WATER TECHNOLOGY
WATER, COASTAL & ENVIRONMENTAL CONSULTANTS

Report

Inverloch Region Coastal Hazard Assessment – Additional Data and Adaptation Option Review

Department of Energy, Environment and Climate Action

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1 TOPOGRAPHIC DATA

1.1 Datasets

The Inverloch Region Coastal Hazard Assessment (CHA) (Water Technology, 2022) utilised the most recently available regional digital elevation map (DEM) at the time which was the "Victorian Coastal LIDAR Level 3 Classification (East & West Victoria)". This data was compiled into the file cep08b-2012-13_coast-c3.asc.

This dataset was developed from LiDAR captured from 2006 through 2010, with the data around Inverloch largely flown in 2007-2008.

A narrow band of LiDAR was captured for the project in August 2021 between Flat Rocks and Screw Creek to provide a "present day" elevation model for the eroded dunes along the Bunurong Road and Surf Beach, along the Ayr Creek coastal lagoon and at the Pymble Ave dog beach.

Following the completion of the CHA project, the Department of Transport captured LiDAR which provides elevation data across the Study Area from Cape Paterson eastward to mid-way between Townsend Bluff and Maher's Landing boat ramp. Figure 1-1 shows the extents of these different datasets.

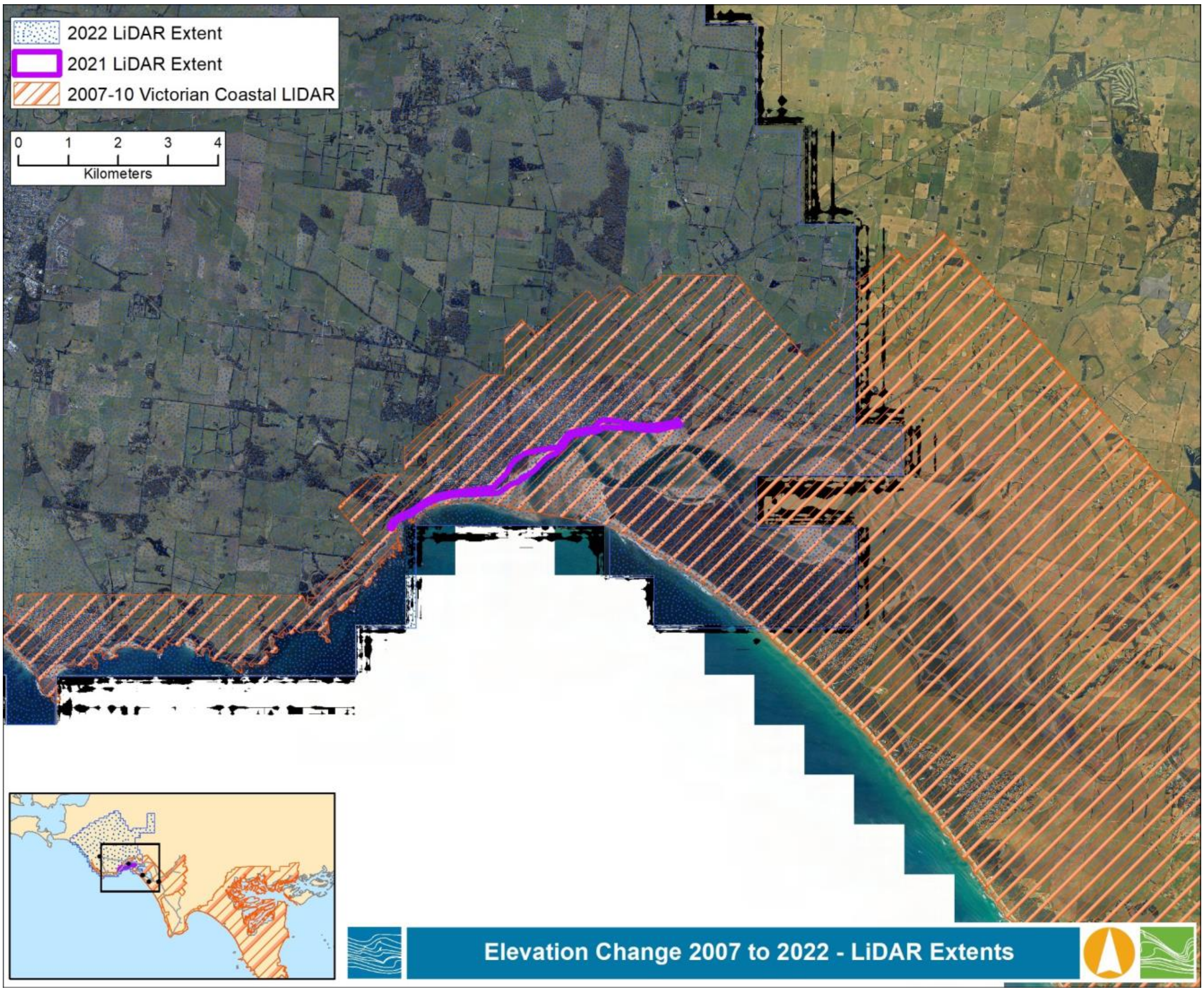


Figure 1-1 LiDAR Datasets

1.2 Topographic Changes

This new topographic data (2021-2022) has been compared to the topography used in the CHA ("FutureCoast", captured in 2007-2010) with key changes noted below. These changes are limited to the area around Inverloch where the new LiDAR is available.

- Overall
  - The maximum change in elevation is a reduction of 9 - 11m of the primary dune along Point Smythe. Specifically, the dune crest of close to 15m AHD measured in 2007-08 has eroded to 4m AHD (Figure 1-2) in 2022.
  - The maximum positive change (i.e. increase in elevation) is located nearby on Point Smythe where the elevation of the beach has increased from 2.5m AHD in 2007-08 to 8m AHD in 2022 (Figure 1-2)
- Cape Paterson to Flat Rocks
  - Differences in elevation along the high cliffs between Cape Paterson and Flat Rocks are observed in the dataset, however most are related to the processing of raw data and resolution rather than actual changes in cliff formation.

    An important exception to this may be on the south and southwest cliff face of "The Caves".

    It is possible that a 6m section of the cliff may have fallen away on the southwest side with smaller changes on the southern face. It is known that there have been collapses in this area since 2016-17. The height of the cliff, resolution of the input LiDAR and data processing to make a DEM means this could still be a processing error but appears more significant than the other errors noted above. The imagery captured around the time of the LiDAR capture could not be used to verify. Inspection of this cliff should be considered to confirm.
- Flat Rocks & Surf Beach Dune
  - The dramatic change along the coastline which led to the commissioning of the CHA is clearly seen in the beach profile comparison of the FutureCoast and 2022 LiDAR (Figure 1-4). The ongoing change from 2021 to 2022 can be seen in the profiles below the map.
  - The area of erosion where elevation has reduced by more than 2m varies in width from 25m in the west to 60m in the east past the Surf Club. The maximum change is 8m in height at a point 65m east of the Surf Club.
  - Accretion at the old mouth of Wreck Creek shows the elevation increasing by up to 2m as the flow path shifted west. This has mainly occurred since the 2021 LiDAR, as shown in Profile D (Figure 1-4).
  - Comparison of the 2021 to 2022 LiDAR is presented in the profiles below the mapping. The profile highlights erosion has continued since the CHA in places, including a reduction in elevation of up to 4m as the primary dune has continued to recede.
- Surf Beach Estate
  - Development of the Surf Beach estate between Lohr Avenue and Toorak Road has resulted in infill of the topography by 0.5 to 1.5m, and excavation of 1.5 to 2.0m of land to construct a retarding basin (Figure 1-8). This change was not picked up in the 2021 coastal LiDAR used for the CHA.
  - Levelling of a dam wall at the northern end of Paperback Place has resulted in a reduction in ground levels at the dam wall by -4 to -4.5m.
- Ayr Creek Lagoon (Figure 1-5)
  - Accretion of over 1m covers an area of over 0.3km^2, 1.3km long and up to 0.3km wide through the build up of sand to form the Ayr Creek lagoon between 2007-08 and 2022.

  - The formation of the dune on the seaward side of the lagoon represents accretion of over 4m, infilling the channel surveyed in 2007-08 from -1m AHD to over 3m AHD in 2022.
  - A further increase in the dune elevation at the lagoon drainage point is observed between the 2021 and 2022 LiDAR as the entrance and lagoon bars have evolved. This increase is countered by a reduction in lagoon dune height further inside the entrance where the tidal channel has begun to cut into the lagoon sand lobe.
  - Elevation along the Rotary Centenary Park adjacent to Holt Court, north of the Ayr Creek lagoon, has also increased from below MSL (-0.5m AHD) to above 3m AHD between 2007-08 and 2022 as part of the lagoon sand lobe.
- Pymble Ave (east of Inverloch Jetty)
  - East of the Inverloch Jetty the shoreline has retreated a width of 50 – 60m for close to 500m along the coast (Figure 1-6) from 2007-08 to 2022.
  - There is a reduction in coastal elevation of over 4m where a dune at the previous shoreline has eroded.
  - Accretion along the coast of 1-2m in height has occurred approximately 1km east of the Pymble Ave beach.
  - The erosion has continued in places since 2021 survey, as shown in Profile H where the dune has retreated between 2021 and 2022 by approximately 15m.
- Broadbeach Estate
  - Development of the Broadbeach Estate adjacent to Screw Creek has resulted in infill of the low-lying areas of the development (Figure 1-7)
  - Fill pads for dwellings have increased by 0.5 to 2.0m compared with pre-development levels.
- Other
  - Reclamation of land by construction of a rock revetment and infill of 2,000m^2 to depths of 2.8m can be seen at Inverloch Charters on Treadwell Road. A low point in the parcel of land to the north of the reclaimed land has also increased in elevation to meet the surrounding topography (infill of 0.5 to 2.0m).
  - An access road has been constructed across the low land which extends westward of the RACV wetlands near the edge of the coastal bluff at Flat Rocks.

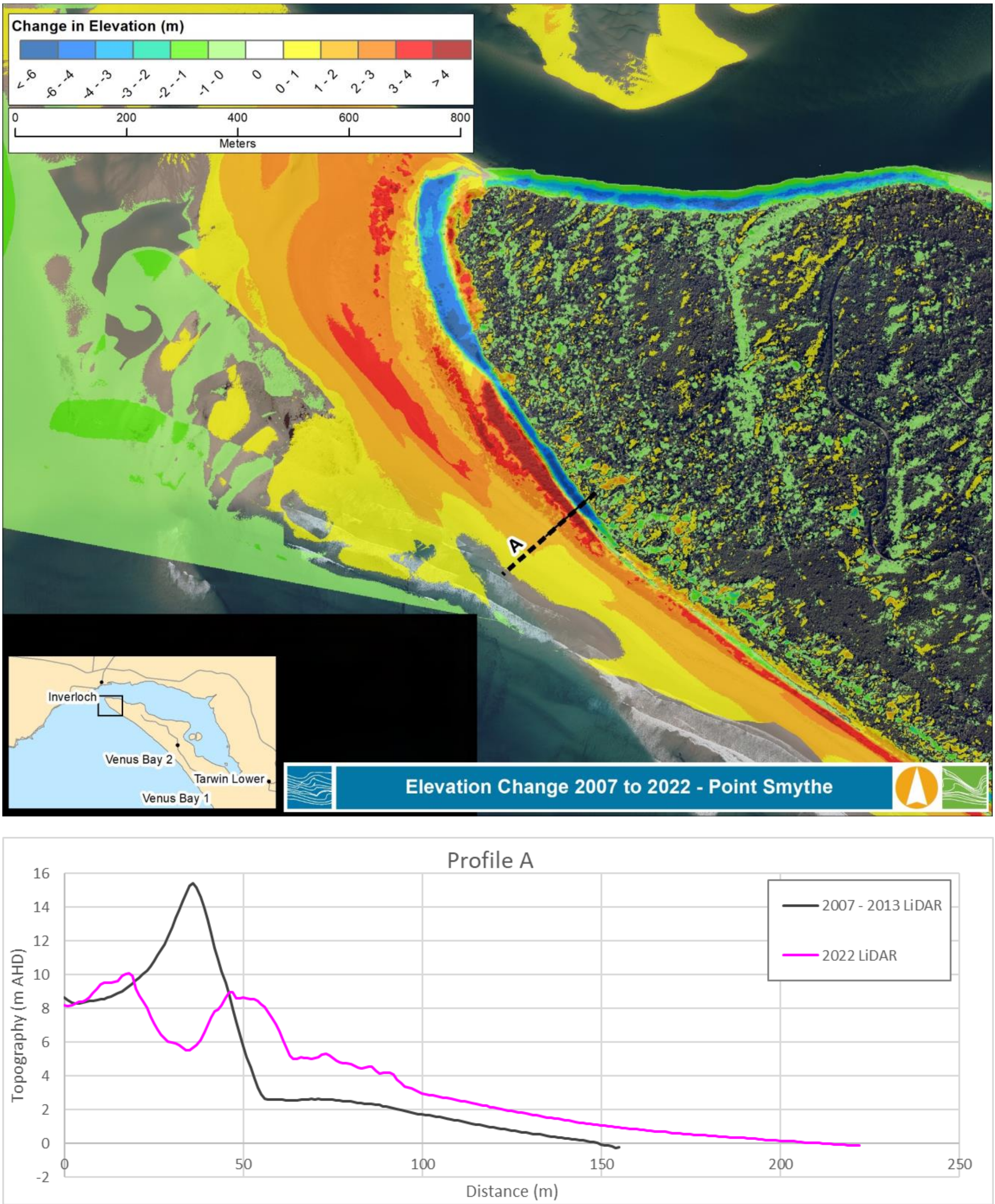
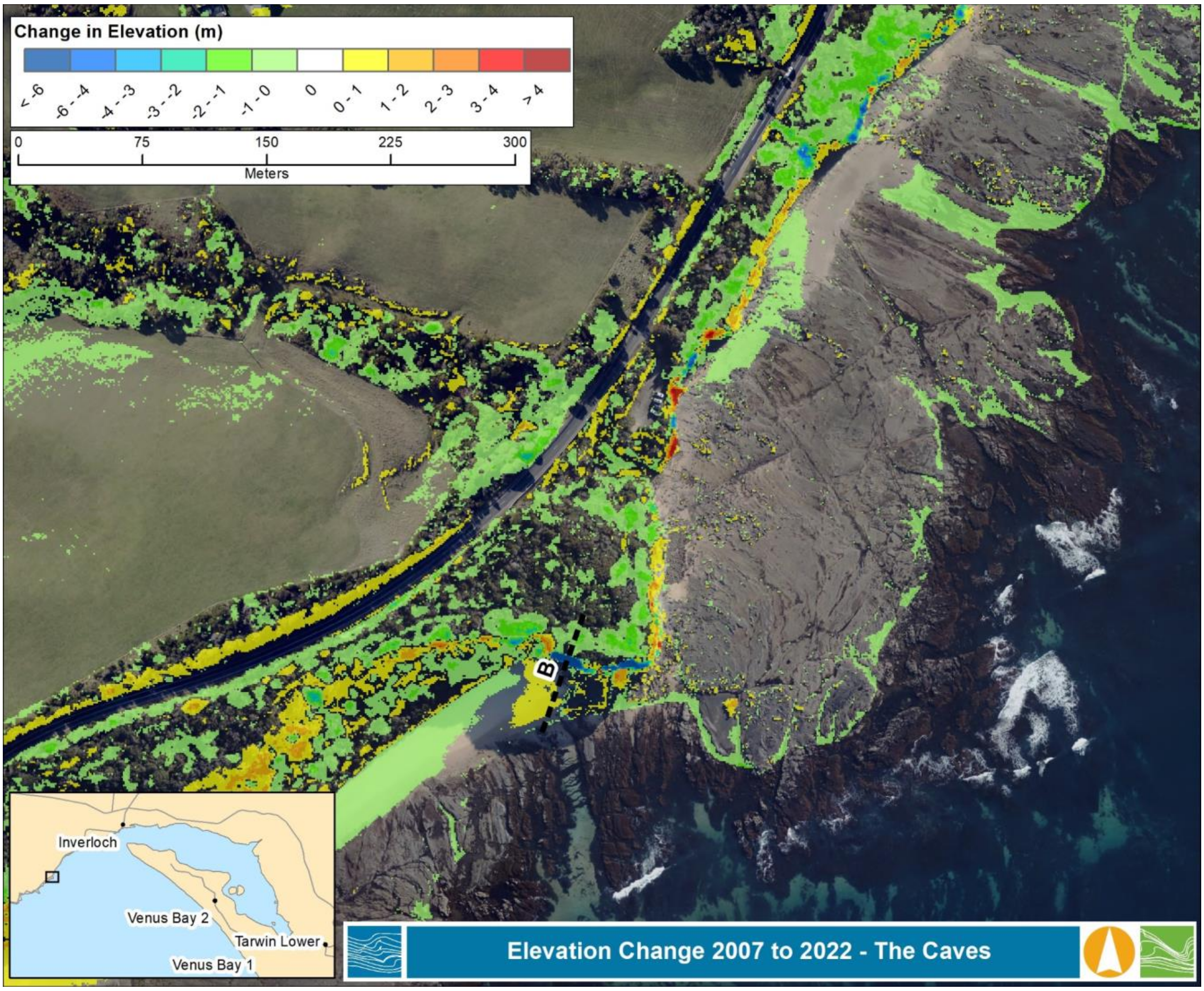


Figure 1-2 Maximum Elevation Change – Point Smythe



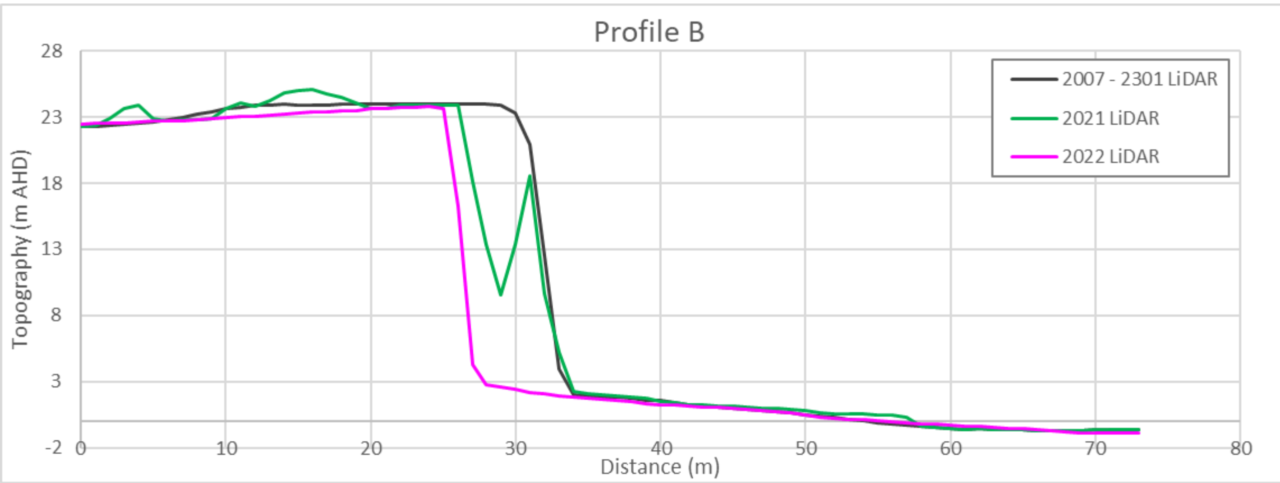


Figure 1-3 Elevation Change – The Caves

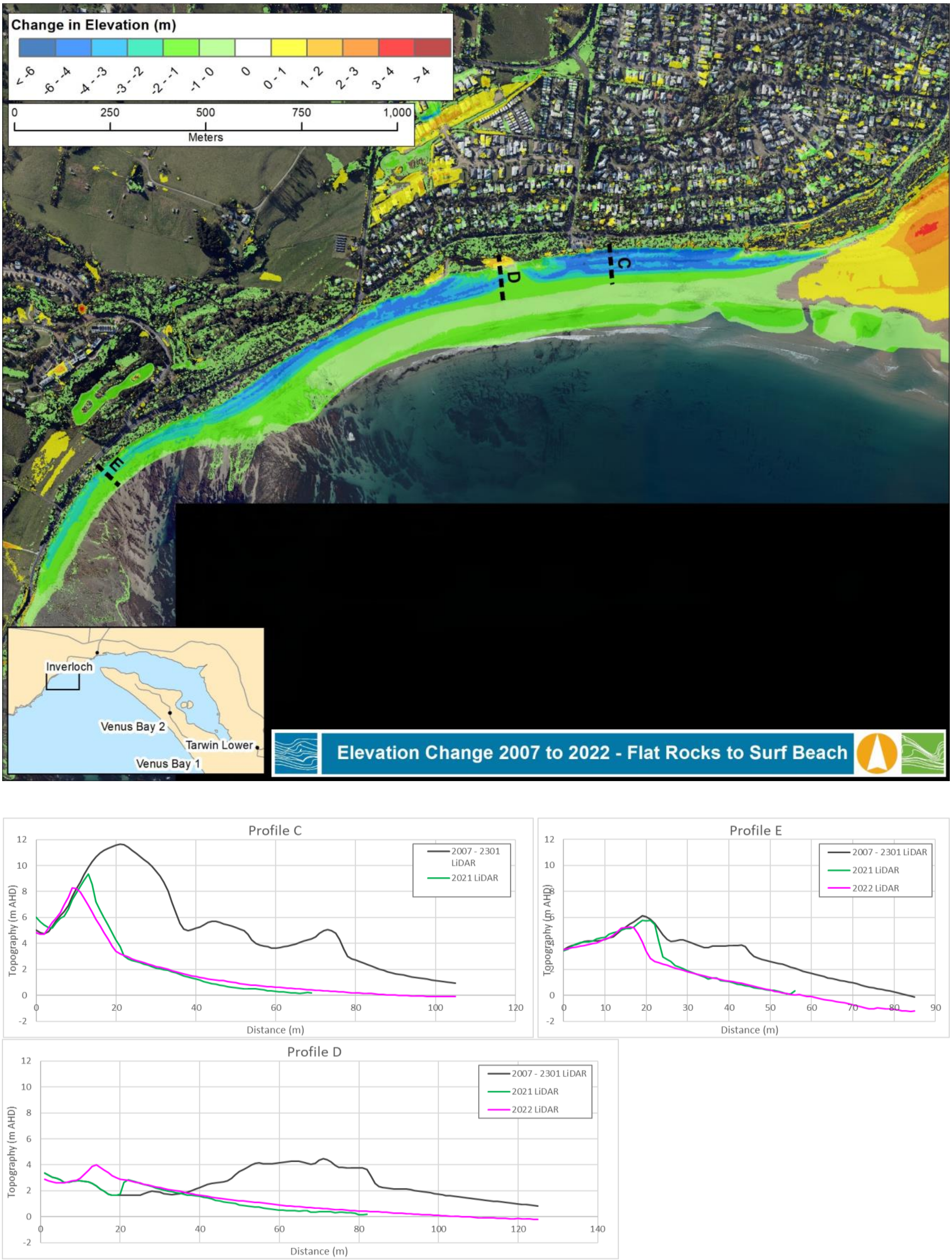


Figure 1-4 Elevation Change – Flat Rocks & Surf Beach

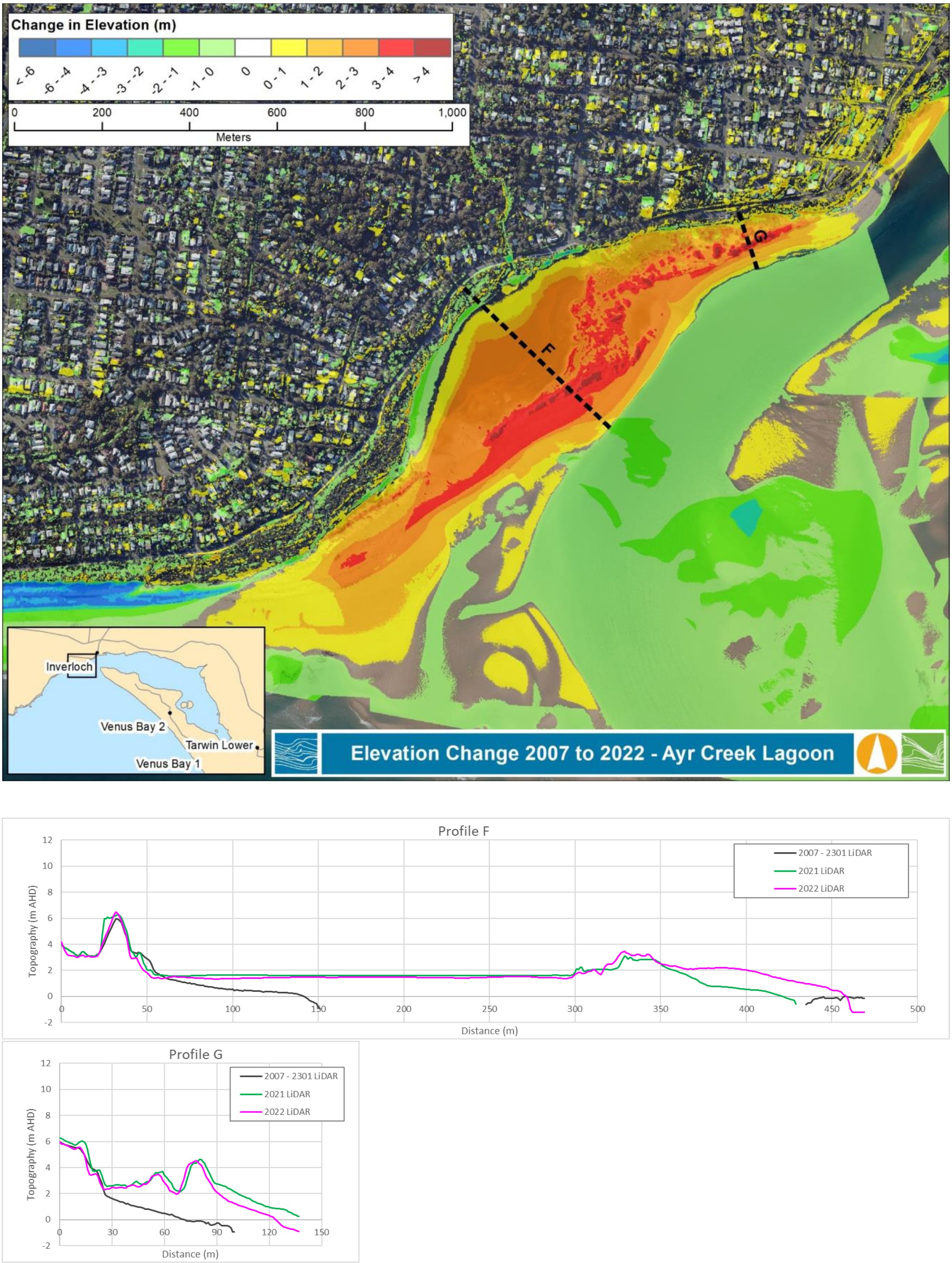
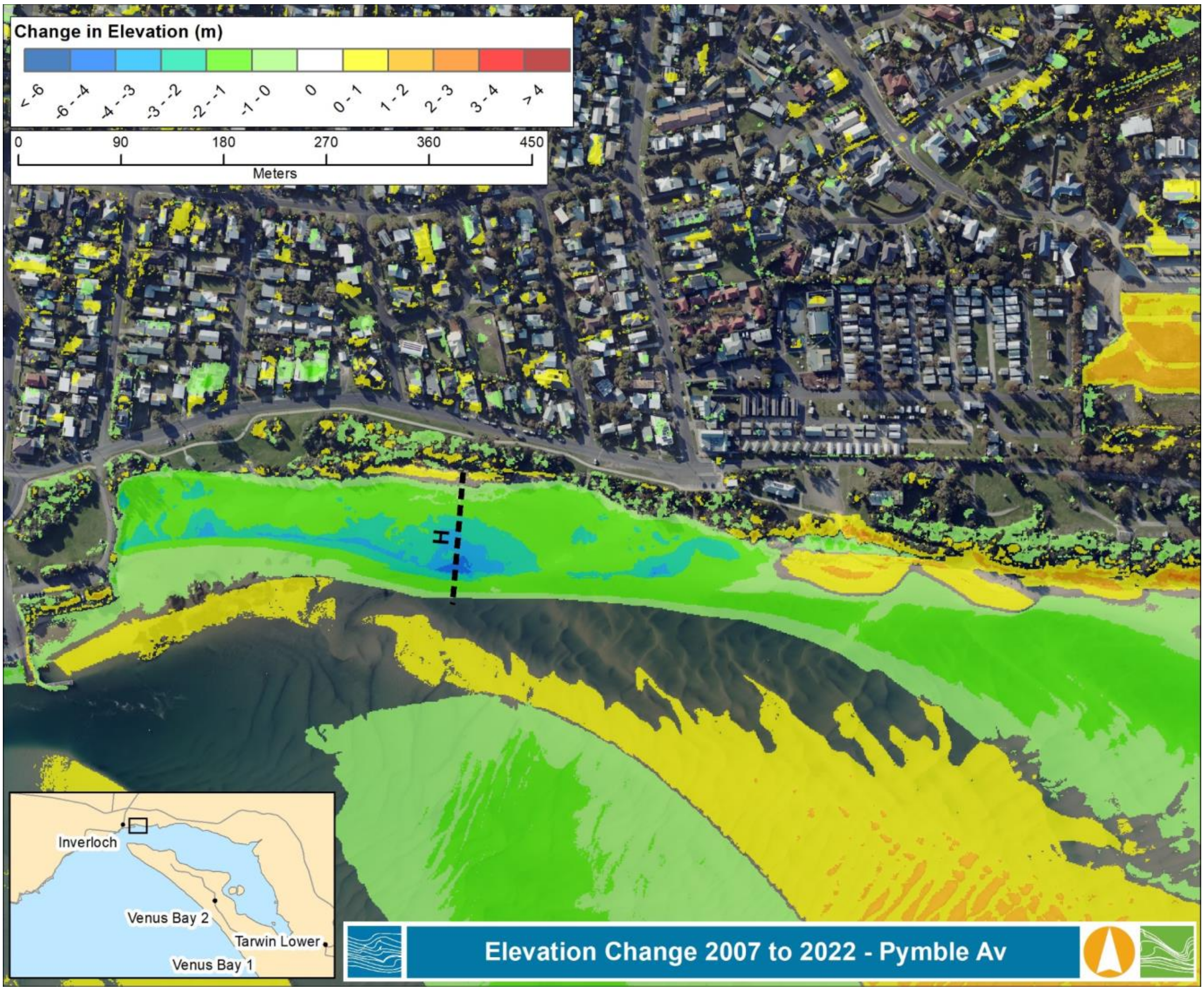


Figure 1-5 Elevation Change – Ayr Creek



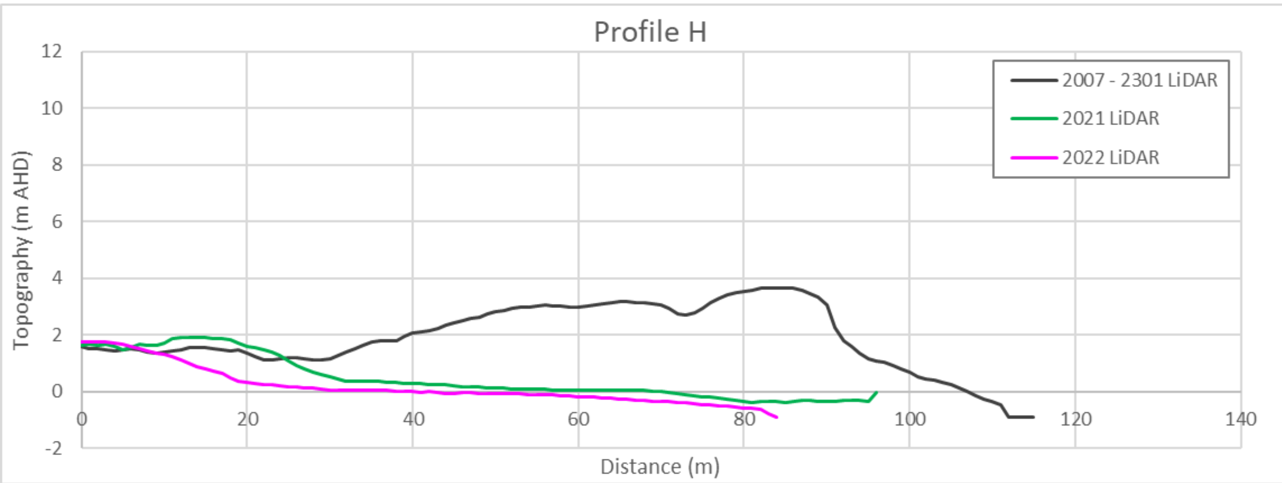


Figure 1-6 Elevation Change – Pymble Ave

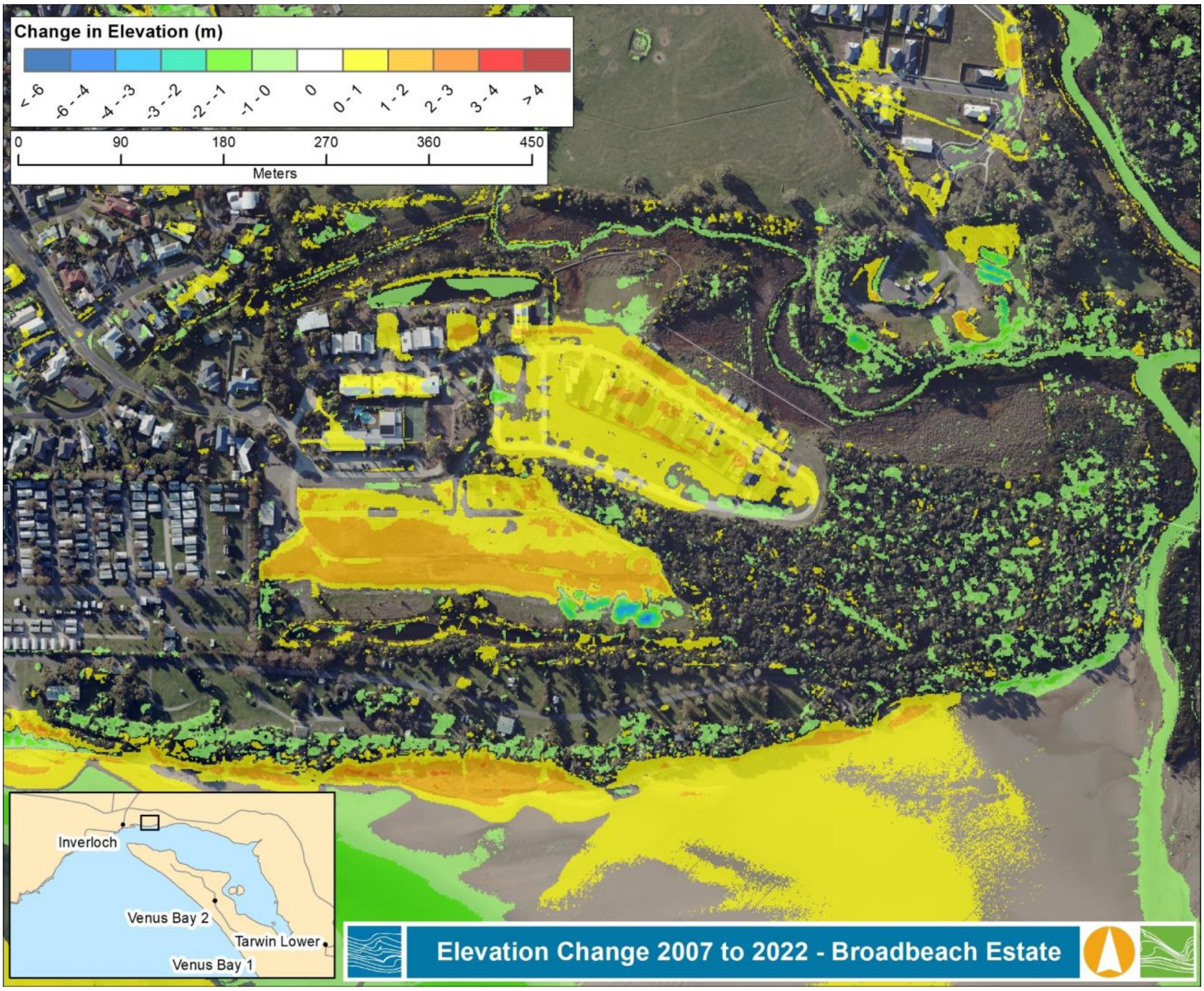


Figure 1-7 Elevation Change – Broadbeach Estate

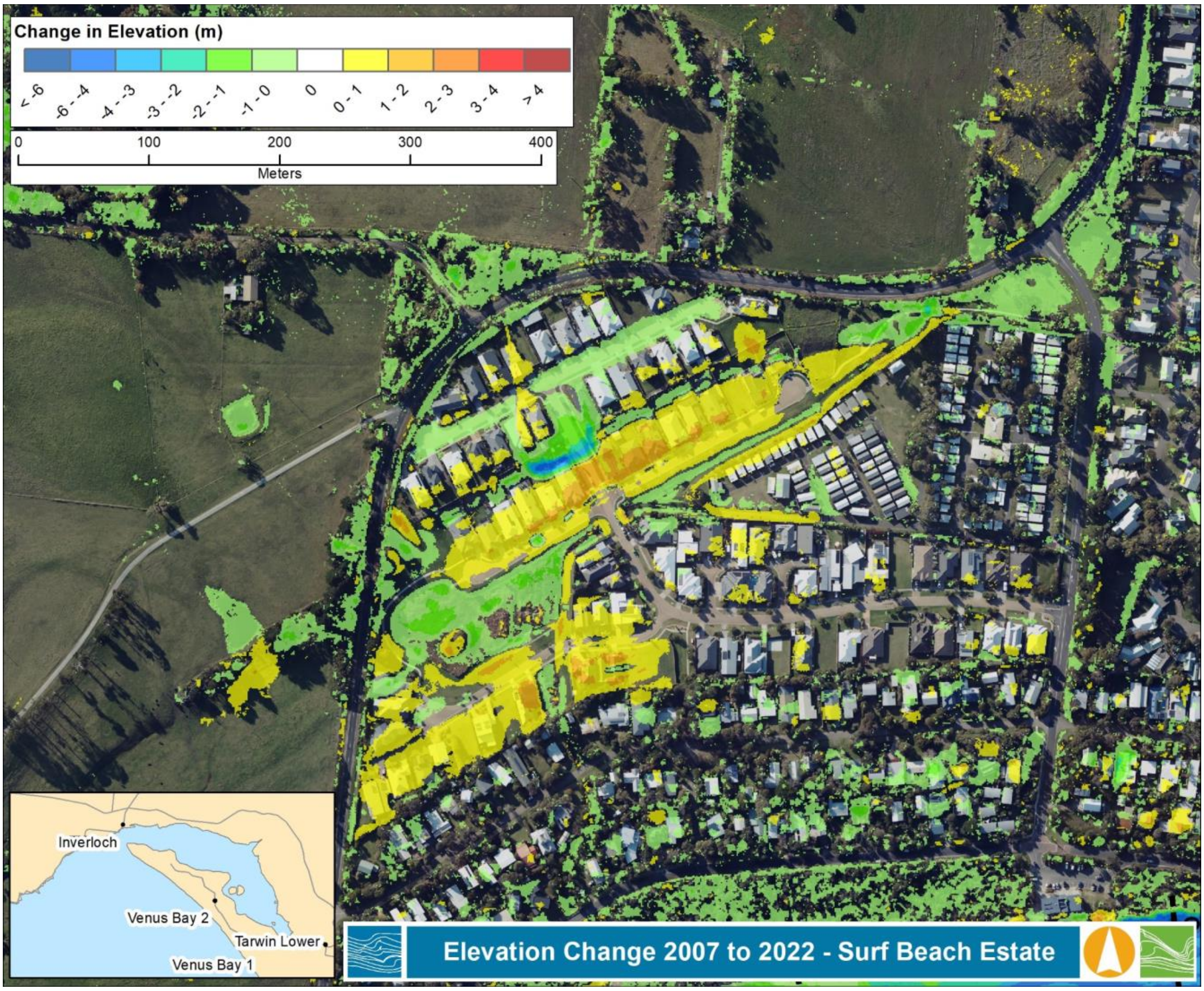


Figure 1-8 Elevation Change – Surf Beach Estate

1.3 Summary

Section 1.2 provides a summary of the observed changes in the surveyed surfaces. Table 1-1 summarises the impacts of these changes in topography on the outcomes of the CHA.

Table 1-1 Impact of topography changes 2007-08 to 2022

Area	Change and Impact	Relative impact on 2022 coastal hazard assessment
Point Smythe	Change in dune location around the point, resulting in large changes in elevation	None. Although major change to Point Smythe remains a significant future hazard to the area and large change at Point Smythe would result in change in the coastal hazards
Cape Paterson to Flat Rocks	Potential collapse of cliff at The Caves	None

Area	Change and Impact	Relative impact on 2022 coastal hazard assessment
Flat Rocks and Surf Beach Dune	Significant loss of dune between 2012 and 2022. Continued loss of dune between 2021 and 2022.	Minor – LiDAR captured in 2021 for CHA did consider the recent rapid change along this coast
	Increase of sand at the old Wreck Creek mouth has blocked the creek discharge path	None – drainage can occur across new discharge path directly south of Surf Parade crossing
Surf Beach Estate	The overland flow paths have changed with development earthworks. Inundation flow paths and extents of flooding from tidal waters are likely to have changed	More significant – several houses within the 2022 flood extent may now be elevated above the inundation level.
Ayr Creek	Accretion of sand that has formed the Ayr Creek lagoon	None – this area is nominated as a flood hazard zone due to the transient nature of the lagoon sand and the change in this area was considered in the CHA.
Pymble Ave	Significant cut back of the shoreline to pre-reclamation line. Loss of vegetation and dry land.	Moderate – Some of this erosion was captured by survey in 2021 and included in the CHA. An additional 15-20m retreat since 2021 may result in retreat of the erosion and flood layers from the current shoreline
Broadbeach Estate	Inundation flow paths and extent of flooding from tidal waters are likely to have changed	More significant – several houses within the 2022 flood extent may now be elevated above the inundation level
Flat Rocks inland	Back flow from high water levels under Bunurong Road may be reduced if this road prevents flow to the northeast	Minor, low wetland area, timing of inundation could be impacted
RACV wetlands, just west	Levels have increased 0 to 1.0m, mainly 0.3 to 0.6m. Could impact the earlier or less frequent flood extents.	Minor, low wetland area, timing of inundation could be impacted

2 BATHYMETRIC DATA

2.1 Datasets

The CHA developed a bathymetric surface model to represent the nearshore coastal topography and the depth and position of tidal channels and sandbars within the entrance to Anderson Inlet.

This digital elevation map (DEM) was compiled from the following sources:

- Future Coast Nearshore Bathymetry – captured 2008-09
- Gippsland Port single beam hydrographic survey – captured April 27-29, 2021
- Beach and bar survey captured by Farren Group – captured April 29, 2021

The top left survey image in Figure 2-1 shows the bathymetric DEM developed for the CHA.

Gippsland Ports and Farren Survey have repeated their survey in February 2023 and an updated bathymetric DEM has been generated for review and analysis. The top right survey image in Figure 2-1 shows the 2023 DEM, and a difference plot, where the 2021 and 2023 surveys overlap, is presented in in the lower pane of Figure 2-1.

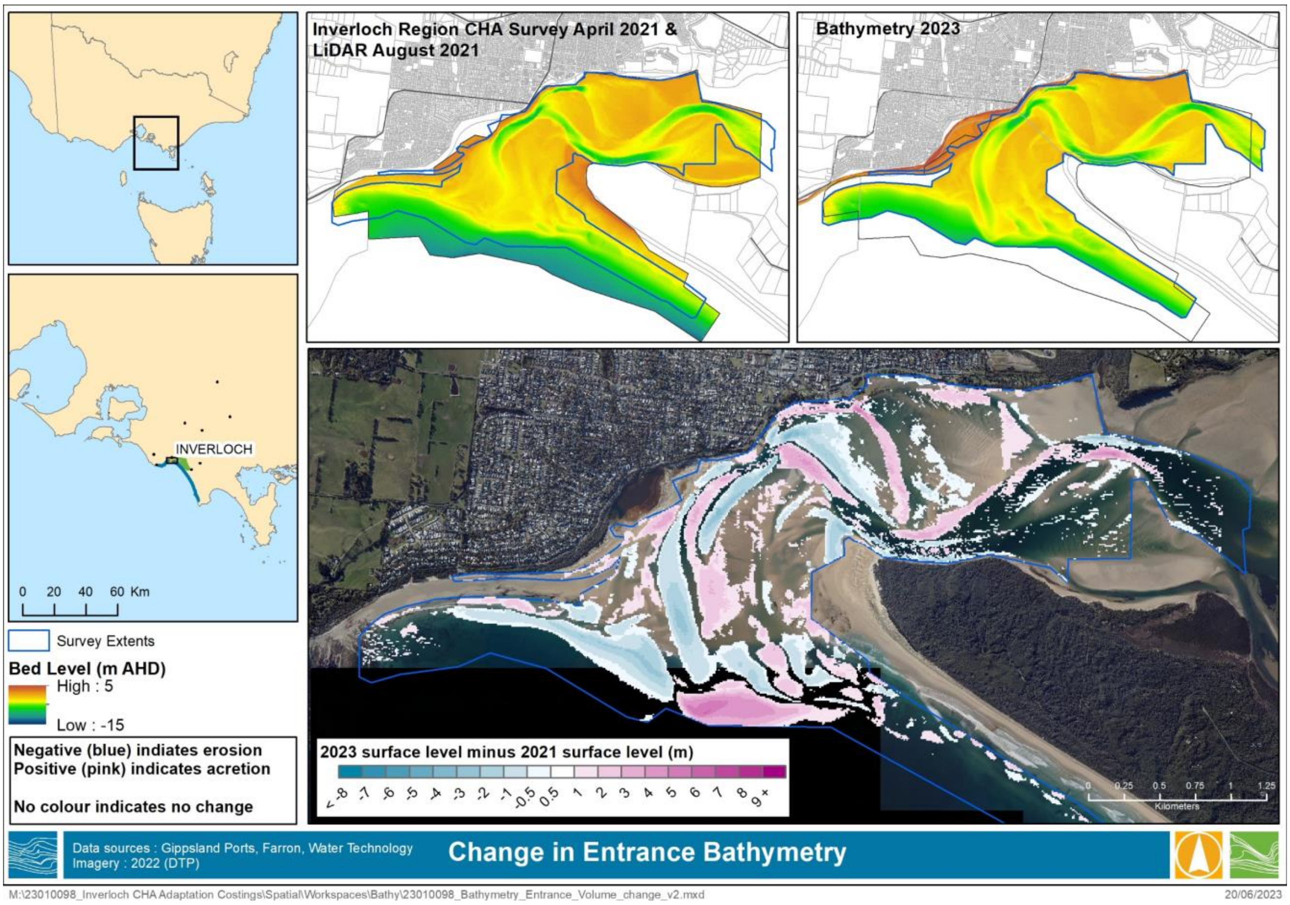


Figure 2-1 Bathymetric DEM used in Inverloch Region CHA

2.2 Bathymetric Changes

Key changes to the bathymetry and the potential impact to coastal processes are noted below.

- There has been further deepening of the area offshore of Surf Beach.
  - There is potential that larger waves can penetrate further inshore at Surf Beach before breaking and storm erosion risk at the dune could increase.
  - There is a gap along Surf Beach in the 2023 survey between +0.8m AHD and -1.5m AHD. A reshaping of the beach may have occurred which will impact the progression of waves to the back shore zone.
- The edge of the ebb tide delta has shifted east across the entrance away from Point Norman. Surf Beach is widest when the delta is closest to Point Norman and sand fills Surf Beach westward.
  - There is potential an increase in eastward longshore transport could occur over the coming winter to infill this area. The edge of the shoal on the Point Norman side has shifted landward 130m.
  - Strong SW conditions over winter driving transport east towards Point Norman could result in an increase in erosion along Surf Beach.
- The tidal channel is more incised through the sand shoals. This could be attributed to the major flooding in 2022. The ebb tide shoal extends further offshore to the southeast away from Point Norman and has shifted the edge of the shoal (at -3m AHD) a further 200m seaward.
- The tidal channel through the main bar has established a greater flood-ebb tide channel difference with the flood tide shifting west alongside the Ayr Creek lagoon, cutting into the sand dunes. The ebb tide channel has shifted east into the main entrance sandbar.
  - These changes could continue to cut into the Ayr Creek lagoon and result in further breakthrough of lagoon water into the entrance.
- The inner channel has become slightly more sinuous, although is someway short of a potential "tipping point" identified in the CHA which results in significant entrance channel reconfiguration.
  - The sharp change in direction of the channel from Point Smythe north towards Inverloch Jetty may allow a stronger secondary channel to cut through around Point Smythe as has happened previously.

2.3 Summary

Overall, there has been a decrease of the volume of sand within the overlapping survey of 210,000m^3. As shown in the difference image in Figure 2-1 this is distributed across the surveyed area, however the greatest bed level change is along the edge of the ebb tide shoal where depth changes from -2m AHD to -5m AHD nearest Point Norman or from -8m AHD to -3m AHD at the seaward end of the tidal channel.

The continued loss of sand within the entrance is notable, acknowledging there is some change in survey extent. The CHA identified a change of -1.755M m^3 in the entrance between 2009 and 2021. Whilst this change was unlikely to have occurred at a constant rate over time, this represents an average change of 150,000m^3/y. The change from April 2021 through January 2023 also averages to 120,000m^3/y, potentially indicating an ongoing trend of net sediment loss within the entrance.

As reported in the CHA, there is insufficient long term data within Anderson Inlet, or offshore of the entrance to determine the fate of this volume of sediment.

Continued loss of sediment from the entrance, whilst influenced by the location of the change, has potential to allow increased wave energy to impact the Inverloch shoreline. Changes in the penetration of the tidal and storm tide waters could also be expected.

3 METOCEAN DATA

Meteorological and oceanographic data measured in the Study Area during and after the completion of the CHA has been reviewed. This includes additional water level data at Tarwin Lower Jetty, Inverloch Jetty (both captured by Gippsland Ports), nearshore and offshore wave data in Venus Bay (captured by the VCMP) and measured water level and discharge of the Tarwin River at Meeniyan (sourced from DEECA). The location of this data is shown in Figure 3-1.

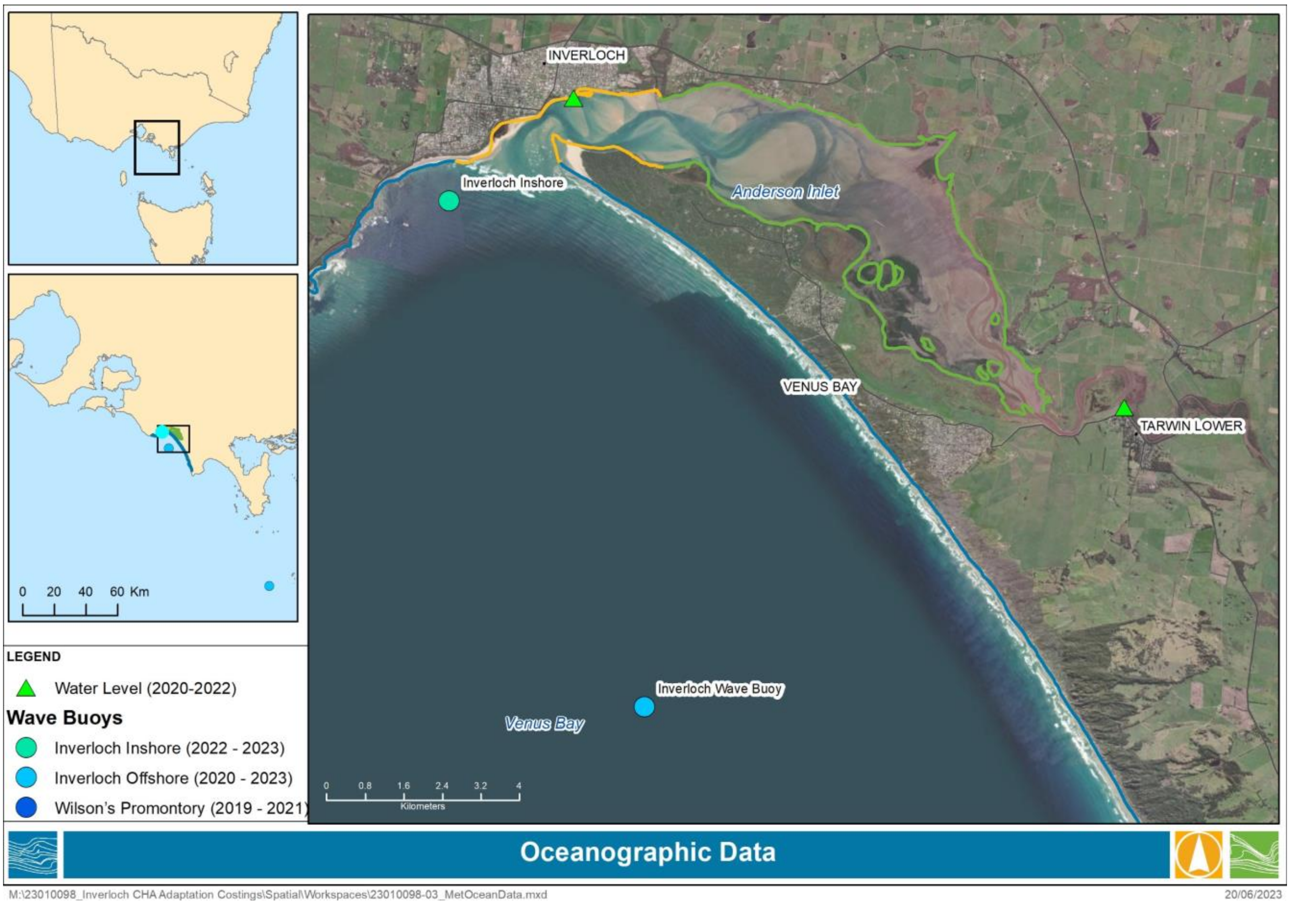


Figure 3-1 Additional Data Reviewed

3.1 Anderson Inlet Water Level Data

A summary of the data captured within Anderson Inlet is provided by Gippsland Ports in Figure 3-2. Timeseries of the data at Tarwin Lower and Inverloch for the periods of record are shown in Figure 3-3. Measured (black) and predicted tidal (blue) water levels as well as the difference – the residual (red) at each location are presented in each figure.

Analysis of the data identifies the following key points:

- Tidal Planes
  - The Mean High Water Spring (MHWS) tidal plane at Inverloch is around 0.1m higher than Tarwin Lower.
  - Tidal Planes are consistent with the nearest “Standard Port” tidal predictions at Stony Point (1.12m AHD) and Port Welshpool (0.98m AHD).

- The MHWS is the average height of the predicted spring high waters, which alternate with the neap (lower) tides roughly every 2 weeks.

  Comparison of the MHWS to the measured data at Inverloch and Tarwin Lower show the MHWS is exceeded on 570 and 756 high tides across a period of 30 and 23 months respectively. This is an average of 22 or 37 times per month where water levels peak above MHWS.

  A seasonal pattern in the Tarwin Lower tide associated with base flows results in the difference in the frequency of higher waters there.

- The Highest Astronomical Tide (HAT) tidal plane is the highest astronomical (predicted) water level in a full tidal cycle which is approximately 18.6 years. Astronomical tides only include variations caused by gravitational bodies (i.e. the sun and moon) and not any variations due to meteorological or other conditions.

  The HAT can be used as an indicator for a rarely exceed water level, however the measured data at Inverloch and Tarwin Lower shows this level can be exceeded fairly frequently within the Study Area (e.g. during large storms).

  - The HAT was exceeded 32 and 41 times during the recording period at Inverloch and Tarwin Lower respectively. This is an average of between 1 and 2 times per month at each site. If the flooding event in August 2022 is removed from the record, the average times of exceedance per month at Tarwin Lower is the same (1.3) as at Inverloch.
  - Exceedance of the HAT is more common during the months of May through October as greater wide-scale storm surges pass through Bass Strait and stream flows contribute to water levels at Tarwin Lower.

- Water Level Extremes
  - The peak water level at Inverloch was 1.768m AHD on 28th July 2021. This is coincident with a series of cold fronts that occurred through July 2021 and resulted in 4 successive surges across the south coast of Australia “pumping” the water into Bass Strait and Anderson Inlet. These storm surges also coincided with a high predicted spring tide of 1.2m AHD to generate the peak water level. The water level remained above 1.6m AHD for only 1.5 hours.
    - The water level at Tarwin River during this period was also elevated, with the peak water level of 1.762m very close to the highest recorded at Tarwin Lower.
  - The actual peak measured water level at Tarwin Lower was 1.772m AHD, recorded on the 16th August 2022. This is coincident with the significant flood event which occurred in the Tarwin River during August. Water levels were elevated for a period of close to 2 weeks with the water level residual above 0.4m for 5.5 days as the flood waters passed Tarwin Lower. The water level was above 1.7m AHD for 2.5 hours.
    - Of note, the water levels at Inverloch through this period are not elevated. The residual water level at Inverloch, which was typically observed to follow closely with Tarwin Lower, shows close to 0m residual over the peak of the flood waters at Tarwin Lower, highlighting the decoupled nature of catchment flooding and storm surges within Anderson Inlet.
    - Similarly, review of measured storm tides at Lorne in the same period show consistency with the Inverloch residual pointing to the wholly flood related spike in water levels at Tarwin Lower during August 2022.
    - It is notable in this respect that large water levels at Tarwin Lower can be caused by both storm surges from Bass Strait and catchment flooding within the Tarwin River.
- Storm Surges / Residual

- The peak recorded storm surge (not total water level) of 0.9m was recorded at Inverloch occurred 15th November 2021. The storm surge occurred at the start of the neap tide, and the peak was coincident with the low tide, nullifying the impact on total water level (0.447m AHD). A low-pressure system accompanied by strong westerly winds passed across Victoria in the week prior to the storm surge, and a similar residual is recorded at Tarwin Lower, and to a lesser extent, within Bass Strait.
- The peak recorded storm surge Tarwin Lower was 1.256m, attributed to the August 2022 flood event noted above. The next largest storm surge at Tarwin Lower occurred at the same time as the peak Inverloch storm surge in November 2021.

- Exceedance frequency
  - Updated exceedance charts, based on the recent measured data are presented in Figure 3-4. The measured data record is too short to establish 1% or 10% AEP design conditions with a reasonable level of confidence.

Anderson Inlet Water Level Monitoring

Tidal Analysis Summary

	INVERLOCH BOAT RAMP JETTY Six-minute sea level observations from 14-May-2020 to 4-Nov-2022	TARWIN LOWER BOAT RAMP JETTY Six-minute sea level observations from 16-Dec-2020 to 4-Nov-2022
Days of data	789	663
Sample Correlation Coefficient	0.9551	0.8774
Standard Devn of the Residuals	0.1585	0.1904
Zero Frequency Level **(Above AHD)**	0.2313	0.4549
HAT	1.502	1.494
MHWS	1.023	0.931
MHWN	0.738	0.780
MSL	0.231	0.455
MLWN	-0.276	0.131
MLWS	-0.561	-0.021
ISLW	-0.850	-0.189
LAT	-0.886	-0.369
Minimum recorded level of	-1.216 metres at 2036 hours 20/01/2022	-0.564 metres at 2154 hours 28/01/2021
Maximum recorded level of	1.768 metres at 1624 hours 28/07/2021	1.772 metres at 1724 hours 16/08/2022

Figure 3-2 Anderson Inlet Water Level Monitoring – summary

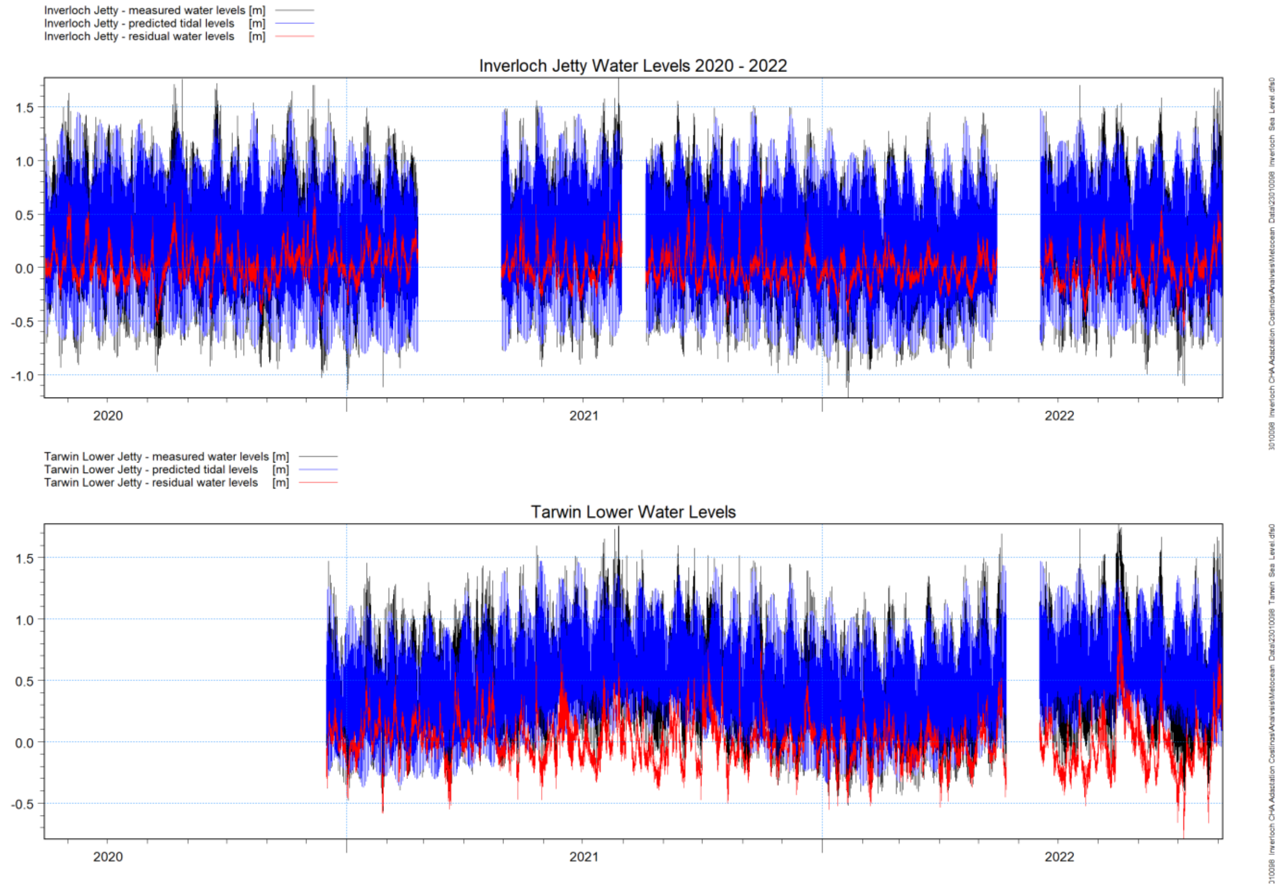


Figure 3-3 Measured water level – Inverloch Jetty (top) and Tarwin Lower Jetty (bottom)

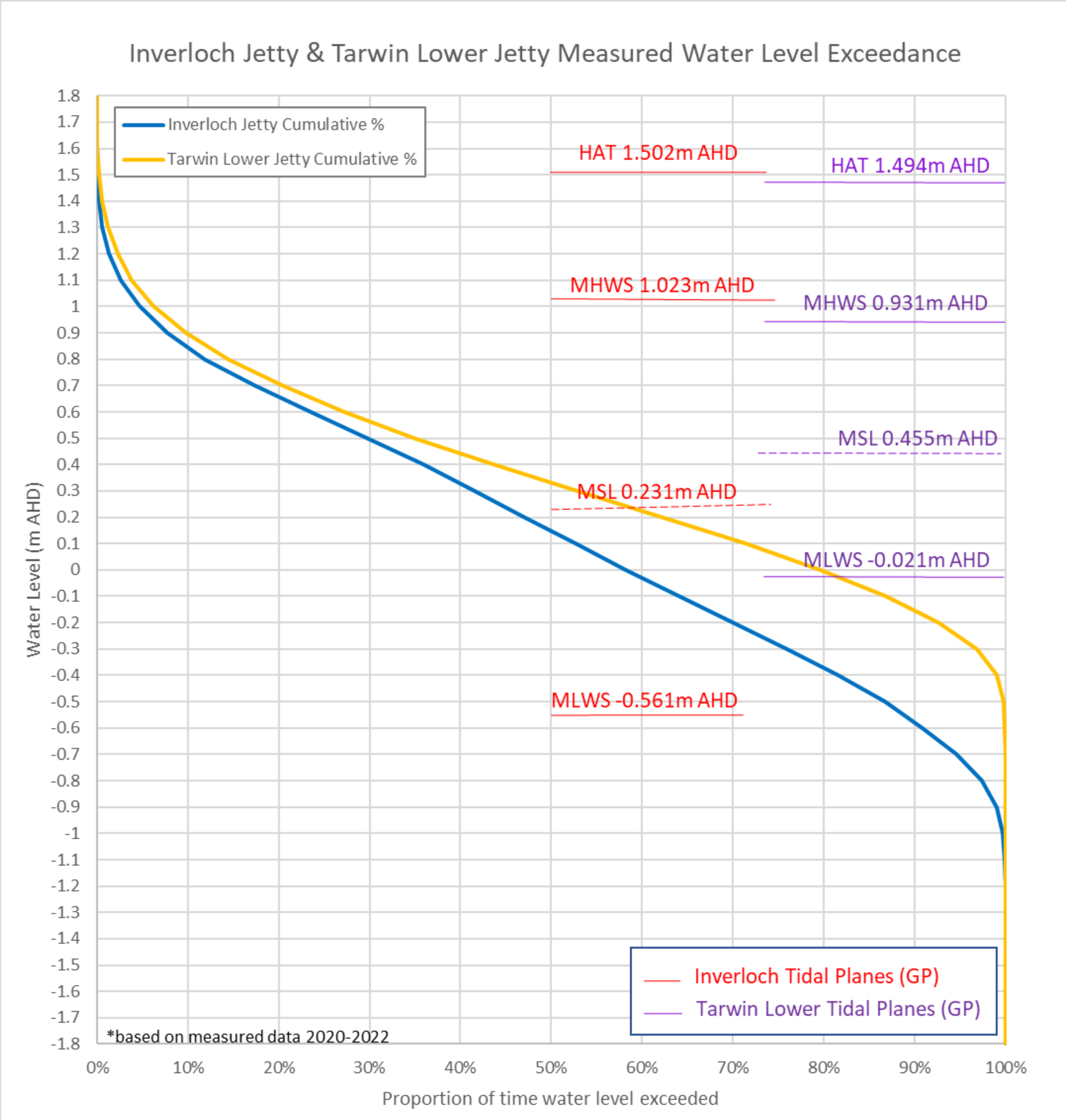


Figure 3-4 Inverloch Jetty and Tarwin Lower Jetty Water Level Exceedance Curves

3.2 Tarwin River Data

The CHA reviewed discharge within the Tarwin River from 1955 through to July 2021. Flooding of low-lying areas between Meeniyan and Tarwin Lower is common with road closures typically occurring on at least an annual basis.

Prior to 2022, the peak flow measured at Meeniyan on the Tarwin River, approximately 40km upstream of Tarwin Lower, was the June 2012 flood event where flow peaked at 301m^3/s. The next 2 highest floods occurred in April 2011 (296m^3/s) and July 1977 (278m^3/s).

A peak flow of 313m^3/s was recorded during the flood event in August 2022 which caused widespread inundation within the catchment area. Figure 3-5 presents hydrographs showing the 2022, 2012, 2011 and 1977 events, highlighting the variability in the flood timing and total volume.

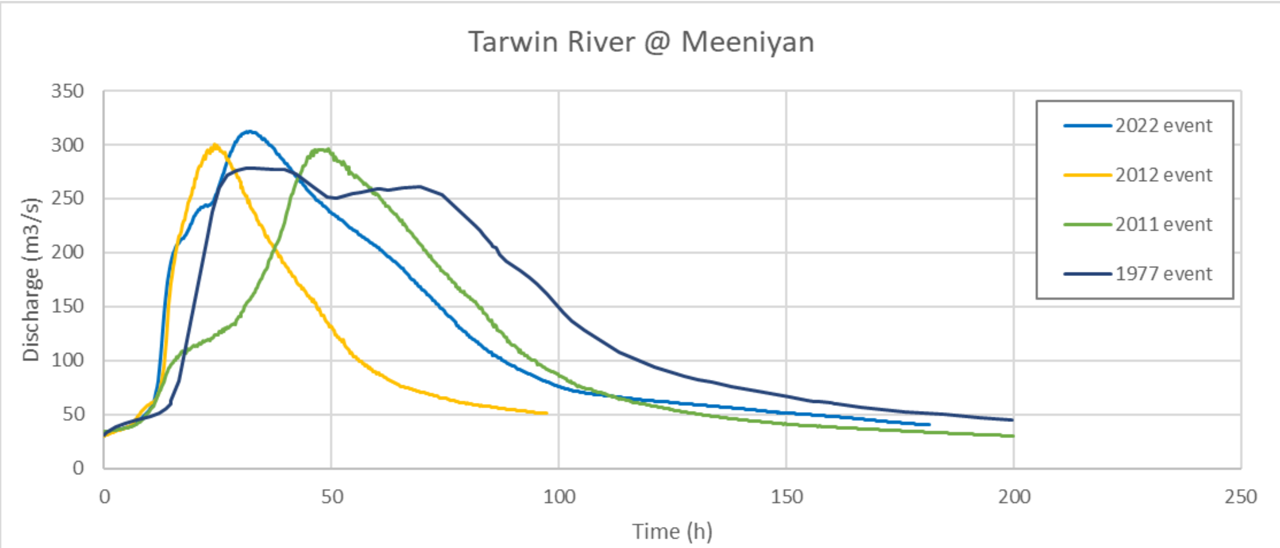


Figure 3-5 Tarwin River Flood Discharge

3.3 Inverloch Wave Data

Wave roses and timeseries of measured wave conditions within Venus Bay and in the nearshore waters of Surf Beach, Inverloch, are presented in Figure 3-6. The full period of record for the Venus Bay (offshore) record is presented as well as a wave rose for conditions coincident with the inshore measurements.

Wave data offshore of the Study Area within Venus Bay shows a high level of wave energy from the southwest. The recent summer (November 2022 through April 2023) has been slightly more southwest and less westerly than the full measurement period of January 2020 through April 2023.

Inshore conditions, from November 2022 through April 2023 are dominated by southerly waves, significantly lower than those recorded offshore.

The following key points are noted with respect to wave conditions measured at Inverloch and Venus Bay with additional analyses shown in Figure 3-7:

- Inshore wave heights follow the same pattern as offshore. Inshore wave height is close to half of the offshore wave height.

- The peak offshore significant wave height of 4.35m during the period of coincident measurement occurs in tandem with the inshore peak significant wave of 2.03m.
- Wave periods also follow a similar pattern inshore and offshore, with inshore mean wave period around 80% of the offshore mean wave period.
- Offshore mean period ranges mainly from 5 – 8 seconds, with records of longer wave periods up to 12 seconds. Inshore mean wave period is largely between 2 and 6 seconds, with some events where mean period increases to above 10 seconds.
- Wave direction rotates approximately 40 degrees eastward from offshore to inshore. A wave from 240 degrees offshore is typically transformed to a 200-degree wave inshore. Offshore waves from a direction east of 220 degrees (i.e. SW to SSW) have less rotation and an offshore wave from 200 degrees transforms inshore to a 180 degree wave.

  Waves from the southeast (or less than 180 degrees) are rare offshore and are likely to be a similar direction, or refract more to the south at the inshore point.

  There is a greater spread in wave direction offshore than inshore.

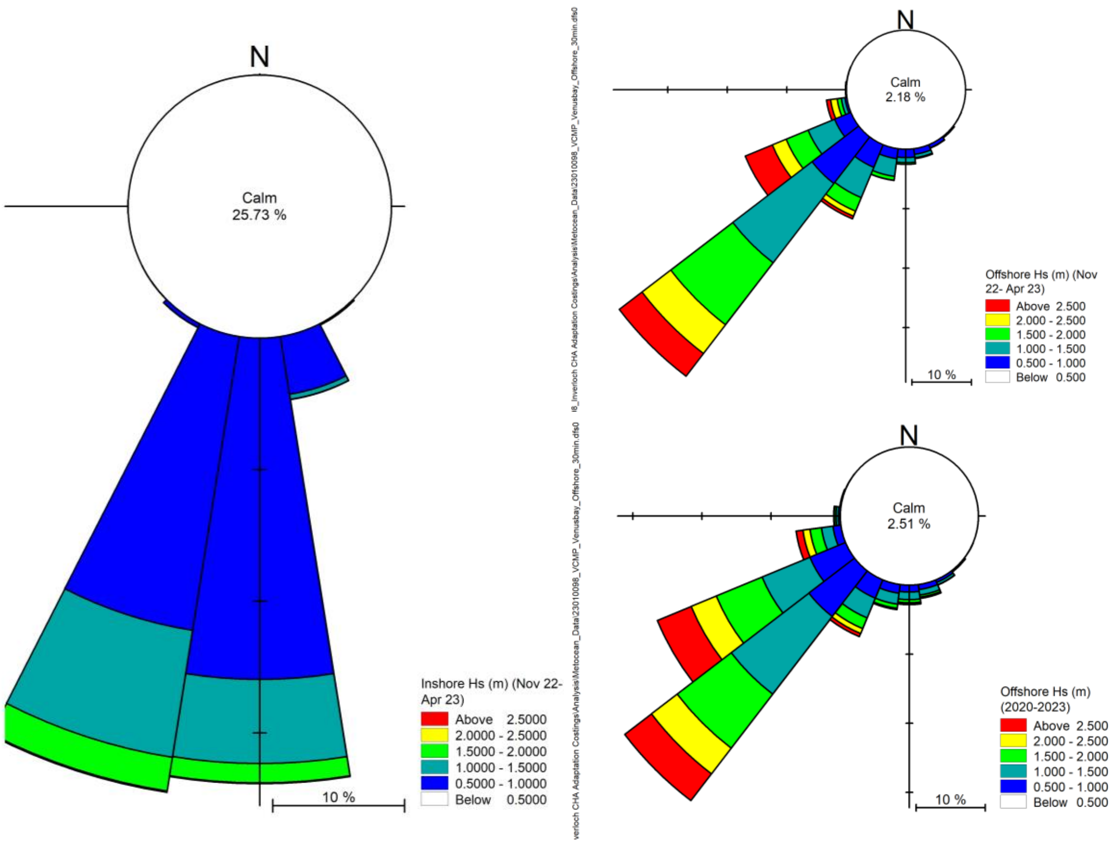


Figure 3-6 Inshore (left) and Offshore (right) wave conditions (offshore coincident with inshore – top, offshore full data record - bottom)

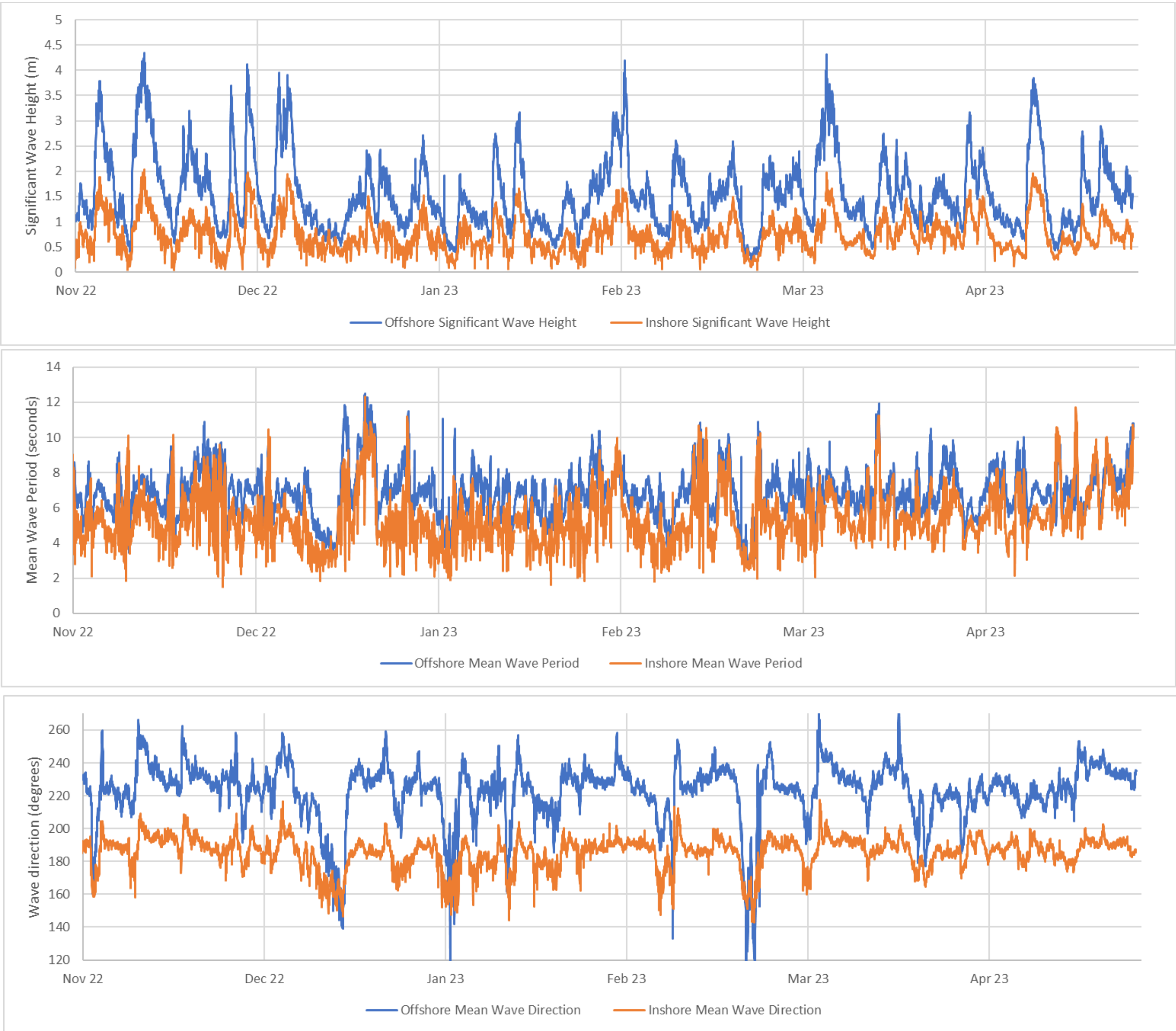


Figure 3-7 VCMP Wave Data

3.4 Summary

3.4.1 Water Level Data

Additional coincident water level measurements have provided insight into the drivers of elevated water levels within the Study Area.

The 2022 flood event which caused both high total water levels and large residual water level at Tarwin Lower had no impact at on water levels at Inverloch. Conversely, a large storm surge from offshore resulted in similarly high residual water levels at both Inverloch and Tarwin Lower.

The different duration of these drivers means that timing of the residual may have a significant, or very insignificant impact on total water levels when considering a shorter duration storm surge compared with the long duration of the catchment flood will elevate waters across a tidal cycle.

The additional measured data also highlights the variation of mean water levels at Tarwin Lower across the year. Water levels are notably higher during the winter months due to the baseflow levels. Extreme flooding which occurs when base flows are already high could result in a larger flood extent than modelled.

3.4.2 Flow Data

The occurrence of another large storm event within the data record is likely to have minimal impact on the Flood Frequency Analysis completed previously. The 1% AEP Tarwin River flow used in the CHA is likely to be similar to the design event if recalculated with the 2022 flood considered.

3.4.3 Wave Conditions

The CHA identified an offshore 1% AEP wave height at the VCMP buoy, based on a 40 year hindcast, of 6.6m. The 1% AEP significant wave used for modelling of storm erosion along Flat Rocks to Surf Beach in the CHA was 3.2m to 3.5m along the coast.

Based on a roughly 50% reduction in measured wave height from offshore to inshore, this is a reasonable estimate of the nearshore wave height.

4 ANDERSON INLET ROAD LEVEES

Two adaption scenarios to change the height of road levees around Tarwin Lower and Venus Bay have been assessed.

Numerical modelling established for the CHA has been used to investigate flooding mechanisms and the impact of increasing road levee heights. The road levees assessed for adaptation are shown spatially in Figure 4-1 with long sections of the crest of the road (based on 2013 LiDAR) presented in Figure 4-2.

The road connecting Venus Bay to Tarwin Lower is represented as Sections 1, 2 and 3 in Figure 4-1 and Figure 4-2 whilst the road along Tarwin Lower and across the floodplains to the south and north of the river are represented as Sections 4, 5 and 6.

The low points along the road are noted, with the lowest areas just under 1.8m AHD on “Section 1” between Venus Bay and the river and on “Section 5” between Tarwin Lower and the bridge (from west to east).

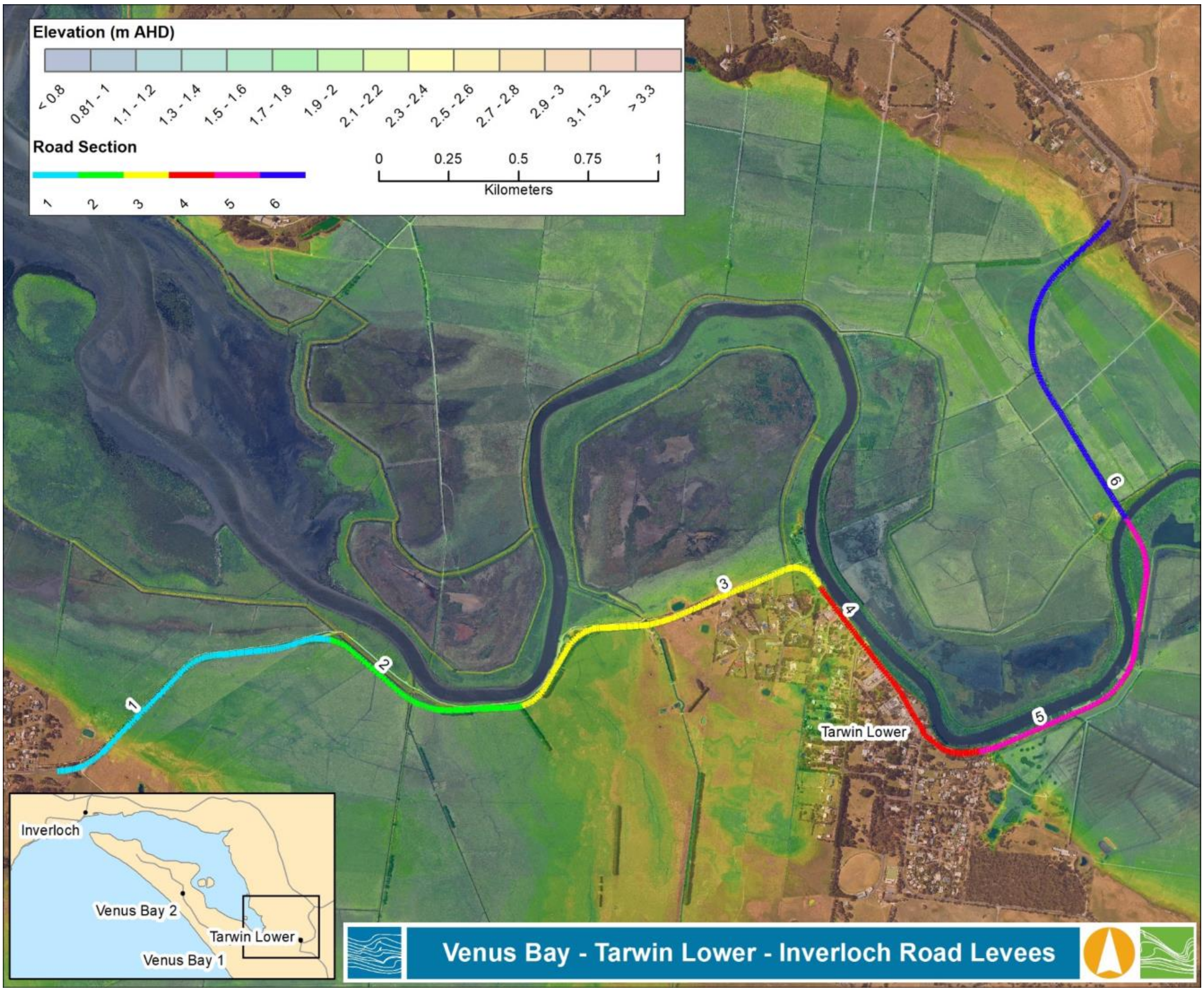


Figure 4-1 Road Sections

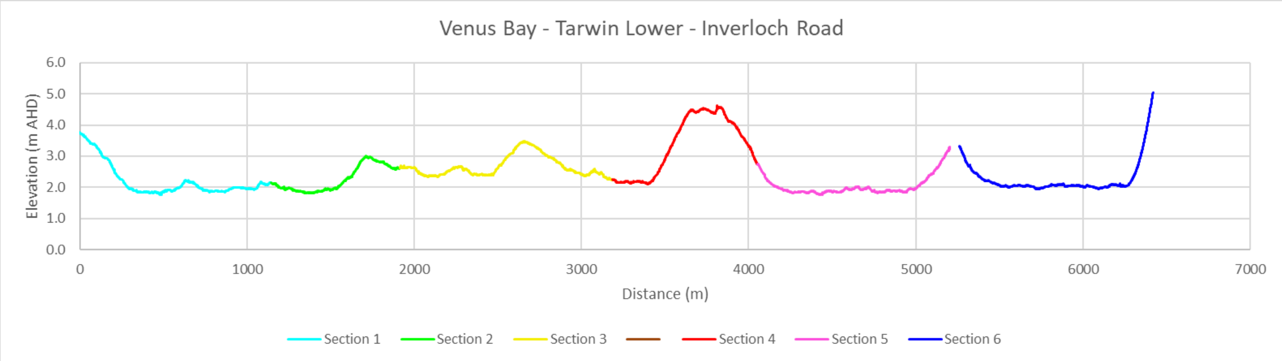


Figure 4-2 Road levee long section

4.1 Storm Tide Inundation

Storm tide and catchment modelling in the CHA indicates the agricultural land either side of the road levees, and sections of the road are inundated under existing and future extreme 1% AEP storm tide conditions and future 10% AEP storm tide conditions. The 1% and 10% AEP storm tide levels have a 1 and 10% chance respectively of occurring in any one year. Modelling predicts extreme water levels as per Table 4-1. Levels which will inundate sections of the road are shaded blue.

Table 4-1 Inverloch CHA Extreme Water Levels at the Tarwin River Mouth

Sea Level Rise (m)	1% AEP Storm Tide + 10% AEP Catchment Flood	10% AEP Storm Tide + 1% AEP Catchment Flood
0.0	2.4	2.2
0.2	2.5	2.3
0.5	2.8	2.6
0.8	3.0	2.8
1.1	3.3	3.0

Based on these levels, there is at least a 10% chance the road between Venus Bay and Tarwin Lower will be inundated in any one year. Maximum depths during the 10% AEP could be greater than 0.5m along Section 1.

The elevated water level caused by a storm tide peaks for a notably shorter duration than a catchment flood, due to the influence of the rising and falling astronomical tides. The modelled water level at Tarwin Lower remains above 2.0m AHD during the 1% AEP storm tide and present-day sea-level rise scenario for 2 high tides (approximately 12-14 hours).

4.2 Regular Inundation

The tidal planes based on the measured data (Section 3.1) are projected to future sea level rises in Table 4-2. The increased future tidal planes suggest the road between Venus Bay and Tarwin Lower could be regularly inundated by predicted tides with 0.8m of sea level rise (shaded blue). This assumes levees along the riverbank remain in their 2013 form and allow water to spread across the floodplain and the road.

However, it is also noted that the measured water levels (which include meteorological and catchment contributions) were regularly above the MHWS and the HAT at Tarwin Lower during the period of measurement from 2020 through 2022. The MHWS was typically exceeded over 35 times per month and the HAT exceeded more than once per month. Thus, it could be expected that in the future the road is likely to be overtopped on average once per month when mean sea level rises 0.2m (shaded blue). Overtopping is more likely to occur in the wetter months from May through September when base flows are higher in the Tarwin River.

Table 4-2 Future Tidal Planes – Tarwin Lower Jetty

Sea Level Rise (m)	MHWS (m AHD)	HAT (m AHD)
0.0	0.9	1.5
0.2	1.1	1.7
0.5	1.4	2.0
0.8	1.7	2.3
1.1	2.0	2.6

The measured water levels at Tarwin Lower (Section 3.1) indicate present day water levels at the upper end of Anderson Inlet have not exceeded the minimum road level in the 2 years measured data is available. However, it is understood that the road between Tarwin Lower and Inverloch was inundated during the large flood event of August 2022. This indicates the road levels may be lower than presented in the available LiDAR and inundation may occur for a longer duration, more frequently and sooner with smaller rises in sea level required for inundation.

4.3 Levee Construction Impact

The numerical model was used to assess the impact of increasing the height of the road levee on the surrounding floodplains. Only Sections 1 & 2 and 5 & 6 (Figure 4-2) were increased to prevent flooding. The model has assumed that the pavement is raised to 4m AHD along these sections of the road.

The maximum inundation depth from a 1% AEP storm tide and 10% AEP catchment flood with the existing and elevated road scenarios under both present day mean sea levels, and with an increase of 1.1m to mean sea levels, are shown in Figure 4-3 and Figure 4-4 respectively.

Under existing mean sea level conditions, the elevated road across the floodplain will prevent inundation of the area between Venus Bay and Tarwin Lower. The existing flood depths east of Venus Bay are typically less than 0.75m with some small depressions where inundation depth can exceed 0.75m. Raising the road will likely prevent this inundation occurring. Inundation depths north of the river with the existing road height are greater than to the south – from 0.5m to over 1.0m across the floodplain. These depths are likely to decrease by less than 0.25m with an increase in the road level as flow can occur directly from the Tarwin River on either side of the elevated road.

Under a future sea level rise of 1.1m the elevated road will prevent the deeper flooding of the area between Venus Bay and Tarwin Lower (shown in the upper plot of Figure 4-4), however flooding may still occur via low points in Sections 3 and 4 of the road and the entire road would need to be raised to completely prevent any flooding of the area. Minor changes to flood depth occurs either side of the elevated Section 5 and 6 of the road north of Tarwin Lower although the depth of inundation with and without the elevated road is still above 1.0m.

The model assumes that drainage through the road levee, with the exception of the Tarwin River path, is not possible. i.e. any rainfall (or even higher storm tide) related flooding in the area between Venus Bay and Tarwin Lower will not be able to drain away, however inundation from rainfall is not shown here. It is also noted that the crest and condition of the levees has not been verified and modelling is based on LiDAR survey from 2013. Changes to the existing and future flood extent may result given this uncertainty in levee condition.

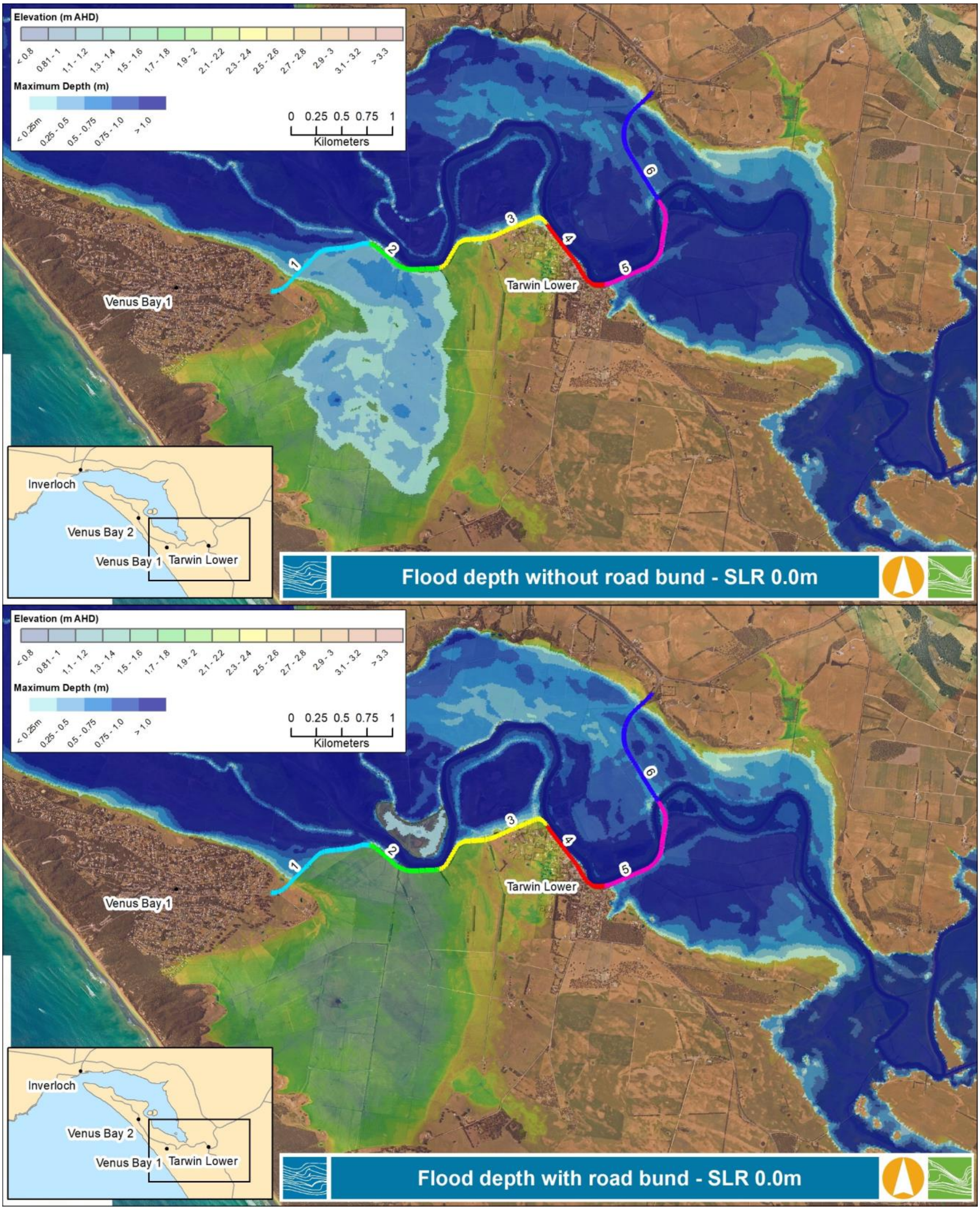


Figure 4-3 Maximum flood depth without (top) and with (bottom) road levee bund, Present Day mean sea level

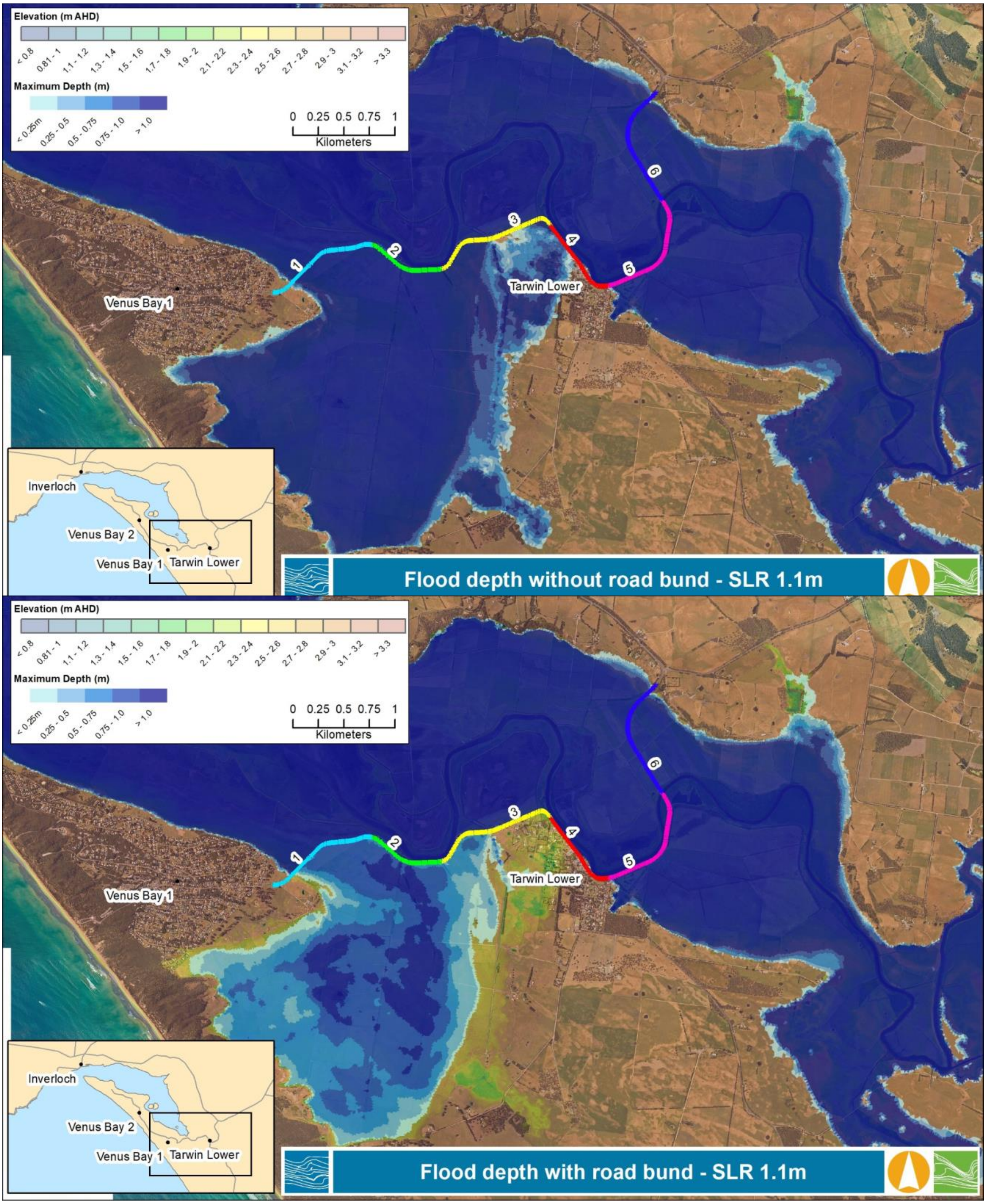


Figure 4-4 Maximum flood depth without (top) and with (bottom) road levee bund, +1.1m SLR

4.4 Summary

This assessment has reviewed both short term frequent flooding, and long term extreme flooding.

To avoid frequent inundation of the road connecting Venus Bay and Tarwin Lower to Inverloch and elsewhere, several actions can be undertaken:

- Increase the height, repair, and maintain the levees running along the banks of the Tarwin River to prevent any tidal or storm event inundation of the floodplain and consequentially the road.
- Provide a small increase the height of the road – to a minimum of 2.0m AHD – to reduce the incidence of inundation until sea levels rise by 0.5m.
- Provide a large increase in road height (+1.0m in parts) to reduce the frequency of inundation towards the end of this century as sea levels rise beyond 1.1m.

More significant change in the road height to allow existing and future access in extreme events will have the following impacts:

- A small reduction in the flood depth north of the river under extreme flooding may occur in the immediate planning horizon (i.e. no additional sea level rise).
- A more significant reduction in the inundation area and depth south of the road between Venus Bay and Tarwin Lower could be expected under future sea level rise conditions.
- Consideration of drainage flow paths through an elevated levee should be considered.

5 WRECK CREEK TIDAL CONTROL

A tidal gate/control at the culvert under Surf Parade (Figure 5-1) is proposed to reduce coastal inundation of the Inverloch residential area landward of Surf Parade. The existing arrangement allows elevated ocean water levels to flow under Surf Parade and into the creek flow path within the residential area.

During coincident catchment and storm tide flood events, this coastal water fills the creek and prevents free drainage of the catchment. The result is greater inundation occurs on nearby land, even where it may be elevated above the storm tide peak level.

The proposed culvert control would prevent the urban drainage areas being inundated by the storm tide and allow rainfall runoff to drain more effectively to the creek.

Figure 5-1 Wreck Creek and Surf Parade

5.1 Storm Tide Inundation

The Inverloch CHA provides estimates of storm tides at Wreck Creek, developed using numerical models to simulate ocean storm surges and astronomical tides, and the impact of sustained offshore wave energy. The extreme storm water levels are presented in Table 5-1 based on the nearshore and beach topography in 2021 and mean sea level of 0.0m AHD.

Future offshore storm tide levels are also provided in the CHA however the impact of wave conditions on the nearshore storm tide level is less certain in the future due to the high level of erosion along Surf Beach and the nearshore bathymetry, and the future vulnerability of the coastal dune which impacts the beach profile and wave setup.

In the future it is likely Wreck Creek will not be separated from the beach by the primary dune and less protection from direct wave energy will be present resulting in increased wave setup.

Table 5-1 Surf Beach at Wreck Creek Extreme Water Levels

Mean Sea Level	1% AEP Offshore Storm Tide (m AHD)	1% AEP Nearshore Water Level (m AHD)
0.0	2.25	3.35
0.2	2.45	-
0.5	2.75	-
0.8	3.05	-
1.1	3.25	-

5.2 Inundation Extent

5.2.1 Topography Change

The inundation extent presented in the Inverloch CHA utilised the available LiDAR topography captured in 2012/13. Since this time, additional LiDAR survey has been captured across Inverloch. The changes and potential implications of the changes are described in Section 1.

5.2.2 Modelling

The TUFLOW model used to simulate coincident urban runoff and storm tide backflow was re-run with the updated topography for the existing mean sea level 1% AEP storm tide scenario. This scenario includes a time varying coastal water level of the existing mean sea level 1% AEP storm tide, including wave setup (Table 5-1) and the 10% AEP rainfall run-off event. The peak of the storm tide was adjusted to meet the peak flow of the urban runoff to provide a conservative estimate of flood extent.

The maximum inundation extent, for both the 2012 and 2022 LiDAR topographies are presented in Figure 5-2. The primary change impacting the residential area is the houses on the southern side of Acacia Court where the elevation has been raised above the floodplain and within the caravan park south of Tee Tree Court. This appears to impact approximately 18-20 housing lots and a large extent of the caravan park, a reduction in the total number of lots impacted under existing mean sea level flood scenarios.

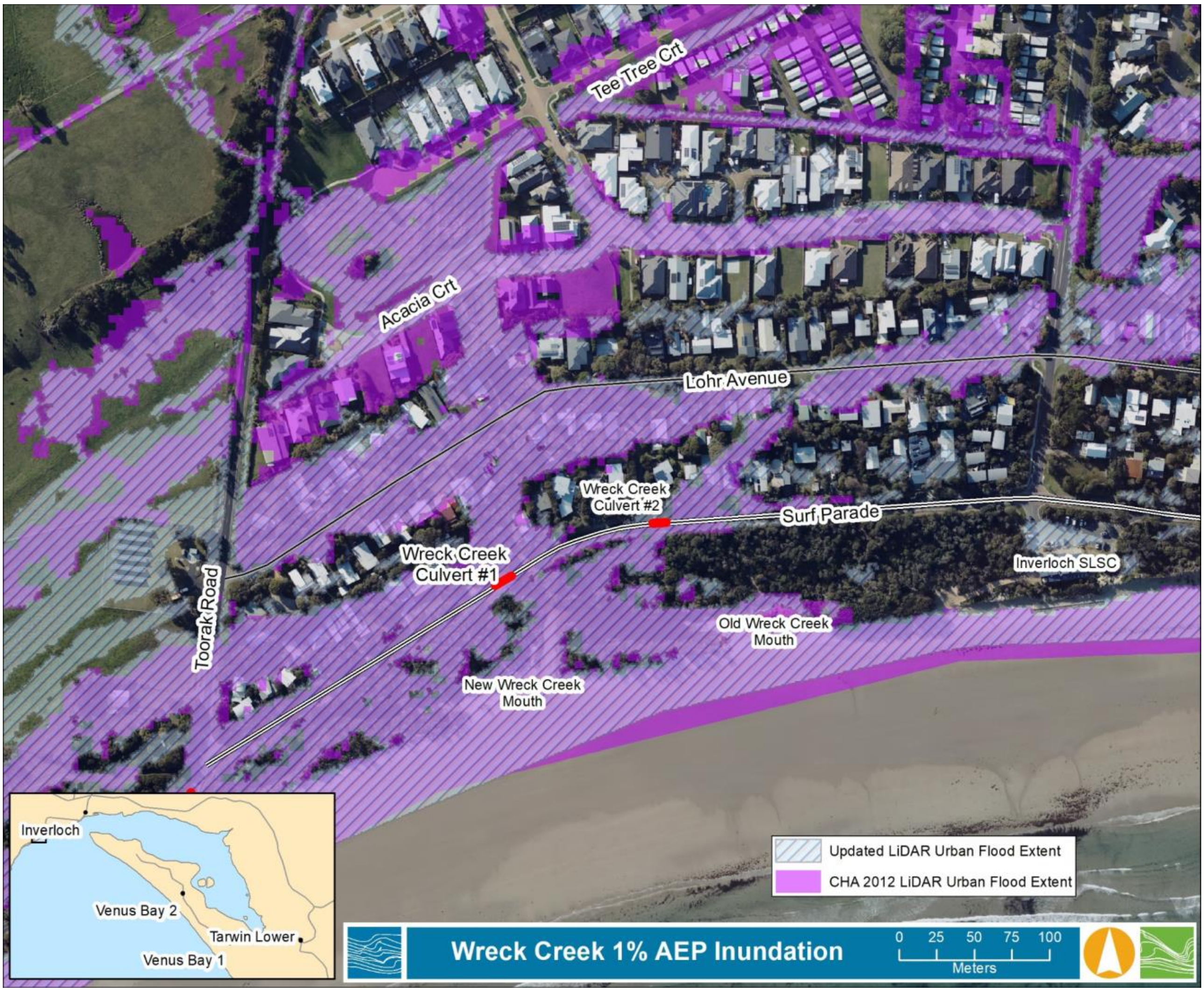


Figure 5-2 Wreck Creek Existing Mean Sea Level 1% AEP Storm Tide +10% AEP rainfall run-off Inundation

The maximum depth of the updated flood model is presented in Figure 5-3. This figure shows the depth of water across Surf Beach Parade at the Wreck Creek culvert is up to 0.4m in depth. To the lower lying land just west of the culvert, depth across the road increases to 0.8m. Whilst the tidal control at the culvert may block storm tide inundation through the culvert, ocean water has potential to overtop the road and utilise drainage volume within the creek, minimising the effectiveness of the control.

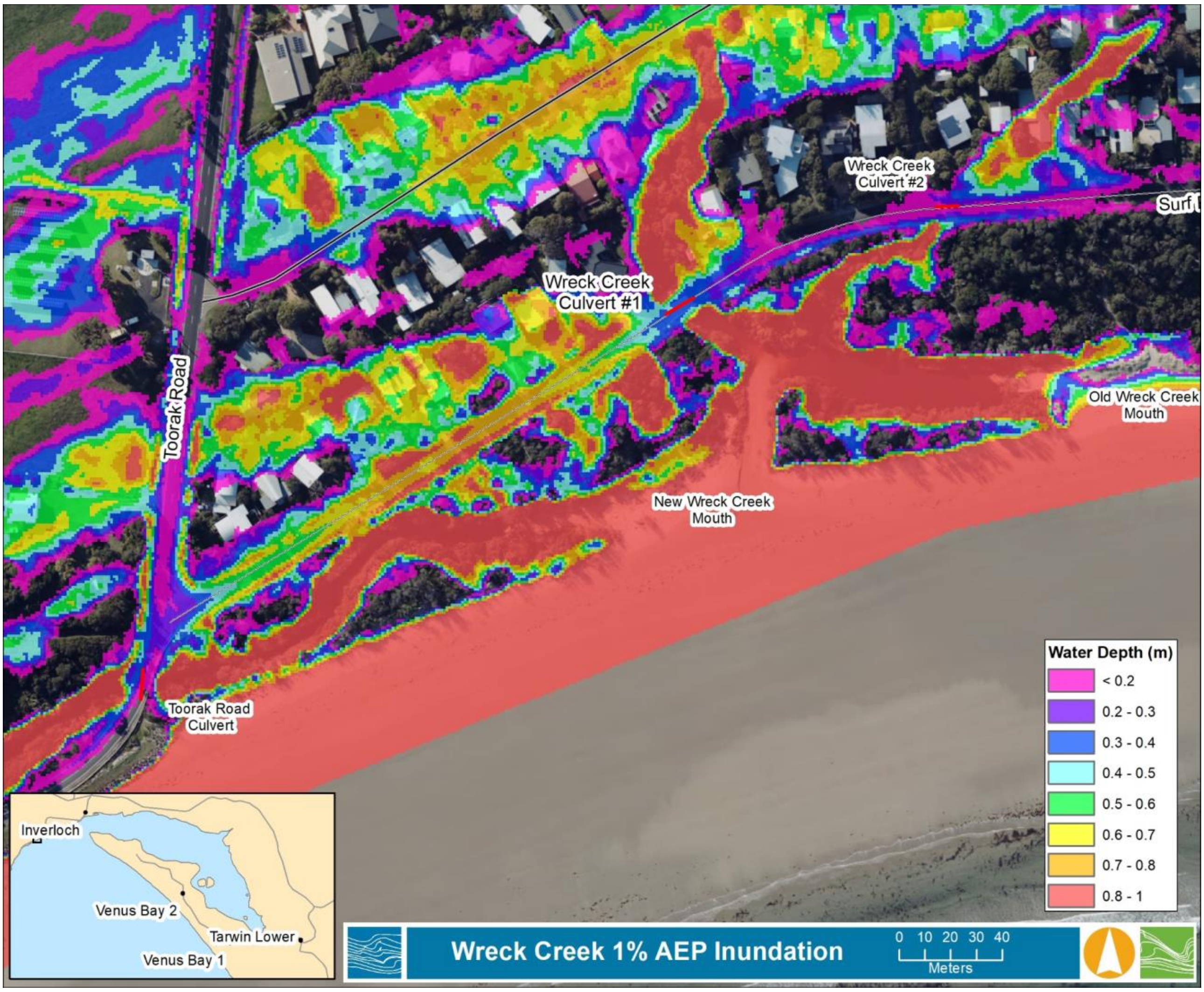


Figure 5-3 Peak Flood Depth, Wreck Creek Existing Mean Sea Level 1% AEP Storm Tide + 10% AEP rainfall run-off

5.3 Summary

Inundation of the Surf Beach residential area is driven by the ingress of elevated ocean water levels and the restriction of free drainage of rainfall runoff through Wreck Creek.

Prevention of the ingress of storm tide by a tidal control gate has been reviewed and deemed not feasible for the following reasons:

- Overtopping of the road is likely to occur without a notable rise in pavement level and available volume in Wreck Creek will be filled with the storm tide overtopping the road.
- A low point in the road to the west allows elevated coastal waters to inundate residential areas north of Surf Beach Parade, not impacted by the presence of a tidal control gate.
- Direct exposure to storm tides and wave action is a high probability along this coast with the erosion risk along Surf Beach. Inundation has potential to find multiple pathways into the future.

6 BEACH NOURISHMENT

A large-scale beach / dune nourishment program along the coastline from Flat Rocks to Surf Beach (Figure 6-1) is proposed to reduce the short term erosion risk of the coastline.

Along with the Bunurong Road (also known as Cape Paterson – Inverloch Road) there are several utility services located within the road corridor (power, water, sewer) and the Inverloch Surf Life Saving Club clubhouse within the erosion hazard extent. The erosion hazard extents were developed in the Inverloch CHA and are shown in Figure 6-1.

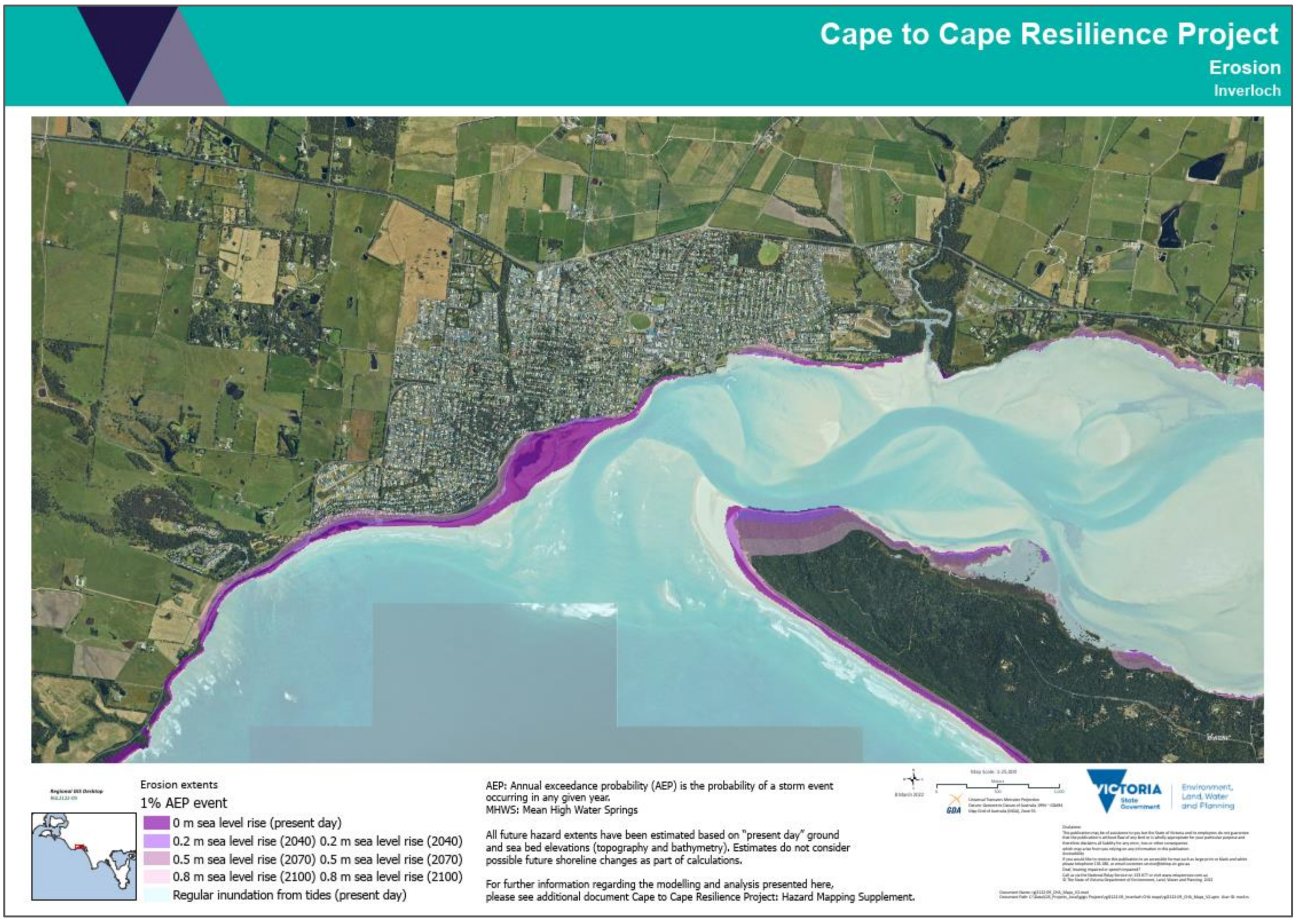


Figure 6-1 Flat Rocks to Surf Beach Erosion Hazard Extent (DEECA, 2022)

6.1 Erosion Hazard

The erosion hazard comprises of existing and future erosion, and erosion from three key processes:

- Short term storm erosion
- Long term recession
- Response to sea level rise

The existing and short-term erosion hazard is driven by the "storm bite" – the erosion predicted to occur from a significant storm event. The CHA has assessed the extent of short-term erosion hazard caused by a 1%, 5% or 10% AEP storm event under existing sea levels. The volume of sand removed from a dune during the 1%, 5% and 10% AEP storm events along the coast are presented in Figure 6-2 along with the equivalent distance based on the 2021 coastal LiDAR used in the CHA.

The long term recession and the response to sea level are future hazards which are not proposed to be mitigated by beach nourishment.

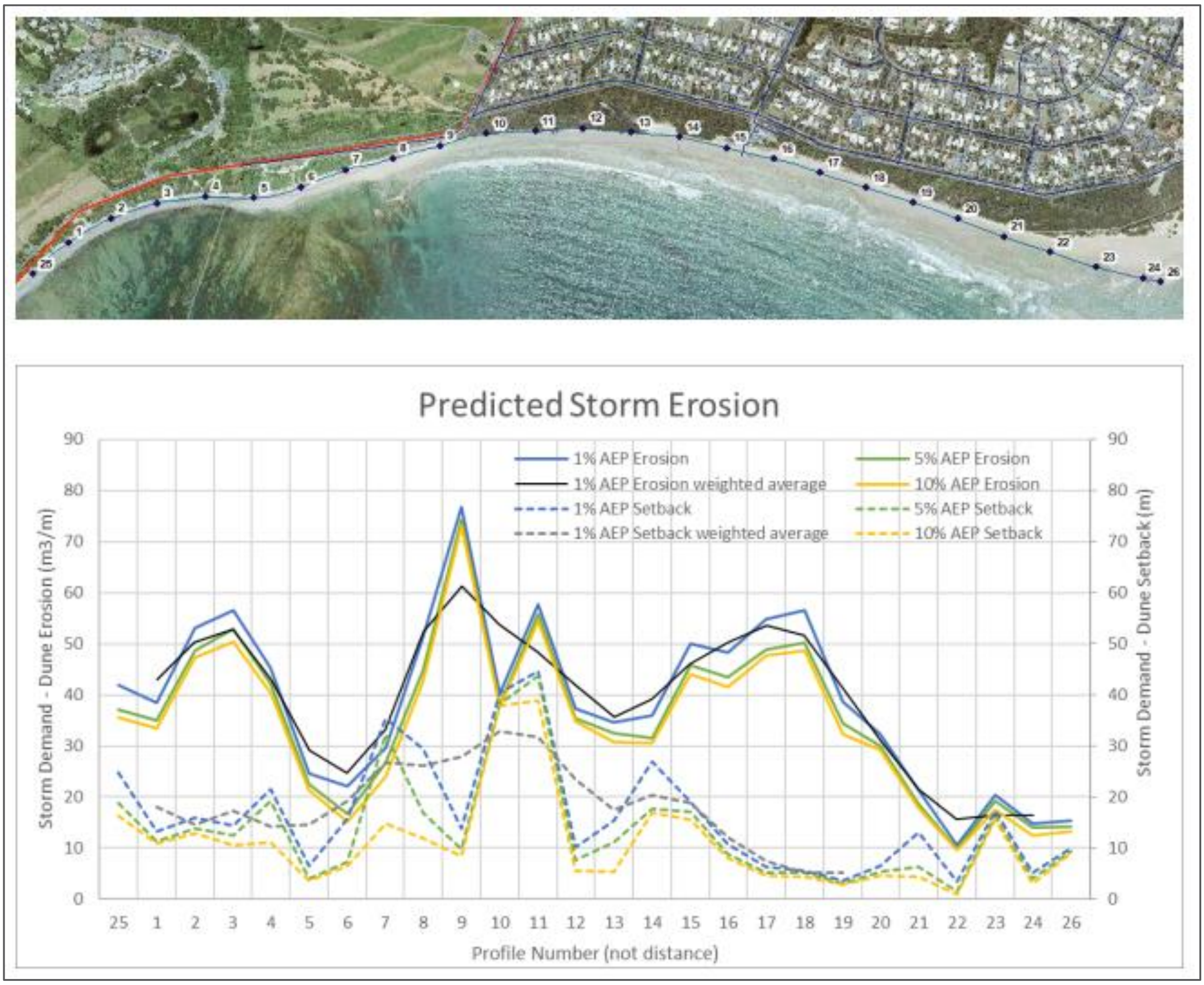


Figure 6-2 Modelled Storm Erosion Volume and Setback

6.2 Storm Probability

The CHA provided a technical assessment of the feasibility of beach nourishment to provide a sacrificial buffer to coastal erosion along the coastline from Flat Rocks to Surf Beach. The CHA considered a sacrificial buffer of the 2% AEP storm event to be a practical balance between probability (there is an 18 – 33% chance of a 2% storm occurring in the next 10 – 20 years), intrusion and cost.

DEECA has requested that a sacrificial sand dune be considered to withstand the 10% AEP storm event to 2040. The 10% AEP storm event has an 86% chance of occurring in the next 20 years. Coupled with the existing strong longshore transport regime along the coastline from Flat Rocks to Surf Beach, it is expected that none of the nourished sand will remain by 2040.

6.3 Storm Demand

The design wave conditions impacting the shoreline from Flat Rocks to Wreck Creek were established in the CHA from a 40-year offshore hindcast which has been transformed inshore. The inshore wave climate has not been calibrated to measured data and wave conditions at the shoreline may be more or less impacted by the rock platform and refraction and diffraction around Cape Paterson than presented.

SBEACH modelling was used in the CHA to determine the existing sea level storm demand along the coast from Flat Rocks to Point Norman for the 2% AEP storm event. The beach profile was adjusted to represent nourishment with this volume and the design storm simulated to ensure the existing dune was protected.

This methodology has been repeated to review changes in storm demand with the new LiDAR and bathymetry data and to review the impact of beach nourishment under a 10% AEP storm event.

The updated 10% AEP storm parameters at selected profiles are presented in Figure 6-3 and compared with those established in the CHA. Results are similar, with the exception of Profiles 9, 12 and 14 where significantly greater erosion is now expected during a 10% AEP storm event. This is the result of the changing beach profile which has a more convex shape above -2m AHD in the recent survey before dropping sharply offshore to -4m AHD.

A convex shaped beach can suggest there is an excess of sand on the beach and is a more common "beach building" shape as opposed to a concave shaped beach which can indicate a beach in equilibrium or one where erosion has occurred. The convex area of sand above -2m AHD is reprofiled and fills the deeper section of the profile (an example in Profile 12 is presented in Figure 6-4).

The beach profiles further along the coast at Profiles 15 through 19 have a profile which is closer to the equilibrium and less sand is lost during a 10% AEP storm event.

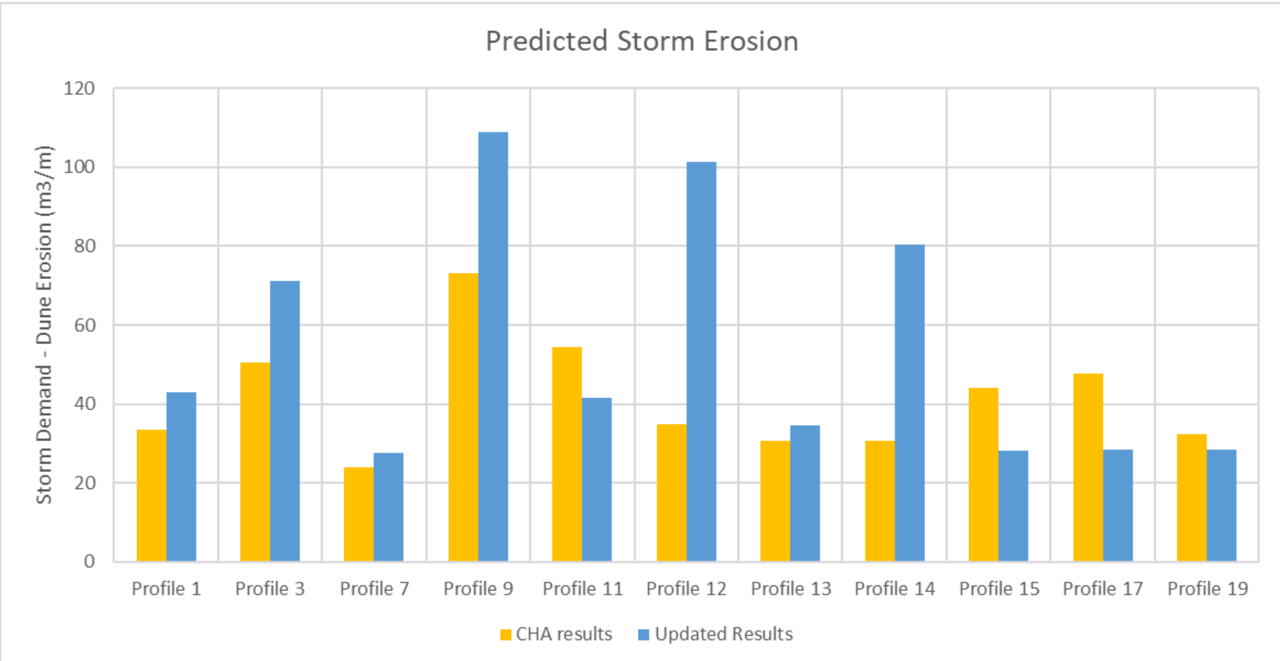


Figure 6-3 10% AEP 2040 Modelled Storm Erosion Volume and Setback

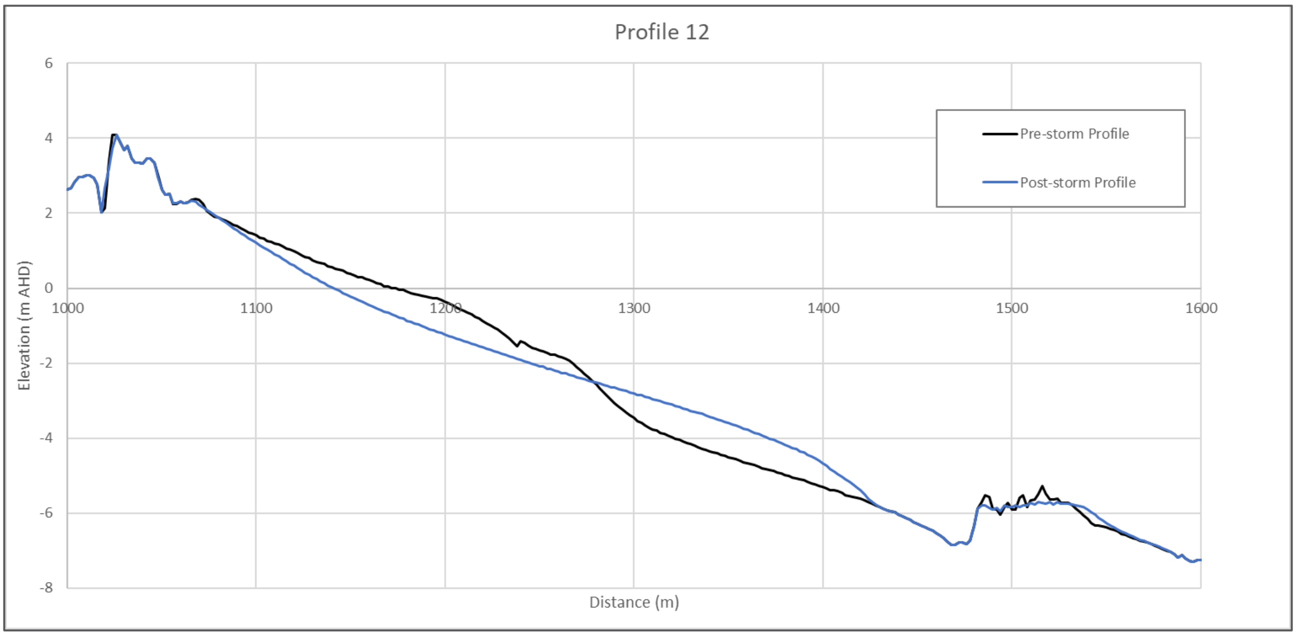


Figure 6-4 Profile 12 Pre- and Post- a 10% AEP storm

6.4 Beach Nourishment Volume

To check the volume of nourishment required along the beach, the profile was adjusted to represent a nourished beach with a crest level of 2.5m AHD and a slope of 1:10 to the existing elevation. The width of the crest was varied until the position of the dune was not impacted during the 10% AEP storm event. For consistency with the CHA, two consecutive 10% AEP events were simulated without beach recovery. Given the high probability of a 10% AEP event occurring before 2040, this is a reasonable approach, however it is noted that often with smaller nourishment volumes tested the existing dune was only eroded during the second storm event.

Updated simulations of nourished profiles and the 2022/23 survey indicates the volumes required for a 10% AEP storm event along the western area from Flat rocks to the rock seawall are in the order of 75 – 100m^3 per meter width of beach. For reference, the volume required for a buffer of the 2% AEP storm event was in the order of 75 – 100m^3 per meter width of beach as well.

There is relatively minor difference in the height of a 10% v 2% AEP wave – in the waters off Surf Beach the 2% AEP wave is approximately 5.0m compared with 4.7m for the 10% AEP storm and the storm demand a similar magnitude for both events (noting the limited level of precision of sediment transport models).

The nourishment volume required has been refined in this assessment by considering the changing demand along the beach. Lower volumes are required towards Point Norman with profiles 12 through 19 (excluding 14) successfully protected with a sacrificial beach of between 40 – 70m^3 per meter. Profile 14 has a notable offshore slope where nourished sand quickly fills and exposes the existing dune. Nourishment along this profile was again in the order of 100m^3 per meter width of beach.

6.5 Discussion

The modelling of storm demand and the estimation of beach nourishment volume is sensitive to the input wave conditions, the beach profile selected, and the grain size of sediment used. The spectral wave model used to establish inshore wave heights has not been verified and the beach profile along this coast is known to change.

Additional on-ground the uncertainties lie in the binding property (and loss of binding) of dune vegetation, longshore transport and potential loss of nourished sand through aeolian (wind) forces. SBEACH modelling in the CHA notes volume lost in a single storm in 2019 is less than the SBEACH estimate, however further slumping and small storm events resulted in mass loss of dune over the subsequent months.

The sacrificial beach nourishment volumes established in the model here deemed to minimise erosion of the existing dune should be considered indicative only and considered as temporary protection works. Beach scraping to retain the volume of sand on the dune could be used to extend the life of the sacrificial nourishment, however it is important to note the protection to the dune could be short lived.

The widths used in the modelling have been projected onto the coastline to provide an indication of the extent of nourishment which could be undertaken. The total volume of nourishment, based on this extent is in the order of 200,000m^3, with around 60,000m^3 to the western end set at +3.0m AHD and the remaining at a crest level of +2.5m AHD from the eastern end of Flat Rocks to Point Norman.

Figure 6-5 Indicative extent of sacrificial beach nourishment

REFERENCES

Water Technology, 2022 *Inverloch Region Coastal Hazard Assessment – Report 1 Summary*, 21010025_R01v02a.pdf, produced for the Department of Environment, Land, Water and Planning, July 2022

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