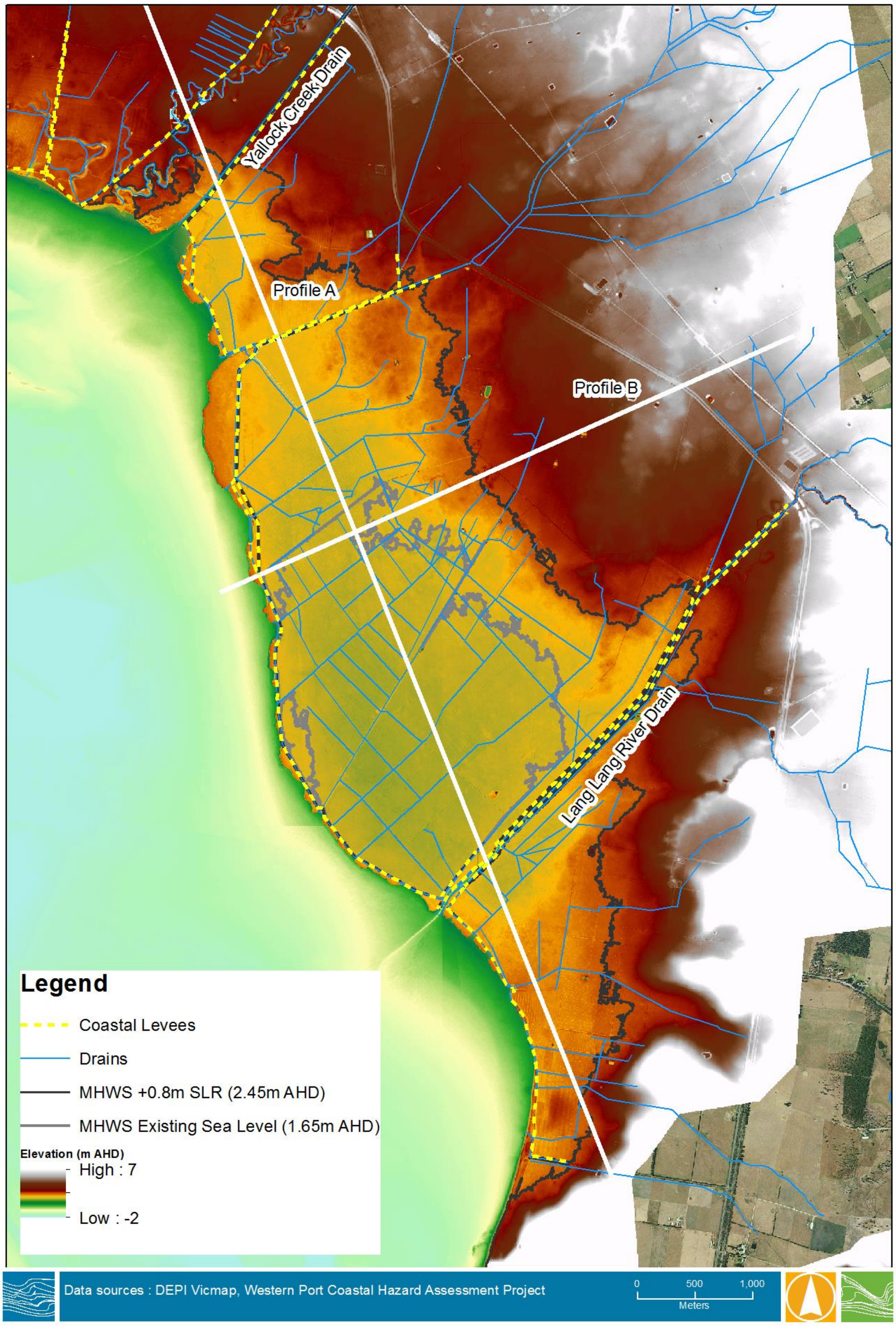
4.1.2 Coastal Geomorphology

The shoreline is comprised of an essentially continuous, low earth cliff. The backshore environment is a very low elevation plain that has been significantly modified by clearing of native vegetation and construction of drainage channels, associated embankments and levees (Figure 4-3).



Data sources : DEPI Vicmap, Western Port Coastal Hazard Assessment Project

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Figure 4-3 Overview of Coastal Geomorphology of Lang Lang Study Area

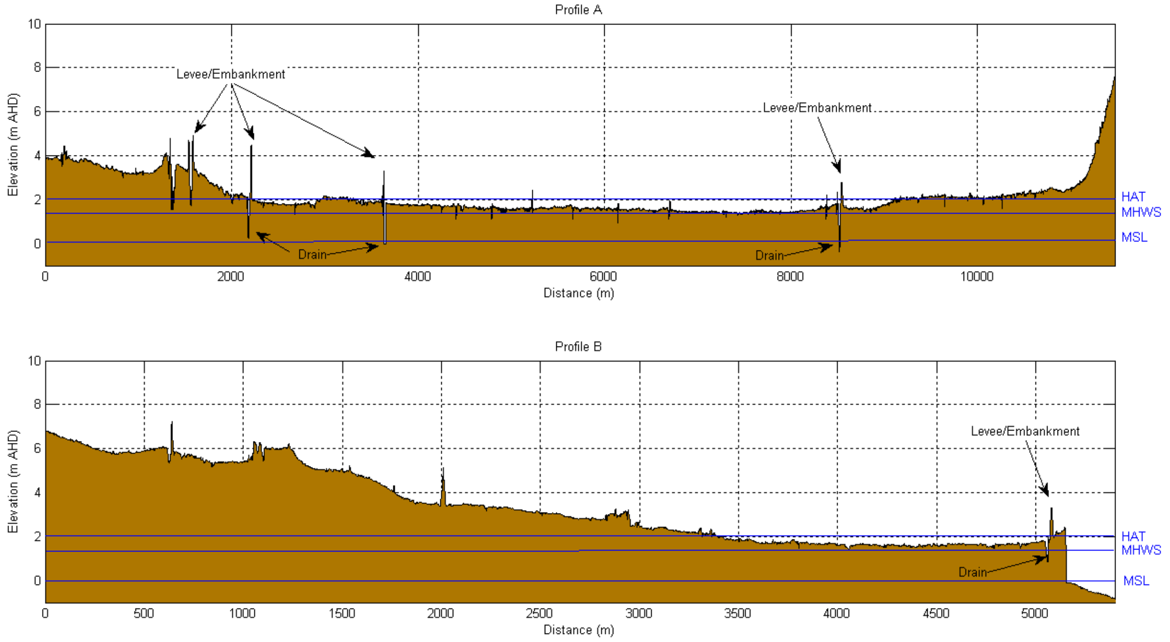

Figure 4-4 **Topographic Cross Sections through Lang Lang Study Area** ***(Cross Section Locations Displayed in Figure 4-3)***

Low Earth, Cliffed Shorelines

The coastal cliff 0.2 m to 2.5 m high is composed of clay and peaty swamp deposits of the former Tobin-Yallock Swamp. Along most of the shore it is near-vertical with a basal sloping ramp of firm clay.

In plan, the shoreline is crenulate with broad rounded weakly indented headlands separated by defined shallow embayments, which are often, but not restricted to, the mouth of a drain. Many of the bays have a veneer of coarse and shelly sand and at times there are small accumulations of sand at the base of headland cliffs. Sand in the embayments has a relatively long residence time and is derived from direct onshore rather than alongshore transport. Once deposited by high tide storm waves, the backwash and ebb currents are insufficient to remove it. Storm waves that overwash the cliffs and embayment heads form cheniers that further remove sand from the coastal transport system.

Figure 4-5 **Sand in Embayment and Cliff Base South of Lang Lang River *(the arrow shows the chenier of sand and shell at cliff top)***

The coastal cliffs are complex landforms in plan and profile and reflect a variety of past and present influences on morphological development. They are composed of weakly consolidated material and are coherent largely through compression, compaction and adhesion of clays. They have weakly defined stratification and no other consistent structure. There is a high percentage of clay, even in the peaty units.

The shore platform has a very low gradient – at the cliff base 0.25% flattening to ~0.1% several hundred metres offshore. It has a complex micro-topography of incised and depositional features and occasional low steps marking a boundary between sediment types. Much of the platform fringing this sector of coast is a planed-off surface of the swamp deposits rather than a modern seafloor accumulation. It has a veneer of mud, and in places sand, but typically is a firm and relatively resistant surface.

Backshore Plain

A low elevation plain exists behind the study area shoreline. The plain is comprised largely of the former Tobin-Yallock Swamp prior to its clearing and draining in the late 19th century. A combination of subsidence and compaction of the swampy sediments associated with drainage and introduction of livestock have likely resulted in a lowering of the elevations of the backshore plain. A large area of the plain is now located at elevations approximately equal to or less than the existing MHWS tidal plane in this region of Western Port (Figure 4-4) . The backshore plain is intersected by a network of levees/embankments and drains which are discussed further below.

Coastal Levees

Almost the entire shoreline of the study area is backed by a raised embankment that has been referred to generically as a 'coastal levee' in this study. It is, however, not necessarily clear whether all the ‘coastal levees’ were originally constructed specifically to prevent coastal inundation. Many of the embankments may simply be the result of the dumping of spoil associated with the construction of drains across the backshore plain. Nevertheless, the levees/embankments now form significant morphological features on an otherwise extremely flat and monotonous backshore environment and play a key role in limiting the extent of coastal inundation even under existing sea levels. Close examination of the LiDAR survey shows that the levee/embankment crests are generally constructed to approximately 3.0 m AHD.

Drains

The backshore plain is criss-crossed by a network of drains (Figure 4-3). The largest are the Yallock Creek and Lang Lang River drains which have well-defined entrances to Western Port. A large number of additional minor drains have been constructed and many of these drains empty into the larger Yallock Creek and Lang Lang River drains, however, multiple small drains empty directly into Western Port via small causeways and pipes. The drains are important features as they provide potential conduits to allow tidal influence and coastal inundation to propagate very significant distances landward of the main shoreline along this study area.

4.1.3 Hydrodynamic Setting

This section summarises aspects of the hydrodynamic setting of the Lang Lang study area relevant for the assessment of coastal erosion and inundation hazards.

Waves

Waves along the study area are generated locally within the northern and eastern arms of Western Port. The confined fetches and shallow depths in this region of Western Port result in relatively small waves, generally less than 0.5m (Figure 4-6). Wave directions are observed to vary with the seasonal wind climate, such that the majority of waves arrive from the north-west in winter and from the south-west in summer.

Due to the large tidal range and low profile shore platform, the amount of wave energy that impacts the shorelines is very strongly modulated by the phase of the tide.

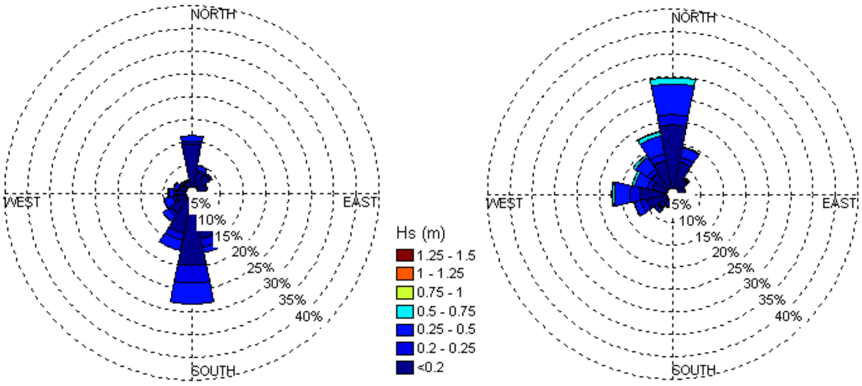

Figure 4-6 Wave Roses Summer (2003), Winter (2003)

Storm Tides

The study area shoreline is subjected to the highest absolute storm tide levels in Western Port due to the resonance of the astronomical tide in this region, as well as additional wind and wave setup from strong westerly quarter winds that frequently accompany large storm surge/coastal trapped wave events in Bass Strait.

4.1.4 Sediment Movements

Water and sediment movement in this location is dominated by flood and ebb tide areas and there are extensive intertidal flat system containing a web of minor channels. Intertidal sedimentation processes associated with the channels dominate, resulting in significant deposition of suspended mud and only limited deposition areas for sand. Catchment sediment inputs have affected this area although volumes appear to be reducing (S. Brizga & Associates, 2001). Significant volumes of muddy sediments are being introduced to the system by the continued erosion of the eastern shoreline.

4.1.5 Coastal Structures

There are few lengths of the study area shoreline which have been modified by the formal construction of coastal structures. The existing coastal structures as defined by the DEPI coastal asset database are shown in Figure 4-7. Informal coastal structures existing along additional sections of this shoreline but are not documented within any existing coastal asset databases.

The main coastal structures shown in this location are rock revetments or walls located along the shoreline at Jam Jerrup, as shown in Figure 4-8. During the site visits in February and May 2013, it was noted that the structures comprised a range of materials, with varying levels of structural stability. Some sections of wall show signs of collapse.

Data sources : DEPI Vicmap, Western Port Coastal Hazard Assessment Project
Imagery : December 2009

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Figure 4-7 Extent of the Coastal Structures in the Lang Lang Study Area

Figure 4-8 **Coastal Structures along the Shoreline at Jam Jerrup**

4.1.6 Historic Shoreline Change

A time series of three historical aerial photographs and survey plans of the Lang Lang study area covering the period from 1889 to 2010 were sourced by the study team.

Analysis of historic shoreline change in the study area was undertaken by digitising the inferred stable vegetation line for each aerial photograph/survey. The digitised shorelines were then overlayed, allowing for trends in shoreline position to be identified.

Figure 4-9 displays the historical shoreline analysis for Lang Lang. The following relevant changes to the Lang Lang shoreline are discussed below:

- The shoreline has receded along the entire length of the study area over the available historic time series, with not a single location along the shoreline observed to have undergone accretion or at the least, remained stable.
- The extent of shoreline recession is generally relatively consistent along the study area with moderately larger extents of recession observed within some small embayments.
- The total recession distances between the 1889 and 2010 time series are generally in the order of 70-80 m with a number of locations exceeding 100 m. Over this timeframe, these recession distances correspond to annual average rates of recession of approximately 0.6-0.7 m/year and a maximum rate at some locations approaching 1.0 m/yearr.

Data sources : DEPI, Western Port Coastal Hazard Assessment Project
Imagery : DEPI 1889, 1947, 1977, 2009

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Figure 4-9 **Analysis of Historical Shoreline Variability along Lang Lang Representative Location**

4.2 Local Hazard Assessment

The sources of potential hazards and the extent of uncertainty relating to the assessment of the impact of sea level rise on these hazards in the study area are analysed and discussed in the following sections. The sources of potential hazards have been grouped under the broad categories of erosion and inundation hazards for ease of understanding and for the purposes of mapping hazard extents.

4.2.1 Erosion Hazards

This section details the key erosion hazard mechanisms and interactions relevant to this representative location. Further background definitions and conceptual models of the different erosion hazard mechanisms described in this section are detailed in the accompanying Erosion Hazards Report (Report 5).

Future Rates of Cliff Recession

Active shoreline recession is an ongoing source of hazard along this study area shoreline. Recession of this coastline more than likely pre-dates European occupation of Western Port. Prior to draining and clearing swamp scrub existed along the shoreline and coastal margin and would have provided some stability and resistance to the exposed earth materials making up the low cliff morphology. This would probably have resulted in lower rates of overall shoreline recession than experienced at present. Following the clearing and draining of the Tobin Yallock swamp, the earth material comprising the shorelines has become more vulnerable to erosion.

The erosion of the low earth cliffed shorelines is a result of direct wave action and processes involving wetting and drying of the cliff material as a result of tidal submergence/emergence, wave splash, runoff and groundwater outflows. These processes result in desiccation of the clay and organic materials which make up the low earth cliffs. Shrinkage and stress release fractures in the exposed material are susceptible to detachment by wave pressure during surges causing detachment of irregular blocks leading to slope failure and eventual dispersal of the blocks by wave run up and backwash (Figure 4-10). For further information on potential groundwater hazards in this area associated with sea level rise, refer to Part A, Report 5.

Figure 4-10 Example of Cliff Overhang and Detached Blocks

Using aerial photographs, Tomkins and McLachlan (2013) showed that between 1947 and 2010 the headlands had become more rounded and the crenulations less pronounced, implying that headland recession was active, resulting in a smoother coastal outline in plan. Tomkins and McLachlan also undertook field monitoring of erosion rates at a site on this shoreline, and over the period of their monitoring (Dec 2012 to March 2013), annualised cliff recession in the order of 0.36 m/year was recorded, with some recession in places up to 1.2 m/year. These rates are consistent with the “long term” rates indicated by comparisons of maps and aerial photographs discussed previously in Section 4.1.6.

Rates of cliff recession on these soft rock type shorelines could be expected to increase at a rate that is approximately proportional to the change in wave energy that the cliffs are subjected to due to the impact of sea level rise (Trenhaile, 2011). Sea level rise will increase the duration of tidal inundation and depths available for wave energy to impact the cliffs. Additional wave transformation modelling has been undertaken along the study area shoreline to refine and confirm the estimated proportional change in wave energy that the earth cliff shorelines could be expected to receive for each relevant sea level rise scenario.

The average percentage change values for each of the three sea level rise scenarios from this modelling resulted in very similar estimates to those developed in the Part A broad scale assessment for this area and do not change the predicted future rate of recession of the low earth cliffed shorelines developed in Part A, and displayed below in Table 4-1.

Table 4-1 Summary of Predicted Future Rates of Shoreline Recession on Low Earth Cliffed Shorelines

Location	Parameter	Sea Level Rise Scenario			
		Existing	+0.2 m (2040)	+0.5 m (2070)	+0.8 m (2100)
Lang Lang	Percentage Change in Annual Cumulative Wave Energy Relative to Existing Sea Level (%)	-	135	190	240
	Annual Shoreline Recession Rate (m/yr)	0.4-1.2	0.5-1.6	0.8-2.3	1.0-2.9
	Cumulative Recession (m)	-	13-39	32-98	59-176

Backshore Tidal Inundation

The estimated cliff recession rates assume that the majority of wave energy will continue to be expended on the cliff face with increasing sea level rise. However, due to the very low backshore elevations along the majority of this study area, certain increments of sea level rise could be expected to result in frequent, fortnightly tidal inundation of the backshore regions. Once this frequent tidal inundation process is consistently initiated across the backshore areas, the assumptions relating to the future rates of cliff recession are not considered valid and a much more dynamic and variable shoreline erosion process could be expected to be initiated.

Backshore inundation initiated by coastal water level variations is a process that occurs occasionally under present mean sea level conditions along this section of shoreline, although the landward extent of inundation remains relatively limited. An example of minor backshore inundation in the study area is displayed in the photos in Figure 4-11 taken from the CSIRO monitoring project (Tomkins and McLachlan, 2013). The photos show a section of shoreline at low and high tides on 13 May 2013. The peak water level at Stony Point corresponding to the afternoon high tide on this date was approximately 1.4 m AHD. This water level could be expected to be exceeded multiple times in any one year on average and is approximately 0.7 m below the 1% AEP storm tide at Stony Point. Figure 4-11 is considered to highlight the potential for significant backshore inundation to develop along this section of the study area even under modest increases in mean sea level conditions.

13 05 2013 9:30am

13 05 2013 3:30pm

Figure 4-11 Example of Backshore Inundation along the Low Earth Cliffed Shorelines

An assessment of the potential sea level rise scenario that would initiate frequent and extensive backshore inundation along the study area can be undertaken by analysis of the digital elevation model of the study area shoreline. Figure 4-12 displays a typical cross section (profile B in Figure 4-4) through the study area shoreline, coastal levee and low elevation backshore plain relative to the estimated MHWS tidal planes under existing mean sea level and for each sea level rise scenario. The cross section displayed in Figure 4-12 is considered very typical of the cross sectional profile observed along the length of this shoreline.

From Figure 4-12 it can be seen that the narrow coastal reserve between the cliffed shoreline and the coastal levee is generally located at an elevation of between approximately 2.0 m and 2.2 m AHD. Comparison of these elevations with the predicted MHWS spring tidal planes in this region of Western Port demonstrate that for sea level rise scenarios of approximately +0.5 m (2050) or greater, frequent and extensive backshore tidal inundation could be expected to develop. Once this frequent, tidal inundation process is initiated, the frequent flood and ebb tide flows across the backshore landscape could be expected to result in relatively rapid dissection of the shoreline as tidal channels develop and expand in response to the extent of frequent backshore tidal inundation.

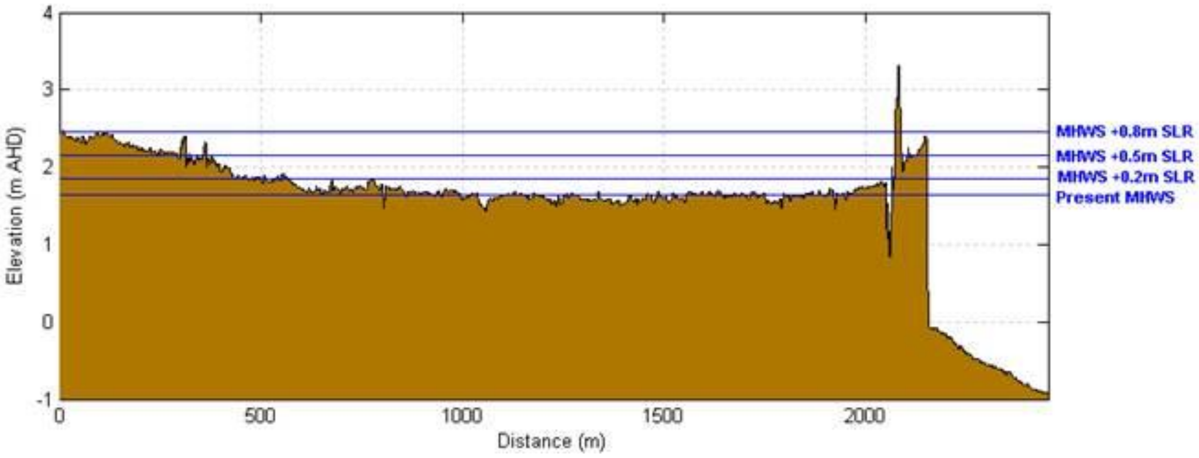

Figure 4-12 Typical Topographic Section through Study Area in Relation to MHWS Tidal Planes

Precise predictions as to how the shorelines could be expected to evolve in response to this step change in the processes governing shoreline erosion are not possible based on available knowledge or predictive tools. However, without the presence of levees and embankments, the maximum landward extent of shoreline erosion hazards that could develop on this shoreline would be expected to be closely controlled by the relationship between the MHWS tidal plane and the backshore topography.

Table 4-2 displays the predicted MHWS tidal plane elevations for Lang Lang for the various sea level rise scenarios. Intersection of these tidal plane elevations with the topography of the study area provides an estimated upper maximum extent of shoreline erosion hazards that could be observed for this area.

In practise however, the evolution of these shorelines will largely be influenced by the extent to which the existing informal coastal levees and embankments are adapted to more frequent and higher coastal water levels and this remains a key source of uncertainty for assessing the potential extent of future erosion hazards along the study area.

Table 4-2 Predicted MHWS Tidal Plane Elevations for Lang Lang

	Sea Level Rise Scenario			
	Existing	+0.2 m (2040)	+0.5 m 2070)	+0.8 m (2100)
MHWS Tidal Plane (m AHD)	1.6	1.8	2.2	2.5

4.2.2 Inundation Hazards

Storm Tide Inundation

In addition to the frequent tidal driven backshore inundation due to sea level rise in the study area, extreme storm tide conditions may generate even more extensive, although infrequent, inundation along this section of shoreline.

To further refine the predicted inundation extents of the 1% AEP storm tide and sea level rise scenarios, the hydrodynamic model mesh was refined to capture in more detail the small scale topographic details associated with the many informal levees and embankment and channel features within the study area.

The presence of the informal levees and embankments significantly influences the extent of coastal inundation during a 1% AEP storm tide scenario under existing mean sea level. However, with progressive increases in mean sea level, the extent of overtopping of the levees and embankments increases significantly such that for the +0.8 m sea level rise scenario (2100), the maximum extent of coastal inundation in the study area is only moderately sensitive to the presence or absence of these features.

Figure 4-13 displays the sensitivity of the predicted 1% AEP storm tide inundation extent under existing sea levels with and without sections of the informal coastal levees and embankments. The informal levees and embankments that were considered were identified from the topography and are also shown in the figure. It can be seen that under existing mean sea level conditions, the 1% AEP storm tide scenario would potentially generate very significant inundation extents within the study area without the presence of these structures.

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\1%AEP_InnundationComparison_ExistingMSL_NoCoastalLevees.mxd

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Figure 4-13 **Estimates of Coastal Inundation under Existing Mean Sea Level Conditions with and without Informal Coastal Levees and Embankments**

4.2.3 Evaluation of Sources of Uncertainty

The sources and significance of uncertainty associated with the assessment of the potential future extent of inundation and erosion hazards in the study area are discussed below:

Rates of Shoreline Recession

The Lang Lang study area is an actively receding shoreline and the physical processes and likely trajectory of change are reasonably clear. The potential extent of coastal hazards along this shoreline are not considered particularly sensitive to the estimated future rates of cliff recession. Rather, they are considered particularly sensitive to the potential extent and evolution of backshore inundation. As discussed below, this is in turn likely to be significantly influenced by the extent of the adaptation responses that may be adopted in relation to the informal coastal levees and embankments.

Informal Coastal Levees/Embankments

Informal adaptation works to counter past and present shoreline recession and inundation hazards have and may be currently being undertaken. Figure 4-14 displays an example of the realignment of a levee/embankment landward of the original levee that was apparently abandoned due to it being compromised by shoreline cliff erosion. In addition, informal shore protection works using a variety of materials and techniques occur along significant sections of the shorelines.

The potential extent of inundation and erosion hazards along the study area shoreline are therefore considered particularly sensitive to future adaptation responses, either by private landholders or through more strategic, Government Agency led interventions.

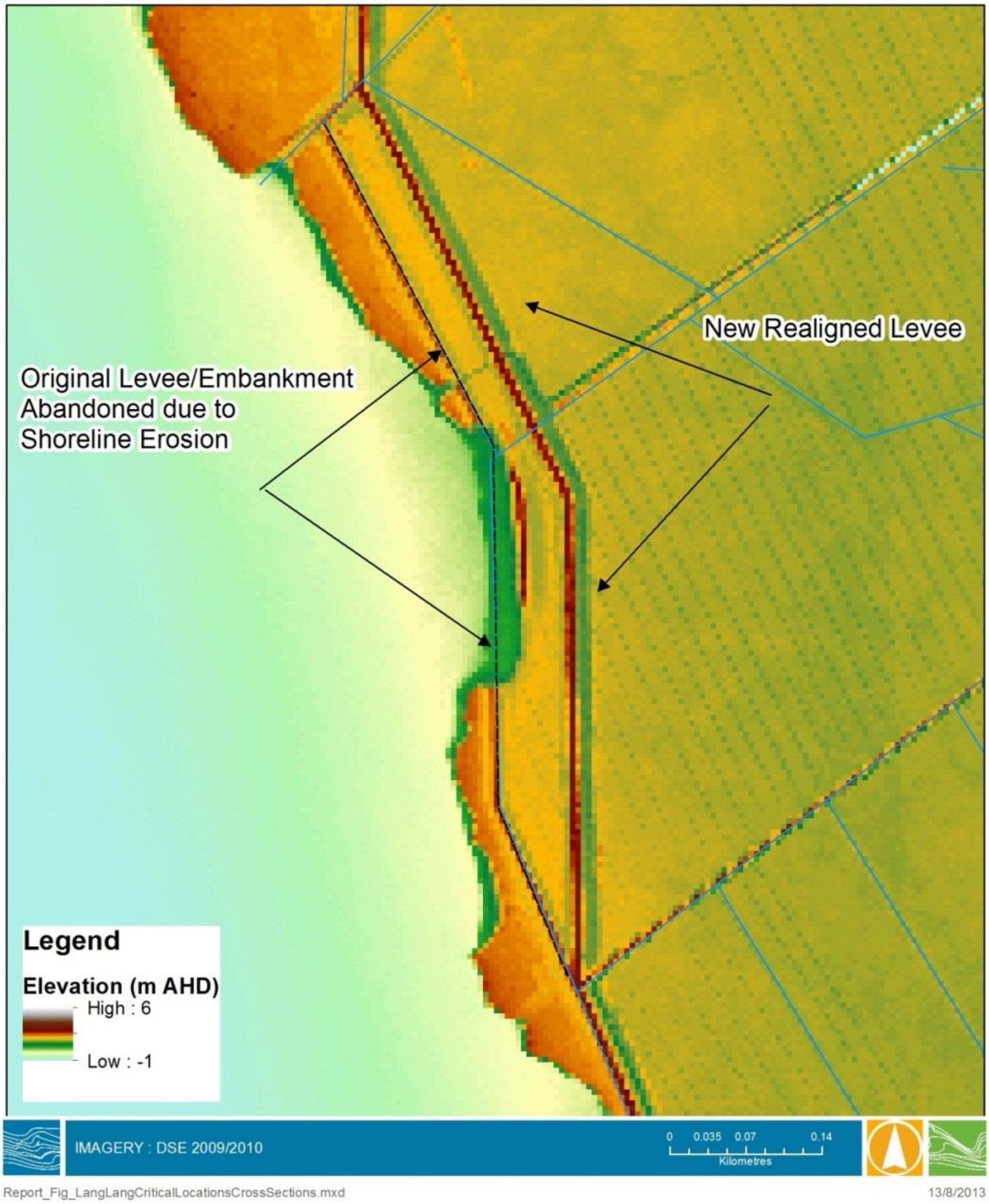


Figure 4-14 Example of Existing Coastal Hazard Adaptation Responses in the Study Area

The formal coastal structures, as defined within the DEPI coastal asset database, are limited in extent and provide localised protection again inundation and erosion hazards. These structures are currently in poor condition. Individually these structures provide limited local protection against erosion or inundation processes but do not impact upon the broader erosion or inundation processes across the study area and have therefore not been explicitly included within the hazard assessment. The effect of the informal levee structures discussed previously has the potential to more significantly affect the coastal hazards in this location.

It is recommended that an audit be conducted of all formal and informal structures along this shoreline, followed by a monitoring program be developed to record the conditions of both formal and informal structures and document any failures or stability issues arising in the future. Further more detailed design assessments of any structure would be required to determine likely failure conditions and design requirement under future sea level rise conditions. This is considered beyond the scope of the current assessment

Drain Networks and Outlets

Future management and adaptation of the extensive drain networks will also significantly influence the extent of potential backshore inundation. At present, multiple minor drainage outlets to Western Port occur through small culvert and causeway structures. Some of these minor drainage outlets have one way tidal gates to prevent ingress of coastal water (Figure 4-15). The potential for significant backshore inundation that could occur due to the propagation of coastal waters through unmanaged or poorly maintained drain outlets is considered another significant source of uncertainty.

Figure 4-15 One Way Tide Gate on Minor Drain Emptying to Western Port (Note poor condition) (GHD, 2010)

4.3 Local Coastal Hazard Mapping

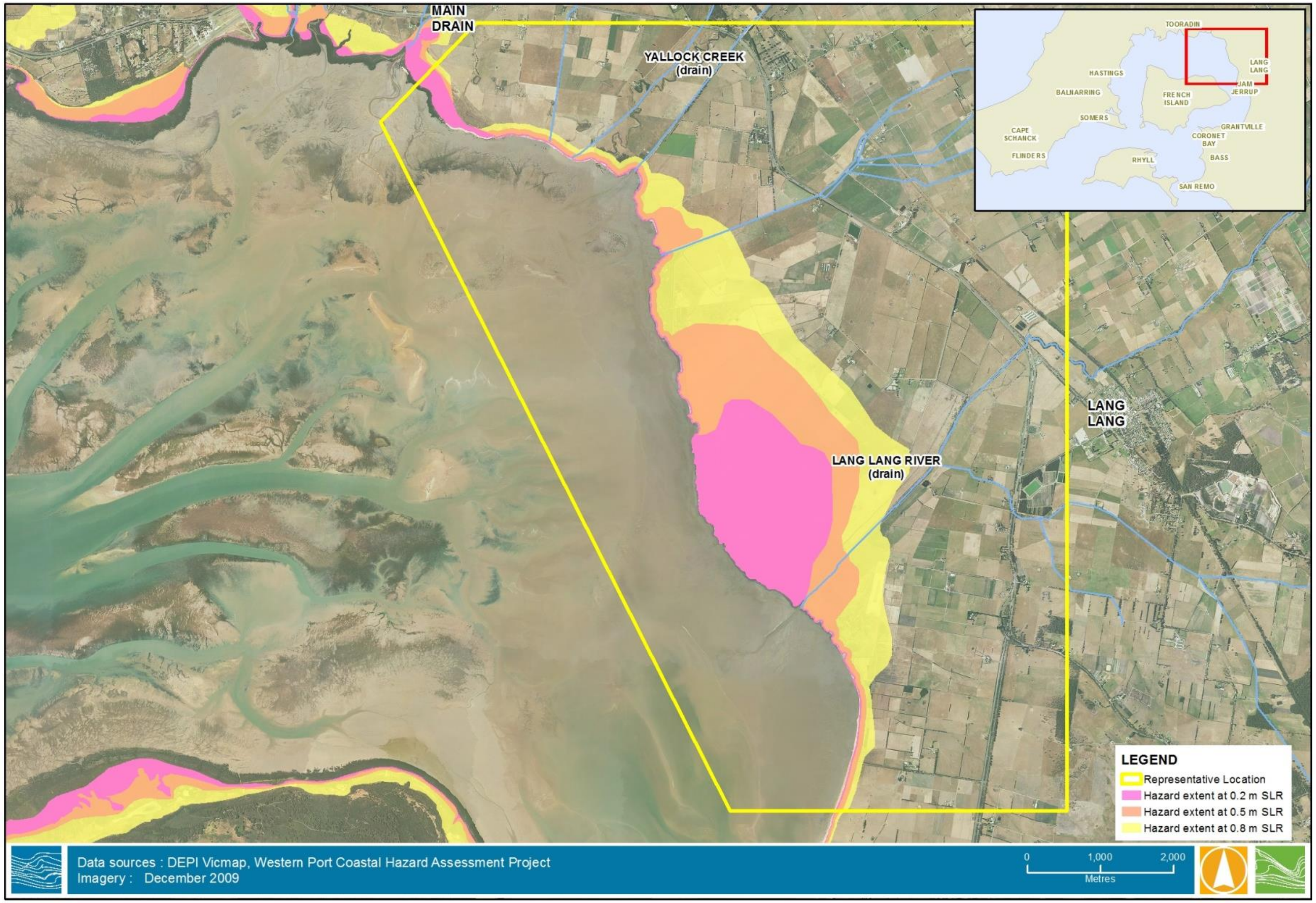
The local models and assessments of future shoreline change/hazards developed in the previous sections have been applied to refine the erosion and inundation hazard extents within the Lang Lang representative location.

Table 4-4 documents the final mapping method adopted and/or hazard extent that was mapped for the Lang Lang representative location. The inundation hazard extent was mapped based on the outputs from the hydrodynamic modelling which has been smoothed to match in with the local elevation model. As per Part A, all hazard extents are relative to a shoreline delineated relative to the MHWS tidal plane and subsequent variation in water level across Western Port.

Figure 4-16 displays the erosion hazard extents for the Lang Lang critical location, while Figure 4-17 displays the inundation hazard extents.

Table 4-3 Summary of Erosion Hazard Mapping Method/Extent for Lang Lang Representative Location

Shoreline Class	Hazard Type	Timeframe		
		2040	2070	2100
Low Earth Cliffed	Cliff Recession	The initial coastal hazard extent estimate is based on existing cliff recession estimates factored for increases in wave energy due to sea level rise. This hazard extent is then buffered from the existing shoreline based on the upper recession estimates provided in Table 4-1 and displayed below for each sea level rise scenario.		
		39 m	98 m	176 m
	Backshore Tidal Inundation	Where the predicted extent of the MHWS tidal limit without levees/embankments extended across low backshore plains along these shorelines, the hazard extent was extended around the tidal inundation extents predicted by the model for each sea level rise scenario.		



Data sources : DEPI Vicmap, Western Port Coastal Hazard Assessment Project
Imagery : December 2009

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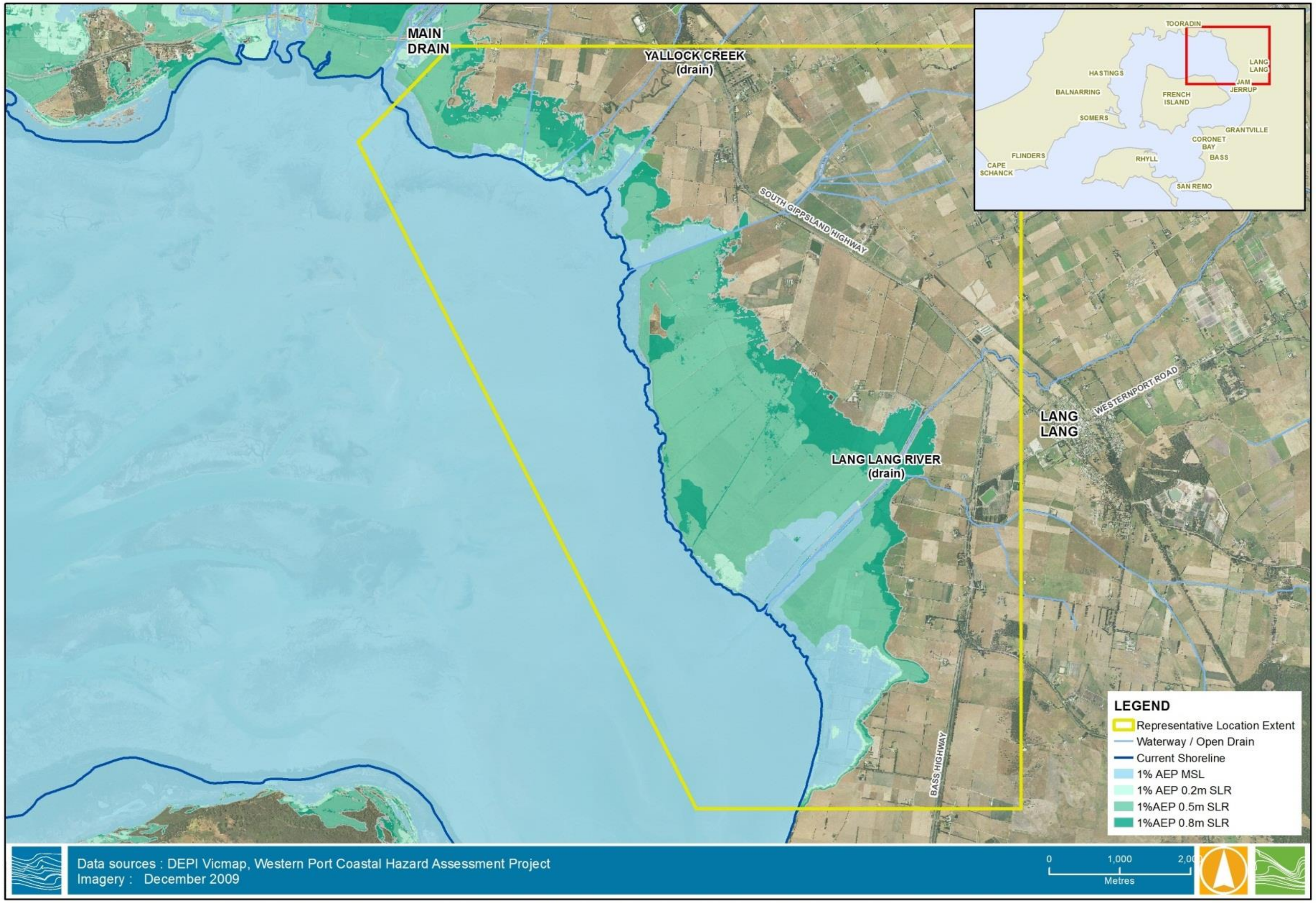
Figure 4-16 **Erosion Hazard Extents for the Lang Lang Representative Location**



Data sources : DEPI Vicmap, Western Port Coastal Hazard Assessment Project
Imagery : December 2009

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Figure 4-17 Inundation Hazard Extents for the Lang Lang Representative Location

4.4 Summary and Recommendations

A summary of the coastal hazards identified within the Lang Lang representative location along with a description of any associated uncertainty is provided in Table 4-4.

The following recommendations are provided from the results of the local coastal hazard assessment of the Lang Lang representative location:

- The extent of uncertainty associated with the potential erosion and inundation hazards within this location is considered low to moderate. The likely trajectory and extent of change is considered reasonably clear and can be predicted within practical limits. The extent of the coastal hazard risks within this location will, however, be strongly influenced by the extent of any adaptive responses to the levees/embankments and drainage infrastructure.
- Specific measures to manage coastal hazards due to sea level rise in this location could include the following:
    - A strategic approach to the management and future adaptation of the existing or future levee/embankment structures and drainage infrastructure including an audit of existing formal and informal structures along with the development of a long term monitoring program; and
    - Initiation of planning measures to minimise the risks within the hazard overlays.

Table 4-4 Example Coastal Hazard Risk Assessment Results for Lang Lang Representative Location

Hazard Category	Specific Hazard	Timeline	Likelihood	Uncertainty	Comments
Coastal Erosion	Cliff Recession	Present	Virtually Certain	**Low**	Ongoing high rates of cliff recession are virtually certain. The uncertainty relating to the trajectory and probable rates of change is considered low.
		2040	Virtually Certain		
		2070	Virtually Certain		
		2100	Virtually Certain		
	Backshore Tidal Inundation	Present	Unlikely	**Moderate**	Extensive backshore tidal inundation is increasingly likely towards the end of the century. The hazard impact as a result of backshore tidal inundation can be relatively confidently predicted; however uncertainty around future adaptive responses to levee/embankments in the study area significantly increases uncertainty around the future risks.
		2040	About as Likely as Not		
		2070	Likely		
		2100	Virtually Certain		
Coastal Inundation	Storm Tide Inundation	Present	Unlikely	**Moderate**	Extensive storm tide inundation is increasingly likely towards the end of the century. The hazard impact as a result of storm tide inundation can be relatively confidently predicted; however uncertainty around future adaptive responses to levee/embankments in the study area significantly increases uncertainty around the future risks.
		2040	About as Likely as Not		
		2070	Likely		
		2100	Virtually Certain		

5. RHYLL INLET AND SILVERLEAVES

5.1 Overview

The Rhyll Inlet and Silverleaves representative location shoreline extends from Erehwon Point at Cowes to Observatory Point and includes the shorelines of Rhyll Inlet as displayed in Figure 5-1. This study area incorporates a major sandy spit landform and extensive coastal wetland shoreline class as identified in the Part A assessment.

The characteristics and susceptibility of this shoreline to coastal hazard impacts is integrally related to the nature and variations in geology, geomorphology, and hydrodynamic setting. The following sections provide a broad overview of the nature and variability of the physical environment of the Rhyll Inlet and Silverleaves critical location as a basis for understanding the potential type, extent, and susceptibility of the shoreline to coastal hazards.

5.1.1 Geology

Hard Rock

Within the study area a marginal bluff marks the higher sea-level coastline associated with the last interglacial period and is split into three consolidated rock units; Mesozoic arkose, Older Volcanics basalt, and ferruginous Baxter Formation sandstone. These units form the southern boundary of the Cowes Embayment.

A seismic survey (traverse shown on Figure 5-2) showed that the depth to basalt (below Quaternary sediments) increases rapidly northwards from zero in front of the abandoned marine cliff to about 20 m near the present shoreline (Marsden and Mallett 1975). This is a buried shore platform and steeply sloping Pleistocene land surface and underlies the tidal channel system offshore of Cowes Bank.

Unconsolidated Sediments

During the late Quaternary period, the Cowes Embayment evolved from a broad open embayment to a tidal estuary complex largely filled with marine, coastal, aeolian and paludal-lacustrine deposits. The nature and distribution of these sediments is the basis of the subaerial, intertidal and sub-tidal geomorphology of the Cowes Embayment and is described further in Section 5.1.2.

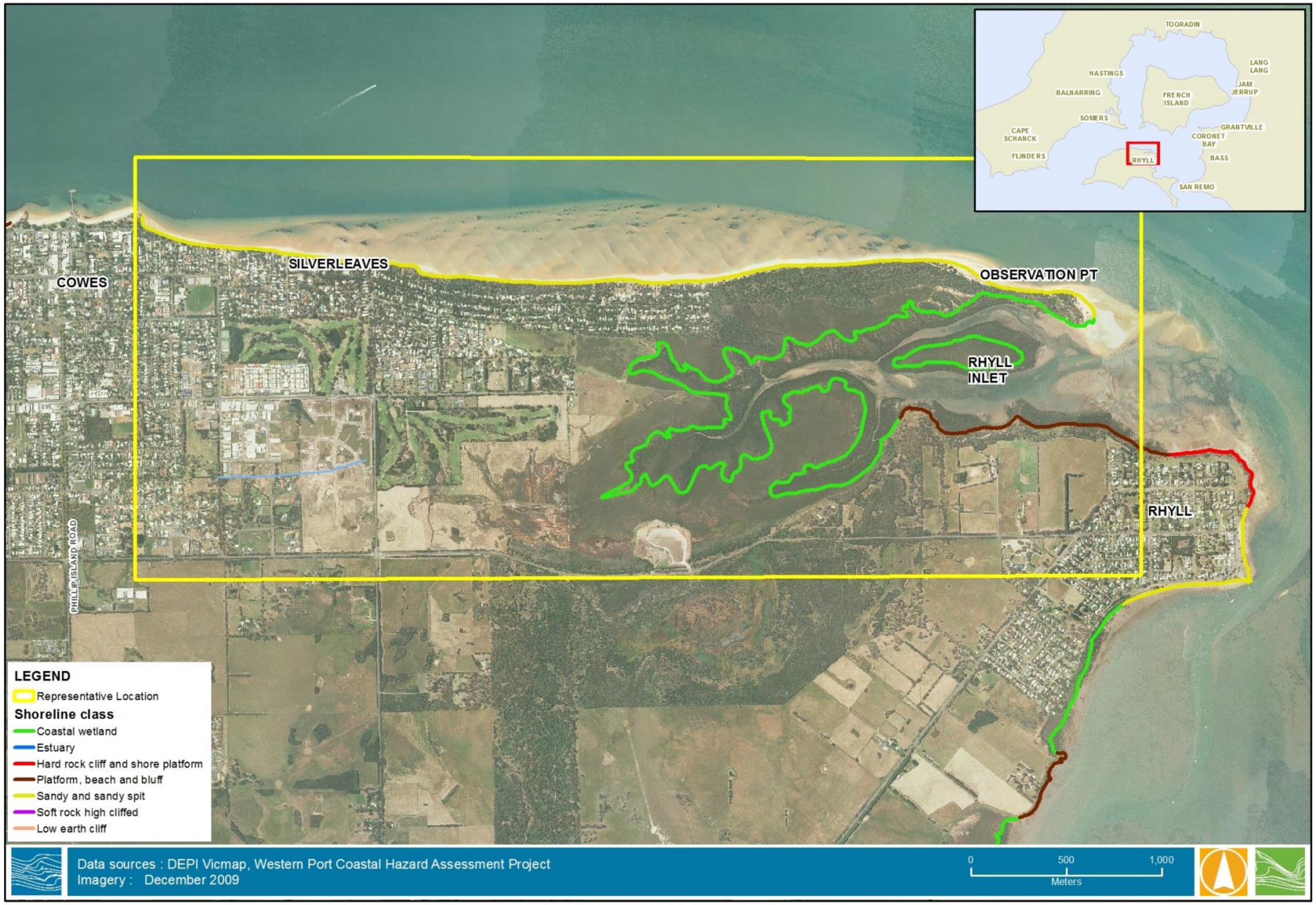

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Figure 5-1 **Rhyll Inlet and Silverleaves Study Area Locality Plan**

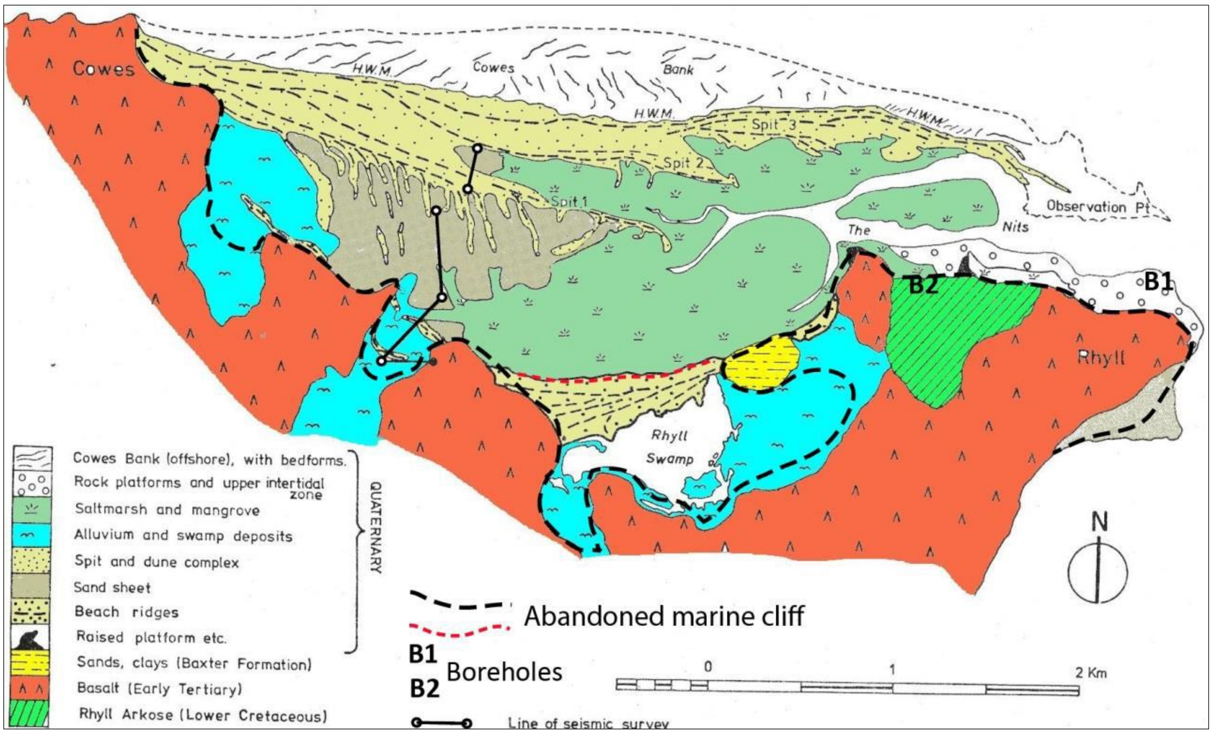


Figure 5-2 **Geology of Rhyll Inlet (after Marsden and Mallet, 1975)**

5.1.2 Coastal Geomorphology

The main relevant components of the coastal geomorphology of the study area are displayed in Figure 5-3 and described in more detail in this section.

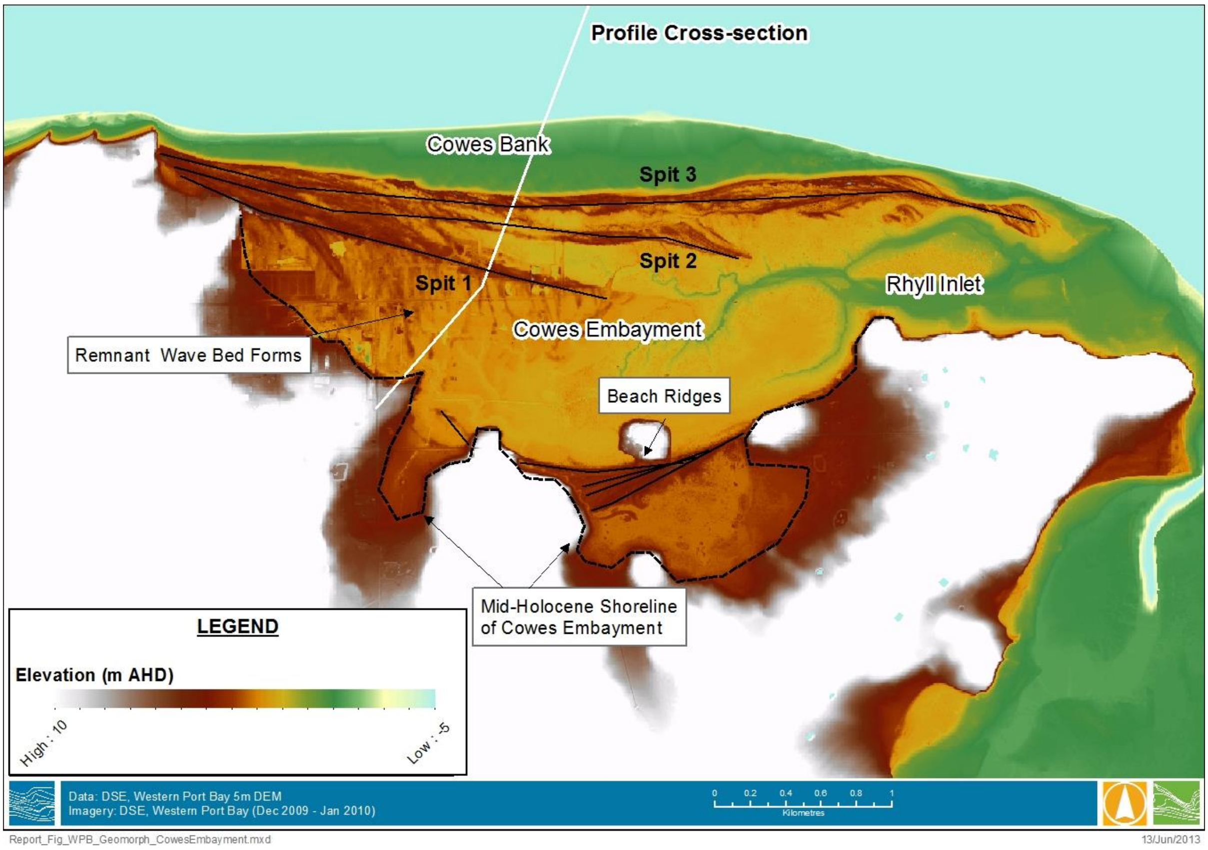


Figure 5-3 **Overview of Coastal Geomorphology of Rhyll Inlet and Silverleaves Study Area**

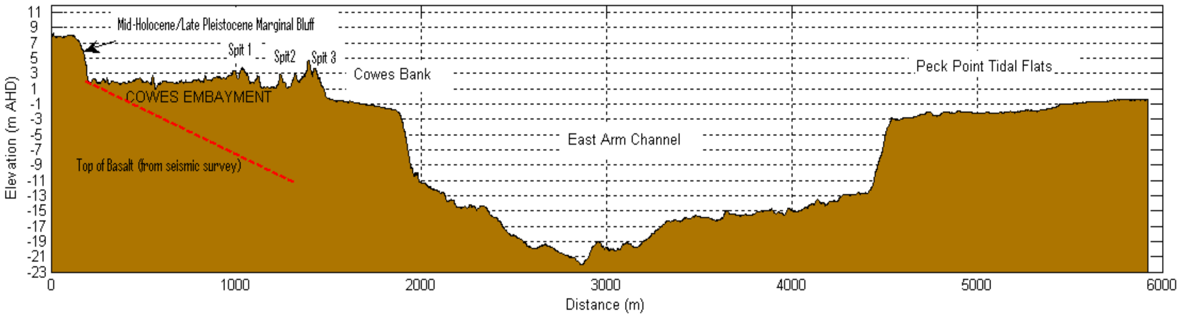


Figure 5-4 **Topographic Cross Sections through Cowes Embayment Study Area (Location Displayed in Figure 5-3)**

Cowes Embayment

The area between Cowes and Rhyll initially existed as an open embayment during Late Pleistocene interglacial high sea levels and was resubmerged during the mid-Holocene. The embayment was backed by sections of wave steepened cliffed coastline where the initial mid-Holocene shoreline intersected outcroppings of Older Volcanics Basalt, Mesozoic arkose and Baxter Formation.

The location of the initial mid-Holocene shoreline can be identified by the steep cliff and emerged shore platforms caused by wave action that occur around the margins of present day Rhyll Inlet. Beach ridge systems developed on the gently sloping shorelines of the embayment between the sections of wave steepened cliff coastline. The beach ridge systems subsequently sealed off minor inlets associated with the broader embayment. Rhyll Swamp was the most significant of these areas to be isolated from the broader embayment by beach ridge development.

Sandy Spits

Evidence of up to three stages of spit evolution are apparent in the morphology of the study area, with the distill end of these earlier spits still preserved in the lee of the most seaward, contemporary spit landform.

The earliest formed spit (Spit 1, Figure 5-3) extended more south easterly from the Erehown Point headland at Cowes across a shallow tidal lagoon with a sandy floor and became fixed by vegetation as beach ridges and foredunes up to 2.5 m high. Extending at a high angle (almost north-south) to the trend of the main ridges are low, closely spaced and relatively straight ridges without recurves. These may be relict sand-wave bedforms that predate the growth of Spit 1, indicating eastward flood-tide dominance (Marsden and Mallett 1975) and may be similar in origin to the sand bar features that exist on present day Cowes Bank.

At least two later phases of spit growth (Spit 2, Spit 3) are evident. These have distal recurves and their discontinuity and truncation indicates episodes of progradation and recession.

The conditions resulting in the distinct stages of spit evolution in the study area are not entirely clear, although they are likely to have been significantly influenced by the relative fall in sea level of approximately 1.5m to 2.0m since the mid-Holocene. Changes to sediment supply may also have contributed to the observed sequences of spit evolution. It has been speculated that the opening of the eastern entrance to Western Port at San Remo caused changes to the tidal dynamics of Western Port that resulted in stronger easterly flood tide dominance (Marsden and Mallet, 1975). Increases in the easterly flood tide currents may have increased the rate of sediment supply along the coastline and assisted in the easterly spit progradation.

It is clear from the spit morphology that the configuration of the coastline has been very dynamic over relatively recent geological history. The alignment of the spit and therefore coastline position is likely to be particularly sensitive to variations in sea level, or a combination of variations in sea level and sediment supply.

Cowes Bank

Cowes Bank is a complex geomorphic feature. The bank is generally intertidal with a low gradient, but the outer subtidal region slopes steeply into the main Eastern Arm channel and it is speculated that this may comprise a defined valley wall cut by the Cardinia Creek, Bunyip, Lang Lang and Bass Rivers that drained through the Eastern Arm lowland during Pleistocene low sea-level phases.

The intertidal zone of the bank shows a complex pattern of asymmetric and obliquely east-west facing sandwaves. The orientation and asymmetry of the sandwaves indicate dominant wave-driven origin, although relatively weak flood tide dominance may also be a contributing factor (Marsden & Mallet, 1974). The oblique components of the sand waves suggest there is a shoreward component to the sand waves that may be nourishing the shoreline, although the processes of sediment exchange between the Eastern Arm channel, Cowes Bank and the shoreline are not well understood.

It is considered that the relative elevation and width of the Cowes Bank strongly influences the distribution of wave energy along the spit shoreline and has significantly influenced the spit evolution and extent of underlying shoreline variability that is observed.

Rhyll Inlet

Rhyll Inlet represents the remaining area of marine influence in what was once a broad expanse of open water of the Cowes Embayment.

The succession of easterly prograding sand spits gradually diminished marine influence in their lee and a succession of tidal inlets subsequently developed and marine influence was gradually reduced within the embayment. Colonisation by mangroves and saltmarsh trapped and consolidated sediments and prograded the shorelines within Rhyll Inlet such that today the open water area is confined to a small number of tidal channels.

5.1.3 Hydrodynamic Setting

This section summarises aspects of the hydrodynamic setting of the local study area relevant for the assessment of coastal erosion and inundation hazards.

Waves

Waves in the study area are generated locally within the Eastern and Western Arms of Western Port. Wave directions are observed to vary with the seasonal wind climate, such that the majority of waves arrive from the north-west in winter (Figure 5-5). Due to the study area's northerly aspect, waves are generally very small in the summer months when winds are larger from the south-west to south-east.

The more persistent and larger waves from the north-west experienced in winter (compared to summer) contribute to the observed net easterly drift of sediment along the spit.

Small, long period swell waves propagating into Western Port from Bass Strait and refracting into the study area coastline are occasionally observed. Their influence on the study area is considered likely to be limited to Cowes Bank.

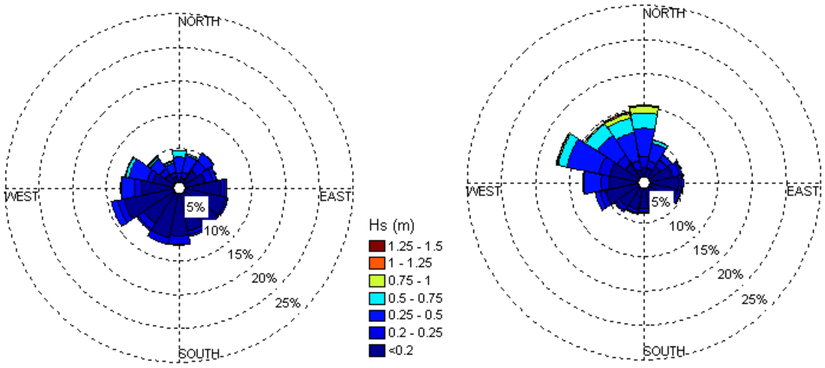


Figure 5-5 **Wave Roses – Summer (2003) & Winter (2003)**

5.1.4 Sediment Movements

The strong tidal currents and circulation patterns through the Western Entrance drive the movement of sandy sediment in this location. Channel sediment, offshore banks and coastal deposits are almost entirely sand. The combination of net flow and wave induced transport make the Western Entrance channel a zone of strong inward movement of sand, providing a supply to the beaches along the northern shore of Phillip Island.

5.1.5 Coastal Structures

A range of coastal protection structures currently exist along the western end of the contemporary spit shoreline. The structures have been constructed primarily to protect residential development that has been threatened by variability in the shoreline position associated with the migration of backshore sand lobes. The existing coastal structures as defined by the DEPI coastal asset database are shown in Figure 5-6. There is also a rock revetment associated with the groyne structures which while not included in the DEPI asset database, is a significant coastal structure in this location.

Figure 5-6 **Extent of the Coastal Structures in the Rhyll Inlet-Silverleaves Study Area**

The coastal protection structures include timber groynes, rock revetments and timber seawalls. The structures have been constructed to varying engineering standards and are currently in varying states of repair. A review of these structures, their condition and function, and future management options including the impacts of future sea level rise has been detailed in a previous study (Water Technology, 2011). An overview is provided herein.

Groynes

The timber groyne field extends east of Erehwon Point, and consists of a mixture of piked and horizontal slat and single and two row palisade construction types. At the time of the previous report (Water Technology, 2010) the protrusion of the groynes above the sand was limited, however as can be seen in Figure 5-7 the majority of structures are currently exposed over the significant sections of their length.

Figure 5-7 Timber Groyne Fields, east of Erehwon Point in January 2014

The structural condition of the groynes is now considered generally poor with the majority of the piles and slats displaying signs of significant deterioration. A number of groynes have been partly removed due to safety concerns associated with their poor condition following an audit by the Department of Sustainability (Parsons Brinckerhoff, 2008).

The effectiveness of the groyne fields along the study area in limiting shoreline recession and maintaining a wide beach is uncertain. As noted in the previous report, without the application of additional quantities of sand to the beaches via beach renourishment, the impact of the groynes in the study area is essentially a zero sum game, where the sand held onto the beach by one groyne is sand denied from the beach immediately downdrift.

The groyne fields are likely to be providing a potentially important function in limiting the level that the beach can lower directly in front of the rock revetment during periods of low sand supply and/or storm conditions. Loss of sand from the footings of the revetments is a common failure mechanism for these types of structures.

Rock Revetment

The rock revetment (referred to as “boulder ramparts” in Water Technology, 2011) have been constructed sporadically along the shoreline with the earliest placed between Erehwon Point and Rose Avenue by the Division of Ports and Harbours in 1947. East of Coghlan Road, a section of then eroding coastline was protected by a boulder rampart in 1977.

The rock revetments have been constructed from quarried basalt with a wide distribution of rock sizes and crest levels. In places wave action has dislodged smaller rocks from the structure and these are now lying seaward of it on the beach. Evidence of overtopping by wave action is visible, resulting in erosion behind the revetment and associated slumping in some isolated locations.

Figure 5-8 Example of rock revetment along Silverleaves shoreline

Based on the review of the historical shoreline changes detailed in Water Technology (2011), the construction of the rock revetment has in general been relatively successful in limiting the degree of shoreline erosion observed, particularly where the erosion has historically threatened private property and council road reserves.

One section of revetment that has resulted in undesirable impacts on the shoreline has been the section of east of Coghlan Road that was constructed in 1977. While this section of revetment has been successful in stopping shoreline recession along this section of shore, the armouring of this shoreline has subsequently locked up a significant volume of dune material that would have naturally been eroded and transported to supply the shorelines to the east. This has resulted in very significant terminal scour and shoreline recession to the east of this revetment since its construction in 1977.

The rock revetments are currently maintained informally by Bass Shire Council on a 6 month to annual basis.

Timber Walls

The Division of Ports and Harbours are believed to have constructed a timber wall between Rose Avenue and Coghlan Road in the 1940's. The PICS study showed beach profiles were lowered in front of the timber wall and high tides were flooding behind the timber wall and reflected waves were scouring the beach sand in front of the walls. Figure 5-9 shows the condition of the timber wall looking west towards Rose Avenue in 2010 and then again in January 2014. The photos show the shoreline is highly variable, with significant accretion shown in the 2010 photo shown by the burial of the wall and colonisation by vegetation, while more recently storm events during 2012/13 have resulted in erosion of sand and additional exposure of the upper part of the structure.

This is discussed in terms of the coastal processes in the following section, particularly the backshore sand lobe migration which dominates sand erosion and accretion along this shoreline.

August 2010

January 2014

Figure 5-9 Timber Walls between Rose Avenue and Coghlan Road

5.1.6 Historic Shoreline Change

Significant changes to the contemporary spit landform and shoreline position have been identified previously by Bird (1987). Two major areas of rapid change have included the infilling of a small embayment along the spit (eg. Silverleaves Bight) and an easterly extension of the spit at Observation Point. An oblique aerial photograph of the study area in 1947 shows the shallow embayment at Silverleaves as a bight cut through the ridges of Spit 3 and into Spit 2 (Figure 5-10). A comparable 2013 photograph shows that the bight has been filled with sand and the area now supports residential development. The easterly extent of the spit has also increased significantly between these two photographs and is now densely colonised by mature vegetation.

This qualitative assessment is in accord with the sequence noted by Bird (1987) using maps and vertical aerial photography. It is evident there has been a historical episode of substantial recession and accretion along this section of the contemporary spit and shoreline.

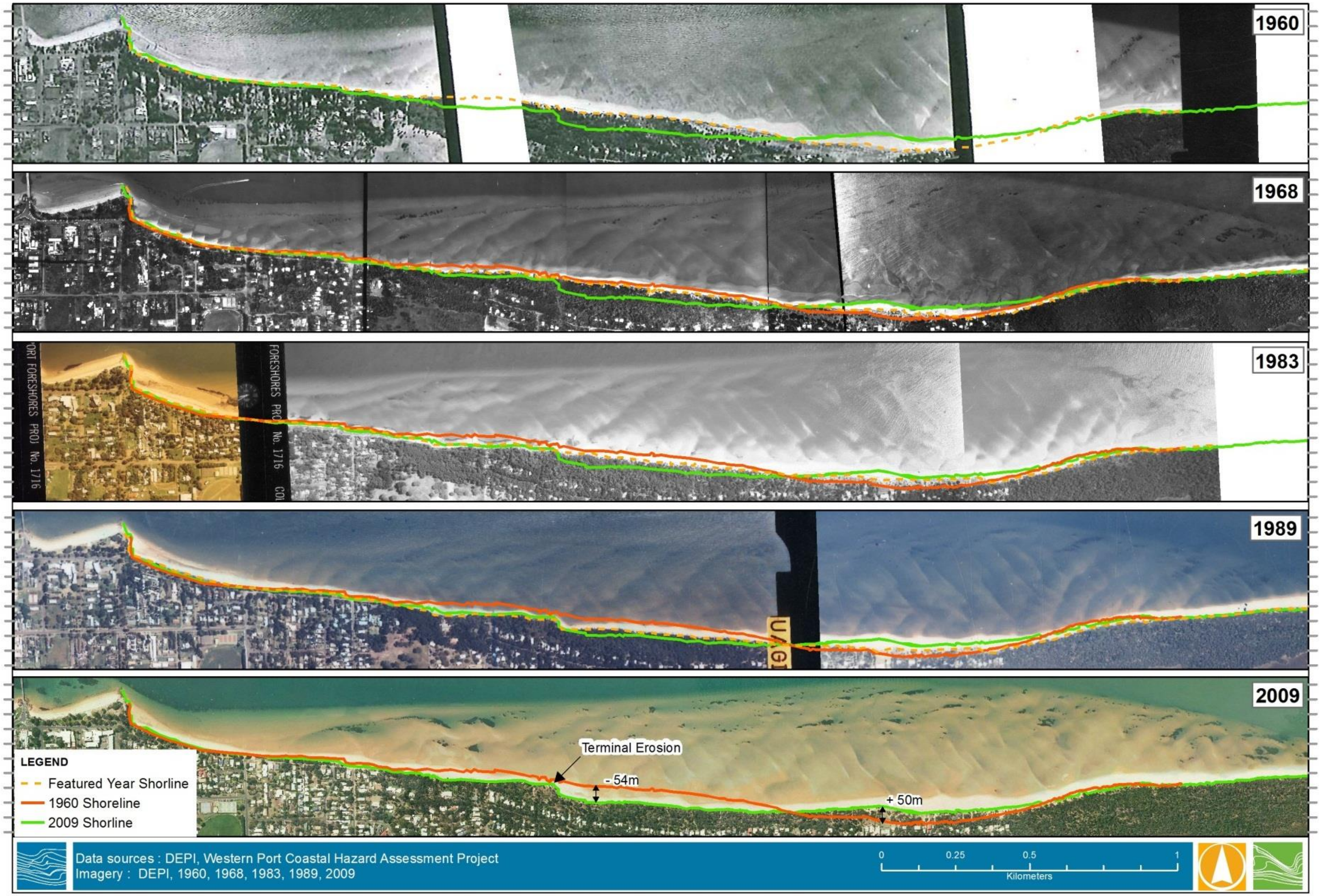
A series of geo-referenced historical aerial photographs of spit shoreline over the period 1960 to 2009 were also available for the study area from previous studies undertaken by Water Technology (Water Technology, 2010).

Analysis of historic shoreline change in the study area was undertaken by digitising the inferred stable vegetation line for each aerial photograph. The digitised shorelines were then overlayed, allowing trends in shoreline position to be identified. Figure 5-11 displays the historical shoreline analysis for the contemporary spit shoreline.

This analysis highlights the extent of underlying variability in the shoreline position at this location. The following relevant changes to the shoreline position are discussed below:

- The significance of the migration of backshore sand lobes is readily apparent with significant variability in shoreline position observed over the historical photographic record.
- Continued infilling of the Silverleaves Bight is apparent, however, shoreline protection works constructed to the west have resulted in acute terminal erosion impacts in this area.
- The maximum extent of shoreline variability observed over the photographic period is approximately 50 m.

Figure 5-10 Comparison of Silverleaves and Rhyll Inlet between 1947 (left) and 2013 (right)



Data sources : DEPI, Western Port Coastal Hazard Assessment Project
Imagery : DEPI, 1960, 1968, 1983, 1989, 2009

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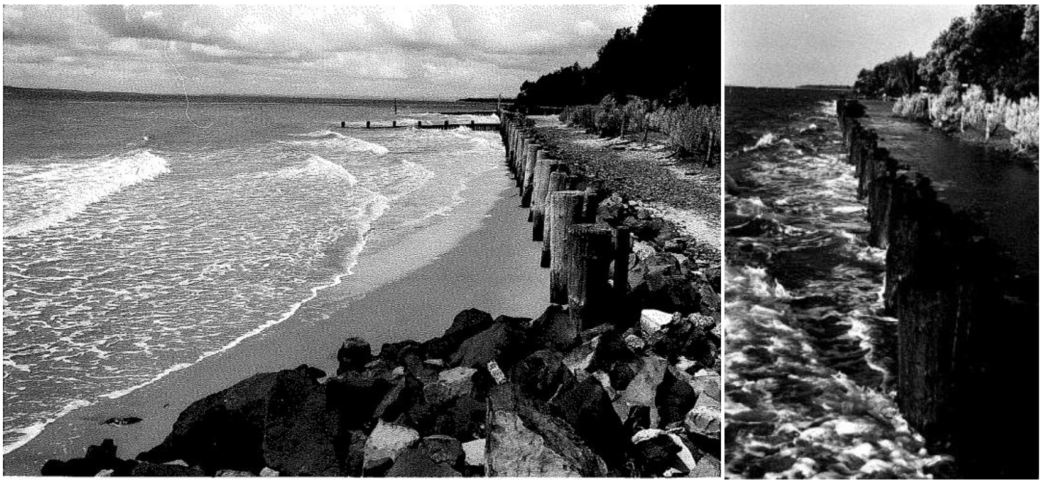
Figure 5-11 **Analysis of Historical Shoreline Variability along Spit Shoreline**

An example of the significance of backshore sand lobes along the spit shoreline can be appreciated in Figure 5-12 which compares photos taken in 1986 with contemporary photos (Water Technology, dated 2010) at the approximate same location, comparing the width and condition of shoreline east of Rose Avenue. In the mid-1980s this section of shoreline was undergoing significant shoreline recession; however, the longshore migration of a broad lobe of sand at this same location by 2010 has resulted in the development of a wide sandy beach. The differences captured in the photos highlight the decadal scale of variability that can be attributed to the migration of backshore sand lobes.



1986

2010 (Photograph provided by Derek Hibbert, Bass Coast SC)

Figure 5-12 **Comparison of beach profile at Rose Avenue between 1986 and 2010 showing the influence of backshore sand lobe migration along this shoreline**

5.2 Local Hazard Assessment

The sources of potential hazards and the extent of uncertainty relating to the assessment of the impact of sea level rise on these hazards in the study area are analysed and discussed in the following sections. The sources of potential hazards have been grouped under the broad categories of erosion and inundation hazards for ease of understanding and for the purposes of mapping hazard extents.

5.2.1 Erosion Hazards

This section details the key erosion hazard mechanisms and interactions relevant to this representative location. Further background definitions and conceptual models of the different erosion hazard mechanisms described in this section are detailed in the accompanying Erosion Hazards report (Report 5).

Backshore Sand Lobe Migration

The genesis of the easterly migrating backshore sand lobes along the contemporary spit shoreline is not well understood but may be initiated by the episodic injection of sand past Erehwon Point (Bird, 1989), as well as complex sediment transport dynamics and interactions with Cowes Bank. It is considered that a number of sediment sources and transport processes possibly combine to cause the high degree of observed shoreline variability over timescales ranging from 5 to 50+ years.

Longshore sediment transport modelling was undertaken along the contemporary spit shoreline to try to develop an understanding of the sediment transport budgets along the spit and test the sensitivity to sea level rise this century. The modelling was undertaken at three profiles along the contemporary spit shoreline and across Cowes Bank; Western, Middle and Eastern. The three cross shore profiles are displayed in Figure 5-13 and demonstrate the variability in the width of Cowes Bank along the spit shoreline.

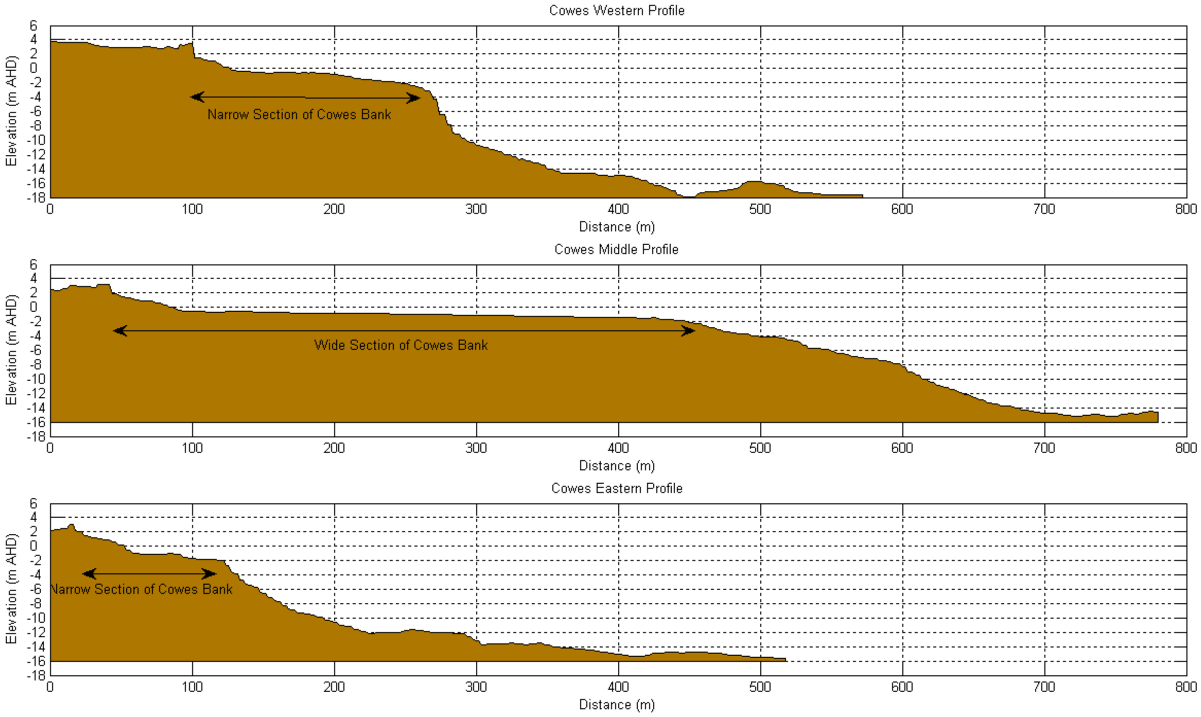


Figure 5-13 Three Cross-Section Profiles across Cowes Bank

The modelling was undertaken for a 12 month period of representative wave and currents (2003). Figure 5-14 displays the predicted cross shore distribution of the potential net longshore sediment transport rates along the three profiles under existing sea levels and for the +0.8 m sea level rise scenario. The positive transport values displayed in Figure 5-14 correspond to net eastward longshore transport. The model predicts that longshore sediment transport is largely confined to the nearshore and beach face along the spit shoreline. This prediction is not well supported by the other sources of evidence such as aerial photography which clearly reveal complex and dynamic sediment transport processes are occurring across Cowes Bank. This suggests the simplified longshore sediment transport model cannot resolve these processes.

The longshore sediment transport model does however provide some means of estimating the potential sensitivity of longshore transport rates on the spit shoreline to sea level rise.

Table 5-1 displays a summary of the gross and net potential transport rates under existing sea levels and for the +0.8 m sea level rise scenario. It shows that the net (eastward) longshore transport rates could increase by approximately 50% under this sea level rise scenario. The predicted increased sediment transport rates are attributed to the greater depths across Cowes Bank which allows larger waves to impact the spit shoreline. The amount of wave energy that impacts the spit shoreline is also modulated to some extent by the width of Cowes Bank which varies considerably along the length of the spit and is possibly contributing to the underlying shoreline variability observed in the historical aerial photography.

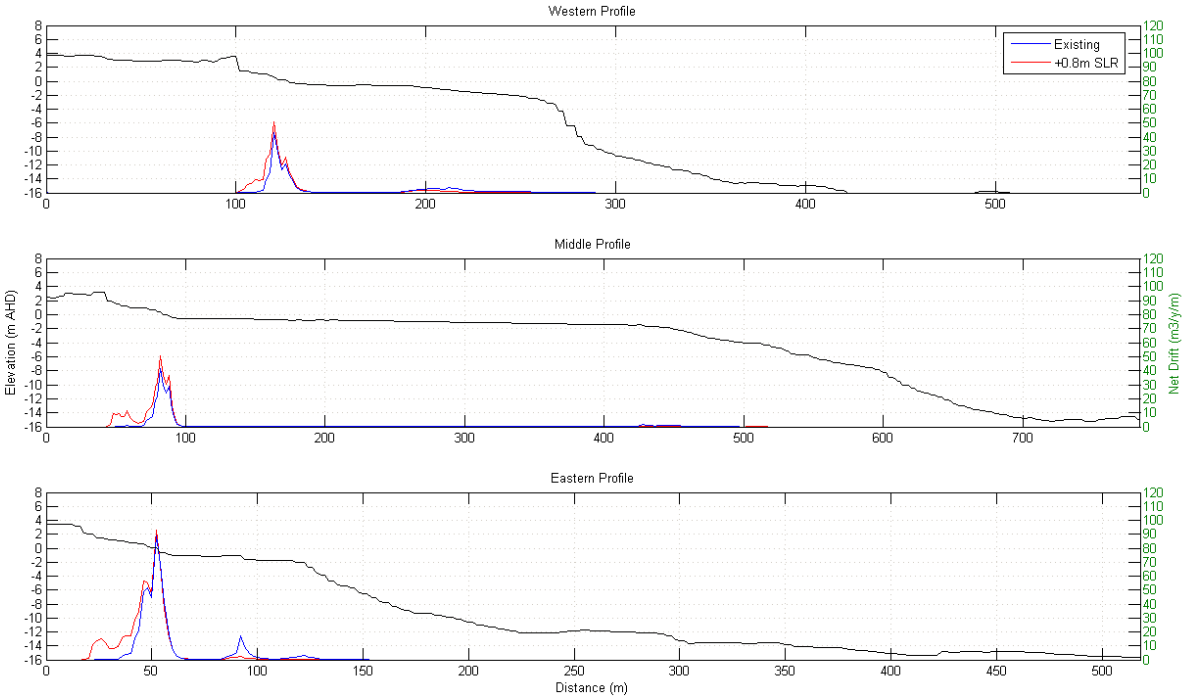


Figure 5-14 Predicted Cross Shore Distribution of Longshore Sediment Transport

Table 5-1 Impact of Sea Level Rise on Longshore Transport Rates

Location	Potential Longshore Sediment Transport Rates			
		Existing MSL	+0.8m SLR	% Increase
Western Profile	Gross	468	702	150%
	Net	402	578	144%
Middle Profile	Gross	590	882	149%
	Net	495	749	151%
Eastern Profile	Gross	1467	1890	129%
	Net	980	1185	121%

The change in longshore transport rates shown in Table 5-1 was used qualitatively within the erosion hazard assessment only in order to highlight the significant change in this landform that could be expected under sea level rise conditions.

Precise estimates of the extent of the coastal hazards that may impact the contemporary spit shoreline due to backshore sand lobe migration and associated longshore sediment transport processes is not possible. The following summarises the key sources of uncertainty in relation to predicting potential future rates of change to this shoreline due to backshore sand lobe migration/longshore sediment transport processes:

- The geomorphologic evolution of the spit landforms in the study area provides evidence of very major changes in the alignment of the successive spit landforms and these may be linked to variations in the rates of eastward sediment supply. Sea level rise will result in significant changes to the amount of wave energy that can impact the spit shoreline across Cowes Bank and the subsequent changes to sediment budgets along the contemporary spit shoreline may contribute to significant shoreline variability.
- While the extent of historical variability of the spit shoreline over the last approximate 50 years reveals significant changes to the spit alignment and subsequent extent of coastal hazard impacts, the historical shoreline variability has been complicated by the progressive construction of coastal protection works which have limited shoreline variability in some locations whilst aggravating erosion at other locations. The extent of historical variability cannot therefore be taken as evidence of an upper limit of change over 100 year future timeframes.

For these reasons, and until major additional investigations and analysis can be undertaken, it is considered to be appropriate to plan for the potential for significant coastal hazard impacts to the contemporary spit landform in the study area due to projected sea level rise this century. In particular, the geomorphic and historic evidence indicates that the eastern half of the contemporary spit landform is highly variable.

Equilibrium Profile Recession

As identified in the Part A assessment, the particular characteristics of the sandy spit shoreline type classes in Western Port are problematic for the application of the Bruun model for estimating equilibrium profile recession distances.

The wide and shallow Cowes Bank is a dynamic environment where sediment is actively being transported and mobilised and is likely to be intermittently supplying the shoreline with sediment. It is therefore not possible to identify a conventional depth of sediment closure for the contemporary spit shoreline. In addition, the geomorphologic evolution of the spit landforms in the study area provide evidence of very major changes in the alignment of the successive spit landforms. The evolution of successive spit landforms may be linked to relative sea level fall in the mid-Holocene. For these reasons, it is not possible to determine the relative influence of mean sea level on the contemporary spit alignment and its subsequent potential sensitivity to projected sea level rise this century.

It is possible that the profile response to sea level rise may be largely limited to the beach face and immediate near shore zone. Table 5-2 displays estimates of equilibrium profile recession based on the nearshore and beach face slopes of three cross sections across Cowes Bank and the contemporary spit displayed in Figure 5-13

From Table 5-2 it can be seen that consideration of the active slopes from these profiles results in relatively low Bruun Factors and subsequent recession distances with sea level rise. However, given the current level of uncertainty that exists in the potential process and magnitude of response of the contemporary spit shoreline to sea level rise, it is considered more appropriate to plan for conventional rates of recession on these shorelines. An assumed Brunn factor of 100 has been adopted for this location, recognising that the particular characteristics of the sandy shoreline at this location may result in relatively lower rates of sea level rise drive equilibrium profile recession than would be expected on more conventional sandy shoreline profiles. The Brunn factor adopted here is higher than that adopted for the Balnarring-Somers sandy shore location as this location shows evidence of much greater change and sensitivity to historical sea level variations.

Table 5-2 Equilibrium Profile Recession Estimates for Silverleaves Spit

Profile	Active Slope (degree)	Bruun Factor	Equilibrium Profile Recession for each Sea Level Rise Scenario		
			+0.2m (2040)	+0.5m (2070)	+0.8m (2100)
Western	3.4	17	3	8	13
	Adopted	**100**	**20**	**50**	**80**
Middle	3.0	19	4	10	15
	Adopted	**100**	**20**	**50**	**80**
Eastern	3.1	18	4	9	15
	Adopted	**100**	**20**	**50**	**80**

Loss of Coastal Wetlands

The relatively extensive expanse of mangrove and saltmarsh fringed shorelines of Rhyll Inlet could be expected to be significantly impacted by changes in inundation regime and depths due to sea level rise.

As has been previously noted, a range of uncertainties exist relating to the trajectory of response and potential rates of change on the coastal wetland fringed shorelines. Nevertheless, it is considered appropriate to plan for the extent of coastal erosion hazards on these shorelines by consideration of the intersection of the MHWS tidal plane extents, including sea level rise, along the coastal wetland fringed shorelines.

The western end of Rhyll Inlet is relatively unique in the context of Western Port as the mangrove and saltmarsh are not backed by bluffs or Cranbourne Sands and this potentially provides the ability for these vegetation communities to migrate landward in response to sea level rise.

Bluff Reactivation

Some of the southern sections of Rhyll Inlet are backed by bluffs of Older Volcanics Basalt, Mesozoic arkose and Baxter Formation. These bluffs were briefly reactivated as marine cliffs during the mid-Holocene and are now fronted by a depositional terrace associated with the saltmarsh and mangroves.

The various formations comprising the bluffs along the southern margin of Rhyll Inlet are all poorly to weakly consolidated and slope instabilities could develop were the bluffs to be oversteepened by wave action due to the loss of fringing vegetation due to sea level rise.

Given the historical precedent of major slope failures in cliffs of similar geology in Western Port and the fact that slope failures can occur with little to no warning, a conservative hazard zone for slope failures along the bluffs in this study area is considered appropriate.

Bluff reactivation is assumed to be initiated where the MHWS tidal plane, including sea level rise scenarios, intersects the base of the bluffs. When this occurs, the hazard extent due to potential slope instabilities has been considered to extend landward from the base of the bluff by a factor of 5 times the height of the bluff along these shorelines. This results in a final failure slope of approximately 11^0 along these bluffs where they are likely to be reactivated by sea level rise.

5.2.2 Inundation Hazards

Storm Tide Inundation

To further understand and asses the inundation risks associated with large storm tides inside Rhyll Inlet, and along the Silverleaves coastline, a detailed local scale hydrodynamic model of the area was developed, and is described in detail in Appendix A. The inundation extents from the 1% AEP storm tide scenarios from this model are displayed for the study area in Figure 5-16. Based on the results of this detailed modelling, the following comments on coastal inundation can be made:

- An isolated low point is potentially vulnerable to the ingress of storm tides centred around Dunsmore Road. A large storm tide event in 2009 caused some minor flooding of the seaward end of Dunsmore Road (Water Technology, 2010).
- The shoreline around Coghlan Road is particularly vulnerable to storm tide inundation and these areas are currently below the existing 1% AEP storm tide.
- Much of the potential inundation hazard to properties and infrastructure is actually likely to originate from within Rhyll Inlet. Storm tides are able to propagate with minimal attenuation into Rhyll Inlet and along the low fingers of land that exist between the successive spit formations towards the contemporary spit shoreline of Western Port.

5.2.3 Evaluation of Sources of Uncertainty

The sources and significance of uncertainty associated with the assessment of the potential future extent of inundation and erosion hazards in the study area are discussed below:

Coastal Protection Works

The development of coastal protection works within the study area now significantly influences the shorelines and the processes operating on them. The construction of rock revetments along significant lengths of the spit shoreline has limited the extent of shoreline variability due to backshore sand lobe migration, but has subsequently denied shorelines to the east of sediment, resulting in acute terminal erosion impacts. The rock revetments have been constructed to a range of standards and crest levels. Evidence of overtopping by wave action has been observed resulting in erosion behind the revetment and associated slumping in some isolated locations along the study area (Water Technology, 2010).

The future extent of erosion and inundation hazards along the contemporary spit shoreline will be influenced by the maintenance and adaptation of these structures to future sea level rise.

At present, the most eastward rock revetment along the spit shoreline ends near Sanders Road and significant terminal erosion scour has occurred on the shoreline to the immediate west. Continued terminal erosion hazard impacts could be expected to evolve on the shoreline west of this rock revetment and may increase the rate of change and extent of hazards locally. However, considering the timeframes and projected sea level rise scenarios to the end of this century, the scale of the potential coastal hazard impacts on these shorelines are not expected to be significantly influenced by terminal erosion associated with this rock revetment.

In assessing the local coastal hazards in this representative location a precautionary approach has been adopted with respect to the effect of coastal structures on the erosion hazards. In locations where a coastal structure (e.g. groynes, rock or timber revetment) is present that is currently or has in the past provided some form of protection against local erosion the determination of the erosion hazard zone does not consider the presence of the structure in limiting potential future erosion. This is because these structures may be damaged, or fail, during extreme storm events and the area vulnerable to erosion is then the same as if the structure had not been present. Erosion behind such structures may occur more quickly during future events if the structure is not maintained to an approved engineering design standard. As noted in Section 1 this approach is in keeping with that adopted in the recently released Queensland Coastal Hazard Technical Guidelines, EHP (2013).

It is recommended that a monitoring program be developed to record the conditions of the structures and document any failures or stability issues. Further more detailed design assessments of each structure would be required to determine likely failure conditions and design requirement under future sea level rise conditions. This is considered beyond the scope of the current assessment.

Backshore Sand Lobe Migration

Aspects of the genesis and processes that transport sediment as large longshore migrating sand lobes along these shorelines remain poorly understood. Their significance to the contemporary processes and variability that is observed on these shorelines cannot be understated and their influence could be expected to significantly influence future coastal hazard extents along these shorelines, regardless of projected sea level rise this century.

Sea level rise is expected to change the amount of wave energy that impacts these shorelines due to greater depths across Cowes Bank and this may increase the underlying variability of the sediment transport processes to the extent that it is considered conceivable that very significant changes to the contemporary spit alignment and configuration may be possible by the end of the century.

5.3 Local Coastal Hazard Mapping

The local models and assessments of future shoreline change/hazards developed in the previous sections have been applied to refine the erosion and inundation hazard extents within the Rhyll Inlet and Silverleaves representative location.

Table 5-3 documents the final erosion mapping method approach and/or the hazard extent that was mapped for the Rhyll Inlet and Silverleaves representative location. The inundation hazard extent was mapped based on the outputs from the fine scale hydrodynamic modelling which has been smoothed to match in with the local elevation model. As per Part A, all hazard extents are relative to a shoreline delineated relative to the MHWS tidal plane and subsequent variation in water level across Western Port.

Figure 5-15 displays the erosion hazard extents for the Rhyll Inlet and Silverleaves, while Figure 5-16 displays the inundation hazard extents.

Table 5-3 Summary of Erosion Hazard Mapping Method/Extent for Rhyll Inlet and Silverleaves Representative Location

Shoreline Class	Hazard Type	Timeframe		
		2040	2070	2100
Sand and Sandy Spit	Equilibrium Profile Recession	Hazard extent equivalent to a Bruun Factor of 100 as per below.		
		20m	50m	80m
	Backshore Sand Lobe Migration	2100 hazard extent extended to cover the eastern end of the contemporary spit landform due to its potential susceptibility to major hazard impacts and reconfiguration.		

Shoreline Class	Hazard Type	Timeframe		
		2040	2070	2100
Coastal Wetland	Loss of Coastal Wetland	The hazard zone was determined by intersection of the modelled MHWS tidal plane extent for each sea level rise scenario with the digital terrain model (DTM). Where they intersect provides an estimate of the landward extent of the mangrove fringe. Where the predicted MHWS tidal plane intersected steeper backshore terrain associated with bluffs, the hazard extent was truncated along this interface.		
Platform Beach and Bluff	Bluff Reactivation	Where the MHWS tidal plane extent intersected the base of the bluff, the hazard extent was buffered landward as a function of the height of the top of the bluff/tan (11^{o}) as a provision for slope failures (Landward hazard distance effectively 5 times the cliff/bluff height). The slope failure hazard zone is constant for all sea level rise scenarios.		

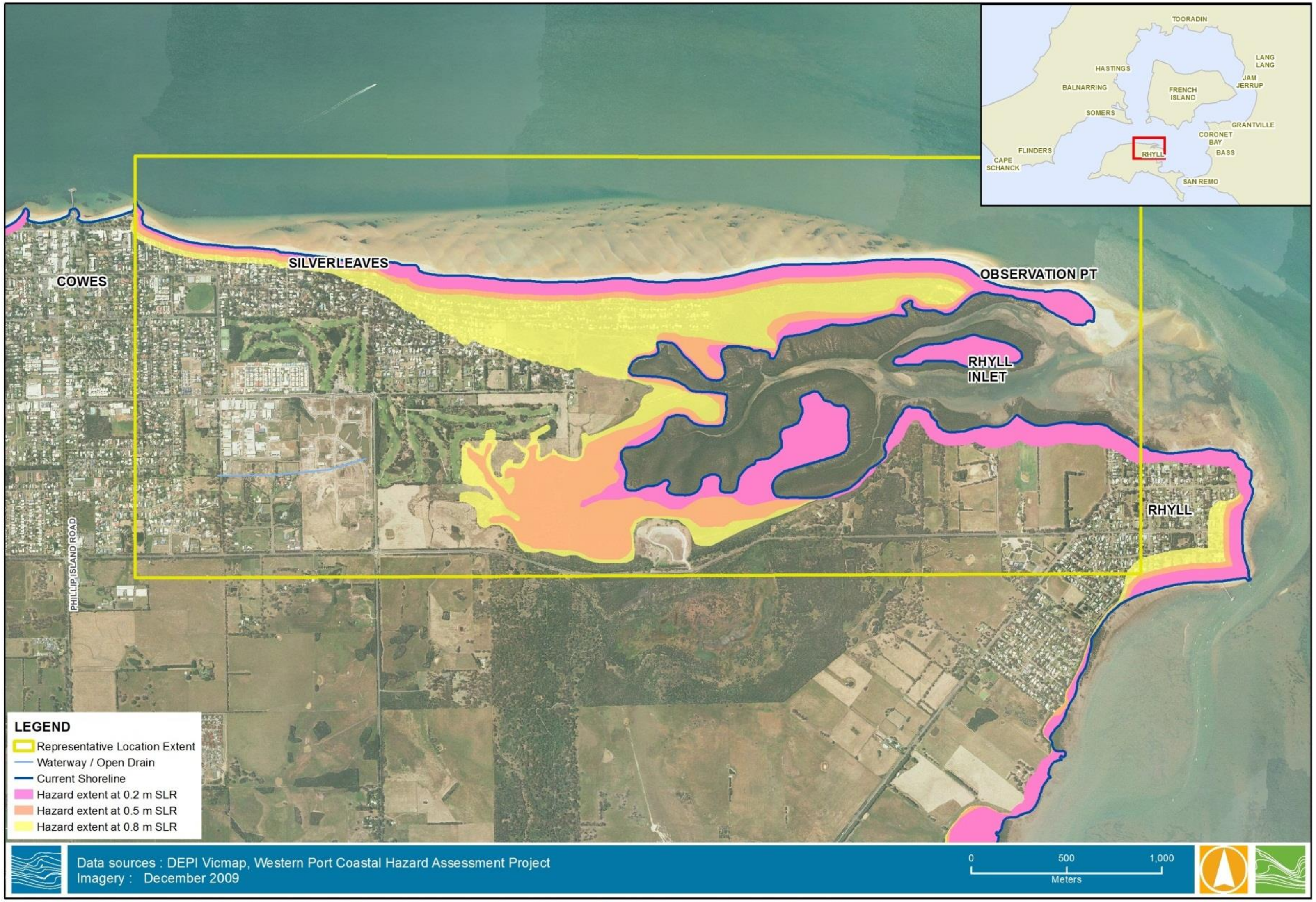


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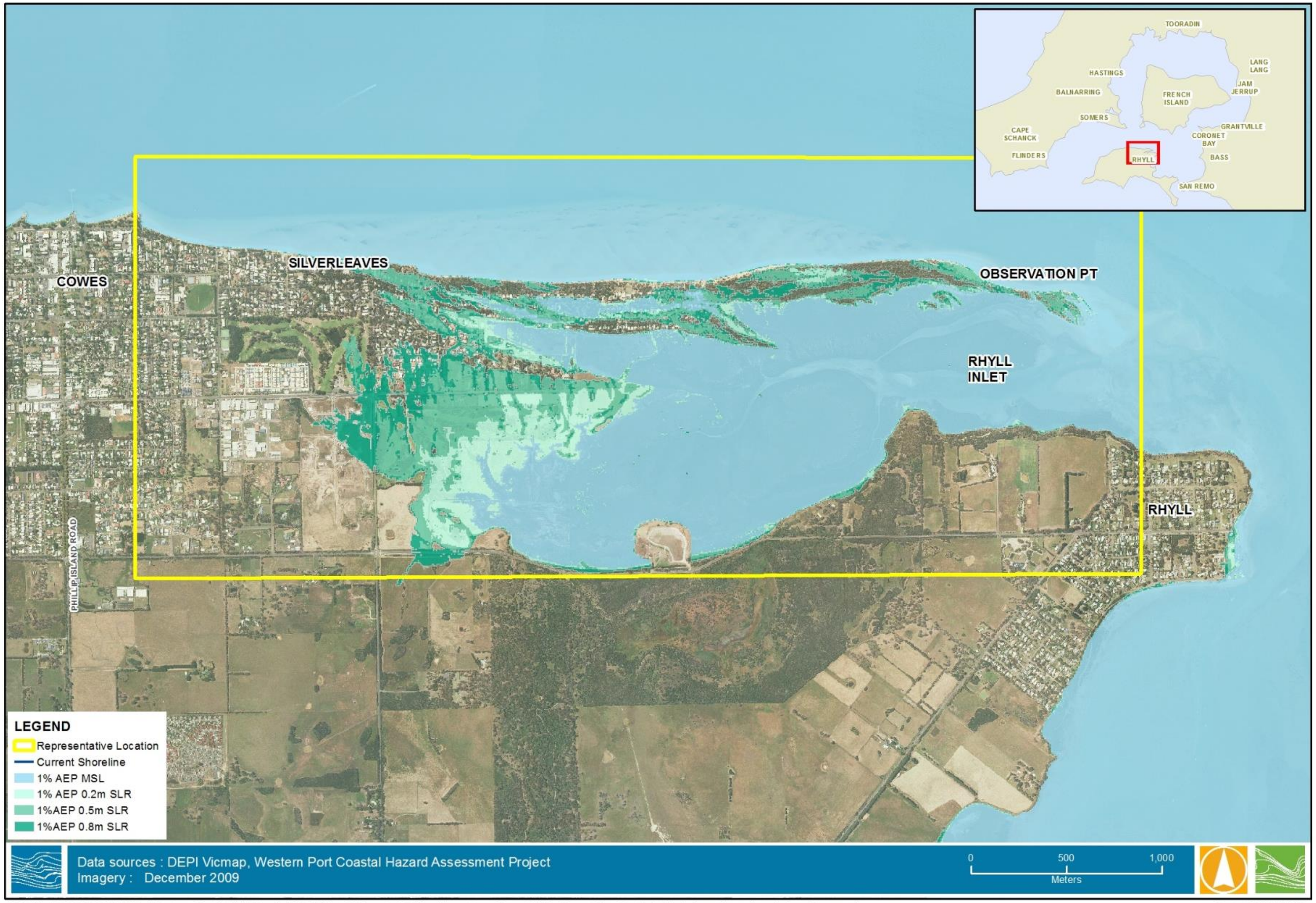
Figure 5-15 **Erosion Hazard Extents for the Rhyll Inlet and Silverleaves Representative Location**



Data sources : DEPI Vicmap, Western Port Coastal Hazard Assessment Project
Imagery : December 2009

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Date: 29/11/2013

Figure 5-16 Inundation Hazard Extents for the Rhyll Inlet and Silverleaves Representative Location

5.4 Summary and Recommendations

A summary of the coastal hazards identified within the Rhyll Inlet and Silverleaves representative location along with a description of any associated uncertainty is provided in Table 5-4.

The following recommendations are provided from the results of the local coastal hazard assessment of the Rhyll Inlet and Silverleaves representative location:

- Dating of the sediments and individual dune ridge sequences of the Sandy Spit landforms would enable the evolutionary trajectory and underlying variability of these landforms to be understood with much greater confidence and may provide the ability to refine hazard extents on these landforms.
- Improved understanding of the drivers and processes involved in genesis and transport of these sand lobes could be gained through additional study of the morphological dynamics of Middle Bank (in the western entrance of Western Port). However, such a study would require a significant field monitoring program and may not result in further refinement of the predicted erosion hazards along the sandy shorelines.
- Collation of further local information, such as oblique photographs, community history and recollections could inform an understanding of how these sand lobes have varied.
- Long term monitoring of the condition and stability of the coastal structures could be implemented and further detailed assessment of design conditions including their effectiveness in managing coastal erosion hazards undertaken prior to future adaption works.
- Specific measures to manage coastal hazards due to sea level rise could include the following:
    - A strategic approach to the management and future adaptation of the existing shoreline protection works;
    - Planning measures to provide adaptation space for the landward migration of saltmarsh and mangrove fringed shorelines in Rhyll Inlet ;
    - Planning measures to minimise the risks within the hazard overlays developed in this study ;
    - Refer future proposed development along the bluffed backed shorelines that lie within the erosion hazard overlays developed in this study for specialist geotechnical assessment.

Table 5-4 Summary of the Coastal Hazard Assessment and Uncertainties for Rhyll Inlet and Silverleaves Representative Location

Hazard Category	Specific Hazard	Timeline	Likelihood	Uncertainty	Comments
Coastal Erosion	Backshore Sand Lobe Migration	Present	Likely	**High**	Ongoing significant shoreline variability due to this process should be expected to 2100 and may exceed that observed in the historical photographic record. Sea level rise may potentially increase variability due to this process due to changes in wave energy on the shoreline. Very high degree of uncertainty on scale of potential erosion associated with this hazard, however, it is considered conceivable that very significant changes to the eastern end of the contemporary spit alignment and configuration may be possible by 2100.
		2040	Likely		
		2070	Likely		
		2100	Likely		
	Equilibrium Profile Recession	Present	Very Unlikely	**High**	Major profile recession due to sea level rise is increasingly likely towards the end of the century. High level of uncertainty on the rates of equilibrium profile recession that may occur due to sea level rise on these shorelines.
		2040	Unlikely		
		2070	Likely		
		2100	Likely		
	Loss of Coastal Wetlands	Present	Unlikely	**Moderate**	Likelihood of significant loss of coastal wetlands is high. Potential ability for coastal wetlands to migrate landward in Rhyll inlet. Level of uncertainty is moderate, some adaptive abilities may limit impact for modest amounts of sea level rise but relatively major loss of coastal wetlands could be expected by the end of the century.
		2040	About as Likely as Not		
		2070	Likely	**Low**	
		2100	Likely		
Marginal Bluff Reactivation	Marginal Bluff Reactivation	Present	Very Unlikely	**Moderate**	Possibility of major slope instability developing towards the end of the century. A moderate level of uncertainty exists due to limited information or understanding of the underlying geology and potential hazard processes. Site specific data and specialist geotechnical assessments are required to improve confidence at lot/parcel scale.
		2040	Unlikely		
		2070	About as Likely as Not		
		2100	About as Likely as Not		
Coastal Inundation	Storm Tide Inundation	Present	Unlikely	**Low**	Scale of impact of storm tide inundation hazards is expected to be extreme towards the end of the century. A significant source of the storm tide inundation
		2040	About as		

Hazard Category	Specific Hazard	Timeline	Likelihood	Uncertainty	Comments
			Likely as Not	🟩	hazard originates from within Rhyll Inlet rather than Western Port itself. Uncertainty is considered low. Extent of inundation hazards will be increased by major changes to the spit configuration.
		2070	Likely		
		2100	Virtually Certain		

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APPENDIX A MODELLING DETAILS

1. INTRODUCTION

The hydrodynamic model developed for Part A of the Western Port Local Coastal Hazard Assessment, and described in Report 4 – Inundation Hazards, Appendix A, was utilised the Part B – assessment along with an additional local scale hydrodynamic model.

For the assessment of inundation hazards at in the area of Tooradin and the Coastal Villages critical location the existing hydrodynamic mesh was further refined in order to increase the accuracy of the topographical representation, a detailed site specific bed roughness map was applied and the specification of hydraulic structures refined further.

For the review of inundation hazards within the Rhyll Inlet location a detailed 5m x 5m fixed grid model of the inlet and surrounding low lying land was incorporated within the Western Port Bay wide model developed for Part A of this project, in order to provide increased detail within this location.

This Appendix describes the refinements made to the existing hydrodynamic model and the development of the fine scale fixed grid hydrodynamic model.

2. REVISED MODEL OVERVIEW

For the Part B local scale inundation hazard assessments the model mesh and roughness delineation was modified within the existing hydrodynamic model. This section describes the modifications made to the model only. For further detail on the model development and calibration refer to Part A – Report 4.

2.1 Hydrodynamic Model Mesh Refinements

Based on the results of the storm tide inundation model results from the Part A assessment the hydrodynamic model mesh was further refined throughout the areas over which inundation occurs. The mesh was primarily refined over the low lying land north of the South Gippsland Highway between Sawtells Inlet and the Drains of Cardinia, Toomuc and Deep Creeks, and the tidal inlets. The revised mesh is shown in Figure 1.

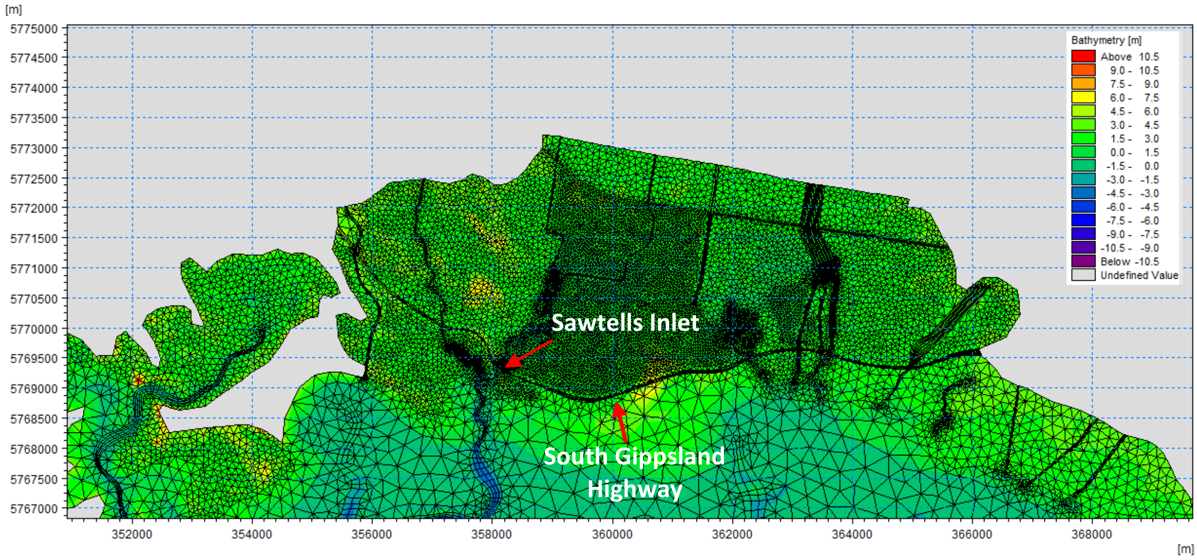

Figure 1 **Refined Hydrodynamic Model Mesh for the Tooradin area**

2.2 Roughness Map Refinements

A refined roughness map was also incorporated into the model for the area of Tooradin and surrounds. The detailed roughness map allowed the specific roughness of roads, developed land, undeveloped land, the inlet and mangrove covered habitat to be incorporated more accurately into the model hydraulics and therefore their influence on the propagation of the storm tide over the model in this area was captured more explicitly.

The refined roughness values were adopted from standard values and based on previous experience of flood modelling in this location. Roughness is typically specified as a Manning's 'n' value, however within the software tool used for this assessment the roughness is specified as a Manning's M value which is 1/n.

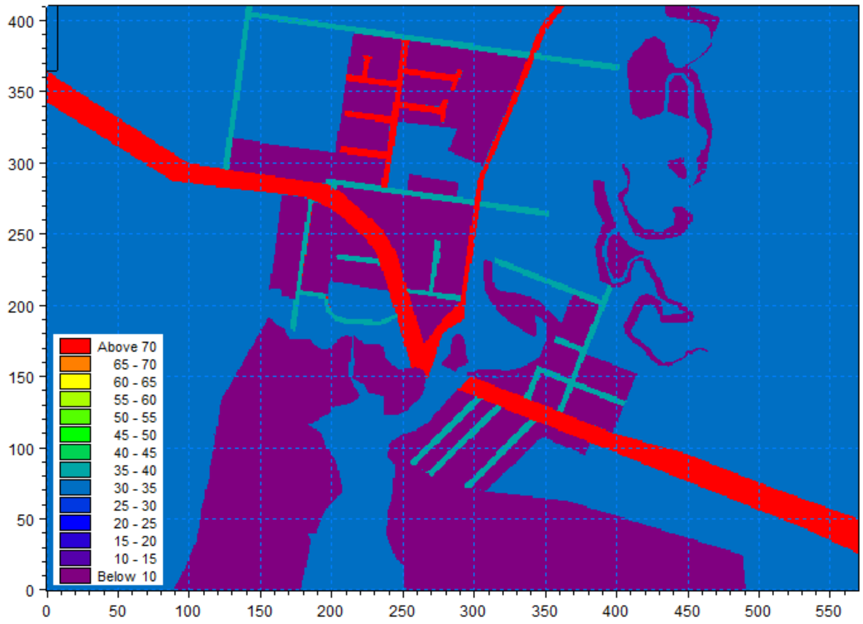

Figure 2 **Example of the Refined Roughness Map around Tooradin.** *The values represent Manning's M Values.*

2.3 Boundary Conditions & Calibration

The boundary conditions used to model inundation associated with the 1% AEP storm tide and sea level rise scenarios were identical to those used in the Part A – Inundation Hazards Assessment. Detailed descriptions of these boundary conditions are given in Report 4 – Inundation Hazards, Section 3.3.1.

All of the refinements and updates to the Tooradin critical location inundation model were made upstream of Sawtells Inlet and over the low lying tidal creeks and floodplains. No water level data was available within the areas of refinement and therefore the model could not be further validated. Although, water levels within Western Port Bay were compared against the inundation model results developed for Part A of the project, and were shown to match identically. However, as the updated Tooradin critical location inundation model mesh was refined, and thus reflect the topography in more detail, the inundation extent results presented in Part B are considered more accurate.

3. RHYLL INLET MODEL OVERVIEW

To model the inundation hazard extent within Rhyll inlet in greater detail a 5m x 5m fixed grid hydrodynamic model of Rhyll Inlet was developed. This model was then nested within the existing hydrodynamic model used for the Part A assessment.

3.1 Hydrodynamic Model Grid

A fixed grid hydrodynamic model was developed of Rhyll Inlet. The model comprised of a 5m x 5m fixed grid model domain which was created from Terrestrial Coastal LiDAR captured as part of the Coordinated Imagery Program. The extent and elevation data of the Rhyll Inlet model are displayed in Figure 3.

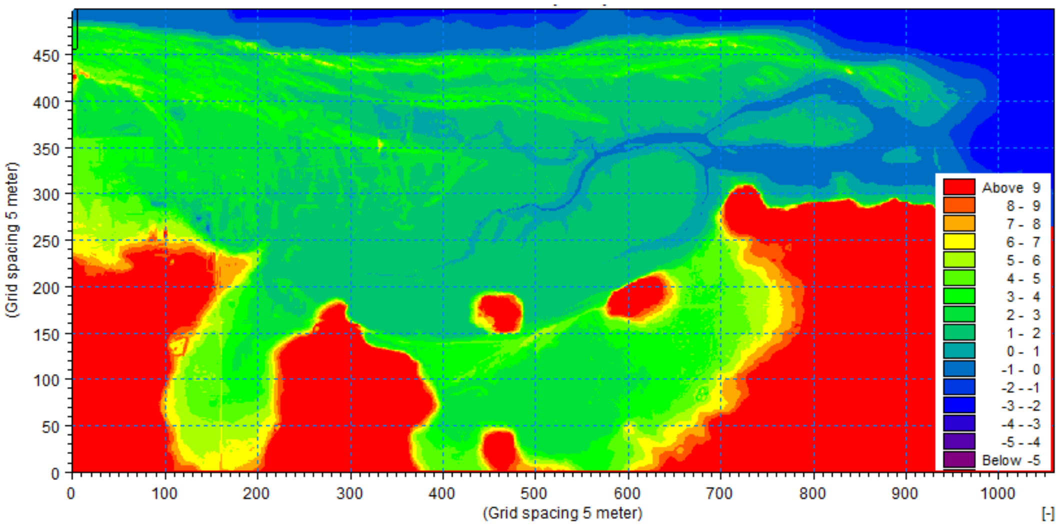

Figure 3 **Rhyll Inlet Hydrodynamic Model Fixed Grid Extent**

3.2 Boundary Conditions

The Rhyll Inlet inundation model was 'one-way' nested into the Western Port Bay wide hydrodynamic model developed for Part A of this project, by applying a time series of water levels extracted from the Western Port wide model along the Rhyll Inlet model boundary. The time series of water levels for the 1% AEP storm tide incorporating the four sea level rise scenarios are shown in Figure 4.

No measured water level data was available inside Rhyll Inlet to calibrate the Rhyll Inlet representative location hydrodynamic model against. However, as the Rhyll Inlet model was one-way nested within the Western Port wide hydrodynamic model the calibration and validation of the rest of Western Port was unaffected. The revised storm tide inundation extents for the Rhyll representative location were simulated using a finer grid scale, which provides a higher resolution of the bathymetry and topography, and therefore, the revised inundation extents are considered more accurate than those modelled in Part A of the assessment.

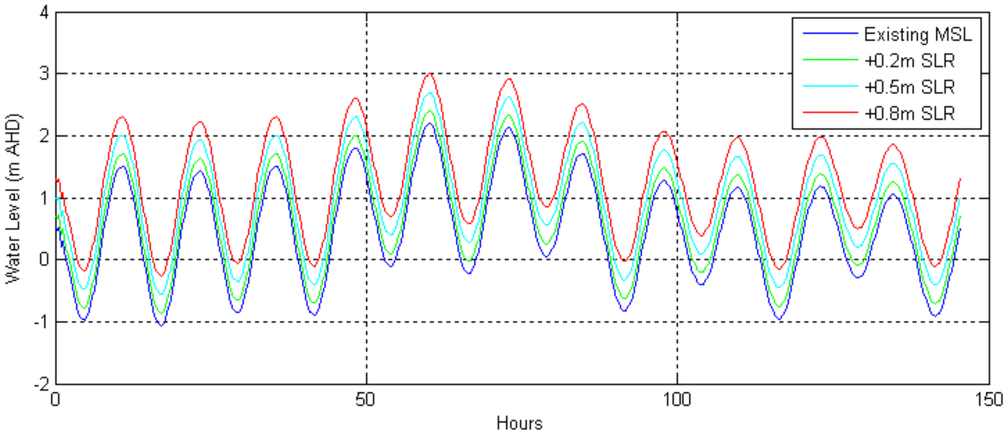

Figure 4 Time Series of Water Levels for the 1% AEP Storm Tide Incorporating the Four Sea Level Rise Scenarios used to Force the Rhyll Inlet Hydrodynamic Model

APPENDIX B MERRICKS CREEK CATCHMENT FLOWS

MERRICKS CREEK 10% AEP DESIGN HYDROGRAPH ESTIMATION

1.1 Peak Flow Estimation

The Australian Regional Flood Frequency (ARFF) method was used to produce estimates of the 10 year ARI flow for Merricks Creek.

1.1.1 Catchment delineation

The catchment was traced by hand using the 5 m Digital Elevation Model (DEM) data and the Melbourne Water Catchments layer as a starting point.

Catchment area	47.5 km^2
Centroid x (MGA 55)	333658 m
Centroid y (MGA 55)	5751947 m
Max elevation	Approx 210 m

1.1.2 IFD Parameters

Intensity-Frequency-Duration (IFD) parameters were determined for the catchment using the Bureau of Meteorology ARR87 IFD Program. IFD Parameters for the Merricks Creek catchment are shown below in Table 0-1. The IFD values were compared to the new IFDs developed as part of the Australian Rainfall and Runoff update, which were found to be within 11% of the ARR87 values. The ARR87 parameters were adopted for design flow estimation.

Table 0-1 IFD Parameters for Merricks Creek

Catchment	Log Normal Intensities (mm)						Geographical Factors		
	2 year ARI			50 year ARI					
	1hr	12hr	72h	1hr	12hr	72h	Skewness (G)	F2	F50
Somers	17.99	3.64	1.01	32.80	6.54	2.00	0.40	4.26	14.92

1.1.3 Australian Regional Flood Frequency Method

The Australian Regional Flood Frequency (ARFF) method has been developed in Project 5 of the Australian Rainfall and Runoff update. This regional method has been recommended in preference to the probabilistic rational method for flood estimation in ungauged catchments from 5 to 1,000 km². The method is based on an interpolation of flood frequency estimates across Australia and requires the input of catchment centroid coordinates and catchment area.

For Merricks Creek, the ARFF returned a 10 year ARI flow of 29 m^3/s, with 5-95% confidence limits of 12-70 m^3/s.

1.2 Hydrograph Estimation

1.2.1 RORB Modelling

A RORB model of seven subareas ranging from 5.1 to 8.3 km^2 was constructed of the catchment (Figure 0-1). The subarea delineation was based on the Melbourne Water catchments and manual tracing of the DEM. All reach types were set to natural. Reach alignments were based on the Melbourne Water waterway layer.

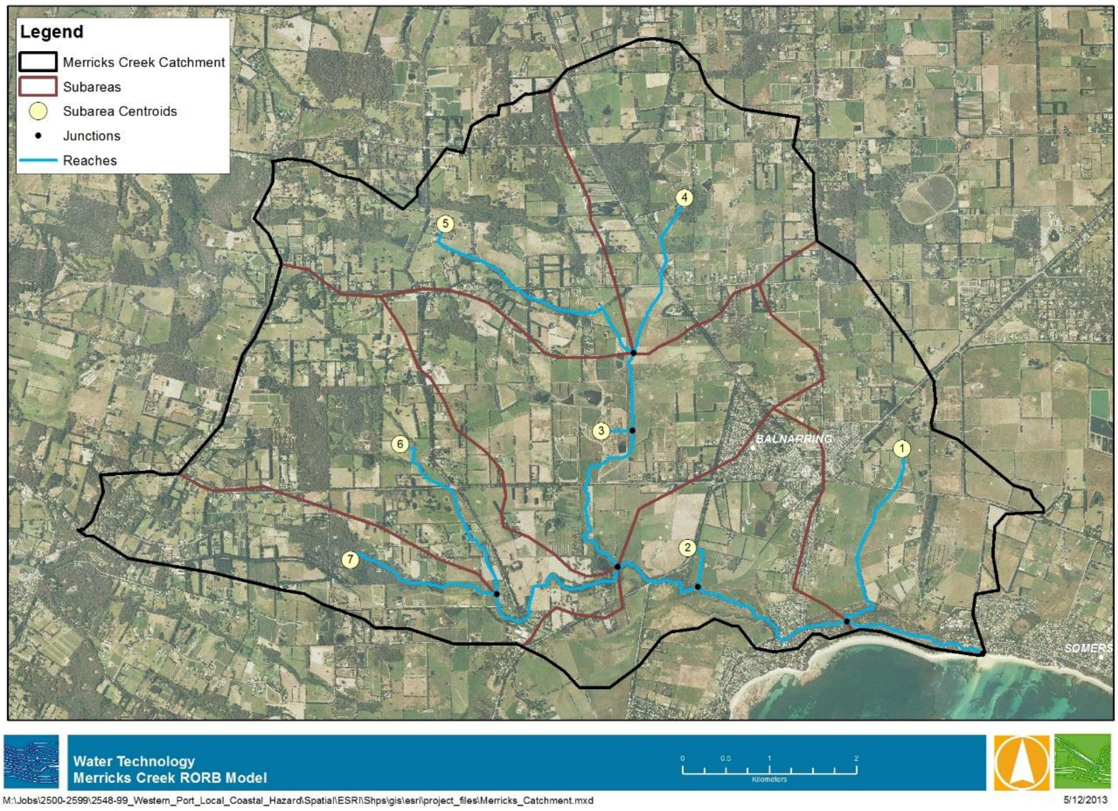

Figure 0-1 Merricks Creek RORB Model

The Fraction Impervious (FI) values across the catchments were determined based on MPSC's planning zones and Melbourne Water Guidelines. Melbourne Water Guidelines recommend value of FI in accordance with land use zone. The main FI values of the Merricks Creek Catchment are presented in **Error! Reference source not found.**.

Table 0-2 FI Values according to Planning Zone for Merricks Creek Catchment

Zone	Zone Code	FI	Zone	Zone Code	FI
Residential Zones	R1Z	0.45	Green Wedge Zone	GWZ1	0.1
	LDRZ	0.2		GWZ2	0.1
Public Land and Zone	PPRZ	0.1		GWZ3	0.1
	PUZ1	0.7	Road Zone	RDZ1	0.7
	PUZ2	0.2		RDZ2	0.6
	PUZ3	0.7	Business Zone	B1Z	0.9
	PUZ6	0.7		B4Z	0.9
	PUZ7	0.1		B5Z	0.8
	PCRZ	0.05			

The model was run for an AEP of 10%. The following parameters and settings were adopted:

- m = 0.8
- IL = 15 mm, RoC = 0.35
- IFD parameters for Merricks Creek catchment centroid
- Flitered temporal patterns
- Uniform areal patterns

- ARR87 Areal Reduction Factors
- Constant losses

Kc was adjusted to reconcile the peak flow to the ARFF estimate of 29 m^3/s. A kc value of 10 was required (Table 0-3).

Table 0-3 RORB model 10% AEP Design Flows for Merricks Creek

Merricks Creek	
kc	10
m	0.8
IL (mm)	15
RoC (10 year ARI)	0.35
RORB Peak Q_{10}	29
Critical Storm (hrs)	12

1.2.2 Design Flow Hydrograph

The resulting 10% AEP design flow hydrograph is shown in Figure 0-2.

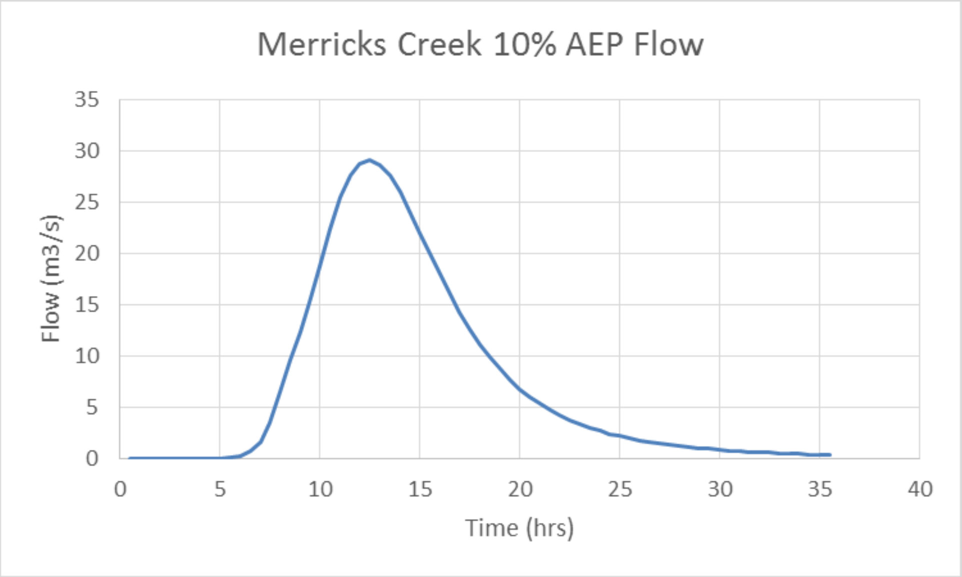

Figure 0-2 10% AEP Design Flow Hydrograph

APPENDIX C COASTAL STRUCTURES

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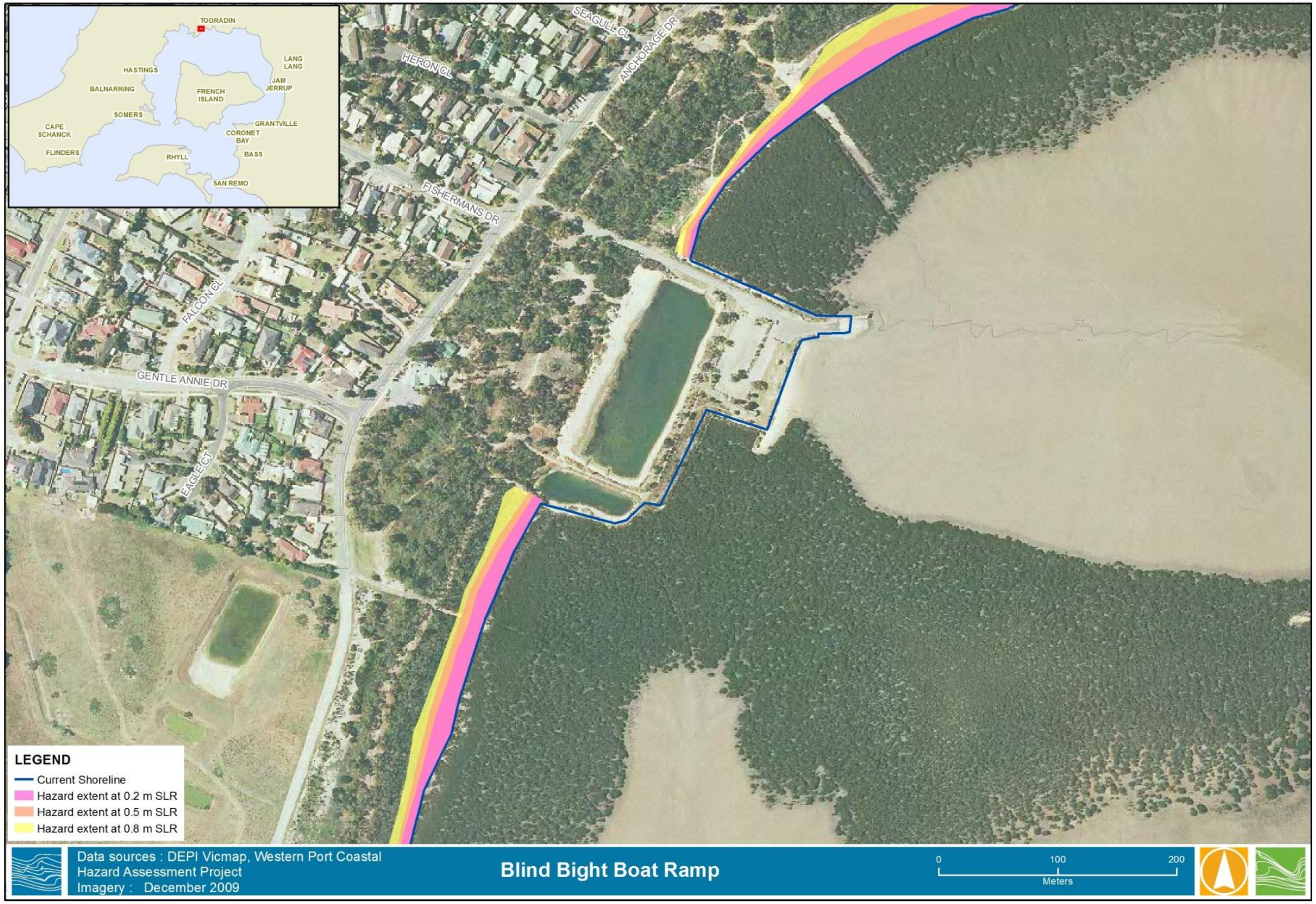

Data sources : DEPI Vicmap, Western Port Coastal Hazard Assessment Project
Imagery : December 2009

Blind Bight Boat Ramp

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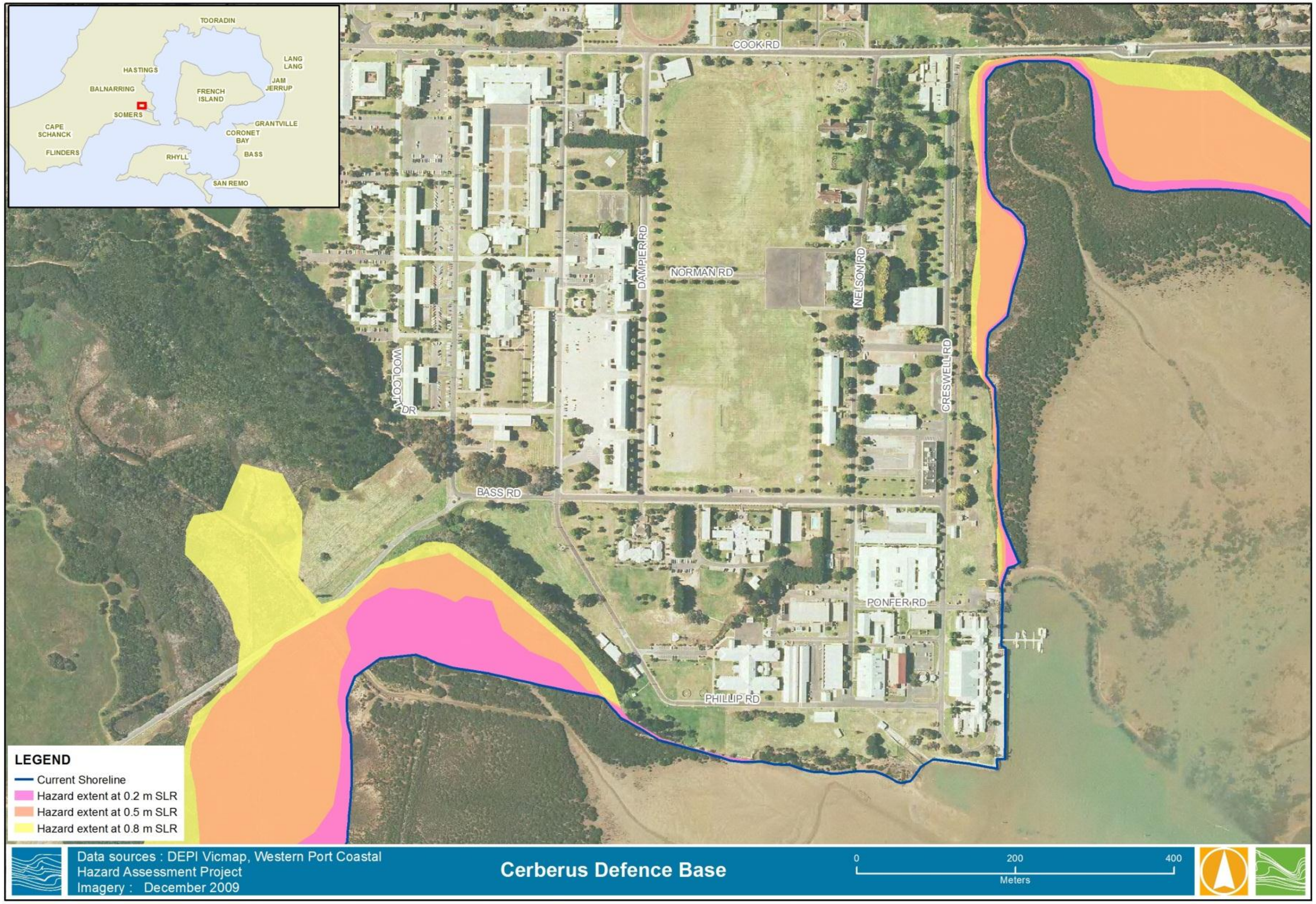

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Data sources : DEPI Vicmap, Western Port Coastal Hazard Assessment Project
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Cowes Jetty

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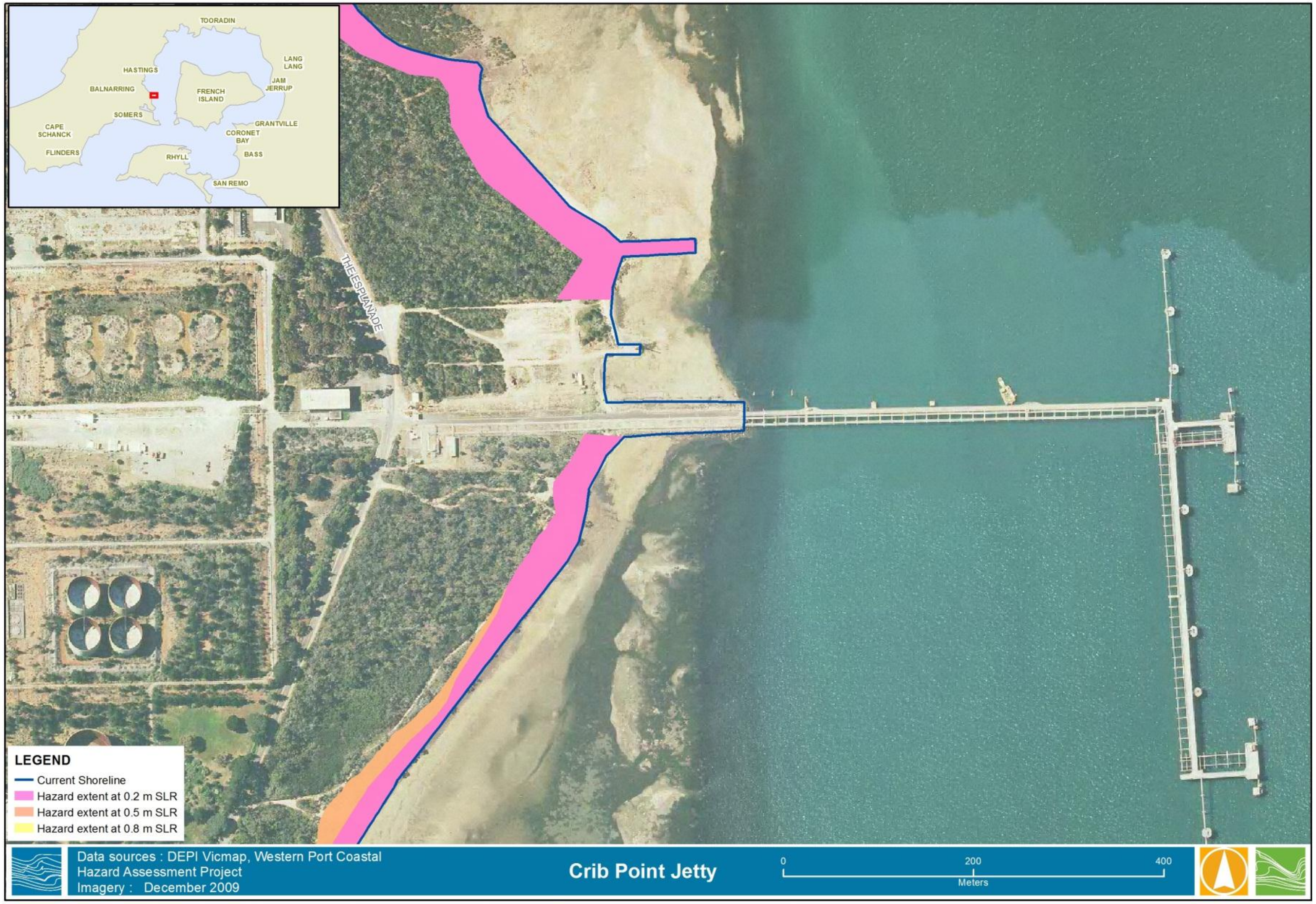

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Data sources : DEPI Vicmap, Western Port Coastal Hazard Assessment Project
Imagery : December 2009

Hastings Marina

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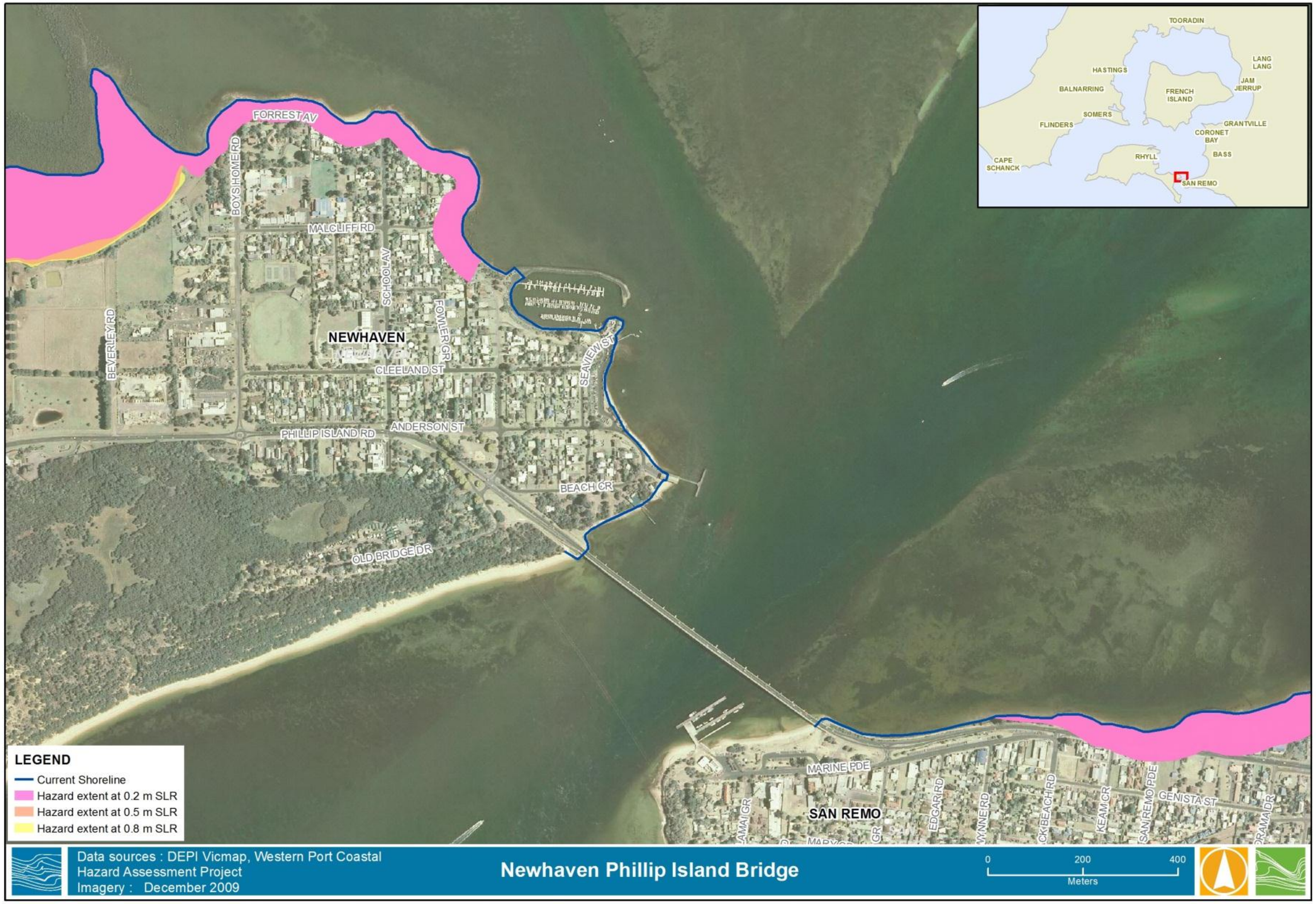

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Imagery : December 2009

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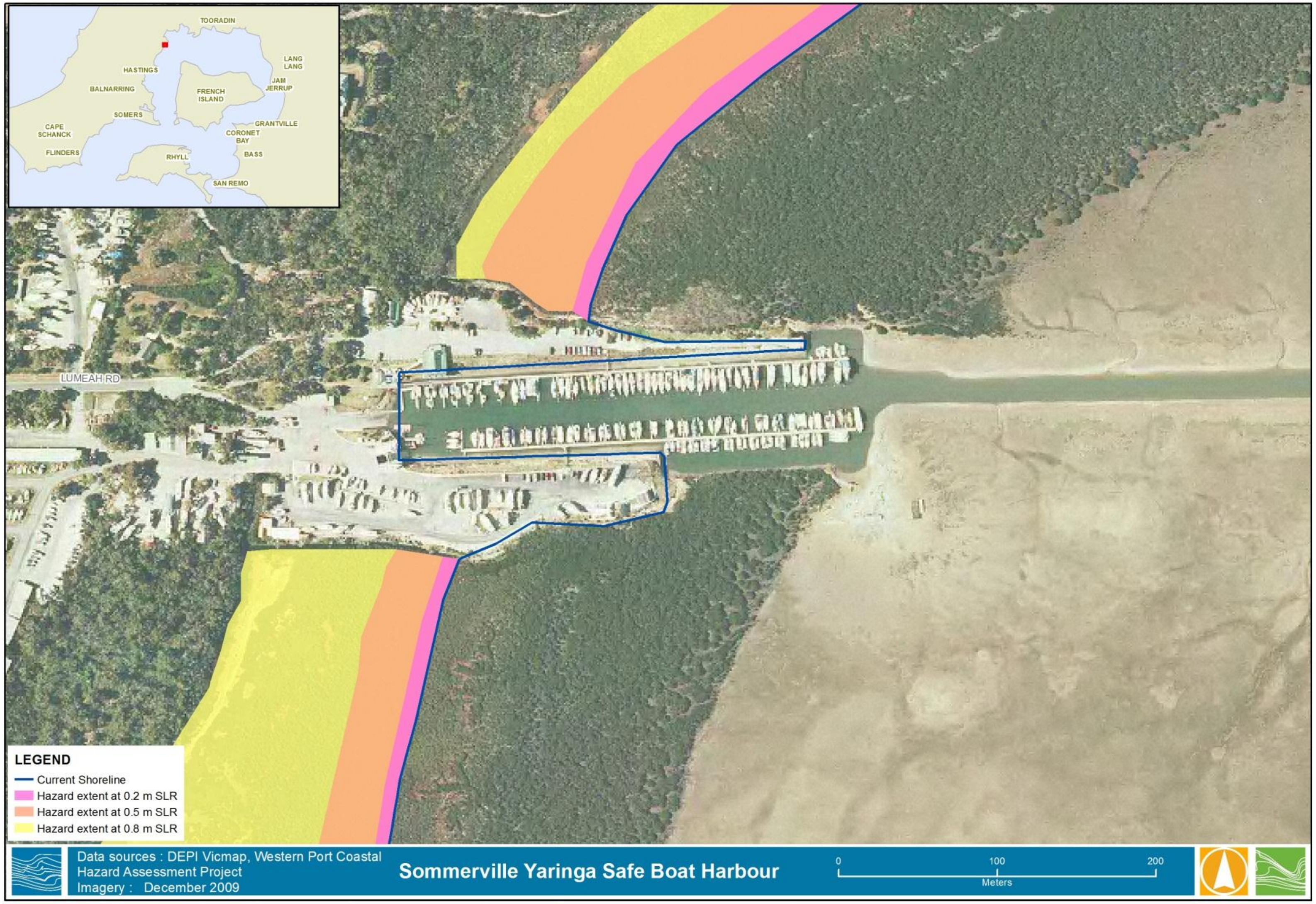

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Data sources : DEPI Vicmap, Western Port Coastal Hazard Assessment Project
Imagery : December 2009

Stony Point Jetty

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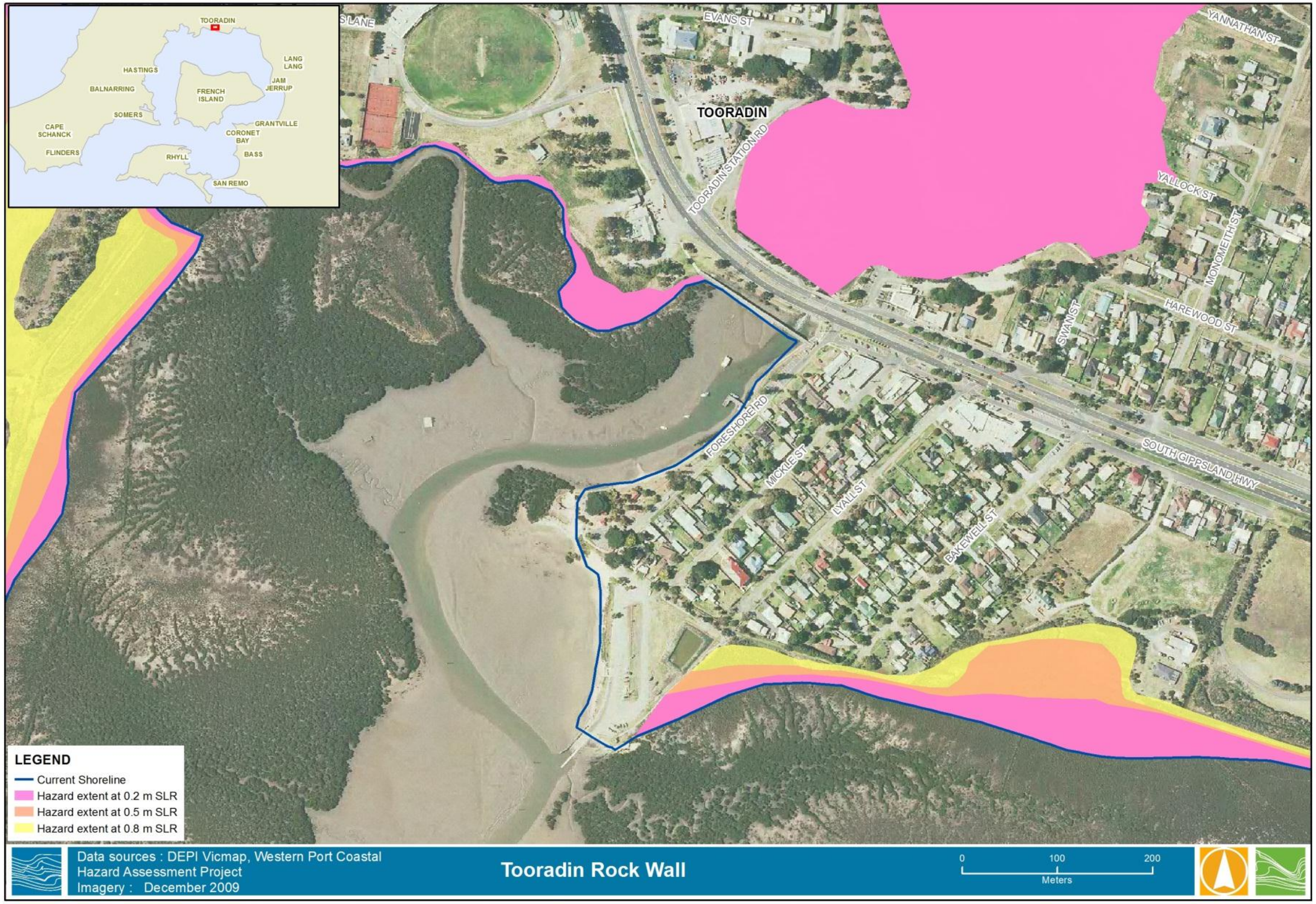

Tooradin Rock Wall

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