**KINGBOROUGH COUNCIL**

# KINGSTON BEACH FLOOD MITIGATION INVESTIGATION

FINAL REPORT

NOVEMBER 2021

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# KINGSTON BEACH FLOOD MITIGATION INVESTIGATION

## FINAL REPORT

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| **Project**<br>Kingston Beach Flood Mitigation Investigation | **Project Number**<br>121043 |
| **Client**<br>Kingborough Council | **Client's Representative**<br>Alexander Aronsson |
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Front page photo: *Browns River mouth at Kingston Beach, taken on 12 May 2021, WMAwater*

KINGSTON BEACH FLOOD MITIGATION INVESTIGATION

# TABLE OF CONTENTS

PAGE

# LIST OF TABLES

# LIST OF FIGURES

## LIST OF DIAGRAMS

# LIST OF ACRONYMS

| | |
|---|---|
| ADR | Australian Disaster Resilience |
| AEP | Annual Exceedance Probability |
| ARF | Areal Reduction Factor |
| ARI | Average Recurrence Interval |
| ARR | Australian Rainfall and Runoff |
| BOM | Bureau of Meteorology |
| DEM | Digital Elevation Model |
| DPIPWE | Department of Primary Industries, Parks, Water and Environment |
| EY | Exceedances per Year |
| FFA | Flood Frequency Analysis |
| GIS | Geographic Information System |
| IFD | Intensity, Frequency and Duration (Rainfall) |
| IL/CL | Initial Loss / Continues Loss |
| LGA | Local Government Area |
| LiDAR | Airborne Light Detection and Ranging |
| m AHD | meters above Australian Height Datum |
| PMF | Probable Maximum Flood |
| PMP | Probable Maximum Precipitation |
| SES | State Emergency Service |
| TUFLOW | Two-dimensional Unsteady FLOW – a 1D/2D flood and tide simulation software (hydraulic model) |
| WRL | Water Research Laboratory |
| XPSWMM | XP Storm Water Management Model – a holistic 1D/2D modelling package for stormwater and wastewater problems. (hydrologic model) |

# ADOPTED TERMINOLOGY

Australian Rainfall and Runoff (ARR, ed Ball et al, 2019, Reference 1) recommends terminology that is not misleading to the public and stakeholders. Therefore, the use of terms such as "recurrence interval" and "return period" are no longer recommended as they imply that a given event magnitude is only exceeded at regular intervals such as every 100 years. However, rare events may occur in clusters. For example, there are several instances of an event with a 1% chance of occurring within a short period, for example the 1949 and 1950 events at Kempsey. Historically the term Average Recurrence Interval (ARI) has been used.

ARR 2019 recommends the use of Annual Exceedance Probability (AEP). Annual Exceedance Probability (AEP) is the probability of an event being equalled or exceeded within a year. AEP may be expressed as either a percentage (%) or 1 in X. Floodplain management typically uses the percentage form of terminology. Therefore a 1% AEP event or 1 in 100 AEP has a 1% chance of being equalled or exceeded in any year.

ARI and AEP are often mistaken as being interchangeable for events equal to or more frequent than 10% AEP. The table below describes how they are subtly different.

For events more frequent than 50% AEP, expressing frequency in terms of Annual Exceedance Probability is not meaningful and misleading particularly in areas with strong seasonality. Therefore, the term Exceedances per Year (EY) is recommended. Statistically a 0.5 EY event is not the same as a 50% AEP event, and likewise an event with a 20% AEP is not the same as a 0.2 EY event. For example, an event of 0.5 EY is an event which would, on average, occur every two years. A 2 EY event is equivalent to a design event with a 6-month Average Recurrence Interval where there is no seasonality, or an event that is likely to occur twice in one year.

The Probable Maximum Flood is the largest flood that could possibly occur on a catchment. It is related to the Probable Maximum Precipitation (PMP). The PMP has an approximate probability. Due to the conservativeness applied to other factors influencing flooding a PMP does not translate to a PMF of the same AEP. Therefore, an AEP is not assigned to the PMF.

This report has adopted the approach recommended by ARR 2019 and uses % AEP for all events rarer than the 50 % AEP and EY for all events more frequent than this.

| Frequency Descriptor | EY | AEP (%) | AEP (1 in x) | ARI |
|---|---|---|---|---|
| Very Frequent | 12 | | | |
| | 6 | 99.75 | 1.002 | 0.17 |
| | 4 | 98.17 | 1.02 | 0.25 |
| | 3 | 95.02 | 1.05 | 0.33 |
| | 2 | 86.47 | 1.16 | 0.5 |
| | 1 | 63.21 | 1.58 | 1 |
| Frequent | 0.69 | 50 | 2 | 1.44 |
| | 0.5 | 39.35 | 2.54 | 2 |
| | 0.22 | 20 | 5 | 4.48 |
| | 0.2 | 18.13 | 5.52 | 5 |
| | 0.11 | 10 | 10 | 9.49 |
| Rare | 0.05 | 5 | 20 | 19.5 |
| | 0.02 | 2 | 50 | 49.5 |
| | 0.01 | 1 | 100 | 99.5 |
| Very Rare | 0.005 | 0.5 | 200 | 199.5 |
| | 0.002 | 0.2 | 500 | 499.5 |
| | 0.001 | 0.1 | 1000 | 999.5 |
| | 0.0005 | 0.05 | 2000 | 1999.5 |
| Extreme | 0.0002 | 0.02 | 5000 | 4999.5 |
| | | | ↓ | |
| | | | PMP/ PMP Flood | |

# EXECUTIVE SUMMARY


WMAwater was engaged by Kingborough Council to update the existing flood modelling for Kingston Beach in accordance with current best practice processes as prescribed in Australian Rainfall and Runoff (ARR) 2019, and the latest climate change projections. The updated flood modelling would then be used to conduct a flood mitigation investigation for the low-lying areas of Kingston Beach.

The existing flood model, developed by Kingborough Council in 2016 and incorporating ARR 1987 processes, was a coupled hydrologic and hydraulic model in XPSWMM platform. In this study, the hydrologic component was updated to ARR 2019 within XPSWMM and validated to historical events and Flood Frequency Analysis (FFA). The hydraulic model was transferred into TUFLOW HPC.

The models were used to characterise flood behaviour and establish flood risk associated with the 1% Annual Exceedance Probability (AEP) design storm events, along with the Year 2050 and Year 2100 Climate Change scenarios in the Kingston Beach Area.

Comprehensive mapping of the design flood information across the catchment was undertaken, including mapping of peak flood extents, levels, depths, and velocities, as well as hydraulic hazards and hydraulic categories.

A desktop assessment and evaluation of potential flood mitigation options, including those proposed in previous studies, was conducted against the updated flood information based on the modelling results. Flood risk was assessed at three identified hotspots along with modelling and feasibility assessment of selected flood mitigation options.

The effectiveness of selected mitigation options was assessed through application of 2d-numerical modelling, followed by a feasibility assessment of effective options, including cost estimation, impacts on amenity, environment, and infrastructure, and other social constraints.

A staged flood mitigation scheme has been recommended which includes structural and non-structural measures.

**Structural mitigation measures** include:

- Procurement of mobile flood barriers and preparation of response strategy for flood protection along Beach Road
- Construction of flood wall (extension of existing seawall) from river mouth upstream to 28 Balmoral Rd to provide flood immunity for properties on eastern area of Kingston Beach
- Increase height of existing seawall to provide protection from storm surge flooding

**Non-structural resilience measures** include:

- Promote flood awareness and flood insurance education to ensure the affected properties are properly insured
- Establish and review flood response plan to ensure strategies and guidelines are up to

date and enacted

- Establish and update planning controls for redevelopment in this area
- Regular review and update of climate change projections in Kingston Beach area to assess vulnerability
- On-going investment on improving flood forecasting and warning system

# 1. INTRODUCTION

Kingborough Council (Council) commissioned WMAwater to undertake an update of the current flood model prepared for Kingston Beach Flood Study (Kingborough Council, 2016, Reference 2). The update involved adoption of the ARR 2019 (Reference 1) processes and the application of the latest climate change projections. WMAwater were also engaged to conduct a flood risk assessment and flood mitigation investigation for Kingston Beach informed by the revised modelling.

The study comprises the updating of existing hydrologic and hydraulic models to characterise design flood behaviour and establish the flood risk in accordance with the current best practice for the 1% AEP flood events and, the Year 2050 and Year 2100 Climate Change scenarios in the low-lying area of Kingston Beach, as well as flood impact and feasibility assessments of potential mitigation options.

The specific tasks undertaken for the study were as follows:

- collection and collation of existing information relevant to the study which includes previous studies, data, and models
- updating the existing XPSWMM hydrologic model in accordance with current best practice (ARR 2019) guidelines and latest climate change projections
- translation of 2d-hydraulic model to the TUFLOW-HPC platform
- the interpretation and presentation of model results to describe and categorise flood behaviour and hazard for 1% AEP storm events for the baseline (“current”), Year 2050, and Year 2100 climate conditions
- identification and desktop assessment of potential flood mitigation options
- effectiveness and feasibility assessment of selected flood mitigation options
- flood mitigation scheme for Kingston Beach

Study outputs include:

- updated hydrologic and hydraulic models
- maps of flood extent, levels, depths, velocities, hazards, and categories for 1% AEP flood events under baseline, Year 2050, and Year 2100 climate scenarios
- flood impact mapping, cost estimation, as well as assessment of social, environmental, and infrastructural impacts of potential mitigation options
- report detailing the study methods, investigations, and conclusions
- digital datasets collected or produced for this project

Study outputs will provide Council with flood intelligence and recommendations on mitigation work in Kingston Beach. A discussion of terminology and a glossary of other flood-related terms is provided in APPENDIX A.

# 2. BACKGROUND

## 2.1. Study Area

The Browns River catchment is the primary contributing catchment for Kingston Beach. It is located close to Kingston Central Business District (CBD) in north-eastern corner of the Kingborough Local Government Area (LGA) in the Southeast of Tasmania. It has a total area of approximately 60 $km^2$ and drains to the Derwent Estuary through a mobile coastal dune system at the northern end of Kingston Beach.

The suburb of Kingston Beach is an old residential area originating from beach-side shacks during the late $19^{th}$ century. The suburb of Kingston Beach (low-lying area) receives inflows from Browns River and Whitewater Creek, a major tributary joining Browns River downstream of Channel Highway. The beach and the vicinity of the Kingston Beach Golf Course are low and flat, ranging from 1 to 3 metres above sea level (Australian Height Datum (AHD)). Kingston Beach is considerably vulnerable to catchment riverine and coastal storm surge flood events.

For details of the study area, refer to References 2 and 3.

## 2.2. Historical Flooding

The suburb of Kingston Beach is one of the highest flood risk areas in Kingborough LGA. There has been and number of ‘frequent’ to ‘rare’ flood events recorded at Kingston Beach over the last 150 years. A review of historical flood events in Kingston Beach/Browns River was conducted by K. Evans in 2015 (Reference 3), which documented 33 flood and storm events in the area between 1870 and 2015.

The Kingston Beach Flood Study (Reference 2) summarised examples of key flood risk factors that caused damages to the properties in the study area, including

- Heavy sea/storm surge (Aug 1908/Jun 1910)
- Heavy storm event (Feb 1917)
- Coincident flood (Jun 1909)
- Sand bar across the mouth of Browns River backed up waters of the river flooded downstream (Sep/Oct 1951)
- Flooded due to drainage blockage at low lying area during high tide (May/Jul 1935)

In addition to above, the greater Hobart area experienced a greater than 1% AEP storm event in May 2018. This event caused widespread damage to Southern Tasmanian catchments including Browns River and Kingston Beach.

## 2.3. Previous Studies

There has been a number of studies focusing on climate change, flooding issues, and/or flood mitigation opportunities in Kingston Beach or wider Tasmania, including:

- Climate Futures for Tasmania: Extreme Events, ACECRC, 2010 (Reference 4)

- Tasmanian Coastal Adaptation Decision Pathways Project: Inundation Control Works for the Kingston Beach Area, Pitt & Sherry, 2012 (Reference 5)
- Kingston Beach/Brown's River: A Flood and Storm History, Evans K., 2015 (Reference 3)
- Tailwater Level for Kingston Beach Flood Study, WRL, 2015 (Reference 6)
- Kingston Beach Flood Study, Kingborough Council, 2016 (Reference 2)
- Kingston Beach Flood Mitigation Options Review, BMT WBM, 2016 (Reference 7)
- Concept Design of a Permanent River Opening at Browns River Kingston Beach Tasmania, WRL, 2017 (Reference 8)
- Kingston Beach Sea Level Rise and Flood Mitigation Options for Consideration, Millin EMS, 2020 (Reference 9)
- Climate Change Information for Decision Making, UTAS, 2020 (Reference 10)

In 2016, Council finalised the flood study for the low-lying areas of Kingston Beach (Reference 2), in which a coupled hydrologic and 1D/2D hydraulic model was established using XPSWMM software based on the ARR 1987. The study, as well as the associated flood model established during the study, was then used as a base for further flood mitigation assessments.

To support the Kingston Beach Flood Study, four (4) mitigation options were reviewed in Flood Mitigation Options Review (Reference 7), including levee, channel straightening, entrance opening, and flood detention basin in the upper catchment. The channel straightening and entrance opening options were identified as preferred measures for implementation. The outcome of the Review was then reflected and incorporated in the Kingston Beach Flood Study.

Following the Kingston Beach Flood Study and the Flood Mitigation Option Review, a concept design of entrance opening was conducted by Water Research Laboratory (WRL) in 2017 (Reference 8), and a high-level staged implementation scheme, including a levee, channel straightening and entrance opening, was established in by Millin EMS 2020 based on review of all flood mitigation measures proposed in the past studies (Reference 9).

This study was initialised by Council for the following reasons:

- The analytical tools and processes used to estimate rainfall and flooding have changed significantly since Kingston Beach Flood Study, i.e., from ARR 1987 (Reference 11) to ARR 2019 (Reference 1).
- The climate change projections on catchment flooding have been updated, i.e., from ACECRC 2010 Study (Reference 4) to UTAS 2020 Study (Reference 10).
- A clearer direction of future works is required for Council to progress forward.

# 3. DATA COLLATION

Data collation was conducted at the onset of the project. Data provided by Council include:

- Previous study reports, as detailed in Section 2.3
- Kingston Beach Flood Models (XPSWMM) for
  - 1% AEP Catchment and 5% AEP Coastal Coincident Design Floods under Year 2050 and Year 2100 climate conditions
  - Mitigation Assessments based on 1% AEP Catchment and 5% AEP Coastal Coincident Design Flood under Year 2100 climate condition
- Historical rainfall and streamflow data used for Kingston Beach hydrologic model calibration
- Tailwater levels produced by WRL (2015) study

In addition to above datasets, following data were collected during this study:

- Aerial imagery of the low-lying area of Kingston Beach (Nearmap)
- Photos of the study area and significant hydraulic features (site inspection)

The review of different versions of XPSWMM models provided by Council indicated that they are identical in terms of model structure and representation of hydraulic structures, and consistent with what presented in 2016 Kingston Beach Flood Study (Reference 2). The principal difference among these models is the representation of climate conditions and mitigation options (unmitigated/mitigated). Based on our review, the following version was selected as a "base" model to be proceeded to model updating and further assessment (Refer Table 1).

Table 1: Base model - XPSWMM

| Base model | 2m_RF2100_1%-5%_PB_DTM_v201601 |
|---|---|

# 4. MODEL UPDATING

The existing flood model, developed by Council, used XPSWMM to undertake the hydrologic and hydraulic modelling based on the ARR 1987 (Reference 11). The model schematics is outlined in Diagram 1.

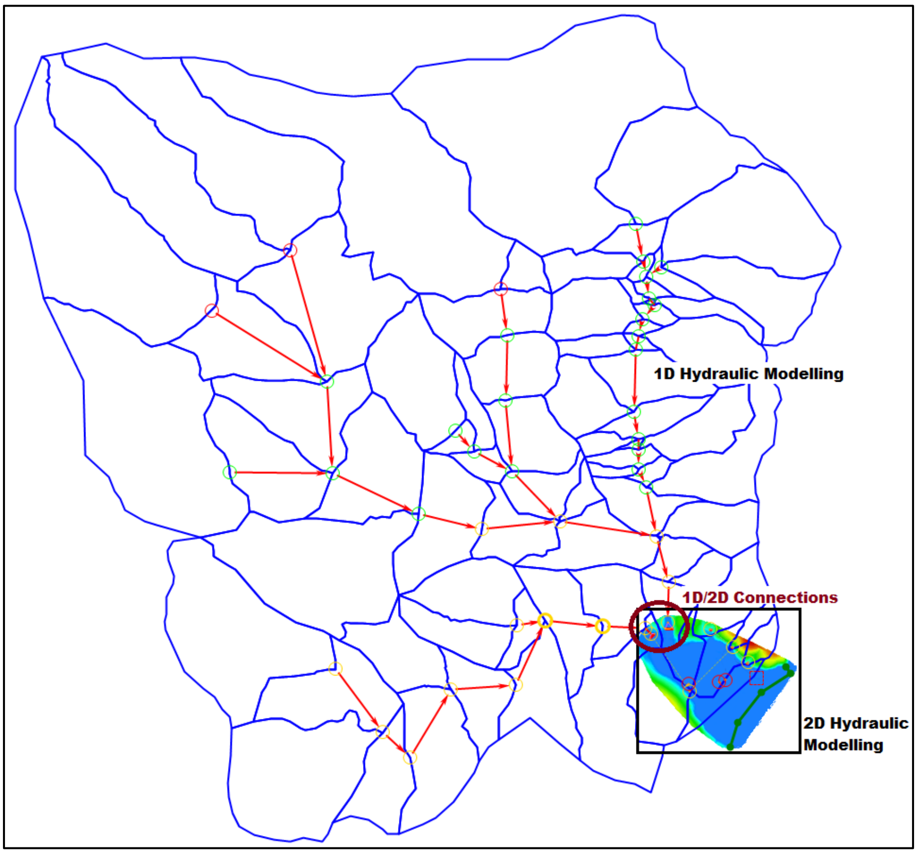


Diagram 1: Hydrologic and Hydraulic Modelling Schematics of Kingston Beach Flood Study (Reference 2)

In this study, the existing hydrologic model (with 1D hydraulic routing) was updated to ARR 2019 (Reference 1) within XPSWMM platform, and further validated to historical flood events and FFA. The 2D hydraulic model was transferred into TUFLOW and updated to the newest HPC build (2020-10-AA_iSP_w64 HPC GPU solver). Model details are summarised below.

## 4.1. Hydrologic Model

### 4.1.1. Model Structure

The model structure, including sub-catchment delineation, pervious and impervious fractions, and 1D hydraulic routing, was directly adopted from Kingston Beach Flood Study (Reference 2), as depicted in Diagram 1.

### 4.1.2. Model Parameters

In the Kingston Beach Flood Study (Reference 2), the hydrologic model was calibrated to the Browns River Gauge (Summerleas Road) for the following historical events:

- 2nd June 1981
- 22nd March 1983
- 17th to 18th December 1985
- 18th May 1986

The calibrated parameters (summarised in Table 2) were then validated by comparing the design event modelling results (ARR 1987) against the Flood Frequency Analysis (FFA) at Browns River Gauge (Summerleas Road) for 5%, 2%, and 1% AEPs.

Table 2: Adopted Hydrologic Parameters for Kingston Beach Flood Study (Reference 2)

| Parameter | | Adopted Value |
|---|---|---|
| Pervious Area | Initial Loss | 20 |
| | Continuous Loss | 2 |
| Impervious Area | Initial Loss | 5 |
| | Continuous Loss | 1 |
| Manning's *n* | | Varies from 0.014 for impervious area to 0.1 for heavy forest |

The original calibration (Reference 2) resulted in a good match of modelled and recorded peak flows for three of the four events, the exception being the 1986 event. However, when implemented to design flood modelling, the simulated peak discharges were notably higher than the FFA for 5%, 2%, and 1% AEPs.

Since the completion of Kingston Beach Flood Study in 2016 (Reference 2), there has been a 'very rare' event, which took place in May 2018. However, no streamflow data was recorded at Browns River Gauge during the event. Therefore, the gauged data used in the Kingston Beach Flood Study (Reference 2) still presents the best available information for model calibration at time of writing.

The modelling results of the design events will be changed due to the change of input rainfall (i.e., new IFDs and temporal patterns) from ARR 1987 to ARR 2019. However, the modelling results of the same calibration events (historical) would not have been affected if the structure of the hydrologic model was not changed. Therefore, the parameter values summarised in Table 2 were directly adopted for the updated model (Section 4.1.3) but were further validated by re-modelling the four historical events and through comparison with the FFA (Section 4.1.4).

### 4.1.3. Model Input and Climate Projection Updating

The hydrologic model update was achieved by updating design rainfall inputs and climate projections. The key points and steps are summarised below:

- The ensemble (10) of burst temporal patterns for each duration from 10min to 72hr were obtained from ARR Data Hub (Reference 12).
- The 2016 IFD were obtained from Bureau of Meteorology (Reference 13) for the catchment. The catchment is covered by 12 IFD pixels, of which the spatial average was adopted for the hydrologic model of the Browns River catchment.
- The pre-bursts and Areal Reduction Factors (ARF) based on the catchment area were obtained from ARR Data Hub and applied to IFD and temporal patterns to create ensemble

design storms.

- The increases of the rainfall intensities (2016 IFD) by Year 2050 and Year 2100 were set to be 8.4% and 15.6%, respectively, based on latest climate change projection information documented in UTAS 2020 Study (Reference 10).
- The critical duration and representative temporal pattern (mean pattern) for each AEP were determined based on the peak flow from the Browns River upstream of Channel Hwy, i.e., the inflow from Browns River to the 2D hydraulic model domain. The selected duration and temporal pattern for each AEP were used for design flood modelling and further mitigation assessment.

### 4.1.4. Model Validation

To ensure the reliability of the model structure and parameters and understand the impact of the update from ARR 1987 to ARR 2019, a validation exercise was carried out by:

- rerunning the four historical events listed in Section 4.1.2; and
- running the 5%, 2%, and 1% AEP design events to validate against FFA.

#### 4.1.4.1. Validation to Historical Events

As the same observed rainfall and parameters (Table 2) were used, the updated model produced similar peak discharge estimates at Browns River Gauge (Summerleas Road) as those presented in the Kingston Beach Flood Study (Table 3). The minor difference between the original and updated model predictions may be caused by different versions of XPSWMM software.

It is noted that the calibrated pervious IL (20mm) and CL (2mm) are lower than those obtained from ARR Data Hub, i.e., 28mm and 3.4mm, respectively. As modelled peak flows are slightly lower than the gauge records for 1981, 1983, and 1985 events, it was decided not to further increase the losses (e.g., to ARR suggested values), which would further reduce the flow predictions, hence the model accuracy.

Table 3: Modelled and Recorded Peak Flows

| Event | Recorded ($m^3/s$) | Modelled ($m^3/s$) | |
|---|---|---|---|
| | | Kingston Beach Flood Study | Updated Model |
| 1981 | 24.2 | 21.0 | 21.1 |
| 1983 | 27.8 | 26.1 | 25.9 |
| 1985 | 22.9 | 20.8 | 20.7 |
| 1986 (Kingston rainfall) * | 24.5 | 14.3 | 14.2 |
| 1986 (Fern Tree rainfall) * | 24.5 | 32.0 | 32.3 |

* Rainfall from Kingston station and Fern Tree station were both tested for the 1986 event. As discussed in Kingston Beach Flood Study (Reference 2), there is considerable variability in the local rainfalls recorded at Kingston and Fern Tree, and this limited the level of calibration that could be reliably achieved.

#### 4.1.4.2. Validation to FFA

FFA of the Browns River Gauge (Summerleas Road) was conducted and presented in Kingston

Beach Flood Study (Reference 2). In this study, modelling was carried out for 5%, 2%, and 1% AEP design events under baseline climate scenario and validated against FFA. To ensure that the model predictions at Browns River Gauge (Summerleas Road) are comparable to the FFA, the ARFs based on the catchment area upstream of Browns River Gauge were used. This is different from the whole catchment model (Section 6), which used the area of the entire Browns River catchment for ARFs calculation.

The updated model (ARR 2019) has a better match with FFA than the Kingston Beach Flood Study (ARR 1987), as shown in Table 4. Specifically, the ARR 1987 was overestimating the peaks for all 5%, 2%, and 1% AEP catchment flood events. The updated model based on ARR 2019 has smaller errors against FFA, despite underestimation and overestimation for 5% and 1% AEP events, respectively, were observed.

Table 4: Adopted Hydrologic Parameters for 2016 Flood Study

| AEP | FFA | FFA 5% | FFA 95% | Kingston Beach Flood Study | Updated Model |
|---|---|---|---|---|---|
| **5%** | 36.20 | 21.90 | 78.40 | 76.30 | 43.39 |
| **2%** | 57.20 | 30.30 | 166.80 | 93.50 | 57.50 |
| **1%** | 77.40 | 36.00 | 292.50 | 111.00 | 67.90 |

## 4.2. 2D Hydraulic Model

The suburb of Kingston Beach is an estalblished residential area which has experienced no significant development since 2016, i.e., since the completion of Kingston Beach Flood Study (Reference 2). Therefore, the 2D hydraulic model was transferred from XPSWMM into TUFLOW, with direct adoption of topography, surface roughness, and hydraulic structures.

The inflow boundary conditions for baseline, Year 2050, and Year 2100 scenarios were extracted from the updated hydrologic model (i.e., ARR 2019), while the downstream boundary conditions (tailwater levels) were directly adopted from Kingston Beach Flood Study (Reference 2). Kingston Beach Flood Study used the tailwater levels derived by WRL in 2015 (Reference 6) for baseline scenario and applied 0.3 m and 1.0 m sea level rise for Year 2050 and Year 2100 scenarios based on a report letter from John Hunter in 2015 (Reference 14). It was noted that those reports were still the best information and the sea level rises applied were reasonably conservative, thus were directed adopted for the updated model.

# 5. SENSITIVITY TO MODEL UPDATING

To understand the model sensitivity to the updates, including the adoption of ARR 2019 and most recent climate change projections, the 1% AEP catchment and 5% AEP coastal coincident flood under Year 2100 climate condition was modelled and compared for below three (3) different setups:

- Setup 1 – ARR 1987 with ACECRC 2010 climate change projection (Reference 4) – original setup as per Kingston Beach Flood Study (Reference 2)
- Setup 2 – ARR 2019 with ACECRC 2010 climate change projection (Reference 4) – updated to new ARR
- Setup 3 – ARR 2019 with UTAS 2020 climate change projection (Reference 10) – updated to new ARR and climate projection

To ensure the above three setups are comparable, they were modelled using the same modelling framework, i.e., XPSWMM 2021.1 x64 for hydrology and 1D hydraulic routing and TUFLOW HPC GPU (Build 2020-10-AA_iSP_w64) for 2D hydraulic modelling. The modelled flood extents (filtered to flood depth ≥ 0.05 m) are illustrated in Figure 1. Flood levels at the reporting locations in Figure 1 are summarised in Table 5.

Table 5: Flood Levels (1% AEP Catchment and 5% AEP Coastal Coincident Event under Year 2100 Climate Condition) at Reporting Locations Shown in Figure 1.

| Reporting Location | Ground / Flood Level (m AHD) | | | | Difference (m) | | |
|---|---|---|---|---|---|---|---|
| | Surface (based on zpt_check) | ARR 1987 (ACECRC 2010) | ARR 2019 (ACECRC 2010) | ARR 2019 (UTAS 2020) | ARR 2019 (ACECRC 2010) - ARR 1987 (ACECRC 2010) | ARR 2019 (UTAS 2020) - ARR 2019 (ACECRC 2010) | ARR 2019 (UTAS 2020) - ARR 1987 (ACECRC 2010) |
| P01 | -1.75 | 3.28 | 2.89 | 2.77 | -0.40 | -0.12 | -0.51 |
| P02 | -2.20 | 3.27 | 2.86 | 2.74 | -0.41 | -0.12 | -0.53 |
| P03 | -2.06 | 3.24 | 2.80 | 2.68 | -0.43 | -0.12 | -0.56 |
| P04 | -0.54 | 3.15 | 2.68 | 2.56 | -0.46 | -0.12 | -0.58 |
| P05 | -2.91 | 2.85 | 2.47 | 2.39 | -0.38 | -0.08 | -0.46 |
| P06 | -1.81 | 2.72 | 2.38 | 2.32 | -0.34 | -0.06 | -0.40 |
| P07 | 0.72 | 2.21 | 2.21 | 2.21 | 0.00 | 0.00 | 0.00 |
| P08 | 2.45 | 3.19 | 2.85 | 2.75 | -0.34 | -0.10 | -0.44 |
| P09 | 2.63 | 3.08 | 2.80 | 2.73 | -0.29 | -0.06 | -0.35 |
| P10 | 2.48 | 3.18 | 2.75 | 2.63 | -0.44 | -0.12 | -0.55 |
| P11 | 2.18 | 2.80 | 2.40 | 2.34 | -0.41 | -0.06 | -0.46 |
| P12 | 1.95 | 2.75 | 2.40 | 2.34 | -0.36 | -0.06 | -0.42 |

The sensitivity testing results suggest that updating to ARR 2019 and most recent climate change projections resulted in significant reduction in flood level and extent. The built-up area of Kingston Beach, which was identified as inundated by the original setup (ARR 1987 with ACECRC 2010 Climate Projection), is now mostly no longer inundated in the updated model setup (ARR 2019 with UTAS 2020 Climate Projection). The flood levels from the reporting locations indicate that the model updating has resulted in 0.4 – 0.6 m decrease of the flood levels, except for the beach area

(P07) which was dominated by the sea level boundary conditions.

The updated model adopted the same model structure and parameters as the original model. It is inferable from Figure 1 and Table 5 that both the updates to the ARR processes and updates to the climate change projections have contributed to the decrease of the flood level and extent. Specifically, following factors are considered to contribute to the observed change in predicted flood characteristics:

- The rainfall intensities (IFD) from ARR 2019 are lower than that from ARR 1987.
- The ARR 2019 applied an ARF, which caused a further reduction of the rainfall intensity for such a big catchment (approximately 60 $km^2$).
- The IFD increase projection by Year 2100 has been reduced from 30% (ACECRC 2010) to 15.6% (UTAS 2020).

The accumulative effect by updating to ARR 2019, i.e., changes in IFD and ARF, accounts for the majority of the reduction in modelled flood level and extent. Specifically, updating to ARR 2019 resulted in 0.3 – 0.5 m decrease of the flood levels at most of the reporting locations, whilst updating to UTAS 2020 climate change projection resulted in another 0.06 – 0.12 m decrease (Table 5). It can also be seen that updating to ARR 2019 had caused bigger impact on flood extent than the updating in climate change projection.

The ARR 2019 is considered to be more reliable and accurate due to following reasons, despite of its significant impact on modelled flood level and extent:

- Theoretically, ARR 2019 is more robust than ARR 1987 as the IFD, ARF, and temporal patterns were derived from more Australia-based observations.
- It has been validated in Section 4.1.4 that ARR 2019 inputs gave less biased and more accurate peak flow predictions for design events compared with ARR 1987 at Browns River Gauge (Summerleas Road).
- Based on Council’s local knowledge of the flood behaviour in Kingston Beach, there has not been a flood as severe as predicted by ARR 1987 (Setup 1), including the May 2018 event which recorded 24-hour rainfall (based on daily record at Kingston) equivalent to a 0.5% AEP event with a 2-hour burst storm (based on pluviograph recorded at Hobart) equivalent to a 1 in 2000 AEP event (Reference 18).

Smaller impacts were observed when updating to new climate change projections. However, no direct validation can be performed to verify the “forecast of future”. Nevertheless, the UTAS 2020 projection represents the most recent scientifical evidence on climate change in Kingborough LGA, hence has been adopted for final design event modelling and mitigation options assessment.

# 6. DESIGN EVENT MODELLING

## 6.1. Modelled Scenarios

As noted in Kingston Beach Flood Study (Reference 2), catchment flooding and oceanic inundation can occur due to the same storm cell and design flood levels in a lower coastal waterway will be influenced by a combination of these sources. Therefore, the modelling of coincident flooding should consider the interaction of the catchment and coastal floods and their joint probability with appropriate assumption on the level of independence between the two variables. Assuming purely independent or dependent could under- or over-estimate the flood magnitude and the consequences (References 15 and 16).

In this study, the 1% AEP flood characteristics in Kingston Beach was determined by the envelope of peak flood levels, depths, and velocities of below two (2) probability scenarios:

- **1% AEP catchment and 5% AEP coastal flooding**
- **5% AEP catchment and 1% AEP coastal flooding**

The flood modelling was carried out for the above two (2) probability scenarios under baseline, Year 2050, and Year 2100 climate conditions (observed/projected), i.e., six (6) coincident flooding scenarios in total as summarised in Table 6, through the following steps:

- The critical storm durations for 1% and 5% AEP catchment flooding were as identified to be 9 hours and 6 hours, respectively.
- Hydrologic modelling (with 1D hydraulic routing) was conducted for the selected duration and temporal pattern of each catchment flood scenario (Table 6) to produce upstream and internal boundary conditions for 2D hydraulic model.
- The 2D hydraulic modelling was carried out using TUFLOW HPC GPU (Build 2020-10-AA_iSP_w64) for each of the six coincident flooding scenarios (Table 6).

Table 6: Summary of Modelled Coincident Flooding Scenarios

| Climate Condition | Catchment Flood Scenario | Coastal Flood Scenario (Water Level Boundary) |
|---|---|---|
| Baseline | 1% AEP | 5% AEP (1.21m AHD) |
| Baseline | 5% AEP | 1 % AEP (1.52m AHD) |
| Year 2050 | 1% AEP + 8.4% Rainfall Increase | 5% AEP + 0.3m SLR (1.51m AHD) |
| Year 2050 | 5% AEP + 8.4% Rainfall Increase | 1% AEP + 0.3m SLR (1.82m AHD) |
| Year 2100 | 1% AEP + 15.6% Rainfall Increase | 5% AEP + 1.0m SLR (2.21m AHD) |
| Year 2100 | 5% AEP + 15.6% Rainfall Increase | 1% AEP + 1.0m SLR (2.52m AHD) |

### 6.1.1. Critical Scenarios

The critical coincident scenario extents (filtered to flood depth ≥ 0.05 m) under baseline, Year 2050, and Year 2100 climate conditions are illustrated in Figure 2 to Figure 4. It is shown that:

- Under baseline and Year 2050 climate conditions, the 1% AEP catchment and 5% AEP coastal flooding is critical for the entire floodplain upstream of the river mouth.
- Under Year 2100 climate condition, the 1% AEP catchment and 5% AEP coastal flooding is critical for Browns River and the Golf Course upstream of 67 Beach Road, Kingston

Beach, as well as the overland flood path between Beach Road and Recreation Street, while the 1% AEP catchment and 5% AEP coastal flooding is critical for Browns River and the Golf Course downstream of 67 Beach Road.

## 6.2. Flood Mapping

The flood mapping based on the modelling results are presented in APPENDIX B as:

- Peak flood depths and levels in Figure B1 to Figure B3
- Peak flood velocities in Figure B4 to Figure B6
- Hydraulic hazard in Figure B7 to Figure B9
- Hydraulic categories in Figure B10 to Figure B12

The maps are also provided in digital format compatible with Council's Geographic Information Systems. The digital data should be used in preference to the figures in this report as they provide more detail. Please note that all flood maps are based on the envelope of the two probability scenarios mentioned above and filtered to flood depth ≥ 0.05 m. Areas with flood depth < 0.05 m are treated as non-inundated area.

### 6.2.1. Hydraulic Hazard

Hazard classification plays an important role in informing floodplain risk management in an area. Provisional hazard categories have been determined for the Kingston Beach in accordance with the Australian Disaster Resilience Handbook Collection (Reference 17).

In recent years, there have been a number of developments in the classification of hazards. Research has been undertaken to assess the hazard to people, vehicles and buildings based on flood depth, velocity, and velocity depth product. The Australian Disaster Resilience Handbook Collection deals with floods in Handbook 7 (Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia). The supporting guideline 7-3 (Reference 17) contains information relating to the categorisation of flood hazard. A summary of this categorisation is provided in Diagram 2.

This classification provides a more detailed distinction and practical application of hazard categories, identifying the following 6 classes of hazard:

- H1 – No constraints, generally safe for vehicles, people and buildings
- H2 – Unsafe for small vehicles
- H3 – Unsafe for all vehicles, children and the elderly
- H4 – Unsafe for all people and all vehicles
- H5 – Unsafe for all people and all vehicles. All building types vulnerable to structural damage. Some less robust building types vulnerable to failure. Buildings require special engineering design and construction
- H6 – Unsafe for all people and all vehicles. All building types considered vulnerable to failure

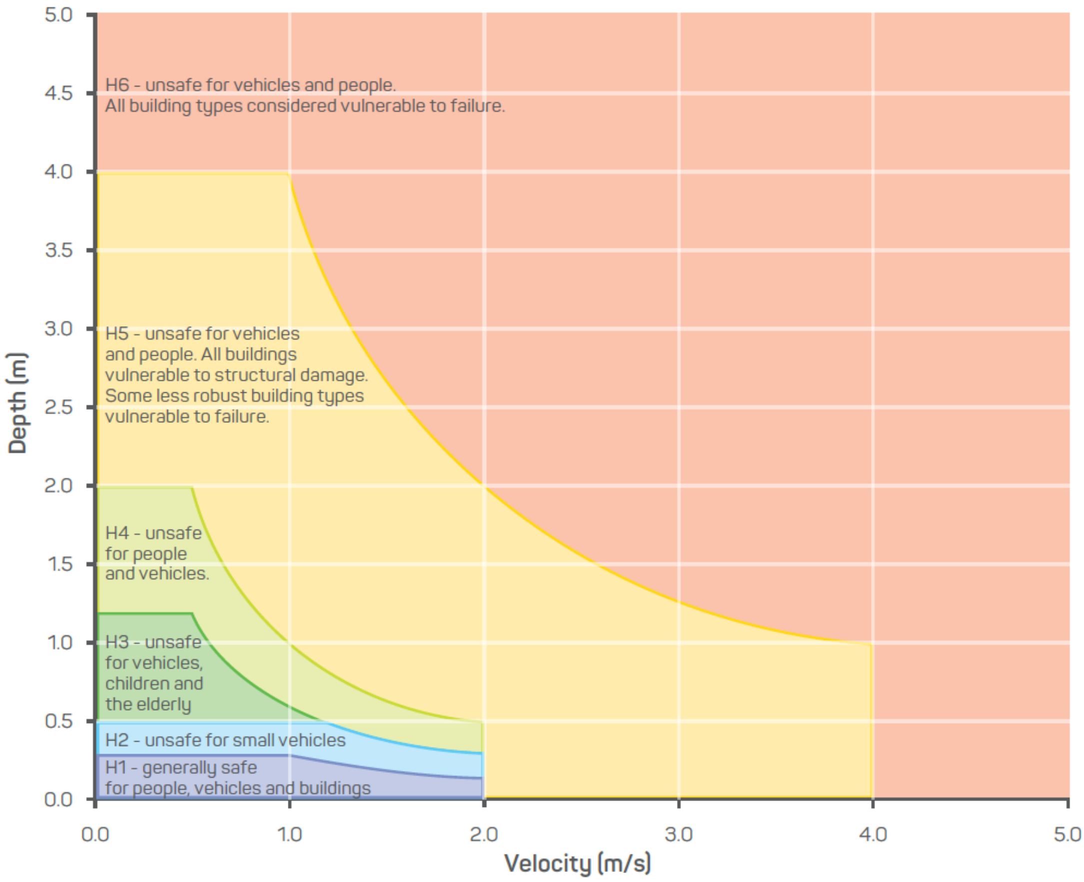


Diagram 2: General Flood Hazard Vulnerability Curves (Reference 17)

The hazard maps created using the Australian Disaster Resilience (ADR) classification are presented in Figure B7 to Figure B9.

### 6.2.2. Hydraulic Categorisation

Floodplains can be classified into the following hydraulic categories depending on the flood function:

- Floodways
- Flood Storage
- Flood Fringe.

There is no quantitative definition of these three categories or accepted approach to differentiate between the various classifications. The delineation of these areas is somewhat subjective based on knowledge of an area and flood behaviour, hydraulic modelling, and previous experience in categorising flood function. A few approaches are available, such as the method defined by Howells *et al* (Reference 19).

For this study, hydraulic categories were defined by the following criteria, which has been tested and is considered to be a reasonable representation of the flood function of this catchment.

- Floodway is defined as areas where:
  - the peak value of velocity multiplied by depth (V x D) > 0.25 $m^2$/s, **AND** peak velocity > 0.25 m/s, **OR**

    - peak velocity > 1.0 m/s **AND** peak depth > 0.1 m.

The remainder of the floodplain is either Flood Storage or Flood Fringe,

- Flood Storage comprises areas outside the floodway where peak depth > 0.5 m, and
- Flood Fringe comprises areas outside the Floodway where peak depth ≤ 0.5 m.

Figure B10 to Figure B12 show the provisional hydraulic categorisations for Kingston Beach.

# 7. MITIGATION OPTIONS

The mitigation option assessment was conducted through two steps:

- Step 1: Review and preliminary assessment of previous proposed mitigation options
- Step 2: Modelling and feasibility assessment of potential mitigation options

It is understood that flood characteristics under Year 2100 climate condition will form the base to guide Council for future floodplain management and planning. The assessment in this section targets at Year 2100 but with consideration of all three climate conditions, i.e., baseline, Year 2050, and Year 2100.

## 7.1. Review of Previous Proposed Mitigation Options

There have been a number of mitigation options proposed, assessed, and recommended throughout previous studies (References 2, 5, 7, 8, and 9). Options included levee and seawall construction, channel widening, river mouth opening and, flood detention basin. The 'preferred' option was a combination of river channel straightening and opening of the river mouth.

### 7.1.1. Levee and Seawall

This option aimed to prevent the water from Browns River and offshore entering the built-up area of Kingston Beach. It proposed:

1) construction of a levee (i.e., flood barricade in Reference 5 or berm in Reference 9) along the western and southern bank of Browns River as it passes through the developed area, i.e., from the north of 87 Beach Road to Browns River mouth; and
2) extending and raising the existing seawall along the beach between Browns River mouth and Kingston Beach Sailing Club.

The Kingston Beach Flood Mitigation Options Review (Reference 7) speculated that flood risk could be increased in higher order events where overtopping may occur. The option, otherwise, was able to mitigate flood impacts during events up to and including the 1% AEP.

Although the updated model shows a notable reduction of flood extent and level, it is shown that flood water still breaches the riverbank or existing seawall at several locations. Therefore, this option was considered to be potentially viable and slated for further investigation through the updated modelling and feasibility assessment.

### 7.1.2. Channel straightening

This option proposed to arrest river flows upstream of the golf course and divert flows using a new channel alignment, through the golf course. This option was 'preferred' due to its effectiveness shown by the modelling assessment (References 2, 7, and 9). However, there are several factors that don't appear to have been considered that affect the feasibility of this option. The following need consideration when assessing viability of this option –

- Impact of the 90º diversion from natural alignment on river hydraulics, and erosive forces

- Impact on Golf Course – loss fairways and holes
- Impact of the channelisation of the River alignment on flow characteristics and lower river ecosystems
- Impact on the section of Brown River below the diversion – consideration of ecosystem and amenity
- High cost of construction, land acquisition (golf course), and ongoing maintenance

The updated modelling results show that the inflow from the contributing catchment could be significantly overestimated by previous flood study (Reference 2), indicating that the benefit of the option would be greatly exaggerated.

### 7.1.3. Open entrance

This option proposed the dredging of the river mouth, removing the sand spit. This option is part of the 'preferred' option. However, the option will not provide a long-term solution. The Browns River discharges to lower River Derwent. The River Derwent at this point is heavily affected by the coastal processes of the Tasman Sea. Coastal tidal movement result in the erosion, transportation and deposition of sand and sediment. The coastal process will return sand deposits to Browns River mouth. A rock groin would be required to maintain river mouth opening for longer durations. Construction of a rock groin would require consideration of the sharp fall observed in the bathymetry of the River Derwent. Regular maintenance will be required. Amenity of beach will be altered. Possible impacts within River Derwent.

Under the updated modelling, the catchment flooding is reduced compared with the original modelling, while the coastal flooding remains the same. The critical scenario mapping (Figure 4) indicates that Brown River downstream of 67 Beach Road, and the properties along the River, are affected more seriously by the 1% AEP coastal flooding than by the 1% AEP catchment flooding under Year 2100 climate conditions. Permanent mouth opening may cause negative effect during coastal flooding events.

### 7.1.4. Flood Detention Basin

Flood detention basin was proposed to capture and control flood flows within catchment. This option has not been explored in detail as land requirement would be significant and/or basin size would be quite large. A dam break assessment would be required to understand impacts of structural failure. The feasibility of this option is extremely low.

The model updating has resulted in significant reduction of inflow from the contributing catchment, therefore, it is less likely that detaining inflow from upper catchment will benefit the flooding issue downstream.

### 7.1.5. Combination *Channel Straightening & Open Entrance

The combination of the two 'preferred' options. It is expected that this solution will be cost prohibitive and not in the best interest of the wider community.

### 7.1.6. Discussion

As analysed above, many of the regional mitigation options proposed in previous studies aimed at relieving the impact caused by catchment flooding, i.e., either increase discharge efficiency to River Derwent (e.g., channel straightening and river mouth opening) or detaining water from upstream (e.g., detention basin). The previously proposed measures provide little to no benefit during coastal flooding events.

Under the updated modelling, the catchment flooding is significantly reduced by updating to ARR 2019, and further reduced under future scenarios through adoption of most recent climate change projections, whilst the coastal flooding and sea level rising are not changed. From this point of view, the focus of the mitigation strategy should be shifted to some extent towards relieving the risk of coastal flooding.

Embankment systems, such as riverbank levees and seawalls, can prevent land from inundation regardless of the origin of flood water (i.e., freshwater or storm surge). Therefore, they can be effective during either catchment or coastal flooding. The continuous embankment system (flood barricade + seawall) was proposed in previous studies, surrounding Kingston Beach township, as almost the entire built-up area was predicted to be inundated during 1% AEP coincident flooding under Year 2100 climate condition. However, only sections of the embankment may be required under new modelled flood characteristics, while the feasibility is not guaranteed due to local restrictions, e.g., height needed, land available, and social impacts. Therefore, the effectiveness and feasibility of embankment systems and other potential localised mitigation options are assessed for each of the flood hotspots in below section.

## 7.2. Modelling and Feasibility Assessment of Potential Mitigation Options

Key areas where flooding is problematic, referred to as “hotspots”, require detailed assessment of flood-related risks and of potential mitigation options. Under the updated flood modelling, there are three (3) principal flood hotspots in affecting Kingston Beach, as highlighted in Diagram 3.


Diagram 3: Flood Hotspots based on Flood Extent under Year 2100 Climate Condition. (Cyan: 1% AEP Catchment and 5% AEP Coastal Coincident Flooding is critical; Red: 5% AEP Catchment and 1% AEP Coastal Coincident Flooding is critical. Similarly hereinafter)

### 7.2.1. Hotspot 1

Flood water breaks through the southwest bank of Browns River and flows towards south causing inundation of properties in the west part of Kingston township. This is predicted to be more serious during 1% AEP catchment flooding than the 1% coastal flooding under Year 2100 conditions.

Cross-section 1 of Diagram 4 indicates that flood level varies from 3 m to 2.75 m AHD, from 87 Beach Road to 4 Balmoral Road along Browns River, under Year 2100 climate condition. The ground levels (according to LiDAR DEM) of the riverside boundaries of the properties adjacent to the Browns River are only 1 m to 1.75 m AHD, indicating that embankment at 1.25 to 2 m high will be required to provide flood immunity if it is feasible.

Cross-section 2 of Diagram 4 shows that the lowest point along the Beach Road is at approximately 2.0 m AHD where the flood level is 2.75 m AHD (i.e., 0.75 m deep). The rest of road surface between the low point and the beach is at around 3.0 m AHD. Therefore, it is not feasible to re-grade the road to convey flood water within the road reserve towards the beach. It should also be noted that the sea level is predicted to 2.52 m AHD during 1% AEP coastal flood event, which is over half metre higher than the low point along the Beach Road. Therefore, re-grading the road surface or introducing underground drainage for conveyance will cause sea water intrusion during coastal flood events.

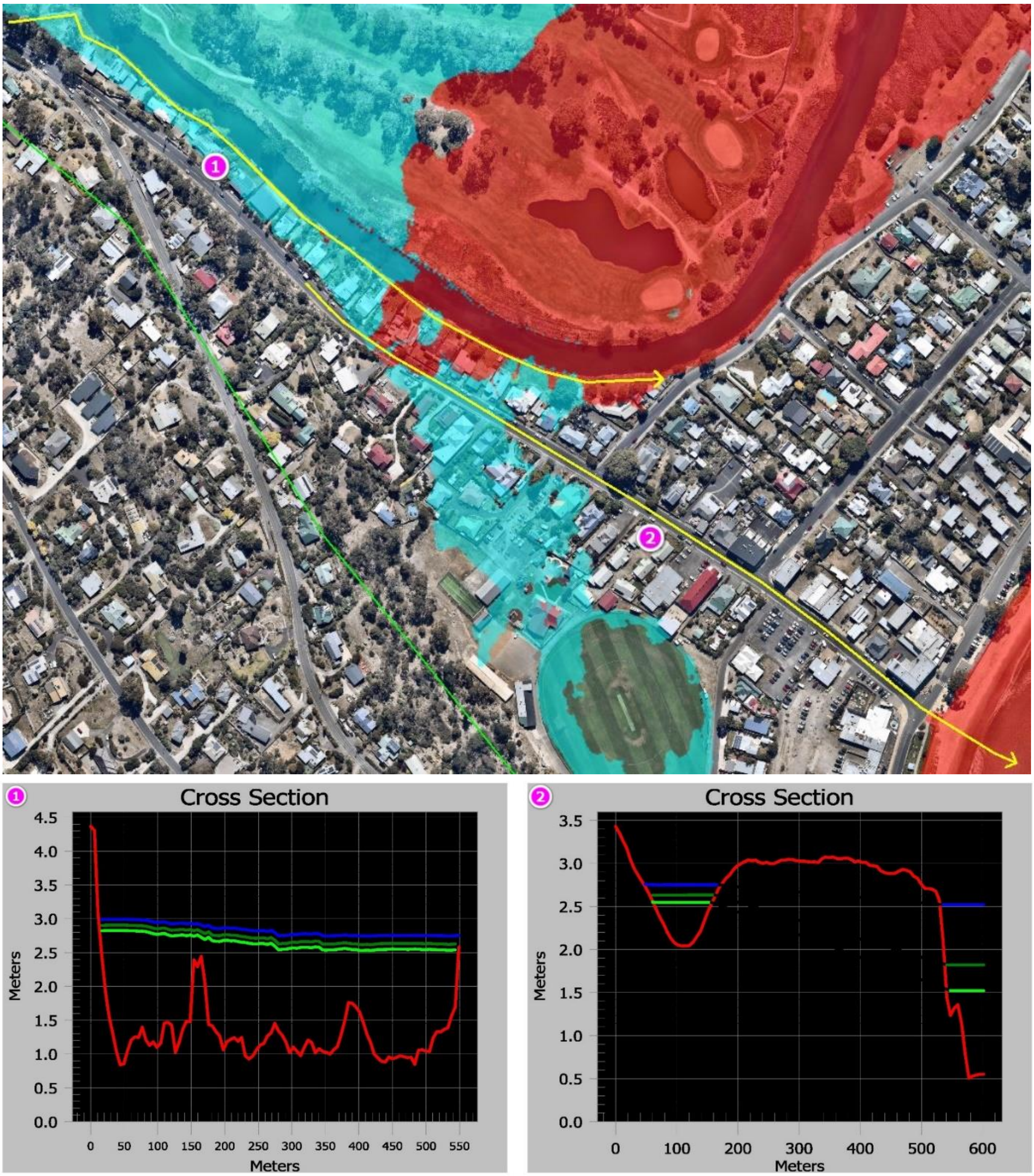


Diagram 4: Cross-sections in Hotspot 1. Green line for Baseline Scenario; Green line for Year 2050 Scenarios; Blue line for Year 2100 Scenarios.

Based on above analysis, two potential options are further assessed for Hotspot 1:

- Option A: embankment along the west bank of Browns River to protect the properties in western area of Kingston Beach Township.
- Option B: embankment along Beach Road to protect the properties south of Beach Road.

#### 7.2.1.1. Option A

***Effectiveness and Flood Impact***

A linear modifier (2d_zsh) was superimposed into the 2D hydraulic model to represent the riverbank embankment. Modelling was carried out for the six (6) coincident flooding scenarios listed in Table 6. The peak flood depths and levels are shown in Figure C1 to Figure C3. The flood impacts are shown in Figure C4 to Figure C6.

As illustrated in the flood mapping (Figure C1 to Figure C6), the proposed embankment is able to prevent flood water breaking out the western bank of Browns River during 1% AEP events. The number of properties prevented from inundation (i.e., flood immunity) under baseline, Year 2050, and Year 2100 climate conditions are summarised in Table 7. The properties protected under Year 2100 climate condition are illustrated in Diagram 5.

Table 7: Number of Properties Protected by Option A

| | Baseline | Year 2050 | Year 2100 |
|---|---|---|---|
| Number of Properties Protected | 31 | 35 | 38 |

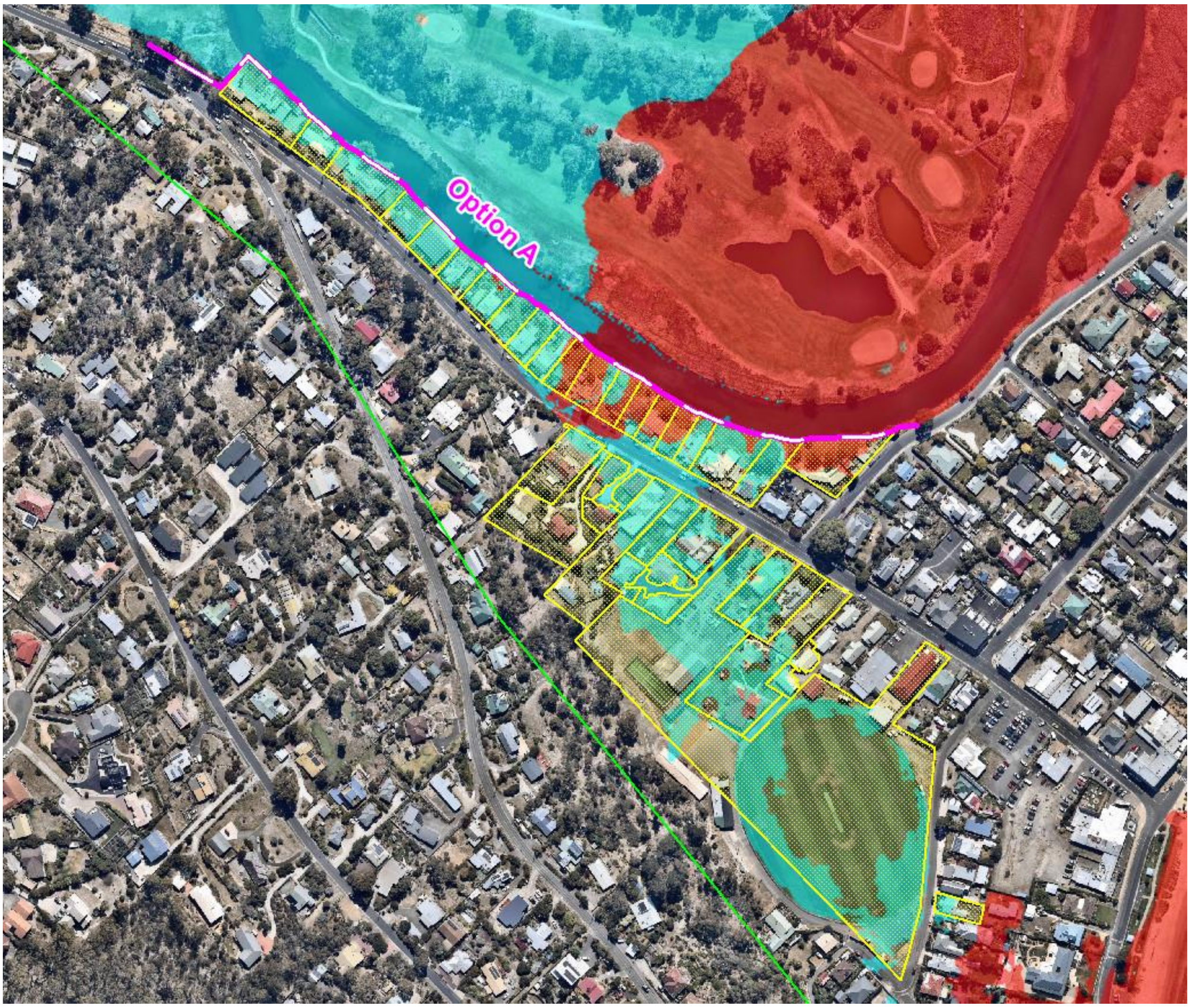


Diagram 5: Properties (highlighted in yellow hatches) Protected by Option A under Year 2100 Climate Condition.

Option A is shown to be effective by providing flood immunity for over 30 properties under all three (3) climate conditions during 1% AEP events. Specifically, the most benefitted are the 20 properties at the northeastern side of Beach Road and adjacent to Browns River, which are subject to significant inundation under all three (3) climate conditions. The number of protected properties southwest of Breach Road increases as the climate changes. The protected properties include Kingston Beach Early Learning Centre and Kingston Crows Cricket Club.

Option A can resulted in up to 50 mm of flood level increase in the northern part of the Kingston Beach Golf Course (mostly below 30 mm), which is a negative impact by this option. However, this level of impact is considered to be minor compared with the flood depth in the Golf Course.

***Structural Implications***

The peak flood level in front of the modelled embankment during 1% AEP events decrease from 87 Beach Road (upstream) to 4 Balmoral Road (downstream), as shown in Table 8. The flood level reaches the highest level at 3.0 m AHD along the northern boundary of 87 Beach Road under Year 2100 climate condition.

Table 8: Peak Flood Level (m AHD) in front of the Start and End of the Embankment during 1% AEP flooding

| | Baseline | Year 2050 | Year 2100 |
|---|---|---|---|
| 87 Beach Road | 2.82 | 2.90 | 3.00 |
| 4 Balmoral Road | 2.54 | 2.60 | 2.75 |

The differences in flood level between baseline and Year 2100 climate conditions are only about 200 mm. Therefore, there is no real need to split the construction into stages for this option.

It is standard practice to provide 600 mm freeboard above the design event, which provides a safety margin to compensate for factors such as wave action, localised hydraulic effects, uncertainties in the design flood levels, climate changes, and future growth and developments. This can be increased or decreased depending on local knowledge, variations in flood height across event probabilities, and the factors accounted in the modeling process. Considering the wave action was reasonably quantified (References 2 and 6) and the modelling results under Year 2100 climate condition are to be used for planning purpose, the freeboard can be reasonably reduced in this case.

The proposed embankment joins Balmoral Road on the eastern side of 4 Balmoral Road. Based on the LiDAR data, the Balmoral Road Section between 4 Balmoral Road and 41 Balmoral Road and the properties on the southeastern side of Beach Road are at 3.0 m AHD or slightly above. Therefore, it is proposed to set the embankment top level from 3.25 m to 3.0 m AHD from upstream (87 Beach Road) to downstream (4 Balmoral Road), i.e., 250 mm freeboard above modelled 1% AEP peak flood level under Year 2100 climate conditions. Consequently, the proposed embankment together with Balmoral Road provides a continuous embankment for flood prevention. As mentioned, the ground levels of the property boundaries adjacent to Brown River varies from 1.0 m to 1.75 m AHD, which implies that the embankment needs to be 1.25 m to 2.25 m above the natural ground level (as depicted in the LiDAR data used in this study).

As illustrated in Photo 1, those properties along the Browns River are directly connected to the River and there is no room to build a earth embankment type levee with required batters (e.g., 1:3). One structurally feasible option is to construct **vertical flood barricade** (as suggested in Reference 5) along the northeastern boundaries of those properties. The barricade can be **concrete flood walls with preinstalled flood gates** allowing access from the properties to Browns River. Photo 2 shows an example of concrete flood walls and sliding flood gates.


Photo 1: Aerial Imagery of Properties along Browns River.


Photo 2: Concrete Retaining Walls (L) and Sliding Flood Gates (R).

***<u>Cost Estimation</u>***

A high-level cost estimation was conducted based on costing information from previous studies (References 5 and 9) and current market rates. The total capital cost is estimated to be approximately **$ 4.5 million**. The cost breakdown is attached in APPENDIX D.

***<u>Social Impacts</u>***

Despite of its considerable effectiveness, the installation of flood walls and gates will have significant negative impacts on both physical and visual accessibility to the river from the 20 properties. Direct connection to Browns River is an important factor affecting the property price.

The access to the river and its aesthetic significance is typically also an important driving force for people who are willing to reside in flood-prone areas, e.g., riverside in this case. Therefore, the willingness of the residents to have a 2-meter-high flood wall in front their property is likely to be low despite the measure providing flood protection to their houses during extreme events.

Public consultation, especially with the owners of the properties along Browns River, will be required to gain community opinions and feedbacks if this option is selected for further investigation and implementation.

The proposed flood walls will very likely occupy part of private lands, as riverside properties directly adjoin the Browns River. This also challenge the feasibility of this option.

***Environmental Impacts***

The constructed flood walls can potentially restrict river channel capacity and increase siltation of the floodplain and river channels, a problem compounded by the deforestation and soil erosion of upper catchments (Reference 20). Flood risk could be increased in higher order events where overtopping may occur or when flood wall failure occurs during flood events (Reference 7). Therefore, civil works for erosion protection and landscape reestablishment are important, and periodic inspection and maintenance are required.

***Alternative Option***

Similar to the concept of the vertical flood walls, the Kingston Beach Sea Level Rise and Flood Mitigation Options for Consideration report (Reference 9) proposed to shift the water course slightly towards the Golf Course to free some room for levee construction. The advantage of that option is the levee can be constructed as earth embankment with proper batters and it will not occupy private land from the riverside properties.

However, there are also many disadvantages associated with that option, including:

- the new water course will occupy a larger private land, which is the Golf Course
- the cost will be higher than the flood wall option, due to the requirement for river rerouting and associated evacuation and backfill
- the owners of the riverside properties will stay further away from the river, i.e., losing the direct connection to Browns River from a certain point of view, and
- it can potentially affect the flow characteristics and river ecosystem.

This alternative option is deemed to be even less feasible compared with the flood walls with flood gates, and thus not further assessed in this study.

#### 7.2.1.2. Option B

***Effectiveness and Flood Impact***

A linear modifier (2d_zsh) was superimposed into the 2D hydraulic model to represent the embankment along Beach Road. Modelling was carried out for the six (6) coincident flooding scenarios listed in Table 6. The peak flood depths and levels are shown in Figure C7 to Figure C9. The flood impacts are shown in Figure C10 to Figure C12.

As illustrated in the flood mapping (Figure C7 to Figure C12), the proposed embankment can prevent flood water flowing across Beach Road and propagating further south during 1% AEP events. The number of properties provided flood immunity under baseline, Year 2050, and Year 2100 climate conditions are summarised in Table 9. The properties protected under Year 2100 climate condition are illustrated in Diagram 6.

Table 9: Number of Properties Protected by Option B

| | Baseline | Year 2050 | Year 2100 |
|---|---|---|---|
| Number of Properties Protected | 11 | 15 | 18 |

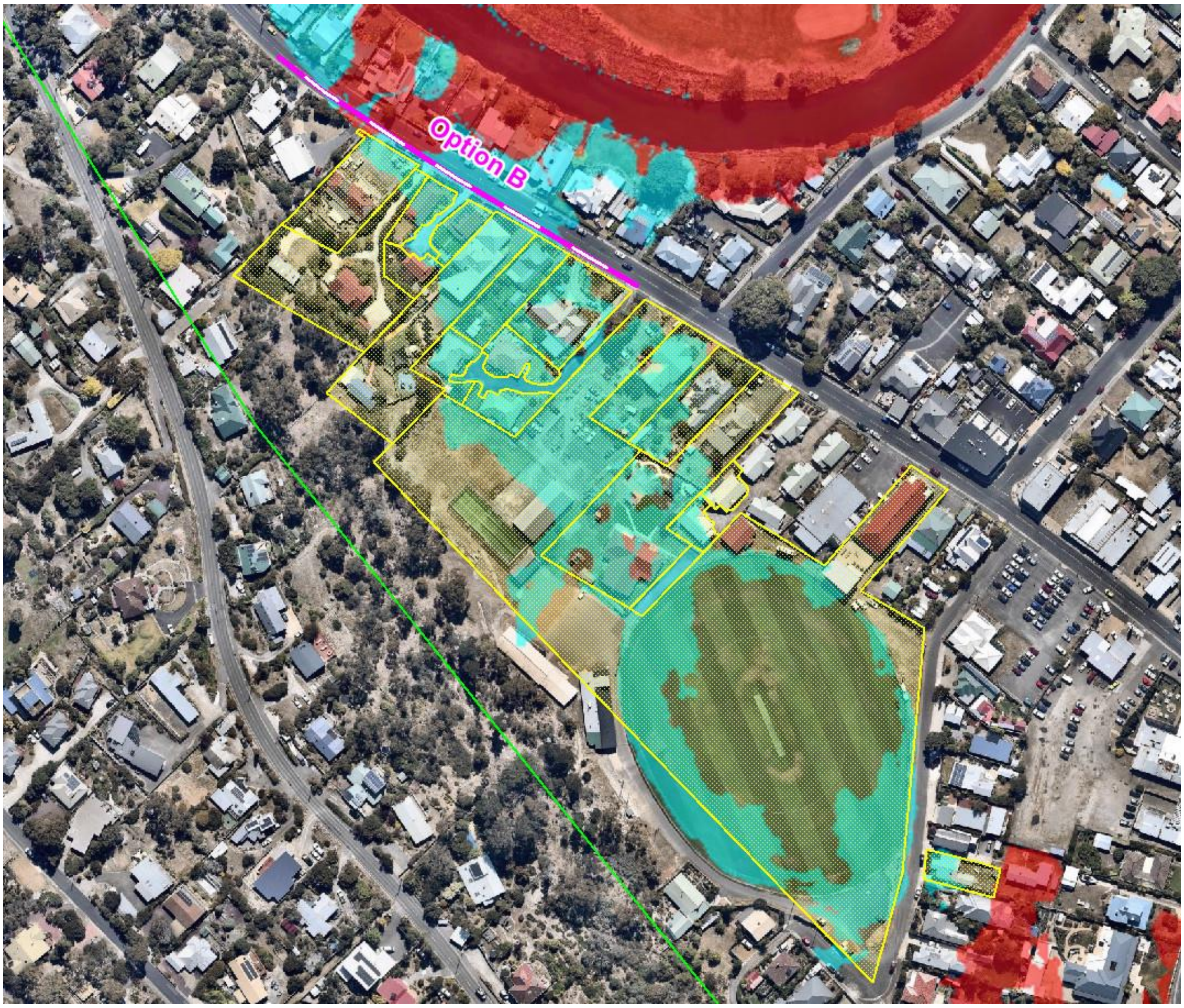


Diagram 6: Properties (highlighted in yellow hatches) Protected by Option B under Year 2100 Climate Condition.

Option B provides flood immunity for 11 – 18 properties during 1% AEP events. The protected properties include Kingston Beach Early Learning Centre and Kingston Crows Cricket Club. The benefit of Option B is smaller compared with Option A, as it provides no protection to the 20 properties adjacent to Browns River. However, it does not cause negative impacts on those riverside properties and the Golf Course in terms of peak flood level, which is superior compared with Option A.

***Structural Implications***

As shown in the impact mapping, flood embankment along the Beach Road (e.g., raising the road crown up) can potentially prevent flood water flows further south. The peak flood level in front of the modelled embankment along Beach Road during 1% AEP events is 2.75 m AHD under Year 2100 climate condition, as summarised in Table 10. The lowest ground level of Beach Road is about 2 m AHD according to LiDAR data, indicating that the road crown needs to be raised at least 0.75 m (without freeboard) to provide flood immunity for the properties south of Beach Road.

Table 10: Peak Flood Level (m AHD) in front of the Embankment along Beach Road during 1% AEP flooding

| | Baseline | Year 2050 | Year 2100 |
|---|---|---|---|
| Beach Road | 2.55 | 2.63 | 2.75 |

Photo 3 is the low point of the Beach Road, and it is relatively flat across the road. The feasibility of raising the road for 0.75 m or over to provide flood immunity will be very low considering the ingress and egress of the properties on two sides of the road.

Photo 3: Low Point along Beach Road.

An alternative solution is to raise the road embankment to a structurally feasible level, to provide flood reduction rather than flood immunity to the properties south of Beach Road. However, a sensitivity analysis (modelling) indicates that the embankment will either provide flood immunity (with embankment level > 2.75 m AHD) or maintain the flood level south of Beach Road (with embankment level < 2.75 m AHD). This is mainly because the peak flood level is driven by both catchment and coastal flooding. The relatively large contributing catchment area and coincident effect result in relatively long peak duration. The flood water overtops Beach Road however does not form an active flow path into River Derwent, i.e., it fills the local storages and then flows north back to Browns River during the recession. Therefore, if the embankment along Beach Road is lower than 2.75 m AHD, the flood level will be driven by the peak level in Browns River. This implies that there is no benefit to raise the road embankment to a level below 2.75 m AHD.

Considering the low feasibility of permanent embankment (raising road) along Beach Road, **mobile flood barriers** are considered to be a better measure. Photo 4 shows the NOAQ Boxwall mobile flood barriers (levee) as an example. It is a manually deployed moulded and stackable mobile flood barrier system. Pumps, hoses, water, or other tools are not required to deploy the barriers. The operating principle is illustrated in Diagram 7. The system is claimed to be fast to deploy, e.g., 100m of the 500mm high barriers can be deployed in less than 23 minutes (approximately 4m per minute), as demonstrated (Reference 21).

In this case, 200 m of 1-m high barriers are proposed to be procured and deployed as directed by flood warning systems.

Photo 4: NOAQ Boxwall Mobile Flood Barriers (Bluemont, Reference 21).

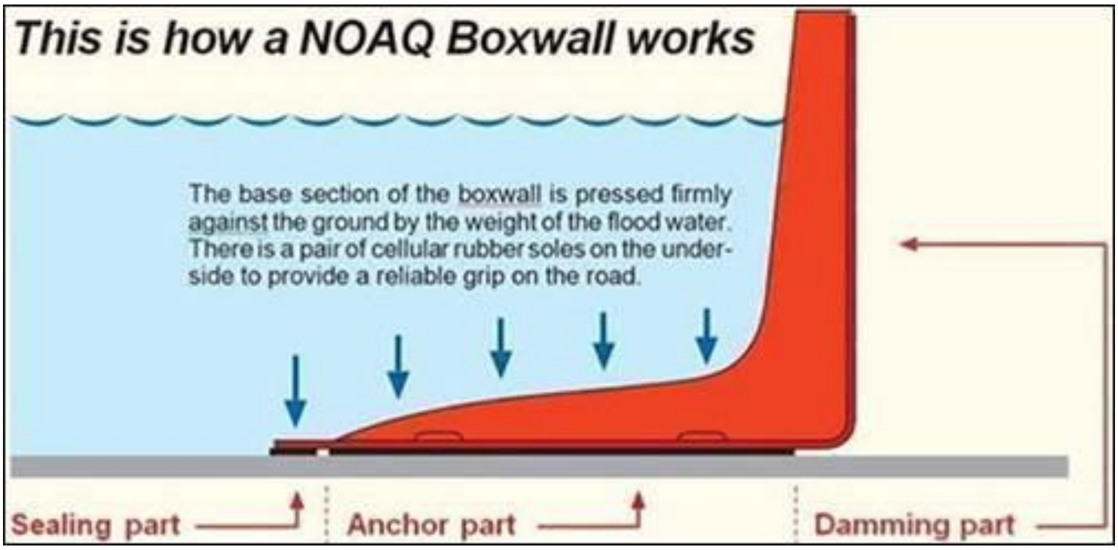


Diagram 7: Operating Principle of NOAQ Boxwall Mobile Flood Barrier.

***Cost Estimation***

A high-level cost estimation was conducted based on unit price information provided by Bluemont and the total length of barriers required. The total capital cost is estimated to be approximately **$ 201,300**. The labour cost to transport, deploy, and remove the flood barriers for each emergency response event is estimated to be **$2,310**, as detailed in APPENDIX D.

The running cost depends on how frequent the flood barriers need to be deployed. Based on the experience from other LGAs in Tasmania, e.g., the City of Hobart, placing flood barriers out each time receiving flood warning from BOM can be a waste of time and labour without consideration of the probability of the event and uncertainties associated with the warnings, e.g., false alarms. The modelling results from this study shows there will be 11 properties subject to inundation which can be protected during 1% AEP flooding under baseline climate condition. The AEP threshold for emergency response can be further determined by modelling of additional design events for a range of AEPs, which is outside the scope of this study though. However, it is suggested that deployment of flood barriers should be considered at least for warnings of 1% AEP flooding under “current” climate condition.

***Social Impacts***

The mobile flood prevention measures, such as the flood barriers nominated above, will not cause any impact or inconvenience to the community during non-flood periods. The modelling shows that the implementation of flood barriers will not cause adverse impacts on properties northeast of Beach Road in terms of peak flood levels. Therefore, it is anticipated that this measure is likely to be well accepted by the community. However, the effectiveness and efficiency of this option highly relies on reliable flood warnings and prompt emergency response mechanism, which requires ongoing research and development in flood forecasting systems, and collaboration between Council, State Emergency Service (SES), and the local community.

***Environmental Impacts***

As the mobile barriers are not deployed during non-flood periods, it has little impacts on amenity, environment, or local ecosystem.

### 7.2.2. Hotspot 2

Properties around the east part of Kingston Beach Township are subjected to inundation during both catchment and coastal 1% AEP flooding, with the critical flood level modelled to be 2.54 m AHD to 2.69 m AHD along the west bank of Browns River, as indicated by Cross-section 1 in Diagram 8. This highlighted the opportunity to extend the existing sea wall (i.e., flood retaining wall) towards upstream of Browns River to provide protection of properties in Hotspot 3.

As indicated by Cross-section 2 in Diagram 8, the flood depth can be up to 0.8 m within the road reserve of Windsor Street during 1% AEP coastal flooding under Year 2100 climate condition; therefore, it is difficult to manage/retain the water within the road reserve to protect residential properties.

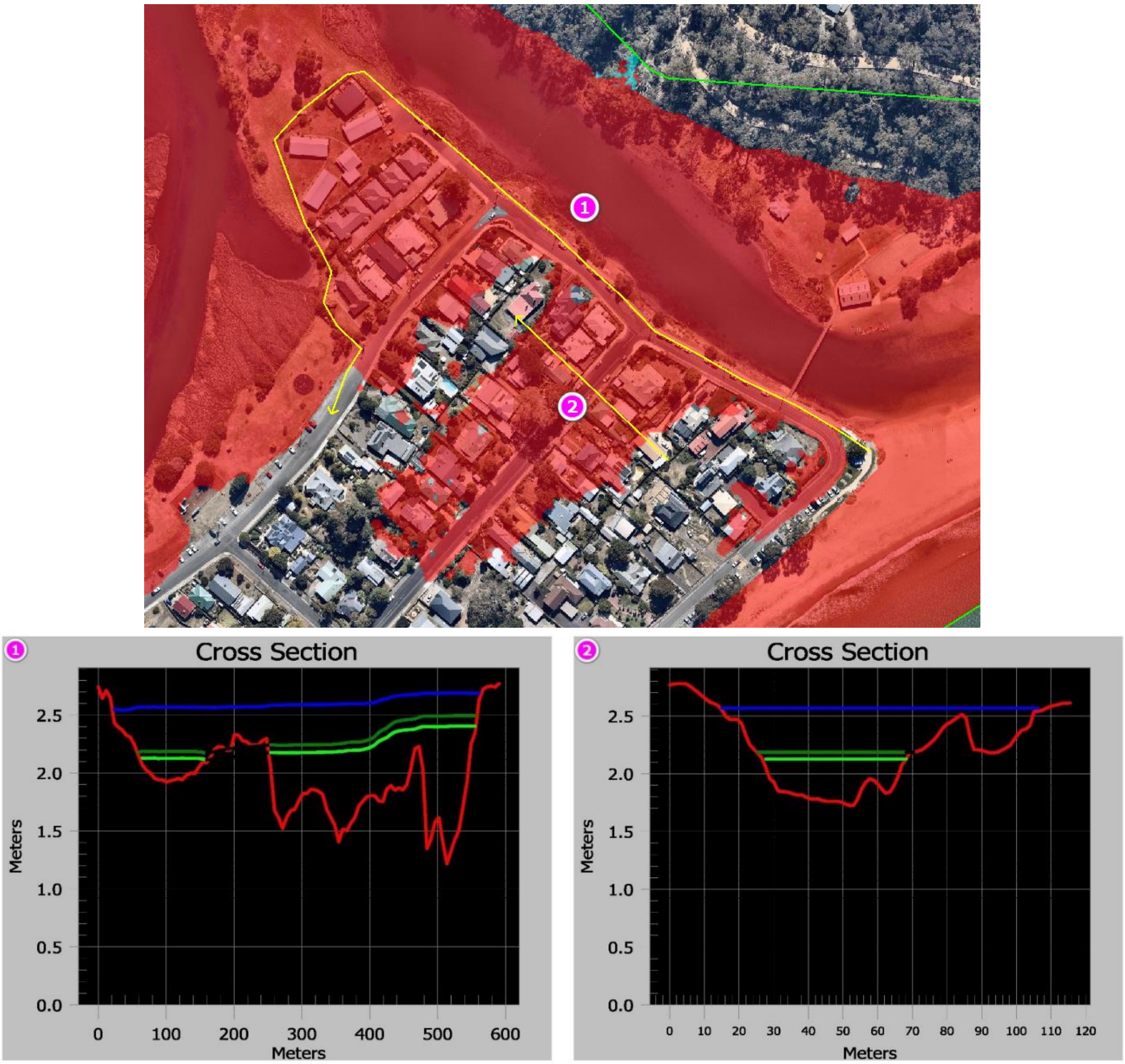


Diagram 8: Cross-sections in Hotspot 3. Green line for Baseline Scenario; Green line for Year 2050 Scenarios; Blue line for Year 2100 Scenarios.

Based on above analysis, a potential option has been proposed for Hotspot 1 for further assessment:

- Option C: construction of flood wall (extending the existing sea wall) from the river mouth towards upstream of Browns River to protect properties in the northeast part of Kingston Beach.

#### 7.2.2.1. Option C

***<u>Effectiveness and Flood Impact</u>***

A linear modifier (2d_zsh) was superimposed into the 2D hydraulic model to represent the flood wall embankment. Modelling was carried out for the six (6) coincident flooding scenarios listed in Table 6. The peak flood depths and levels are shown in Figure C13 to Figure C15. The flood impacts are shown in Figure C16 to Figure C18.

As illustrated in the flood mapping (Figure C13 to Figure C18), the proposed flood wall can prevent the properties in northeast of Kingston Beach Township from inundation during 1% AEP events. The number of properties prevented from inundation (i.e., flood immunity) under baseline, Year 2050, and Year 2100 climate conditions are summarised in Table 11. The properties protected under Year 2100 climate condition are illustrated in Diagram 9.

Table 11: Number of Properties Protected by Option C

| | Baseline | Year 2050 | Year 2100 |
|---|---|---|---|
| Number of Properties Protected | 19 | 27 | 52 |


Diagram 9: Properties (highlighted in yellow hatches) Protected by Option C under Year 2100 Climate Condition.

Option C is shown to be effective by providing flood immunity for 52 properties during 1% AEP events under Year 2100 climate condition. The number of properties benefited from Option C increase significantly from baseline condition to Year 2100 due to the significant change of the sea levels and associated storm surge effect.

Option C can result in minor impact upstream, i.e., up to 30 mm of flood level increase. The extent of the impact under baseline and Year 2050 climate conditions are relatively small, i.e., only small areas in 40 Balmoral Road (DPIPWE Crown Land) and 6-26 Balmoral Road (Council Land), which are all reserves. The extent of the impact under Year 2100 climate condition is relatively larger, including the southern part of the Golf Course and the properties in Hotspot 1. Nevertheless, the impact is considered to be very small (less than 30 mm) and should be reduced from Hotspot 1 when implemented together with Options A or B.

***Structural Implications***

The peak flood level in front of the modelled embankment during 1% AEP events decrease from 28 Balmoral Road (upstream) to the river mouth (downstream), as shown in Table 12. The flood level reaches the highest level at 2.69 m AHD along the northern boundary of 28 Balmoral Road under Year 2100 climate condition.

Table 12: Peak Flood Level (m AHD) in front of the Start and End of the Embankment during 1% AEP flooding

| | Baseline | Year 2050 | Year 2100 |
|---|---|---|---|
| 28 Balmoral Road | 2.41 | 2.50 | 2.69 |
| River Mouth | 2.13 | 2.19 | 2.55 |

Staged implementation would not be required due to the relatively small difference in design flood levels between Baseline and Year 2100 conditions. The proposed embankment starts from the south side of 28 Balmoral Road, which is about 3.0 m AHD, and joins the existing seawall at the river mouth, which is about 2.8 m AHD, according to LiDAR data. It is suggested that the flood wall embankment is designed at 3.0 m AHD to ensure there is suitable freeboard to protect the properties against 1% AEP events under Year 2100 condition.

It was assumed that the embankment is connected to the existing seawall and constructed as a **concrete flood wall along** the riverbank. Integration of the Option C seawall into the streetscape can be achieved by raising the exiting footpath along Balmoral Road to 3.0 m AHD, as illustrated in Photo 5. Alternatively, the seawall can be constructed adjacent the footpath with access to the river being provided by stairs or removable flood gates.


Photo 5: Proposed Flood Wall by Raising the Footpath along Balmoral Road.

***Cost Estimation***

A high-level cost estimation was conducted based on costing information from previous studies (References 5 and 9) and current market rates. The total capital cost is estimated to be approximately **$ 3.55 million**. The cost breakdown is attached in APPENDIX D.

***Social Impacts***

Option C is an extension of the existing seawall upstream along Browns River. The proposed works does not occupy or impede upon private land/property. Therefore, it is anticipated that the community is likely to be supportive of the Option, considering the number of properties that can be protected. Raising the footpath will potentially affect the accessibility of Browns River from Balmoral Road and reduce the riverside leisure space, however, it is not considered to be a significant issue as the beach area provides the main leisure functionality for the region.

***Environmental Impacts***

The constructed flood walls can potentially restrict river channel capacity and increase siltation of the floodplain and river channels. However, this issue is much less significant as there is still enough space between the footpath and the riverbank. Appropriate earth work can be taken to minimise the erosion and sedimentation associated risks. The flood wall failure risk is also considered to be lower than Option A due to the wider space and smaller depth required for the flood walls. Regular inspection and maintenance are required to minimise failure risks.

### 7.2.3. Hotspot 3

The existing sea wall, illustrated in Photo 6, is generally above the sea level during 1% AEP coastal flood event under Year 2100 conditions, except for the section near Hotspot 2. Properties in Hotspot 2 are predicted to be inundated by coastal flood water under Year 2100 conditions, as the existing sea wall is slightly under 2.5 m AHD at several points, as indicated by the Cross-sections 1 and 2 in Diagram 10.

Photo 6: Existing Sea Wall along Kingston Beach.

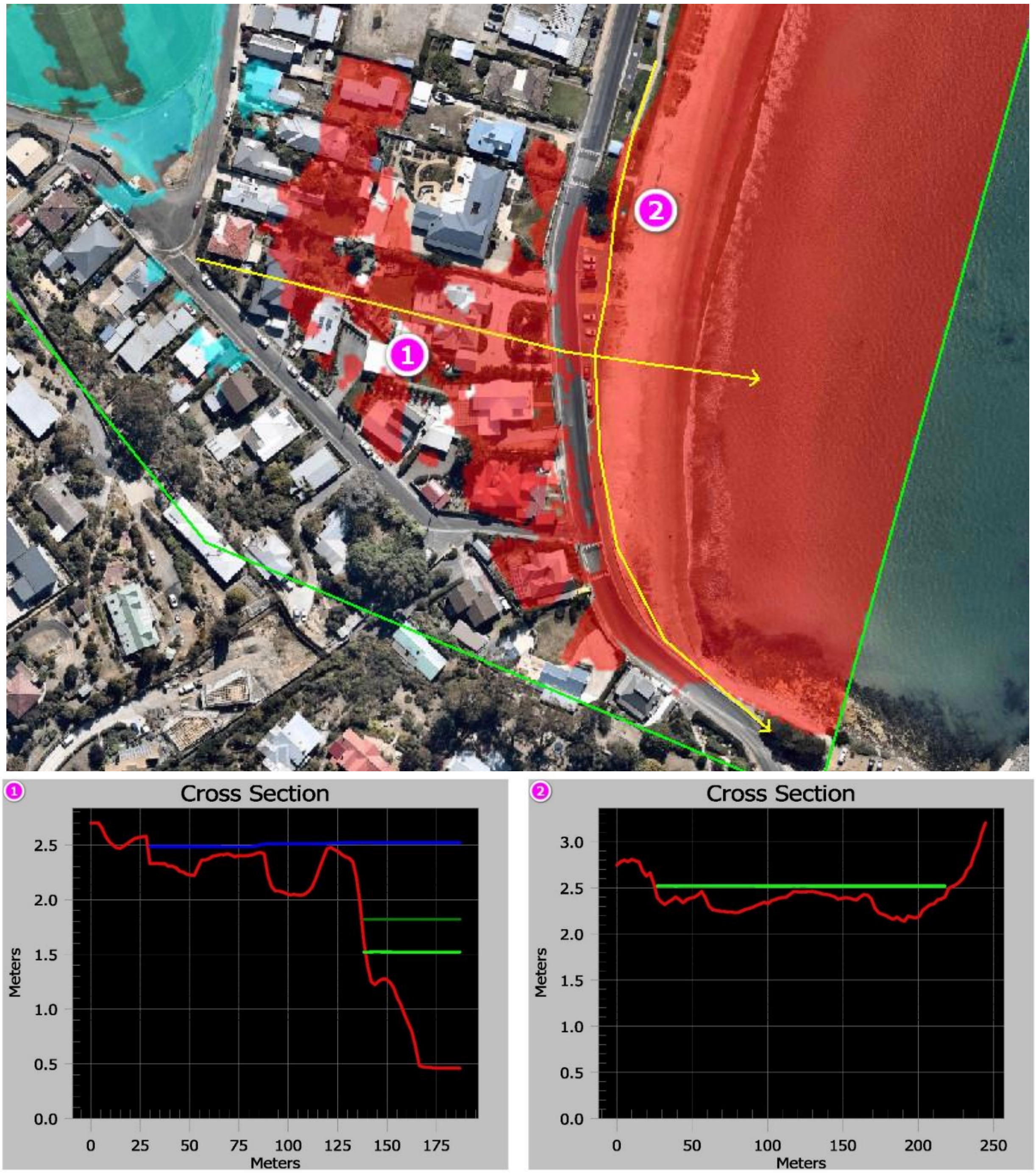


Diagram 10: Cross-sections in Hotspot 2. Green line for Baseline Scenario; Green line for Year 2050 Scenarios; Blue line for Year 2100 Scenarios.

Based on above analysis, below option has been proposed for Hotspot 3 for further assessment:

- Option D: increasing the south section of the existing sea wall to prevent sea water intrusion.

#### 7.2.3.1. Option D

***Effectiveness and Flood Impact***

A linear modifier (2d_zsh) was superimposed into the 2D hydraulic model to represent the enhanced seawall embankment. Modelling was carried out for the six (6) coincident flooding scenarios listed in Table 6. The peak flood depths and levels are shown in Figure C19 to Figure C21. The flood impacts are shown in Figure C22 to Figure C24.

As illustrated in the flood mapping (Figure C19 to Figure C24), the increased seawall can provide flood immunity or significant flood level reduction for the properties in southwest of Kingston Beach Township during 1% AEP coastal flooding. The number of properties benefited under baseline, Year 2050, and Year 2100 climate conditions are summarised in Table 13. The properties benefited under Year 2100 climate condition are illustrated in Diagram 11.

Table 13: Number of Properties Protected by Option D

| | Baseline | Year 2050 | Year 2100 |
|---|---|---|---|
| Number of Properties Protected/benefited | 0 | 0 | 17 |

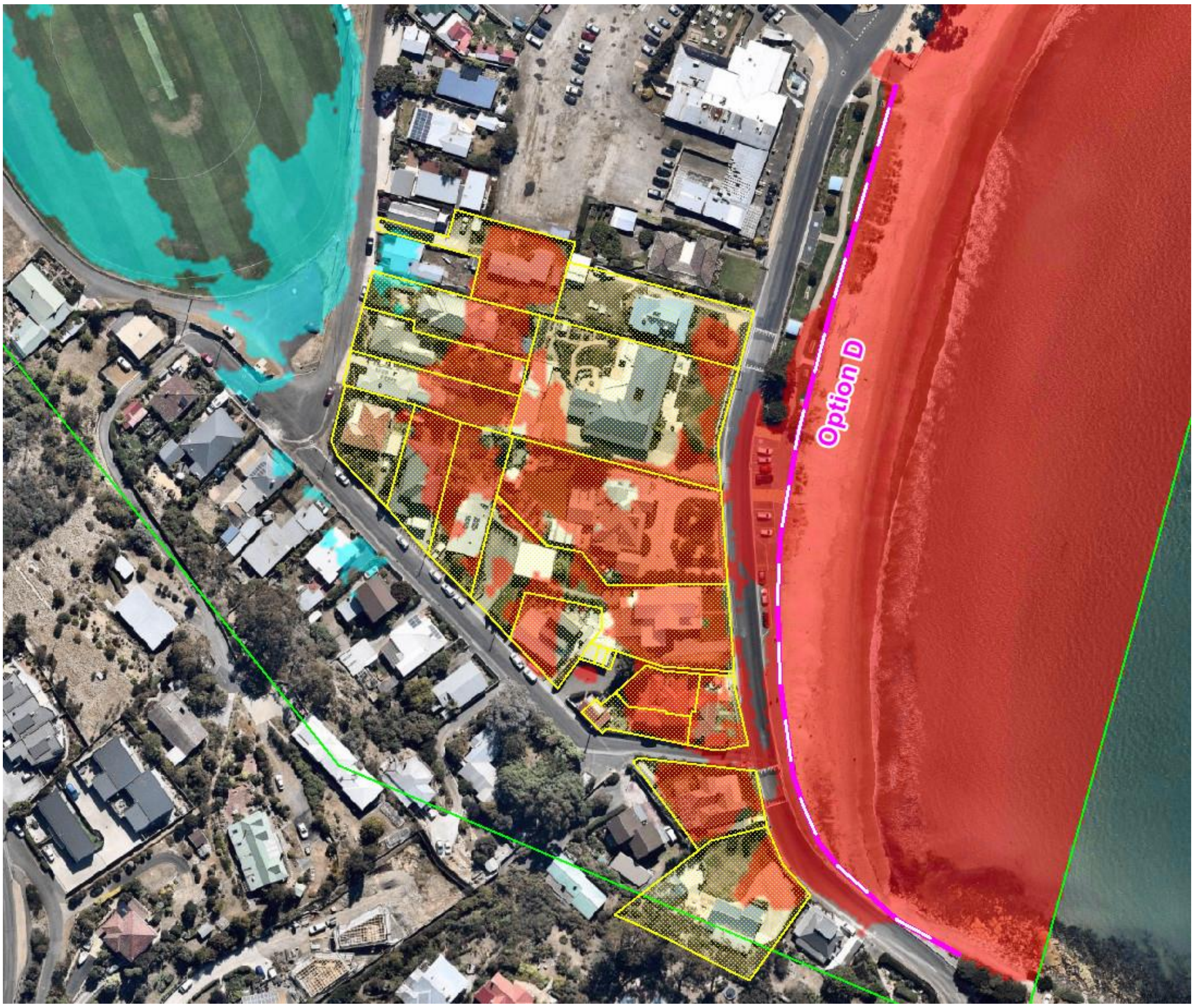


Diagram 11: Properties (highlighted in yellow hatches) Protected by Option D under Year 2100 Climate Condition.

The sea water intrusion is not expected to happen under baseline and Year 2050 conditions; therefore, Option D is explicitly designed for Year 2100 condition. It is shown to be effective by providing flood immunity or significant flood level reduction for 17 properties during 1% AEP events under Year 2100 climate condition. No negative flood impacts are generated by Option D.

***Structural Implications***

As the sea water intrusion is not expected to happen under baseline and Year 2050 conditions, this option can be placed at a later stage.

It is suggested to raise the existing seawall to 3.0 m AHD to ensure there is enough freeboard to protect the properties against 1% AEP storm surge events under Year 2100 condition.

It is recommended to make the maximum use of the existing seawall foundation and **raise the footpath on existing seawall to 3.0 m AHD**, as illustrated in Photo 7.


Photo 7: Proposed Sea Wall Upgrade – Raising the Footpath on Exsiting Sea Wall.

***Cost Estimation***

A high-level cost estimation was conducted based on costing information from previous studies (References 5 and 9) and current market rates. The total capital cost is estimated to be approximately **$ 1.74 million**. The cost breakdown is attached in APPENDIX D.

***Social Impacts***

Construction of seawalls can potentially raise concerns from the community, due to its potential impact on the amenity and functionality of the beach, as well as the tourism. However, this is not considered to an issue for this case due to following reasons:

- The seawall has already been constructed, and the proposed work is just an upgrade of the existing seawall structure to provide better flood protection.
- The increase of the existing seawall is only about 0.5 m, which will not cause notable impact on the amenity and functionality of that section of Beach.

- Only the southern section of the seawall requires upgrade, i.e., less than 300 m in length.

***Environmental Impacts***

It is not anticipated that raising a section of the existing seawall will cause considerable environmental issue to the Beach. Periodic maintenance of the seawall should be continued to ensure the seawall is in good condition and erosion and sedimentation is appropriately controlled.

### 7.2.4. Other Resilience Measures

The structural flood mitigation options, such as those proposed above, can be effective by providing flood immunity to affected properties. However, they can also be expensive and less feasible to be implemented. There are another group of measures, known as non-structural resilience measures, which may be easier to be implemented and have a wide range of benefits.

#### 7.2.4.1. Proper Flood Insurance

As discussed above, permanent flood and sea walls can be expensive, and some of them, e.g., Option A, can have a very low feasibility to be implemented. Therefore, getting flood-affected properties appropriately insured can be an important measure in Kingston Beach. Especially for those properties along the river, enjoying the direct connection to the river might be more important for the residents than getting flood immunity of their properties. In that case, proper insurance is an effective tool to minimise the potential total loss caused by flooding. It improves the way people can live with floods, rather than fight against floods.

#### 7.2.4.2. Flood Warnings

Kingston Beach subjects to coincident flooding from Browns River catchment and storm surges. The Browns River catchment is relatively a big catchment with reasonable concentration time to facilitate flood forecasting and emergency response. Reliable forecasting and warnings can provide important information for flood preparedness and emergency response. For instance, in this case, the mobile flood barriers option relies on reliable flood warnings heavily.

BOM and some local agencies are responsible for delivering rainfall and flood warnings. However, there are various uncertainties in the warnings. Therefore, improving the current forecasting and warning systems, e.g., through installation of flow gauges, can be an on-going effort, which can provide benefits for flood risk management.

#### 7.2.4.3. Flood Response Plan

Establish appropriate flood response and emergency management plan is also an effective measure for flood risk management. It is recommended that Council works closely with SES to review their flood response and emergency management plan and ensure that the required response for the study area is up to date and includes feedback from recent flood events. Priority should be given to the implementation of this process once completed, which will continue to involve ongoing community education and awareness.

As illustrated in the flood mapping, some of the properties, e.g., those along Browns River and Beach Road, are hard to be protected from inundation. However, they have relatively easy access to the higher area, e.g., the centre of the township. Therefore, an efficient flood response plan can help residents get out of flood risks, and thus save lives.

#### 7.2.4.4. Planning Control for redevelopment

As noted, Kingston Beach is an old developed residential area. Therefore, it is unlikely significant development will happen in the near future. For those properties with high flood risks, it is hard to enforce a floor level of their existing dwellings. However, planning controls can be placed to restrict future redevelopment, to ensure that any new buildings should have a floor level above designed flood levels with defined freeboard.

This measure should work nicely with insurance measure, i.e., proper insurance provides protection of the existing buildings, while planning control provides protection for future redevelopments.

### 7.2.5. Holistic View of Mitigation Options

#### 7.2.5.1. Joint Effect of Structural Options

Based on above assessment, raising existing seawall (Option D) and extending it upstream to protect the eastern part of Kingston Beach township (Option C) are effective and can be feasible, regardless of implementation of Option A or B for Hotspot 1. From the holistic perspective, following two (2) combinations of mitigation measures were further modelled:

- Option ACD – flood immunity for the Kingston Beach built-up area
- Option BCD – “living with flood” for the riverside properties along Beach Road while flood immunity for the rest area of Kingston Beach built-up area

Modelling was carried out for the six (6) coincident flooding scenarios listed in Table 6. The peak flood depths and levels are shown in Figure C25 to Figure C27 for Option ACD and Figure C31 to Figure C33 for Option BCD. The flood impacts are shown in Figure C28 to Figure C30 for Option ACD and Figure C34 to Figure C36 for Option BCD.

The impact mapping indicates that Option ACD can result in up to 50 mm increase of flood levels in the Golf Course under all three climate conditions, while Option BCD can result in up to 30 mm increase of flood levels in a smaller extent, especially under baseline and Year 2050 climate conditions. However, Option BCD also causes up to 30 mm increase of flood levels in the riverside properties along Beach Road under Year 2100 condition.

#### 7.2.5.2. Feasibility Summary

The detailed feasibility assessment for each mitigation option is summarised in Table 14.

Table 14: Feasibility Summary

| Mitigation Option | Property Benefited | Flood Impact | Costing | Structural Implications | Social Impact | Environmental Impact | Feasibility |
|---|---|---|---|---|---|---|---|
| Option A – Flood Wall with Flood Gates along Riverside Properties | 31 – 38 | Up to 50 mm flood level increase in Golf Course (joint effect with Option C) | $ 4.5 million | Flood Wall with Flood Gates (3.25 to 3 m AHD) | Properties losing access to River, potentially low community acceptance | Erosion and siltation issues, failure risk | Low |
| Option B – Mobile Flood Barriers along Beach Road | 11 – 18 | Up to 30 mm flood level increase in Golf Course and riverside properties (joint effect with Option C) | $ 201,300 + $2,310 running cost per deployment | Mobile Flood Barriers (1-metre fence) | Potentially high community acceptance, on-going efforts by Council, SES, and Community | Minor impact | Medium |
| Option C – Extended Seawall along Riverbank | 19 – 52 | Joint effect with Option A or B | $ 3.55 million | Raising footpath where possible (3 m AHD) | Affecting amenity, potentially medium to high community acceptance | Erosion and siltation issues, failure risk, but less than Option A | Medium |
| Option D – Raised Seawall along the Beach | 17 (Year 2100 only) | No adverse impact | $ 1.74 million | Raising footpath on existing seawall (3 m AHD) | Potentially medium to high community acceptance | Minor impact | Medium |
| Flood Insurance for Affected Properties | All affected Properties | No adverse impact | On-going cost on landowner | – | Willingness can vary among owners, potentially medium community acceptance | No impact | Medium |
| Improved Flood Forecasting | All affected Properties | No adverse impact | On-going investment | – | Beneficial if improved | No impact | Medium |
| Flood Response Plan | All affected Properties | No adverse impact | Low | – | Potentially high community acceptance, efforts by Council, SES, and Community | No impact | High |
| Planning Control for Redevelopment | All affected Properties | No adverse impact | Low | – | Additional requirement but beneficial, potentially medium community acceptance | Minor impact | High |

# 8. PROPOSED FLOOD MITIGATION SCHEME

Non-structural resilience measures can be beneficial, more financially feasible. Structural measures, e.g., flood and sea walls, can be more expensive and requires more considerations on the environmental and social impacts, but can provide flood immunity for many affected properties. After the assessment of the flood characteristics in Kingston Beach, it is recommended that the preferred mitigation scheme should consider both structural and non-structural measures.

Construction of flood walls along the riverbank (Option A) is more beneficial than the mobile flood barriers along the Beach Road (Option B), however, the community acceptance of Option A can also be much lower. Therefore, community consultation is highly recommended before progress further with any of the structural mitigation options. Considering the low feasibility of Option A, it is proposed the combination of structural Option B, C, and D supported by non-structural resilience measures to be the preferred scheme for this study.

The proposed flood mitigation scheme for Kingston Beach is summarised as below:

Stage 1 (2021 - 2030):

- Procurement of mobile flood barriers and start to implement for flood protection along Beach Road (Option B).
- Promote flood awareness and flood insurance education to ensure the affected properties are properly insured as many as possible.
- Establish and review flood response plan to ensure appropriate guideline are up to date and put in place.
- Establish and update planning controls for redevelopment in this area.

Stage 2 (2030 - 2050)

- Construction of flood wall (extending seawall) from river mouth upstream to 28 Balmoral Rd to provide flood immunity for properties on eastern area of Kingston Beach (Option C).
- On-going investment on improving flood forecasting and warning system.

Stage 2 (2050 - 2090)

- Review climate change projections in Kingston Beach area.
- Raising the existing seawall to required level, e.g., 3.0 m AHD based on current climate projection, to protect properties from storm surge flooding (Option D).

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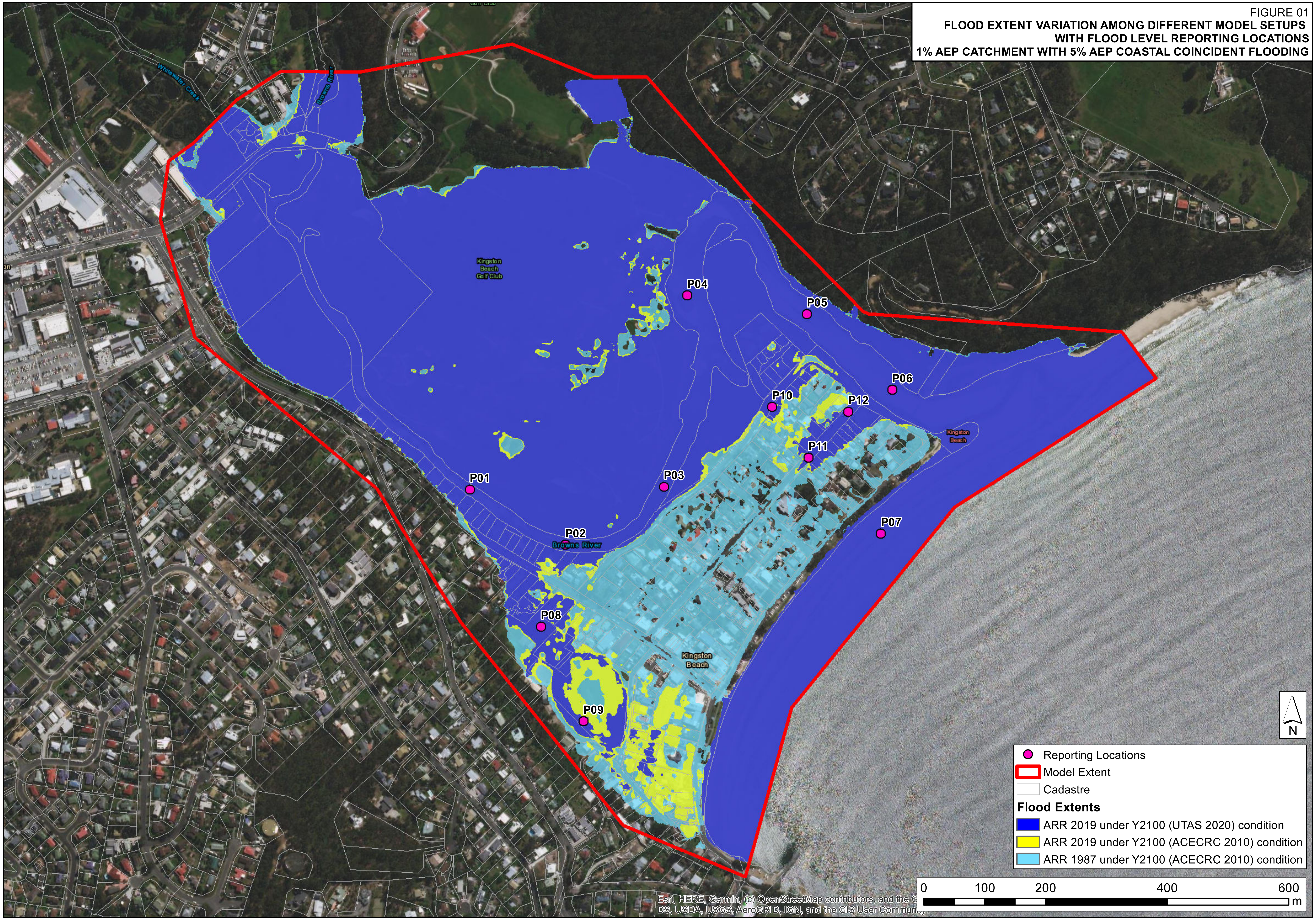
Figures

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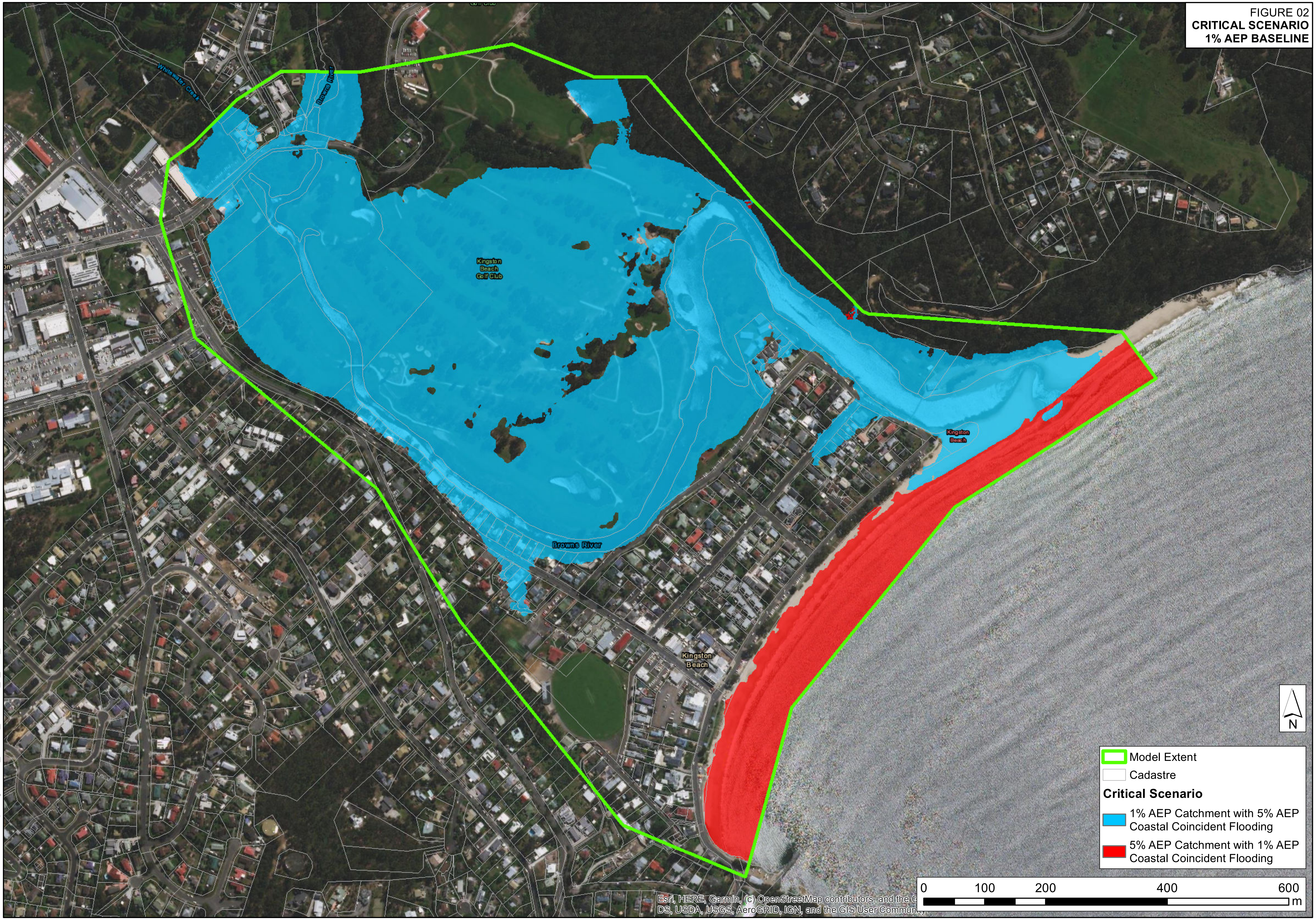


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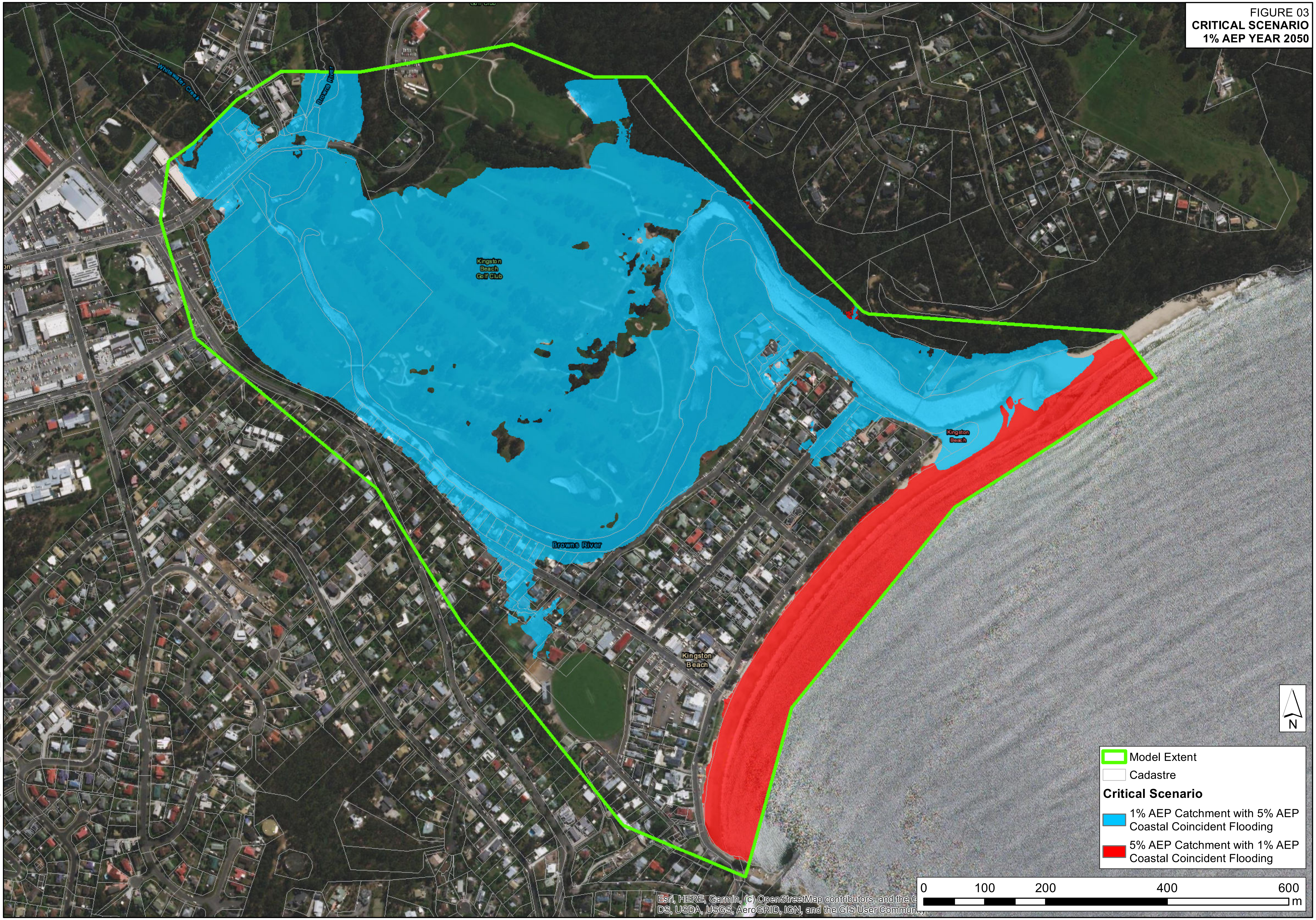


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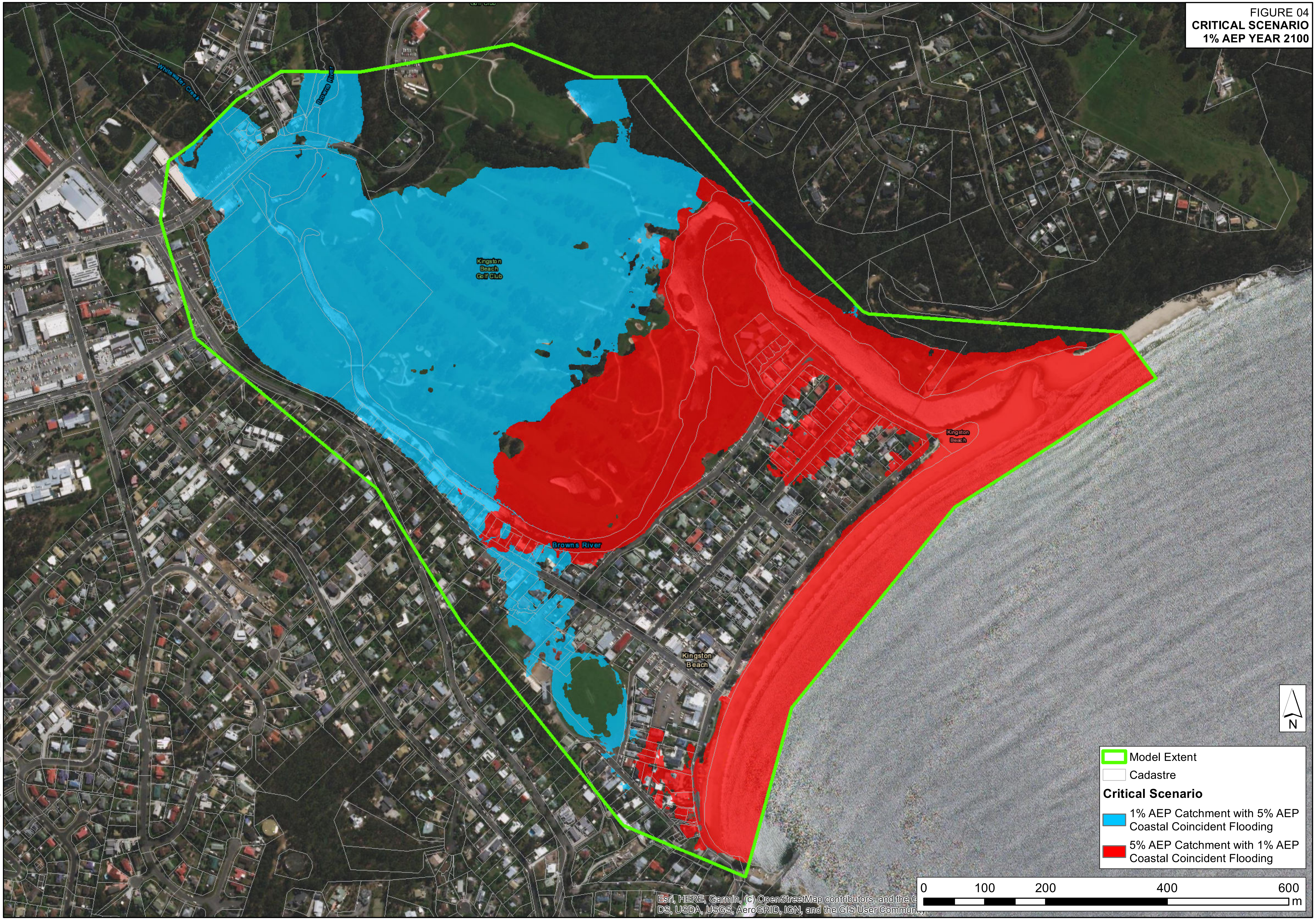


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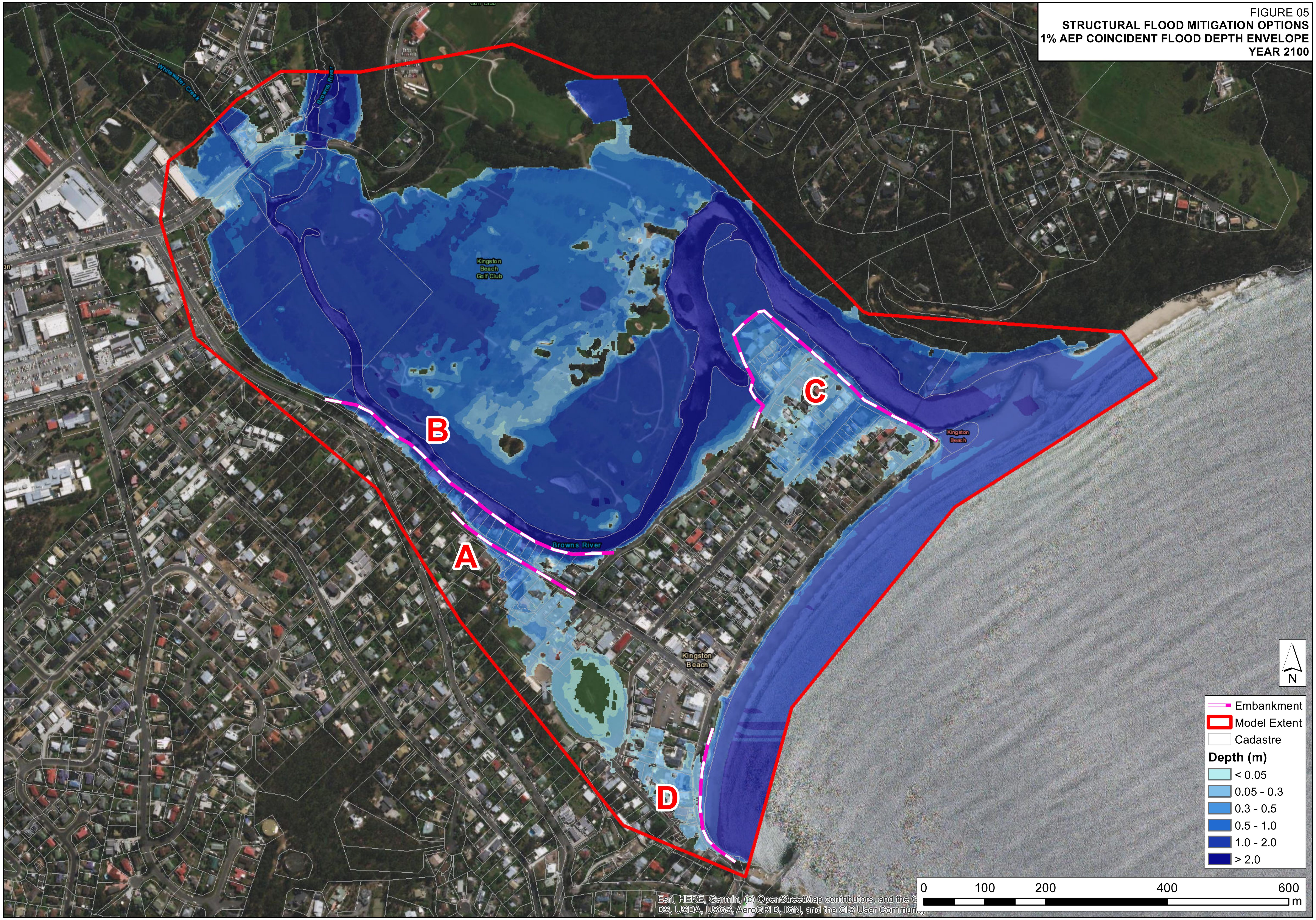


FIGURE 05
**STRUCTURAL FLOOD MITIGATION OPTIONS**
**1% AEP COINCIDENT FLOOD DEPTH ENVELOPE**
**YEAR 2100**

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# Appendix A

# APPENDIX A. GLOSSARY

Taken from the Floodplain Development Manual (April 2005 edition), which was developed for NSW but generally applied within Australian water industry.

| | |
|---|---|
| **acid sulfate soils** | Are sediments which contain sulfidic mineral pyrite which may become extremely acid following disturbance or drainage as sulfur compounds react when exposed to oxygen to form sulfuric acid. More detailed explanation and definition can be found in the NSW Government Acid Sulfate Soil Manual published by Acid Sulfate Soil Management Advisory Committee. |
| **Annual Exceedance Probability (AEP)** | The chance of a flood of a given or larger size occurring in any one year, usually expressed as a percentage. For example, if a peak flood discharge of 500 $m^3/s$ has an AEP of 5%, it means that there is a 5% chance (that is one-in-20 chance) of a 500 $m^3/s$ or larger event occurring in any one year (see ARI). |
| **Australian Height Datum (AHD)** | A common national surface level datum approximately corresponding to mean sea level. |
| **Average Annual Damage (AAD)** | Depending on its size (or severity), each flood will cause a different amount of flood damage to a flood prone area. AAD is the average damage per year that would occur in a nominated development situation from flooding over a very long period of time. |
| **Average Recurrence Interval (ARI)** | The long-term average number of years between the occurrence of a flood as big as, or larger than, the selected event. For example, floods with a discharge as great as, or greater than, the 20-year ARI flood event will occur on average once every 20 years. ARI is another way of expressing the likelihood of occurrence of a flood event. |
| **caravan and moveable home parks** | Caravans and moveable dwellings are being increasingly used for long-term and permanent accommodation purposes. Standards relating to their siting, design, construction and management can be found in the Regulations under the LG Act. |
| **catchment** | The land area draining through the main stream, as well as tributary streams, to a particular site. It always relates to an area above a specific location. |
| **consent authority** | The Council, government agency or person having the function to determine a development application for land use under the EP&A Act. The consent authority is most often the Council, however legislation or an EPI may specify a Minister or public authority (other than a Council), or the Director General of DIPNR, as having the function to determine an application. |
| **development** | Is defined in Part 4 of the Environmental Planning and Assessment Act (EP&A Act).<br><br>**infill development:** refers to the development of vacant blocks of land that are generally surrounded by developed properties and is permissible under the current zoning of the land. Conditions such as minimum floor levels may be imposed on infill development.<br><br>**new development:** refers to development of a completely different nature to that associated with the former land use. For example, the urban subdivision of an area previously used for rural purposes. New developments involve rezoning and typically require major extensions of existing urban services, such as roads, water supply, sewerage and electric power. |

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| | **redevelopment:** refers to rebuilding in an area. For example, as urban areas age, it may become necessary to demolish and reconstruct buildings on a relatively large scale. Redevelopment generally does not require either rezoning or major extensions to urban services. |
| **disaster plan (DISPLAN)** | A step-by-step sequence of previously agreed roles, responsibilities, functions, actions and management arrangements for the conduct of a single or series of connected emergency operations, with the object of ensuring the coordinated response by all agencies having responsibilities and functions in emergencies. |
| **discharge** | The rate of flow of water measured in terms of volume per unit time, for example, cubic metres per second ($m^3/s$). Discharge is different from the speed or velocity of flow, which is a measure of how fast the water is moving for example, metres per second (m/s). |
| **ecologically sustainable development (ESD)** | Using, conserving and enhancing natural resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be maintained or increased. A more detailed definition is included in the Local Government Act 1993. The use of sustainability and sustainable in this manual relate to ESD. |
| **effective warning time** | The time available after receiving advice of an impending flood and before the floodwaters prevent appropriate flood response actions being undertaken. The effective warning time is typically used to move farm equipment, move stock, raise furniture, evacuate people and transport their possessions. |
| **emergency management** | A range of measures to manage risks to communities and the environment. In the flood context it may include measures to prevent, prepare for, respond to and recover from flooding. |
| **flash flooding** | Flooding which is sudden and unexpected. It is often caused by sudden local or nearby heavy rainfall. Often defined as flooding which peaks within six hours of the causative rain. |
| **flood** | Relatively high stream flow which overtops the natural or artificial banks in any part of a stream, river, estuary, lake or dam, and/or local overland flooding associated with major drainage before entering a watercourse, and/or coastal inundation resulting from super-elevated sea levels and/or waves overtopping coastline defences excluding tsunami. |
| **flood awareness** | Flood awareness is an appreciation of the likely effects of flooding and a knowledge of the relevant flood warning, response and evacuation procedures. |
| **flood education** | Flood education seeks to provide information to raise awareness of the flood problem to enable individuals to understand how to manage themselves and their property in response to flood warnings and in a flood event. It invokes a state of flood readiness. |
| **flood fringe areas** | The remaining area of flood prone land after floodway and flood storage areas have been defined. |
| **flood liable land** | Is synonymous with flood prone land (i.e., land susceptible to flooding by the probable maximum flood (PMF) event). Note that the term flood liable land covers the whole of the floodplain, not just that part below the flood planning level (see flood planning area). |
| **flood mitigation standard** | The average recurrence interval of the flood, selected as part of the floodplain risk management process that forms the basis for physical works to modify the impacts of flooding. |

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| **floodplain** | Area of land which is subject to inundation by floods up to and including the probable maximum flood event, that is, flood prone land. |
| **floodplain risk management options** | The measures that might be feasible for the management of a particular area of the floodplain. Preparation of a floodplain risk management plan requires a detailed evaluation of floodplain risk management options. |
| **floodplain risk management plan** | A management plan developed in accordance with the principles and guidelines in this manual. Usually includes both written and diagrammatic information describing how particular areas of flood prone land are to be used and managed to achieve defined objectives. |
| **flood plan (local)** | A sub-plan of a disaster plan that deals specifically with flooding. They can exist at State, Division and local levels. Local flood plans are prepared under the leadership of the State Emergency Service. |
| **flood planning area** | The area of land below the flood planning level and thus subject to flood related development controls. The concept of flood planning area generally supersedes the Aflood liable land@ concept in the 1986 Manual. |
| **Flood Planning Levels (FPLs)** | FPLs are the combinations of flood levels (derived from significant historical flood events or floods of specific AEPs) and freeboards selected for floodplain risk management purposes, as determined in management studies, and incorporated in management plans. FPLs supersede the standard flood events in the 1986 manual. |
| **flood proofing** | A combination of measures incorporated in the design, construction and alteration of individual buildings or structures subject to flooding, to reduce or eliminate flood damages. |
| **flood prone land** | Is land susceptible to flooding by the Probable Maximum Flood (PMF) event. Flood prone land is synonymous with flood liable land. |
| **flood readiness** | Flood readiness is an ability to react within the effective warning time. |
| **flood risk** | Potential danger to personal safety and potential damage to property resulting from flooding. The degree of risk varies with circumstances across the full range of floods. Flood risk in this manual is divided into 3 types, existing, future and continuing risks. They are described below.<br><br>**existing flood risk:** the risk a community is exposed to as a result of its location on the floodplain.<br><br>**future flood risk:** the risk a community may be exposed to as a result of new development on the floodplain.<br><br>**continuing flood risk:** the risk a community is exposed to after floodplain risk management measures have been implemented. For a town protected by levees, the continuing flood risk is the consequences of the levees being overtopped. For an area without any floodplain risk management measures, the continuing flood risk is simply the existence of its flood exposure. |
| **flood storage areas** | Those parts of the floodplain that are important for the temporary storage of floodwaters during the passage of a flood. The extent and behaviour of flood storage areas may change with flood severity, and loss of flood storage can increase the severity of flood impacts by reducing natural flood attenuation. Hence, it is necessary to investigate a range of flood sizes before defining flood storage areas. |

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| **floodway areas** | Those areas of the floodplain where a significant discharge of water occurs during floods. They are often aligned with naturally defined channels. Floodways are areas that, even if only partially blocked, would cause a significant redistribution of flood flows, or a significant increase in flood levels. |
| **freeboard** | Freeboard provides reasonable certainty that the risk exposure selected in deciding on a particular flood chosen as the basis for the FPL is actually provided. It is a factor of safety typically used in relation to the setting of floor levels, levee crest levels, etc. Freeboard is included in the flood planning level. |
| **habitable room** | **in a residential situation:** a living or working area, such as a lounge room, dining room, rumpus room, kitchen, bedroom or workroom.<br><br>**in an industrial or commercial situation:** an area used for offices or to store valuable possessions susceptible to flood damage in the event of a flood. |
| **hazard** | A source of potential harm or a situation with a potential to cause loss. In relation to this manual the hazard is flooding which has the potential to cause damage to the community. Definitions of high and low hazard categories are provided in the Manual. |
| **hydraulics** | Term given to the study of water flow in waterways; in particular, the evaluation of flow parameters such as water level and velocity. |
| **hydrograph** | A graph which shows how the discharge or stage/flood level at any particular location varies with time during a flood. |
| **hydrology** | Term given to the study of the rainfall and runoff process; in particular, the evaluation of peak flows, flow volumes and the derivation of hydrographs for a range of floods. |
| **local overland flooding** | Inundation by local runoff rather than overbank discharge from a stream, river, estuary, lake or dam. |
| **local drainage** | Are smaller scale problems in urban areas. They are outside the definition of major drainage in this glossary. |
| **mainstream flooding** | Inundation of normally dry land occurring when water overflows the natural or artificial banks of a stream, river, estuary, lake or dam. |
| **major drainage** | Councils have discretion in determining whether urban drainage problems are associated with major or local drainage. For the purpose of this manual major drainage involves:<br>- the floodplains of original watercourses (which may now be piped, channelised or diverted), or sloping areas where overland flows develop along alternative paths once system capacity is exceeded; and/or<br>- water depths generally in excess of 0.3 m (in the major system design storm as defined in the current version of Australian Rainfall and Runoff). These conditions may result in danger to personal safety and property damage to both premises and vehicles; and/or<br>- major overland flow paths through developed areas outside of defined drainage reserves; and/or<br>- the potential to affect a number of buildings along the major flow path. |
| **mathematical/computer models** | The mathematical representation of the physical processes involved in runoff generation and stream flow. These models are often run-on computers due to the |

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| | complexity of the mathematical relationships between runoff, stream flow and the distribution of flows across the floodplain. |
| **merit approach** | The merit approach weighs social, economic, ecological and cultural impacts of land use options for different flood prone areas together with flood damage, hazard and behaviour implications, and environmental protection and wellbeing of the States rivers and floodplains.<br><br>The merit approach operates at two levels. At the strategic level it allows for the consideration of social, economic, ecological, cultural and flooding issues to determine strategies for the management of future flood risk which are formulated into Council plans, policy and EPIs. At a site-specific level, it involves consideration of the best way of conditioning development allowable under the floodplain risk management plan, local floodplain risk management policy and EPIs. |
| **minor, moderate and major flooding** | Both the State Emergency Service and the Bureau of Meteorology use the following definitions in flood warnings to give a general indication of the types of problems expected with a flood:<br><br>**minor flooding:** causes inconvenience such as closing of minor roads and the submergence of low-level bridges. The lower limit of this class of flooding on the reference gauge is the initial flood level at which landholders and townspeople begin to be flooded.<br><br>**moderate flooding:** low-lying areas are inundated requiring removal of stock and/or evacuation of some houses. Main traffic routes may be covered.<br><br>**major flooding:** appreciable urban areas are flooded and/or extensive rural areas are flooded. Properties, villages and towns can be isolated. |
| **modification measures** | Measures that modify either the flood, the property or the response to flooding. Examples are indicated in Table 2.1 with further discussion in the Manual. |
| **peak discharge** | The maximum discharge occurring during a flood event. |
| **Probable Maximum Flood (PMF)** | The PMF is the largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation, and where applicable, snow melt, coupled with the worst flood producing catchment conditions. Generally, it is not physically or economically possible to provide complete protection against this event. The PMF defines the extent of flood prone land, that is, the floodplain. The extent, nature and potential consequences of flooding associated with a range of events rarer than the flood used for designing mitigation works and controlling development, up to and including the PMF event should be addressed in a floodplain risk management study. |
| **Probable Maximum Precipitation (PMP)** | The PMP is the greatest depth of precipitation for a given duration meteorologically possible over a given size storm area at a particular location at a particular time of the year, with no allowance made for long-term climatic trends (World Meteorological Organisation, 1986). It is the primary input to PMF estimation. |
| **probability** | A statistical measure of the expected chance of flooding (see AEP). |
| **risk** | Chance of something happening that will have an impact. It is measured in terms of consequences and likelihood. In the context of the manual it is the likelihood of consequences arising from the interaction of floods, communities and the environment. |

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| **runoff** | The amount of rainfall which actually ends up as streamflow, also known as rainfall excess. |
| **stage** | Equivalent to water levels. Both are measured with reference to a specified datum. |
| **stage hydrograph** | A graph that shows how the water level at a particular location changes with time during a flood. It must be referenced to a particular datum. |
| **survey plan** | A plan prepared by a registered surveyor. |
| **water surface profile** | A graph showing the flood stage at any given location along a watercourse at a particular time. |
| **wind fetch** | The horizontal distance in the direction of wind over which wind waves are generated. |

# APPENDIX B. DESIGN FLOOD MAPPING

Appendix B

# APPENDIX D. COSTING

Appendix D

**Option A**

| Item No | Description | QTY | Unit | Rate | Amount |
|---|---|---|---|---|---|
| **A** | **CIVIL WORKS** | | | | |
| 1.1 | Site establishment, Construction Management Plan and Environmental management Plan | 1 | Item | $40,000.00 | $40,000.00 |
| 1.2 | Survey | 1 | Item | $12,000.00 | $12,000.00 |
| 1.3 | Construction of Flood Walls and Gates | 600 | m | $5,000.00 | $3,000,000.00 |
| 1.4 | Non return valves on outlet culverts | 6 | Item | $4,000.00 | $24,000.00 |
| 1.5 | Improvements riverbank to prevent erosion | 1 | item | $50,000.00 | $50,000.00 |
| 1.6 | Re-instatement of landscaping | 1 | Item | $10,000.00 | $10,000.00 |
| | **TOTAL CIVIL WORKS** | | | | $3,136,000.00 |
| B | **PROVISIONAL ITEMS AND CONTINGENCIES** | | | | |
| 2.1 | PROVISIONAL ITEM<br>Contingencies (20%) | 1 | Item | | $627,200.00 |
| 2.2 | PROVISIONAL ITEM<br>Design, documentation, contract administration and supervision of works (10%) | 1 | Item | | $313,600.00 |
| | **TOTAL CONTINGENCIES** | | | | $940,800.00 |
| A | **CIVIL WORKS** | | | | **$3,136,000.00** |
| B | **PROVISIONAL ITEMS AND CONTINGENCIES** | | | | $940,800.00 |

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| **SUBTOTAL:** | $4,076,800.00 |
| **GST:** | $407,680.00 |
| **TOTAL AMOUNT (Including GST):** | $4,484,480.00 |

**Option B**

| Item No | Description | QTY | Unit | Rate | Amount |
|---|---|---|---|---|---|
| **A** | **CAPITAL COST** | | | | |
| 1.1 | Purchase of Mobile flood Barries | 224 | iterm | $817.00 | $183,008.00 |
| | **TOTAL CAPITAL COST** | | | | $183,008.00 |

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| **SUBTOTAL:** | $183,008.00 |
| **GST:** | $18,300.80 |
| **TOTAL AMOUNT (Including GST):** | $201,308.80 |

| Item No | Description | QTY | Unit | Rate | Amount |
|---|---|---|---|---|---|
| **A** | **ENMERGENCY RESPONSE (Each Time)** | | | | |
| 1.1 | Mobile Barries Transporatoin, Installation, and Removal (2 people) | 4 | hr | $400.00 | $1,600.00 |
| 1.2 | Veichal Expense | 1 | iterm | $500.00 | $500.00 |
| | **TOTAL CAPITAL COST** | | | | $2,100.00 |

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| **SUBTOTAL:** | $2,100.00 |
| **GST:** | $210.00 |
| **TOTAL AMOUNT (Including GST):** | $2,310.00 |

**Option C**

| Item No | Description | QTY | Unit | Rate | Amount |
|---|---|---|---|---|---|
| **A** | **CIVIL WORKS** | | | | |
| 1.1 | Site establishment, Construction Management Plan and Environmental management Plan | 1 | Item | $40,000.00 | $40,000.00 |
| 1.2 | Survey | 1 | Item | $12,000.00 | $12,000.00 |
| 1.3 | Construction of Flood Barricade | 590 | m | $4,000.00 | $2,360,000.00 |
| 1.4 | Non return valves on outlet culverts | 6 | Item | $4,000.00 | $24,000.00 |
| 1.5 | Improvements riverbank to prevent erosion | 1 | item | $30,000.00 | $30,000.00 |
| 1.6 | Re-instatement of landscaping | 1 | Item | $15,000.00 | $15,000.00 |
| | **TOTAL CIVIL WORKS** | | | | $2,481,000.00 |
| B | **PROVISIONAL ITEMS AND CONTINGENCIES** | | | | |
| 2.1 | PROVISIONAL ITEM<br>Contingencies (20%) | 1 | Item | | $496,200.00 |
| 2.2 | PROVISIONAL ITEM<br>Design, documentation, contract administration and supervision of works (10%) | 1 | Item | | $248,100.00 |
| | **TOTAL CONTINGENCIES** | | | | $744,300.00 |
| A | **CIVIL WORKS** | | | | **$2,481,000.00** |
| B | **PROVISIONAL ITEMS AND CONTINGENCIES** | | | | $744,300.00 |

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| **SUBTOTAL:** | $3,225,300.00 |
| **GST:** | $322,530.00 |
| **TOTAL AMOUNT (Including GST):** | $3,547,830.00 |

**Option D**

| Item No | Description | QTY | Unit | Rate | Amount |
|---|---|---|---|---|---|
| **A** | **CIVIL WORKS** | | | | |
| 1.1 | Site establishment, Construction Management Plan and Environmental management Plan | 1 | Item | $20,000.00 | $20,000.00 |
| 1.2 | Survey | 1 | Item | $6,000.00 | $6,000.00 |
| 1.3 | Increase Existing Seawall | 290 | m | $4,000.00 | $1,160,000.00 |
| 1.4 | Non return valves on outlet culverts | 3 | Item | $4,000.00 | $12,000.00 |
| 1.5 | Improvements beach to prevent erosion | 1 | item | $15,000.00 | $15,000.00 |
| 1.6 | Re-instatement of landscaping | 1 | Item | $6,000.00 | $6,000.00 |
| | **TOTAL CIVIL WORKS** | | | | $1,219,000.00 |
| B | **PROVISIONAL ITEMS AND CONTINGENCIES** | | | | |
| 2.1 | PROVISIONAL ITEM<br>Contingencies (20%) | 1 | Item | | $243,800.00 |
| 2.2 | PROVISIONAL ITEM<br>Design, documentation, contract administration and supervision of works (10%) | 1 | Item | | $121,900.00 |
| | **TOTAL CONTINGENCIES** | | | | $365,700.00 |
| A | **CIVIL WORKS** | | | | **$1,219,000.00** |
| B | **PROVISIONAL ITEMS AND CONTINGENCIES** | | | | $365,700.00 |

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| **SUBTOTAL:** | $1,584,700.00 |
| **GST:** | $158,470.00 |
| **TOTAL AMOUNT (Including GST):** | $1,743,170.00 |

Notes: Assumptions
Seawall Construction is based on the existing Seawall