Port Fairy landfill sites coastal hazard assessment

Synthesis of VCMP data, previous studies, and projections of future shoreface change

Final Report, April 2023, Jak McCarroll

VICTORIA
State Government
Energy, Environment and Climate Action

Acknowledgment

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We are committed to genuinely partner, and meaningfully engage, with Victoria's Traditional Owners and Aboriginal communities to support the protection of Country, the maintenance of spiritual and cultural practices and their broader aspirations in the 21st century and beyond.

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Executive Summary

This report provides a coastal hazard assessment for the Port Fairy / East Beach compartment, with a focus on the landfill sites located near the middle of the beach that are under threat from coastal erosion. An extensive array of consultancy reports and academic papers have been published on this site in recent years. This report provides: (i) a brief review of the existing work; (ii) analysis of the monitoring work of the VCMP (drone surveys, wave buoy); and (iii) additional analysis of sediment budget and projections of future shoreface change. The document structure and key points include:

1. Background: A brief description of the issue, and a series of project management focussed questions that form a list of aims for this report.
2. Data synthesis:
    - Summary of data sets, consultant reports, and published papers used in this assessment.
3. Wave climate:
    - Contains new analysis of VCMP Port Fairy wave buoy.
4. Water levels and inundation:
    - Contains new analysis of maximum total water levels on ocean and lagoon side of barrier.
5. Coastal geomorphology, interventions, and historical shoreline change:
    - Substantial new analysis of VCMP drone data and multi-method time series (aerial, satellite, drone).
6. Predicting coastal change (I): Existing studies.
7. Predicting coastal change (II): Shoreface translation modelling:
    - Major new analysis. Profile change predictions for 2020 – 2050, including storm demand risk.
    - New hazard rating system introduced (Fig. E1).
    - Brief analysis of potential impacts of soft (nourishment) and hard (seawall/revetment) intervention strategies.
8. Predicting coastal change (III): Embayment processes and sediment budget.
    - Accounting for cross-shore and alongshore sediment transport, nourishment and sea level rise.
    - Considers nourishment placement strategy.

Summary of recommendations:

- The Nov – Mar period experiences marginally lower wave energy and water levels, suggesting this is the preferred time of year for conducting engineering works; however, extreme events may occur at any time of year.
- The DEECA site is currently at ‘imminent risk’, i.e., it is within the 1-in-100 yr erosion zone (Fig. E1, top row).
- Immediate renourishment is recommended, and potentially some form of temporary protection (e.g., sandbags), while site remediation is planned and conducted.

- Ongoing renourishment (given sufficient volumes) could maintain the present shoreline for the next few decades (Fig. E1, middle row).
- There is conflicting evidence on where nourishment material should be placed. Some reports recommend placement at the southwestern end of the bay; however, other modelling results suggests that may be ineffective. Placing nourishment material directly in front of the landfill sites should also be considered.
- Building a seawall, and assuming no additional renourishment, will result in the beach being nearly entirely eroded by 2050 (Fig. E1, bottom row).
- Timelines are outlined for various hazard levels and trigger points (Sections 7-8), with direct answers to project management questions (Section 9).

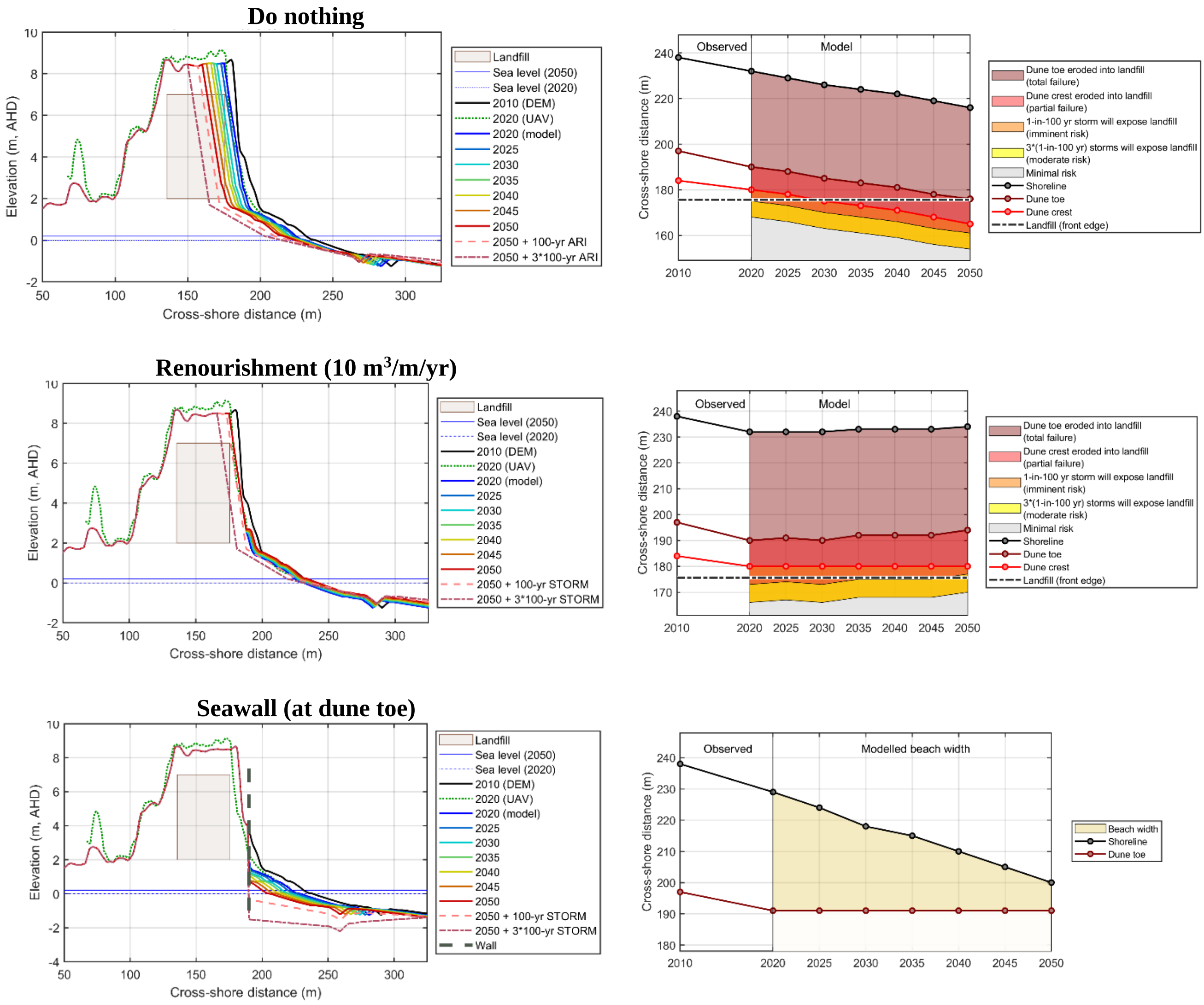


Figure E1: DEECA landfill site, profile change predictions (2020 – 2050). Detailed descriptions of these figures are given in Section 7.

Contents

1. Introduction

Two disused landfill sites along East Beach at Port Fairy (Fig. 1-1) have become increasingly exposed due to erosion over recent years. Of these landfill locations, DEECA is responsible for a site near the mid-point of East Beach and Moyne Shire Council (MSC) is responsible for a site further to the northeast. Impacts will become more severe if continued erosion occurs in the future, in particular as sea level rise (SLR) accelerates. Options to remediate and/or protect the sites from further erosion have been extensively investigated previously, including soft and hard engineering solutions. The timeframe for remediation and the requirement of coastal protection may extend up to 30 years (to 2050).

East Beach is on the western Victorian coast, 250 km west of Melbourne. The dominant wave climate is high-energy south to southwesterly swell from the Southern Ocean (see Section 3). The embayment is 5.6 km long, the south facing eastern end more exposed to ocean swells, and the southwestern corner facing east, with greater protection from ocean swells provided by Griffiths Island and training walls of the Moyne River. The town of Port Fairy is located at the protected southwest corner of East Beach. The southwest section of the beach which is backed by housing is protected by a seawall. The mid- to eastern section is backed by natural sand dunes. A low seawall has been constructed in front of the MSC landfill site, at the rear of the active beach. Further details of geomorphology and engineering interventions at East Beach are given in Section 5.

To inform this coastal hazard assessment, data from the Victorian Coastal Monitoring Program (VCMP) and other sources can be used to ascertain current shoreline trends and estimate potential future rates of coastal change at Port Fairy, and in particular, the area around the landfill site. This report provides an assessment of shoreline change near the landfill, projects future shoreface changes, and suggests future work to complete.

The following questions are used to guide the analysis:

1. When can we expect SLR induced erosion and/or current trends in erosion (unrelated to SLR) to impact on the landfills?
2. What would the impact be of a 1-in-100 year storm event, or a series of extreme events, when added to trend rates of erosion and SLR impacts?
3. How would beach renourishment as an interim treatment help avoid, reduce, or mitigate the impacts?
4. What triggers could be set to initiate interim interventions, including:
    a. A review of modelled future impacts because actual trends are deviating significantly from current predictions.
    b. Re-assessment after installing temporary engineering solutions.
    c. Bringing forward plans for a long term permanent solution.
5. Given the wave climate and the potential for storms and high water levels, at what time of year is it best to conduct engineering works?

This analysis should inform:

- Timing and planning for implementation of the long term solution (e.g., staged removal of the waste).
- Urgency for an interim intervention (e.g., revetment) if implementation of the long term solution will not be possible in the short or medium term.
- Options for an emergency response.

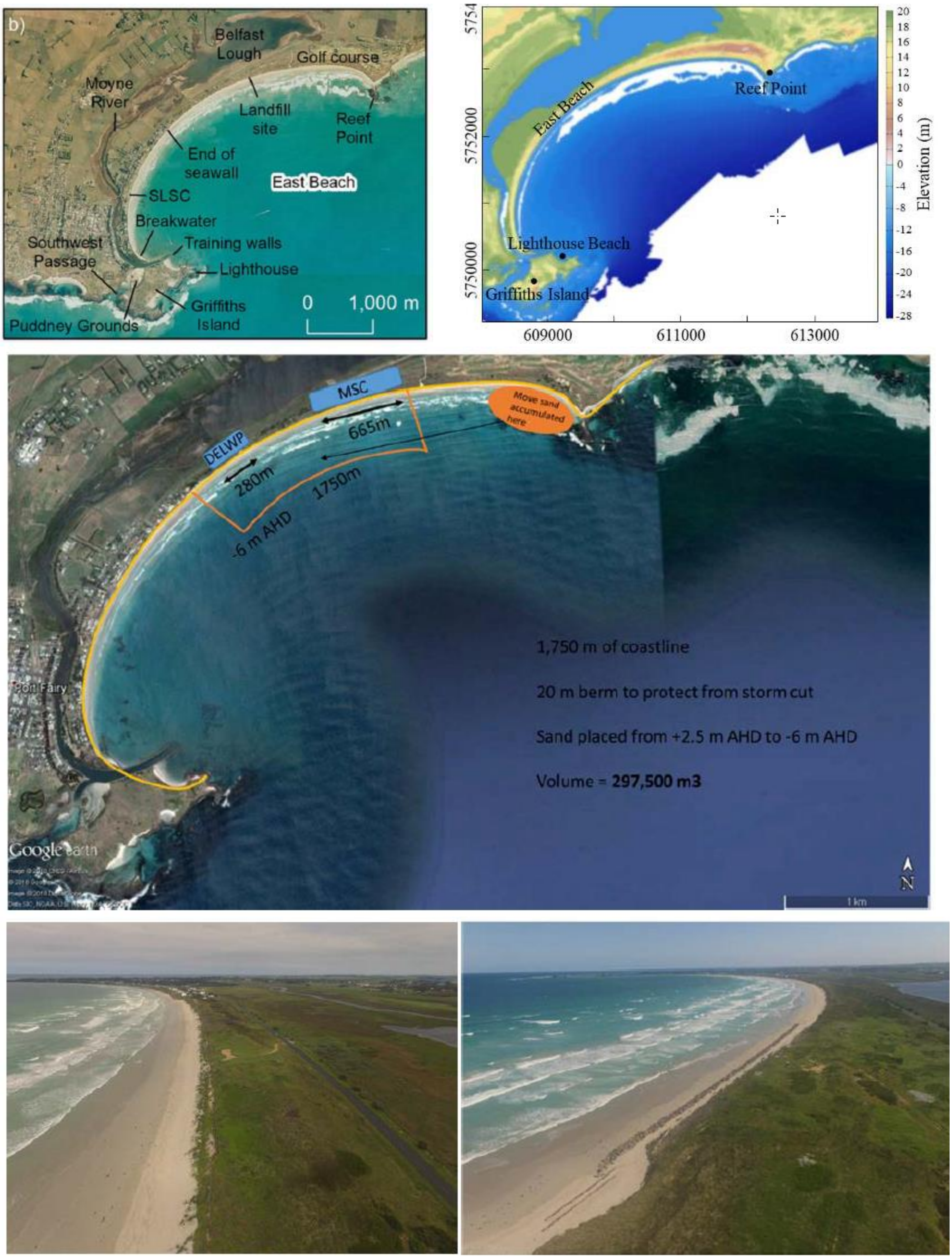


Figure 1-1. Port Fairy (town) and East Beach. (Top left) Map and key locations [Carvalho et al., 2020]; (top right) topo-bathymetry [Leach et al., 2020]; (middle) map of landfill sites with plan details for nourishment [T&T, 2019]; (bottom left) DEECA landfill site; and (bottom right) Moyne Shire Council [MSC] landfill site.

2. Data synthesis

This section lists the available data sets, consultant reports and academic papers synthesised for this report. A large number of reports have been published over recent years, and the degree of review provided in this report is relatively brief, as the focus has been to synthesise the most relevant existing data and provide new analysis, to directly answer the questions posed in Section 1. The primary data sources for this report include:

Datasets

- Victorian digital elevation model 'DEM2010' (compiled in 2010, original lidar data obtained in 2007)
- VCMP drone survey data (2018 - 2020)
- VCMP Port Fairy wave buoy data (2018 – 2021)
- Bureau of Meteorology monthly summary of Portland Tide Gauge (1982 – 2021)
- Digital Earth Australia (part of Geoscience Australia), mean annual satellite extracted shorelines (1988 – 2018)
- CoastSat (Water Research Lab, UNSW), high-frequency satellite extracted shorelines (1988 – 2021)

VCMP publications

- Determining beach volumetric change over decadal scales (Carvalho et al., 2020).
- Predicting Compartment-scale Climate Change Impacts Related to Southern Ocean Wave Forcing: Port Fairy, Victoria, Australia (Leach et al., 2020).
- Citizen science for monitoring seasonal-scale beach erosion and behaviour with aerial drones (Pucino et al., 2021).
- Port Fairy shoreline evolution pilot study using the MIKE 21 shoreline morphology model (DHI, 2021).

Primary consultancy reports

- WRL (2013) – "Future Coasts – Port Fairy Coastal Hazard Assessment", prepared for MSC by Water Research Laboratory, UNSW.
- CES (2013a) – "Port Fairy Sand Sourcing Study", prepared for MSC by Coastal Engineering Solutions.
- T&T (2019) - "East Beach Landfills Long Term Management Plan, Summary Report", prepared for MSC by Tonkin and Taylor.

The consultancy report list above is non-exhaustive. Additional reports that have not been extensively reviewed include: WBM (2007); Aurecon (2010); CES (2013b); T&T (2018); and BMT (2020). These additional reports were considered to have been superseded by more recent reports, were not available (in the case of T&T, 2018) or were not directly relevant to the landfill sites.

3. Wave climate assessment

3.1 Nearshore wave climate: VCMP wave buoy

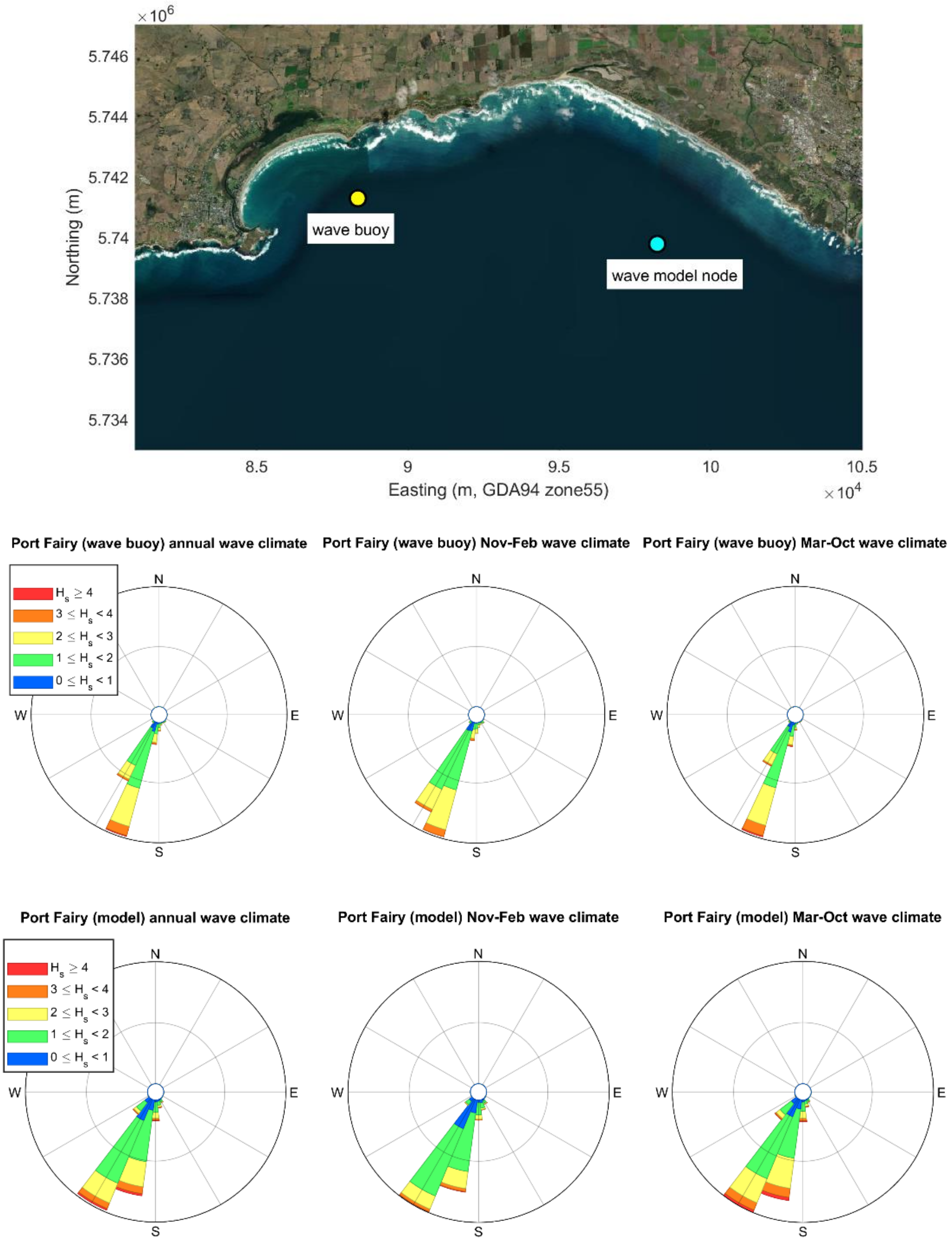
An analysis of wave climate was completed to inform when the best time of year is to complete engineering works at Port Fairy. Wave data were obtained from the VCMP Port Fairy wave buoy and at a single node from a global wave model (Fig. 3-1). The wave buoy was deployed in Sep 2018, with data freely accessible on https://vicwaves.com.au/. The VCMP Vicwaves program includes 7+ buoys on the open coast and 6 buoys in Port Phillip Bay. Over 10 years of wave model data (2009-2019) were obtained for the WAVERYS model, from the Copernicus Marine website (https://resources.marine.copernicus.eu). This model provides a reasonable fit to the observations (Fig. 3-1 to 3-3) and represents the best model available at this time; however, improved model data (e.g., higher resolution) should be obtained in future.

Wave climate is high energy from the SW, with refraction into the bay and wave shadowing (reducing wave heights) in the protected southwest corner of East Beach (mean H_s = 1.9 m; T_p = 12.7 s; D_p = 200°; based on wave buoy data). Peak wave direction is unidirectional and narrow-banded (between 180 – 220°). However, an analysis of secondary (wind wave) components is required to determine magnitudes and trends of shorter-fetch easterly waves. This is recommended but will require further work (e.g., obtaining spectral output from the wave buoy). Maximum nearshore wave heights reach H_s > 6 m Hs, T_p > 20 s (Fig. 3-2), with a high energy event occurring recently on April 11, 2021 (Fig. 3-3).

Clear seasonal trends are apparent for wave height and direction (Fig. 3-2, top right panels), with inter-annual trends in direction (Fig. 3-2, bottom right). Average wave heights and periods are slightly lower from Nov-Feb (termed 'summer'; H_s = 1.82 m; T_p = 12.1 s), and higher in Mar-Oct ('winter'; H_s = 1.89 m; T_p = 13.1 s).

A regression analysis was performed on the wave buoy and wave model (Fig. 3-4). A correction was applied to increase the wave model significant wave height ($H_{s,modified} = H_{s,model}^{1.25}$) and offset peak direction ($D_{p,modified} = D_{p,model} - 25°$) to provide the comparison in Fig. 3-3. The modified WAVERYS global model node provides a reasonable fit for wave height and period (Fig. 3-3, left, middle). A higher resolution model is required to improve modelled wave direction (Fig. 3-3, right). The modified wave model is assessed to have sufficient skill to provide an analysis of monthly wave climate (Fig. 3-4).

Monthly wave statistics for the model and buoy are presented in Figure 3-5. The model assessment period is longer (2009 – 2019; Fig. 3-5, left), but is limited by the accuracy of the model. The wave buoy provides direct observation, but covers a brief time period (2018 – 2021; Fig. 3-5, right). Examining the model data monthly wave statistics, significant wave heights average < 1.9 m for the Nov-Feb ('summer') period (Fig. 3-5, top-left), peaking at > 2 m from May – Oct. Extreme events (taken as Hs > 6 m; red symbols in Fig. 3-5, top-left) are more common in Mar – Sep. Peak period is over 13 s in Apr – Sep (Fig. 3-5, second row) with the model predicting a more southwesterly direction in Jun-Oct (Fig. 3-5, left, third row). Model predicted wave power (a function of wave height and period) is above average in Apr-Oct, peaking in August (Fig. 3-5, bottom panel). The limited period of wave buoy observations show a similar pattern of higher wave power in the winter months (Fig. 3-5, bottom-right), though with less variation between summer and winter, and June is an exception, with lower wave power than neighbouring months.



Port Fairy (wave buoy) annual wave climate

Port Fairy (wave buoy) Nov-Feb wave climate

Port Fairy (wave buoy) Mar-Oct wave climate

Port Fairy (model) annual wave climate

Port Fairy (model) Nov-Feb wave climate

Port Fairy (model) Mar-Oct wave climate

Figure 3-1. (Top) wave buoy and wave model locations; (middle) annual, ‘summer’ [Nov-Feb] and ‘winter’ [Mar-Oct] for wave buoy; and (bottom) equivalent wave roses for modified wave model node.

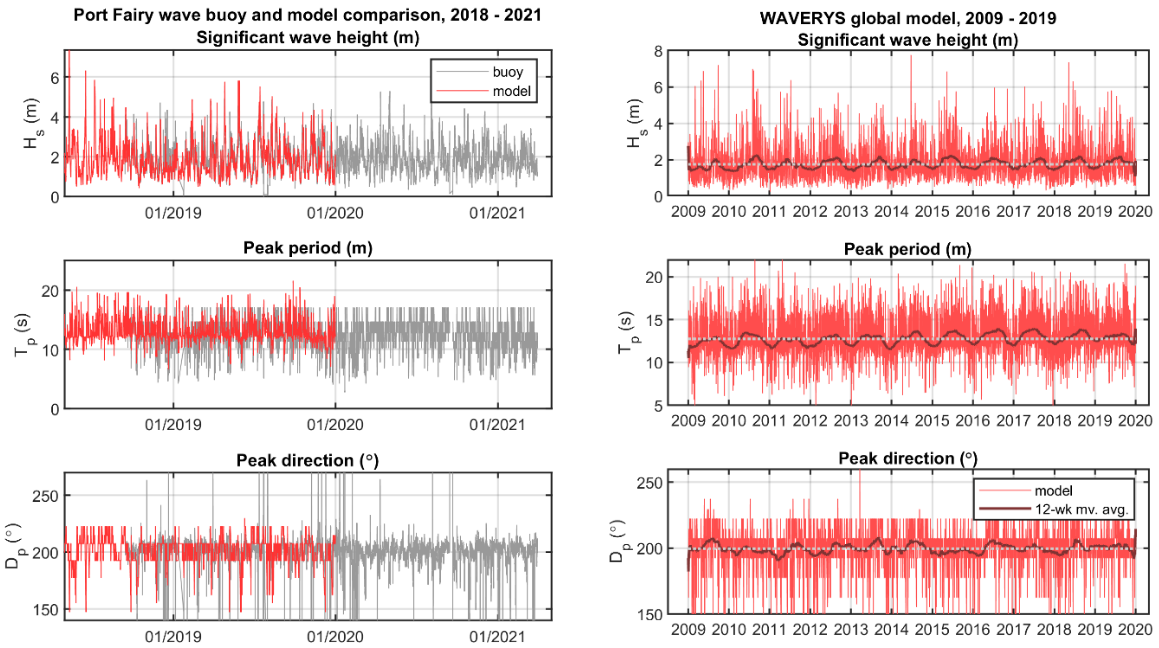
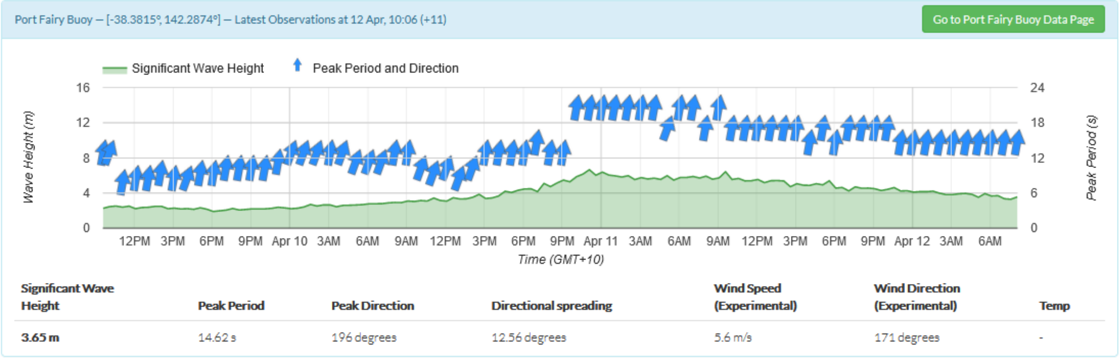


Figure 3.2. Wave time series. (Left) wave buoy and modified model, 2018 – 2021; and (right) wave model, 2009 – 2019.



Significant Wave Height	Peak Period	Peak Direction	Directional spreading	Wind Speed (Experimental)	Wind Direction (Experimental)	Temp
3.65 m	14.62 s	196 degrees	12.56 degrees	5.6 m/s	171 degrees	-

Figure 3-3. April 11, 2021 high-energy wave event at the Port Fairy buoy, Hs = 6.7 m, Tp = 20.5 s.

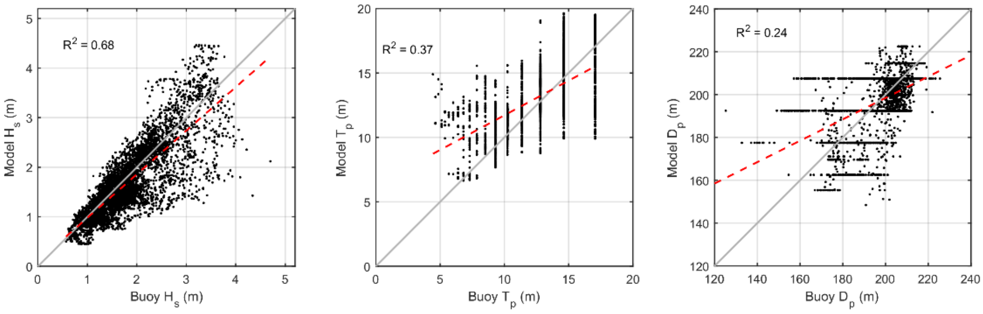


Figure 3-4. Wave buoy and model linear regressions for: (left) significant wave height; (middle) peak period; and (right) peak direction.

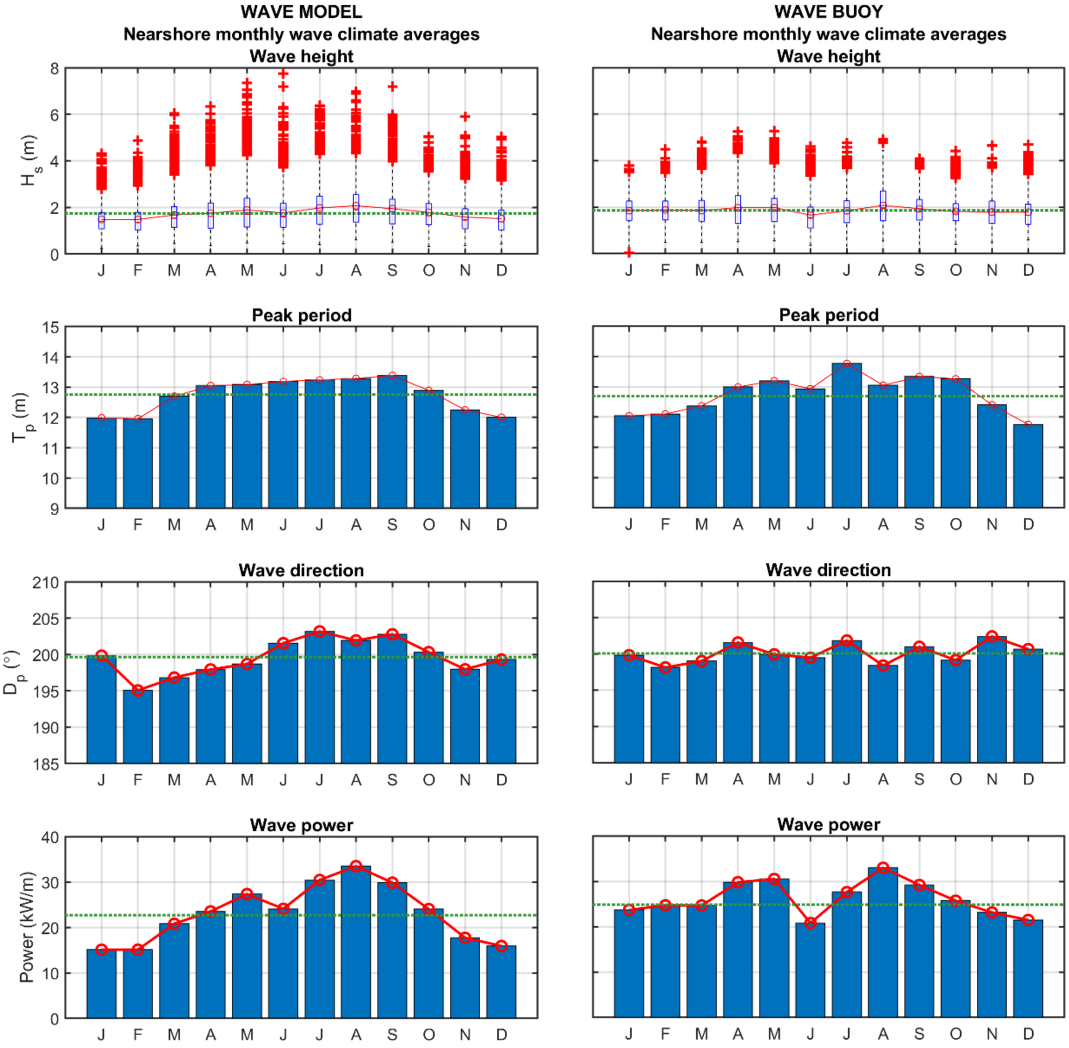


Figure 3-5. Monthly wave climate. (LEFT) WAVERYS model data from 2009 – 2019. (RIGHT) VCMP wave buoy data (2018 -2021). For the boxplots of Hs in the top panel, 50% of data are within the blue box, whiskers represent the bottom and top quartiles, red (+) symbols are outliers, representing high/extreme wave events.

3.2 Inshore breaking wave heights (WRL, 2013)

WRL (2013) conducted an extensive analysis of maximum breaking wave heights for various locations and East Beach. Using the SWAN numerical wave model, 50-year and 100-year recurrence intervals were determined for the DEECA and MSC landfill locations (Table 3-1). Predicted maximum breaking wave heights (~5 m) are somewhat lower than the nearshore wave heights observed at the buoy (~6 m), this can be expected due to refraction into the bay. Maximum breaking significant wave heights (100 yr ARI) are > 4 m for the DEECA site and > 5 m for the MSC site. The various datasets (wave buoy, WAVERYS global wave model, and WRL's local SWAN model) are broadly consistent.

Table 3-1. Maximum wave height characteristics at the landfill sites (WRL, 2013 – SWAN wave model)

Site	Significant wave height (m)		Peak period (s)		Peak direction (°)	
DEECA landfill	4.79	4.51	15	15	155	155
MSC landfill	5.39	5.12	15	15	165	165

Section 3 Summary

The Port Fairy compartment experiences a slightly lower-energy wave climate in summer (Nov-Feb). The buoy data (over a limited 3 year deployment period) shows only marginally lower wave energy over summer. Extreme event can occur at any time of year. Additional analysis should be conducted to determine the magnitudes and trends of secondary easterly swell and wind waves, as this may influence some planning decisions. Maximum nearshore wave heights (at the buoy) can exceed 6 m, while breaking wave heights (100 yr ARI) are predicted to exceed 5 m, with increasing protection and lower wave heights towards the southwest.

4. Total water levels and preliminary inundation analysis

4.1 Total water levels

Total water levels (Fig. 4-1) describe the maximum height ocean waves will reach relative to dunes, cliffs, engineered structures or infrastructure at the back of the beach. This includes contributions to water level from:

- Astronomical tides: Driven by gravitational forcing of the moon and sun.
- Storm surge: Elevated water level due to low atmospheric pressure associated with storms, and onshore winds.
- Seasonal water level anomalies: For example, due to seasonal wind patterns.
- Inter-annual water level anomalies: For example, due to ENSO cycles.
- Setup: Elevation of mean water level at shoreline due to breaking waves pushing water onshore. Increases with wave height.
- Runup: Swash moving up and down the beach with individual waves and wave groups.

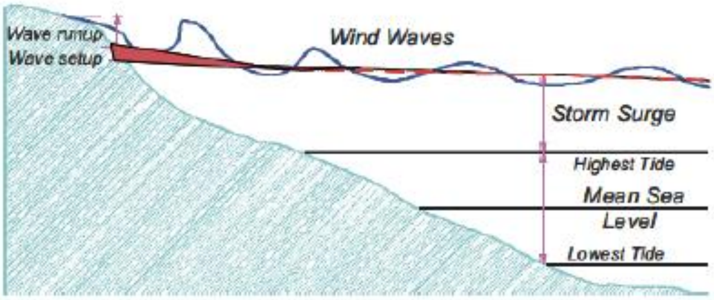


Figure 4-1. Contributing factors to total water levels (Source: Water Technology, 2016; CSIRO, 2009)

A comprehensive assessment of the components of water levels at Port Fairy were conducted by WRL (2013). These data are supplemented by an assessment of seasonal fluctuations using summary data for the Portland tide gauge from the Bureau of Meteorology (BoM, 2021) and annual water level anomalies at Portland (Cardno, 2018), resulting in part due to ENSO cycles (Cardno, 2018). The seasonal and annual anomalies are likely to be regional in nature and therefore it is considered appropriate to use data for nearby Port Fairy.

Tidal regime at Port Fairy is microtidal, with a Mean High Water Springs (MHWS) of 0.43 m (WRL, 2013). Significant contributions are also made by storm surge and seasonal to annual water level anomalies. The water level components are summarised in Table 4-1. This is a conservative estimate that assumes the maximums of each contributing factor all coincide (i.e., a 100-yr storm, at spring high tide, with the seasonal and annual oscillations also peaking).

A time series of monthly water levels (Fig. 4-2) indicates monthly maximum water levels can vary by > 0.5 m, with a long-term SLR trend of 2.4 mm/yr. The average maximum water level for each month of the year at the Portland tide gauge (Fig. 4-3) indicates a clear bi-annual oscillation, with maximum water levels peaking June (>0.8 m AHD) and a lower peak in December (<0.7 m AHD). A time-series of the annual water level anomaly for Portland (Fig. 4-4) indicates the annual range of variability in water level is approx. +/- 5 cm.

Table 4-1. Contributing factors to maximum total water level for Port Fairy, for present day. SLR is taken for 2021, relative to 1982

Component	2020 Max. water level (m)	2050 Max. water level (m)	Source
Non-wave effects (ocean and lagoon side)			
Astronomical tide (Mean Higher High Water)	0.43		WRL, 2013
Storm surge	0.6		WRL, 2013
Seasonal water level anomaly	0.16		BoM, 2021
Inter-annual water level anomaly	0.05		CSIRO, 2009
Sea level rise	0.1	+ 0.2	BoM, 2021
Max. water level: Lagoon side	***1.34 m AHD***	***1.54 m AHD***	
Wave effects (ocean side only)			
Setup (100 yr ARI)	1.0		WRL, 2013
Runup (100 yr ARI)	1.5		WRL, 2013
Max. water level: Ocean side	***3.84 m AHD***	***4.04 m AHD***	

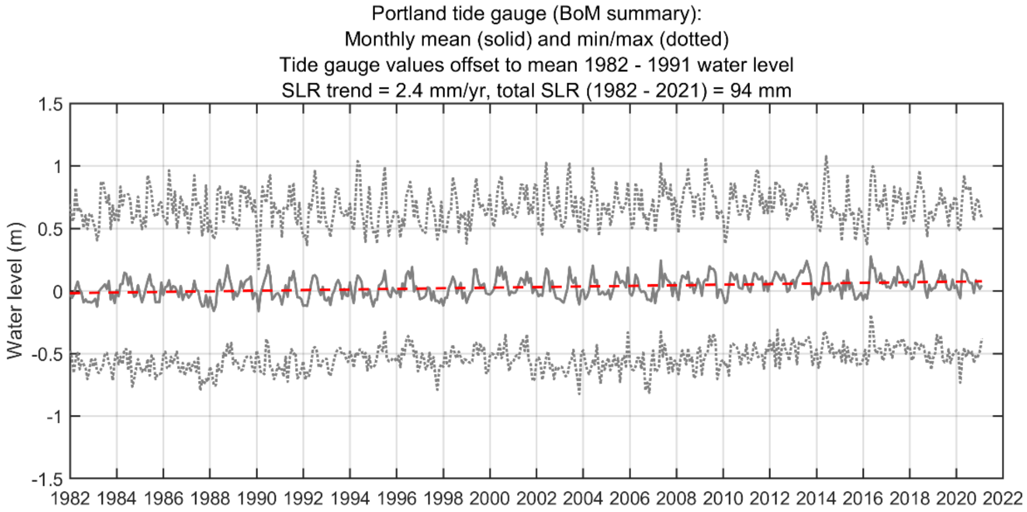


Figure 4-2. Monthly water levels from Portland tidal gauge (BoM, 2021), solid grey line is the mean water level for each month, offset to the mean from 1982 – 1991 (approx. 0 m AHD), dashed grey lines are the monthly minimums and maximums. Dashed red line is the long-term trend, with 94 mm of SLR from 1982 to 2021.

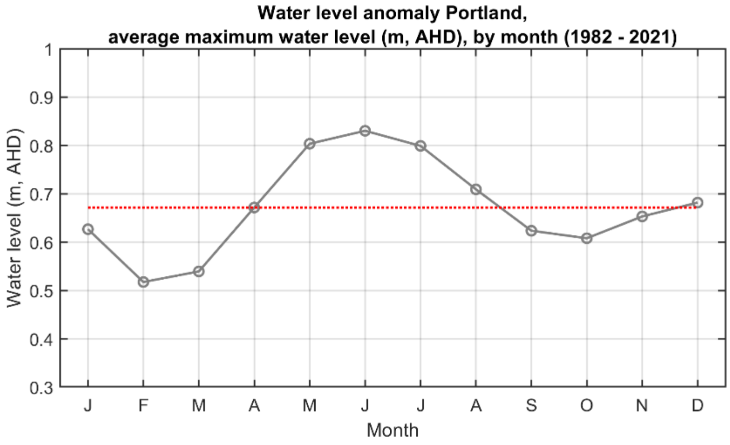


Figure 4-3. Average monthly maximum water levels by month for Portland tidal gauge.

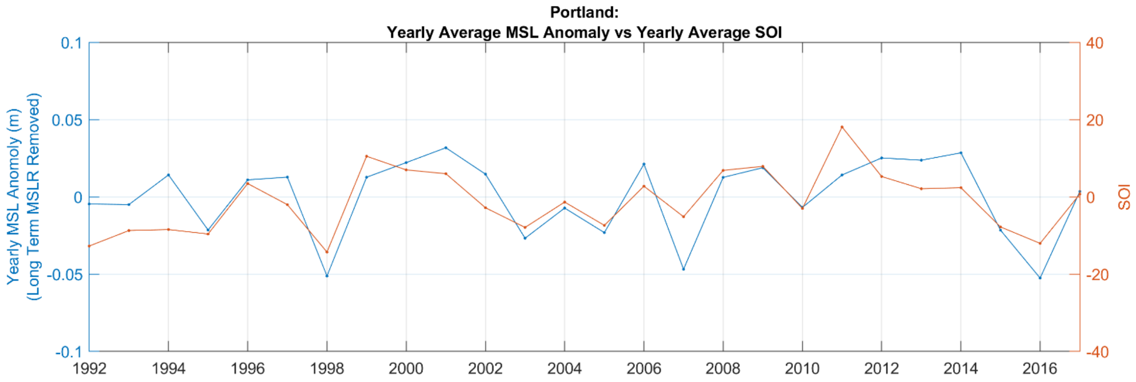


Figure 4-4. Annual water level anomaly at the Portland tidal gauge (Cardno, 2018).

Section 4.1 Summary and recommendation on optimal time of year for coastal works

Wave energy at Port Fairy is *marginally* lower from Nov – Feb (Section 3). Lower water level maximums occur around February. Given the combination of wave energy and monthly water level anomalies, the preferred time of year for engineering works would be around the months of Nov – Mar. However, it should be noted that extreme wave and water level events can occur at any time of year.

4.2 Inundation analysis

Total water levels for 2020 and 2050 (Table 4-1) are plotted against modelled cross-shore profiles at the DEECA landfill site (Fig. 4-5), for both the front (ocean side) and back (lagoon side) of the profile. shoreface translation methods used to obtain these profiles are described in detail in Section 7. The large dune at this location is predicted to be higher than maximum water level on the ocean side, by several metres. This indicates the dune crest would stand well above the maximum water level in 2050, thought the landfill (if still present) would be inundated. The road on the lagoon side is predicted to be only marginally above maximum water levels in 2050. A more thorough assessment of potential dune breaching is provided in WRL (2013).

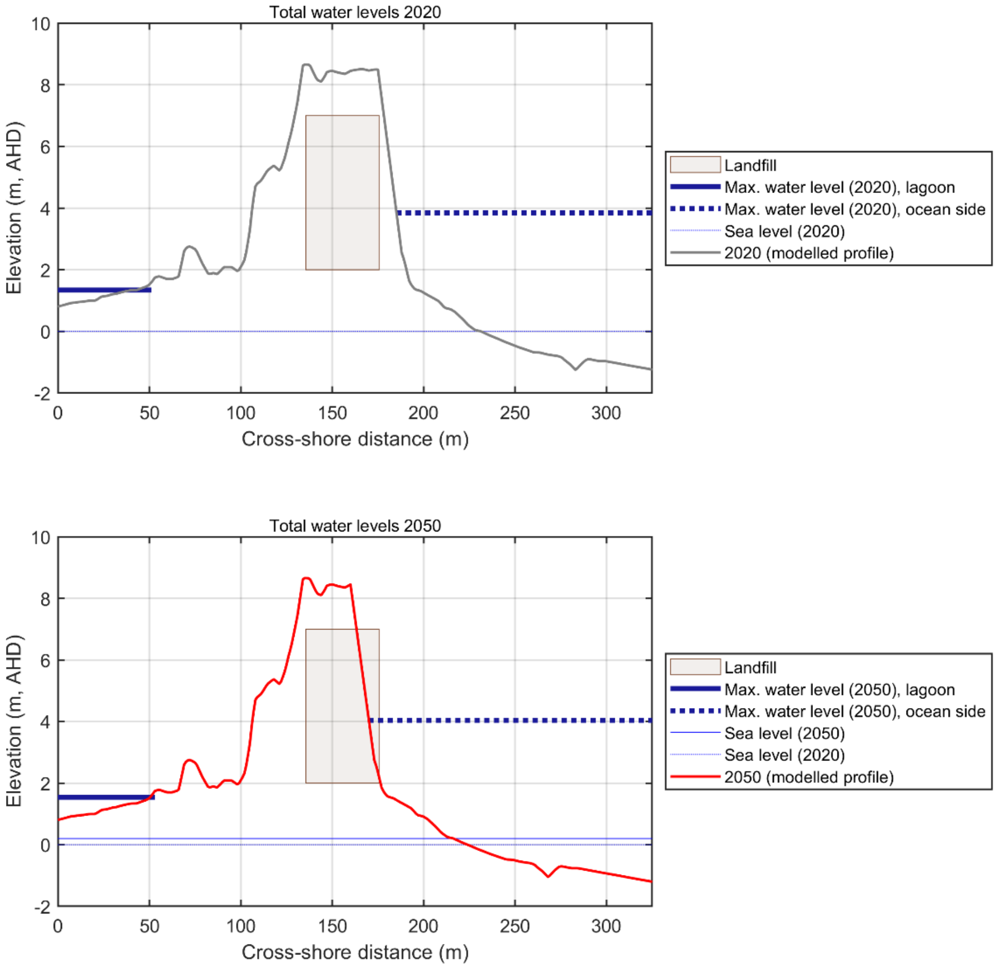


Figure 4-5. Total water levels (from Table 4-1), applied to modelled 2020 and 2050 shoreface, for ocean side and lagoon side of profile. The ocean side water level indicates the highest level wave runup is predicted to reach.

Brief analyses of ‘bath-tub’ inundation have been conducted internally and by CSIRO using their CFAST inundation modelling suite (Fig. 4-6). Consistent with the analysis Fig. 4-5, results suggest the landfill site is not under immediate threat from passive inundation. However, the road behind the dune may become inundated for more extreme water levels (> 2 m AHD), which are likely to occur in the years beyond 2050 (beyond the scope of this study).

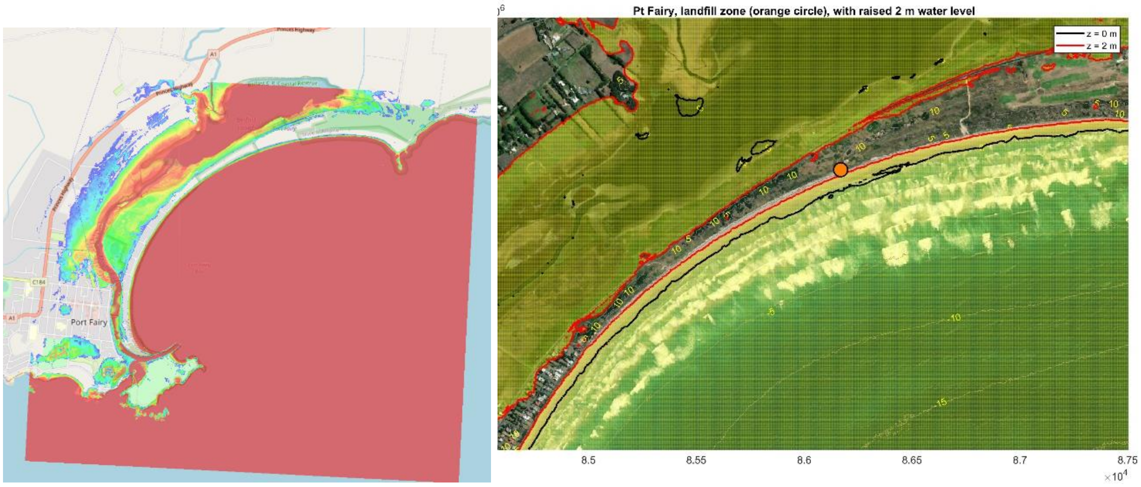


FIgure 4-6. Passive inundation ‘bathtub’ models, (left) CSIRO CFAST model of 2.6 m AHD water level; and (right) 2 m AHD water level.

5. Coastal geomorphology, interventions, and historical shoreline change

5.1 Geology, geomorphology, and sediments

Geology includes limestones capped with basalt (Carvalho et al., 2020). Wave energy, surf zone width, dune extent and dune height increase towards the northeast. Dune height is 7.5 m in the exposed central to northeast of East Beach. Beach state includes a single continuous inner attached bar, an outer bar and inner rips occur to the northeast. Sediment size is medium sand (WRL, 2013).

5.2 Storm erosion (short term variability)

Studies on storm demand volumes are limited. WRL (2013) applied the SBeach morphodynamic model to determine the erosion volumes produced by a 1-in-100-year average return interval (ARI) storm, and for a cluster of extreme storms (3 x 1-in-100 yr ARI). Storm demand ranged from 8 to 43 m^3/m for the 1 x 100 yr ARI event and up to 120 m^3/m for 3 x 100 yr ARI event. These values are moderate or low compared to some coastlines, e.g., NSW beaches can typically lose >100 m^3/m across extreme storm events or clusters. VCMP drone surveys (Section 5.4) indicate the short-term shoreline variability, due to storm erosion and post-storm recovery, has a range of >20 m.

5.3 Coastal interventions

Summarised from Carvalho et al. (2020).

Structures

- Training walls were built at the entrance of the Moyne River in the late 1800s (Fig. 5-1). The Southwest Passage was closed a few decades later, this led to erosion issues at East Beach and accumulation of sand updrift.
- A basalt breakwater was built in 1910s at the southwest end, to protect the shoreline.
- A 2.2km boulder seawall was constructed in the 1950s, gradually extended northeast over subsequent 3 decades.
- Timber groynes were built in the 1970s, to protect the shoreline from re-occurring erosion.

Renourishment

- Sand dredged to maintain navigation into the river was placed in the Puddney Grounds until the early 1990s and more recently near the southern end of East Beach.
- Approximately 5,000 – 10,000 m^3/yr is added to the system from dredging the Moyne River (CES, 2013a; Kane Church, Moyne Shire Council, pers. comm.)
- A detailed sand sourcing study was conducted in May 2013 (CES, 2013a), estimating that 500,000 m^3 has been lost from the embayment since the construction of the training walls. That study recommends 100,000 m^3 to initially nourish the beach, then 20,000 m^3 annually.
- CES (2013a) recommends depositing the nourishment material at the southwest end of the beach, allowing wave-action to transport the sediment to the northeast (Fig 5-1). This approach assumes a steady northeast transport from the SW to NE of East Beach; however, that assumption is contradicted by the longshore transport modelling of DHI (see Sec. 6.1 and Sec. 8.2).

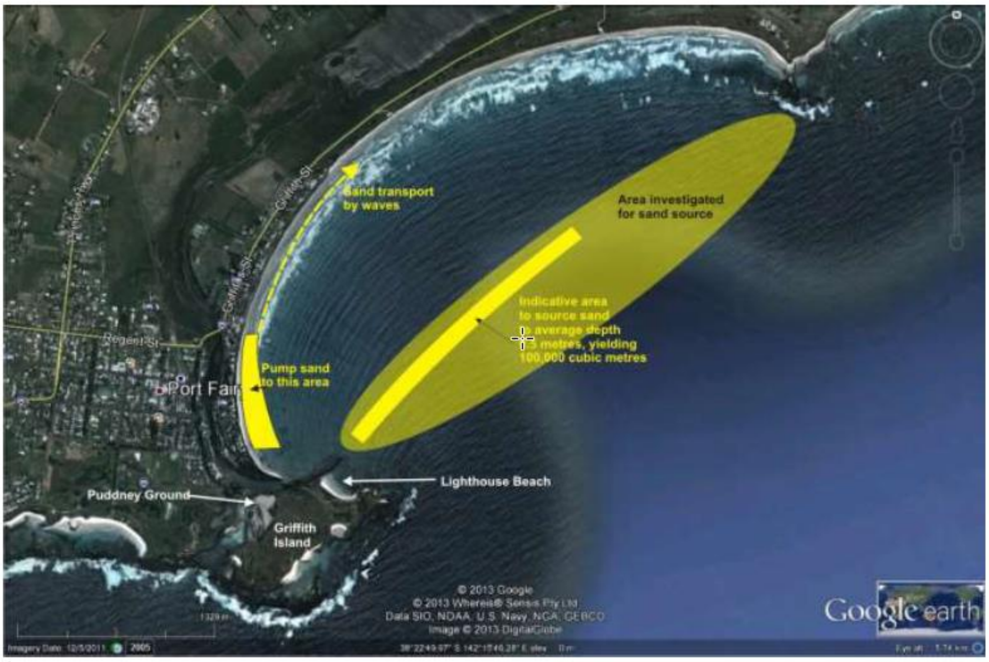


Figure 5-1. Proposed renourishment strategy (CES, 2013a).

Landfill sites

Two landfill sites are located along the middle to northeast of East Beach (Fig. 1-1), within the dunes backing the shoreline east from the end of the seawall. Beach recession has exposed contaminants and debris, in particular at the council site, to the northeast.

- Site 1: DEECA site, operation to the early 1980’s. No protective structures built. Contains “night soil” and other municipal waste.
- Site 2: Moyne Shire Council (MSC) site, filled with municipal waste from 1970’s to 1998. A seawall to prevent further erosion was constructed in 2015.

5.4 Shoreline change rates: Aerial imagery, satellite and VCMP drone observations

This analysis has been expanded to cover a wider range of available data, including the VCMP unmanned aerial vehicle (UAV, or 'drone') observations. The focus of this analysis is on the landfill sites section. Data sets include:

- Aerial photos with vegetation line extracted:
    - 1948, 1970, 1986, 2013, 2016, 2020.
- Lidar, 2007, vegetation line extracted (labelled DEM2010 in some figures).
- VCMP UAV surveys, includes orthomosaics and digital surface models:
    - 2018 – present, at approx. 6-weekly intervals.
    - Area of coverage is the mid-section of East Beach, including both landfill sites (Fig. 5-1)
    - Not all drone surveys have been included in the following analysis.
- Satellite (Landsat) shorelines:
    - Digital Earth Australia (DEA), from Geoscience Australia, annual mean shorelines available at https://maps.dea.ga.gov.au
    - CoastSat (Vos et al., 2019), high-frequency shorelines

Analysis of aerial imagery at the DEECA site (Fig. 5-1, 5-2), taking the vegetation line as a proxy for the shoreline (Carvalho et al., 2020; DHI, 2021), indicate the shoreline was stable from 1948 to 1986, with a dune erosion event prior to 2013. Subsequent to 2013, incipient vegetation has grown further seaward, though this does not necessarily imply the dune has recovered volume.

Comparing aerial and satellite trends across the full embayment (Fig. 5-3) indicates higher rates of erosion over the satellite period (1988 - 2018; -0.24 m/yr, averaged across East Beach), in contrast to the longer aerial image period (1948 – 2016; -0.04 m/yr). Rates calculated for the aerial imagery period are higher around the DEECA site (-0.2 m/yr), while a more intense zone of erosion is present between the sites over the more recent satellite period (up to -0.7 m/yr), in particular around the MSC site. The higher rates of recent erosion may include cross-shore storm erosion that could potentially return to the beach over several years (WRL, 2013), though this is somewhat speculative, and higher recent erosion rates could also be an indicator of SLR starting to have an impact. An even longer term shoreline change trend is given in WRL (2013), based on a navigation chart from 1870 (Fig. 5-4), which estimates an underlying trend rate of -0.1 to -0.4 m/yr.

A multi-method analysis comparing DEM2010, drone survey profiles and time series of the various survey methods indicates both sites experienced a period of severe erosion from 2011-2012, with 5 to 10 m of dune erosion (Fig. 5-5, top). The MSC dune also experienced erosion in the period between 1948 and 2016, not observed at the DEECA site. The most onshore position of the shoreline occurred around 2012 (Fig. 5-5, bottom row). Partial exposure of the landfill occurred during this time. The isolated seawall in front of the landfill site was built in 2015 (Carvalho et al., 2020). Aerial imagery suggests the wall may have somewhat aided in revegetation of the area between the dune toe and wall (not shown).

Modelling studies (Leach et al., 2020; DHI, 2021; see Section 6.1) suggest the erosion trend at the centre of East Beach is due to longshore transport gradients (i.e., waves breaking at a slight angle to the shoreline push more sediment out to the east than is pushed in from the west).

Section 5.4 Summary

The long-term (1948 – 2016) vegetation line change trend for the full embayment is close to zero, though there is a slightly higher erosion rate near the DEECA site (-0.2 m/yr). The medium term (1988 – 2018) trend over the satellite period is cause for concern (-0.3 to -0.7 m/yr), given the proximity of the landfill to the dune face at both sites. Therefore, it is recommended the satellite derived underlying shoreline trend be projected forward for estimates of future shoreline change that will be used to inform planning decisions.

Figure 5-1. Vegetation lines and VCMP drone survey boundary at East Beach. 1948 – 2016 vegetation lines extracted from aerial imagery, 2020 shoreline from drone orthophoto.

Figure 5-2. Aerial imagery of the DEECA landfill site, overlaid with vegetation line positions. The yellow shaded area is the approx. extent of landfill, based on Tonkin and Taylor (2019).

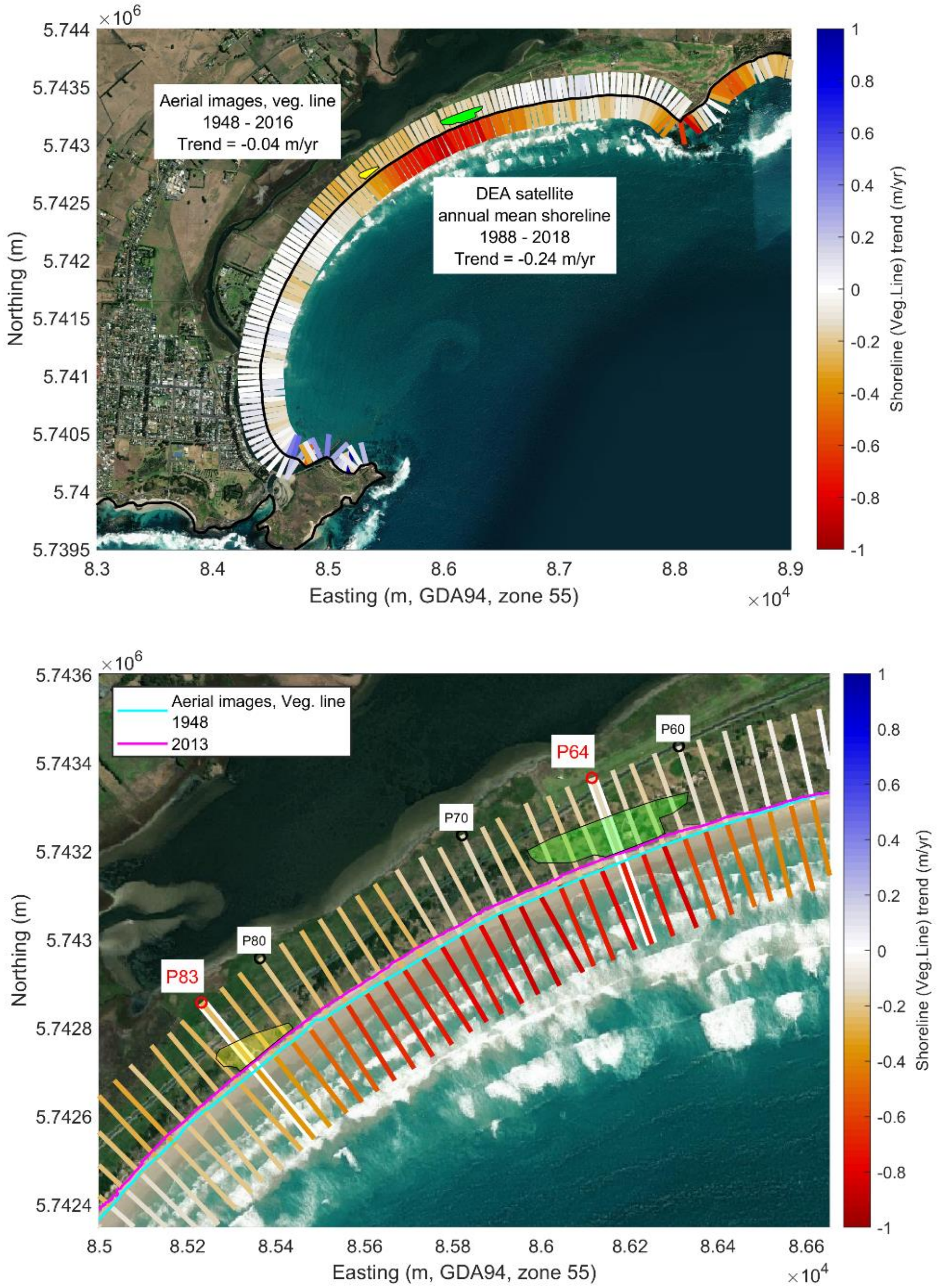
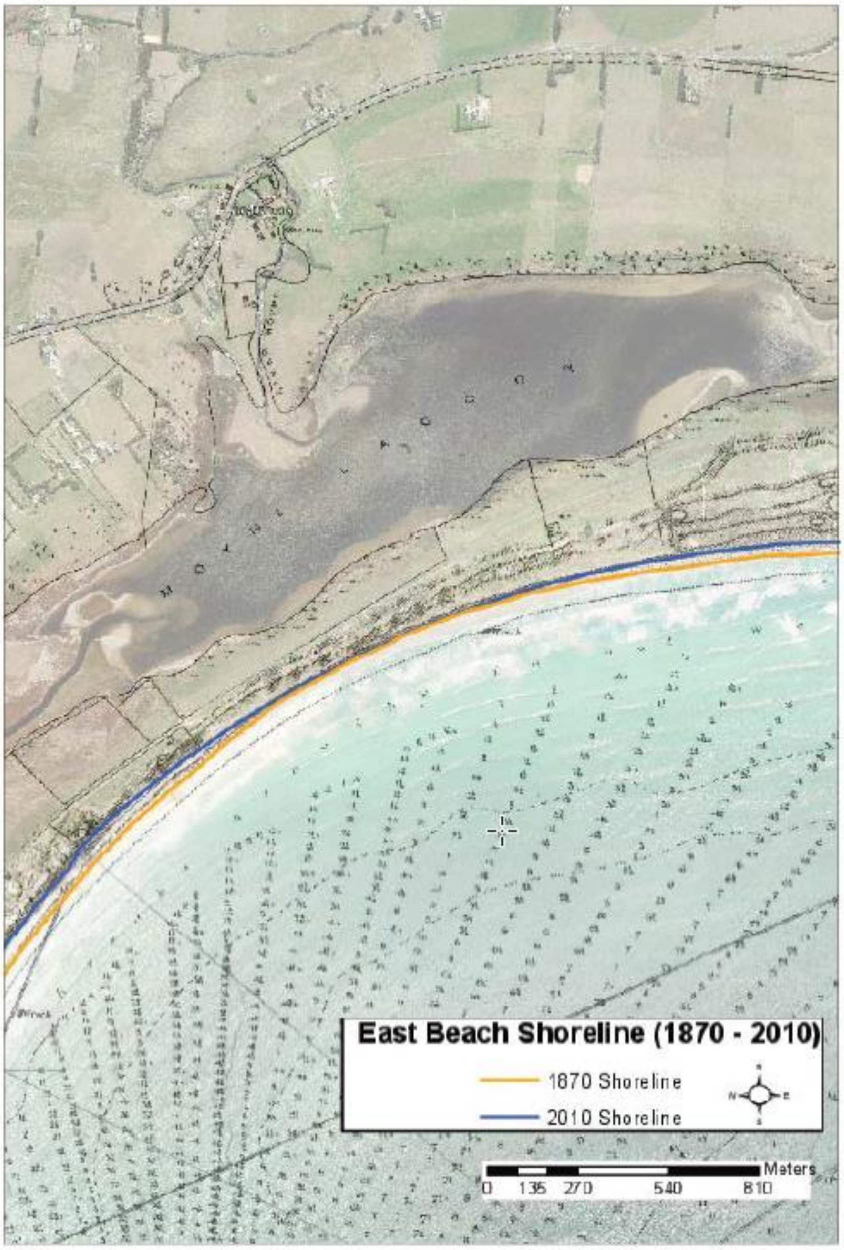


Figure 5-3. Rates of shoreline change from aerial imagery extracted vegetation lines (1948 – 2016), and satellite image extracted shorelines (1988 – 2018. (Top) East Beach / Port Fairy; and (bottom) area of interest, including the DEECA landfill site (yellow shading, to southwest) and MSC site (green shading, to northeast).



Shoreline Evolution between 1870 (Stanley) and 2010 Aerial Photography

Fig. 5-4. East Beach shoreline from 1870 to 2010 (WRL, 2013)

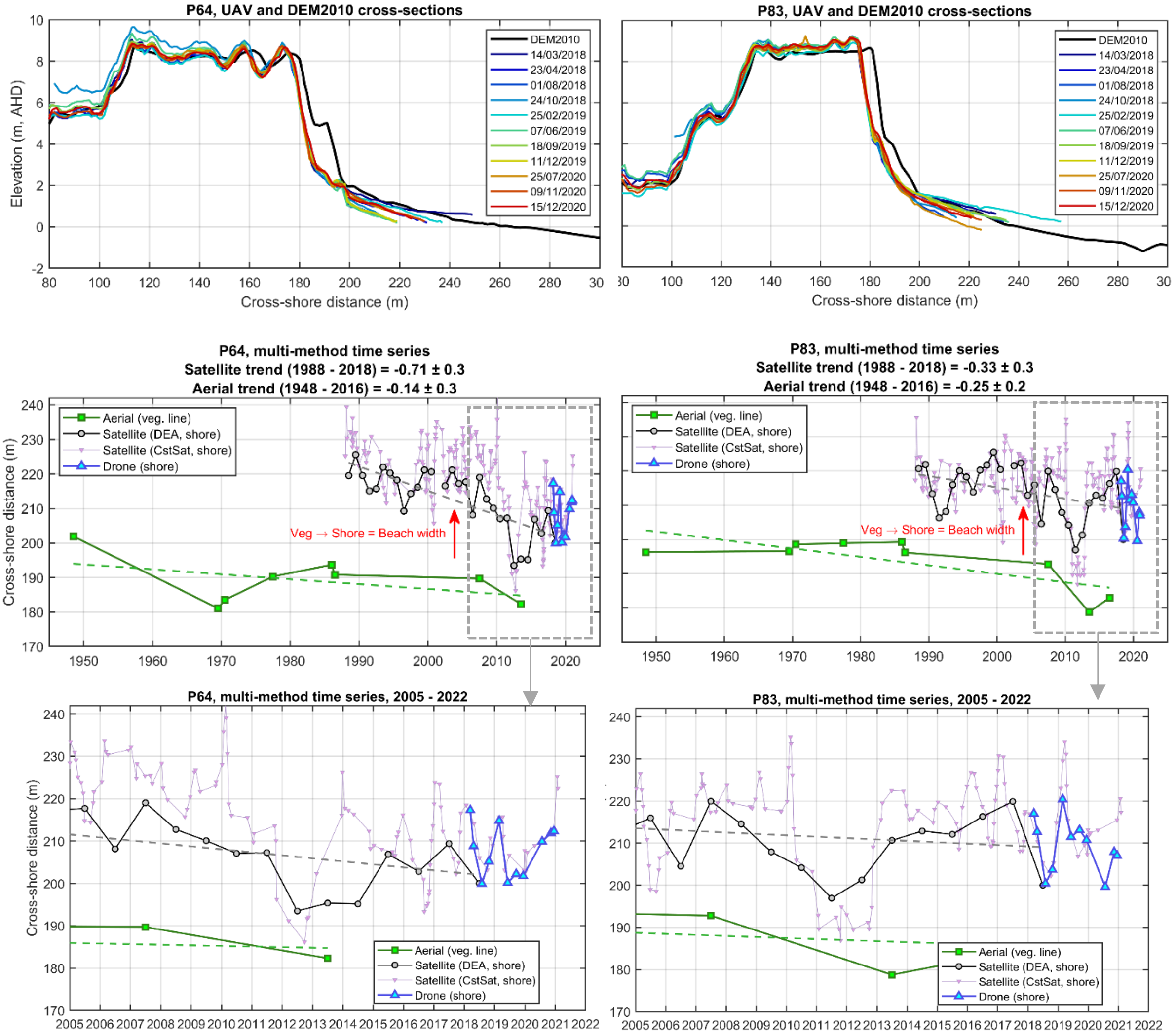


Figure 5-5. Multi-method cross-section and shoreline analysis. (Top row) Cross-sections of DEM2010 [black] and drone [UAV] survey profiles [cold to hot colours]; (middle row) time series of aerial image vegetation line, satellite shorelines, and UAV shorelines; and (bottom row) the same time series, zoomed on 2005 onward. Left column is the MSC site (P64), right column is the DEECA site (P83; see Fig. 5-3 for locations).

6. Predicting coastal change (I): Existing studies

6.1 Wave climate and coastal change models

DHI (2021), as part of the VCMP, developed a sophisticated hybrid model that is capable of estimating complex shoreline change over long time periods (Fig. 6-1). This model was partially validated against observations and represents the most robust shoreline model developed for East Beach. The DHI model assumes zero sediment input at the southwest boundary (i.e., no nourishment input). A key output from the DHI model was to identify a divergence point near the centre of the embayment (Fig. 6-2). This divergence point has critical implications for nourishment sites, and if this is correct, it implies that any nourishment placed at the southwest end of the beach **will not** be transported northeast toward the landfill sites (see Sec. 8.2 for further discussion).

Leach et al. (2020) and DHI (2021) examined future wave climate predictions to assess potential changes to rates of shoreline change. Both studies suggest that changes to longshore transport gradients in the region of the landfill are likely to be small; however, even small changes in transport can results in significant changes over long time periods. Given the current level of uncertainty, a conservative approach is to assume current rates of shoreline erosion will continue into the future. This assumption can be revised with future observations and more detailed numerical modelling.

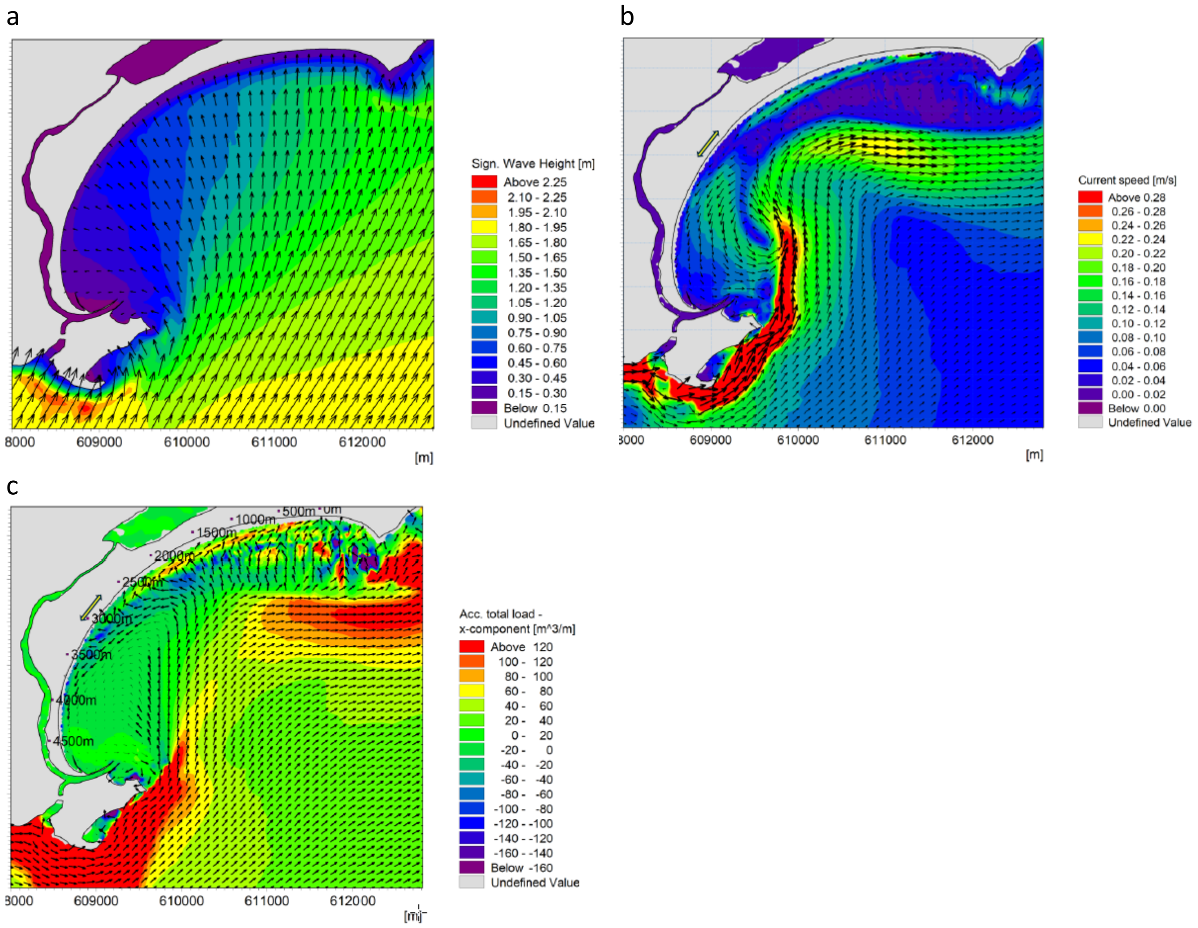


Figure 6-1. Outputs from the DHI (2021) MIKE 21 ST/SM model for a typical SSW wave event, including: (a) wave height and direction; (b) current vectors; and (c) cumulative sediment transport.

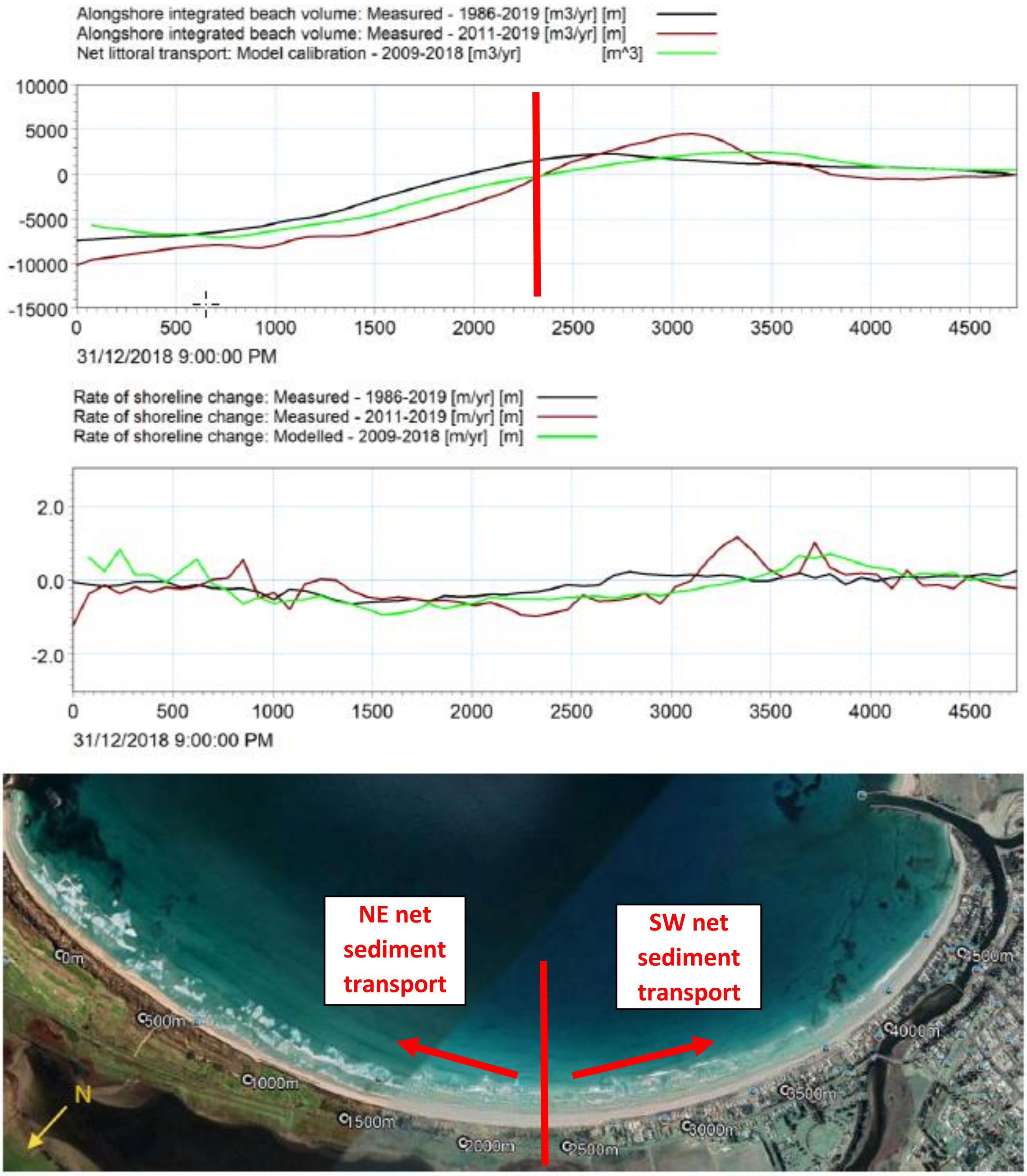


Figure 6-2. DHI (2021) observations and modelling of alongshore sediment transport in Port Fairy. In top panel, positive values indicate SW transport (negative values are NE transport). Red lines and arrows have been added to emphasise alongshore transport direction. A divergence point occurs at ~2300 m alongshore, just west of the end of the seawall.

6.2 Shoreface erosion and dune breaching

WRL (2013) and T&T (2019) provide a comprehensive assessment of erosion hazard, including assessment of:

- Short term storm erosion (S1)
- Dune stability (S2)
- Underlying long-term recession (S3)
- Future recession due to SLR (S4)

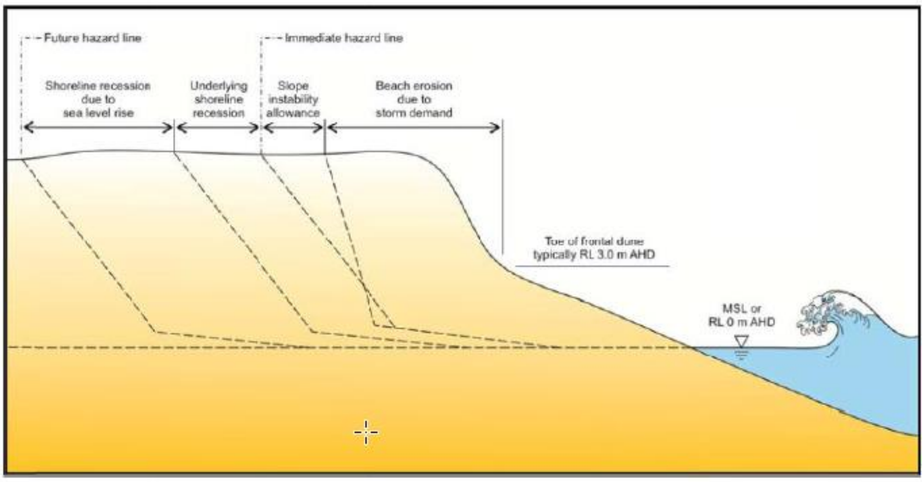


Figure 6-3. Estimation of coastal hazard used in WRL (2013), sourced from Tonkin and Taylor (2019)

The first two components are added together to provide the present-day hazard (i.e. the potential extent of storm erosion). The four components are added together to define potential future erosion distances (to 2050, 2080 and 2100). These distances, from the present day shoreline, are summarised in Table 1 for different time horizons.

Table 6-1. Erosion hazard lines (from WRL, 2013)

Location	S = S1 + S2	S = S1 + S2 + S3 + S4		
	Present day (m)	2050 (m)	2080 (m)	2100 (m)
DELWP site	22	39	55	71
MSC site	25	41	57	73

The 2050, 2080 and 2100 hazard lines are projected onto the DEECA landfill site in Fig. 6-4.

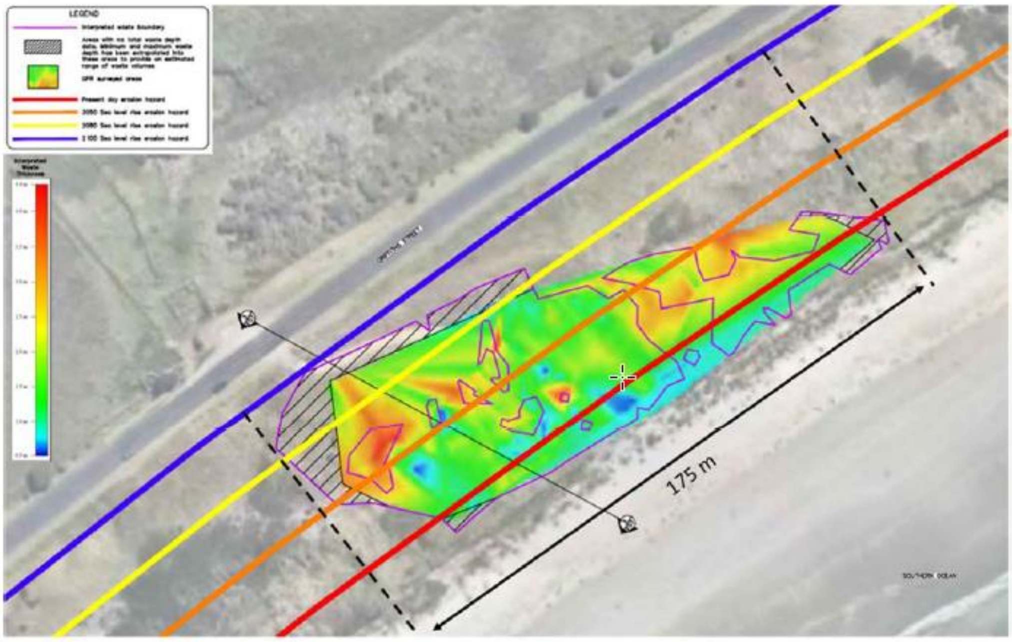


Figure 6-4. From Tonkin and Taylor (2019) using data from WRL (2013). Erosion hazard lines for present, 2050, 2080 and 2100 projected onto DEWLP landfill.

Section 6.2 Summary

The WRL (2013) report provides a detailed examination of future hazard lines, and this is supplemented by Tonkin and Taylor (2019). The current day setback limits (i.e., the areas that could be eroded by a series of extreme storms) are projected to be 22 – 25 m. For 2050, the projected setback is ~40 m.

7. Predicting coastal change (II): Novel shoreface translation modelling

The ShoreTrans (shoreface translation) tool (McCarroll et al., 2021a) was used to predict coastal change at Port Fairy. The ShoreTrans model is a simple, rules-based, user-input driven, shoreface translation and sediment budgeting model, that applies the surveyed 2D-profile (not a parameterization), for estimating change to realistic coastlines, resulting from SLR and variations in sediment supply, while accounting for armouring, hard-rock cliffs, and outcropping rocks. The tool can be applied to sand, gravel, rock, and engineered coasts at a temporal scale of 10–100 years, accounting for shoreline trends as well as variability. The method accounts for: (1) dune encroachment/accretion; (2) barrier rollback; (3) non-erodible layers; (4) seawalls; (5) lower shoreface transport; (6) alongshore rotation; and (7) other sources and sinks, including renourishment activities.

A conceptual model of a gradually eroding beach is presented in Fig. 7-1. Here, the shoreline and dune crest are both eroding at the same rate, when averaged over a long time period. This erosion may be due to a deficit in the sediment budget. For example, waves breaking at an angle to shore may move more sand away from a particular section of beach than is being moved in (i.e., an alongshore sediment transport gradient). This background trend in shoreline change is unrelated to SLR; however, SLR is expected to accelerate a negative trend. The shoreline has a large range of short-term variability, it erodes rapidly in storms, then accretes during more moderate periods. By contrast, the dune crest is expected to move in infrequent 'jumps', eroding only during the most extreme storm events (or clusters), then will grow again very slowly.

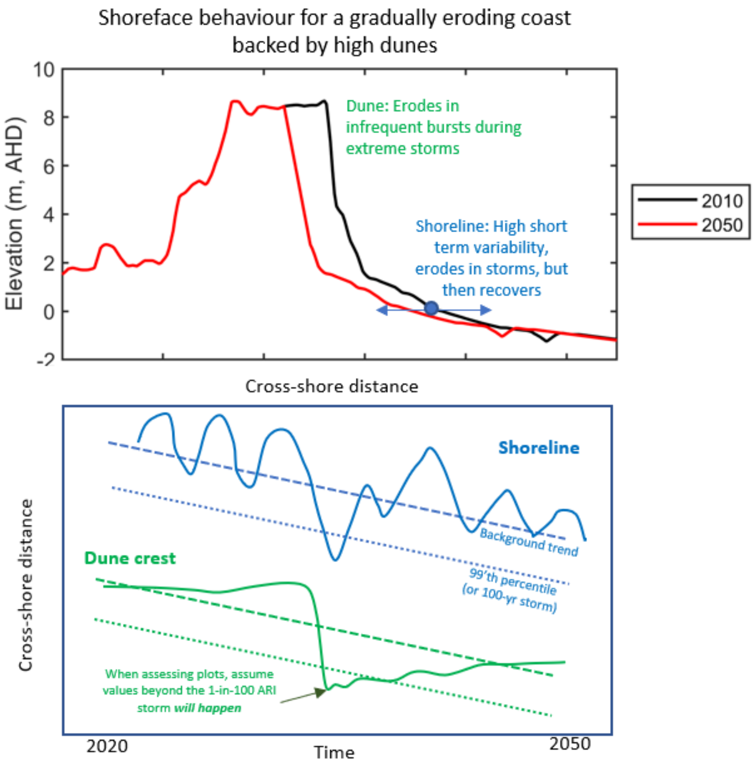


Figure 7-1. Conceptual model of rates of shoreline and dune crest background erosion, similar to Port Fairy. (Top) Cross-section of the dune and upper shoreface; and (bottom) example time series.

A hazard rating (Fig. 7-2) was developed based on the position of the front of the landfill relative to the dune face. The lowest hazard level (1) occurs when the front edge of the landfill is onshore of the projected impact envelope of a cluster of 3 x 100 yr ARI storms. The highest level of risk (5) occurs when the landfill front is projected to be offshore of the predicted position of the dune toe.

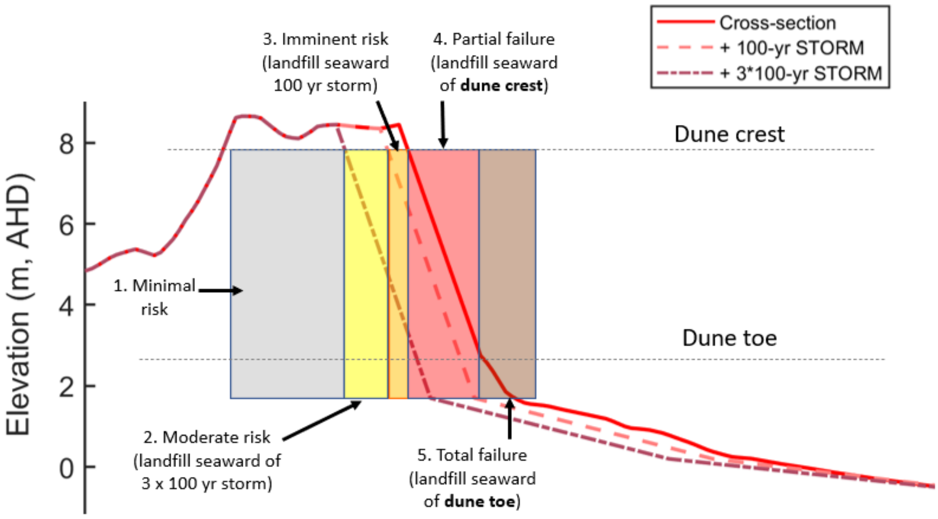


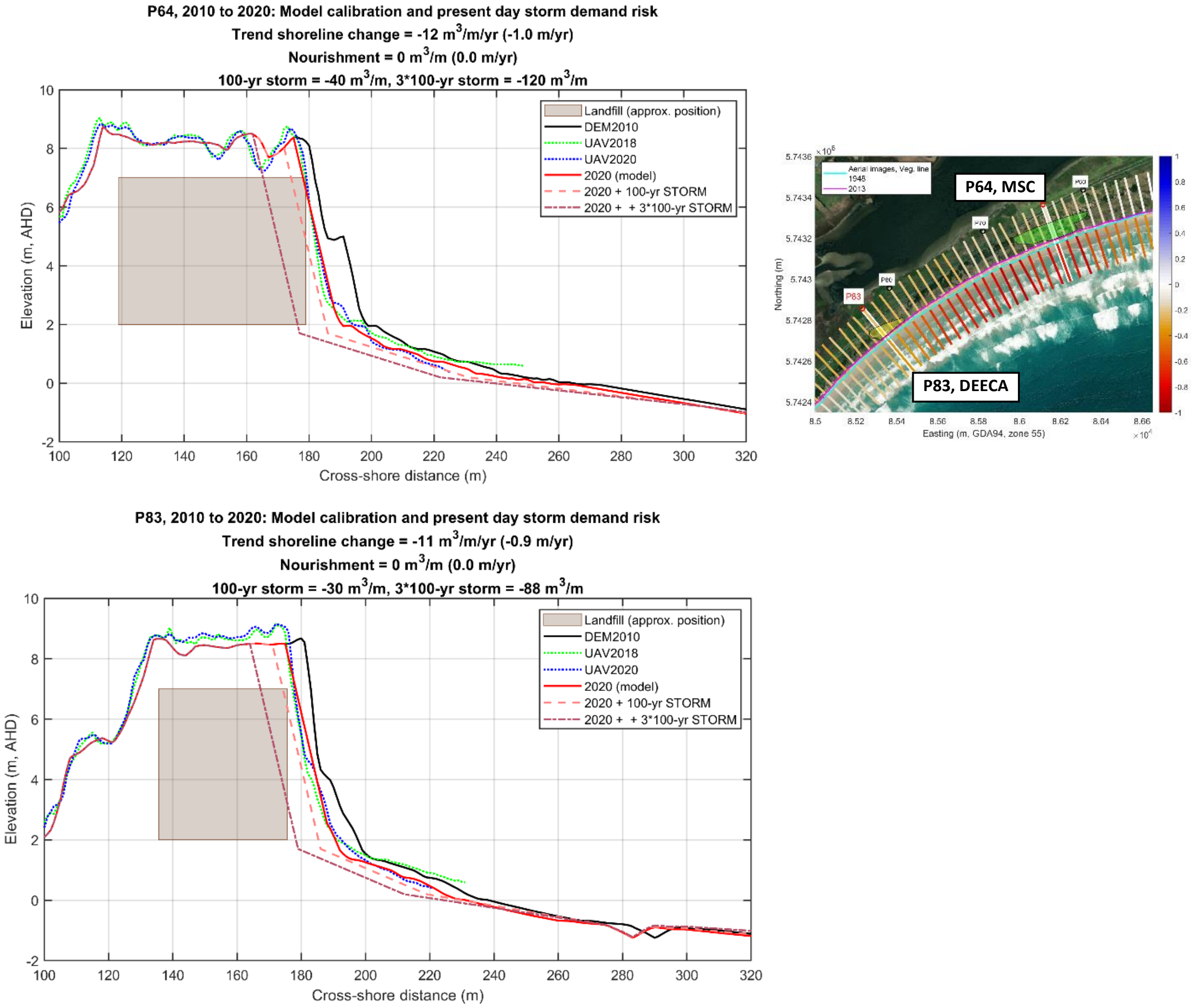
Figure 7-2. Hazard rating developed to assess landfill erosion risk, based on the position of the landfill relative to the dune face. Shaded areas (grey, yellow, orange, red, brown) represent location of the landfill. Hazard level ranges from ‘Minimal Risk’ (1) to ‘Total Failure (5)’.

Shoreface modelling was initially applied to two profiles, P64 at the MSC site and P83 at the DEECA site (Fig. 7-3). For the MSC site, the small seawall in front of the dune (or ‘Wave Energy Dissipation Structure’ [WEDS]; T&T, 2019) has not been included in the analysis. The approximate landfill location was copied from Tonkin and Taylor (2019; see Fig. 6-4 for an example).

The model was run using profiles extracted from the 2007 lidar (DEM2010). Drone (UAV) data from 2018-2020 were used to calibrate the ShoreTrans model. A sediment budget deficit was applied to the DEM2010 based on the volume change between DEM2010 and the 2020 UAV survey, between 1 m AHD and the dune crest (Fig. 7-3, left panels, area between black solid and green dotted lines), to obtain a modelled full shoreface extent for 2020 (Fig. 7-3, left panels, red line), which provides a good qualitative fit to the UAV survey profiles.

Storm demand estimates were then applied using the approach of Kinsela et al. (2017), using the values prescribed in WRL (2013) for 1-in-100-year average recurrence interval (ARI) event and a cluster of 3 consecutive 1-in-100-year events. For the DEECA site, the storm volumes were 30 m^3/m (100 yr ARI) and 88 m^3/m (3 x 100 yr ARI), based on the ‘Night Soil’ profile in WRL (2013). For P64, no direct profile from WRL (2013) is available for comparison, so a worst-case estimate of 40 m^3/m (100 yr ARI) and 120 m^3/m (3 x 100 yr ARI) was applied, based on the highest estimates for other profiles assessed. *As a matter of pragmatic interpretation, it should be assumed that the 100 yr ARI can and will occur at any time, and the 3 x 100 yr ARI is the maximum possible erosion (used as a setback line for future planning).*

The present day assessment suggests the landfill at the MSC site (Fig. 7-3, top left, P63) is already starting to be encroached by the dune face (as evidenced by garbage being exposed by earlier storm events). At the DEECA site (Fig. 7-3, bottom left, P83), the landfill is estimated to be within ~3 m of the dune face, and falls within the 100 ARI event (Fig. 7-3, "2020 + 100-yr STORM" dashed line). For both sites, the landfill falls well with the "3 x 100-yr ARI" line.



P64, 2010 to 2020: Model calibration and present day storm demand risk
Trend shoreline change = -12 m^3/m/yr (-1.0 m/yr)
Nourishment = 0 m^3/m (0.0 m/yr)
100-yr storm = -40 m^3/m, 3*100-yr storm = -120 m^3/m

P83, 2010 to 2020: Model calibration and present day storm demand risk
Trend shoreline change = -11 m^3/m/yr (-0.9 m/yr)
Nourishment = 0 m^3/m (0.0 m/yr)
100-yr storm = -30 m^3/m, 3*100-yr storm = -88 m^3/m

Figure 7-3. ShoreTrans calibration and present day storm demand potential. (Top left) MSC site cross-section; (Bottom left) DEECA site; and (top right) profile locations.

7.1 Shoreface change prediction (2020 – 2050) with no intervention

A projection of coastal change from 2020 to 2050 was applied at both the MSC (P64) and DEECA (P83) sites. A rise in sea level of 0.2 m from 2020 to 2050 was applied linearly, at 5-year time steps, based current IPCC estimates for RCP8.5. A “lower erosion” and “higher erosion” estimate were applied based on the differing shoreline trend rates obtained from the aerial imagery vegetation line and satellite images shorelines (Fig. 5-3). It is plausible that the lower underlying erosion rate will eventuate over time; however, it is recommended that all planning decisions are based on the higher rate.

The hazard rating (described in Fig. 7-2) is shown here as a time series (Fig. 7-4, bottom panels), taking +7 m AHD as the crest of the dune, to avoid issues with irregular profiles. For the MSC site, over the 2020 – 2050 time horizon (Fig. 7-4) the landfill starts within the “Imminent risk” range (Fig. 7-4, bottom panels, orange band) and passes into the “Partial failure” (red band) within 1-2 years. However, this analysis does not take into account the low seawall, and also note the actual dune face erosion may substantially lag or lead the mean trend (see Fig. 7-1). For the high erosion case for the MSC site, the dune is predicted to encroach on the landfill after 2035 (Fig. 7-4, bottom-left, “total failure” band).

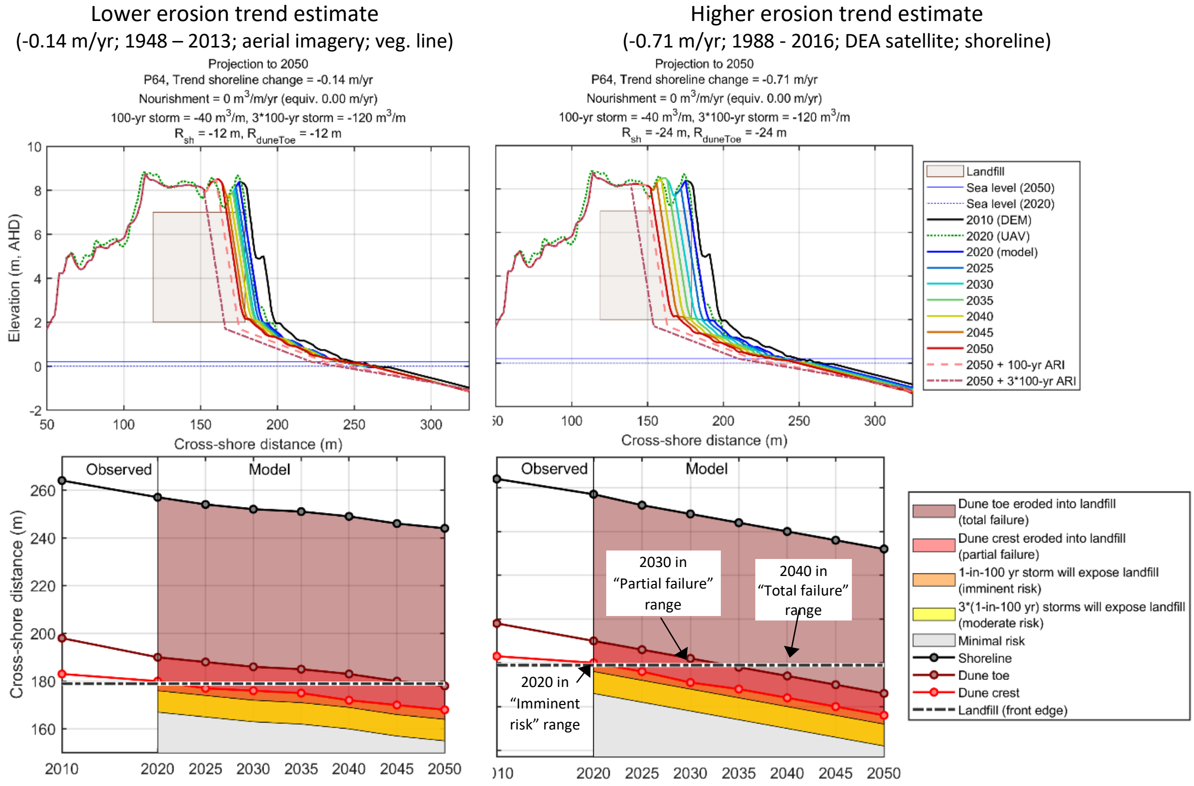
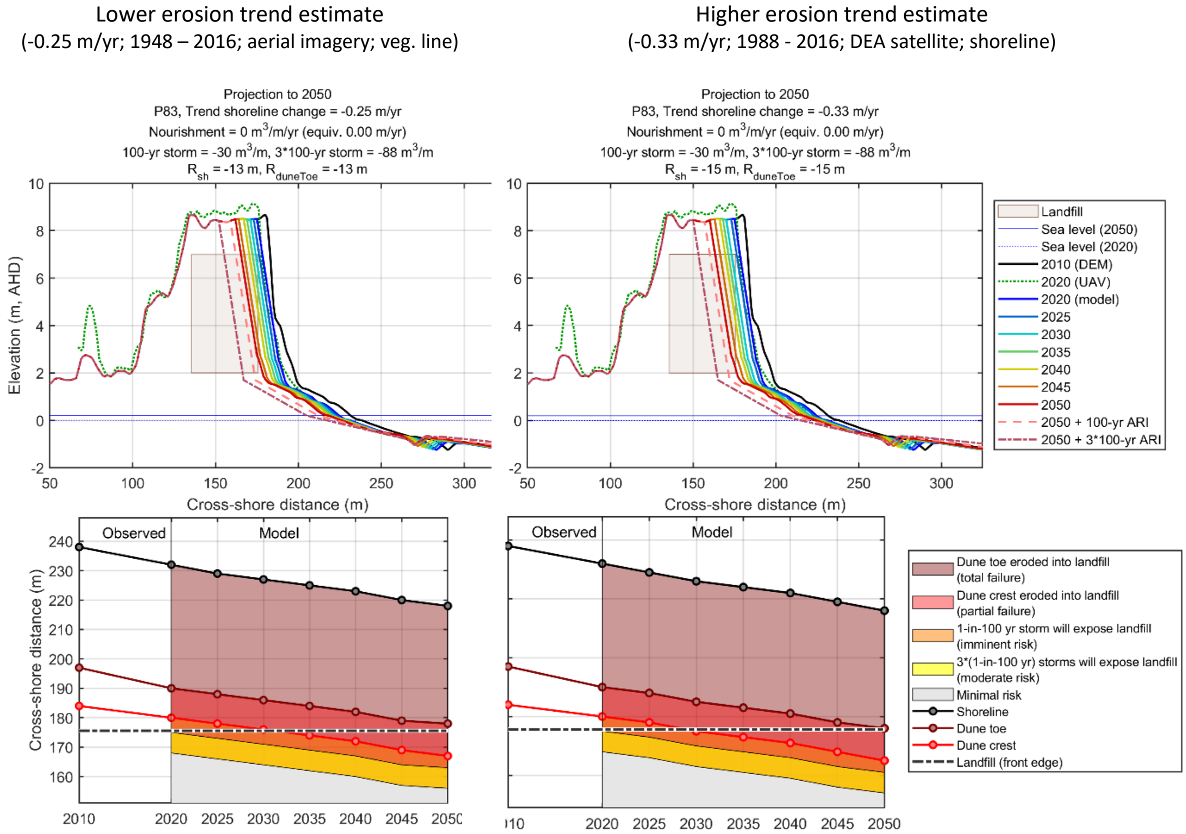


Figure 7-4. ShoreTrans forecast for MSC SITE (P64) with short-term storm demand potential . (Left panels) lower erosion rate estimate, based on 1948 – 2016 aerial imagery of the vegetation line; (right panels) higher erosion rate estimate, based on 1988 – 2018 DEA satellite imagery of the shoreline. (Top panels) cross-sectional shoreface evolution; (bottom panels) time series’ of shoreline and dune crest, with hazard levels indicated. Landfill position is estimated from Tonkin and Taylor (2019).

For the DEECA site, from 2020 – 2050 (Fig. 7-5), the shoreline is predicted to erode by 13 to 15 m. Here, the landfill hazard trend line also begins within the ‘imminent risk’ zone, progressing to ‘partial failure’ by 2028 to 2030.



Lower erosion trend estimate
(-0.25 m/yr; 1948 – 2016; aerial imagery; veg. line)

Higher erosion trend estimate
(-0.33 m/yr; 1988 - 2016; DEA satellite; shoreline)

Figure 7-5. ShoreTrans forecast for DEECA SITE (P83) with short-term storm demand potential . (Left panels) lower erosion rate estimate, based on 1948 – 2016 aerial imagery of the vegetation line; (right panels) higher erosion rate estimate, based on 1988 – 2018 DEA satellite imagery of the shoreline. (Top panels) cross-sectional shoreface evolution; (bottom panels) time series’ of shoreline and dune crest, with hazard levels indicated. Landfill position is estimated from Tonkin and Taylor (2019).

7.2 Shoreface change with soft (renourishment) and hard (seawall, revetment) interventions

A preliminary analysis of renourishment and structural interventions is presented for the DEECA site (Fig. 7-6). Including renourishment, construction of a seawall at the dune toe, and a combination of renourishment and a seawall. For the renourishment only approach (7-6, top row), a nourishment rate of +10 m^3/m/yr (in addition to the current net sediment budget) is suggested to be sufficient to maintain or even prograde the shoreline. However, this is only for a single profile and underlying trend rates of erosion vary along the bay. In order to maintain the shoreline across the full embayment, a nourishment rate on the order of 50,000 m^3/yr would be required (Section 8). This is an order of magnitude estimate, and should be revised based on ongoing observations and modelling.

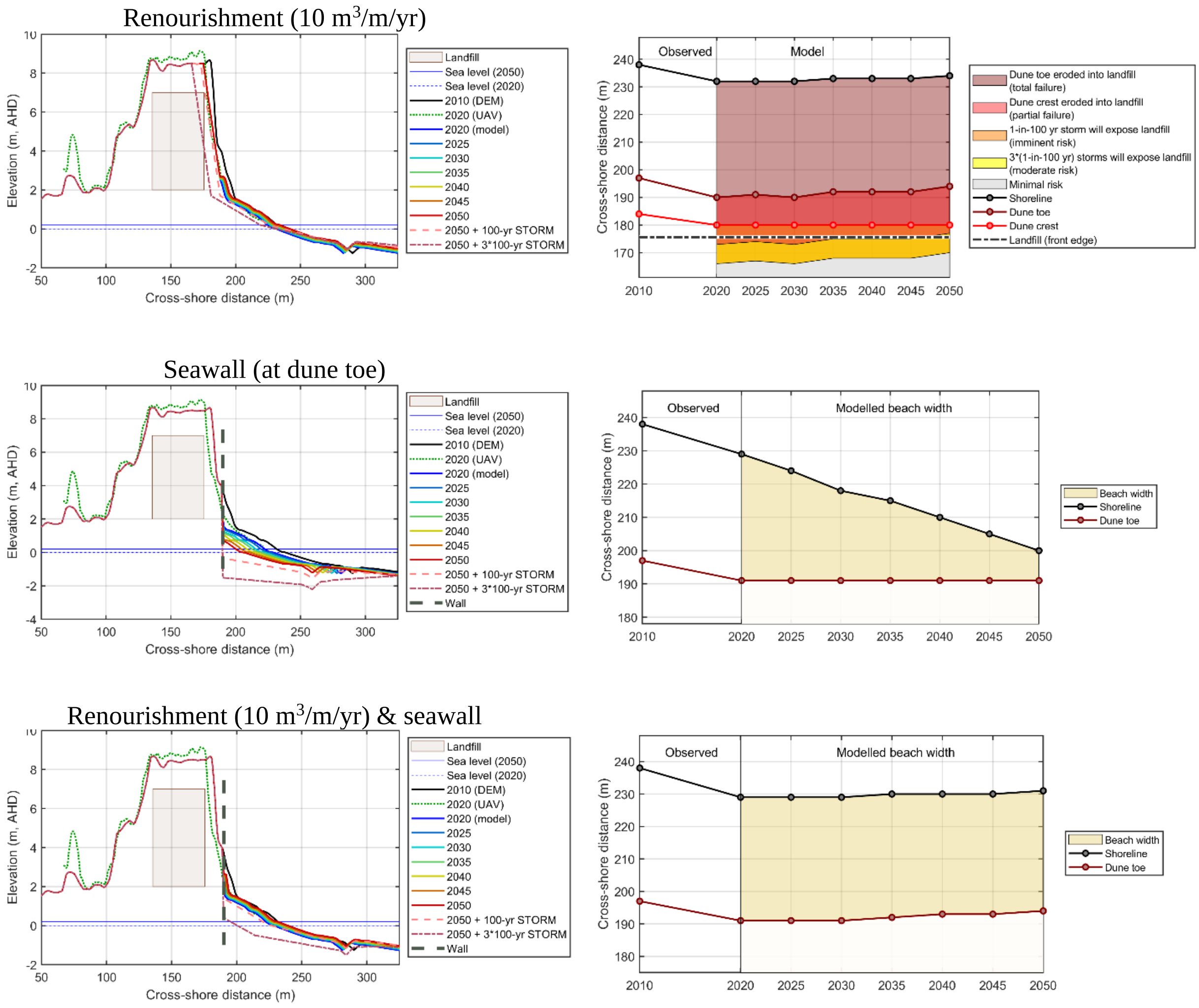


Figure 7-6. Example soft and hard interventions at the DEECA site (P83), for 2020 – 2050, with 0.2 m SLR, and underlying erosion trend of 0.33 m/yr (as per Fig. 7-5, 'higher trend', based on satellite data). (Top) Renourishment of 10 m^3/m/yr; (middle) construction of a seawall at dune toe; and (bottom) renourishment and seawall. (Top right) hazard level time series, as per Fig. 7-5. For the seawall backed profiles (middle and bottom), the right panels show projected beach width.

Adding a hypothetical seawall at the dune toe of the DEECA site (Fig. 7-6, second row), will act to protect the landfill. This analysis assumes an idealised wall, with no erosion occurring onshore of the wall. The feasibility of such a wall from an engineering perspective is not considered. As no erosion can occur behind the wall, the hazard rating is irrelevant (the landfill is assumed to be at zero risk). Instead, a prediction of beach width is provided (Fig. 7-6, bottom right panels). For a wall-backed profile with no nourishment, the beach will gradually erode due to the underlying sediment deficit and SLR impacts, with the wall acting to accelerate the rate of erosion (Beuzen et al., 2019). From 2020 to 2050, the mean beach width is predicted to reduce from 40 m to 10 m (Fig. 7-6, middle panels); however, during high tides and after periods of storm erosion the beach will disappear entirely. A hypothetical scenario of renourishment (+10 m^3/m/yr) and construction of a seawall (Fig. 7-6, bottom row) predicts the beach width would be maintained or increase slightly over the 2020 to 2050 period.

7.3. Hazard lines based on shoreface modelling

The ShoreTrans method was applied to all profiles (50-m alongshore spacing), across the two landfill sites. An assessment of present day and 2050 shorelines and storm demand (volumes described in Section 7.2) expand the cross-sectional approach to the full coastline. The results are broadly comparable with previous assessments (e.g., WRL, 2013; T&T, 2019); however, the ShoreTrans approach provides a greater degree of integration between processes (e.g., SLR and storm demand; seawalls and nourishment), with greater detail and transparency on the degree to which various coastal processes are driving the rate of shorelne change.

Section 7 summary

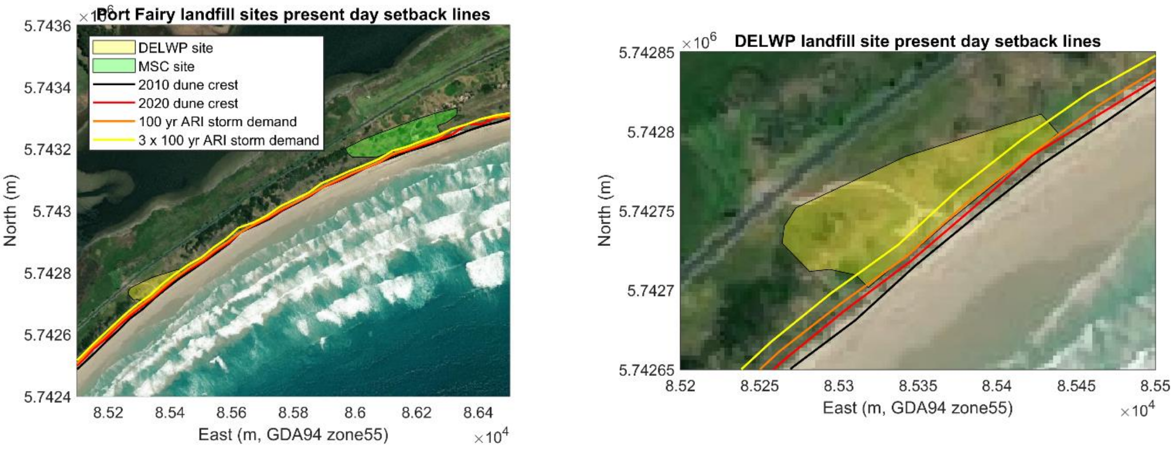
The ShoreTrans model was used to project how: (i) storms may impact on the landfill sites at present; (ii) how the shoreface is projected to change to 2050, and the degree of encroachment into the landfill; and (iii) the impact of soft and hard interventions on projected profile evolution.

A novel hazard rating was introduced. The primary outcome is to show the present situation is in the ‘imminent risk’ range, suggesting that immediate action should be taken. The DEECA site is projected to pass into the ‘partial failure’ phase by 2028. Recall that the dune face moves in rapid jumps (Section 7.1), so the dune may be above the long-term trend, waiting for the next extreme storm to rapidly erode.

The various levels of risk can be used as trigger points for action or to re-assess ongoing shoreline change rates.

Note: An immediate large renourishment (e.g., 300,000 m^3), with subsequent steady erosion, has not been modelled. It would be useful to model such a strategy for consideration against other intervention options.

Hazard and setback lines 2020



Hazard and setback lines 2050

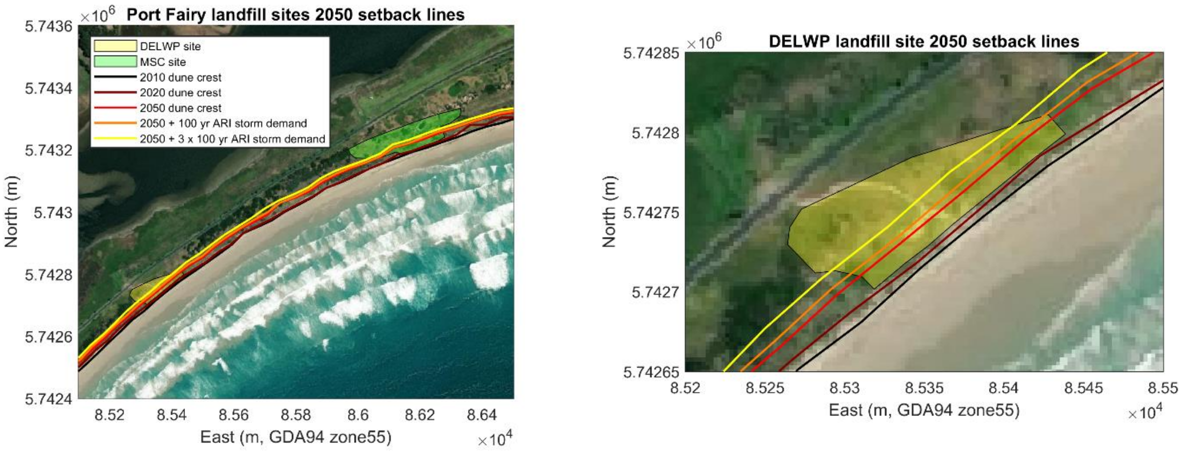


Figure 7-7. Coastal hazard and setback lines for the East Beach landfill sites. (Top) present day risk; and (bottom) setback lines for 2050.

8. Predicting coastal change (III): Embayment processes and sediment budget

The components of a total sediment budget comprise:

Shoreline change = **Cross -shore** + **Alongshore** + **Sources/ Sinks** + **Sea level translation**

“Source/sinks” includes nourishment. A detailed description of the approach is given in McCarroll et al. (2021a). The above sediment budget components (excepting SLR) can be broken down into:

- *Trend* or *underlying* rates (a steady change over many years)
- Short-term *variability* or *fluctuations* (an envelope of change that can vary unpredictably from year to year)

Budgets can be reported in units of:

- Shoreline position (m or m/yr)
- Profile volume (m^3 or m^3/year for a compartment, m^3/m or m^3/m/yr for a profile)

By assessing a total sediment budget, we can:

- Identify/isolate components of the budget that are unknown, and direct future efforts to determine these.
- Estimate required nourishment volumes more effectively.
- Better estimate when hard interventions will be required.
- Assess the system as a whole, assisting decision making on interventions.

8.1. Sediment budget calculation for East Beach compartment

A sediment budget can be calculated for an entire compartment, for a section of shoreline, or for an individual profile. Several consultant reports (CES, 2013a; Water Technology, 2020; BMT, 2020; DHI 2021) have provided partial estimates of sediment budgets. A total sediment budget of -2,100 m^3/yr to -8,400 m^3/yr is estimated by WRL (2013).

For each section of shoreline, the sediment budget (ΔV) can be estimated as

$$\Delta V\ (m^3/m\ /yr) = h_a \Delta X$$

where h_a is the height of the active shoreface and ΔX is the rate of shoreline change (m/yr). Taking the height of the active shoreface as 12.5 m (depth of closure at -10 m AHD, and height of dune toe at +2.5 m AHD), a budget can be calculated for both the aerial (1948 – 2016) and satellite (1988 – 2018) periods (Fig 8-1). This gives a range of -3,000 to -17,000 m^3/yr, broadly consistent with the WRL estimate.

An ***example*** sediment budget is provided graphically Figure 8-2, with quantitative details in Table 2. This demonstrates how the sediment budget method can be used to aid decision making. Values for the input variables are broad estimates, which can be revised in future iterations.

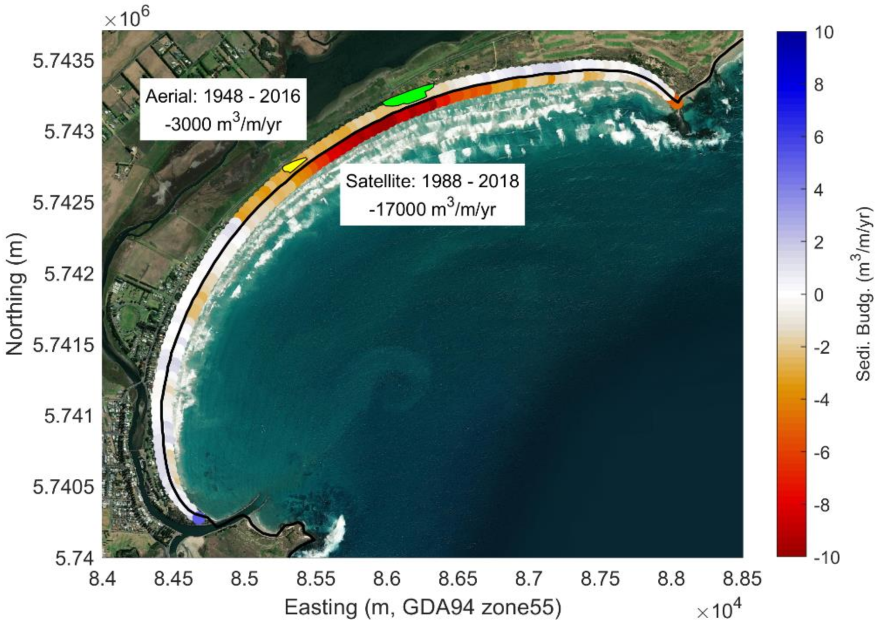


Figure 8-1. Sediment budgets for Port Fairy based on aerial imagery (top-left line) and satellite (bottom-right line).

Sediment budget summary

- An initial *net* sediment budget of -10,000 m^3/yr is used, taking the mid-point between the low- and high-end estimates in Fig 8-1. In addition, this is informed by estimates in WRL (2013), DHI (2021), CES (2013a), and communications with Moyne Shire Council,
- There is contradictory evidence regarding nourishment volumes and longshore transport rates, in particular:
    - DHI (2021) assumes zero nourishment, which validates reasonably well against observations, and predicts a divergence point in alongshore flux near the end of the seawall (Fig. 8-3).
    - Moyne Shire Council reports 10,000 m^3/yr is added to the system from dredging the Moyne River.
    - If the divergence point is accurate, any nourishment should effectively be trapped in the SW section of the beach (the implications of this are expanded on in Sec. 8.2).

- To account for the above uncertainty, a nourishment range from 0 to 10,000 m^3/yr is given in Fig. 8-2.
- The net loss from the system must then be in the range of -10,000 to -20,000 m^3/yr, which occurs due to waves moving sand around the headland to the northeast.
- Given these assumptions, the average rate of shoreline change across the embayment (Scenario 1 in Table 2) is presently -0.15 m/yr, but this is concentrated around hotspots (Fig. 8-1).
- If 0.2 m of SLR occurs from 2020 to 2050 (Scenario 2), the average rate of shoreline recession will increase to -0.56 m/yr), using the Bruun rule approach (shoreline change = SLR / active profile gradient).
- To offset this amount of SLR, the required additional nourishment rate across the full ~5 km embayment (Scenario 3), is predicted to be 47,000 m^3/yr. I.e., this volume would maintain the current shoreline across the entirety of East Beach, given our assumptions.

- The total nourishment volume may be reduced if only the section covering the landfill sites were targeted, though precise estimates would require further analysis, and more sophisticated modelling.
- Building large groynes that could effectively trap sediment from moving alongshore would allow recalculation assuming a reduction in net annual loss of sediment alongshore. However, groynes can cause severe downdrift erosion, and other disruptions to the sediment budget.
- Building revetments and seawalls can prevent onshore movement of the shoreline, but at the cost of losing the sandy beach (see Sec. 7, Fig. 7-6).
- Uncertainty has not been accounted for adequately in this analysis. Large uncertainty exists and should be incorporated in subsequent work. Some terms are highly uncertain, and have not been accounted for at all, e.g., cross-shore flux to the lower shoreface is assumed to be zero.
- SLR over recent decades has not been explicitly included in Figure 8-2 and Table 8-1 (Scenario 1); though it is noted that SLR may in part be responsible for accelerated rates of shoreline erosion over recent decades. A brief analysis was applied assuming a rate of 2.4 mm/yr of SLR from 1988 – 2018 (total 7.2 cm; Fig. 4-2), using the same parameters as Table 8-1. Given these assumptions, it is estimated that of the bay-wide total erosion rate of -0.24 m/yr from 1988 – 2018 (Fig. 5-3), only -0.09 m/yr is due to an underlying trend, and -0.15 m/yr is due to SLR. This potentially means that underlying shoreline change rates for recent decades are overestimated, and therefore future rates of erosion will be lower than those presented through Sections 6 to 8 of this report. However, given the high level of uncertainty, it is prudent to apply more conservative assumptions (as per Section 7 and 8). Over coming years, as more data become available and SLR impacts become increasingly apparent, estimates of sediment budget and shoreline change rates may be revised.

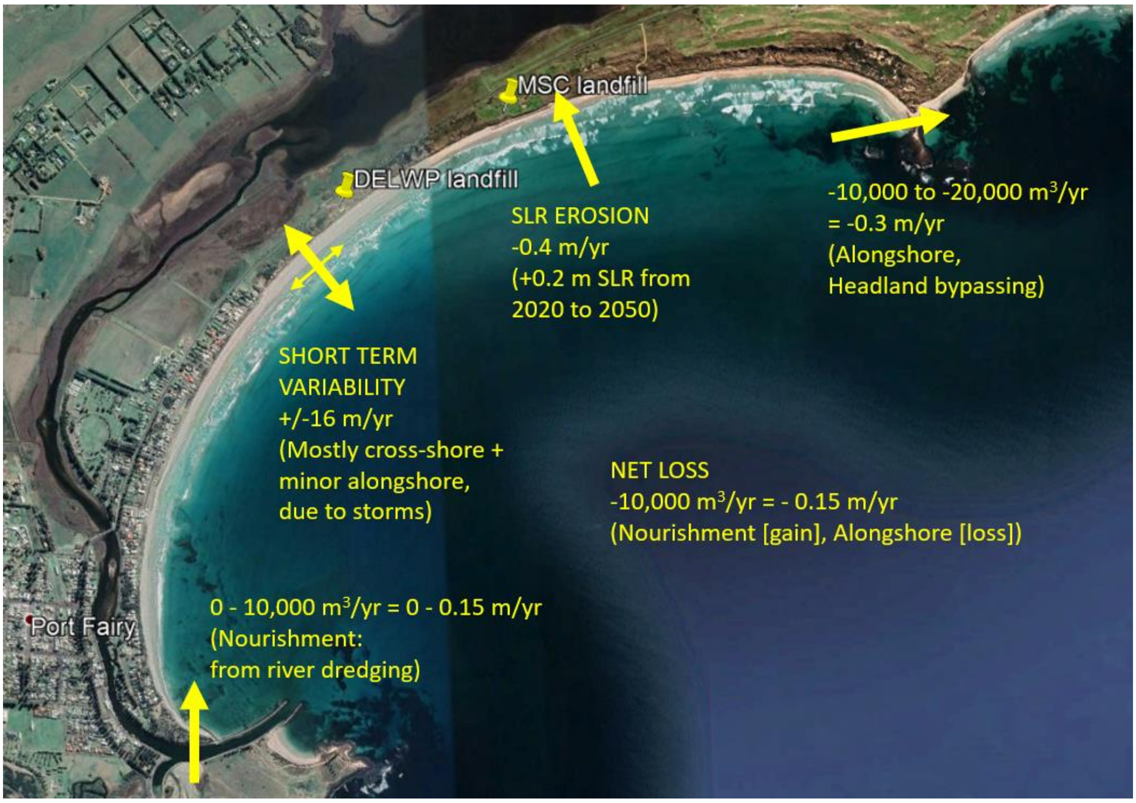
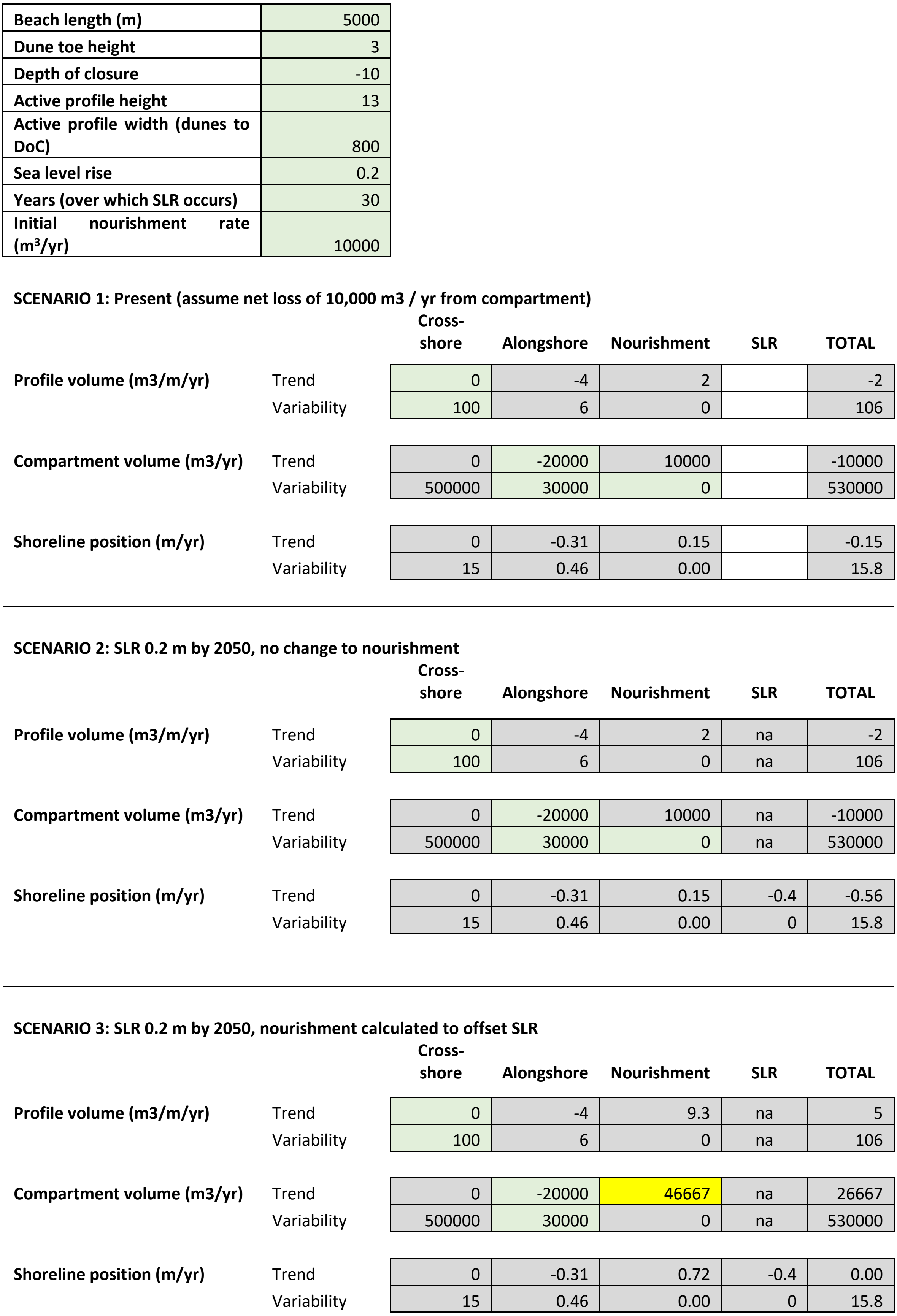


Figure 8-2. Example sediment budget summary map for Port Fairy and East Beach.

Table 8-1. Example sediment budget for East Beach, assuming a nourishment of 10,000 m^3/yr (Green cells are inputted, grey cells are calculated, yellow cell is highlighted to show the required nourishment to offset SLR)



Beach length (m)	5000
Dune toe height	3
Depth of closure	-10
Active profile height	13
Active profile width (dunes to DoC)	800
Sea level rise	0.2
Years (over which SLR occurs)	30
Initial nourishment rate (m^3/yr)	10000

SCENARIO 1: Present (assume net loss of 10,000 m3 / yr from compartment)

		Cross-shore	**Alongshore**	**Nourishment**	**SLR**	**TOTAL**
Profile volume (m3/m/yr)	Trend	0	-4	2		-2
	Variability	100	6	0		106
Compartment volume (m3/yr)	Trend	0	-20000	10000		-10000
	Variability	500000	30000	0		530000
Shoreline position (m/yr)	Trend	0	-0.31	0.15		-0.15
	Variability	15	0.46	0.00		15.8

SCENARIO 2: SLR 0.2 m by 2050, no change to nourishment

		Cross-shore	**Alongshore**	**Nourishment**	**SLR**	**TOTAL**
Profile volume (m3/m/yr)	Trend	0	-4	2	na	-2
	Variability	100	6	0	na	106
Compartment volume (m3/yr)	Trend	0	-20000	10000	na	-10000
	Variability	500000	30000	0	na	530000
Shoreline position (m/yr)	Trend	0	-0.31	0.15	-0.4	-0.56
	Variability	15	0.46	0.00	0	15.8

SCENARIO 3: SLR 0.2 m by 2050, nourishment calculated to offset SLR

		Cross-shore	**Alongshore**	**Nourishment**	**SLR**	**TOTAL**
Profile volume (m3/m/yr)	Trend	0	-4	9.3	na	5
	Variability	100	6	0	na	106
Compartment volume (m3/yr)	Trend	0	-20000	46667	na	26667
	Variability	500000	30000	0	na	530000
Shoreline position (m/yr)	Trend	0	-0.31	0.72	-0.4	0.00
	Variability	15	0.46	0.00	0	15.8

8.2 Implications for nourishment placement location

As noted above, there is an inconsistency between the prediction of longshore sediment transport (DHI, 2021) and the sand sourcing study (CES, 2013a). The model of DHI assumes no current nourishment and predicts a divergence point near the end of the seawall (Fig. 8-3, left), while the sand sourcing study suggests the nourishment sand should be pumped to the SW of East Beach (Fig. 8-3, right) then assumes steady transport from SW to NE. The standard practice for beach nourishments is to place the sand directly on the beach (or shoreface) of the section of shoreline being eroded.

If nourishment is to be placed at the SW end of the beach, then convincing evidence is required to: (i) demonstrate longshore transport is steadily SW to NE along the full bay, contrary to DHI (2021); and (ii) model the evolution of the nourishment to predict when and to what degree the shoreline at the landfill sites will benefit from sand that is placed several kilometres away. The alternative placement option to investigate is directly in front of the landfill targets.

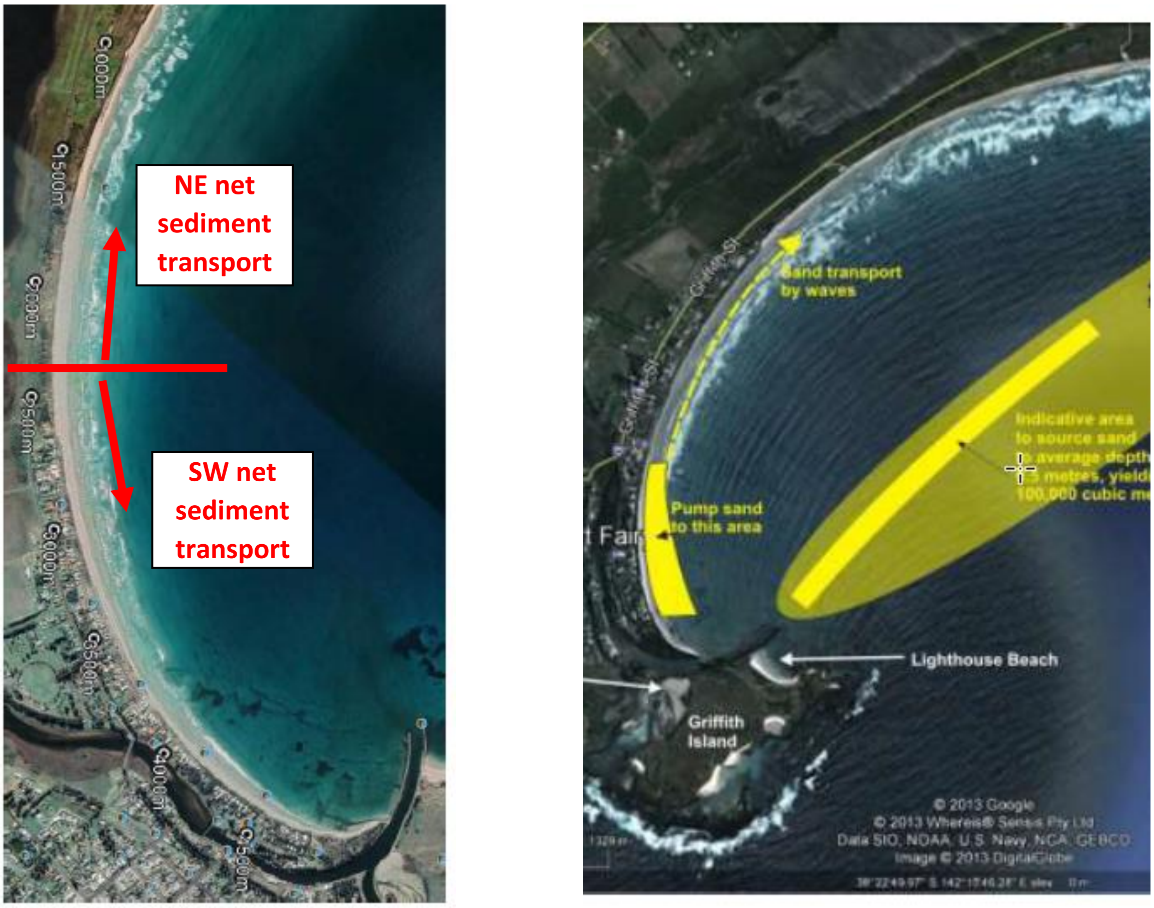


Figure 8-3. Contradictory assumptions of longshore transport, with implications for nourishment strategy. (Left) Approximate location of flux divergence point in DHI (2021); and (right) sand placement strategy at southwest end of beach, from CES (2013a).

9. Summary and recommendations

- Over the long term (1948 – present), the East Beach embayment has a low to moderate sediment budget deficit, causing beach erosion (0.04 m/yr across the bay, up to 0.2 m/yr near the DEECA site). The embayment has likely been experiencing gradual sediment loss for many decades, dating back to the Moyne River training walls being built in the 1870's, preventing sand from entering the system from around the headland to the southwest.
- Over the more recent period of available satellite observation data (1998 – 2018), the middle section of the beach, including the two landfill sites, has experienced rates of shoreline erosion from 0.3 m/yr (near the DEECA site) to 0.7 m/yr (near the MSC site).
- Given the higher rates of erosion over the medium term (since the 1980's), a precautionary approach is to assume these underlying rates of change will continue, and be exacerbated by SLR (we project to 2050).
- An assumption that present rates will continue is reasonable, but this is not predictive, and must be revised with changes in shoreline behaviour (or improvements in predictive capacity).
- A report on coastal hazards by WRL (2013) and an assessment using the ShoreTrans tool in this report both suggest *the landfill sites are currently within the erosion envelope of an extreme storm event. This should be motivation to act rapidly.*
- Renourishment can be scheduled for as soon as possible (following the guidance of the Coastal Engineering Solution Report, 2013, but ensuring sand is not taken at depths <12 m offshore of East Beach).
- A novel hazard rating was introduced, with the DEECA landfill site currently falling within 'imminent risk' of eroding due to a 100 yr ARI event, and is projected to enter 'partial failure' by 2028.
- While the site falls within the 'imminent risk' envelope, it would be prudent to provide some form of temporary additional protection (e.g., sandbags).
- Assuming an urgent renourishment and temporary protection occurs, hard interventions could be delayed temporarily (a period of years) as further monitoring occurs, and site remediation is initiated.
- If nourishment is sufficient high (10 m^3/m/yr for the DEECA site, which loosely extrapolates out to 50,000 m^3/yr for the full bay), then the present shoreline could be maintained, even with 0.2 m of SLR by 2050. These numbers are broad estimates, and require refinement.
- The are inconsistencies between longshore transport rates and nourishment planning. One model suggests that if nourishment material is placed at the SW end of the bay, it may be trapped there, without benefitting the landfill sites. More robust modelling of nourishment evolution should be conducted.
- Recommended additional and ongoing analyses:
    - Extend the application of the ShoreTrans tool to investigate placement of a large short-term renourishment, as well as other renourishment options (e.g., various volume per year options).
    - Detailed calibration of VCMP drone data against satellite data shorelines to improve the accuracy and precision of satellite shorelines.
    - Use of VCMP wave buoy data and VCMP drone data to calibrate future wave, hydrodynamic and morphodynamic models (e.g., the DHI hybrid shoreline model).

- Analyses of existing data and additional hydrodynamic modelling (e.g., XBeach) to constrain storm demand volumes.
- Obtain geomorphologic / geological / coastal engineering data on the locations of cliffs, outcropping rocks, walls, and structures, and also depth to bedrock, if possible.

Answers to management questions

1. When can we expect SLR induced erosion and/or current trends in erosion (unrelated to SLR) to impact on the landfills?
    - Erosion has already impacted on the landfills, or is at imminent risk of exposing them.
    - The trend line for the dune crest at the DEECA site is projected to encroach into the landfill in 2028 ('partial failure'). However, this neglects variability around the trend (see next question).

2. What would the impact be of a 1-in-100 year storm event, when added to trend rates of erosion and SLR impacts?
    - The DEECA landfill is currently in the 'imminent risk' zone, where a single extreme storm (or cluster of storms), could expose the landfill.
    - After 2028 (if trends continue as predicted), and if the landfill has not yet been exposed, it will only take a moderate series of storms to expose the landfill.

3. How would beach renourishment as an interim treatment help avoid, reduce, or mitigate the impacts?
    - If nourishment is sufficient high (10 m^3/m/yr for the DEECA site, which loosely extrapolates out to 50,000 m^3/yr for the full bay), then the present shoreline could be maintained, even with 0.2 m of SLR by 2050. These numbers are broad estimates, and require refinement.
    - Further consideration should be given as to where to place the nourishment. If sand is to be placed to the SW of East Beach, robust modelling should be presented to demonstrate over what time frame it will be transported to benefit the landfill sites.

4. What triggers could be set to initiate interim interventions, including:
    - A review of modelled future impacts because of actual trends are deviating significantly from current predictions.
    - Re-assessment after installing temporary engineering solutions.
    - Bringing forward plans for a long term permanent solution.
        - The analysis in Section 7, and new hazard rating system, give clear projected trends. Given that analysis of the VCMP drone data and other sources (e.g., satellite data) are ongoing, a periodic review (e.g., every 1 – 2 years), could determine how the trends are progressing against observations.

5. Best time of year to conduct engineering works at Port Fairy, given the wave climate?
    - Nov – Mar is recommended, based on a combination of marginally lower wave heights (Section 3) and lower water levels (see Section 4). However, extreme events can happen at any time of year.

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(BMT, 2020) “Port Fairy Rock Revetment Design, Peer Review”, prepared by BMT.

(CES, 2013a) “Port Fairy Sand Sourcing Study”, prepared for Moyne Shire Council, by Coastal Engineering Solutions.

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Vos, K., Splinter, K. D., Harley, M. D., Simmons, J. A., & Turner, I. L. (2019). CoastSat: A Google Earth Engine-enabled Python toolkit to extract shorelines from publicly available satellite imagery. Environmental Modelling & Software, 122, 104528.

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Appendix 1: ShoreTrans model, brief description

A full description of the ShoreTrans model is given in McCarroll et al. (2021), a brief description follows. ShoreTrans is a rules-based approach that applies sediment budgeting concepts and existing methods for shoreface translation, due to surpluses or deficits in the sediment budget, and/or SLR (Fig. A1.1 and Equation A1)

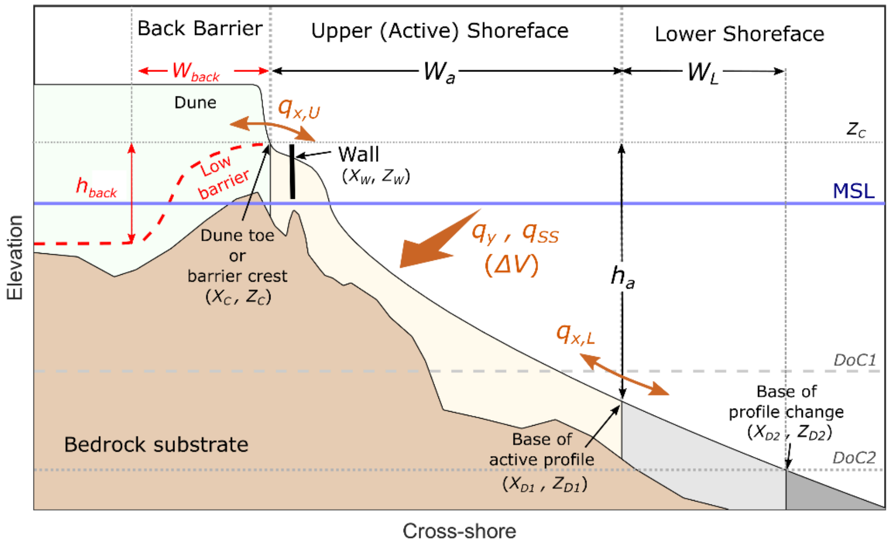


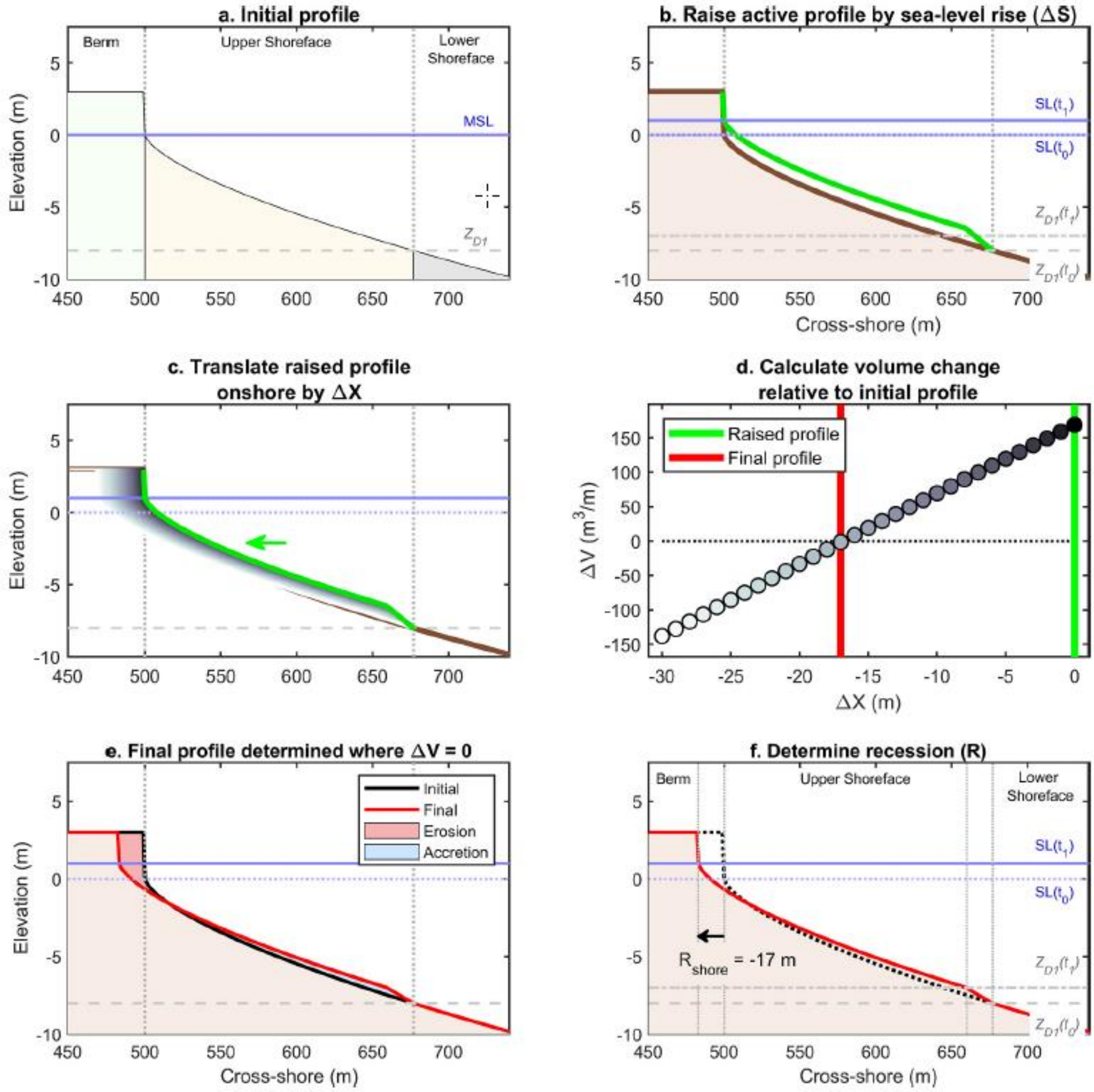
Figure A1. Components of ShoreTrans model (from McCarroll et al., 2021)

The shoreline can be expressed as a function of changes due to SLR and sediment budget as

$$\Delta X = \Delta X_{SLR} + \underbrace{\frac{\Delta V_{x,U} - \Delta V_{x,L}}{h_a}}_{\text{Cross-shore flux. No change to total profile volume.}} + \underbrace{\frac{\Delta V_y + \Delta V_{SS}}{h_a}}_{\text{Longshore flux \& sources/sinks. Gains/losses to total profile volume.}} \tag{7}$$

Where ΔX is total change in shoreline position, ΔX_{SLR} is change in shoreline due to SLR, $\Delta V_{x,U}$ is cross-shore exchange between the active shoreface and backbarrier, $\Delta V_{x,L}$ is cross-shore exchange with the lower shoreface, ΔV_y is alongshore flux and ΔV_{ss} represents other sources and sinks (e.g., renourishment), and h_a is the height of the active shoreface.

The basic mechanism for shoreface translation is as per Atkinson et al. (2018), raising and shifting the profile onshore according to SLR and the active profile gradient (Fig. A2). This will give a result equivalent to the so called ‘Bruun rule’. However, there are many additional rules, settings and modification that can be applied within ShoreTrans, that may cause the profile response to differ from the Bruun rule. For example, coastal structures (Fig. A3, left column), rocky outcrops (Fig. A3, right column) and coastal dunes (Fig. A4). For the applications in this report, the approach of Kinsela et al. (2017) was used to estimate how storm demand is distributed across a 2D profile (Fig. A5).



a. Initial profile

b. Raise active profile by sea-level rise (ΔS)

c. Translate raised profile onshore by ΔX

d. Calculate volume change relative to initial profile

e. Final profile determined where ΔV = 0

f. Determine recession (R)

Figure A2. ShoreTrans basic method for profile translation (from McCarroll et al., 2021)

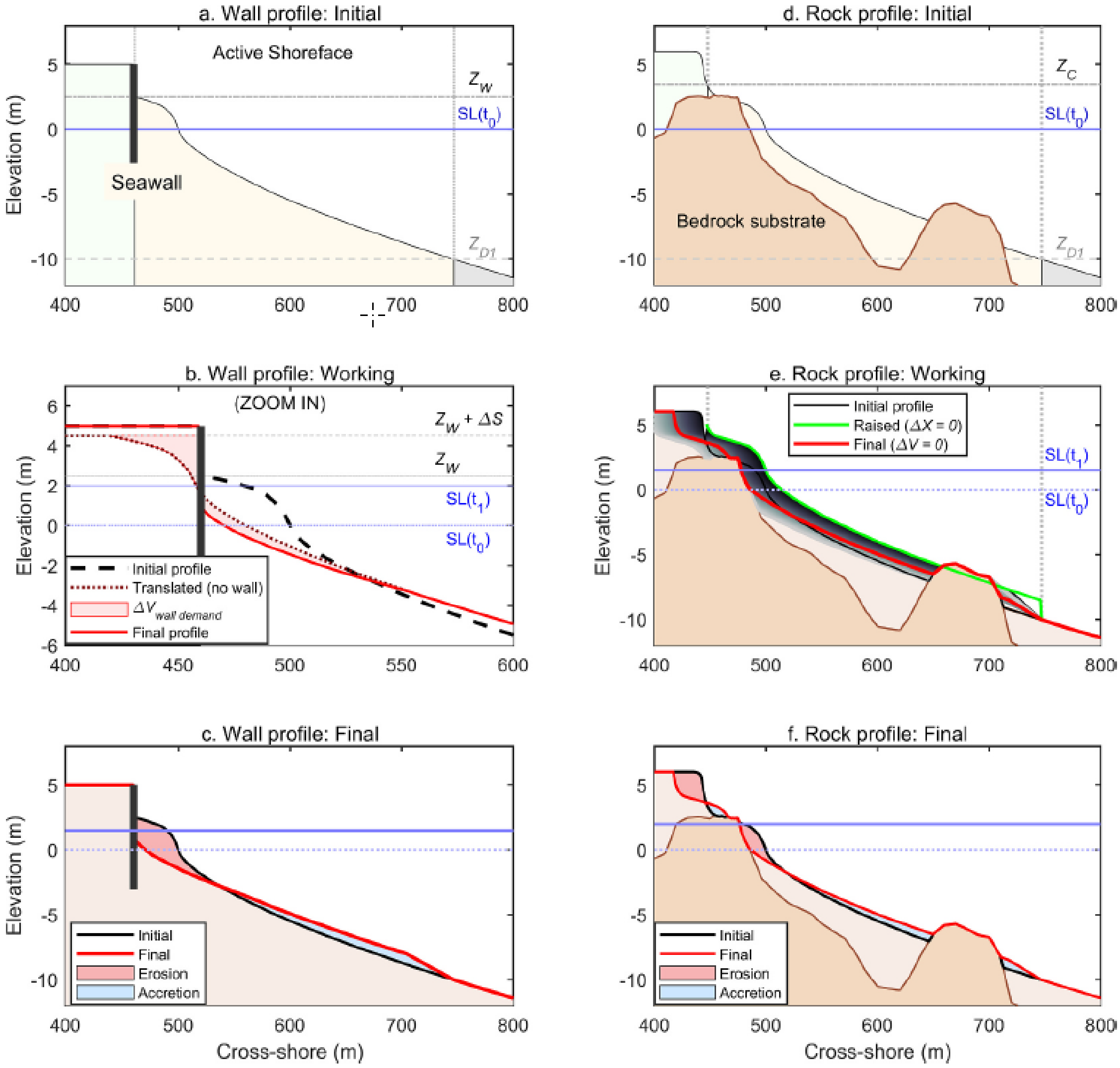


Figure A3. ShoreTrans treatment of seawalls/revetments and rocky outcrops (from McCarroll et al., 2021).

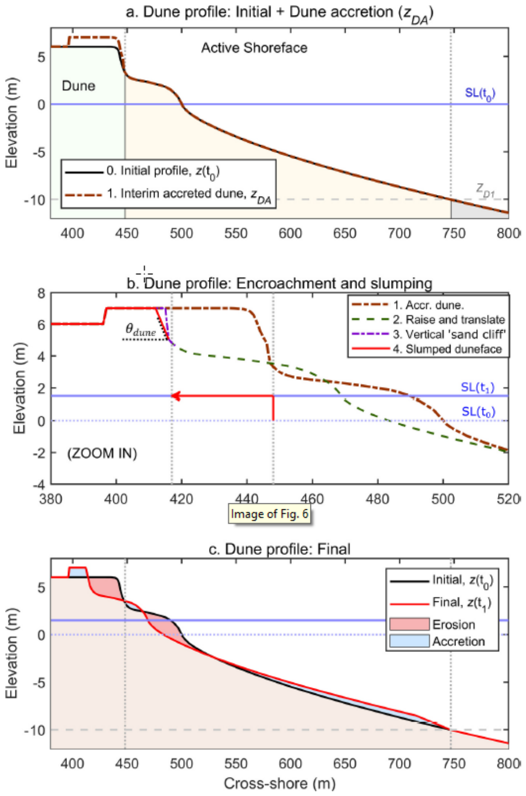


Figure A4. ShoreTrans treatment of dunes (from McCarroll et al., 2021).

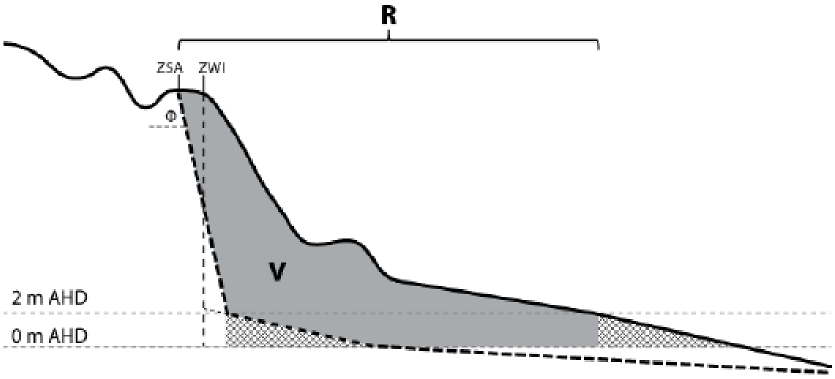


Figure A5. Storm demand volume method, from Kinsela et al. (2017).