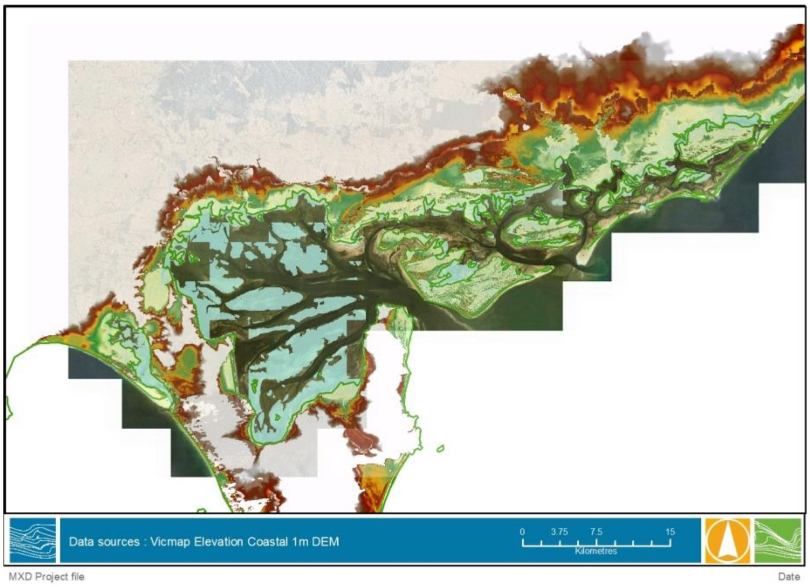
Corner Inlet Dynamic Storm Tide Modelling Assessment



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GLOSSARY

Australian Height Datum (AHD)	A common national plane of level corresponding approximately to mean sea level
ARI	Average Recurrence Interval
AEP	Annual Exceedance Probability: The measure of the likelihood (expressed as a probability) of an event equalling or exceeding a given magnitude in any given year
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
Calibration	The process by which the results of a computer model are brought to agreement with observed data
Exceedance Probability	The probability of an extreme event occurring at least once during a prescribed period of assessment is given by the exceedance probability. The probability of a 1 in 100 year event (1% AEP) occurring during the first 25 years is 22%, during the first 50 years the probability is 39% and over a 100 year asset life the probability is 63%
Geomorphology	The study of the origin, characteristics and development of land forms
Holocene	The period beginning approximately 12,000 years ago. It is characterised by warming of the climate following the last glacial period and rapid increase in global sea levels to approximately present day levels
HAT	Highest Astronomical Tide: the highest water level that can occur due to the effects of the astronomical tide in isolation from meteorological effects
MHHW	Mean Higher High Water: the mean of the higher of the two daily high waters over a long period of time. When only one high water occurs on a day this is taken as the higher high water
Intertidal	Pertaining to those areas of land covered by water at high tide, but exposed at low tide, eg. intertidal habitat
Inverse Barometric Pressure Effect	The inverse response of sea level to changes in atmospheric pressure
LiDAR	**Li**ght **D**etection **a**nd **R**anging – also known as airborne laser scanning, is a remote sensing tool that is used to generate highly accurate 3D maps of the Earth's surface
Littoral Zone	An area of the coastline in which sediment movement by wave, current and wind action is prevalent
MSL	Mean Sea Level
Neap Tides	Neap tides occur when the sun and moon lie at right angles relative to the earth (the gravitational effects of the moon and sun act in opposition on the ocean)
Pleistocene	The period from 2.5M to 12,000 years before present that spans the earth's recent period of repeated glaciations and large fluctuations in global sea levels
Semi-diurnal	A twice-daily variation, e.g. two high waters per day
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
Storm tide	Coastal water level produced by the combination of astronomical and meteorological (storm surge) ocean water level forcing
Tidal Constituent	A harmonic element in a mathematical expression which represents a tidal signal. The tidal signal at a specified location can be described as a combination of tidal constituents, each of which have a characteristic amplitude (height) and phase (relative timing of the high and low tide)
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 Range	The difference between successive high water and low water levels. Tidal range is maximum during Spring Tides and minimum during Neap Tides
Tides	The regular rise and fall in sea level in response to the gravitational attraction of the Sun, Moon and Earth
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
Wave Setup	In shallow waters, the dynamics of waves in shallow depths including wave breaking process can result in an additional setup of water levels shoreward of the surf zone due to balance of the wave-induced shoreward momentum fluxes
Wind Setup	The action of wind on the water surface creates shear stresses that can drag water in the downwind direction. In shallow depths and/or intertidal areas, the rate at which water is transported downwind exceeds the rate at which it can return under gravity and an elevation of water levels is observed at the downwind location

1. INTRODUCTION

Water Technology has been engaged by the West Gippsland Catchment Management Authority (WGCMA) to undertake dynamic modelling of storm tide and sea level rise in Corner Inlet and the Nooramunga Marine Park. The wording 'Corner Inlet' is used throughout this document to collectively refer to the whole of Corner Inlet and Nooramunga Marine Park embayment combined.

The main advantage of dynamic storm surge and storm tide hydrodynamic modelling over previous bathtub type coastal inundation modelling is that it allows the time limiting characteristics of the tide and surge to be resolved, and therefore, provides a more realistic representation of inundation extents.

1.1 Project Scope and Objectives

The aim of this project is to assess and quantify the effects of tidal dynamics on potential inundation extents associated with a 1% Annual Exceedance Probability (AEP) storm tide, under existing mean sea level, and for a predicted future +0.82 m of sea level rise.

The principal objectives of the project were the following:

- Identify whether differences in coastal inundation extents exist between previous bathtub type storm tide inundation as modelled in the Victorian Coastal LiDAR Inundation Modelling and Mapping (2012) project and the dynamically modelled storm tide inundation from this study; and
- Where areas of significant difference exist, particularly around townships, quantify and map the differences.

To achieve these objectives a detailed hydrodynamic model of Corner Inlet was developed, calibrated and used to simulate storm tide and future sea level rise conditions. The results of the modelling were then compared to the Victorian Coastal LiDAR Modelling and Mapping (2012) inundation extents.

2. REVIEW OF STORM TIDE PROCESSES IN CORNER INLET

2.1 Overview

Figure 2-1 depicts the key physical processes which interact and combine to produce extreme elevated water levels, known as storm tides.

The following section provides an overview of the physical processes influencing water levels within Corner Inlet and the coastal geomorphology, including man-made landscape features, which affect the extents of coastal inundation under extreme water level conditions.

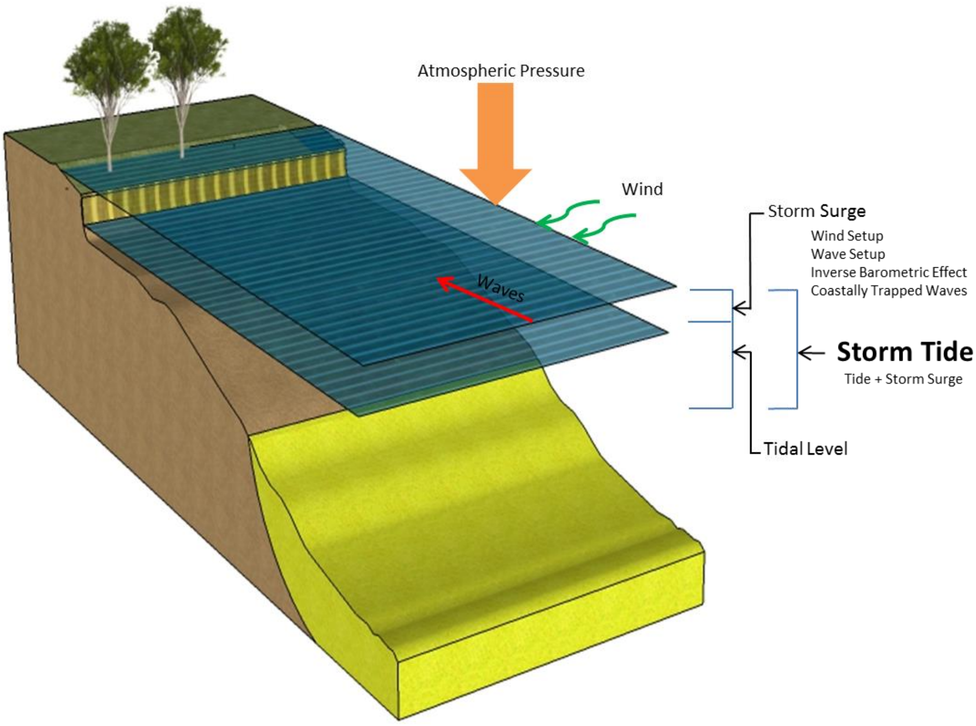

Figure 2-1 Schematic Showing Key Storm Surge and Storm Tide Components

2.2 Astronomical Tides

The astronomical tide is the primary process influencing water levels within Corner Inlet. Astronomical tides are caused by the gravitational attraction of the sun and the moon on the ocean surface. In Corner Inlet, the astronomical tides are semi-diurnal (twice daily). Table 2-1 provides a list of key representative tidal levels at Port Welshpool.

Table 2-1 Tidal Plane Levels for Port Welshpool (DoD, 2013)

Tidal Plane	Tidal Level (m MSL)
Highest Astronomical Tide (HAT)	1.3
Mean High Water Spring (MHWS)	0.9
Mean High Water Neap (MHWN)	0.6
Mean Sea Level (MSL)	0
Mean Low Water Neap (MLWN)	-0.6
Mean Low Water Spring (MLWS)	-1
Lowest Astronomical Tide (LAT)	-1.6

Figure 2-2 displays an example of a predicted astronomical tide time series for five locations across Corner Inlet, derived from 2-4 months of measured tide data (described further in Section 4.2). The tidal range in Corner Inlet decreases from west to east, with the tidal range at McLoughlins Beach almost half that of Port Franklin during spring tidal conditions.

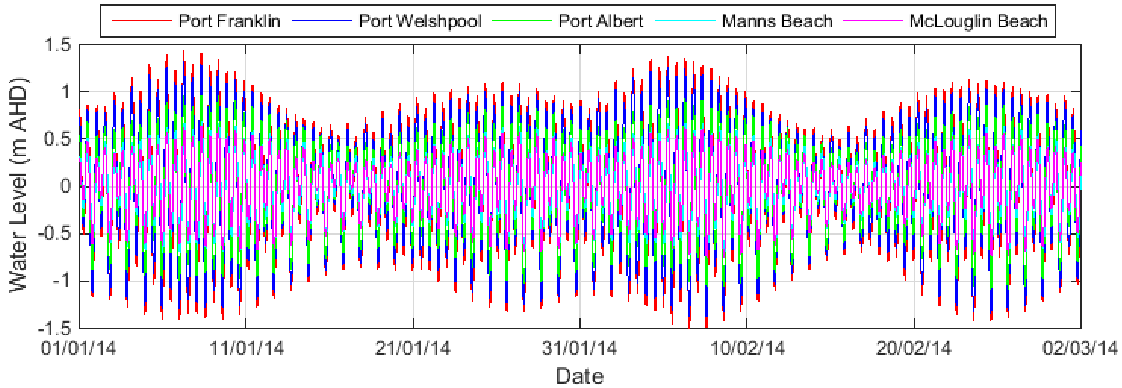

Figure 2-2 Comparisons of Astronomical Tides at Five Locations throughout Corner Inlet, Based on the 7 Largest Tidal Constituents.

2.3 Storm Surge Components

Storm tides in Corner Inlet are a function of a number of different physical pressures and processes, including coastally driven water levels (inverse barometric pressure effects and coastally trapped waves), wind and wave set-up, wave run-up and the astronomical tide.

2.3.1 Coastally Driven Water Levels

Coastally driven water levels in Corner Inlet are the result of the effects of changes in barometric pressure and the generation of coastally trapped waves, in addition to the astronomical tide. These conditions dominate the offshore environment.

During the passage of low pressure systems (storms), the inverse barometric pressure effect results in uplift in the ocean surface, while the interaction of weather systems and coastal waters generate coastally trapped waves along the southern margin of the continental Australian landmass.

The matter is further complicated as there are three main types of storms contributing to surges in the area:

- Frontal Systems: with predominantly west-southwest winds. These generate the highest surges immediately offshore from Corner Inlet.
- Tasman Lows: with predominantly south- southwest winds. These occur less frequently than frontal systems (23% vs. 70%) and generate lower surges offshore (McInnes et al., 2005).
- East Coast Lows: with predominantly east-southeast winds. These occur less frequently (7%) and generate lower offshore surges than the Tasman Lows (McInnes et al., 2005).

2.3.2 Local Wind

Wind effects contribute to storm surge through the conditions associated with coastally driven water levels, described above, and due to local wind shear effects.

The action of local wind on the water surface creates shear stresses that can drag water in the downwind direction. In shallow depths, such as the intertidal flats present throughout Corner Inlet, the rate at which water is transported downwind exceeds the rate at which it can return under gravity, and an increased elevation of water levels is observed at downwind locations. The local wind effects of the three main types of storms described above can generally be described as follows:

- Frontal Systems: with predominantly west-southwest winds. These will create higher storm surge levels in the east and lower levels in the west of Corner Inlet
- Tasman Lows: with predominantly south- southwest winds. These would be expected to generate higher surge levels in the northeast and lower surges in the southwest of Corner Inlet.
- East Coast Lows: with predominantly east-southeast winds. These can generate higher storm surges locally in the west and northwest part of the inlet.

2.3.3 Waves

The action of wind on the water surface also generates waves which propagate in the downwind direction. Along a shoreline, the dynamics of waves in shallow water depths, including wave breaking process, can result in further increases in water levels shoreward of the surf zone, due to processes known as wave set-up and wave run-up.

Wave set-up and wave run-up are unlikely to have a major impact on storm surge levels in Corner Inlet. This is because most of the coastline of interest is located behind a barrier island system (e.g. Snake Island and Clonmel Island), and therefore, is not directly exposed to large wave heights. Although, there may be substantial wave set-up on the seaward faces of Wilsons Promontory and the barrier islands, wave heights and hence wave set-up and wave run-up within Corner Inlet is likely to be much lower. In addition, there are numerous relatively deep channels close to the coast within the inlet which provide for return flows, which prevent the build-up of significant wave set-up. Waves are considered to contribute to only a minimal component of the total storm tide level.

2.4 Storm Tide Levels in Corner Inlet

As discussed, storm tide levels consist of the combination of astronomical tide and storm surge. The average recurrence interval of extreme storm surges and storm tide (astronomical tide plus storm surge) has previously been estimated for the Victorian coastline by the CSIRO (McInnes, 2009), and are displayed in Table 2-2. The tight distribution of storm tide levels is a characteristic of storm surges and is an important consideration when evaluating the inundation vulnerability, as relatively small changes in storm tide elevation can result in large changes in exceedance probabilities.

Table 2-2 Estimated Storm Tide Height Return Periods for Port Welshpool (McInnes, 2009)

Annual Exceedance Probability (Return Period)	Storm Tide Elevation (m AHD)
10% (10 years)	1.35
5% (20 years)	1.46
2% (50 years)	1.57
1% (100 years)	1.63

2.5 Coastal Landscape

2.5.1 Geomorphology

The mainland shorelines of Corner Inlet and the Nooramunga Marine Park are typically backed by a relatively flat depositional terrace of varying width, which formed during a phase of higher mean sea level during the Holocene (Bird, 1993). Elevations of the depositional terrace typically range between 1.0 and 1.7 m AHD (the pale green colours in Figure 2-3).

Behind the Holocene depositional terrace is the relatively steeply rising bluff, where elevations quickly rise to 3-5 m or more above AHD (red/brown to white colors in Figure 2-3). This bluff represents the coastline during the period of higher mean sea levels in the Holocene (Bird, 1993). The elevation and width of the depositional terrace, coastal levee structures (described in the following section), cliffed shorelines and bluffs are further illustrated as a series of representative cross-sections in Figure 2-4. The locations of the cross-sections are illustrated in Figure 2-3.

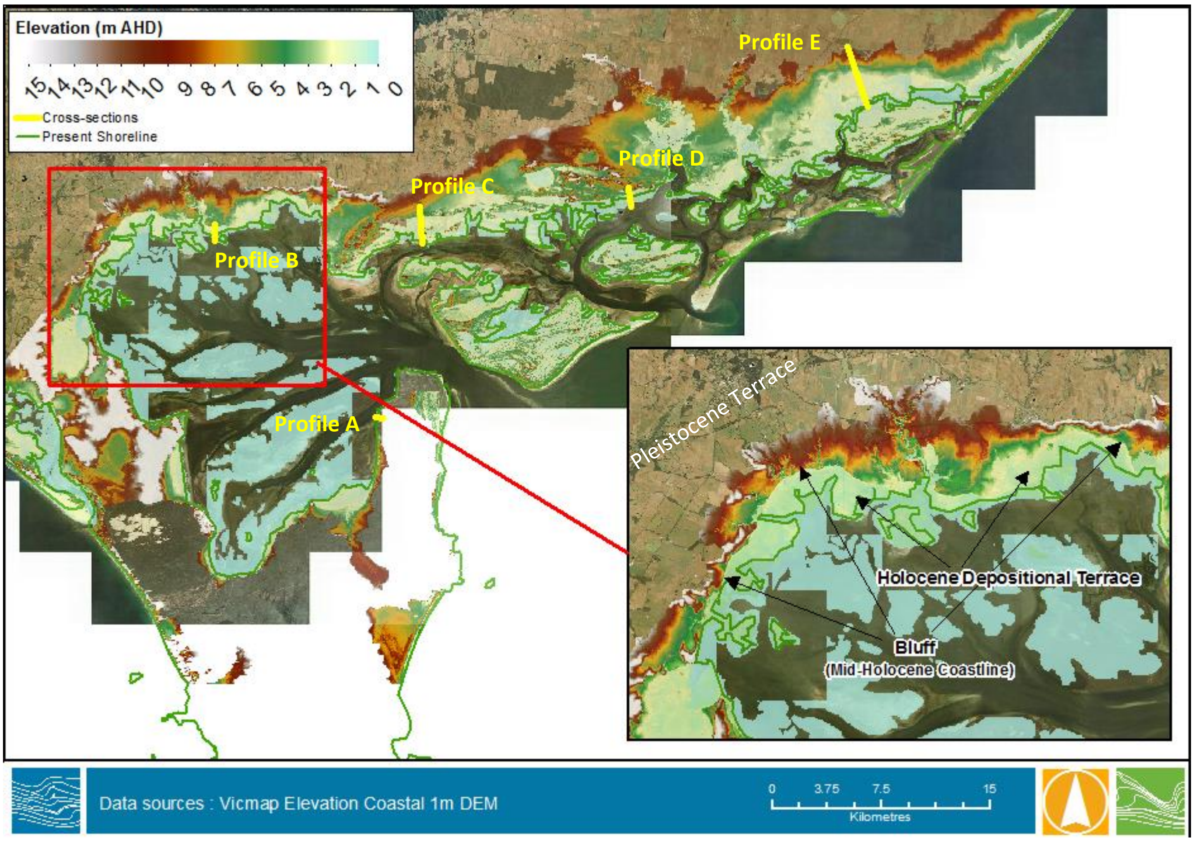

Figure 2-3 Corner Inlet Elevations and Geomorphologic Features

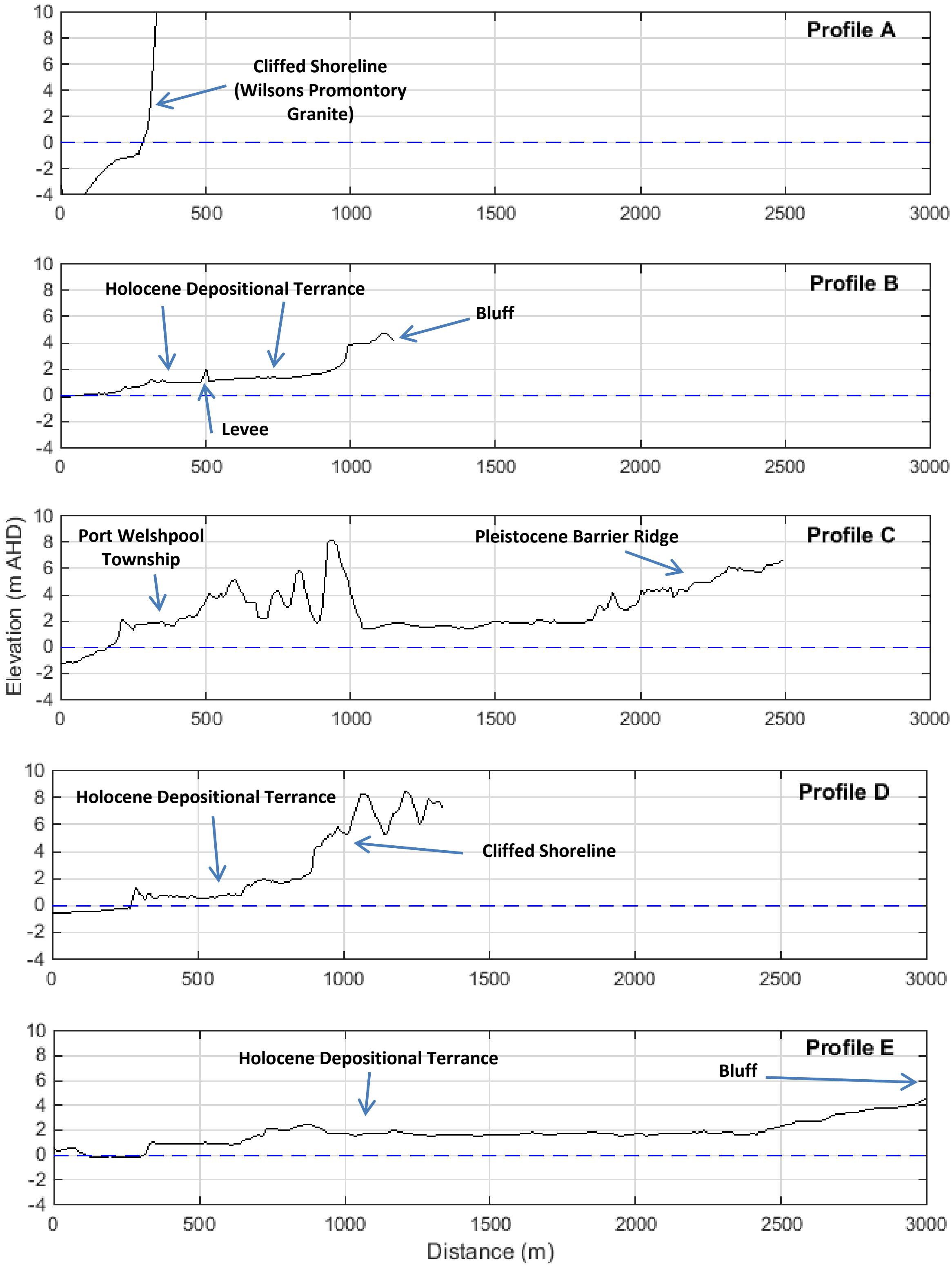

Figure 2-4 **Topographic Cross-sections Illustrating the Key Geomorphic Features of the Backshore Landscape around Corner Inlet**

2.5.2 Coastal Levees

There is an extensive network of coastal levee banks which line large sections of the northern shorelines of Corner Inlet, as shown in Figure 2-5, spanning approximately 50km of shoreline.

The coastal levees (also often referred to as seawalls) west of Toora were originally built by local farmers between 1910 and 1940, to prevent tidal inundation of low lying farm land. Following their construction, these levees were not formally maintained. The Drainage Areas Act was introduced in 1958, and after 1964 all of the coastal levees were re-built, and have since been maintained through local landowner and State Government funding (Geoffrey Davis, pers. comm., 08/05/2014 & Harle, 2012).

Little information is available on the development or condition of coastal levees east of Toora, although the CSIRO Corner Inlet Environmental Audit report (Molloy et al., 2005) describes the levees within the Port Albert Salinity Management Area, which stretches from Toora to Seaspray, as being constructed in the late 19th Century and currently in various states of disrepair.

The LiDAR data analysis shows that the crest height along the majority of the levee banks typically ranges between approximately 1.6 and 2.6m AHD (Figure 2-6). This crest height is sufficient to provide protection against the 1% AEP storm tide under existing mean sea level (1.63 m AHD at Port Welshpool, McInnes, 2009). However, there are a number of breaks and low points in the levees (Figure 2-5, inset map), which are below the 1% AEP storm tide level under existing mean sea level conditions. This limits the structures' ability to fully protect the backshore areas against extreme storm tide inundation.

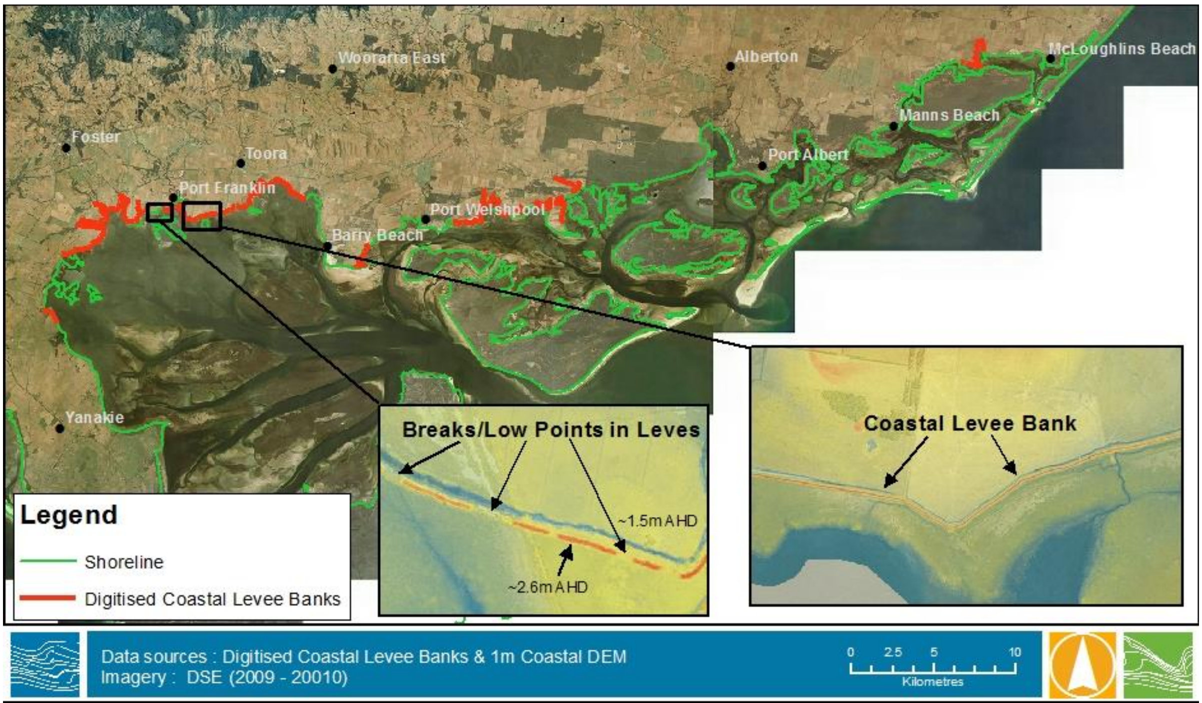

Figure 2-5 Coastal Levee Banks along the Shoreline of Corner Inlet

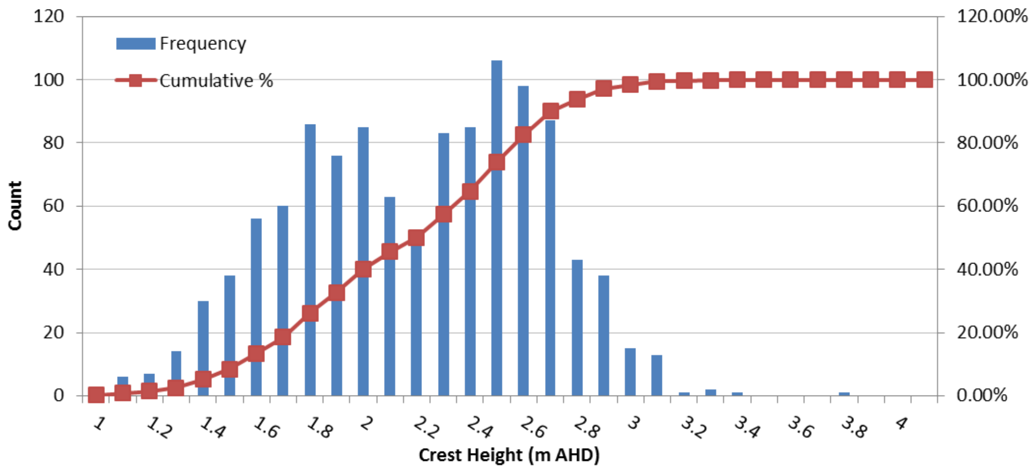

Figure 2-6 **Histogram of Coastal Levee Crest Heights based on 50m Interval Point Samples of the Digitised Levees shown in Figure 3-3 and the 1m Coastal LiDAR DEM**

3. INUNDATION MODELLING APPROACHES

3.1 Bathtub Modelling

In 2009 the University of Tasmania (UTAS) was engaged by the Victorian Department of Sustainability and Environment (now known as the Department of Environment and Primary Industries, DEPI) to model coastal inundation due to storm tides and predicted sea level rise for Victoria.

The modelling technique employed for the Victorian Coastal LiDAR Inundation Modelling and Mapping project is known as bath tub modelling. Bath tub modelling is a relatively simple technique, which only requires two input datasets; a Digital Elevation Model (DEM), and a single water surface elevation level. The water surface elevation level is intersected with the DEM, and all elevations below the specified water surface elevation are considered to be areas where potential inundation could occur. Advantages of the bathtub modelling technique include its low computational requirements and that it requires no additional parameterisation of inputs or processes, which can often be difficult to define in large scale models (Water Technology, 2012). However, one disadvantage of bathtub inundation modelling of storm tides is that it only considers the peak storm tide elevation, and does not take into account the tidal dynamics and time varying aspect of a storm tide as observed in the real world.

The time varying aspect of a storm tide means that the peak water level only lasts for a limited period of time, typically around 20-60 minutes. Over relatively flat, low sloped backshore areas, this duration is not always long enough for the peak water level to propagate inland until it intersects higher topography. Therefore, bathtub storm tide inundation modelling can often over predict inundation extents when viewing the results at a local scale.

The purpose of this current assessment is to assess and quantify any over predictions in inundation extents around Corner Inlet associated with the existing bathtub modelling based on a dynamic storm tide model, which are described further below.

3.2 Dynamic Inundation Modelling

Dynamic inundation modelling involves the simulation of the dynamic physical processes and subsequent motion of water which contribute to inundation. This is achieved through the use of a hydrodynamic model which solves a set of mathematical equations which describe the motion of fluids (water in this case), known as the Navier-Stokes equations.

The two main advantages of dynamic inundation modelling over bathtub inundation modelling are that it preserves the hydrodynamic principles of mass conservation and flow connectivity.

The bathtub model is a static model, and is based on the assumption that the topography below the input water level is inundated instantaneously, which effectively means the storm tide has an infinite volume. However, as noted in the previous section, in reality a storm tide maintains its peak water level for only a relatively short time in comparison to the entire storm surge duration, and has a limited inundation volume. This duration and volume may not always be sufficient to entirely inundate all of the topography below the peak water level. A dynamic hydrodynamic model is able to simulate the temporally varying characteristics of a storm tide and to accurately determine the total volume of water available for inundation (mass conservation).

A dynamic inundation model is able to distinguish between areas that are, and are not, hydraulically connected (flow connectivity), and therefore can accurately model where, and where not water can flow between. In contrast, bathtub modelling assumes that water can flow between all areas below the input elevation. Therefore subjective interpretation is often required during post processing to remove isolated inundated areas.

4. DYNAMIC INUNDATION MODELLING

4.1 Model Development

The Danish Hydraulic Institute's (DHI) MIKE21 Flexible Mesh (FM) hydrodynamic model was used to dynamically model the extent of storm tide inundation across the study area. The following sections describe the development and calibration of this model.

4.1.1 Model Layout

The MIKE 21 FM hydrodynamic model is based upon an unstructured mesh, which comprises of triangular or triangular and rectangular elements of varying size. This allows high resolution elements to be applied over areas of interest or complex bathymetry, and large elements to be applied away from the areas of interest, thus optimizing the computational time required.

For this study, the model domain and mesh layout of the Corner Inlet model is shown in Figure 4-1. The model domain encases all of Corner Inlet and the surrounding low lying areas up to approximately 4.0 m AHD. The southern and eastern extents of the model are open model boundaries which extend out to approximately 25 km offshore, in water depths ranging between 30 and 50 m.

The model mesh consists of both triangular and quadrilateral elements, with lengths ranging in the order of 1-2 km offshore outside of Corner Inlet, to approximately 20 m and 30 m in the small tidal channels and low lying land surrounding the major townships neighbouring Corner Inlet respectively.

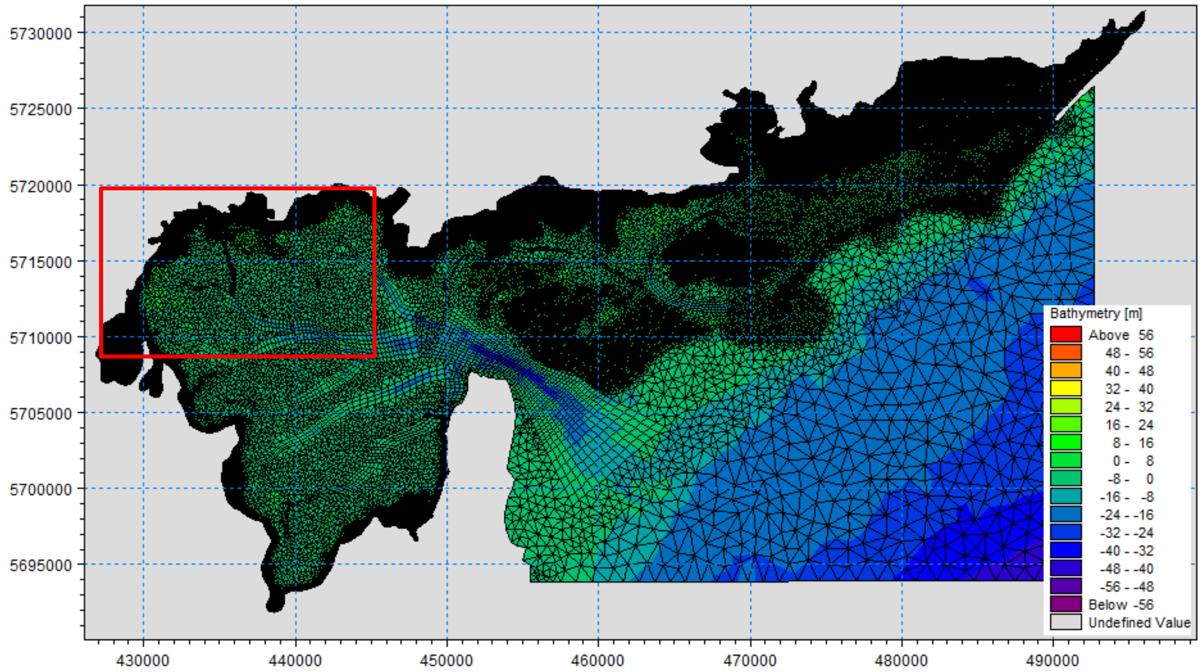

Figure 4-1 **Hydrodynamic Model Domain and Bathymetric Mesh (Close up of the highlighted area shown below)**

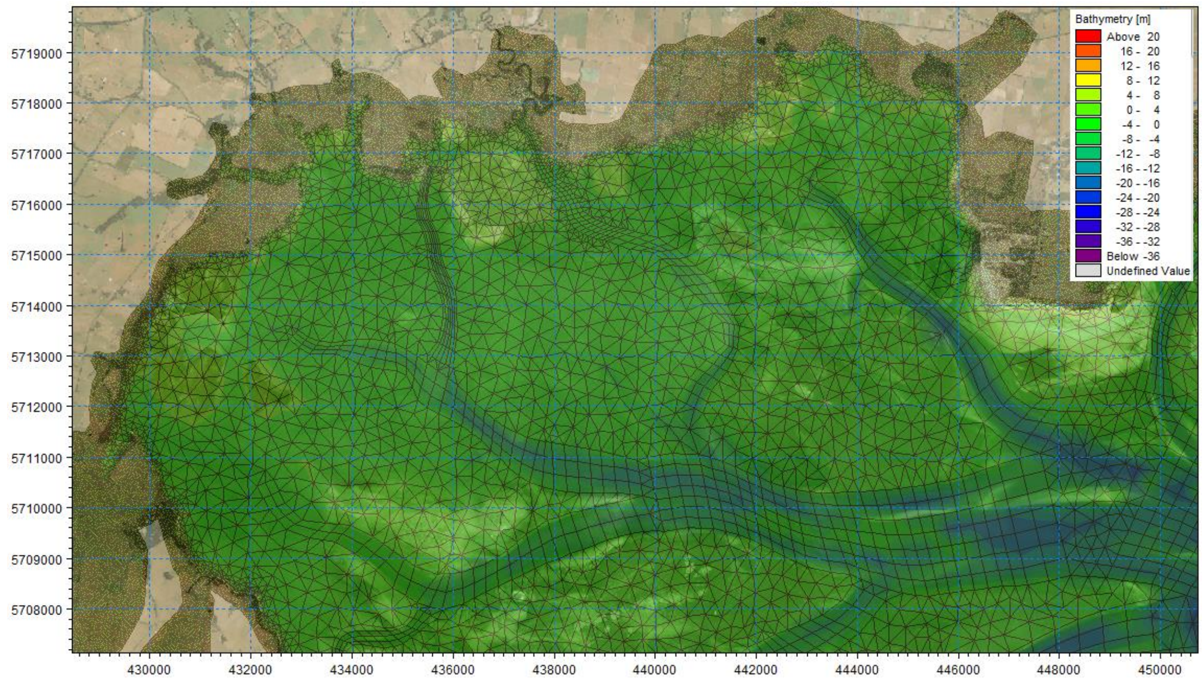

Figure 4-2 **Close up of Bathymetric Mesh for the Area Highlighted in Figure 3-1**

The coastal levee banks were incorporated into the hydrodynamic model as MIKE 21FM Dikes structures. The crest heights of the levees were sampled from the 1m Coastal DEM at a 50 m interval and specified in the dike structure model setup.

4.1.2 Topographic and Bathymetric Datasets

Topographic and bathymetric data were interpolated onto the model mesh using a nearest neighbour technique, with a priority routine applied to ensure the highest resolution or most recently available data was applied where appropriate. A range of available bathymetric and topographic data sets were used, and their source and coverage are listed below:

- **Terrestrial LiDAR** (*VicMap Elevation Coastal 1m DEM* : DSE, Sep 2007 – Sep 2009)
    - Almost entire coverage between +4m AHD and approximately -0.25m AHD
- **Bathymetric LiDAR** (*Victorian Bathymetric 2.5 DEM 4.0 Release* : DSE, Sep 2007 – Sep 2009)
    - Almost entire coverage below approximately 0.25m AHD, with the exception of some of the deeper tidal channels, between Bennison Channel and Millers Landing, and north of Saint Margaret Island
- **Bathymetric Multibeam Survey** (*Various multibeam surveys* : Gippsland Ports, 2000–2008)
    - West Channel to Barry Beach
    - East Channel to Barry Beach
    - Inlet Channel from Bass Strait to Port Welshpool
    - Toora Channel near Toora Beach
    - Channel between Little Snake Island and La Trobe Island
    - McMillan Bay leading up to Alberton
    - McLoughlin's Beach through the Saint Margaret channel
- **20m Offshore Bathymetry Data** (*Victorian Coastal Nearshore Bathymetry 20m Resolution DEM* : DSE, March 2012)
    - Outside of Corner Inlet, to depths of approximately -15 to -20m AHD
- **9s Coastal DEM** (*Australian Bathymetry and Topography Grid* : Geosciences Australia, 2005)
    - All deep water areas offshore of Corner Inlet

4.1.3 Astronomical Tidal Boundary Conditions

Open tidal boundaries were defined along the southern and eastern offshore extents of the model. The astronomical tidal components of the offshore open boundaries were derived from an existing calibrated fixed grid model of Corner Inlet previously developed by Water Technology (Water Technology, 2008), and included the 7 largest tidal constituents.

The southern boundary condition consisted of a uniformly varying water level along the entire southern ocean boundary, which was derived from the tidal constituents for Rabbit Island as listed in the Australian National Tide Tables (DoD, 2006).

The eastern offshore tidal boundary was forced using a spatially varying water level boundary in order to account for the general trend of decreasing constituent amplitude in the northward direction, towards McLoughlins Beach. The optimum tidal constituents used to derive this spatially varying water level boundary were from Water Technology (2008).

4.2 Model Calibration

Five water level tide gauges were deployed in Corner Inlet by Water Technology, and Jon Hinwood in 2008, for the Corner Inlet Sediment and Nutrient Modelling Project (Water Technology, 2008) and a parallel study looking at sedimentation in Corner Inlet. Two to four months of measured water level data was successfully obtained from the five tide gauges. The locations of the five tide gauges are shown in Figure 4-3.

The astronomical tidal component of the hydrodynamics was calibrated by applying the astronomical tidal water levels along the offshore boundaries. Modelled water levels were then compared against predicted astronomical tidal time series derived from four gauged water level datasets and the Australian National Tide Tables (Port Welshpool only).

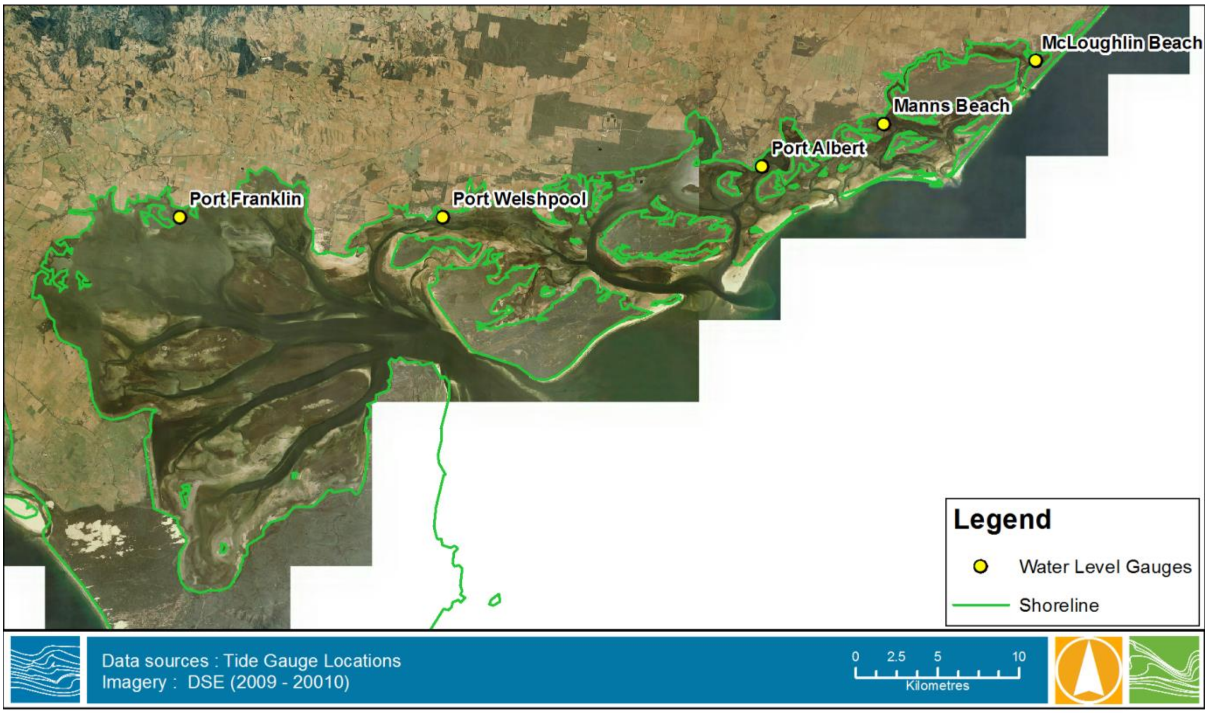

Figure 4-3 2008 Tide Gauge Deployment Locations

The results of the astronomical tidal water level calibration are presented in Figure 4-4 as a series of water level time series plots, and scatter plots comparing predicted versus modelled water levels.

Three of the five (Port Franklin, Port Welshpool and Port Albert) sites were shown to have a high level of correlation with R^2 (square of the correlation coefficient) values above 0.95. Although the remaining two sites, Manns Beach and McLoughlin's Beach, had R^2 values of 0.69 and 0.59 respectively, the model accurately simulated the peak tidal water levels at both sites.

The lower R^2 values at the last two sites is likely due to a change in morphology (width and/or depth) of the two small sandy entrances which feed the channels leading to Manns Beach and McLoughlins Beach between when the bathymetric data was collected and when the tidal gauges were deployed. The change in entrance morphology at these two sites resulted in a change in phase and amplitude of the main tidal constituents. These changes in tidal properties were partially accounted for by adjusting the offshore boundary conditions. However, the boundary conditions could not be modified further to account for these changes without compromising the level of calibration at the other three sites.

Given the high R^2 values at three of the five locations and good agreement in peak water levels at the remaining two locations, the hydrodynamic model is considered to be able to accurately simulate water levels throughout Corner Inlet for the purposes of dynamic storm tide modelling.

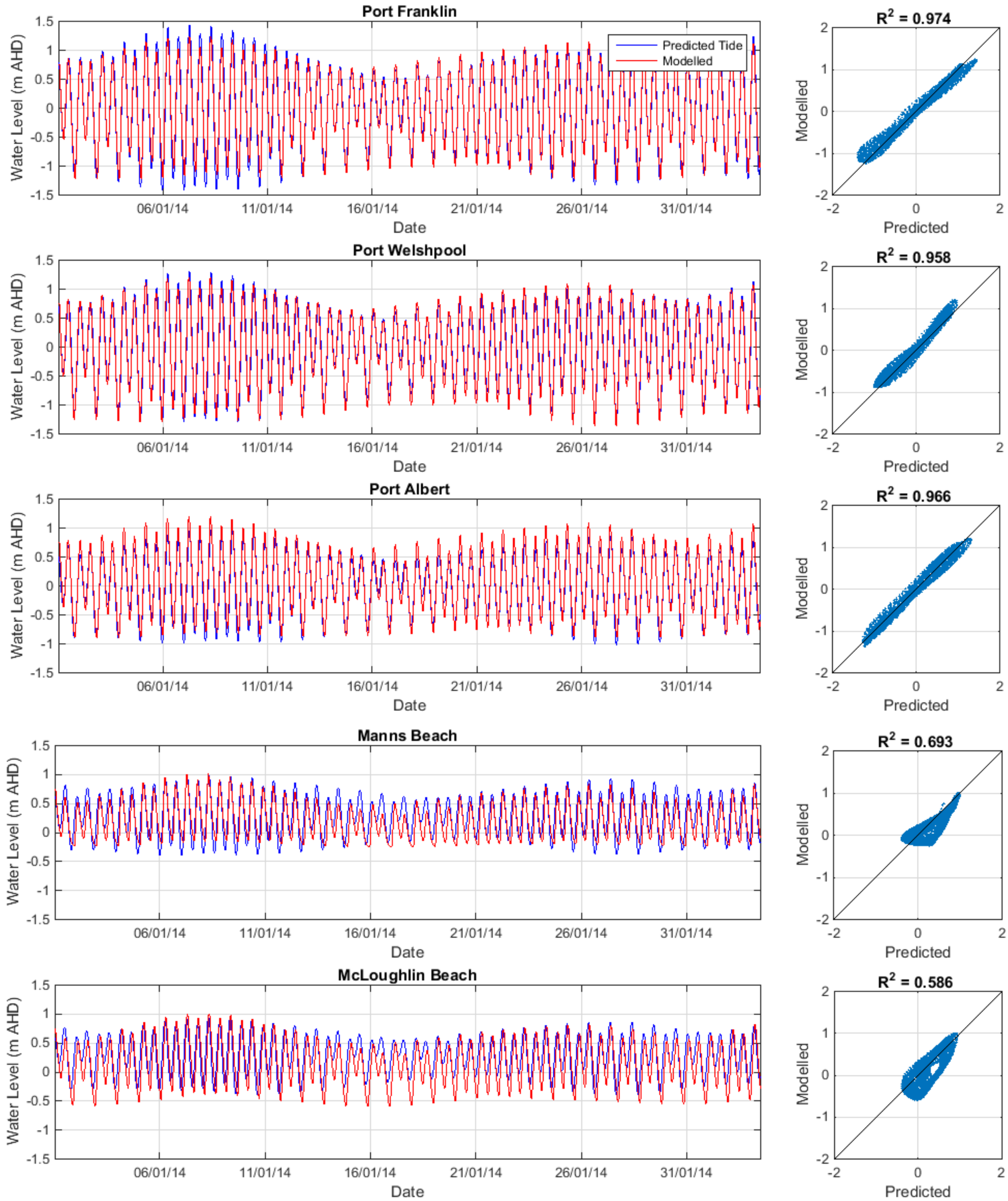

Figure 4-4 Astronomical Tidal Water Level Calibration

4.3 Storm Tide Scenarios

4.3.1 Overview

A series of storm tide scenarios have been undertaken to provide a comparison in coastal inundation extents around Corner Inlet with the previous bath-tub model derived extents.

Three storm tide scenarios have been adopted:

- Scenario 1- 1% AEP storm tide under existing mean sea level conditions,
- Scenario 2 - 1% AEP storm tide incorporating +0.82 m of sea level rise; and
- Scenario 3 - 1% AEP storm tide incorporating an increase in storm surge magnitude due to climate change and +0.82m of sea level rise.

1% AEP storm surge and storm tide heights at Port Welshpool under existing mean sea level conditions (0.72 m and 1.63 m AHD respectively), as determined by McInnes (2009), have been adopted as the basis for the scenario assessment.

Table 4-1 provides an overview of the three storm surge and sea level rise components, and how they combine to provide the 1% AEP storm tide scenarios at Port Welshpool.

Table 4-1 Sea Level Rise and Storm Tide (at Port Welshpool) Scenarios Adopted for this Project

Scenario	1% Storm Surge Magnitude (m)	Sea Level Rise (m AHD)	Total 1% AEP Storm Tide Level (m AHD)
Scenario 1	0.72	0	1.63
Scenario 2	0.72	0.82	2.45
Scenario 3	0.99*	0.82	2.68

* Present day 1% AEP storm surge magnitude incorporating a 19% increase in wind speeds due to climate change

Scenario 3 was developed to enable a direct comparison between the current model outputs and the Victorian LiDAR Inundation Modelling and Mapping project. A 1% AEP storm tide scenario incorporating +0.82 m sea level rise and a 19% increase in wind speed for 2100 was developed in McInnes et al. (2009) and subsequently used for the Victorian Coastal LiDAR Modelling and Mapping project, and therefore, also adopted for this project.

McInnes et al. (2005) concluded that there is a linear 2:1 relationship between increases in wind speed and storm surge heights in Bass Strait, with a 1% increase in wind speed resulting in approximately a 2% increase in storm surge height. Therefore, to incorporate a 19% increase in Bass Strait wind speeds into Scenario 3 the present day 1% AEP storm surge height was increased by 38%. Scenario 3 is therefore consistent with the scenario assessed in the Victorian LiDAR Inundation modelling project and originates from Scenario 2 – 2100 for Port Welshpool as listed in McInnes et al. (2009).

It should be noted that although the 1% AEP storm tide water levels for the Victorian Coastal LiDAR Inundation Modelling and Mapping were based on the results of McInnes et al. (2009). This modelling was undertaken at a 1 km resolution, supplemented by finer resolution data in Port Phillip Bay, Western Port Bay, Corner Inlet and the Gippsland Lakes region. However, although a level of 1.63 m AHD is given in McInnes et al. (2009) at Port Welshpool, a level closer to 1.8 m AHD was mapped at Port Welshpool in the Victorian Coastal LiDAR Modelling and Mapping assessment.

Based on discussions with CSIRO it is our understanding that the difference between the modelled results for Port Welshpool from McInnes et al (2009) and the final mapped outputs in the Victorian Coastal LiDAR Modelling and Mapping assessment arises from the following:

- For the Victorian Coastal LiDAR Modelling and Mapping assessment a series of points were specified along the coastline. This included points within Corner Inlet. The exact location of the data points used was not available for this assessment.
- Modelled storm tide information from McInnes et al. (2009) was then interpolated onto these points so that levels could be extracted.

- The interpolated data was then used for the mapping assessment.

Offshore Water Levels

The offshore (Bass Strait) water level is the primary driver of extreme elevated water levels within Corner Inlet. Therefore, characterisation of the offshore water level boundary conditions which simulate the 1% AEP storm tide inside Corner Inlet is crucial.

The offshore water level boundary was developed by applying a cosine wave with an amplitude equal to that of the 1% AEP storm surge at Port Welshpool to a time series of predicted astronomical tidal water levels for Port Welshpool. The time series was then analysed and a 72 hour period which had a peak water level equal to the 1% AEP storm tide level for Port Welshpool was selected.

The 72 hour storm surge time series was then added to the offshore astronomical tidal boundary over the corresponding time period. In order to ensure a peak storm tide level equal to that of the 1% AEP storm tide level at Port Welshpool, as given in McInnes (2009), the amplitude of the surge along the offshore boundary was manually adjusted as part of the calibration process. Figure 4-5 displays the 72 hour time series that applied along the southern open model boundary for the existing mean sea level scenario.

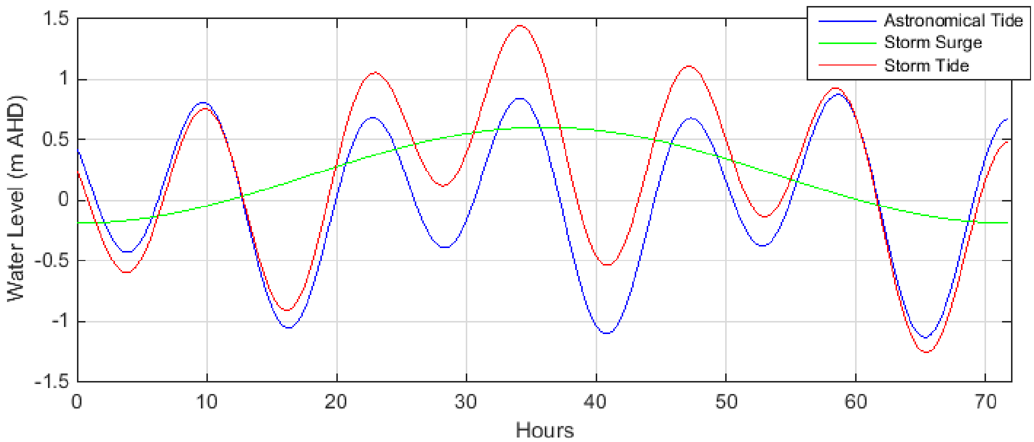

Figure 4-5 Example of the Astronomical Tide, Storm Surge and Storm Tide Boundary Condition Applied Along the Southern Offshore Boundary for the 1% AEP Storm Tide Under Existing Mean Sea Level Scenario.

Local Wind

Different types of storm weather systems, described in Section 2.2, typically produce different local wind conditions throughout Corner Inlet, leading to local changes in storm surge level. Therefore, one single representative 1% AEP storm surge level for the whole of Corner Inlet is not easily determined without conducting a full Monte Carlo type assessment. Due to the complexity of determining a single fully representative storm surge scenario, and as local wind set-up is typically less than the sustained surge levels from the Bass Strait, local wind effects have been omitted from this present study.

Assessment by CSIRO (2006) has shown that under existing mean sea level conditions, increases in local wind effects result in changes in the 1% AEP storm tide level in the order of +0.2 m along the main northern coast of Corner Inlet.

Waves

As described in Section 2.2, wave run-up and wave set-up are minimal components of the total storm tide water level inside Corner Inlet. As for wind set-up, there is no single set of conditions which result in a 1% AEP wave run-up and wave setup throughout all of Corner Inlet at the same time. Therefore, for the purposes of this assessment, wave conditions, and thus wave set-up and run-up, have not been included in the modelling.

Increases in water level due to wave set-up and wave run-up are only produced when waves occur at approximately right angles to the shoreline. Due to the irregular and vast range of shoreline orientations within Corner Inlet, the influence of wave set-up and wave run-up are spatially limited for each wind direction.

Of the main townships within Corner Inlet, the south-western shoreline of Port Welshpool is likely to experience the largest wave set-up and wave run-up due to the largest available fetch during west-south-west wind directions. Under these specific wind conditions, wave set-up and wave run-up may contribute to an additional increase in water levels of up approximately 0.1 m respectively.

At Port Albert, an additional increase in water level due to the combined influence of wave run-up and wave set-up of up to 0.1 m may occur along the south-western shoreline under south-westerly wind conditions. Wave set-up and wave run-up are considered negligible for all wind conditions at Port Franklin, Manns Beach and McLoughlins Beach, due to their location and the presence of offshore islands limiting the available wind fetch for wave generation.

5. MODELLING RESULTS

5.1 Overview

The resultant storm tide inundation extents for each of the three scenarios are presented and described in the following sections.

5.1.1 Scenario 1 (Present MSL)

The dynamically modelled 1% AEP storm tide inundation extent for Scenario 1 is shown in Figure 5-1. Five topographic cross-sections are displayed in Figure 5-2, and aid in highlighting the influence of the geomorphology of Corner Inlet on storm tide inundation extents.

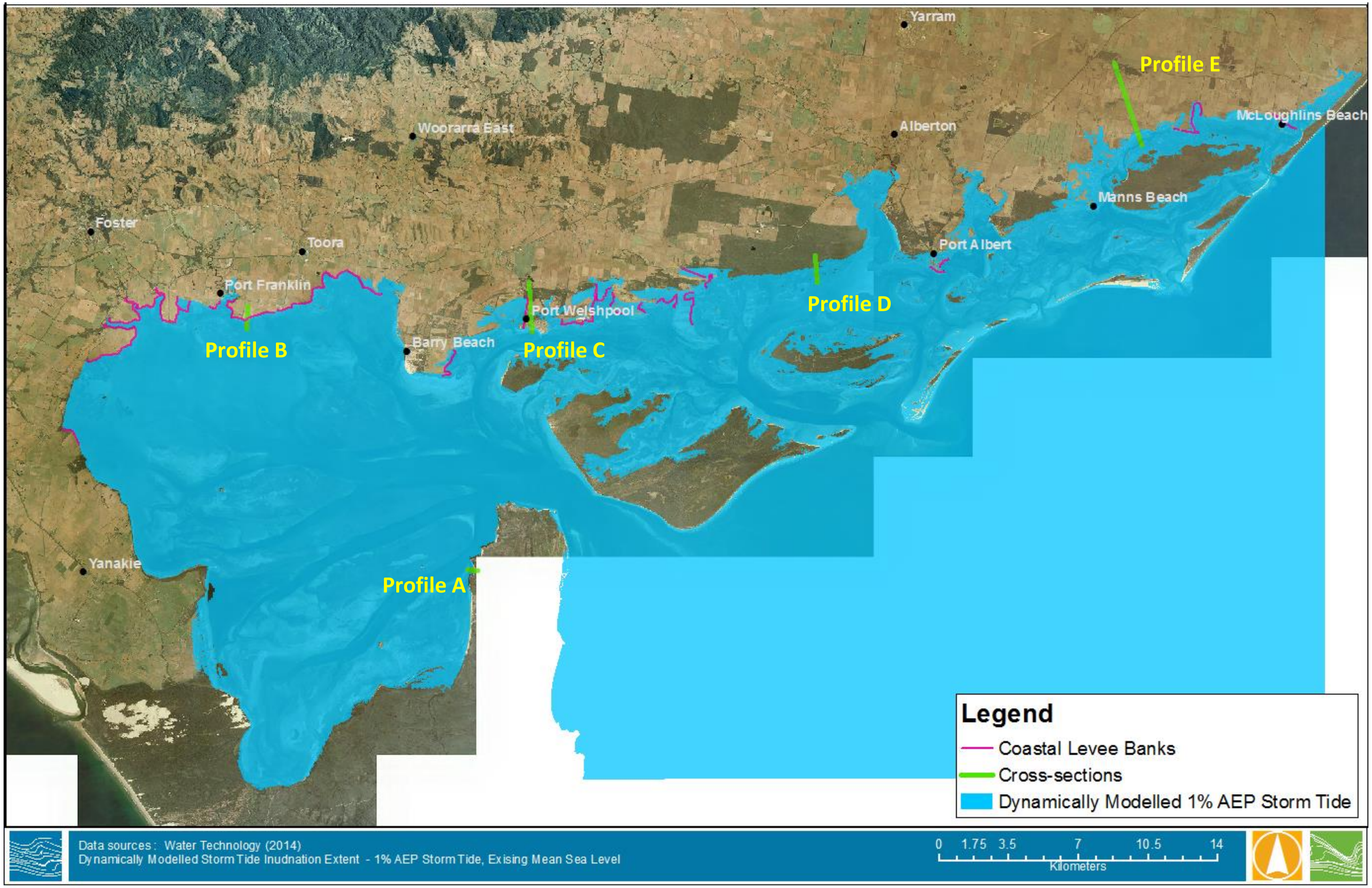

Figure 5-1 Modelled Inundation Extent for Scenario 1

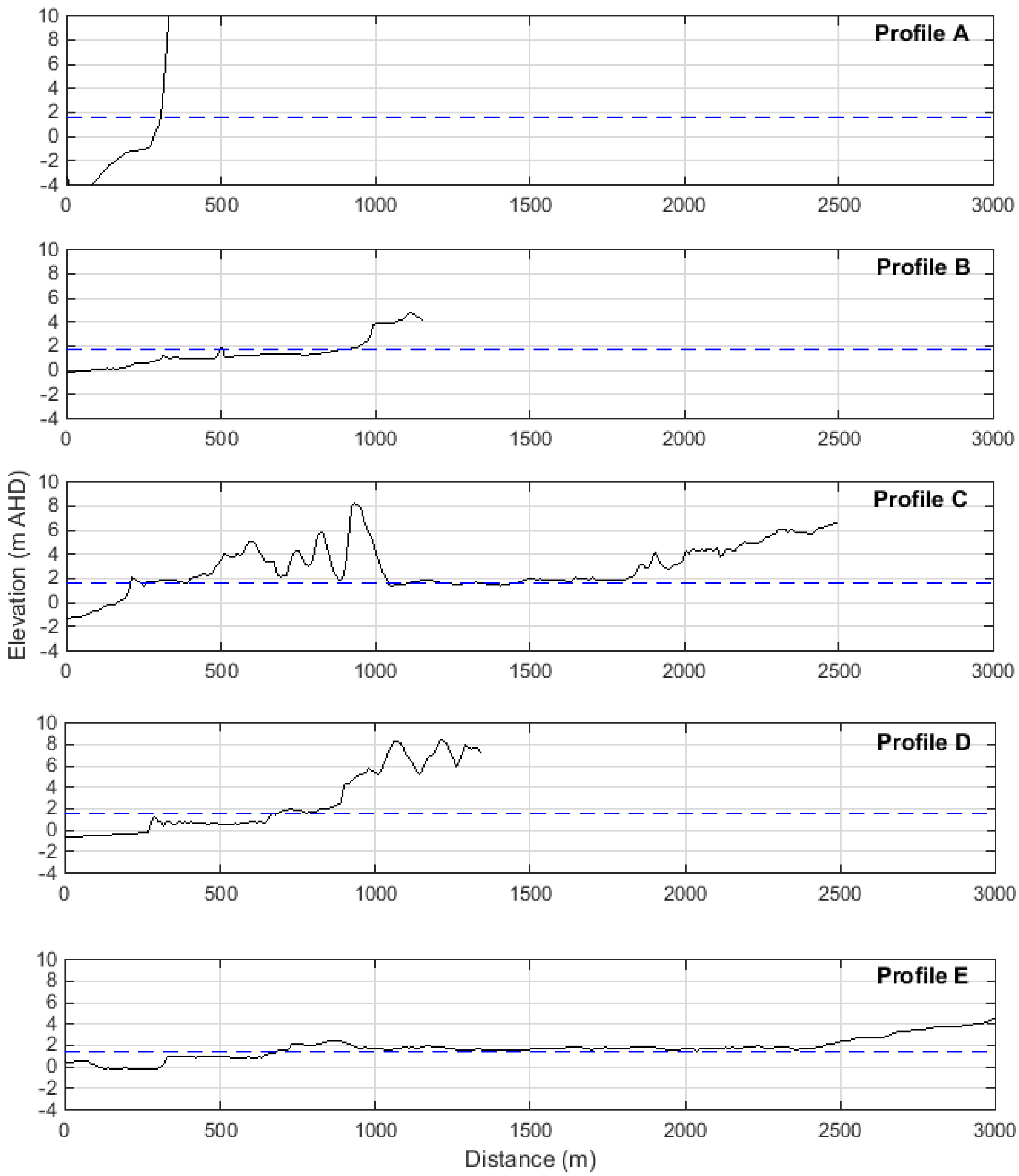

Figure 5-2 Topographic Cross-sections and Peak 1% AEP Storm Tide Levels for Scenario 1 (peak storm tide elevation in blue)

The key features of the dynamically modelled 1% AEP storm tide inundation extents for Scenario 1 can be summarised as follows:

- Along the south-western and western shorelines of Corner Inlet the inundation extents are largely constrained by the steeply cliffed shorelines as shown in Profile A, Figure 5-2.
- Inundation extents along the north-western of Corner Inlet are predominately constrained by the presence of the coastal levees. As shown in Profile B, the peak storm tide is below the crest of the levees. However, there are a number of localised low points and breaks in the levees, and therefore, there are a number of areas where overtopping of the levees occur.

- Inundation extents along the north-eastern and eastern shorelines consist of both regions where localised high topography prevents inundation and areas where the inundation extents are limited by the limited duration of the storm tide (the mass conservation principle).

5.1.2 Scenario2 (+0.82m SLR)

The dynamically modelled 1% AEP storm tide inundation extent for Scenario 2 is shown in Figure 5-3. Five topographic cross-sections are displayed in Figure 5-4.

The key features of the dynamically modelled 1% AEP storm tide inundation extents for Scenario 2 can be summarised as follows:

- Along the south-western and western shorelines of Corner Inlet the inundation extents are constrained by the steeply cliffed shorelines as shown in Profile A, Figure 5-4.
- Inundation extents along the north-western of Corner Inlet are no longer constrained by the presence of the coastal levees. As shown in Profile B, the peak storm tide is above the crest of the levees. The extent of inundation along this section of coastline is constrained by the location of the Bluff.
- Inundation extents along the north-eastern and eastern shorelines are primarily constrained by the topography.

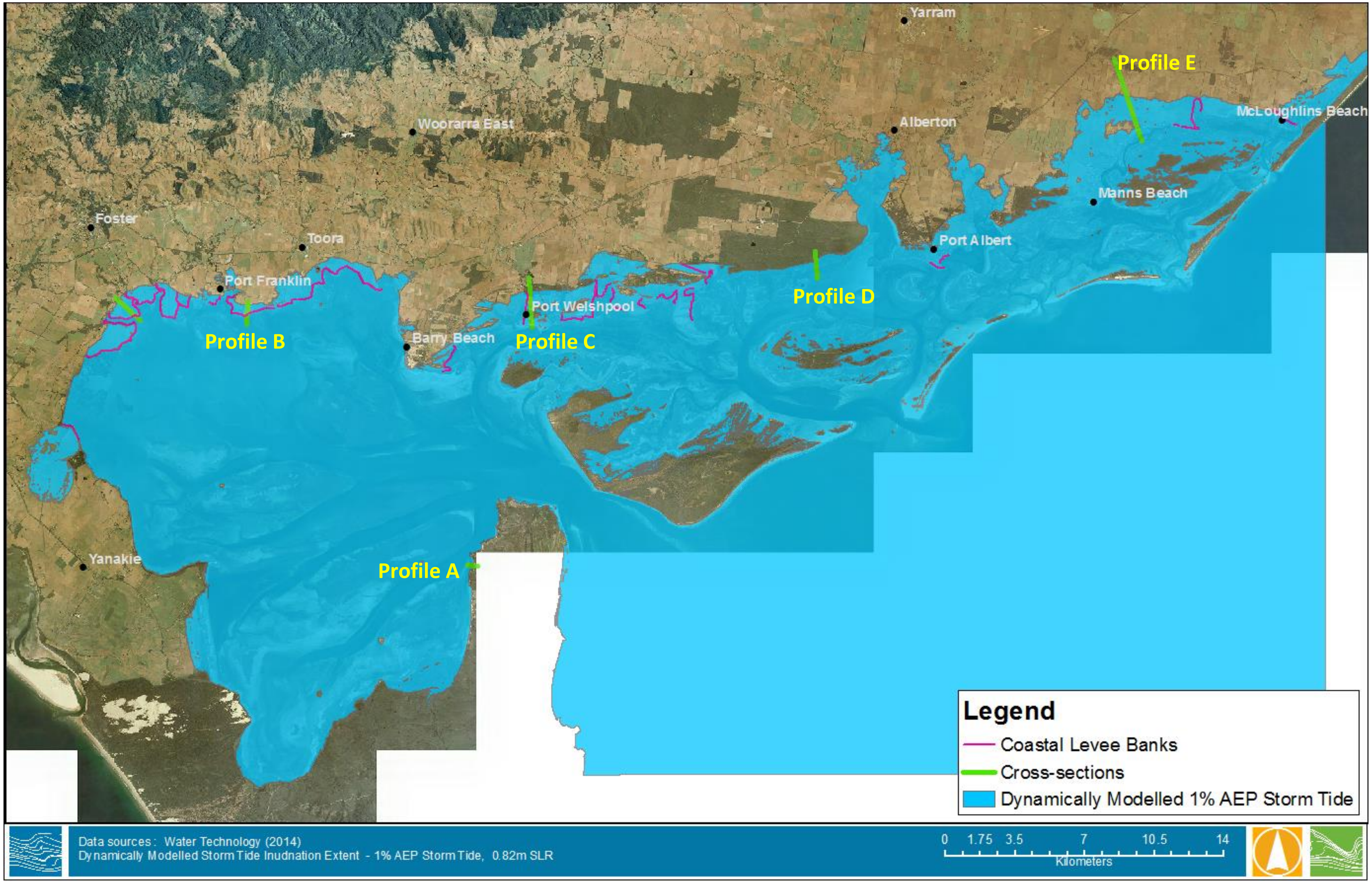

Figure 5-3 Modelled Inundation Extent for Scenario 2

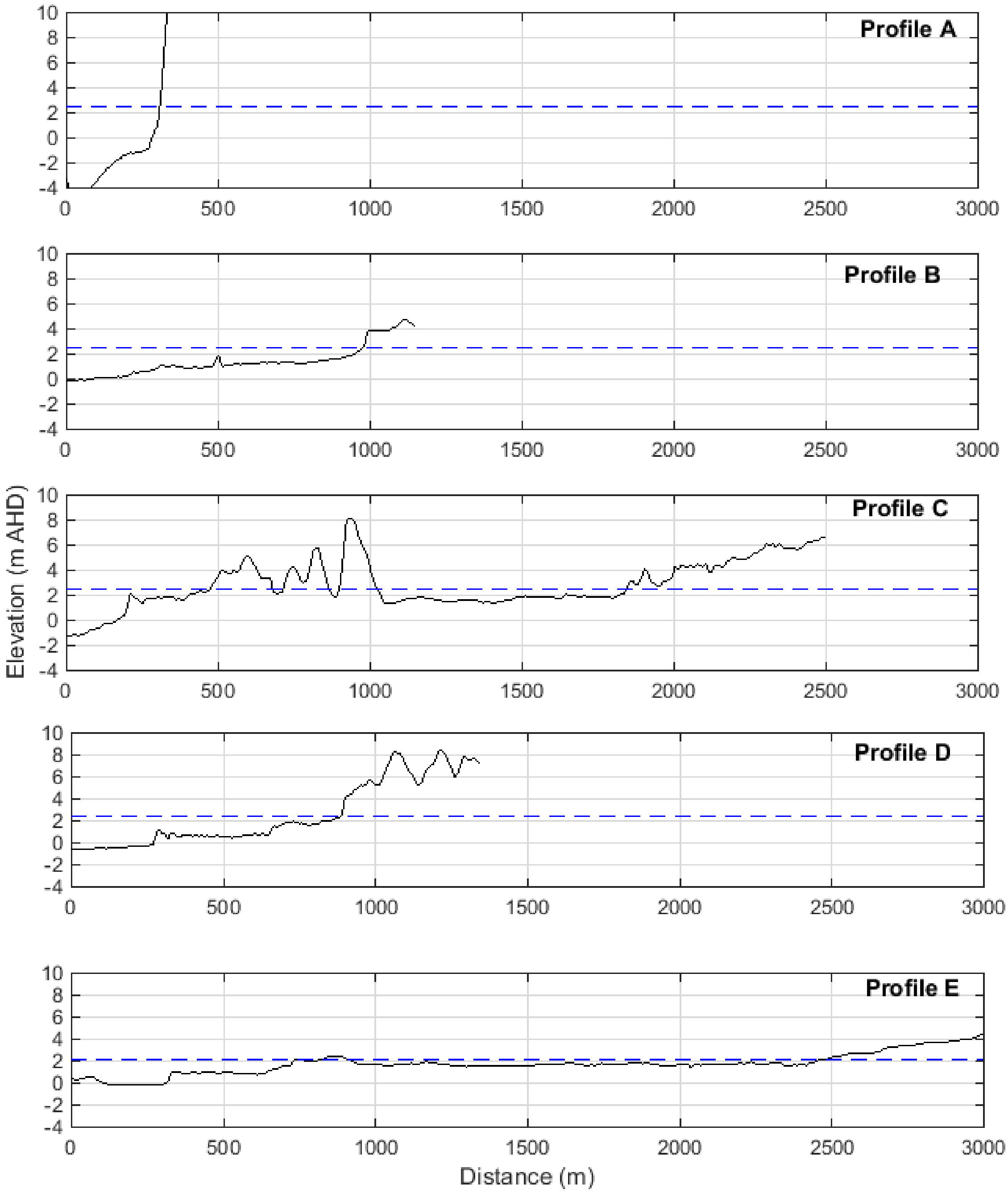

Figure 5-4 Topographic Cross-sections and Peak 1% AEP Storm Tide Levels for Scenario 2 (peak storm tide level in blue)

5.1.3 Scenario 3 (+0.82m SLR)

The dynamically modelled 1% AEP storm tide inundation extent for Scenario 3 is shown in Figure 5-5. Five topographic cross-sections are displayed in Figure 5-6.

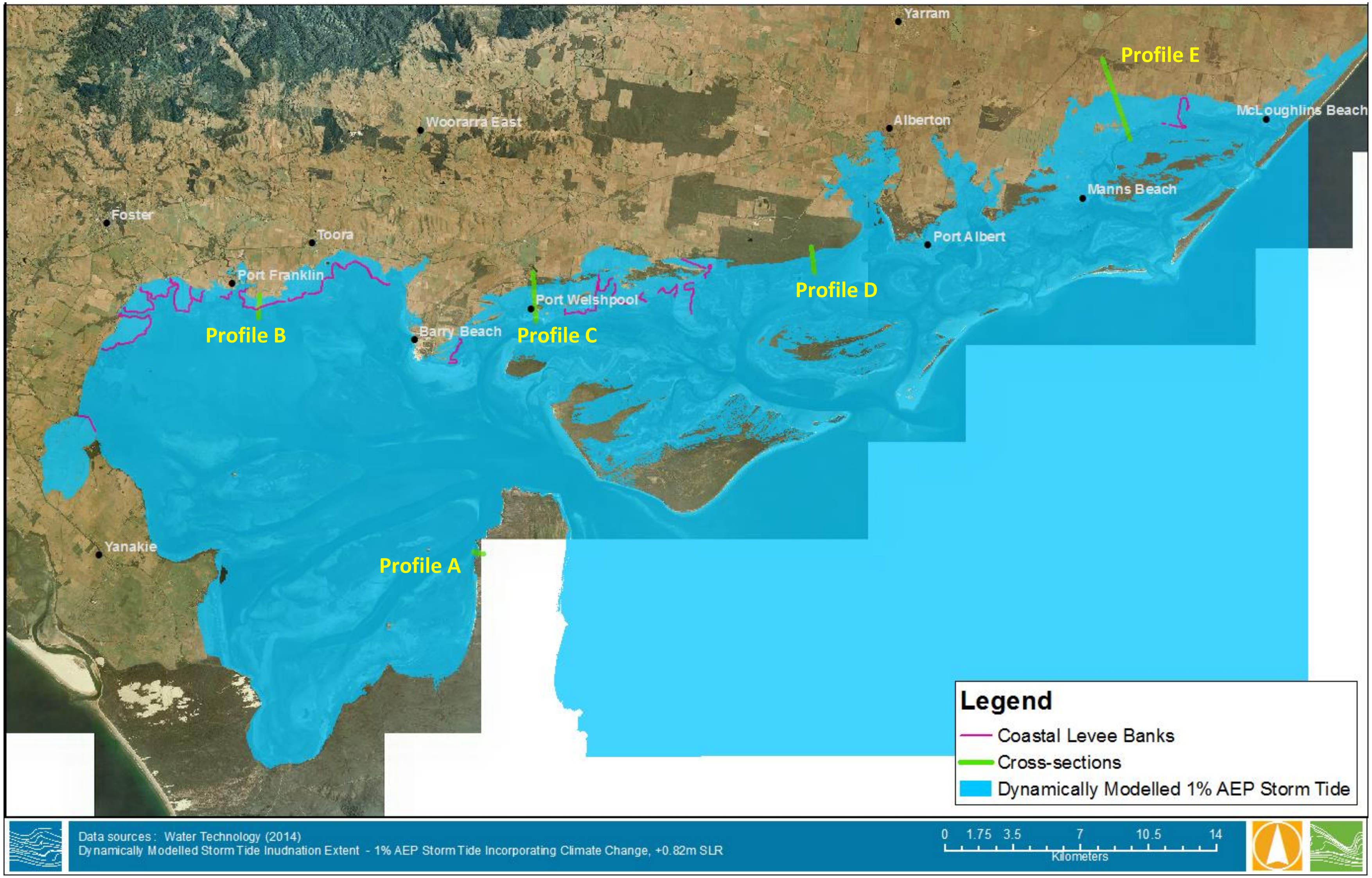

Figure 5-5 Modelled Inundation Extent for Scenario 3

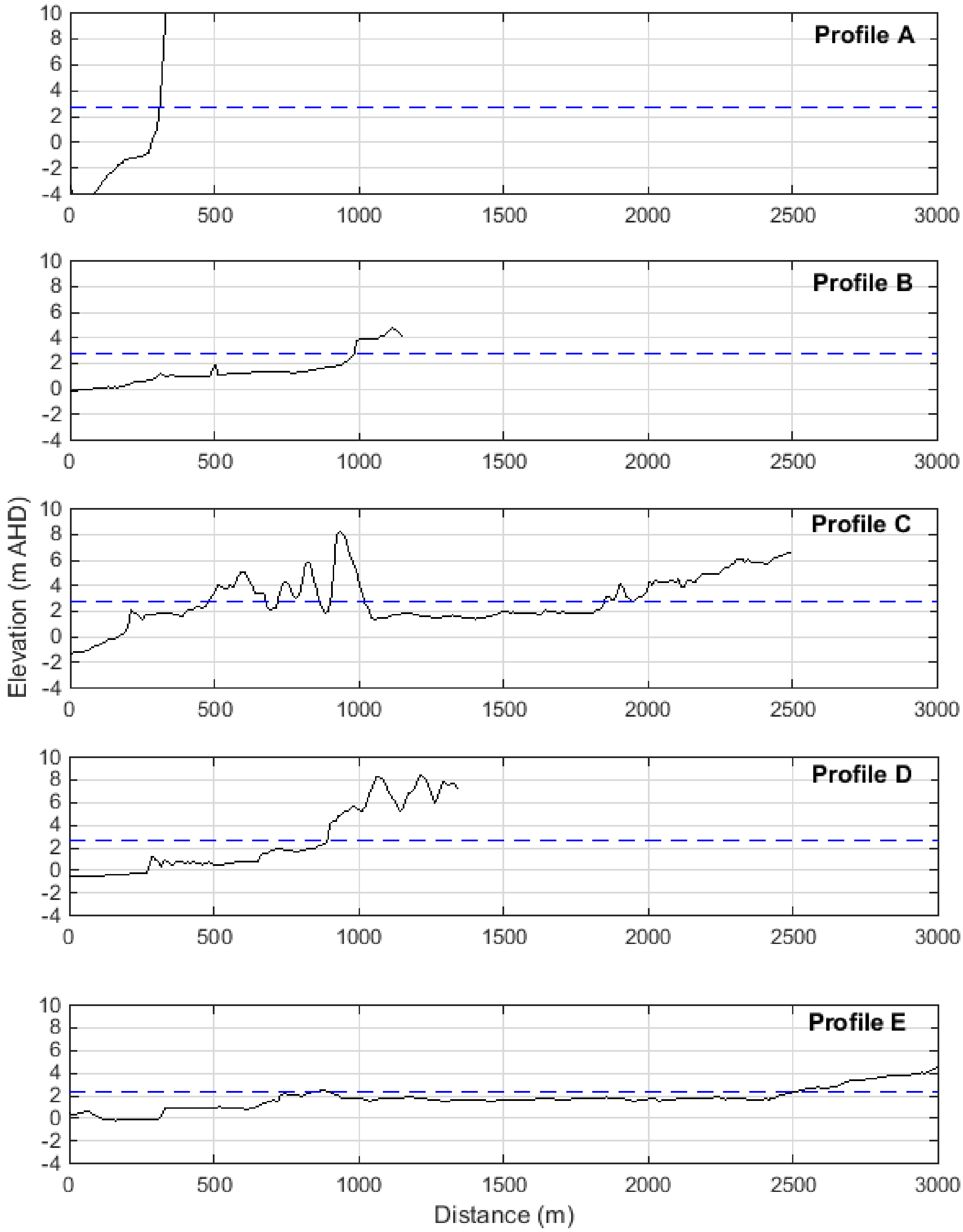

Figure 5-6 Topographic Cross-sections and Peak 1% AEP Storm Tide Levels for Scenario 3

The key features of the dynamically modelled 1% AEP storm tide inundation extents for Scenario 3 can be summarised as follows:

- As for the other scenarios, along the south-western and western shorelines of Corner Inlet the inundation extents are constrained by the steeply cliffed shorelines as shown in Profile A, Figure 5-6.
- As with Scenario 2, inundation extents along the north-western of Corner Inlet are no longer constrained by the presence of the coastal levees. As shown in Profile B, the peak storm tide

is above the crest of the levees. The extent of inundation along this section of coastline is constrained by the location of the Bluff.

- Inundation extents along the north-eastern and eastern shorelines are primarily constrained by the topography.

5.2 Comparison with Previous Modelling

The following section compares the dynamically modelled 1% AEP storm tide inundation extents with the previous bathtub modelled inundation extents from the Victorian Coastal LiDAR Inundation Modelling and Mapping project (2012). Comparisons are only drawn for Scenarios 1 and 3 as they are directly comparable. Scenario 2 was not modelled as part of the Victorian Coastal LiDAR Inundation Modelling and Mapping project.

5.2.1 Scenario 1

Figure 5-7 displays a comparison of the Scenario 1 dynamically modelled inundation with the bathtub modelled inundation extent. At a broad scale, the two inundation extents are relatively similar due to the broad constraint imposed by the geomorphology of the mid Holocene coastal bluff. However, there are two main areas of significant difference.

The first area of significant difference is in the north-west of Corner Inlet (labelled as #1). In this area' the dynamic storm tide modelling did not overtop the coastal levees, whereas the bathtub modelling extends inland past these features.

The second area of significant difference is in the north-east near Nooramunga, north of Manns Beach. In this area, the dynamic storm tide modelling did not extend as far inland as the bathtub inundation extent. This is primarily because of differences in the resolution of the two modelling approaches and the resulting differences in the astronomical tidal component of the storm tide.

The water surface elevation grid representing the 1% AEP storm tide incorporating climate change and +0.82 m of sea level rise used for the bathtub modelling was derived from a storm surge model based on a 1 km grid cell resolution. A grid cell of this size is sufficient for the modelling of storm tide along the open coast, and in large open bays such as Port Phillip Bay. However, it is not sufficient to accurately simulate the hydrodynamics through the small and complex network of channels in the Nooramunga Marine and Coastal Park.

Also, modelled results for the 1% AEP storm tide level for Corner Inlet from McInnes et al (2009) were interpolated into a series of points along the shoreline of Corner Inlet. These interpolated values were then mapped for the Victorian Coastal LiDAR Inundation Modelling and Mapping assessment within Corner Inlet. The location of the mapped data points was not available for this assessment. However this has resulted in difference in the mapped inundation water levels and the modelled storm tide elevations at specific locations.

Local scale maps are also provided for the main townships surrounding Corner Inlet.

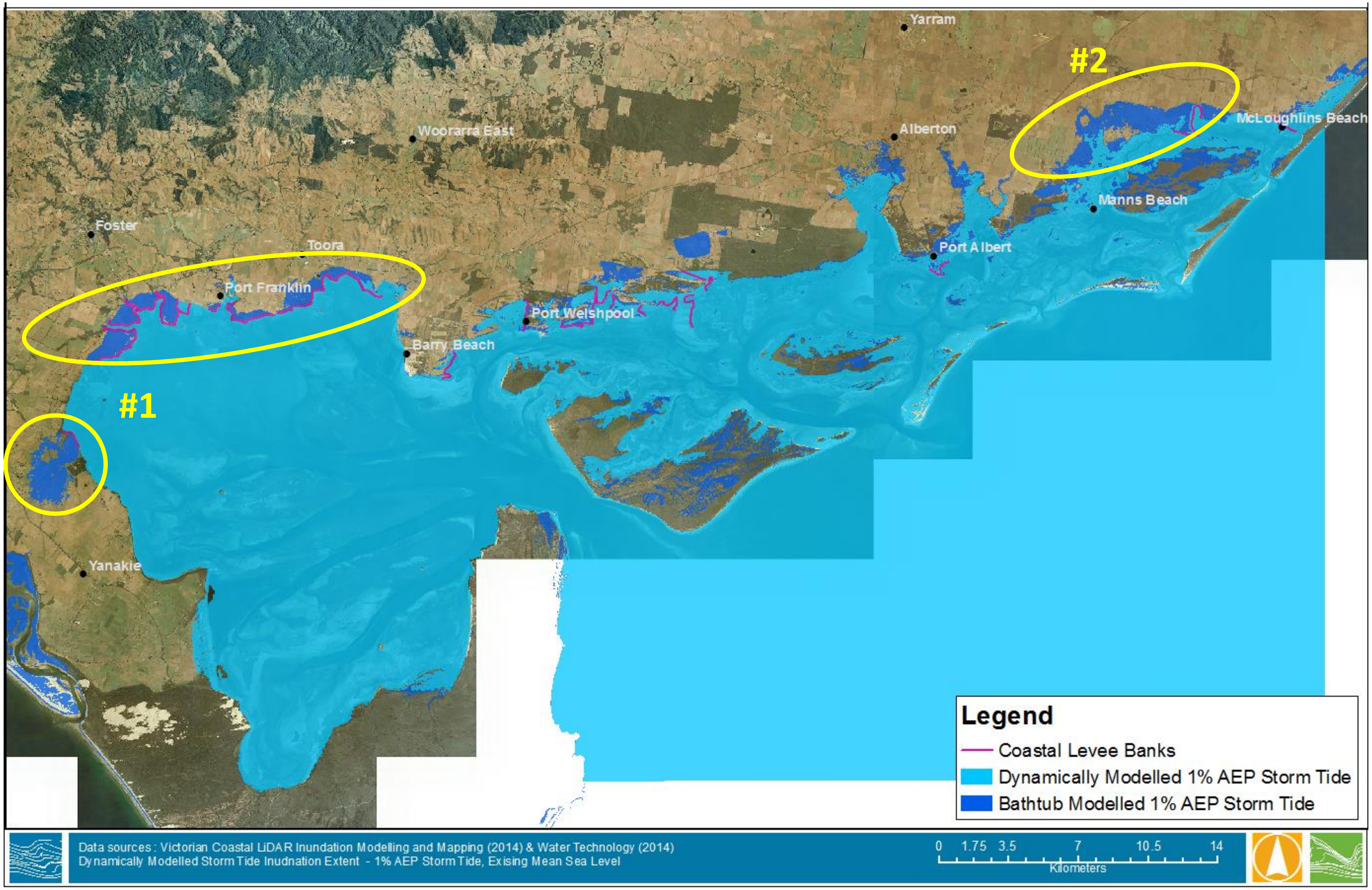

Figure 5-7 Comparison of the 1% AEP Storm Tide under Existing MSL Modelled Using the Bathtub Technique and a Dynamic Hydrodynamic Model

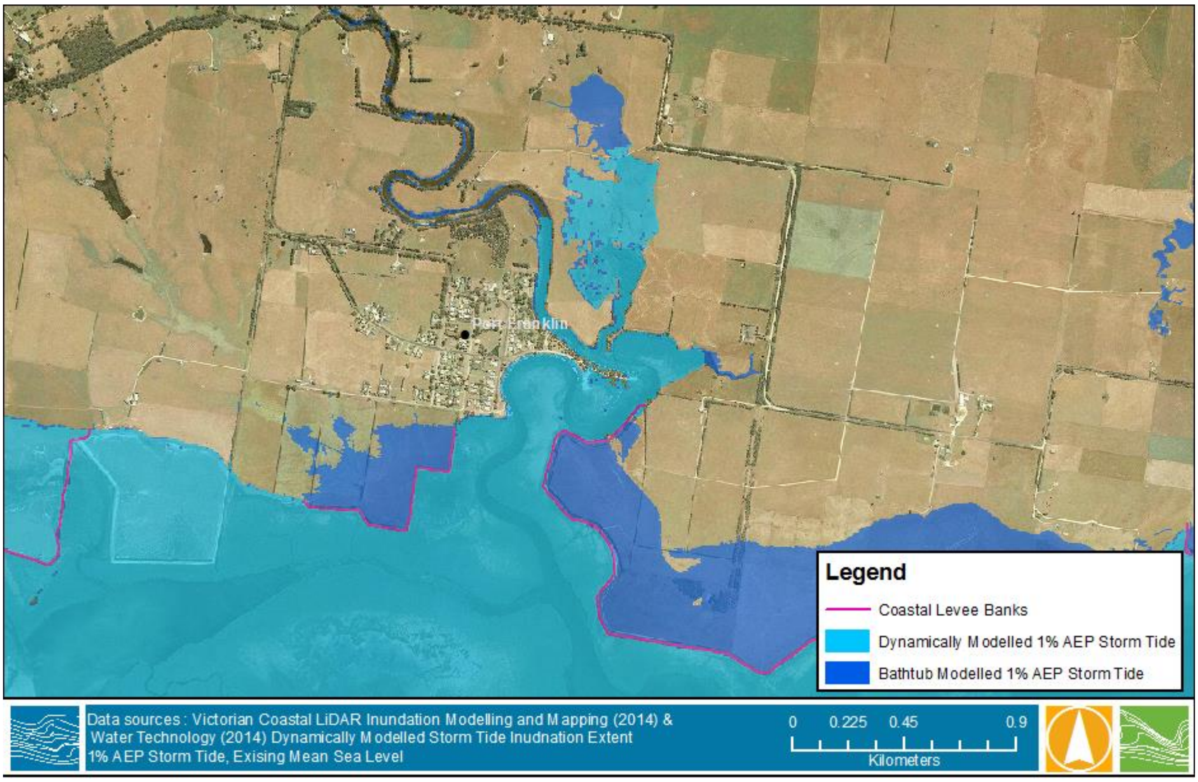

Figure 5-8 **Comparison of the 1% AEP Storm Tide under Existing MSL, Modelled Using the Bathtub Technique and a Dynamic Hydrodynamic Model – Port Franklin (Note: This figure does not show inundation extents from riverine flooding from the Franklin River).**

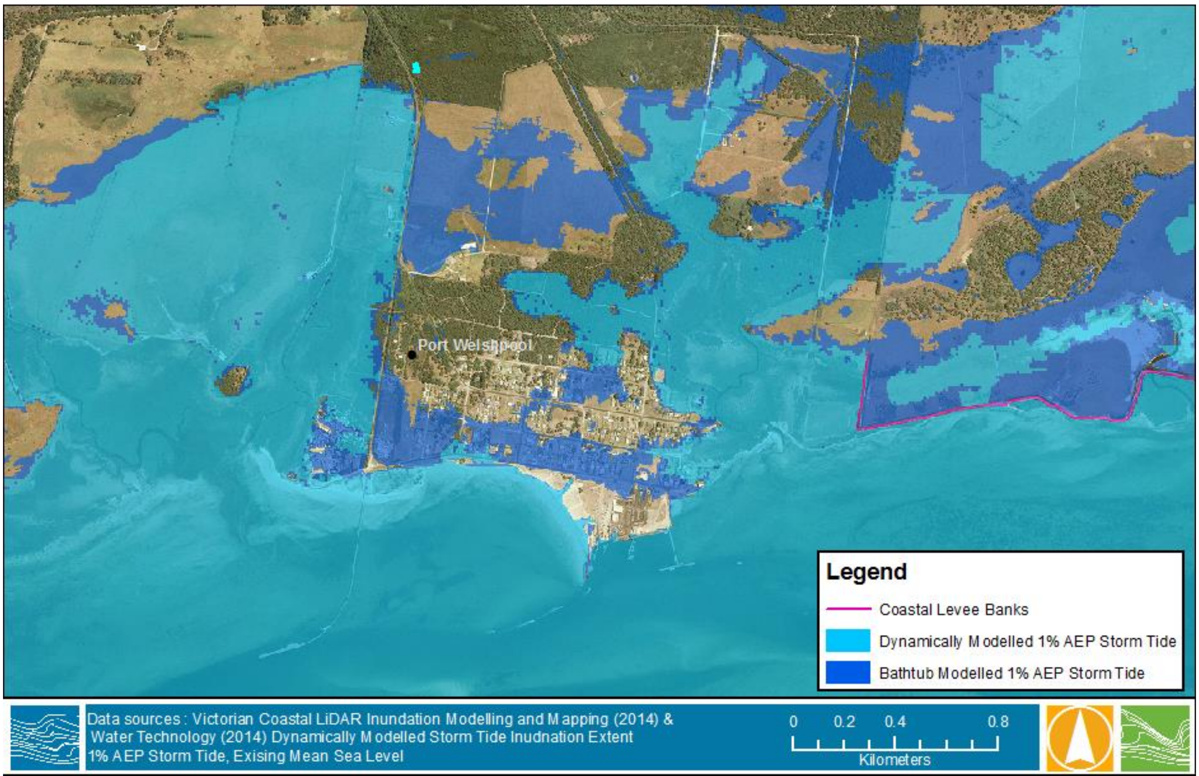

Figure 5-9 **Comparison of the 1% AEP Storm Tide under Existing MSL, Modelled Using the Bathtub Technique and a Dynamic Hydrodynamic Model – Port Welshpool**

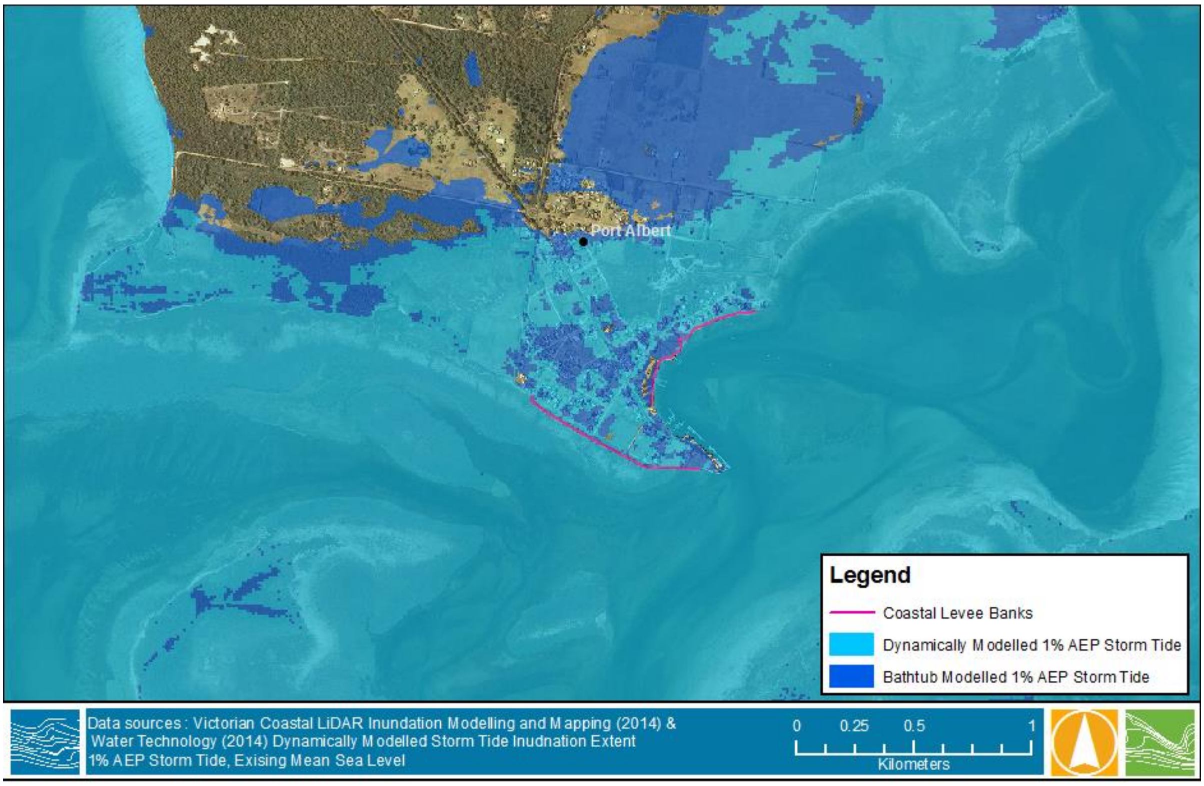

Figure 5-10 **Comparison of the 1% AEP Storm Tide under Existing MSL, Modelled Using the Bathtub Technique and a Dynamic Hydrodynamic Model – Port Albert**

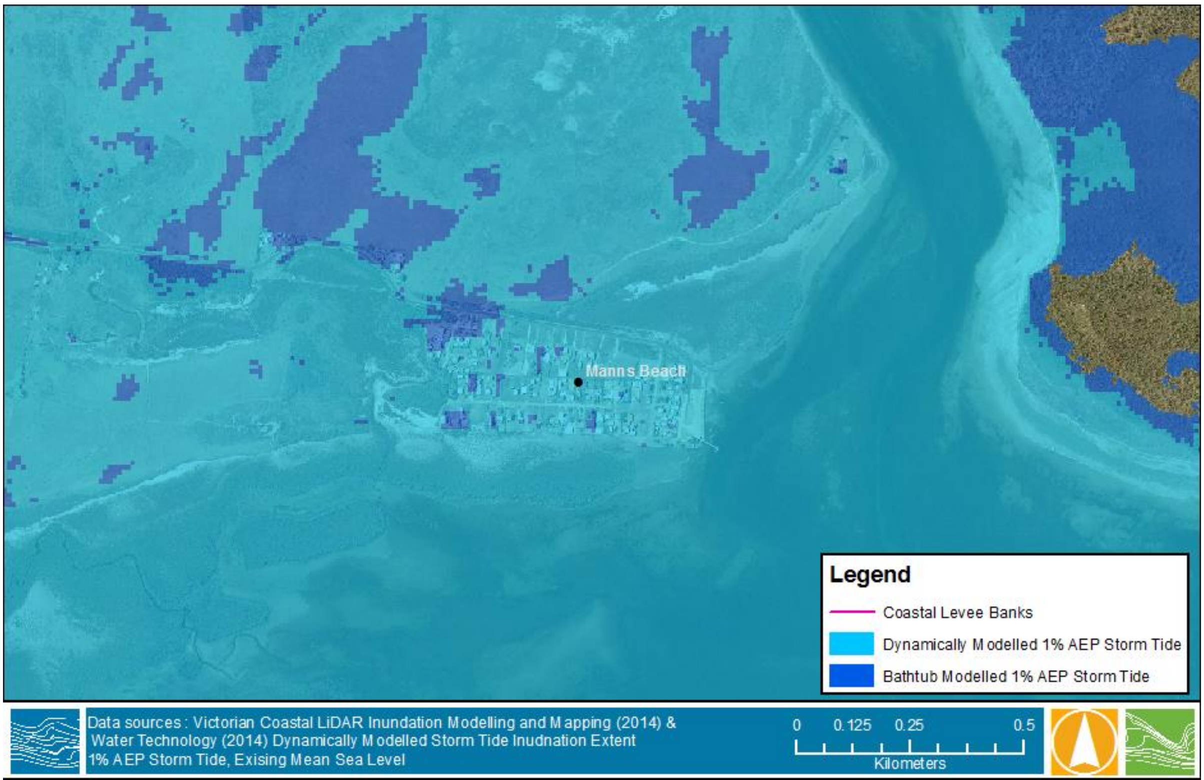

Figure 5-11 **Comparison of the 1% AEP Storm Tide under Existing MSL, Modelled Using the Bathtub Technique and a Dynamic Hydrodynamic Model – Manns Beach**

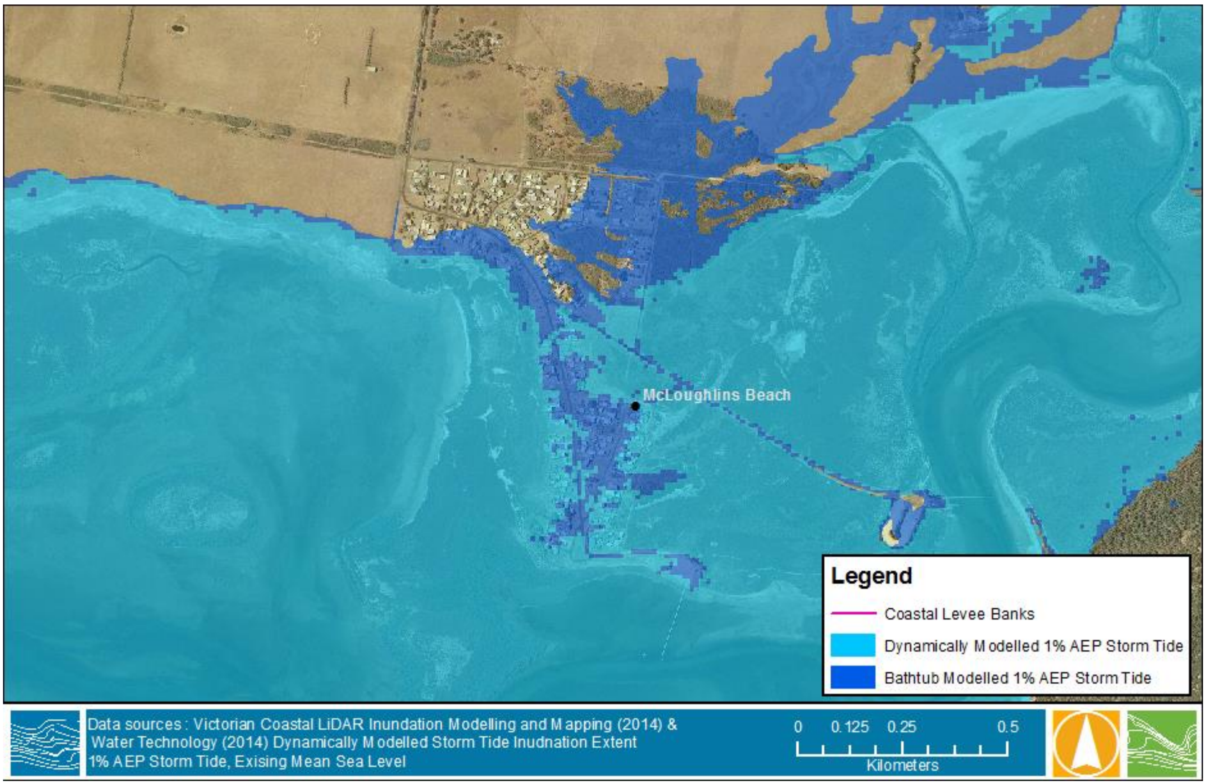

Figure 5-12 Comparison of the 1% AEP Storm Tide under Existing MSL, Modelled Using the Bathtub Technique and a Dynamic Hydrodynamic Model – McLoughlins Beach (Note: This figure does not show inundation extents from riverine flooding from the Bruthen Creek).

5.2.2 Scenario 3

Figure 5-13 to Figure 5-18 displays a comparison of Scenario 3 dynamically modelled storm tide inundation extent with the bathtub modelled inundation extent. Again, at a broad scale the two inundation extents are similar, particularly along the western shoreline of Corner Inlet.

Inundation extents along the stretch of shoreline from Chinaman Beach to Port Welshpool are almost identical. This is because the bluff and cliffs immediately back, or are within a short distance of the present shoreline. Therefore, the time varying characteristics have less influence as the storm tide is able to propagate the short distance inland to intersect the higher topography almost immediately.

However, there are two main areas within Corner Inlet where significant differences occur. The first area of significant difference is to the north-east of Port Welshpool (labelled as #1 on Figure 5-13). In this area, the dynamic storm tide modelling did not result in inundation as far inland as the bathtub inundation extent. Although the available topography data did not allow accurate resolution of the channel in the dynamic model, given the apparent size and capacity of the channel it is very unlikely that sufficient volumes of water would be able to propagate up the channel during the storm tide and fill the low lying region shown as #1.

The second area of significant difference is in the northern extent of Nooramunga, between Port Albert and Manns Beach (Figure 5-13), and to a lesser extent, from Port Albert to McLouglins Beach (Figure 5-16 and Figure 5-18). In these areas the dynamically modelled extent did not extend as far inland as the bathtub inundation extent. As noted for Scenario 1, difference also arise due to interpolation of the modelled data to specific points for the purposes of the bathtub inundation mapping.

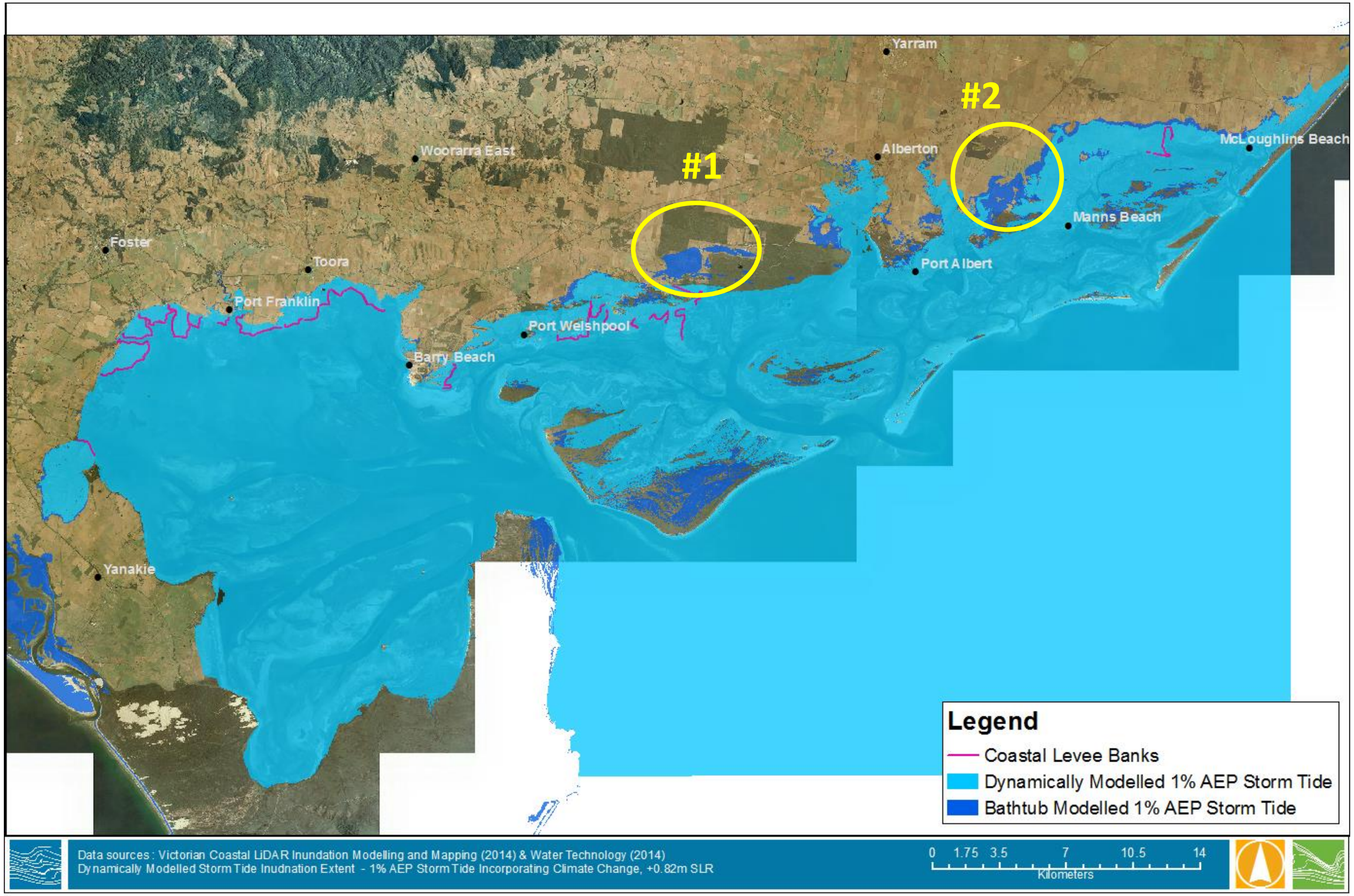

Figure 5-13 Comparison of the 1% AEP Storm Tide Incorporating Climate Change under +0.82m SLR Modelled Using the Bathtub Technique and a Dynamic Hydrodynamic Model

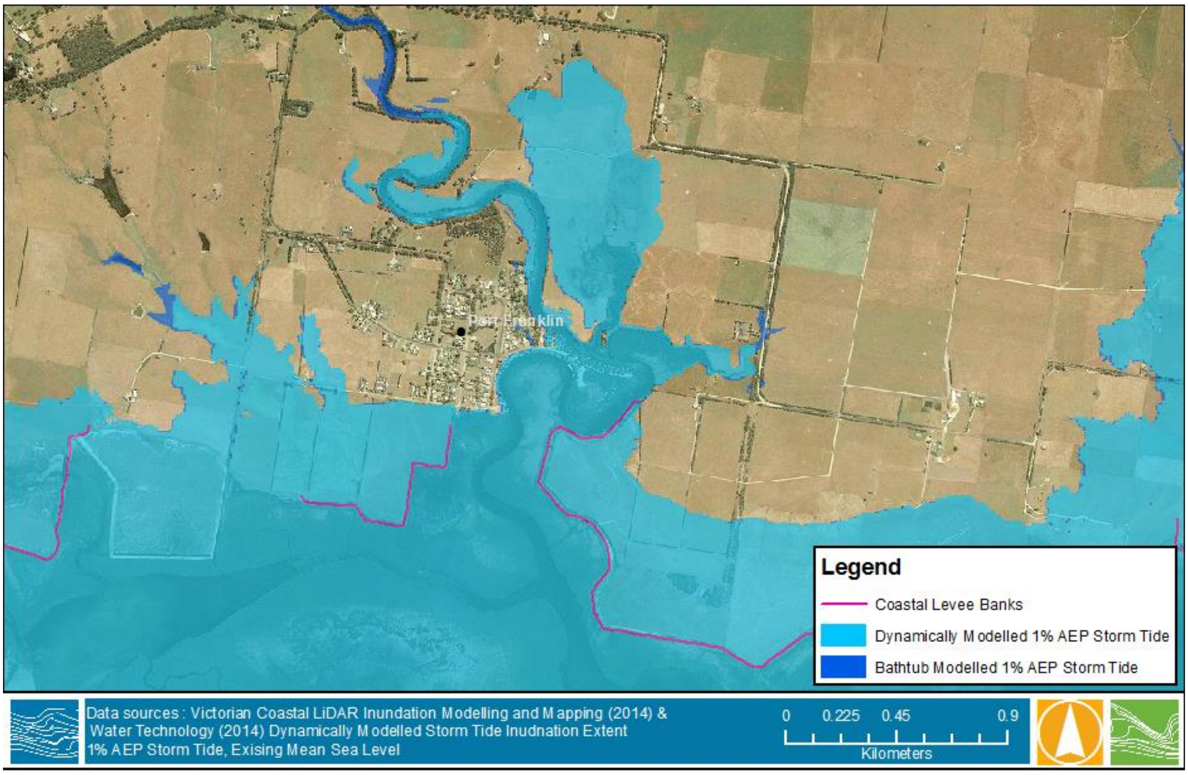

Figure 5-14 **Comparison of the 1% AEP Storm Tide Incorporating Climate Change under +0.82m SLR, Modelled Using the Bathtub Technique and a Dynamic Hydrodynamic Model – Port Franklin** **(Note: This figure does not show inundation extents from riverine flooding from the Franklin River).**

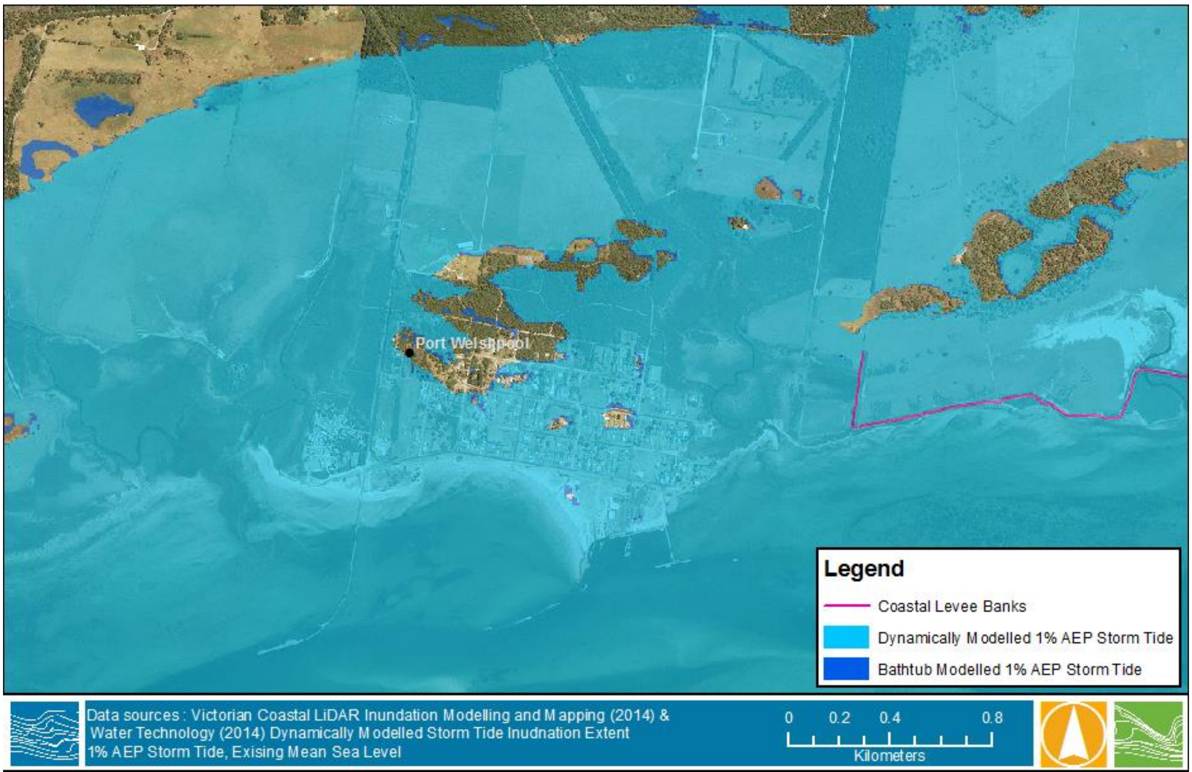

Figure 5-15 **Comparison of the 1% AEP Storm Tide Incorporating Climate Change under +0.82m SLR, Modelled Using the Bathtub Technique and a Dynamic Hydrodynamic Model – Port Welshpool**

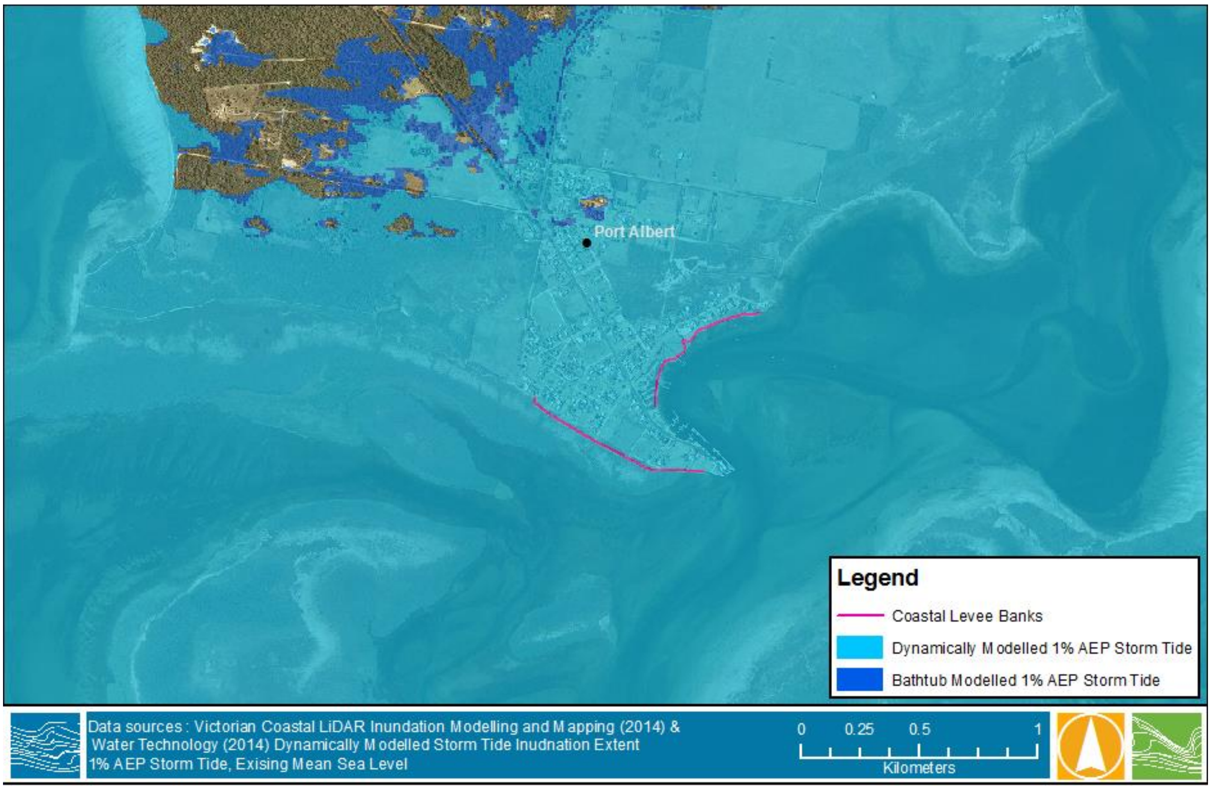

Figure 5-16 **Comparison of the 1% AEP Storm Tide Incorporating Climate Change under +0.82m SLR, Modelled Using the Bathtub Technique and a Dynamic Hydrodynamic Model – Port Albert**

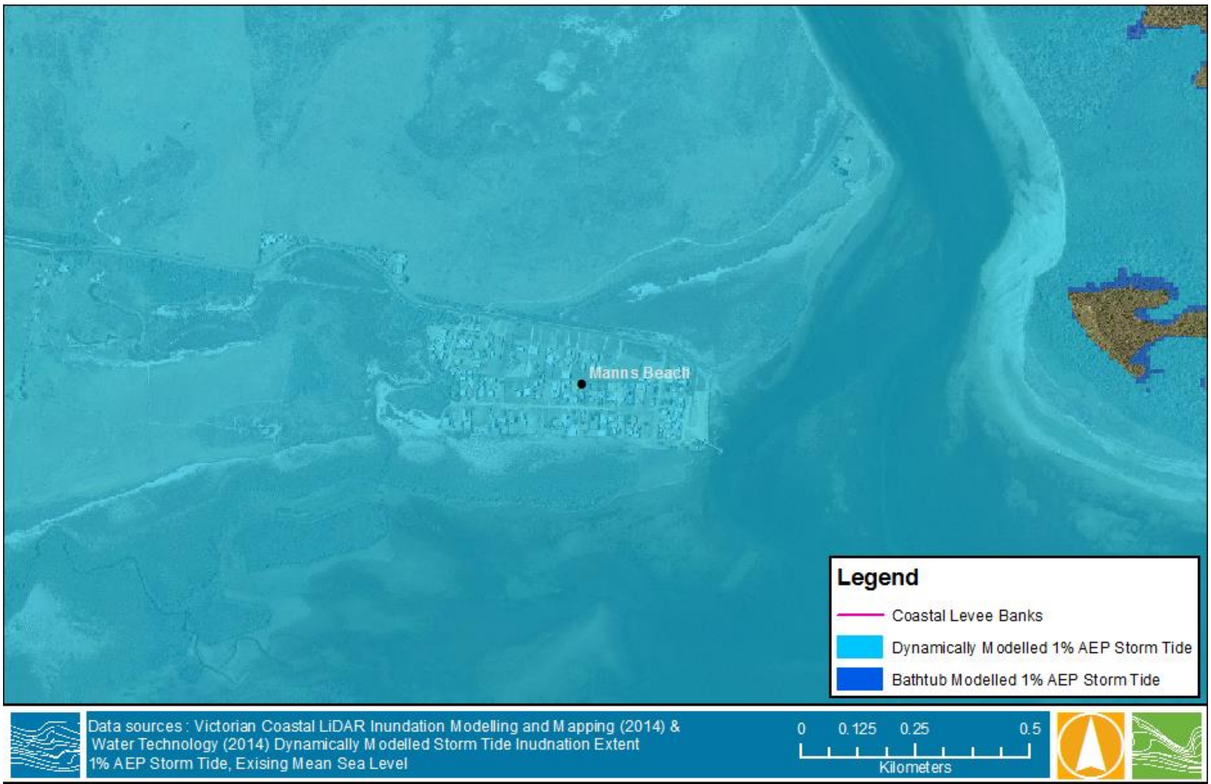

Figure 5-17 **Comparison of the 1% AEP Storm Tide Incorporating Climate Change under +0.82m SLR, Modelled Using the Bathtub Technique and a Dynamic Hydrodynamic Model – Manns Beach**

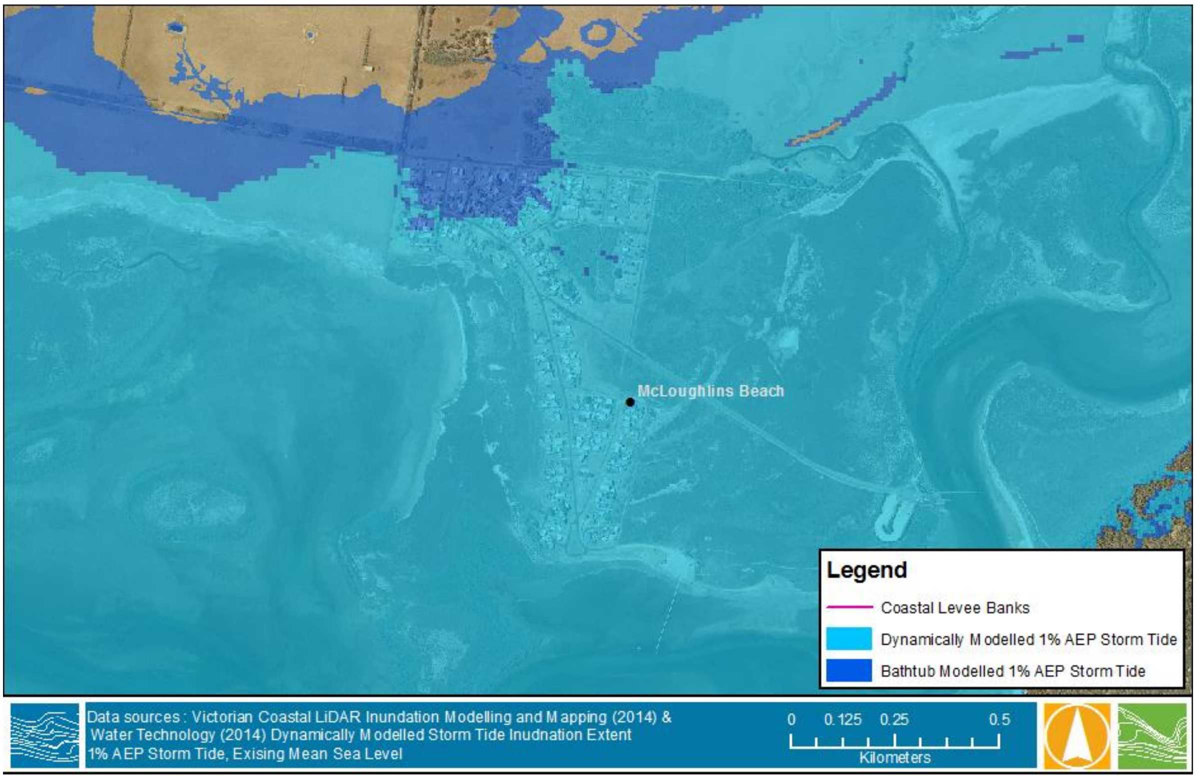

Figure 5-18 Comparison of the 1% AEP Storm Tide Incorporating Climate Change under +0.82m SLR, Modelled Using the Bathtub Technique and a Dynamic Hydrodynamic Model – McLoughlins Beach (Note: This figure does not show inundation extents from riverine flooding from the Bruthen).

6. CONCLUSIONS & RECOMMENDATIONS

6.1 Conclusions

The aim of this project has been to assess and quantify the effects of tidal dynamics on potential inundation extents associated with a 1% Annual Exceedance Probability (AEP) storm tide, under existing mean sea level, and for a predicted future +0.82 m of sea level rise.

To do this, a detailed hydrodynamic model of Corner Inlet has been developed, calibrated and applied to simulate storm tide and future sea level rise conditions. The results of the modelling were then compared to the previous Victorian Coastal Inundation (2012) bathtub model coastal inundation extents. In addition, 1% AEP storm tide animations for the towns of Port Welshpool and Port Albert have been produced and provided to the West Gippsland Catchment Management Authority.

The following key conclusions are drawn from the dynamic storm tide modelling assessment:

- Inundation extents at a regional scale within Corner Inlet are largely controlled by geomorphic features rather than dynamic storm tide processes.
- Along the south-western and western shorelines of Corner Inlet, the inundation extents are largely constrained by the steeply cliffed shorelines and bluff, for both the present and +0.82m sea level rise scenarios.
- Inundation extents along the north-western part of Corner Inlet are predominately constrained by the presence of the coastal levees for the present mean sea level scenario. However, there are a number of localised low points and breaks in the levees, and therefore, there are a number of areas where overtopping of the levees occur.
- The influence of the coastal levees is significantly reduced for Scenarios 2 and 3. Widespread overtopping of the levees occurred under both of these scenarios, and the storm tide propagated inland until the extent was constrained by the Bluff.
- Inundation extents along the north-eastern and eastern shorelines consist of both regions where localised high topography prevents inundation and areas where the inundation was limited by the time varying aspect of the dynamically modelled surge.

Comparisons between the dynamically modelled and bathtub storm tide extents show that:

- Only a few areas of significant differences of inundation extents exist between the two modelling methods under existing mean sea level. Examples of where significant differences existed occur behind the regions protected by coastal levees, and along the north-eastern shorelines of Corner Inlet, where dynamic modelling was able to more accurately simulate the attenuated tidal range in comparison to the bathtub modelling.
- Even less difference occurs between the modelled extents for the +0.82m sea level rise scenarios. This is because the inundation extents are largely controlled by the local geomorphology for this scenario and the levee features are overtopped under these conditions.
- Significant inundation was demonstrated to occur in both the bathtub modelling and dynamic storm tide modelling approaches at the following townships for the 1% AEP storm tide under existing mean sea level conditions:
  - Manns Beach
  - McLouglins Beach
  - Port Albert
- Significant inundation was demonstrated to occur in both the bathtub modelling and dynamic storm tide modelling approaches at the following townships for the 1% AEP storm tide incorporating climate change and +0.82m of sea level rise:

- Port Welshpool
- Port Albert
- Manns Beach
- McLouglins Beach

6.2 Recommendations

Based on results and findings of this project, it is recommended that:

- Local wind conditions have not been examined in this study, they could contribute to further wind set-up of storm tide levels across Corner Inlet, particularly along the eastern shorelines. This would affect the peak storm tide levels and inundation extents where inundation is not constrained by the local geomorphology. This can be examined through further analysis and modelling of storm tide conditions in order to determine the influence of local wind conditions from the various storm systems. As noted in Section 2.3.3 wave set-up and wave run-up are not likely to be significant components of storm tide inundation in Corner Inlet and, therefore, further assessment of these processes is not considered crucial for refinement of inundation extents.
- As there will not be large increases in inundation extent due to the presence of the bluff and cliffs within a short distance of the current shoreline, an assessment of the frequency of inundation associated with a range of sea level rise levels would improve understanding of inundation risks in these areas. Extension of the current inundation assessment to include consideration of the frequency of inundation associated with different sea level rise scenarios could address this.
- The sensitivity of entrance dynamics, particularly Shoal Inlet and St Margaret Inlet was not investigated by this study, although it was noted to be important during the model calibration process. The equilibrium size and configuration of these small sandy inlets is likely to increase under sea level rise due to a larger volume of water flowing through the inlets per tidal cycle. An increase in the size of these inlets would reduce the attenuation of the astronomical tide, and therefore result in higher peak storm tide levels at the far eastern areas within Corner Inlet.
- At a local scale, finer detail site specific modelling assessments, which incorporate the local storm water drainage networks, could be undertaken to further refine the inundation extents and to assess impacts on local infrastructure.

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