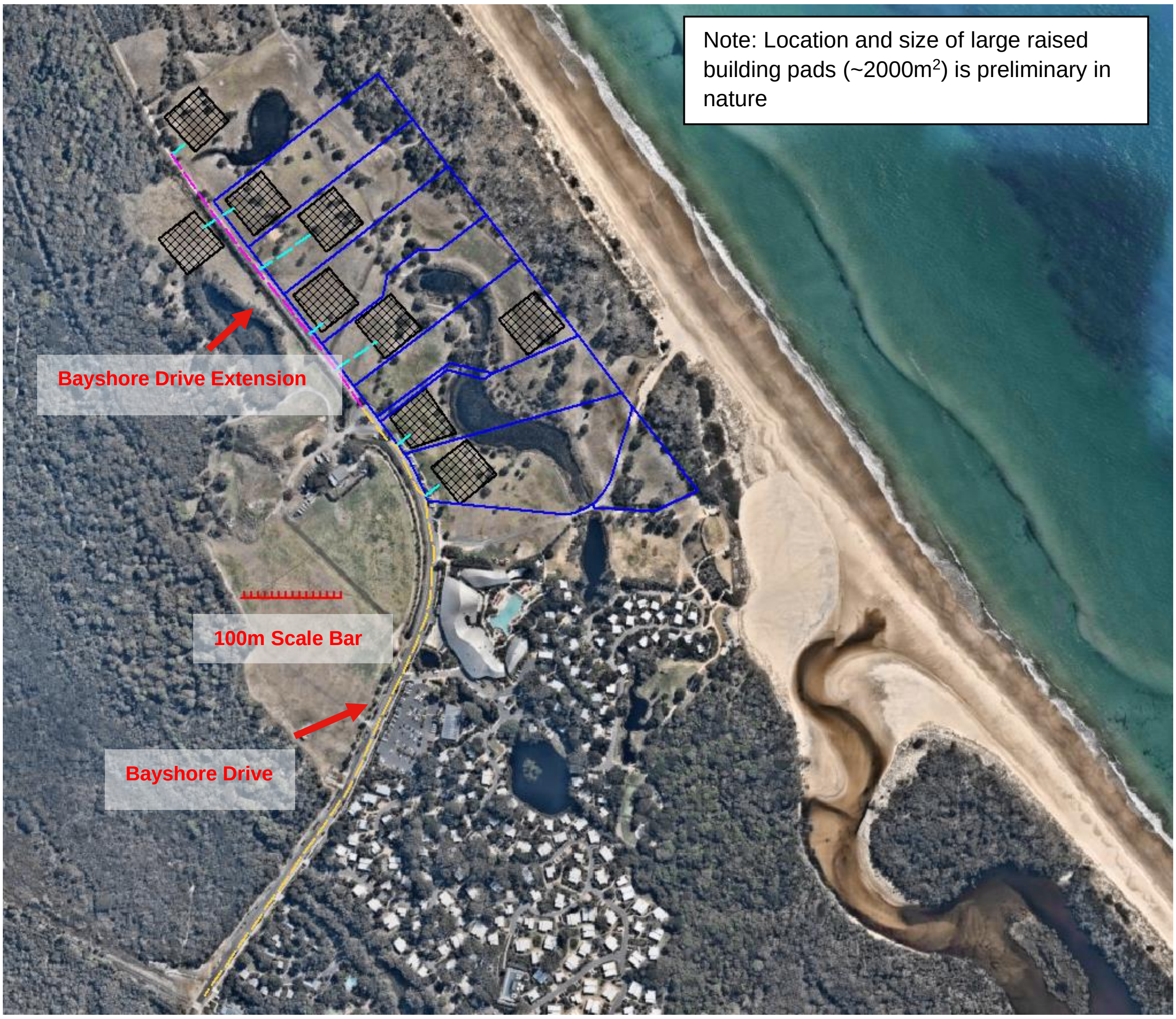


Figure 2: Proposed Bayshore Drive Extension and Preliminary Location of Large (2000m^2) Building Pads

Notes:
- black hatched areas are nine, 45 x 45m raised pads (location of the pads is preliminary with the actual location and size of the buildings to be determined at a later date after consideration of coastal hazard and other design considerations).
- dark blue lines are preliminary lot boundaries
- pink line is extended Bayshore Drive (may be raised to 2.1, 2.5mAHD or 3.1mAHD)
- light blue line is potential driveways
- orange line is existing Bayshore Drive (crest is minimum 2.5mAHD)

2.3 Potential Safe Evacuation Options

Potential options for safe evacuation of the proposed development include:

2.3.1 Site Evacuation - Option A

Extend Bayshore Drive at 3.1 m AHD, raise existing Bayshore Drive to 3.1 m AHD. This option is feasible and would only increase flood levels by 1-3 cm (refer Section 4) as the volume of road raising is negligible compared to the volume of tidal flood inundation. As the road is still overtopped by some 0.3 m, water can still pass over the road. Water can also pass around the road and driveways along the main flow path to the north/east of the site. Raising the existing section of Bayshore Drive would be difficult and costly due to the requirement to cover existing services and required changes in grades to existing driveways and road entrances.

2.3.2 Site Evacuation - Option B

Extend Bayshore Drive at 3.1 m AHD, raise existing Bayshore Drive based on SLR trigger (refer Section 2.4). This option combines future proofing the new raised section of the road, but leaves raising the existing length of Bayshore Drive until at least 0.4 m of sea level rise has occurred (noting that the existing 2.5 m AHD road level would only be flooded by a maximum 0.3m in the 100yr tide and fluvial event with 2050 levels of SLR (i.e. 0.4m)).

2.3.3 Site Evacuation - Option C

Extend Bayshore Drive at 2.5 m AHD, raise all Bayshore drive to 3.1 m AHD based on SLR trigger (refer Section 2.4). The installation of a flood warning system to provide minimum 1 hour evacuation allowance, would further increase the level of safety associated with this option. Given the small area covered by the development, a standalone siren based system would be appropriate.

2.3.4 Site Evacuation - Option D

Do not raise the Bayshore Drive extension but install appropriate flood warning system and set SLR trigger for raising the road in the future. The flood warning system could range from a simple system (using a combination of water level and rainfall gauges along with appropriate trigger levels) or a more complex modelling system (with a continuous 6-12 hour forecast windows providing minimum 2 hours evacuation window). Provision of a tractor or vehicle (i.e. Unimog) that can safely travel in water above a minimum 1.2 m should be considered. Examination of flood results indicate that a downstream water level (tidal) gauge with a trigger set at approximately 1.5 m AHD would provide 1-2 hours warning for a tidal inundation event. Warnings for fluvial events could be based on either observed or forecast rainfall. An example would be to evacuate the area if say 300mm of rain in the past 24 hours was recorded or 400mm over the next 12 hours is forecast (using a numerical weather prediction product). The exact trigger levels would be determined using a site specific study. The warnings could be delivered by SMS or given the small area of the site a flood warning siren could be installed.

2.3.5 Site Evacuation - Option E

Slightly raise the Bayshore Drive extension and combine with features of Option D. By raising the road to say 2.1mAHD, this would make the existing evacuation conditions even safer, and would allow a higher SLR trigger level to be considered. For the 100yr ARI (no SLR) design event, the maximum flood hazard for the proposed development in presented in **Figure 6** and shows a worst case H2 classification along the evacuation route which means that people of 4WD could safely move along the evacuation route.

2.4 Sea Level Rise Trigger Considerations

Given that under the existing (no SLR) conditions, the site does not currently have a flood risk that could create an evacuation hazard, the requirement to implement a solution for a problem that is yet to occur does not seem a wise use of limited natural resources. While the safety of the proposed development does need to be considered, the use of a SLR trigger would allow current development of the site to occur with the development consent to include a trigger or timed consent condition that states that, for example, Bayshore Drive must be raised when a trigger of 0.2m of SLR is observed to have occurred. Alternatively the consent could include a timed consent that requires that say every 10 years an assessment of the flood risk is re-assessed in relation to evacuation requirements. These conditions of consent are described in Section 4.7 of the NSW Coastal Planning Guideline – Adapting to Sea Level Rise (NSW Department of Planning, August 2010).

The re-assessment of flood risk every 10 years would allow both:

- an assessment of the actual changes to the rate and magnitude of SLR
- allow for an analysis of recorded Belongil Creek water levels to determine a more accurate peak 100yr ARI level for tidal inundation to occur.

2.5 Evaluation of Evacuation Approaches

A recommended approach to evacuation is presented below. It is based on:

- a consideration of current (i.e. no SLR) and future flood mechanisms at the proposed development site and
- a consideration of the five potential evacuation options as presented in Section 2.3.

While **Option A** (raising the Bayshore Drive extension to 3.1 m AHD and raise existing road from 2.5m to 3.1mAHD) would provide a very safe and future proofed evacuation option for the proposed development, it would result in a road/driveway that is some 1.3 m above the existing ground levels and may not sit well with the current natural setting. In addition the existing Bayshore Drive was only constructed some 6 years ago, so raising it in such a short timeframe would seem a waste of resources.

Given that there is currently (i.e. under no SLR conditions) no significant evacuation risk at the site and the uncertainty associated with SLR predictions (refer Section 5), this option is not currently considered appropriate for the low level of risk current risk and high level of uncertainty associated with both SLR predictions and the accuracy of the 100yr ARI storm tide.

However, it is important to note, that if this option was required, Section 4 shows that there is not significant adverse flood impact associated with raising the new and existing parts of Bayshore Drive to 3.1 m AHD.

Option B (raising the Bayshore Drive extension to 3.1 m AHD and raise existing road from 2.5m to 3.1mAHD based on SLR trigger) is not recommended because in the event a severe flood does occur prior to raising the existing parts of Bayshore Drive, residents may experience hazardous conditions traversing from 3.1 m AHD down to 2.5 m AHD.

Option C (extend Bayshore drive at 2.5 m AHD, raise all Bayshore drive to 3.1 m AHD based on SLR trigger). This option seems a reasonable compromise, though does not really consider there is currently minimal evacuation hazard at the site and assumes that the current prediction of the 100yr ARI tide level is appropriate, when likely it is very conservative and is not backed up by the current observed flood record.

Option D (do not raise the Bayshore Drive extension but install appropriate flood warning system and set SLR trigger for raising the road in the future), is an appropriate option that considers the relatively low level of current flood evacuation risk at the site. It takes into account that adopting an FPL of 3.9 m AHD means that the 9 proposed residences are above the PMF level (so shelter in place is considered safe provided a medical evacuation is not required). Given the development only includes nine residences, the very low population at risk, means the likelihood of requiring a medical evacuation is extremely low. However, a flood warning system, that allows residents to safely evacuate would further reduce evacuation risk. Likewise the provision of a dedicated tractor or vehicle (i.e. Unimog) that can safely travel in water above a minimum 1.2 m should be considered to further reduce evacuation risk without the requirement for road raising.

Option E (raise the Bayshore Drive extension to 2.1 m AHD and set SLR trigger for raising the road in the future) is an appropriate option that provides a reduction in evacuation hazard compared to Option D. Because the extended section of Bayshore Drive is raised to within 0.3 m of the peak 100yr ARI existing condition flood level and flood warning system may no longer be required (though could be used to further reduce the potential for medical evacuation during a severe flood event). This lower crest road should be easier to provide landscaping that reduces the visual impact such that site amenity is largely retained, while a defined evacuation route would reduce flood hazard if an emergency evacuation was required during a severe flood event. It would also increase the period of time before a SLR trigger may require further raising of the road level. During this period an increased understanding of SLR and design tides could be gained to better understand the future flood risk.

3 Hazard Classification Maps

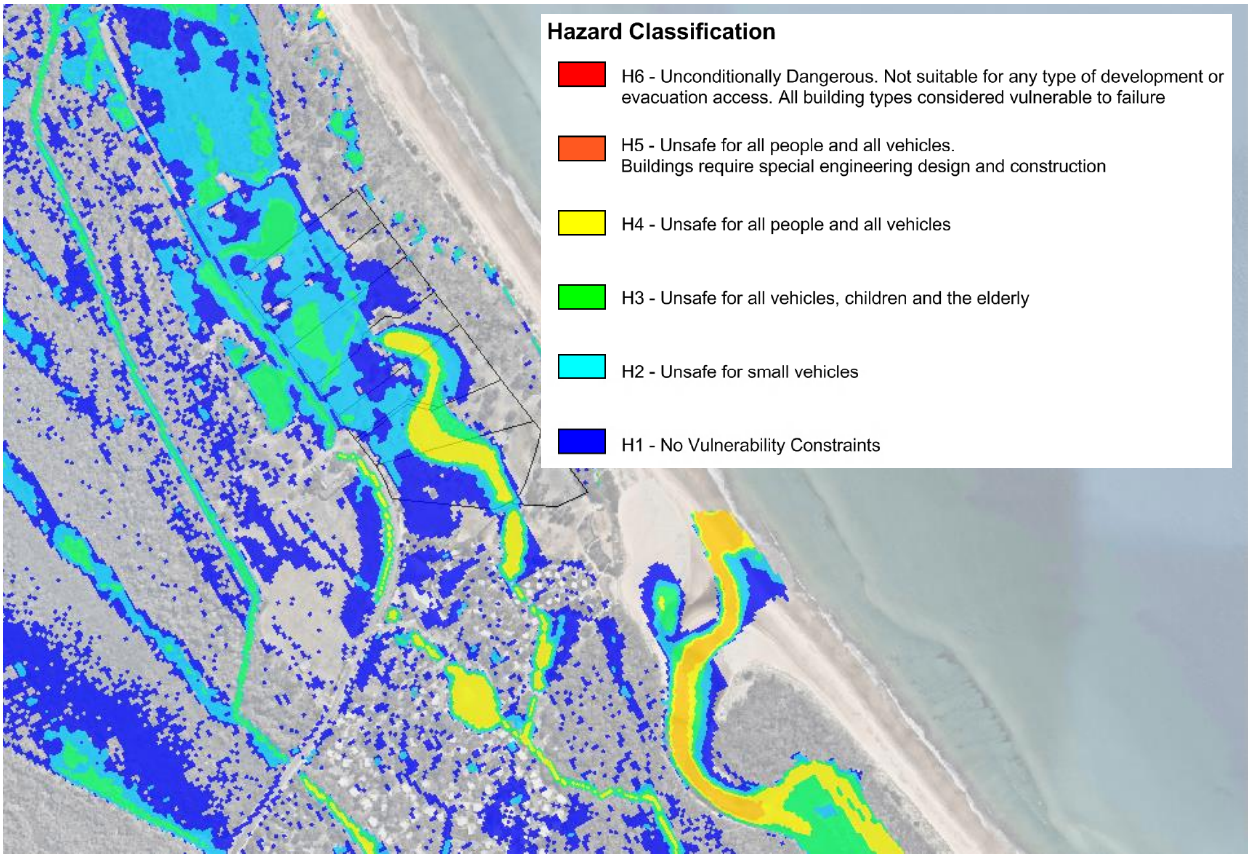


Figure 3: *20yr ARI Fluvial with Neap Tide and no SLR - Flood Hazard*

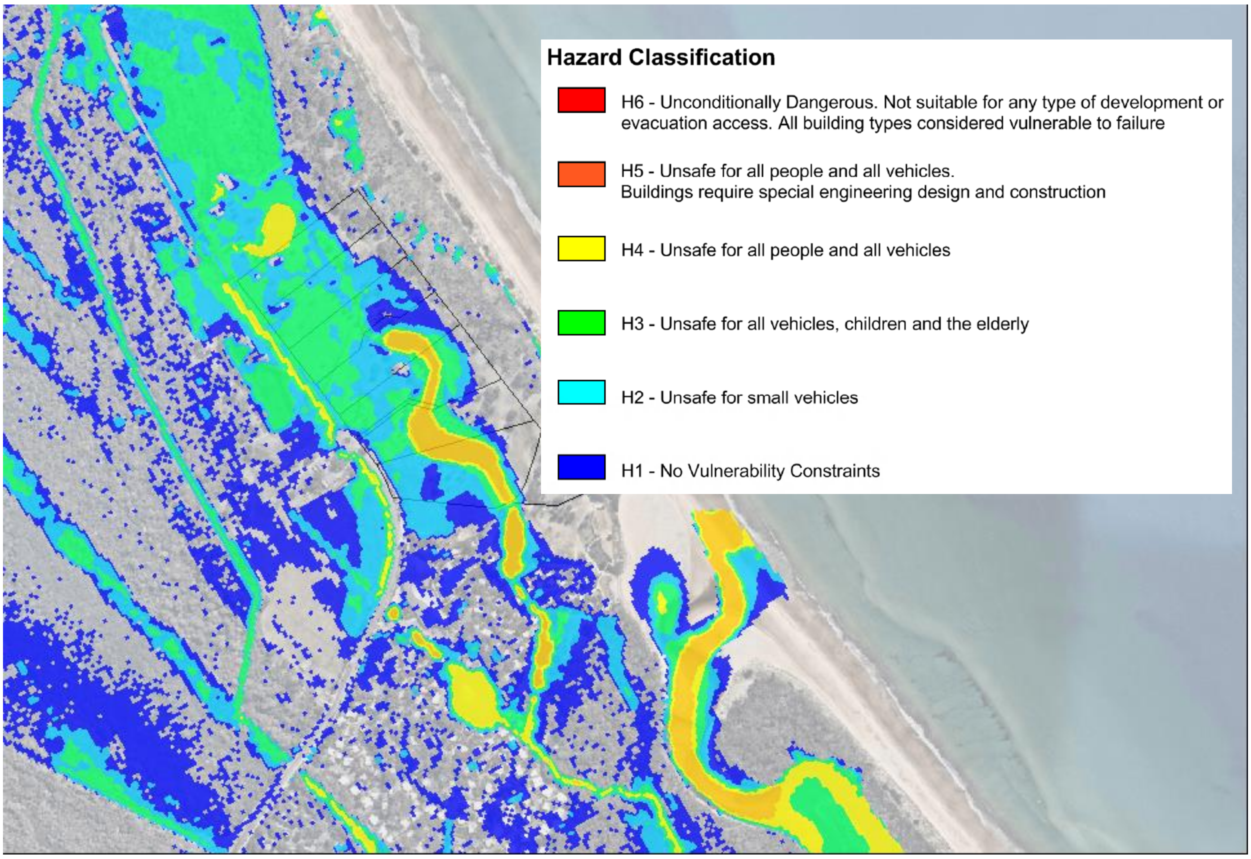


Figure 4: *100yr ARI Fluvial with Neap Tide and no SLR - Flood Hazard*

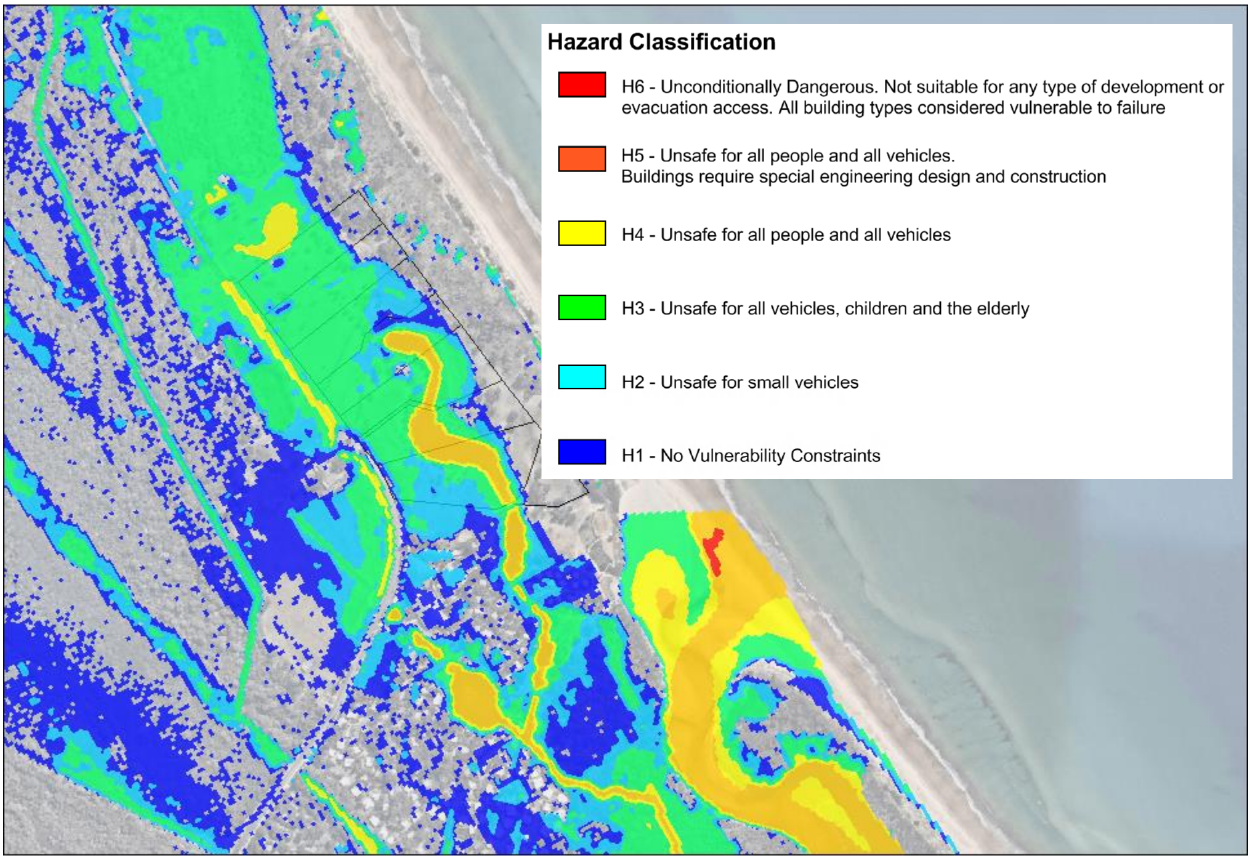


Figure 5: *100yr ARI Fluvial with 100yr ARI Storm Tide and no SLR - Flood Hazard*

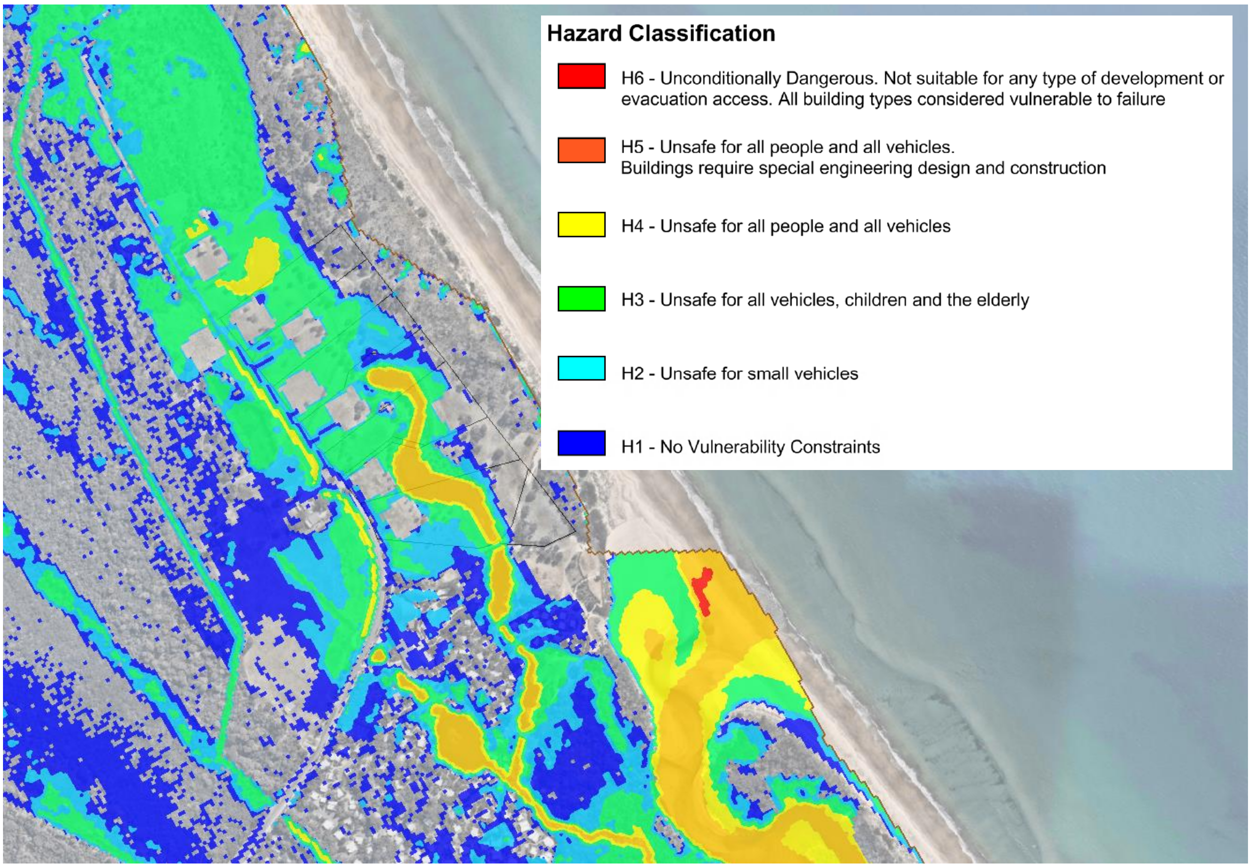


Figure 6: *100yr ARI Fluvial with 100yr ARI Storm Tide and no SLR - Flood Hazard (Option E – Bayshore Extension at 2.1mAHD)*

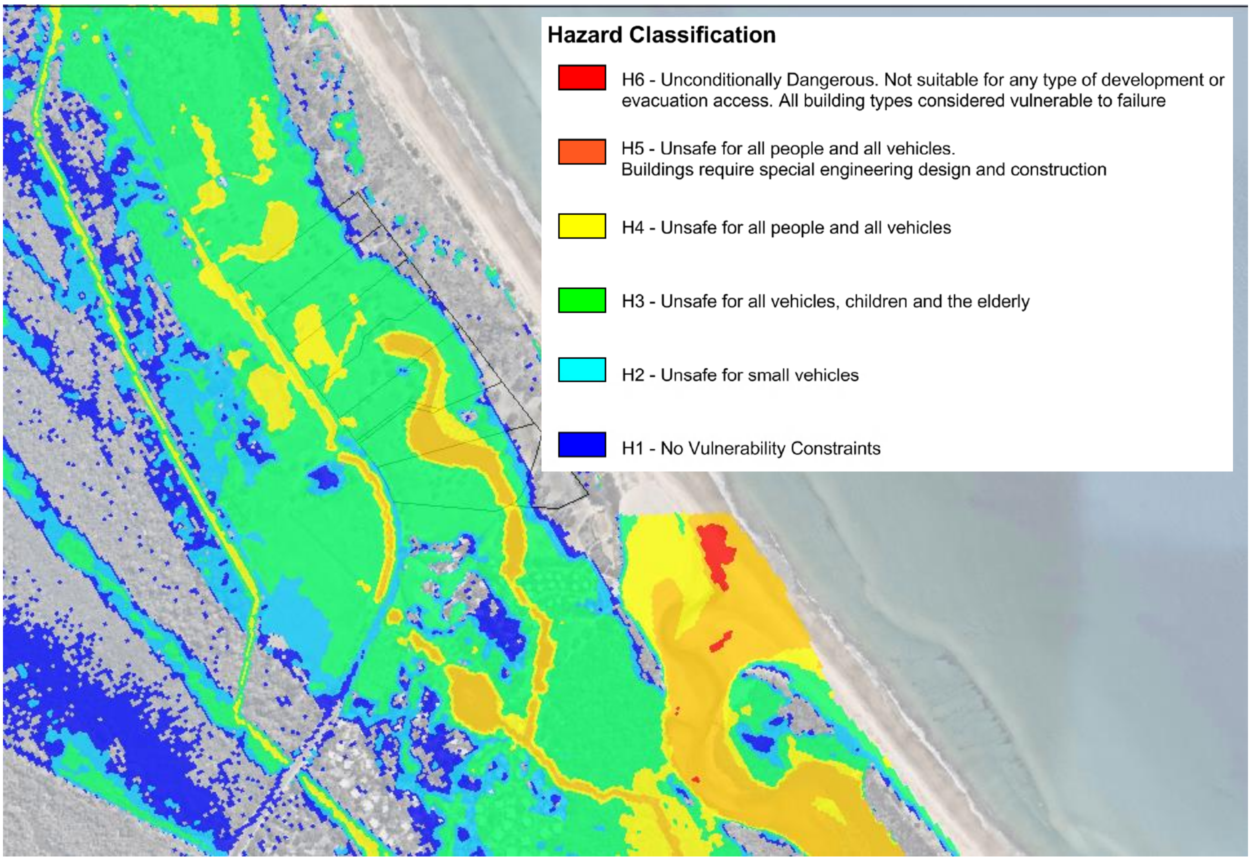


Figure 7: *100yr ARI Fluvial with 100yr ARI Storm Tide and 2050 SLR - Flood Hazard*

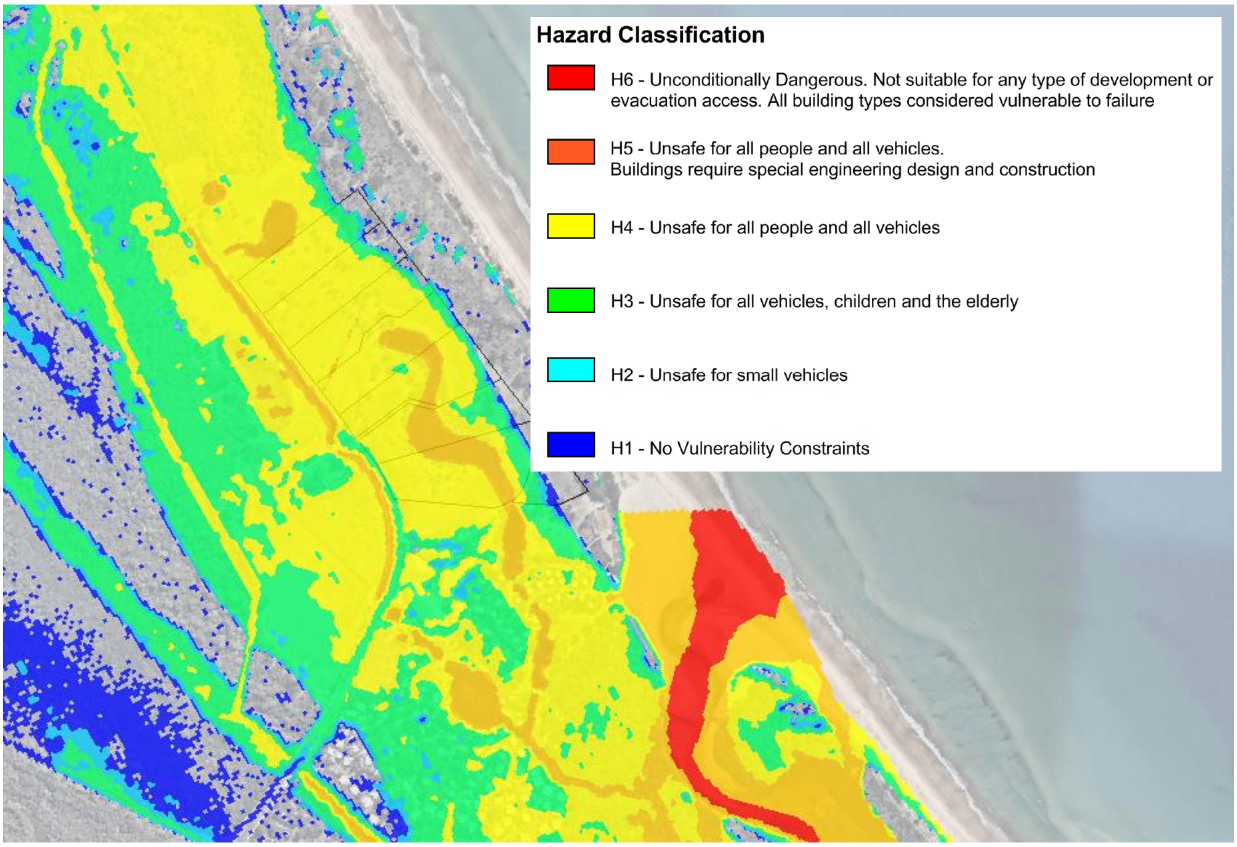


Figure 8: *100yr ARI Fluvial with 100yr ARI Storm Tide and 2100 SLR - Flood Hazard*

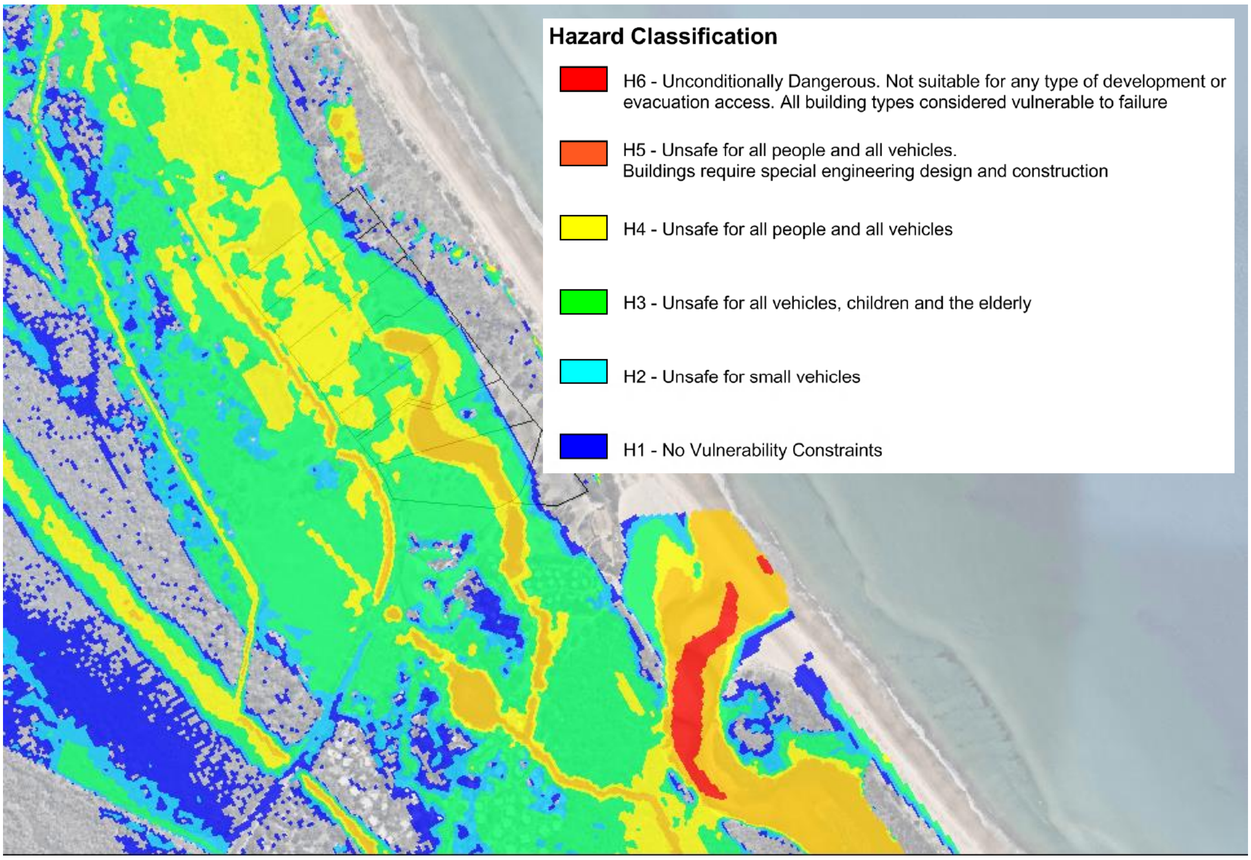


Figure 9: *PMF no SLR - Flood Hazard*

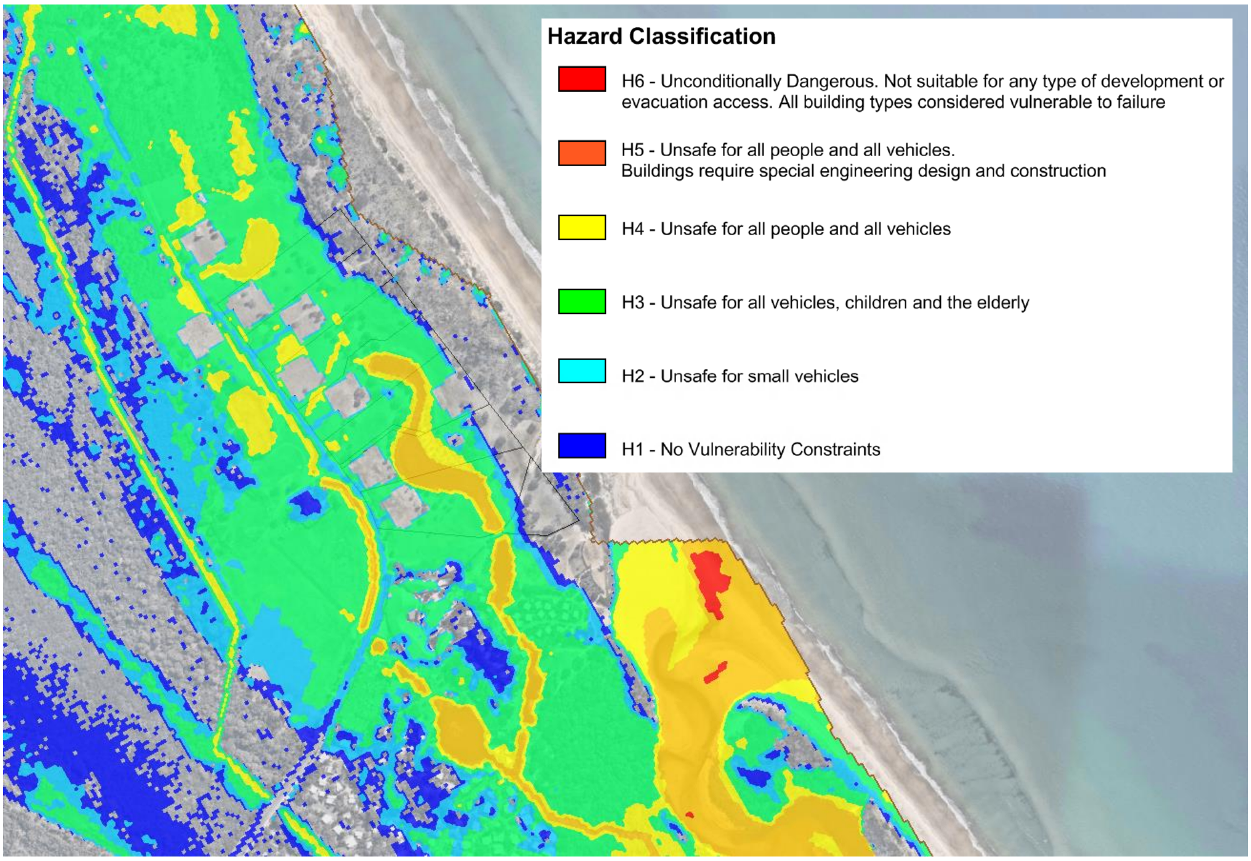


Figure 10: *100yr ARI Fluvial with 100yr ARI Storm Tide and 2050 SLR - Flood Hazard (Bayshore Drive Extension @ 2.5 m AHD)*

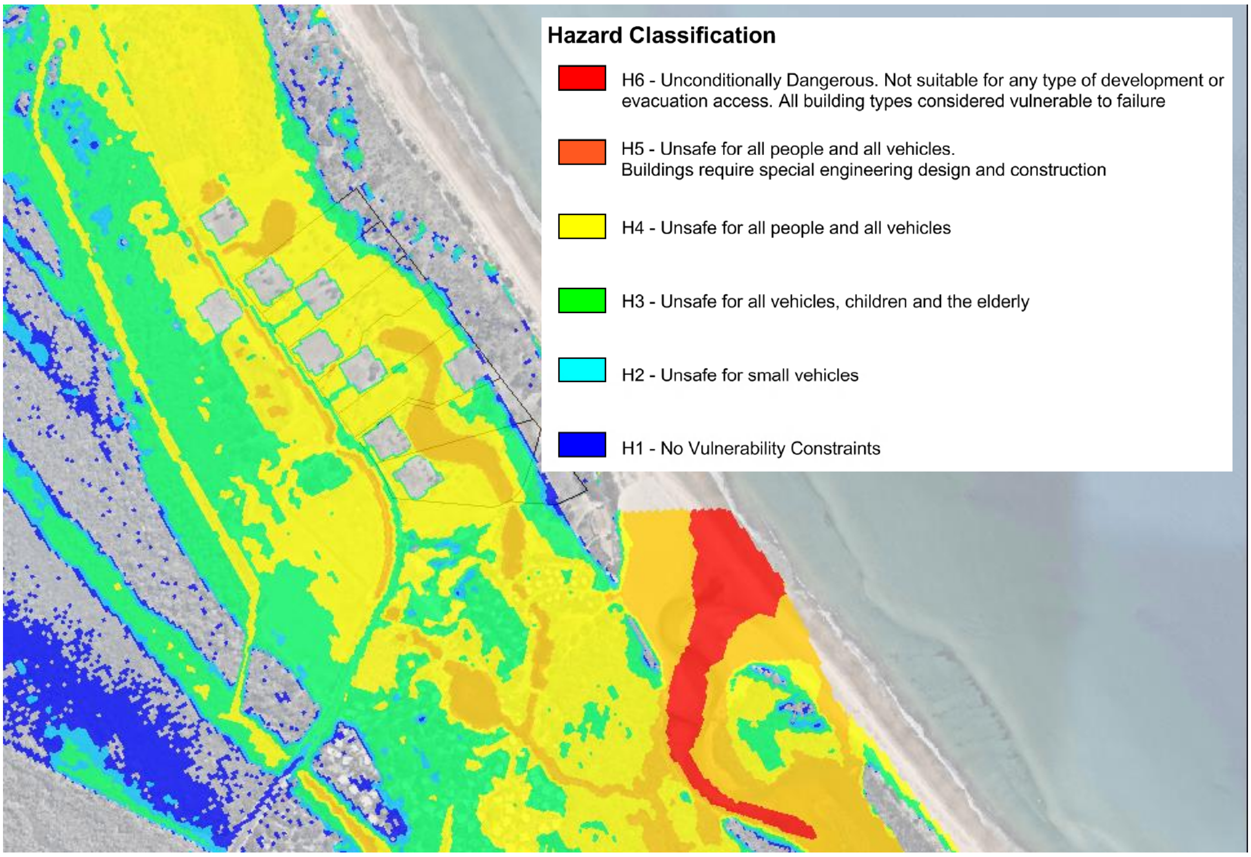


Figure 11: *100yr ARI Fluvial with 100yr ARI Storm Tide and 2100 SLR - Flood Hazard (Bayshore Drive Extension @ 2.5 m AHD)*

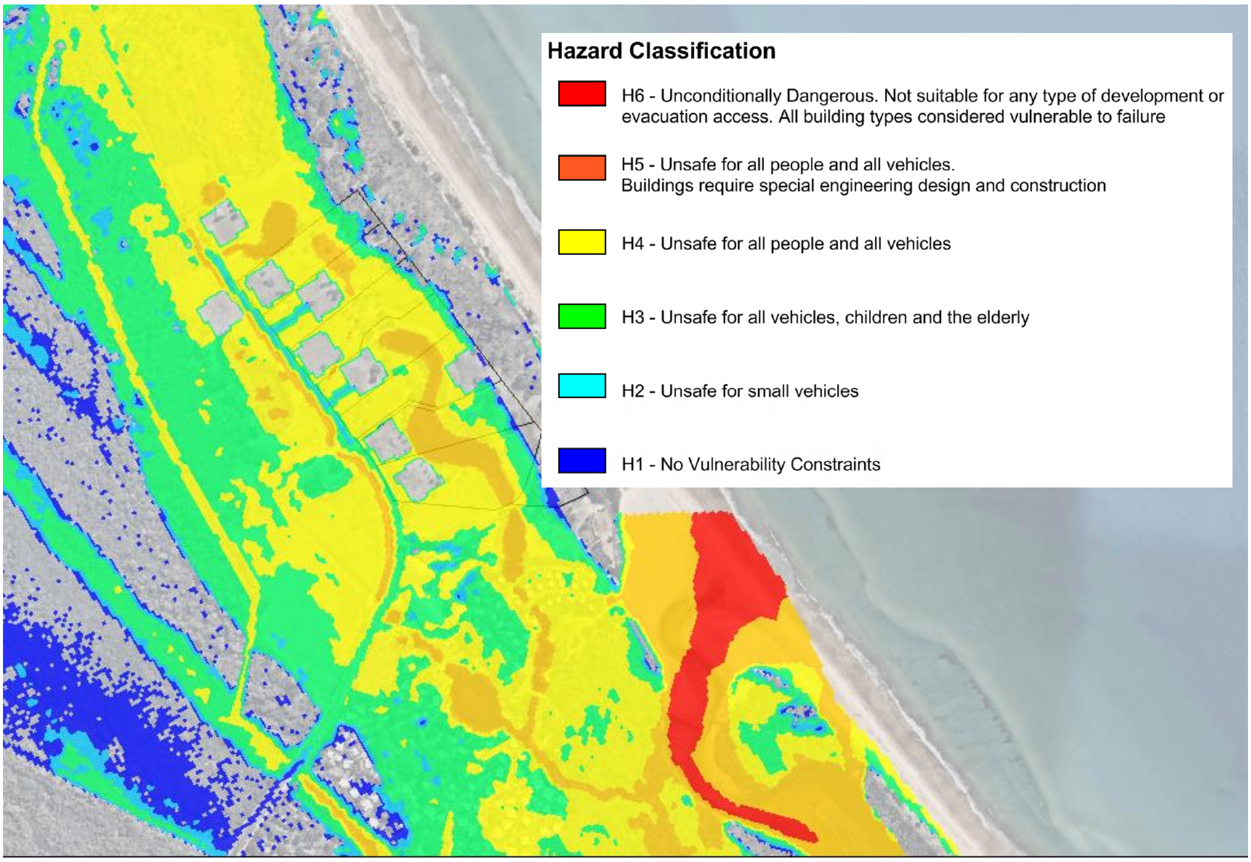


Figure 12: *100yr ARI Fluvial with 100yr ARI Storm Tide and 2100 SLR - Flood Hazard (Bayshore Drive Extension @ 3.1 m AHD)*

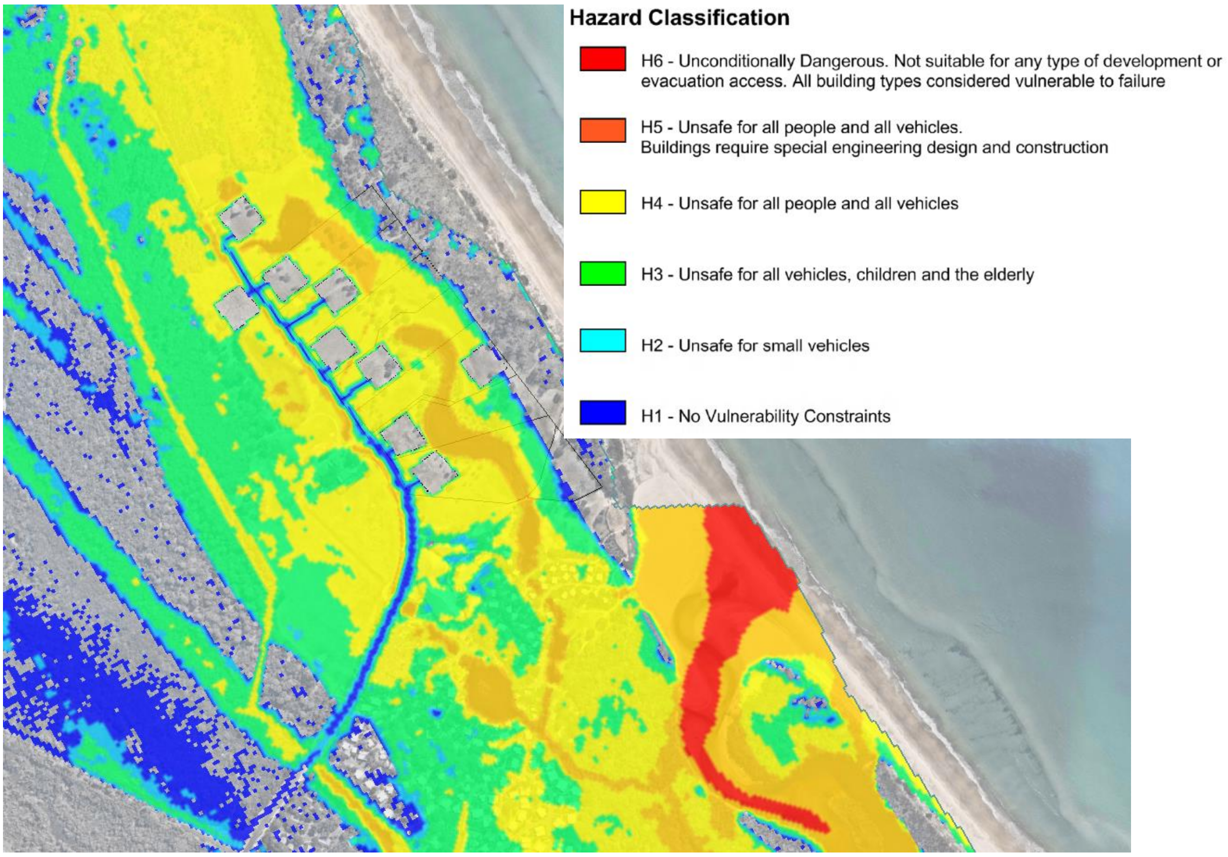


Figure 13: *100yr ARI Fluvial with 100yr ARI Storm Tide and 2100 SLR - Flood Hazard (Bayshore Drive & Extension @ 3.1 m AHD)*

4 Flood Impact of Raising Bayshore Drive Extension

The TUFLOW model described in Royal HaskoningDHV (2019d) was updated to include an approximation of the proposed development including a number of raised road options.

It should be noted that the very large (45x45m) building pads (as previously reported in Royal HaskoningDHV (2019b)) were adopted, however, the location of one building pad was moved closer to the Bayshore Drive extension to prevent a raised driveway interrupting a key flow path. It should be noted that the exact location of the raised pads is yet to be determined. If a driveway is required across the flowpath, the use of bridging or culverting may need to be considered.

The model was used to simulate the raising of the proposed Bayshore Drive extension to 2.5m for the existing conditions (**Figure 14**) and raising the proposed and existing sections of Bayshore Drive to 3.1m for the 2100 scenario (**Figure 15**). The impact of the proposed development and raising the extended Bayshore Drive crest to 2.5 mAHD is less than 2-3cm but does not extend offsite. This impact occurs because the road level is at a similar level to the peak flood level, so the road crest acts to redistribute flow and the raised pads also reduce flood storage volume.

In the 2100 SLR event, the peak flood level of 3.4 m AHD is above the crest of the road, so the impact of the development and road raising is less than 1 mm (**Figure 15**).

Figure 14: Location of Large (2000m^2) Building Pads and Predicted Flood Impact (Q100/T100 yr ARI)

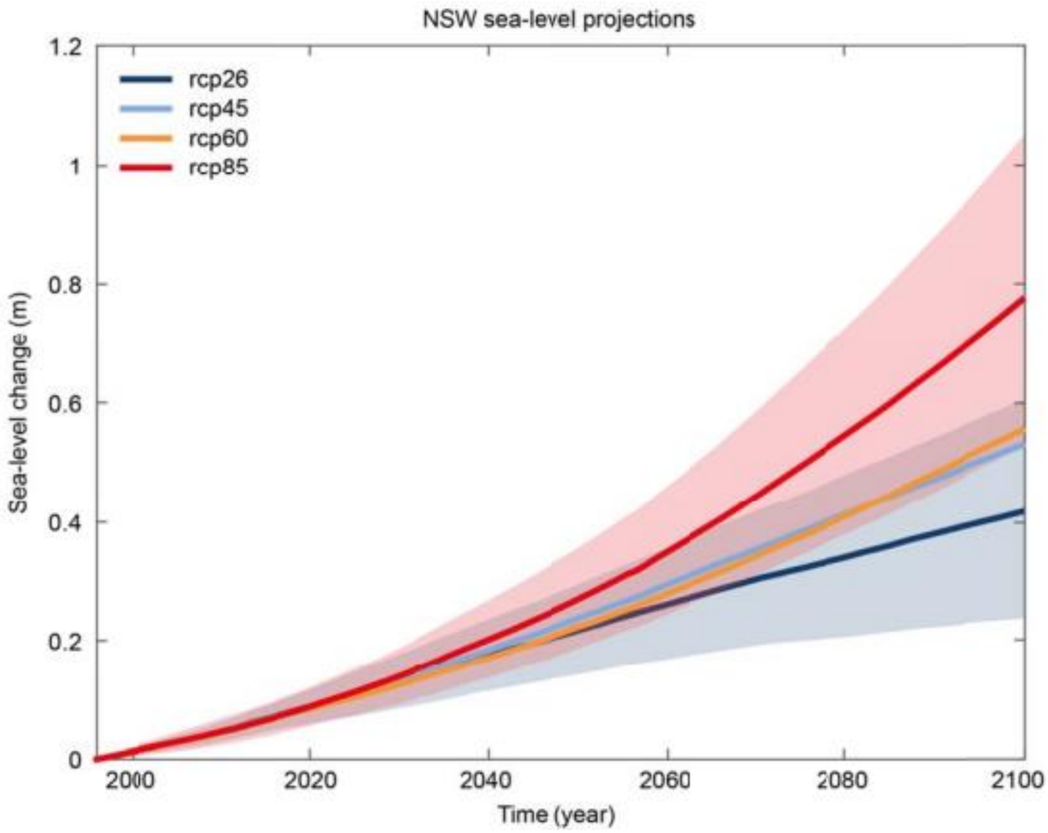
Notes: - black hatched areas are nine, 45 x 45m raised pads (location of the pads is preliminary with the actual location and size of the buildings to be determined at a later date after consideration of coastal hazard and other design considerations).
- light blue line is extended Bayshore Drive raised to 2.5mAHD or 3.1mAHD (impact is same as road is not overtopped)
- orange to red is increased flood levels between 1-5 cm

Figure 15: Location of Large (2000m^2) Building Pads and Predicted Flood Impact (2100)

Notes:
- black hatched areas are nine, 45 x 45m raised pads (location of the pads is preliminary with the actual location and size of the buildings to be determined at a later date after consideration of coastal hazard and other design considerations).
- light blue line is existing an extended Bayshore Drive raised to 3.1mAHD
- orange to red is increased flood levels between 1-5 cm

5 Consideration of Estimated Sea Level Rise Data

WRL Tech Report 2015/15 - Sea Level Rise Science and Synthesis for NSW, shows that the range of predicted 2100 SLR is from 0.24m (low RCP2.6) to 1.06 m (high RCP8.5) above 1996 levels and shows Byron Shire Councils adoption of 0.9m is considered conservative. The uncertainty in SLR predictions will reduce as climate science further matures and global greenhouse gas emissions reduction responses and pathways are clearer.



Scenario	RCP2.6	RCP4.5	RCP6.0	RCP8.5
	Sea Level rise relative to the coast (m)			
2030	0.13 [0.09-0.18]	0.13 [0.09-0.18]	0.13 [0.08-0.17]	0.14 [0.10-0.19]
2050	0.22 [0.14-0.29]	0.24 [0.16-0.31]	0.22 [0.15-0.30]	0.27 [0.19-0.36]
2070	0.30 [0.19-0.42]	0.35 [0.24-0.48]	0.34 [0.23-0.46]	0.45 [0.31-0.59]
2090	0.38 [0.22-0.54]	0.47 [0.30-0.65]	0.48 [0.32-0.66]	0.66 [0.45-0.88]
2100	0.42 [0.24-0.61]	0.53 [0.34-0.74]	0.56 [0.37-0.77]	0.78 [0.54-1.06]
	Rate of Rise (mm yr^{-1})			
2081-2100	3.9 [1.5-6.4]	5.9 [3.1-8.8]	7.4 [4.5-10.5]	11.7 [7.6-16.6]

Note: The central values are given for each greenhouse gas scenario with the ***likely*** range (66% confidence limits) in brackets. The last row gives the rate of rise over the last two decades of the 21st century. The central values provides an estimate of the ***likely*** range (66% confidence limits). The values for 2030, 2050, 2070 and 2090 are twenty year averages.

Figure 16: *Projection of Sea Level Rise, Averaged Along the New South Wales Coast, from 1996 to 2100*

6 Summary and Conclusions

This memo provides information relating to the formulation and assessment of evacuation options for the proposed development at North Byron. The options indicate that there are a range of evacuation options that are suitable for dealing with the current and future levels of flood risk at the site. The selected option will partly depend on the exact details of the development (including size, number and location of buildings) which will be defined at the development application stage, when a detailed evacuation management plan would be required.

6.1 Existing and Future Flood Evacuation Risk

The current flood risk to the site is quite low, with events less than a 20yr ARI resulting in only minor flood depths. This means that evacuation would likely to only be required for events above the 20yr ARI fluvial level. The existing hazard (using H1-H6 criteria) for the 20yr ARI fluvial event is shown in **Figure 3** and shows that the highest hazard along the likely evacuation route (walking or driving up to 300m to the existing raised Bayshore Drive) is less than H2 (so safe walking or passage in a 4WD would be possible). In the 100yr ARI fluvial event (refer **Figure 4**) it can be seen that there are now some H3 hazard areas, so children or the elderly may require assistance for evacuation. The 100yr ARI tidal event produces inundation lower than the 20yr ARI fluvial event meaning that a similar evacuation response would be relevant. During a combined coincident 100yr fluvial and 100yr tidal event (i.e. Q100/T100) the extent of H3 hazard is slightly larger (refer **Figure 5**). However, it should be noted that the estimate of the T100 level is very severe and is significantly greater than any tidal flood events observed in Belongil Creek.

While the current (i.e. no SLR) flood hazard seems low, combining conservative estimate of the 100yr design tide events with 0.4 and 0.9m of sea level rise (SLR) produces flood levels and associated flood hazards in which safe evacuation becomes more of an issue. It is important to note that there exists a significant uncertainty regarding the timing (i.e. rate) and magnitude of future SLR (refer Section 5).

Because a house is likely to have a design life of 50+ years, and is typically difficult to raise once constructed, the adoption of a flood planning level (FPL) that considers future increases in sea level rise important. However, because roads and driveways can more easily be raised in the future, a wait and see approach is considered reasonable for the requirement of a flood evacuation route.

The setting of a high floor level that is above the PMF level, also significantly reduces the requirement for evacuation, in that it eliminates any drowning risk and leaves only the potential risk of a medical emergency.

6.2 Discussion and Summary of Evacuation Options

It is considered that either Option D or Option E provide a suitable evacuation option that is commensurate with the existing flood risk at the site. The setting of the floor level above the PMF, means that evacuation is only required if a medical emergency occurred in one of the nine properties during the up to 16 hour isolation window.

The provision of SLR triggers for raising the road in the future provide a suitable mechanism for ensuring safe evacuation is available in the future when SLR increases the impact of tidal inundation.

While a flood warning system (FWS) (Option D) would be effective at given people the opportunity to evacuate early, raising the road to 2.1m (Option E) would mean that safe evacuation would be available in events up to and including the 100yr ARI. For the 100yr ARI (no SLR) design event, the maximum flood hazard for the proposed development in presented in **Figure 6** and shows a worst case H2 classification along the evacuation route which means that people or a 4WD could safely move along the evacuation route.

Both the options are future proofed in that they incorporate SLR triggers that require raising of Bayshore Drive when certain levels of SLR are observed. The benefit of Option E is that because the extended section of the road has already been raised to 2.1mAHD, a higher trigger level would be applicable.

Potential risk associated with Option E would further be reduced by the availability of a FWS, while the residual risk of both these options would be further reduced by the provision of a dedicated tractor or vehicle (i.e. Unimog) that can safely travel in water above a minimum 1.2 m. The funding, storage, maintenance and operation of such a vehicle would need to be appropriately considered and the mechanism/instrument to link it to development consent determined. Likewise the mechanism/instrument to link both FWS requirements and SLR triggers to development consent conditions would also need to be determined.

If appropriate planning mechanisms that incorporate timed or trigger based consent conditions cannot be established, then Option C (extend Bayshore drive at 2.5 m AHD) is considered an appropriate option that considers future risk and existing site constraints. Option B (extend Bayshore drive at 3.1 m AHD) is not considered safe (unless the existing Bayshore Drive is also raised). While Option A (raising the Bayshore Drive extension to 3.1 m AHD and raise existing road from 2.5m to 3.1mAHD) is not considered an appropriate use of resources or necessary given the existing and likely future flood risk, given the potential difficulty in incorporating trigger based consents into planning approvals, this option can be considered a viable way forward, as there is no adverse flood impact associated with this option.

Option C (extend Bayshore drive at 2.5 m AHD) would provide a flood free evacuation route under the existing conditions and would provide safe pedestrian evacuation (i.e. H2 hazard (refer **Figure 10**) under the predicted 100yr ARI, 2050 conditions (0.4m of SLR (with additional 0.2 storm surge). Under predicted 2100 (0.9m of SLR (with additional 0.3 storm surge), this option could be combined with a FWS to provide nearly a 1 hour evacuation window if a 2.0mAHD evacuation trigger was adopted. It should be noted that adopting a 1 m/s walking speed and an evacuation distance of 900m, only 15 minutes is needed to safely evacuate. It is important to remember that given the proposed floor level is above the PMF, shelter in place is a safe option and evacuation is only required in the case of a potential medical emergency in the proposed 9 lot development.

6.3 Potential Flood Impact of Road Raising

The potential flood impact of raising the existing or extended portion of Bayshore Drive has also been assessed. If the road was raised to 2.4 or 3.1 m AHD, there may be 2-3cm of locally increased water levels in the no SLR 100yr ARI design event. In the 2100, 100yr ARI design event, because the road is overtopped by 0.3m depth, there is less than 1 mm peak flood level/depth impact.

Should you have any queries regarding this technical memo, please do not hesitate to contact Rohan Hudson on 4926 9506 or Ben Patterson on 4926 9503.

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7 References

Royal HaskoningDHV (2019) 'North Byron Beach Resort Development - Flood Assessment ', Report for North Byron Beach Resort, November 2019.

Royal HaskoningDHV (2021a) 'North Byron Beach Resort Development - Flood Assessment – Flood Planning Level Advice ', Report for North Byron Beach Resort, 14 July 2021.

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Royal HaskoningDHV (2021d) 'North Byron Beach Resort Development - Flood Assessment – Hydraulic Model Setup and Verification ', Report for North Byron Beach Resort, 16 September 2021.