Victorian Guideline for Modelling the Interaction of Catchment & Coastal Flooding

Report for Glenelg Hopkins Catchment Management Authority

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Glossary

Term	Definition
Annual Exceedance Probability (AEP)	Refers to the probability or risk of a flood of a given size occurring or being exceeded in any given year. A 90% AEP flood has a high probability of occurring or being exceeded; it would occur quite often and would be relatively small. A 1% AEP flood has a low probability of occurrence or being exceeded
ABSLMP	Refers to the Australian Baseline Sea Level Monitoring Program which has been collecting high quality measured water levels at Portland, Lorne, and Stony Point in Victoria since 1991
Astronomical tide	Water level variations due to the combined effects of the Earth's rotation, the Moon's orbit around the Earth and the Earth's orbit around the Sun.
Australian Height Datum (AHD)	A common national surface level datum approximately corresponding to mean sea level. Introduced in 1971 to eventually supersede all earlier datums.
Average Recurrence Interval (ARI)	Refers to the average time interval between a given flood magnitude occurring or being exceeded. A 10-year ARI flood is expected to be exceeded on average once every 10 years. A 100-year ARI flood is expected to be exceeded on average once every 100 years. The AEP is the ARI expressed as a percentage.
Backshore	The backshore extent landward from the swash limit.
Berm	A coastal berm is a nearly horizontal shore parallel ridge formed on the beach due to the onshore movement of sand by wave action. Berms form at the entrance to estuaries when the catchment flows are insufficient to prevent or limit the onshore movement and disposition of sand by wave action.
Catchment	The area draining to a site. It always relates to a particular location and may include the catchments of tributary streams as well as the main waterway.
Coastal Hazard	A term to collectively describe physical changes and impacts to the natural environment which are significantly driven by coastal or oceanographic processes.
Delta	A complex association of geomorphic settings, sediment types and ecological habitats, at a point where a freshwater source enters an estuarine water body
Design flood	A design flood is a probabilistic or statistical estimate, being generally based on some form of analysis of flood or rainfall data. An average recurrence interval or exceedance probability is attributed to the estimate
Discharge	The rate of flow of water measured in terms of volume over time. It is to be distinguished from the speed or velocity of flow, which is a measure of how fast the water is moving rather than how much is moving.
Embayment	A coastal indentation which has been submerged by rising sea-level in the past and has not been significantly infilled by sediment.
Estuary	The seaward limit of a drowned valley which receives sediment from both river and marine sources and contains geomorphic and sedimentary conditions influenced by tide, wave and river processes
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 overland runoff before entering a watercourse and/or coastal inundation resulting from elevated sea levels and/or waves overtopping coastline defences.
Flood hazard	Potential risk to life and limb caused by flooding. Flood hazard combines the flood depth and velocity.

Term	Definition
Floodplain	Area of land which is subject to inundation by floods up to the probable maximum flood event, i.e., flood prone land.
Geomorphology	The study of the origin, characteristics, and development of landforms
HAT	Highest Astronomical Tide
ICE	Intermittently closed and open estuary
Intertidal	Pertaining to those areas of land covered by water at high tide, but exposed at low tide, e.g., intertidal habitat
Inundation	Flooding because of oceanic conditions is often referred to as inundation rather than flooding although the terms are interchangeable. In this guide the term flooding is used in preference to inundation.
LiDAR	Spot land surface heights collected via aerial light detection and ranging (LiDAR) survey. The spot heights are converted to a gridded digital elevation model dataset for use in modelling and mapping
MHWS	Mean High Water Springs, i.e., the mean of spring tide water levels over a long period of time.
MSL	Mean Sea Level.
Nearshore	The region of land extending from the backshore to the beginning of the offshore zone.
Nominal flood protection level (NFPL)	Is the minimum level (elevation) requirement for building floors and services (e.g., sewer openings & electrical fittings) and is measured in metres AHD. The NFPL affects the height of floors and building services above the ground surface
Ocean water level boundary	The ocean water level(s) used as the downstream boundary level for hydraulic modelling for a flood study in a coastal waterway.
Offshore	The zone seaward of where waves interact with the seabed
Shoal	A shallow area within a water body; a sandbank or sandbar.
Sea Level Rise (SLR)	A permanent increase in the mean sea level.
Spring Tides	Tides with the greatest range in a monthly cycle, which occur when the sun, moon and earth are in alignment (the gravitational effects of the moon and sun act in concert on the ocean).
Storm Surge	The increase in coastal water levels caused by the barometric and wind set-up effects of storms. Barometric set-up refers to the increase in coastal water levels associated with the lower atmospheric pressures' characteristic of storms. Wind set-up refers to the increase in coastal water levels caused by an onshore wind driving water shorewards and piling it up against the coast.
Swash limit (wave runup)	This is the oscillating line marking the limit to which water from a breaking wave extending landward. It defines the wet-dry beach margin and is best recorded by video photography from aerial or fixed ground cameras. Swash is driven by wave height, wavelength, and beach slope while the runup distance is determined largely by beach grain size, wave turbulence, swash-backwash interaction, and infiltration.1
Storm tide	Coastal water level produced by the combination of astronomical and meteorological (storm surge) ocean water level forcing
Tidal Planes	A series of water levels that define standard tides, e.g. 'Mean High Water Spring' (MHWS) refers to the average high water level of Spring Tides.
Tidal Prism	The volume of water moving into and out of an estuary or coastal waterway during the tidal cycle.
Tidal Range	The difference between successive high water and low water levels. Tidal range is maximum during Spring Tides and minimum during Neap Tides.

[1] Erikson, et al., (2007) Swash zone characteristics, California, Coastal engineering 2006: proceedings of the 30th international conference: San Diego, California, USA, 3-8 September 2006.

Term	Definition
Tidal Waterways	The lower portions of coastal rivers, creeks, lakes, harbours, and ICEs affected by tidal fluctuations.
Topography	A surface which defines the ground level of a chosen area.
Wave Setup	The increase in mean water level due to the presence of waves
Wave runup	See Swash limit above.
Wind Setup	The vertical rise of the water surface above the still water level caused by wind stresses on the water surface.
Wind Shear	The stress exerted on the water's surface by wind blowing over the water. Wind shear causes the water to pile up against downwind shores and generates secondary currents.

Abbreviations

ABSLMP	Australian Baseline Sea Level Monitoring Project
ARR	Australian Rainfall and Runoff
DELWP	Department of Environment Land Water and Planning
SCARM	Standing Committee on Agriculture and Resource Management
SLR	Sea level rise
OEH	Office of Environment and Heritage (now within the Department of Planning and Environment)
VCMP	Victorian Coastal Monitoring Program
WRL	Water Research Laboratory, University of New South Wales

contents

1. Introduction

1.1. Overview

Flooding in coastally connected waterways (such as estuaries and coastal lagoons) can occur due to catchment or coastal flooding and may also happen due to a combination of both mechanisms being driven by the same meteorological event.

Interaction of catchment and coastal flooding processes is a very important consideration in determining overall flood risk in coastal waterways. The influence of these two processes on flooding varies with ocean level, due to both tidal fluctuations and storm impacts, the condition of the waterway entrance (e.g., the estuary, river or creek mouth), the interface between the coastal waterway and the ocean, the distance from the coast, and the size and shape of the waterway and catchment draining to the coast.

The 1% AEP flood is set out under Policy 13a of the Victorian Floodplain Management Strategy (DELWP, 2022) as the "*design flood event for land use planning and building systems in Victoria*." In delineating the extent of 1% AEP flood risk in coastally connected waterways, it is essential that the flood risk assessment process considers the relative significance of flood levels and hazard posed by catchment and/or coastal flooding mechanisms.

The absence of such an analysis raises the risk that flood controls (e.g., Land Subject to Inundation and Floodway Overlays, Special Building Overlay, and the associated Nominal Flood Protection Level) founded on flood risk maps derived from the study, fail to fully account for the level of risk posed by both a 1% AEP catchment flood and a 1% AEP coastal flood (where a coastal flood event is often referred to as a 'Storm Tide' event).

This guide provides:

- Advice on the need to ensure complete analysis of the range of flood risk factors affecting the level of risk associated with coastally connected waterways and their floodplains; and
- Advice on appropriate approaches to analysing flood risks including:
    - Coastal boundary conditions,
    - Classes of coastally connected waterways found in Victoria,
    - Different modelling approaches from simple to detailed, and
    - Ways to incorporate the joint probability of catchment and coastal flood mechanisms.

Decisions made based on the information provided in this guide should be assessed and reviewed by suitably qualified industry professionals. It is based around the NSW Floodplain Risk Management Guide (OEH, 2015) but brings together Victorian specific information and new knowledge gained since the original OEH guide was released. Commentary is also provided on sea level rise and how this additional risk factor may be appropriately accounted for in flood studies for coastal floodplains.

1.2. **Purpose**

This guide provides advice on best practice approaches to modelling flood risks associated with coastally connected waterways. In the Victorian context, many of the coastal waterways are wave dominated estuaries and coastal lagoons. The guide is therefore largely focussed on modelling flood risk associated with coastal floodplains connected to these waterways. However, the modelling approaches detailed are applicable to all coastally connected waterways.

The guide is intended to ensure flood investigations for coastal floodplains provide a robust foundation for development, implementation and revision of coastal floodplain management initiatives including:

- Strategic land use planning,
- Setting development controls such as Nominal Flood Protection Levels (NFPLs),
- Assessing and managing the impacts of development on flood behaviour,
- Design and implementation of flood warning/alerting systems,
- Development and review of Municipal Flood Emergency Plans (MFEPs), and
- Addressing broader floodplain risk management issues.

To achieve this, flood investigations must apply appropriate methods that consider the full range of factors that can influence overall flood risk associated with coastal floodplains. These factors include the relative dominance of catchment flooding versus storm tide flooding for a location in terms of flood risk and derivation of information that adequately addresses the level of additional risk posed by coincidence of these two flood mechanisms.

In developing the guide, consideration has been given to:

- Different classes of Victorian coastal waterways as defined in Victoria's Resilient Coast - Adapting for 2100+ Guidelines (DELWP, 2022).
- Deriving design flood estimates for the interaction of catchment and oceanic flooding considering:
    - Design ocean levels and their variability along the Victorian coast,
    - Inclusion of wave setup where appropriate, and
    - The joint probability and relative timing of catchment and oceanic derived flood events together with future sea level rise and climate change.

1.3. **How to Use this Guide**

The guide is structured as a series of steps, as summarised in Figure 1, and include:
- Section 1 - An introduction and background,
- Section 2 - Background studies and data required,
- Section 3 - Identifying the coastal waterway type and entrance condition
- Section 4 - Selecting a modelling approach (or combination of approaches), including:
    - Entrance morphology considerations.

- Selecting and setting a coastal water level boundary.
- Extent timing.
- Sea level rise scenario considerations.
- Joint probability including an envelope approach to assessing risks.
- Sensitivity testing of key parameters.

Model Consideration	Choose a modelling approach that best meets the project objectives		
	Simplistic	General	Detailed
Entrance Morphology	Apply a steady state (fixed) entrance condition	Apply a steady (fixed) entrance for permanent open entrances such as tidal creeks and ICE Type A and C or unsteady (dynamic) entrance conditions for ICE Types A and B	Apply a steady (fixed) entrance for permanent open entrances such as tidal creeks and ICE Type A and C or unsteady (dynamic) entrance conditions for ICE Types A and B
Coastal Water Level Boundary	Static coastal water level boundary	Generally, a dynamic water level boundary should be applied, although a static boundary may be appropriate depending on available data or study specific considerations	Dynamic coastal water level boundary
Joint Probability	Adopt conservative approach - 1% AEP catchment flood and 1% AEP ocean boundary level	Initial 'envelope' of catchment and ocean flood events. Further scenarios may be required depending on flood risks	Initial 'envelope' of catchment and ocean flood events. Further scenarios or full joint probability analysis may be required depending on flood risk
Relative Timing	Peak catchment flood level with static ocean boundary	Peak catchment flood level coincident with peak ocean boundary level	Analysis should include sensitivity testing to establish suitable event timing relationship for design events
Sea level rise & climate change	Sea level rise increments only, rainfall increases can be considered. Minimum is 0.8m of sea level rise relative to baseline. Increased berm heights for ICEs.	A selection of sea level rise increments. Rainfall increases should be considered. Increased berm heights for ICEs	A selection of sea level rise increments. Rainfall increases should be considered. Increased berm heights for ICEs

Figure 1 Overview of coastally connected waterway flood approach as defined in this guide

2. Background Studies and Data

2.1. Overview

Any investigation into flood behaviour in coastal floodplains should start with collating and reviewing background and foundational information to support robust model development, calibration, and validation. This may include:

- Suitably accurate ground level data.
- Flood level information from historical storm events including catchment or ocean generated flooding.
- Waterway entrance condition records together with available survey of the waterway and entrance areas.
- Historic and recent aerial imagery with a focus on the entrance but considering the broader estuary (where relevant)
- Photos and records from the community, particularly in relation to flooding following storms.
- Any management strategy for the entrance.
- Riverine flow gauging and records and records of any large riverine flood events that pre-date the gauging record.
- Tide gauge records.
- Available studies i.e., flood studies or coastal hazard investigations relevant to the current investigations.
- Available information on waterway structures that may influence flood behaviour.
- For site specific assessments, flood related development controls requirements of the relevant council or development consent authority.

Where previous flood studies have been completed, they should be critically reviewed to determine their fitness of the intended purpose of the current work, considering the approaches recommended in this guide and any significant flood events that have occurred since the work was completed.

Any gaps in the available information that are likely to increase the uncertainty of the modelling outputs should be addressed prior to commencing a study or by specifying the additional requirements in the flood study brief.

2.2. Coastal Data Sources

The updated Victoria's Resilient Coast - Adapting for 2100+ Guidelines (DELWP, 2022) contains a high-level guide specifically on coastal hazard data and information, including example sources, organisations, databases, and libraries that hold the relevant data. A summary is provided herein.

2.2.1. Topography and Bathymetry

In addition to the LiDAR datasets typically available for catchment flood studies, topographic and bathymetric data will likely be required to characterise the waterway or estuary entrance area. State-wide high resolution topographic (and bathymetric) data is available from DELWP, collected regularly as part of the Co-ordinated Imagery Program (CIP).

The FutureCoast LiDAR Digital Elevation Model (DEM) (2008-2011) provides high resolution bathymetric data along the full extent of the Victorian coastline. The coverage is close to complete with small sections of bathymetry missing in turbid waters or where there was wave breaking at the time of capture. The Future Coast DEM is available as a 1.0 m grid resolution with 0.1 m accuracy (horizontal and vertical), from approximately the 5 m AHD to -20 m AHD contours. The custodian of this dataset is DELWP, and access is via request only.

It should be noted that the FutureCoast LiDAR data is now over 10 years old, and in some locations, it may no longer accurately reflect the current topography given change that has occurred since its collection. The availability of more recent LiDAR data sets should always be checked with the relevant local council(s) and DELWP CIP to ensure the best available ground level data is utilised to underpin the flood risk modelling outputs (DELWP, 2022).

For some waterways, Port Authorities/Managers (e.g., Gippsland Ports) should be approached regarding the availability of more recent bathymetric data surveys of coastal waterway entrance areas. Localised bathymetric survey may also be available from research agencies (for example Deakin University have also undertaken extensive multi beam surveys along the coast to depths of approximately 70 m (DELWP, 2022). The multi-beam data is available through the AusSeabed (www.ausseabed.gov.au) website and data portal. Other bathymetric datasets may also be uploaded to this site over time, as it is intended to be a national repository of bathymetric datasets from across Australia.

Localised topographic survey data for specific locations along the Victorian coast is available from the Victorian Coastal Monitoring Program[2] (VCMP) Citizen Science Drone Program. The VCMP program captures drone-based photogrammetry of beaches across Victoria. This may include datasets covering the entrance of the waterway. It should be noted the VCMP program captures drone-based **photogrammetry** (not LiDAR) of beaches across Victoria and the accuracy and quality should be checked for each project (DELWP, 2022).

2.2.2. Waterway Details and Management

The type of connection between the waterway and the coast is an important consideration when assessing flood risk for coastally connected waterways. This connection is referred to as the waterway "entrance" and is discussed further in Section 3.

Estuary entrance condition data including aerial imagery and repeat surveys of the entrance channel(s) and berm heights are important for defining the type of waterway being considered

[2] https://www.marineandcoasts.vic.gov.au/coastal-programs/victorian-coastal-monitoring-program

(Section 3) and will inform the modelling process such as the requirements for a dynamic versus static entrance channel morphology. In Victoria the Estuary Entrance Management Support System (EEMSS) holds records of Estuary Water Level, Mouth Status (open/closed), the height at which natural openings occur (where water level sensors are available).

If detailed morphological modelling of the entrance is likely to be necessary to best capture the entrance dynamics, information on the sediment characteristics will be required such as the particle size distribution. Such data may be available from previous coastal process studies or coastal hazard assessments.

2.2.3. Oceanographic Data

In general, Victoria's coastal region is influenced by wind and wave forces from the Southern Ocean, and the relatively shallow waters of Bass Strait which limits the degree and direction of waves and storms along the central coastline.

Requirements for oceanographic data will depend on the modelling approach adopted (Section 4) for a given study. The following section provides details of different datasets that may be needed. Refer to the Victorian Coastal Hazard Guidelines (DELWP, 2022) for further references.

Water Level Data

Astronomical tide and storm surge water level data and information may be required to calibrate numerical modelling and support assessments of the joint probability of catchment and coastal flooding.

Measured tidal water level data is available via the Bureau of Meteorology (BOM) Australian Baseline Sea Level Monitoring Program (ABSLMP) which has been collecting high quality ocean water level data for Victoria since 1991. The relevant gauges are located at Portland, Lorne, and Stony Point in Figure 2 below. Data is available at hourly intervals as well as monthly statistics. The hourly data is based on a six-minute sea level measurement interval.

Monthly sea level data is also available for other tide gauge stations from the BOM website. This data is based on hourly sea level observations. These are operated and maintained by various Port Authorities and are not part of the ABSLMP network. For access to the hourly data, you need to contact the Tide Gauge Owner.

Relatively reliable sea surface information can also be sourced from a number of global and regional climate reanalysis models. These models are operated by a variety of national and international research organisations, including the BOM and CSIRO. See the BOM OceanMAPS portal for details: http://www.bom.gov.au/climate/data-services/ocean-data.shtml#tabs=Forecasts-and-model-data.

Predicted astronomical tide levels are available from the BOM (contact the NOC Tidal Unit for details: tides@bom.gov.au) and specific tidal levels (e.g., Mean High Water Springs) for different locations along the Victorian coast can be found in the Victorian Tide Tables (VRCA, 2021) which are available online. Higher resolution tidal predictions can be generated using the AusTides program which can be downloaded from the Australian Hydrographic Office (https://www.hydro.gov.au/prodserv/publications/ausTides/tides.htm)

Extreme coastal water levels (i.e., storm tides) were analysed by McInnes et al (2009) which provides peak storm tide levels for a range of annual exceedance probabilities (AEPs) for a baseline (1980-1999) mean sea level and a series of predicted future sea level increments. These storm tide levels do not include any wave setup component.

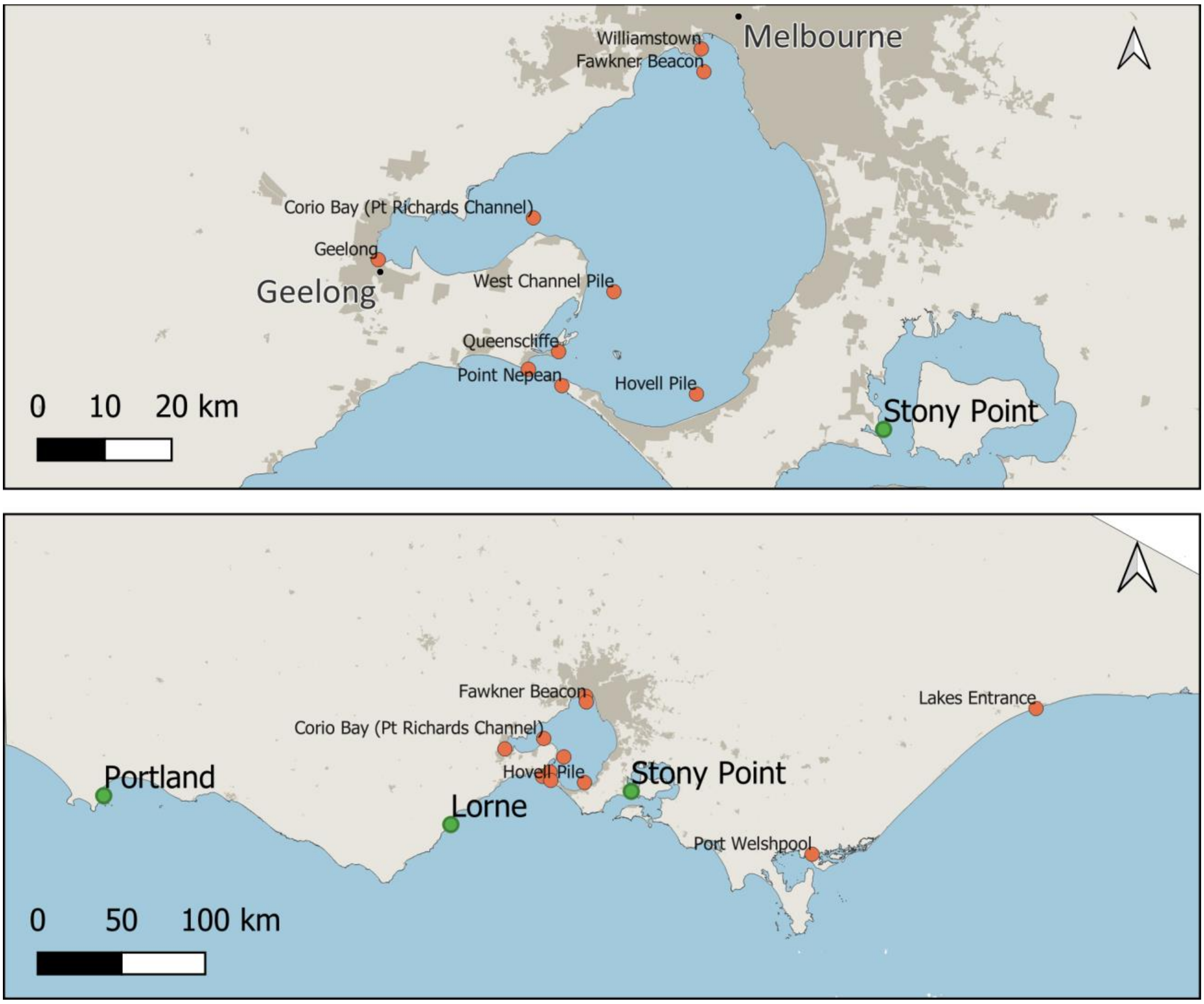

Figure 2 Tide Gauge Locations on the Victorian coast – green sites are ABSLMP gauge stations, red sites are operated by other Authorities

Wave Data

Long term wave climate data may be required to estimate wave setup and for extreme event analysis. Historically, long-term measured wave data has not been readily available in Victoria beyond data captured by the Port of Melbourne at Point Nepean.

To address this data gap, wave data has been captured by the VCMP at various locations along the Victoria coast since around December 2019. This data is provided as a time series of significant wave height, peak and mean wave period and peak wave direction. The data can be accessed via the http://www.vicwaves.com.au/ website.

Offshore wave climate information can also be sourced from several global and regional wave reanalysis models. These models are operated by a variety of national and international research organisations, including the BOM and CSIRO. For example, the CSIRO CAWCR Wave Hindcast model can be accessed via the CSIRO Data Access Portal https://data.csiro.au/collection/csiro:39819. The University of Melbourne in 2021 completed a detailed numerical hindcast modelling study as part of the VCMP to provide high resolution wave conditions along the Victorian coastline. The wave model is based on the WaveWatch III[3] modelling system. The hindcast wave data is available for the period 1981-2020 and is available upon request via the National Tidal Unit (http://www.bom.gov.au/oceanography/projects/ntc/ntc.shtml).

2.2.4. Climate Change Predictions

Flood hazards should consider both current and future conditions, particularly for coastally connected waterways which are likely to be affected by increases in mean sea level. In addition to sea level increases, changes to rainfall, wind conditions and catchment antecedent conditions as well as waves may need to be considered for detailed assessments. These changes can affect the river inflows as well as coastal wave conditions and behaviour.

Sea Level Rise

Victoria's planning policy has long recognised the need to actively manage flood related sea level rise risk. The first iteration of the Victorian Coastal Strategy (2008) established overarching policy for managing the sea level rise risk and clause 13.01-2S of the Victoria Planning Provisions translates this into Victoria's landuse and development planning system. Most importantly, Clause 13.01-2S says the landuse and development planning system will "plan for sea level rise of not less than 0.8 metres by 2100". Catchment Management Authorities (CMAs) are Victoria's regional Floodplain Management Authorities and are charged with providing advice on flood risk. The relevant CMA will therefore provide advice as to the sea level rise projections required to be considered in any modelling study. The draft Coastal and Marine Strategy supports a review of sea level rise thresholds in 2022/23.

Sea level projections are estimates of future sea levels based on modelling of a range of future climate change scenarios. Sea level projections are produced periodically by the Intergovernmental Panel on Climate Change (IPCC), which is the United Nations body for assessing the science related to climate change (https://www.ipcc.ch/). The IPCC has recently (August 2021) finalised the first part of the Sixth Assessment Report. This is called "Climate Change 2021: The Physical Science Basis, the Working Group I contribution to the Sixth Assessment Report".

[3] https://polar.ncep.noaa.gov/waves/wavewatch/

The IPCC 6th Assessment Report Sea Level Projection Tool https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool provides rate of rise projections for Portland, Lorne, and Stony Point. The nearest additional projections are available for Eden (NSW), Burnie (Tasmania) and Victor Harbour (South Australia).

Rainfall and Climate

The BOM and CSIRO produce a biennial “State of the Climate” summary, with the most recent summary released in 2020. This report details the observed changes in Australia’s climate and surrounding oceans. Of note, there has been a decline of rainfall in the southeast of Australia since the late 1990s which is predicted to continue and will contribute to continuing decline in streamflow. Whilst total rainfall has reduced, storms are becoming more intense with greater rainfall over a short period, resulting in more frequent short duration flash flooding events.

Future changes to rainfall and other climate parameters may be required to be assessed as part of the catchment flood component of any study. Past approaches have involved application of percentage increases in design rainfall intensity and therefore volumes. The Australian Rainfall and Runoff (ARR) guidelines Book 2 (Ball et al, 2019) provides a procedure for adjusting design rainfalls for climate change and interim climate change factors can be downloaded from the ARR Data Hub (https://data.arr-software.org/). Advice should be sought from the relevant CMA on these requirements and appropriate values or scenarios to adopt.

Waves

Following on from their wave hindcast modelling study, the University of Melbourne is also undertaking further modelling to assess the implications of climate change scenarios on wave conditions along the Victorian coastline. This data should be considered in any detailed study once it becomes available. Access is likely to be available through the VCMP.

Detail on the model and model parameters can be found in the PhD Thesis being prepared by Jin Lui (publication expected 2023) and via published papers of Liu (2022) and others in the VCMP wave modelling project.

2.3. Previous Coastal Inundation Studies

2.3.1. Coastal Hazard Studies

Victoria has implemented a three-pass approach to deriving coastal erosion and flood risk information. The three 'passes' of assessment can be defined as (from Sharples et al, 2008):

- **First pass:** the identification of shores likely to be physically sensitive to coastal hazards at all, providing a useful indicative coastal risk assessment.
- **Second pass:** defined as a ‘regional’ assessment involves identifying regional variations in the processes driving the physical impacts on the potentially sensitive shores identified in the first pass.

- **Third pass:** a more detailed or 'site-specific' assessment to identify and evaluate critical local variations in shoreline sensitivity and exposure, as the basis for final design and selection of appropriate responses to the identified hazards.

A "first pass" coastal vulnerability assessment was undertaken by the Federal Government in the 2009 National Coastal Risk Assessment: https://www.awe.gov.au/science-research/climate-change/adaptation/australias-coasts/national-coastal-risk-assessment. This was a screening level assessment using nationally available datasets.

A "second pass" coastal inundation dataset was derived for the entire Victorian coastline (the Victorian Coastal Inundation spatial layer, available through the Data Vic website). This dataset was an output of the Victorian Government's Future Coasts Project and used "bathtub" mapping techniques[4] to provide indicative flood extents for 1% AEP storm tides for present day (2009) sea level conditions, along with the increase in risk posed by 0.2 m, 0.47 m and 0.82 m increases in mean sea level. This work was based on McInnes (2009). The accompanying report (Spatial Vision, 2017) utilises this dataset along with other spatial datasets to assess the likely impact of climate change on assets along the Victorian coast. The results of this assessment are limited and some local flood studies which predated this analysis provide more detailed outputs (e.g., the Port Fairy Regional Flood Study and Surry River Flood Study from 2008, the Warrnambool Flood Study from 2007).

More detailed "third pass" coastal hazard studies have been undertaken for specific locations along the Victorian coast. Most of these studies considered both coastal inundation as well as erosion hazards and undertook a detailed numerical modelling approach to the analysis. These studies all consider current sea level conditions as well as future predictions of sea level rise. An overview of studies completed to date along with the geographical extents is provided in Table 1.

[4] Bathtub mapping refers to a simple bathtub or bucket-fill approach which assumes that the storm tide will inundate all locations at or below the specified storm tide elevation. Dynamic processes are neglected in this approach.

Table 1 Detailed Coastal Inundation Studies Completed along the Victorian Coast

Study	Geographical Location
Gippsland Lakes and Ninety Mile Beach Local Coastal Hazard Assessment (Water Technology, 2014)	The open coast from Lakes Entrance to Seaspray and the Gippsland Lakes.
Western Port Local Coastal Hazard Assessment (Water Technology, 2014)	The study area included the following coastline: • Cape Schanck to West Head, along the shoreline of Western Port to the bridge at San Remo • All of the coast of French Island and the north side of Phillip Island from the bridge at Newhaven to the western extremity of Phillip Island (Seal Rocks), but excluding the south side of Phillip Island from Seal Rocks to the Bridge at Newhaven
Bellarine Peninsula - Corio Bay Local Coastal Hazard Assessment (Cardno, 2016)	The entire Bellarine Peninsula and the northern side of Corio Bay, from Point Wilson in the north, to Breamlea in the south.
Port Fairy Local Coastal Hazard Assessment (WRL, 2013)	The study area covers the coastline from Cape Reamur to Cape Killarney and included the Moyne River channel and the south of Belfast Lough.
Port Phillip Bay Coastal Hazard Assessment (CSIRO, in draft)	Approximately 310 km of shoreline around Port Phillip, from Point Lonsdale to Point Nepean.
Inverloch Coastal Hazard Assessment (Water Technology, in draft)	The study area extends from the eastern end of Cape Paterson's most eastern beach "Undertow Bay" to the eastern end of Morgan Beach, located just west of Cape Liptrap. Also included are the shorelines of Venus Bay and Anderson Inlet.
Corner Inlet Dynamic Storm Tide Modelling (Water Technology, 2014)	Whole of Corner Inlet and Nooramunga Park embayment

Any flood study being undertaken using these guidelines will likely be considered a second or third pass assessment, depending on the level of detailed modelling completed in the assessment. This is described further in Section 4.

2.3.2. Flood Studies (or investigations)

Several coastally connected waterway flood studies have been completed across Victoria to date. They have applied a range of modelling approaches. The mapping and reporting outputs of any pre-existing flood study should be obtained from the relevant CMA or Local Government Authority and thoroughly reviewed prior to use, taking into account any recommendations presented in this guide, such as how assumptions can be reasonably derived (such as selection of coincident events) and ensuring modelling approaches follow contemporary best practice.

3. Identifying Coastally Connected Waterway Types

3.1. Overview

The degree of influence that coastal processes have on flooding in a coastal waterway depends on the connectivity of the waterway to the ocean. This in turn depends on the type of estuary linked to the coastal waterway, the morphology, and any modifications or training of the waterway entrance (i.e., training walls, breakwaters, or revetments) together with any management interventions, particularly in relation to entrance opening. The first step in building a model capable of producing outputs that reliably account for the interaction between catchment and coastal flooding is to understand what type of estuary or tidal channel is being modelled and more specifically, how the morphology of the estuary or tidal channel entrance influences flood behaviour.

There is no consistent typology or description of coastal waterways in Victoria. However, the updated coastal hazard guidelines in Victoria's Resilient Coast - Adapting for 2100+ Guidelines (DELWP, 2022) has defined "shoreline classes". These are a length of coast with similar characteristics. Most relevant to this guide are the "estuarine and tidal channels", which are defined as "a partially enclosed coastal waterway that is influenced by tides and coastal processes, a zone where freshwater mixes with salt water" (DELWP, 2022). Within the estuarine and tidal channel shoreline class are the following variants:

- Embayments and drowned river valleys
- Wave or tidally dominated estuaries and deltas
- Coastal lagoons and creeks
- Tidal creeks and drains

An overview of each category along with the implications for flooding and flood modelling approaches is provided in the following sections.

3.2. Embayments and Drowned River Valleys

Significant embayments such as Port Phillip or Western Port, or drowned river valleys such as Corner Inlet, are marine dominated and have little or limited influence of freshwater flows on coastal water levels. Coastal flooding for these shoreline classes should be assessed through a detailed coastal hazard assessment as oceanographic processes are the dominant drivers of flooding and to understand them requires detailed coastal modelling approaches and expertise which are outside the scope of this guide.

3.3. Estuaries & Coastal Lagoons

Estuaries on the Victorian coast are typically wave dominated micro-tidal (< 2m) systems, meaning that the entrance is constricted by wave deposited beach sand and ebb-flood tide deltas. In many cases a coastal lagoon is also present. Ninety percent of Victoria’s open coast estuaries intermittently close to the ocean (McSweeney et al. 2017). The entrances of most of Victoria's estuaries are not permanently open to the sea but oscillate between an open and a closed state due to the build-up of sand berms at the river mouth and variations (typically seasonal) in flushing flows. These are the most complicated type of coastal waterway from a flood modelling perspective as consideration needs to be given to the potential for flooding under open, closed, and potentially intermediate entrance conditions.

McSweeny et al (2017) developed a classification system for these types of estuaries on the Victorian coast based on their entrance morphology, defining the grouping as intermittently open or closed estuaries. The term "intermittent closed estuaries" (ICEs) is used in this guide:

- **Type A:** the largest ICE which both open and close infrequently for the longest durations. They predominantly persist in a closed entrance state with closures lasting from months to years. However, conversely there are examples such as Mallacoota Inlet which persist in a predominantly open state.

- **Type B:** medium size ICE which open and close several times per year for weekly to monthly durations. The entrance berm is typically steep, and the height is highly variable. Entrance openings last for weeks to months.

- **Type C**: tidal creeks, the smallest ICE exists in a predominantly open state. Entrance closures are infrequent and of short duration, persisting over a daily or tidal scale.

The analysis by McSweeney et al (2017) found that these three types of ICE showed an order of magnitude difference in entrance closure duration. The channel width, catchment area and lagoon size proved to be key geomorphic indicator on opening and closure frequency and duration whereby a larger channel area, estuarine basin and tidal prism resulted in less frequent openings but both openings and closures of a longer duration. The typical catchment and estuary characteristics for each ICE type are summarised in Table 2.

Table 2 Summary of catchment and estuary characteristics for different ICE types.

ICE Type	Catchment and Estuary Characteristics
Type A	They exhibit the largest estuary dimensions in terms of channel width (> 200 m), estuary water surface area (> 5 km^2), length (> 10 km), perimeter (> 12 km), catchment size (> 500 km^2) and tidal prism (> 10 x 10^6 m^3)
Type B	Dimensions include channel widths of 75-200 m, estuary water surface area of 1-5 km^2, length of 2-10 km, perimeter of 2-12 km, catchment size ranging from 75-1000 km^2 and with a tidal prism of 1.5-10 x 10^6 m^3.
Type C	Channel widths of < 75 m, estuary water surface area of <1 km^2, lengths <2 km, perimeters <3 km, catchment size <75 km^2 and with a tidal prism of <1 x 10^6 m^3.

There are few permanently open estuaries on the open coast of Victoria. Those with unmodified entrances include the Barwon River, Andersons Inlet, and Shallow Inlet. Others are kept open through human intervention (e.g., entrance training walls and dredging at the Moyne River, and

Lakes Entrance). For flood modelling purposes these permanently open estuaries are treated similarly to tidal creeks and drains.

Appendix A provides a summary of the McSweeney at al. (2017) classification of Victoria's estuaries.

3.4. **Tidal Creeks and Drains**

The tidal creek shoreline class represents those coastal waterways with a permanently open entrance. The entrances can be either on the open coast or within embayments, inlets, or coastal lagoon systems and may be unmodified or kept open through human interventions (e.g., dredging and training walls at Patterson River in Port Phillip). Where the entrance is actively managed (i.e., dredging) or the entrance channel capacity is reduced (but not closed) at different times it may be necessary to consider several options when undertaking flood modelling.

Drains (constructed) are a category of small coastally connected waterways that have been artificially formed to assist in draining low lying coastal land predominantly for agricultural purposes. They are typically located within embayments or drowned river valleys. Examples include Monomeith Drain and Yallock Outfall Drain in Western Port, while urban examples include Elster Creek (Elwood Canal) and Mordialloc Creek. The entrance to these waterways is permanently open but the drain invert may be elevated to limit tidal inflows.

Drains (natural) represent the small informal waterways typically on steep rocky coasts with only limited direct catchment areas. For example, along the South Gippsland coast from Cape Paterson to Inverloch there are several natural drainage lines that drain a small local catchment area and discharge across pocket beaches such as at Shack Bay. Another example exists just west of Port Fairy near the Southern Ocean Mariculture site. The entrances of these waterways are often ill-defined.

3.5. **Waterway Connection and Management**

Information on entrance conditions and how it is managed is necessary so that decisions can be made as to the most appropriate approach to modelling the influence of the entrance on flood behaviour and the types of sensitivity tests that may be needed to test the validity of various modelling assumptions.

Permanently modified entrances, such as those directed through or by manmade structures (e.g., training walls or breakwaters) or where the entrance profile is actively managed by dredging, can be assumed to be essentially stable (Figure 3) with limited on-going management actions.

Figure 3 Entrance of Martha Cove Marina, formerly Brokil Creek, showing breakwaters which 'train' the entrance to maintain its location and dimensions (Neville Rosengren, June 2019)

The morphology of unmodified entrances is generally highly dynamic because of the interaction of coastal and catchment processes. These changes can influence flood behaviour and therefore information on the spatial and temporal scale of change is needed to assist in the selection of modelling approach, in setting up the model, and defining model simulations required to characterise flood behaviour including requirements for test sensitivity to estuary entrance morphology. These changes can be assessed through analysis of estuary entrance condition data including aerial imagery and repeat surveys of the entrance channel(s) and berm heights (Section 2.2.2).

An example of the small relatively unmodified entrance at Balcombe Creek in Port Phillip Bay is shown in Figure 4, while the highly dynamic entrance to Andersons Inlet is shown in Figure 5.

Figure 4 Entrance of Balcombe Creek, where the entrance is relatively unmodified except for the roadway bridge immediately upstream of the beach (Neville Rosengren, June 2019)

Figure 5 Unmodified entrance of Andersons Inlet at Inverloch showing the highly dynamic sand bar and channel system (Water Technology, in draft)

Some unmodified entrances are artificially opened from time to time to limit flooding of adjacent low-lying land (Figure 6). In Victoria the Estuary Entrance Management Support System (EEMSS) is used to assess the need to artificially open estuaries which close from time to time following the formation of a sand bar at the ICE entrance mouth. Decisions to artificially open an estuary require balancing socio-economic impacts often related to "dry weather" flooding around estuaries when the mouth is closed, with the risks of conducting artificial openings under inappropriate conditions (with adverse consequences such as increased fish kills occurring). Catchment Management Authorities (CMAs) are the responsible authorities for approving and managing permitted artificial openings under the Water Act 1989. The relevant CMA should be consulted regarding management of specific estuaries in their region and the availability of historical records concerning the dynamics of the entrance.

Figure 6 Example of an estuary entrance being artificially opened

4. **Modelling Approaches**

4.1. **Overview**

Having selected the coastally connected waterway type appropriate to the location, the next step is to select the modelling approach used for determining a coastal water level boundary condition and entrance configuration(s).

Peak flood levels at the coastal interface can vary significantly with the waterway entrance type and the specifics of the location and can be difficult to model and resolve. The decision on the analysis approach used for their calculation needs to weigh up the degree of reliability required from the modelling outputs against the effort of production.

This guide adopts the three generalised modelling approaches detailed in the NSW guidelines (OEH, 2015):

- **Simplistic** - This approach generally aims to derive design flood levels as the basis for determining site specific flood risk information, such as the flood planning level for an individual house where no flood information is available from council. The conservatism of this approach may warrant the additional cost of undertaking one of the less conservative approaches (general or detailed).
- **General** - This requires a more detailed and rigorous modelling approach. It should be used where information is required to provide the basis for strategic land use planning and floodplain management actions including amendment of a planning scheme to update or introduce flood controls. It is also appropriate for delineating flood risks associated with large scale developments. This approach will involve modelling to derive design flood levels and flow velocities across a range of design flood events including scenarios that account for the likely change in risk associated with climate change (incorporating sea level rise and rainfall intensity).
- **Detailed** - This approach may be needed where the general approach for an entrance waterway type may be considered conservative or where specific characteristics of the waterway entrance require complex analysis. This approach will involve detailed modelling to derive design flood levels and flow velocities across a range of flood events including scenarios that account for the likely change in risk associated with climate change (incorporating sea level rise and rainfall intensity).

An overview of the three approaches is provided in Figure 1 and repeated here in Figure 7.

Model Consideration	Choose a modelling approach that best meets the project objectives		
	Simplistic	General	Detailed
Entrance Morphology	Apply a steady state (fixed) entrance condition	Apply a steady (fixed) entrance for permanent open entrances such as tidal creeks and ICE Type A and C or unsteady (dynamic) entrance conditions for ICE Types A and B	Apply a steady (fixed) entrance for permanent open entrances such as tidal creeks and ICE Type A and C or unsteady (dynamic) entrance conditions for ICE Types A and B
Coastal Water Level Boundary	Static coastal water level boundary	Generally, a dynamic water level boundary should be applied, although a static boundary may be appropriate depending on available data or study specific considerations	Dynamic coastal water level boundary
Joint Probability	Adopt conservative approach - 1% AEP catchment flood and 1% AEP ocean boundary level	Initial 'envelope' of catchment and ocean flood events. Further scenarios may be required depending on flood risks	Initial 'envelope' of catchment and ocean flood events. Further scenarios or full joint probability analysis may be required depending on flood risk
Relative Timing	Peak catchment flood level with static ocean boundary	Peak catchment flood level coincident with peak ocean boundary level	Analysis should include sensitivity testing to establish suitable event timing relationship for design events
Sea level rise & climate change	Sea level rise increments only, rainfall increases can be considered. Minimum is 0.8m of sea level rise relative to baseline. Increased berm heights for ICEs.	A selection of sea level rise increments. Rainfall increases should be considered. Increased berm heights for ICEs	A selection of sea level rise increments. Rainfall increases should be considered. Increased berm heights for ICEs

Figure 7 Overview of the modelling approach as defined in this guide

The simplistic and general approaches comprise components related to elevated coastal water levels, tidal anomalies and wave setup and can be considered conservative in some situations, particularly where these factors are reduced or negated by entrance conditions. This degree of conservatism is in lieu of a more sophisticated analysis outlined in the detailed approach.

For example, a detailed approach was adopted for the Seaspray Flood Study (Water Technology, 2016) where the condition of the entrance has considerable impact on flood levels in the township which is located adjacent to the entrance. A more general approach was applied to assess coastal water levels on catchment flooding in the Fitzroy River (Water Technology, 2017), where the flood risks to built infrastructure in the affected floodplain were low due to the rural nature of the floodplain.

Having selected a modelling approach appropriate to the situation and waterway type, an appropriate method must be applied in the derivation of critical elements of ocean boundary conditions and design flood level estimation. The following sections provide guidance on best practice approaches to these study elements. For some aspects it may be necessary to seek advice from a coastal engineer to confirm the appropriateness of the approach selected and to provide input to technical elements.

4.2. **Entrance Morphology Considerations**

Having selected the waterway entrance type appropriate to the location and the overarching modelling approach, the next step is to select the approach to representing this entrance in the hydraulic model.

The entrance can be represented in the model as either being in a steady (fixed) or unsteady (dynamic) state. The methodology selected needs to be fit for purpose given the specific morphological conditions of the entrance to be modelled and how it is managed.

4.2.1. **Steady State (fixed) Entrance Conditions**

Steady state entrance conditions are used in the simplistic approach. Steady state entrance conditions are also applicable for the General and Detailed approaches where:

- The entrance channel morphology is stable due to some form of management (i.e., training walls); or
- For some waterway classes (ICE Types A and C, tidal creeks, and drains) where the entrance state is predominantly open or closed.

Where adopted, a steady state entrance condition needs to be conservative and account for potential variations in conditions over time. The steady state approach only considers conditions where the entrance is fully open or fully closed (where appropriate).

To do this involves defining the current entrance geometry (generally confirmed by survey) and historic entrance configurations based upon the interpretation of historical aerial photos and other relevant information (see Section 2.2.2). This information is used to assess how dynamic the entrance is and whether there is a 'typical' state which can be represented in the model (open, partially open, or closed conditions).

In the case of some ICEs where entrances are managed, there may be a policy of artificially opening an entrance before a flood occurs or before the berm can contribute to elevation of the water level in the waterway to a height that could result in significant flood impacts on the surrounding community. Advice should always be sought from the relevant Catchment Management Authority (CMA) or Local Council as to the existence of local policies and/or plans governing artificial opening of entrances.

In this instance, the modelling should adopt the 'open' condition for the entrance for the main flood modelling scenario with the 'closed' condition assessed as a sensitivity test. This was the approach adopted for the Snowy River Regional Flood Mapping Study (Water Technology, 2017). In the case of the Snowy River study, a series of prior investigations had assessed the entrance conditions in detail and this information was used to inform the selection of entrance planform for the flood model simulations (Figure 8 below). The figure shows the 'constricted entrance' which was found to be typical of conditions where the entrance was almost closed, which was common during periods of low river flow and / or high wave energy and an 'open' entrance which was typical of periods of moderate to high river flow.

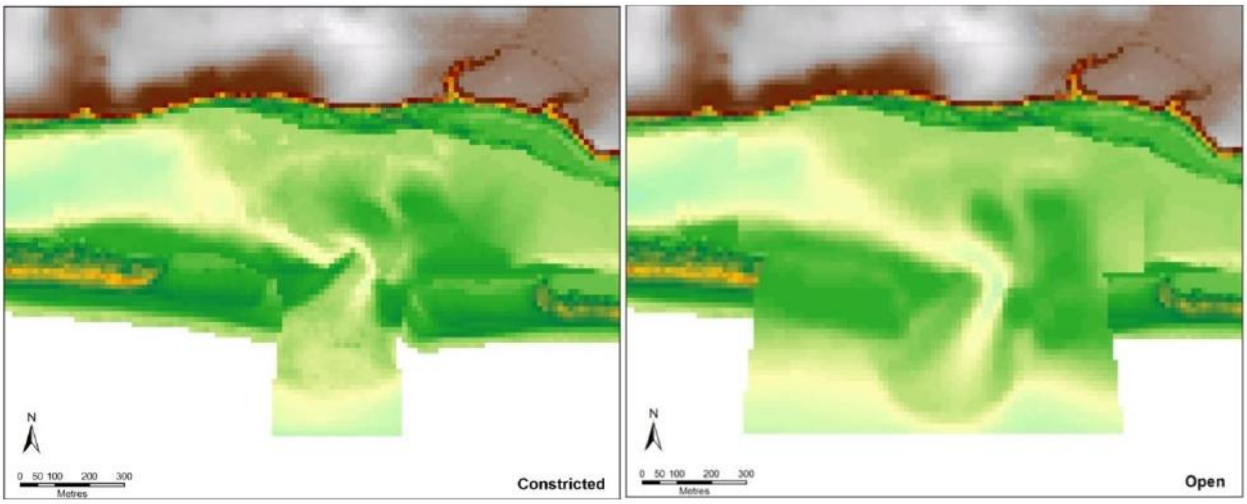

Figure 8 Typical constricted and open entrance channel configurations on the Snowy River (Water Technology, 2017) Light green to green represents lower elevation, while orange and brown are higher elevation areas.

The adoption of this fixed entrance(s) approach should be agreed with the relevant CMA prior to commencement.

4.2.2. Unsteady State (dynamic) Entrance Conditions

In the general and detailed approaches, unsteady state entrance conditions are used to represent changes to the downstream flood control mechanism over time during an event which is most relevant for ICEs Type A and B. Scouring and enlargement of the entrance in response to a catchment flood is likely for these entrance types. Representation of unsteady entrance conditions is also appropriate for tidal creeks that shoal (i.e., shallows) significantly but don't close between catchment flood events. This approach is less conservative than using the open, steady state entrance condition.

Initial entrance geometry conditions would be based upon the steady state entrance condition approach. An understanding of the entrance dynamics and physical limits can be derived from:

- A particular historical event. This may require alteration to the entrance configuration within realistic limits in the model to match available calibration data.
- Peak shoaled (governing peak flood levels) and peak scoured (governing peak flow velocity and ocean inflow) states over time.
- The limits of the potential dynamics such as vertical and lateral limits of scour, including any headlands, rock shelfs, or reefs known to exist in the locality.

For ICEs, a more sophisticated approach to simulate the breakout of the entrance involves detailed modelling via a built-in dynamic scour model or by interfacing with a breach model to examine scouring. The dynamics of the situation may be complex, i.e., different conditions may dominate flooding at different times during an event and different starting conditions can govern peak flood levels and entrance flow velocities. Therefore, several model runs may be required to develop upper boundary or envelope curves for flood levels and flow velocities. An example of this type of scour modelling approach is provided in the Seaspray Flood Study (Water Technology, 2016) (Figure 9 below). This dynamic approach would have also been necessary for the Snowy River flood modelling if the detailed entrance studies had not been completed prior to the flood study.

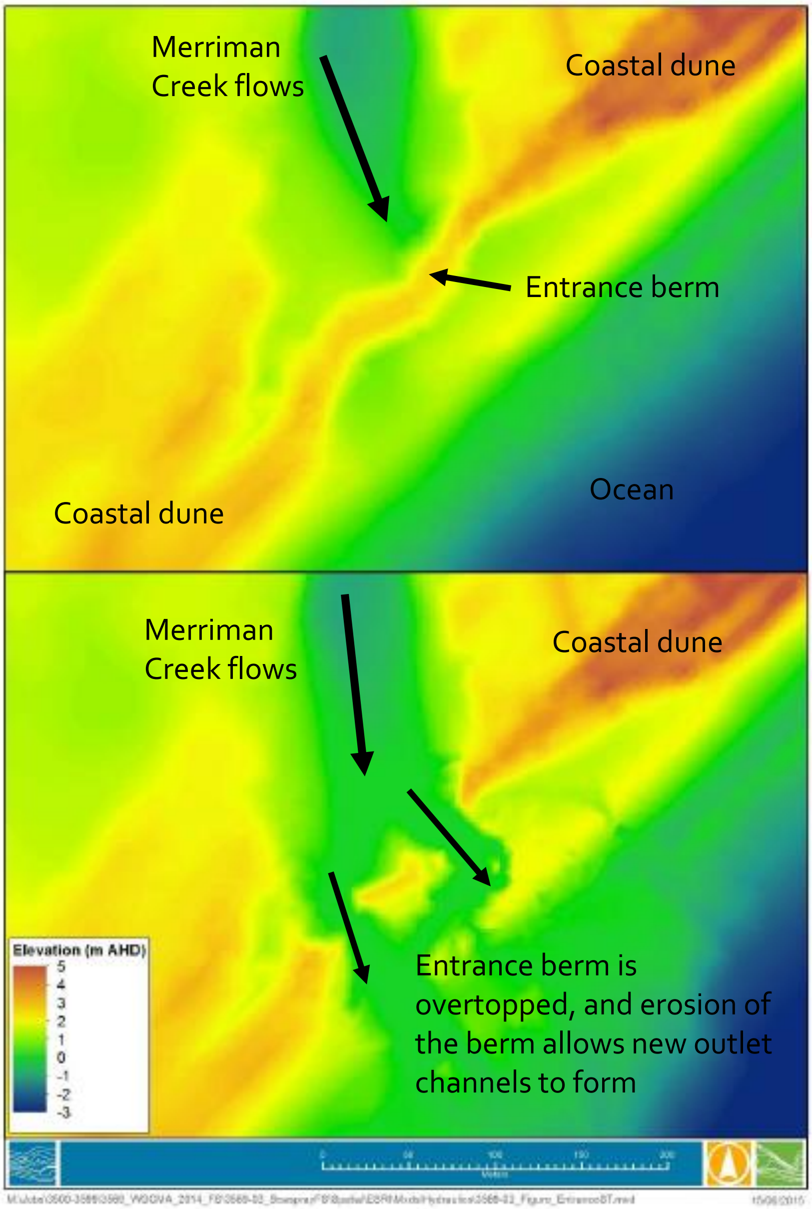

Figure 9 Entrance berm of Merriman Creek, Seaspray with initially closed (top) and dynamically scoured (bottom) entrance during 10% AEP flood event

4.3. **Coastal Water Level Boundary**

The coastal water level boundary represents the influence of oceanographic processes on the coastal connected waterway. The coastal water levels relevant to catchment and coastal flood studies are astronomical tides and storm tides (including or excluding wave setup), defined in Figure 10. Wave runup generally only needs to be considered for low lying floodplain areas on the open coast or where runup results in overtopping of the entrance or adjacent dunes.

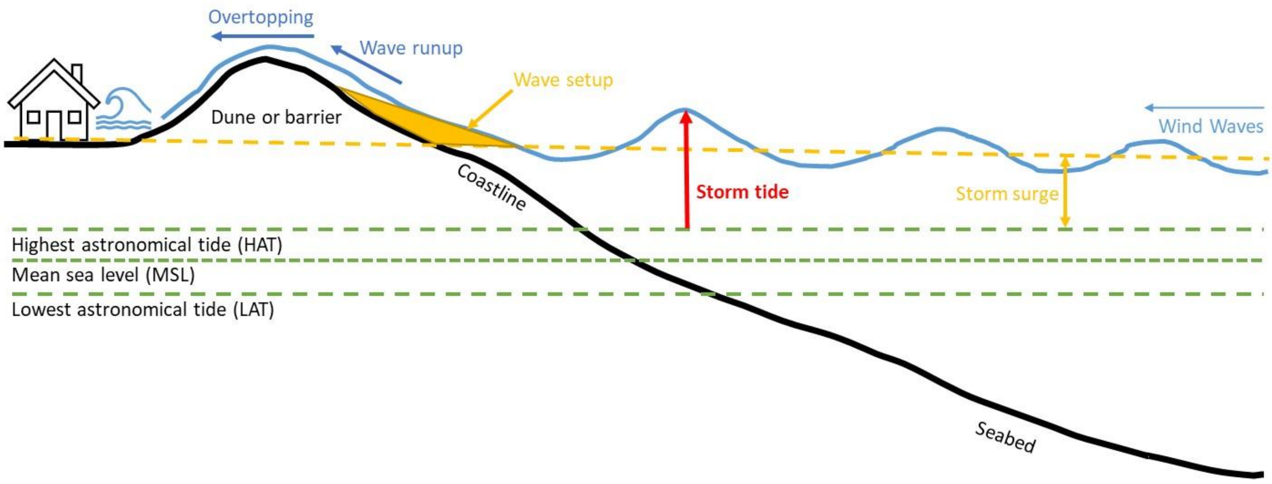

Figure 10 Schematic showing the components of a storm tide including wave setup, wave run-up and overtopping

4.3.1. **Static Water Level**

This approach uses a conservative static water level assumption for the elevated water level at the coast. It is applicable for the simplistic approach and may also be applicable for a general modelling approach where an unsteady (dynamic) coastal water level boundary condition is not readily available for the storm tide estimate. The modeller should check previous flood studies, coastal hazard studies and local tide gauges for suitable information.

The static coastal water levels relevant for a flood study will be:

- Mean High Water Springs[5]
- Peak storm tide elevation (1% AEP as a minimum).
- Allowance for wave setup (see Section 4.3.3)

Sources of appropriate tidal and storm tide levels are discussed above in Section 2.2.3 and Section 2.3. Within Port Phillip Bay and Western Port Bay, Melbourne Water has provided specific AEP coastal boundary levels to be used to assess catchment and coastal flood conditions[6].

[5] MHWS (Mean High Water Springs) is the long term mean of the heights of two successive high waters during a 24hr period when tidal range is greatest (approx. once a fortnight). In some instances, the Highest Astronomical Tide (HAT) may also be considered.
[6] Melbourne Water Planning for Sea Level Rise
https://www.melbournewater.com.au/sites/default/files/Planning-for-sea-levels.pdf

All coastal flood studies should consider current and future (accounting for sea level rise) coastal boundary conditions. The relevant CMA can provide guidance as to the future sea level increments which should be assessed. This is discussed further in Section 4.3.4.

4.3.2. **Dynamic Water Level**

This approach is suitable for both general or detailed modelling approaches and assumes an unsteady state (dynamic) coastal water level boundary condition is applied to the model. While there is no generalised coastal boundary condition available for use on the Victorian coast, dynamic coastal water levels have been developed for several of the previous coastal flood and hazard studies (e.g., Port Fairy Regional Flood Study Sea Level Rise Addendum, Water Technology 2010; Gippsland Lakes and Ninety Mile Beach Coastal Hazard Assessment, Water technology, 2013). These previous studies have typically derived both peak water levels and dynamic model boundary conditions either based on a historic storm tide event or statistical analysis of recorded coastal water levels.

An example of a dynamic water level boundary is shown in Figure 11 for Venus Bay coastline (Water Technology, in press). Here, a dynamic storm tide boundary was defined by analysis of previous storm events to generate a "representative" storm tide modelling scenario that captured the critical temporal and spatial characteristics of storm tides in Venus Bay. The width of the dynamic boundary time series is defined in the analysis of storm duration based on known events and the vertical height is scaled by AEP wave height. Typical storm durations determined through analysis of events along the Victorian coast are in the order of 48 hours to 72 hours (Water Technology, in press).

A methodology for developing such a dynamic coastal boundary level is outlined in Harrison et al., (2019). Typically, a triangular or cosine time series is developed comprising an astronomical tide time series, combined with a representative storm surge (often referred to as the tidal anomaly). An allowance for wave setup, if relevant (see Section 4.3.3) should also be included.

Alternatively, a coupled hydrodynamic and wave model approach could be adopted to explicitly simulate storm tide and wave setup conditions. This type of modelling should be undertaken by a qualified coastal engineer.

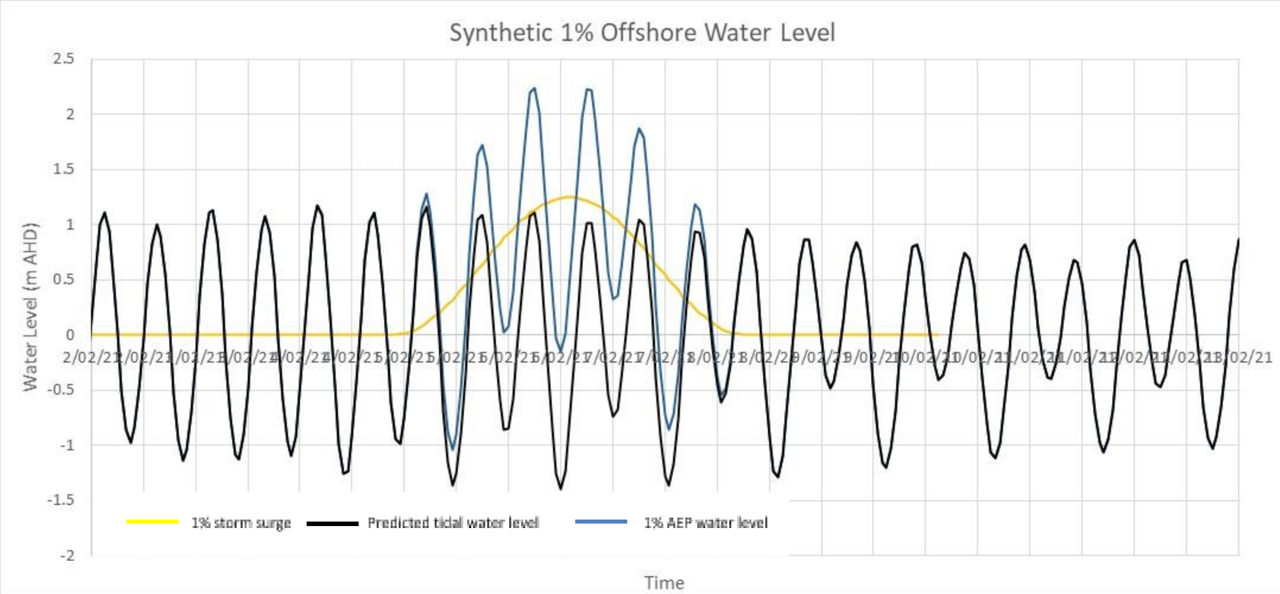

Figure 11 Design 1% AEP storm surge and storm tide water levels in Venus Bay (Water Technology, in press).

4.3.3. Wave Setup

Wave setup is an increase in the mean water level at the shoreline due to wave breaking (refer to Figure 10). It can be a significant component of the total storm tide elevation on open coasts, however the dynamics of wave setup at river or estuary entrances is different to that observed on the open coast. The factors that contribute to these differences include estuary entrance morphology, freshwater flows, and currents, along with wave breaking characteristics. There is no generally agreed approach to how wave setup should be included in coastal water level boundaries for coastally connected waterway flood studies. Therefore, a brief overview of current understanding is provided in this section along with suggested approaches and their applicability to different entrance morphologies.

Current Understanding

A useful summary of wave setup investigations at river and estuary entrances to date is provided in Mohd Zaki (2020) who recently completed an experimental investigation of wave setup at estuary entrances. Interestingly the investigations to date, while showing a reduction in wave setup at river and estuary entrances compared to adjacent open coasts, present variable results as to the magnitude of these reductions. A brief overview of relevant studies is provided below.

Hanslow & Neilsen (1992) and Hanslow et al (1996) presented water level measurements from the river entrances on the NSW north coast and found that the contribution of wave setup to the super-elevation of river entrance water levels is quite small. This was thought to be due to the influence of the river outflows and the propagation of storm tides through the entrance during extreme conditions. Further studies by Dunn et al (1999) also found wave diffraction processes at the entrance also affected the wave setup. Dunn et al (2000) found that for shallow river mouths (<5m) negligible wave setup occurred.

However, in contrast to these studies, Tanaka et al (2000) found that wave setup was between ten to twenty percent of significant deep water wave height for two river mouths in Japan. This was supported by investigations by Tanaka and Tinh (2008) for eight river entrances which showed that for average water depths at the entrance of between 1 to 6.5 m the wave setup was 2 to 14% of the significant offshore wave height. They found that the wave setup was not only dependent on the wave height but also the river discharge.

Nguyen et al. (2007) investigated other rivers in Japan and found that the wave setup for shallow and narrow river entrances was 10 to 14% of the offshore wave height. However, for deep and wide river mouths the wave setup was 0.2 to 4% of offshore wave height. Discharge from the river, the bed slope, bed roughness and estuary morphologies all influenced the formation of wave setup in the estuary.

In a numerical modelling-based storm tide study for Moreton Bay, Queensland, Treloar et al. (2011) found that wave setup can increase the water levels by up to 15% inside coastal inlets.

The experimental results of Mohd Zaki (2020) into river discharge impacts on wave setup at entrances found:

- For the case of zero river flows, wave setup systematically decreases with increasing estuary depth. Shallow depths result in greater wave setup.
- As river flows increase, setup increases with significant setup observed for entrance depths where no setup was observed under zero flow conditions. Wave setup was observed to decrease in the landward direction.
- Wave angle also affects setup, with higher estuary setup occurring as the incident wave angle increases (for angles up to 45 degrees) in some cases.

In a numerical modelling study, Irish and Canizares (2009) evaluated the wave setup contribution to flows through tidal inlets during storm events. The findings of the study indicated that wave-induced flow contributions make up 15 - 35% of the total storm surge, where the wave-induced flow contribution increases with increased inlet efficiency. This concept was applied in a 2017 coastal inundation study for the Avon-Heathcote estuary inlet, in Christchurch New Zealand (Tonkin & Taylor, 2017). Wave setup at the tidal delta was calculated using a standard wave transformation model and added to this was an additional 15% and 35% to provide the resultant increase in elevation at the estuary inlet because of wave induced breaking and setup gradients.

Calculation Methods for Wave Setup

Wave setup can theoretically occur at an estuarine or tidal channel entrance where there is wave breaking caused by shoaling (WRL, 2013). Wave setup at the open coast can be determined using a range of approaches:

a. For a preliminary estimate, an initial approximation for wave setup at a sandy shore is typically 10-15 % of the offshore wave height (Carley et al, 2008).
b. If information on beach slope and wave period are available, empirical estimates of wave setup such as Stockdon et al (2006) could be used. It is recommended advice be sort from a coastal engineer as to the suitability of data and application of the method.
c. A range of numerical methods are available for calculating wave setup on the coast including for profiles along the entrance of an estuary or tidal channel. A simplified

approach is described in Harrison et al (2019) which uses Dally et al (1984) to calculate a time series of wave setup along a single cross-shore profile. It is recommended advice be sort from a coastal engineer as to the suitability of data and application of the method.

d. **A detailed numerical wave model** can simulate wave conditions on the coast. The model could be coupled to a hydrodynamic model to simulate both waves and storm tide conditions. This method is recommended for the detailed assessment approach and will require input from a coastal engineer.

Recommended Approach

For the simplistic and general approach, where detailed wave modelling is not justified, when and what proportion of the wave setup calculated at the coast is applicable at different waterway entrances is not straightforward to determine. The NSW Floodplain Risk Management Guide includes an approach whereby wave setup as a component of the coastal boundary condition is defined as follows:

- Waterway Type 1 [7] - no wave setup component. This would be appliable to coastally connected waterways in the Victorian context that drain to the open coast, such as embayments, permanently open estuaries, or tidal creeks and have deep channels (nominally > 5 m) such that there is little tide attenuation. This includes entrances that operate as ports and harbours.
- Waterway Type 2[8] - 6% of offshore significant wave height (or a site-specific assessment). This would be appliable to coastally connected waterways in the Victorian context that drain to the open coast, such as embayments, permanently open estuaries, or tidal creeks that have shallower entrances (< 5 m).
- Waterway Type 3[9] - 12% of offshore significant wave height. This would be applicable to many estuary entrances in the Victorian context, refer to Appendix A for further details.

The guidance above was based on work detailed in WRL (2013), and generally reflects the outcomes of the various research and investigations to date. It can be adopted if no detailed modelling or estimates from previous coastal studies are available. Sensitivity testing as described in Section 4.6 should also be undertaken.

For the detailed approach, numerical modelling will generally be required although there may be some instances where a simplified numerical method can be applied. Advice should be sought from an appropriately qualified coastal engineer to confirm the methodology and potentially to undertake the modelling tasks.

[7] As defined in the NSW guide this type includes oceanic embayments and tide dominated estuaries which have large deep entrances with tidal ranges similar to the open ocean. Can sometimes include wave dominated estuaries (defined below) with trained entrances.

[8] Defined in the NSW guide as wave dominated estuaries - entrances that are constricted by wave-deposited beach sand and flood-tidal deltas but are permanently open.

[9] ICOLLS (term used in NSW to define coastal water bodies that become isolated from the sea for extended periods) and wave dominated entrances that may fully close from time to time. Defined as ICEs in Victoria

4.3.4. **Wave Runup (Swash zone)**

Wave runup is the limit to which a breaking wave will travel landward and is sometimes referred to as the "swash zone". It is mainly a concern for coastal flooding where wave runup results in overtopping. This may be a consideration for coastally connected waterways where overtopping of the entrance berm may occur or overtopping of the adjacent dunes or foreshore may allow additional flows into the waterway, coastal lagoon or floodplain. Overtopping can also be an important flooding mechanism where structures such as seawalls are present. WRL (2013) did note that wave runup and overtopping of the entrance berm may be important for ICEs when setting initial water levels for design flood assessments.

Empirical equations for wave runup have been assessed for Australian beaches (Atkinson et al., 2017). The height to which waves can runup the coast R relative to the still water level (where the still water level is made up of the storm surge and astronomical tide) has been formulated as,

$$\boldsymbol{R = \alpha H_{s0} \beta \left(\frac{H_{s0}}{L}\right)^{-1/2}},$$
$$\boldsymbol{L = g {T_{p0}}^2 / (2\pi)}$$

where H_{s0} is the deep-water significant wave height, L is the wavelength which is a function of the deep water spectral wave peak period T_{p0}, β is the intertidal beach slope and α is a constant parameter. The parameter α has been calibrated as 0.73 for international and 0.99 for Australian sandy beaches (Stockdon et al., 2006; Atkinson et al., 2017). The use of empirical equations is appropriate for the general approach however this provides estimates of the runup level only, not the overtopping flow or flow volume. It is unlikely that wave runup would be considered within a simplistic assessment. Advice should be sought from a coastal engineer as to the appropriateness of such assessments.

To estimate overtopping flows and flow volumes approaches such as those detailed in EurOtop (http://www.overtopping-manual.com/) are recommended.

For the detailed approach, numerical modelling will be required to estimate wave runup and overtopping flows. Advice should be sought from a coastal engineer to confirm the methodology and potentially to undertake the modelling tasks.

4.3.5. **Sea Level Rise**

Depending on the purpose of the study, it will likely be necessary to assess the potential implications of sea level rise on flood levels. Sea level rise is typically included for all modelling approaches as a static increase in water level. The sea level rise increments were discussed in Section 2.2.4. Generally, there is no additional consideration for changing wind or wave setup due to increases in mean sea levels due to the uncertainty around how these aspects will change with sea level rise.

A recent paper by Melet et al (2020) provides details of current research on potential changes in wave setup under future sea level scenarios. Projected changes in wave setup were a combination of projected changes in wind-wave-induced setup and of swell-induced setup. They found that at a global scale the wave setup changes mostly average out, but at a regional or local scape, wave setup changes, while small, are a nonnegligible compared to changes in mean sea level over the next 30 to 80 years. Potential changes to wave setup because of sea level rise could be considered in future detailed coastal modelling studies should suitable methodologies for predicting these changes become available.

The suggested sea level rise scenarios for coastal waterway flood assessments are discussed further in Section 4.5.2. They do not include changing wind or wave setup as this is an area of active research and industry standardised approach currently exists for predicting these changes.

4.4. **Initial Estuary Water Level**

For dynamic modelling, initial water levels in the waterway also need to be established. For permanently open waterways these should be developed considering water levels based on the MHWS water level for the closest available tide gauge site.

For ICEs, the initial water levels are often independent of ocean levels. They can be determined based upon the following approaches:

- Considering estuary management strategies which often include a maximum water level in the ICE as a trigger for management response, such as consideration of artificial berm opening.
- Recorded water levels in the estuary where sufficient record exists.
- The maximum historic height of the berm, noting that this approach is likely to be conservative.

If wave runup and overtopping of the entrance berm has been observed at the entrance, further advice should be sought from a coastal engineer. Wave runup may need to be considered when setting the initial water levels.

4.5. **Joint Probability of Catchment Flooding and Oceanic Inundation**

4.5.1. **Overview**

Flooding in low lying coastal areas can be caused by extreme rainfall events (catchment generated floods), storm tides (coastally generated inundation) or a combination of both processes occurring at the same time or in close succession. Flood modelling therefore needs to consider their interaction for areas affected by both catchment and oceanic flooding processes.

A critical output from the flood modelling is defining the extent over which catchment and coastal flood mechanisms interact and where each process is dominant.

For instance, understanding of the relative importance of catchment versus coastal flood events on flood depths is essential for ensuring planning controls fully account for the maximum level of 1% AEP risk across the study area.

Figure 12 is taken from the Australian Rainfall and Runoff (ARR) guidelines (Book 6, Chapter 5) (Ball et. al. 2019) and summarises the potential interaction of catchment (fluvial) and coastal flood mechanisms and their influence on flood levels. The term 'dependence' is used to describe the level of interaction between these processes, while the joint probability zone represents those low-lying areas potentially affected by both catchment and oceanic flooding at the same time.

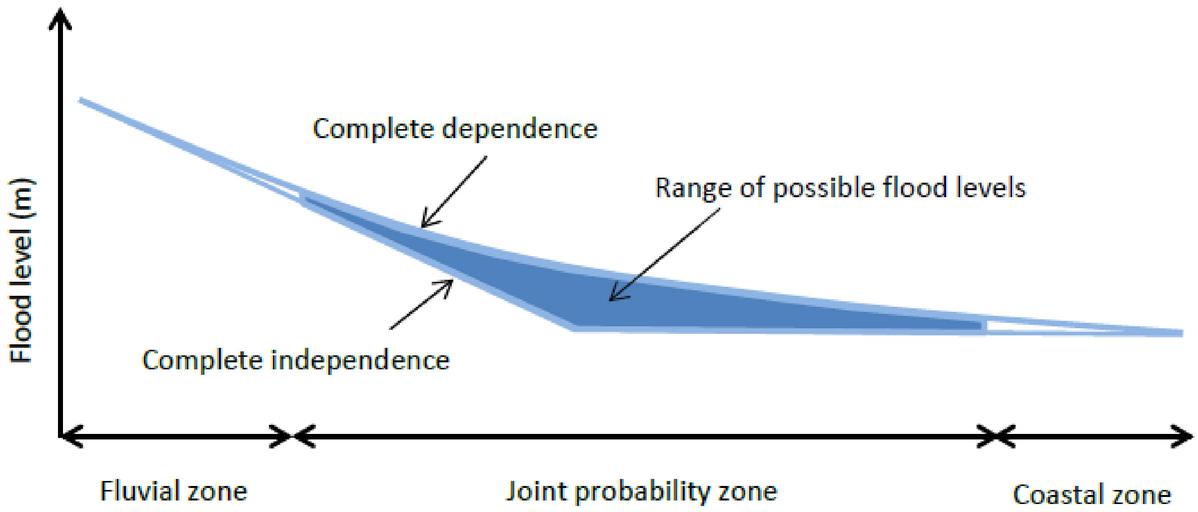

Figure 12 Schematic of a longitudinal section of an estuary, which shows two hypothetical water levels: the level obtained by assuming that fluvial floods will always coincide with storm tides of the same exceedance probability (upper curve); and the level assuming fluvial processes and ocean processes are completely independent and thus will almost never coincide (lower curve) (from Ball et al, 2019).

It is important to consider the likely dependence of catchment and oceanic storm events to generate a realistic estimate of the required AEP flood levels for low-lying coastal areas affected by both flood mechanisms (Figure 12). For instance, if the 1% AEP catchment flood and 1% AEP storm tide are dependent events (i.e., they occur as a result of the same storm system, red line in Figure 13) then the resultant flood levels could be considered the joint 1% AEP flood level.

However, if they are independent events (i.e., as shown by the green and blue lines in Figure 13) then the red line would represent a flood profile with an AEP << 1% (i.e., a much rarer event).

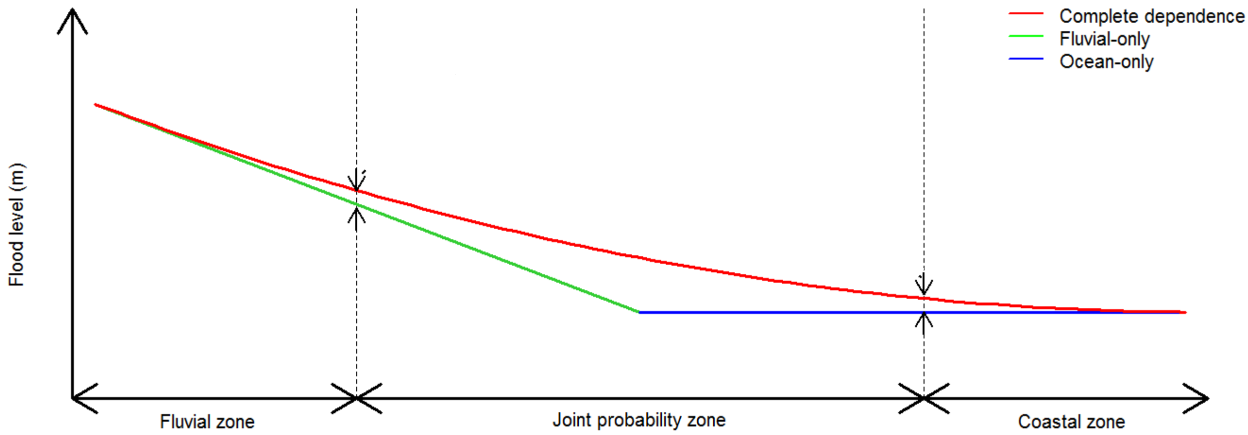

Figure 13 Schematic showing the difference between completely dependent and independent flood events (from Australian Rainfall and Runoff Book 6 Section 5, Ball et al, 2019)

4.5.2. Joint probability scenarios

How likely is it that catchment flooding and oceanic flooding of low-lying coastal areas occurs at the same time in Victoria? Studies completed to date for coastal waterways in Victoria (e.g., Water Technology, 2008) have found limited evidence of catchment flood peaks occurring at the same time as the peak of a storm tide event. This is reflected in work completed for the ARR Book 6 Section 5 (Ball et al, 2019) which undertook an analysis of the joint probability of extreme rainfall and storm tide events. They calculated dependence parameters for the Victorian coast of 0.95 to 0.98, where values closer to 1 represent weak dependence and values closer to 0 represent strong dependence (refer to ARR Book 6 Figure 6.5.6). There does appear to be a difference in the dependence parameter with duration that suggests dependence is increased for storms of duration of 12 to 48 hours. Despite the weak level of dependence, assuming no dependence will likely underestimate flood risks in low lying coastal areas. The challenge is that to accurately determine the specific joint probability of catchment and coastal flood events can be complicated and time consuming.

The simplistic approach conservatively assumes that catchment and coastal flood events occur together. The resultant flood levels will provide the upper envelope for a given AEP design flood. The 1% AEP catchment flood and 1% AEP coastal water level boundary scenario should be assessed to understand the maximum extent of flooding that could possibly occur for the study area for combined 1% AEP events. This then sets a very conservative design flood level, which will have a joint AEP of at least 1% but likely << 1%. The exact AEP it represents is not defined in this approach. **<u>This upper envelope approach is the starting requirement for any assessment of catchment and coastal flood mechanisms</u>.**

For the general and detailed approaches, a version of the 'pre-screening' level analysis as outlined in ARR Book 6 Section 5.5 (Ball et al, 2019) is recommended. This extends the upper envelope (simplistic approach) and is the **minimum requirement for both the general and detailed approaches**.

The **minimum matrix of flood scenarios** are presented in Table 3 and generally reflects ARR Book 6 Table 6.5.6 together with advice in the earlier Floodplain Management in Australia: Best Practice Principles and Guidelines (see Appendix C, Section C.10; SCARM, 2000); which has been widely applied in Victorian flood studies and coastal hazard studies for the derivation of flood zones and overlays to date. As there is typically < 0.2 m difference in peak water level between a 10% and 1% AEP storm tide along the Victorian coast (see McInnes et al, 2009) the events selected provide a pragmatic range of likely conditions that could be realised using a reasonable number of model runs (7 in total), and the results of the flood modelling will show the where different flood drivers dominate across the study area, as well as the likely maximum flood extent that could reasonably be expected.

Table 3 Minimum flood modelling scenario matrix (current conditions)

Catchment flood scenario	Coastal water level boundary		
No rainfall	MHWS	10% AEP	1% AEP
10% AEP	-	-	1% AEP
1% AEP	MHWS	10% AEP	1% AEP

The aim of the minimum flood modelling scenario analysis is to calculate the envelope of flood estimates (i.e., the red, green, and blue lines shown in Figure 13). If there is < 0.3 m[10] difference across the modelled area between the upper flood level estimates (i.e., the 1% AEP catchment and 1% AEP coastal flood combination, shown as 'complete dependence' in Figure 13) and the 'no rainfall' scenarios or the 10% AEP catchment and 1% AEP coastal flood scenarios (green and blue lines in Figure 13), then the upper flood level estimate can be adopted as the design flood level. This was the approach adopted for the Seaspray Flood Study (Water Technology, 2016), where this initial pre-screening analysis showed the 1% AEP storm tide combined with 1% AEP catchment flooding resulted in flood levels that were only 0.05 m higher than the 1% AEP catchment only flood event.

If there are considerable differences in flood level for the different scenarios or across the modelled area, then additional catchment flood and coastal water level boundary scenarios can be included to further refine your understanding of the flood mechanisms and drivers. In some instances, a full joint probability flood modelling analysis may be required although this could necessitate more than 49 flood modelling scenarios to be completed. Before undertaking a full joint probability analysis, the results of the minimum scenario matrix should be discussed further with the relevant floodplain manager (CMA and/or Local Government).

[10] The proposed 0.3 m difference is arbitrary as no specific guidance on appropriate levels of tolerance are provided in ARR 2019. Lower tolerance levels may be appropriate where the potential flood risk may be high.

Depending on the study there may also be a requirement to include a wider range of catchment flood scenarios (from the 20% AEP to the 1% AEP typically). In this case is it recommended that the minimum scenario matrix be modelled first to assess the dominance of the different flood drivers and then the coastal water level boundary modelling requirements for modelling intermediate catchment AEP events be discussed and agreed with the CMA.

The minimum flood modelling scenario matrix assumes current mean sea level conditions for the coastal boundary level and current extreme rainfall conditions for the catchment flood events. Consideration of changes in rainfall intensity are discussed further below.

The MHWS ocean level boundary has also been included along with storm tide scenarios as there is increasing evidence (Hague et al 2020; Lauchlan Arrowsmith, 2022) that flooding because of typical tidal levels is becoming increasingly important as sea level rises. For instance, Figure 14 shows a comparison between different AEP storm tide levels at Port Fairy and the MHWS tidal levels under current and future sea levels assuming the projected sea level rise based on the IPCC 6th Assessment report for future scenario SSP8.5 (IPCC, 2021).

The modelling of tidal impacts under current conditions provides a baseline for assessing future conditions, particularly when considering adaptation options to reduce flood risks.

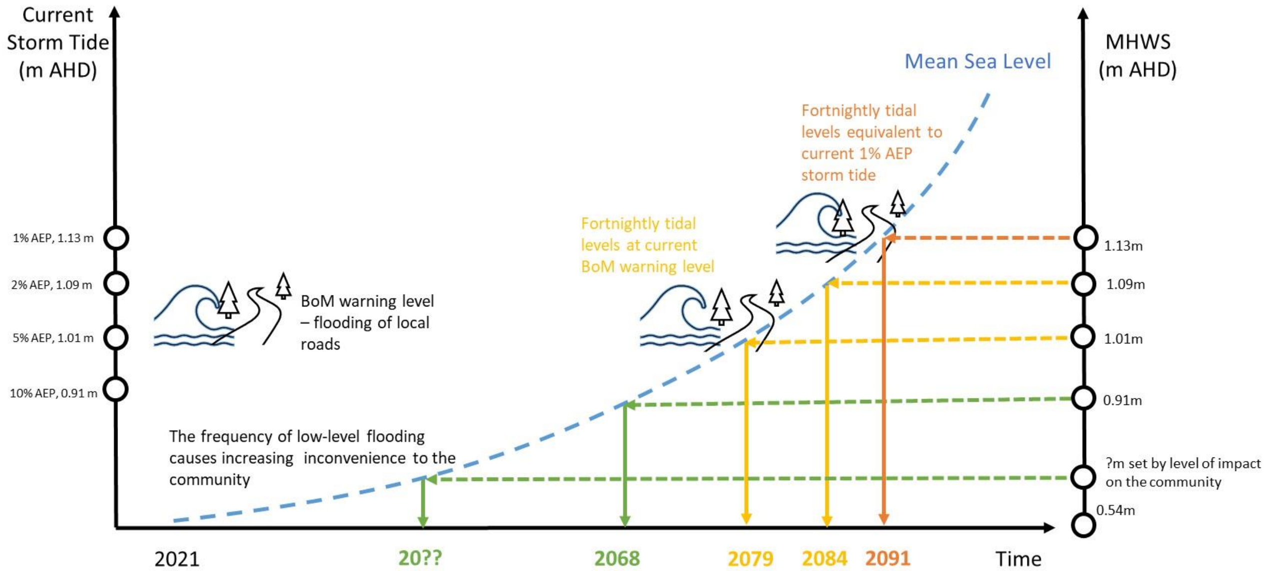

Figure 14 Example of current storm tide AEP levels compared to mean high water springs tidal levels under current and future sea levels

Relative timing of events

The timing of catchment and coastal flooding can have significant impacts on the interaction of these two flood mechanisms and the peak flood levels or velocities.

For the simplistic approach, the choice of a constant peak coastal level boundary means that the catchment flooding will always interact with the peak coastal level.

For the general and detailed approaches, the use of a dynamic coastal water level boundary means that the scenarios will need to explicitly consider the relative timing of peak design flows. For large catchments, or where the low-lying coastal areas provide significant floodplain storage, there may be some disparity in the timing of the catchment flood peak (applied at the upstream boundary of the model) and the peak storm tide level (applied at the coastal boundary).

As suggested in the NSW guidelines, for simplicity of modelling the recommendation is to adjust the peak of the catchment flood hydrograph and the peak of the coastal boundary condition to coincide at the key location of interest (e.g., township) in the waterway or an appropriate point in the catchment to balance several points of interest. This may require several initial hydraulic model runs to accurately determine the appropriate catchment flow or ocean water level timing adjustments (see Section 4.6.3 for suggestions).

Dynamic modelling of the entrance also brings in another level of complexity. The same approach is recommended but again, initial model runs will be required to define the appropriate relative timing of the events considering both the flood model boundaries as well as the change in the entrance conditions as the entrance responds to the flows.

Sea level rise & climate change

The effects of sea level rise and changes to extreme rainfall because of climate change need to be considered when assessing flood risk for coastal waterways. The ARR recommended approach is to assume the same level of dependence of catchment flooding and coastal flooding as under current climate conditions but allow for changes in extreme rainfall and increased coastal water levels.

The selection of sea level rise increments to be tested should be agreed with the relevant CMA. Current Victorian Planning Policy is to allow for SLR of not less than 0.8 m, and this threshold is expected to be reviewed through the Victorian Marine and Coast Strategy. Future planning will likely require analysis of SLR increments of more than 0.8 m and the latest predictions (IPCC, 2021) indicate SLR of >1.2 m may be realised by 2100 under certain climate scenarios (e.g., SSP8.5 low confidence, 95^{th} percentile). Suggested sea level increment scenarios to adopt are summarised in Table 4. For simplistic assessments, a reduced number of scenarios may be possible depending on agreement with the relevant CMA.

For ICEs the entrance berm height is likely to increase in response to sea level rise. However, there is also considerable uncertainty as to how a given entrance morphology might change under future conditions and therefore defining a future berm condition is highly uncertain. It is suggested that for future scenarios, the maximum berm height be increased by the same amount as the sea level increment. The implications of this assumption should be assessed using sensitivity tests.

Changes to rainfall and therefore catchment flows because of climate change are complex. The recently updated report (DELWP, 2021) by the Victorian Water and Climate Initiative notes that "Victoria's rainfall is highly variable and how Victoria's rainfall changes in response to climate change differs between seasons." The analysis of a range of future climate scenarios found that extreme, short-duration rainfall events are becoming more frequent and more intense, particularly in summer. There is no current requirement to assume a specific change in rainfall conditions when assessing design flood levels in Victoria, however general guidance is provided in ARR Book 2 and the Victorian Flood Data Mapping Guidelines (DELWP 2016) note that the primary mechanism for linking to climate change is through ARR. At Port Fairy, Council has adopted flood levels associated with approximately a 20% increase in rainfall intensity in the future. This equated to a change in catchment flood AEP from a 10% AEP event to a 5% AEP event. If detailed hydrologic analysis is being undertaken as part of the flood assessment, the change in catchment flows associated with a 20% increase in rainfall intensity can be assessed explicitly for the 1% AEP catchment flood event. This increase could be applied to SLR increment scenarios of 0.8 m or greater.

An extended envelope of flood modelling scenarios outlined in Table 4 shows the increased number of model runs (at least 36) that could be required to account for future sea level and climate conditions. Further consultation should be undertaken with the relevant CMAs to define a reasonable number of model runs that would best meet the project outcomes, considering the output requirement of the study itself (e.g. for planning, adaptation etc), the latest sea level rise projections, an allowance for increases in rain intensity and a range of flood events, and/or including rarer floods than the 1% AEP flood (if requested in the study brief). Within the catchment flood scenarios, it is suggested that a least one climate change (1 xCC) scenario be included to account for changes in rainfall.

Table 4 Extended flood modelling scenarios for the future sea level and climate scenarios

Sea level increment	Ocean water level boundary scenario	Catchment flood scenario
0.2	MHWS, 1%	10%, 1%, 1xCC
0.4	MHWS, 1%	10%, 1%, 1 xCC
0.8	MHWS, 1%	No rainfall, 10%, 5%, 1%, 1 xCC
1.2	MHWS, 1%	5%, 1%, 1xCC
1.6	MHWS, 1%	5%, 1%, 1 xCC
2.0	MHWS, 1%	5%, 1%, 1xCC

4.6. Sensitivity Testing

Testing and reporting on the sensitivity of results to key parameters reflects best practice in flood investigations. This sensitivity is generally undertaken for a key flood event, typically the 1% AEP flood event. For coastal boundary conditions sensitivity testing would relate to coastal boundary condition, entrance condition, and relative timing of catchment and coastal flooding.

ARR Book 7 Section 7, 9.2 and 10 also provides useful information on sensitivity testing.

4.6.1. Sensitivity to design coastal boundary condition

Sensitivity to coastal boundary condition can be tested by increasing the coastal boundary condition and initial water levels in the waterway to provide an allowance (or increased allowance) for wave setup where detailed modelling is not being undertaken. If the predicted flooding demonstrates significant sensitivity to this level a more detailed examination of wave setup at the entrance may be warranted. The NSW guidelines suggested a nominal increase of 0.3 m initially above the wave setup value adopted (as defined in Section 4.3.3), however a wave setup allowance of 1-1.5 m was applied to the Moyne River entrance at Port Fairy based on local wave modelling. It is suggested that for waterways connected to the open coast, the sensitivity tests should consider increases of up to 1 m while 0.3 m is sufficient for those waterways within embayments such as Port Phillip Bay.

4.6.2. Sensitivity to entrance elevation (ICEs)

The height of the entrance berm is related to wave height, beach flow and grain size (e.g. Sunamura, 1994; Hanslow et al, 2000). The height of the berm is also likely to increase in response to sea level rise. Where there is limited recent topographic information for the entrance berm elevation under current mean sea level, the effect of a higher berm can be tested by increasing the initial berm height.

An initial test can be undertaken whereby the berm height is increased by a nominal 0.3 m above the available elevation data. This nominal increase considers the measured sea level increase along the Victorian coast since 1990 (of up to 0.15 m) and the resultant change in wave runup. The crest elevation of any adjacent dunes and/or the maximum swash lines could also be assessed where data is available to provide an indication of the maximum wave run-up at the shoreline.

If the predicted flooding demonstrates significant sensitivity to this level change, then further, more detailed examination of the downstream water level may be warranted. This may include capture of new survey data for the entrance berm.

4.6.3. Sensitivity to catchment timing

The assumption made in this guide in aligning the peak of the catchment flood hydrograph to the peak of the coastal storm tide hydrograph should be tested where the estuary has a reasonable volume (for example, Type B medium sized ICEs with a tidal prism of 1.5-10 x 10^6 m^3 as described in McSweeney et al, 2017) and the time of concentration of the catchment flooding is greater than 6 hours. Suggested sensitivity testing includes:

- If catchment time of concentration to the entrance is moderate (6–24 hours):
  - Dynamic coastal boundary water level but with the peak of the catchment flow offset by +/-3 hours of the peak of the coastal boundary level time series at the location of interest to test sensitivity.

- If catchment time of concentration is long (24 hours or longer):

- Dynamic coastal boundary water level but with the peak of the catchment flow offset by +/-6 hours of the peak of the coastal boundary level time series at the location of interest to test sensitivity.

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Appendix A - Estuaries of Victoria

The following table provides a summary of the classifications of 110 estuaries across Victoria developed by McSweeney et al (2017).

Estuary class is defined as follows:

- 1 = ICE Type A
- 2 = ICE Type B
- 3 = ICE Type C
- 4 = PO, permanently open
- 5 = PC, permanently closed

#	lat	long	Name	CMA region	Class	Entrance
1	-38.061	140.984	Glenelg River	GHCMA	1	ICE
2	-38.2231	141.2997	Swan Lake	GHCMA	2	ICE
3	-38.26	141.704	Surrey River	GHCMA	2	ICE
4	-38.263	141.85	Fitzroy River	GHCMA	2	ICE
5	-38.2711	141.9046		GHCMA	3	ICE
6	-38.337	142.053	Lake Yambuk	GHCMA	1	ICE
7	-38.39	142.2458	Moyne River	GHCMA	4	PO
8	-38.347	142.371	Merri River I	GHCMA	2	ICE
9	-38.4031	142.4727	Merri River II	GHCMA	2	ICE
10	-38.399	142.509	Hopkins River	GHCMA	2	ICE
11	-38.495	142.685	Buckley Creek	CCMA	3	ICE
12	-38.608	142.883	Curdies River	CCMA	1	ICE
13	-38.618	142.992	Port Campbell Crk	CCMA	3	ICE
14	-38.644	143.057	Sherbrook River	CCMA	2	ICE
15	-38.707	143.157	Gellibrand River	CCMA	2	ICE
16	-38.763	143.38	Johanna River	CCMA	2	ICE
17	-38.807	143.461	Aire River	CCMA	2	ICE
18	-38.845	143.561	Parker River	CCMA	3	ICE
19	-38.794	143.619	Elliot River	CCMA	3	ICE
20	-38.766	143.668	Barham River	CCMA	2	ICE
21	-38.7358	143.6837	Wild Dog Crk	CCMA	3	ICE
22	-38.725	143.712	Skenes Crk	CCMA	3	ICE
23	-38.7171	143.7294	Petticoat Crk	CCMA	3	ICE
24	-38.7146	143.7389	Brown Crk	CCMA	3	IOCE
25	-38.704	143.763	Smythe Crk	CCMA	3	ICE
26	-38.6969	143.7967	Sugarloaf Crk	CCMA	3	ICE
27	-38.692	143.81	Carisbrook Crk	CCMA	3	ICE
28	-38.6824	143.8392	Grey River	CCMA	3	ICE
29	-38.667	143.862	Kennet River	CCMA	3	ICE
30	-38.635	143.891	Wye River	CCMA	3	ICE

#	lat	long	Name	CMA region	Class	Entrance
31	-38.631	143.8981	Seperation Crk	CCMA	3	ICE
32	-38.596	143.919	Jaimeson Crk	CCMA	3	ICE
33	-38.576	143.948	Cumberland River	CCMA	3	ICE
34	-38.5668	143.9664	Sheoak Crk	CCMA	3	ICE
35	-38.555	143.977	St George River	CCMA	3	ICE
36	-38.532	143.979	Erskine River	CCMA	2	ICE
37	-38.5114	143.9985	Reedy Crk	CCMA	3	IOCE
38	-38.484	144.031	Grassy Crk	CCMA	3	ICE
39	-38.4755	144.0362	Spout Crk	CCMA	3	ICE
40	-38.4717	144.0466	Coalmine Crk	CCMA	3	ICE
41	-38.468	144.066	Moggs Crk	CCMA	3	ICE
42	-38.4687	144.101	Paincalak Crk	CCMA	2	ICE
43	-38.413	144.191	Angelsea River	CCMA	2	ICE
44	-38.3432	144.3183	Spring Crk	CCMA	2	ICE
45	-38.3233	144.3323	Deep Crk	CCMA	2	ICE
46	-38.305	144.377	Thompson Crk	CCMA	2	ICE
47	-38.2848	144.4966	Barwon River	CCMA	4	PO
48	-38.4896	144.914	Main Creek	Melbourne Water	2	ICE
49	-38.264	145.015	Balcombe Crk	Melbourne Water	2	ICE
50	-38.457	145.194	Saltwater Creek	Melbourne Water	2	ICE
51	-37.9736	144.6846	Werribee River	Melbourne Water	4	PO
52	-38	144.5897	Little River	Melbourne Water	4	PO
53	-38.0745	144.4048	Hovell's Creek	Melbourne Water	4	PO
54	-38.1558	144.5489	Grigg's Creek	Melbourne Water	4	PO
55	-37.8989	144.7997	Skeleton Creek	Melbourne Water	4	PO
56	-37.8807	144.8079	Laverton Creek	Melbourne Water	4	PO
57	-37.8441	144.8994	Yarra River	Melbourne Water	4	PO
58	-38.0103	145.0851	Mordialloc Creek	Melbourne Water	4	PO
59	-38.0728	145.1216	Patterson River	Melbourne Water	4	PO
60	-38.1627	145.098	Kackeraboite Creek	Melbourne Water	2	IOCE
61	-38.1718	145.0833	Ballar Creek	Melbourne Water	2	IOCE
62	-38.1778	145.0773	Earimil Creek	Melbourne Water	2	IOCE
63	-38.3187	144.9866	Dunns Creek	Melbourne Water	2	IOCE
64	-38.392	145.148	Merricks Crk	Melbourne Water	2	ICE
65	-38.4341	145.0474	Stony Creek	Melbourne Water	4	PO
66	-38.216	145.3224	Rutherford Creek	Melbourne Water	4	PO
67	-38.2141	145.3774	Sawtell's Inlet	Melbourne Water	4	PO
68	-38.2186	145.4529	Bunyip River	Melbourne Water	4	PO
69	-38.4953	145.4344	Bass River	Melbourne Water	4	PO
70	-38.555	145.482	Bourne Creek	WGCMA	3	ICE
71	-38.583	145.511	Powlett River	WGCMA	2	ICE
72	-38.6597	145.5811	Coal Creek	WGCMA	2	ICE
73	-38.6472	145.6974	Wreck Creek	WGCMA	3	ICE

#	lat	long	Name	CMA region	Class	Entrance
74	-38.6461	145.7267	Andersons Inlet	WGCMA	4	PO
75	-38.8627	146.1826	Shallow Inlet	WGCMA	4	PO
76	-38.9717	146.2698	Darby River	WGCMA	3	ICE
77	-39.035	146.31	Tidal River	WGCMA	3	ICE
78	-39.071	146.343	Fraser Creek	WGCMA	3	ICE
79	-39.06	146.345	Growler Creek	WGCMA	3	ICE
80	-39.0707	146.4269	Freshwater Creek	WGCMA	3	ICE
81	-39.0369	146.4604	Hobbs Creek	WGCMA	3	ICE
82	-38.9749	146.4365	5 Mile Creek	WGCMA	3	ICE
83	-39.021	146.442	Sealers Creek	WGCMA	3	ICE
84	-38.9164	146.4742	Miranda Creek	WGCMA	3	ICE
85	-39.042	146.465	Cove Creek	WGCMA	3	ICE
86	-38.915	146.474	Chinaman Creek	WGCMA	3	ICE
87	-38.891	146.481	Johnny Souey Cove	WGCMA	3	ICE
88	-38.4971	147.0403	Jack Smith Lake	WGCMA	5	PC
89	-38.3815	147.1833	Merriman Creek	WGCMA	2	ICE
90	-37.953	147.6593	Tom Roberts Creek	WGCMA	2	ICE
91	-37.89	147.9722	Lakes Entrance	EGCMA	4	PO
92	-37.866	148.045	Lake Bunga	EGCMA	1	ICE
93	-37.843	148.115	Lake Tyers	EGCMA	1	ICE
94	-37.805	148.557	Snowy River	EGCMA	1	ICE
95	-37.791	148.775	Yeerung River	EGCMA	2	ICE
96	-37.783	148.839	Dock Inlet	EGCMA	5	PC
97	-37.781	149.017	Sydenham Inlet	EGCMA	1	ICE
98	-37.779	149.148	Tamboon Inlet	EGCMA	1	IOCE
99	-37.784	149.311	Thurra River	EGCMA	2	ICE
100	-37.781	149.326	Mueller River	EGCMA	2	ICE
101	-37.749	149.513	Wingan Inlet	EGCMA	4	PO
102	-37.741	149.522	Easby Creek	EGCMA	1	ICE
103	-37.727	149.563	Red River	EGCMA	2	ICE
104	-37.7	149.622	Benedore River	EGCMA	2	ICE
105	-37.664	149.681	Seal Creek	EGCMA	3	ICE
106	-37.649	149.699	Shipwreck Creek	EGCMA	2	ICE
107	-37.585	149.742	Betka River	EGCMA	2	ICE
108	-37.577	149.75	Davis Creek	EGCMA	3	ICE
109	-37.569	149.763	Mallacoota Inlet	EGCMA	1	ICE
110	-37.5195	149.9327	Lake Wau Wauka	EGCMA	2	ICE