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# UAV Surveying of Wyong Coastline – June 2016

WRL Technical Report 2016/14
July 2016

By C D Drummond and A J Harrison

Water Research Laboratory
University of New South Wales
School of Civil and Environmental Engineering

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# 1. Introduction

The Water Research Laboratory (WRL) of the School of Civil and Environmental Engineering at UNSW Australia was engaged by Central Coast Council (Council) to undertake rapid response Unmanned Aerial Vehicle (UAV or drone) surveying of the Wyong coastline following an intense East Coast Low (ECL) storm event on the 3rd – 6th of June 2016. WRL has previously undertaken drone surveying of Wyong's coastline as outlined in WRL Technical Report 2016/04. In this report, WRL provides a coastal engineering analysis and comparison of data collected in June 2016 with the data collected November 2015. This report includes quantification of changes in sand volumes and a comparison of representative beach profiles between each survey date.

In this report, analysis is provided separately for the following locations:

- Location 1: Lakes Beach;
- Location 2: Hargraves Beach;
- Location 3: Cabbage Tree Harbour;
- Location 4: The Entrance North at Curtis Pde to The Entrance at Richard Rd;
- Location 5: Toowoon Bay to Blue Bay; and
- Location 6: Shelly Beach.

This report includes the following sections:

- **Section 2:** Surveying methodology and post-processing techniques;
- **Section 3:** Background information on the wave conditions prior to surveying and information regarding the coastal engineering analysis undertaken; and
- **Section 4:** Discussion and analysis of the impact of the June 2016 storm at each of the above locations.

**Figure 1-1: Photo of Toowoon Bay looking south towards Shelly Beach (photo taken 13/6/2016)**

## 2. Survey Methodology and Post-Processing

The use of UAVs as a mapping and measurement tool has grown significantly in recent years and has been pioneered in Australia by WRL coastal engineers to provide high quality coastal survey data sets at numerous locations on the NSW coastline. While traditional land-based (e.g. RTK-GPS) or airborne (e.g. LiDAR) methods of collecting topographic data over large areas can be labour-intensive and/or costly, UAV surveying provides cost-effective, rapid airborne sampling of the coastal zone at high-accuracy and very high spatial resolution.

WRL completed UAV surveys utilising a Sensefly eBee RTK UAV equipped with a Canon Ixus RGB camera with key features summarised in Table 2.1. This platform is a fully autonomous survey-grade mapping UAV which carries an on-board RTK-GNSS receiver. During flights, the eBee RTK maintains radio connection to a ground-based GNSS base station, providing in-flight processing of Real Time Kinetic (RTK) corrections via the CORSnet-NSW network of permanent GPS base stations. This results in high precision navigation and individual image geo-tagging.

Surveying was completed by Civil Aviation Safety Authority (CASA) approved pilot Chris Drummond between $10^{th}$ – $29^{th}$ June 2016, at the locations shown in Figure 2-1. The survey was georeferenced to the GDA94/MGA Zone 56 datum. A number of ground control points were also surveyed at each site to verify the accuracy of the UAV derived data.

**Table 2.1: Specifications of the UAV System**

| Feature | Description |
|---|---|
| Type | Fixed wing UAV |
| Wingspan & weight | 96 cm, 700 g |
| Endurance | Up to 40 minute flight time |
| Cruise speed | 40-90 km/hr |
| Wind resistance | Gusts up to 45 km/hr |
| Coverage per flight | Up to $2km^2$ |
| Onboard Sensors | RGB/NIR camera<br>RTK receiver<br>Inertial measurement unit<br>Pitot probe<br>Optical ground sensor |

Post processing was completed using Postflight Terra 3D software to produce a geo-rectified orthomosaic image and 3D digital elevation model for each location. This software uses advanced photogrammetry techniques to produce elevation data through the automatic detection of common features between many overlapping images, and results in a dense topographic point cloud dataset. The data output is based on the photographic image and may represent the upper surface of dense vegetation or building roof rather than a ground return where these features dominate an area of the imagery. The algorithm relies on the assumption that ground features remain stationary while the survey platform is in motion. For this reason, the algorithm is generally limited to mapping stationary objects thereby limiting the possibility of mapping dynamic objects such as water surfaces or the wave run-up zone. Surveys were measured at low tide where possible to maximise coverage of the beach profile. This resulted in data that generally extends to a minimum level of 1 to 2 m AHD.

The data products produced include a densified point cloud as well as an ortho-rectified mosaic image of each survey area. The point cloud data has RGB pixel colours assigned to it which provides a powerful 3D visualisation tool. Typical ground resolutions of the imagery produced by the UAV in this study vary from 2 to 3 cm/pixel and an average density of 50 points per $m^2$. Accuracy of UAV derived survey data was analysed by Turner, *et al* (2016) through comparison with RTK-GPS data taken from an All-Terrain-Vehicle (ATV) at Narrabeen Beach, Australia. A comparison of 15,000 data points from the two methods indicated a standard deviation error of ±7 cm for UAV photogrammetry that had not incorporated ground control points in its post processing. At all beach locations presented in this report, ground control points have been used in post processing to maximise the accuracy of the produced UAV survey data. As a result, the accuracy of the UAV derived data used for this report has a nominal accuracy of +/- 7 cm and is suitable for analysis of beach volume change. This data should not be used for other applications without prior checks for suitability of purpose.

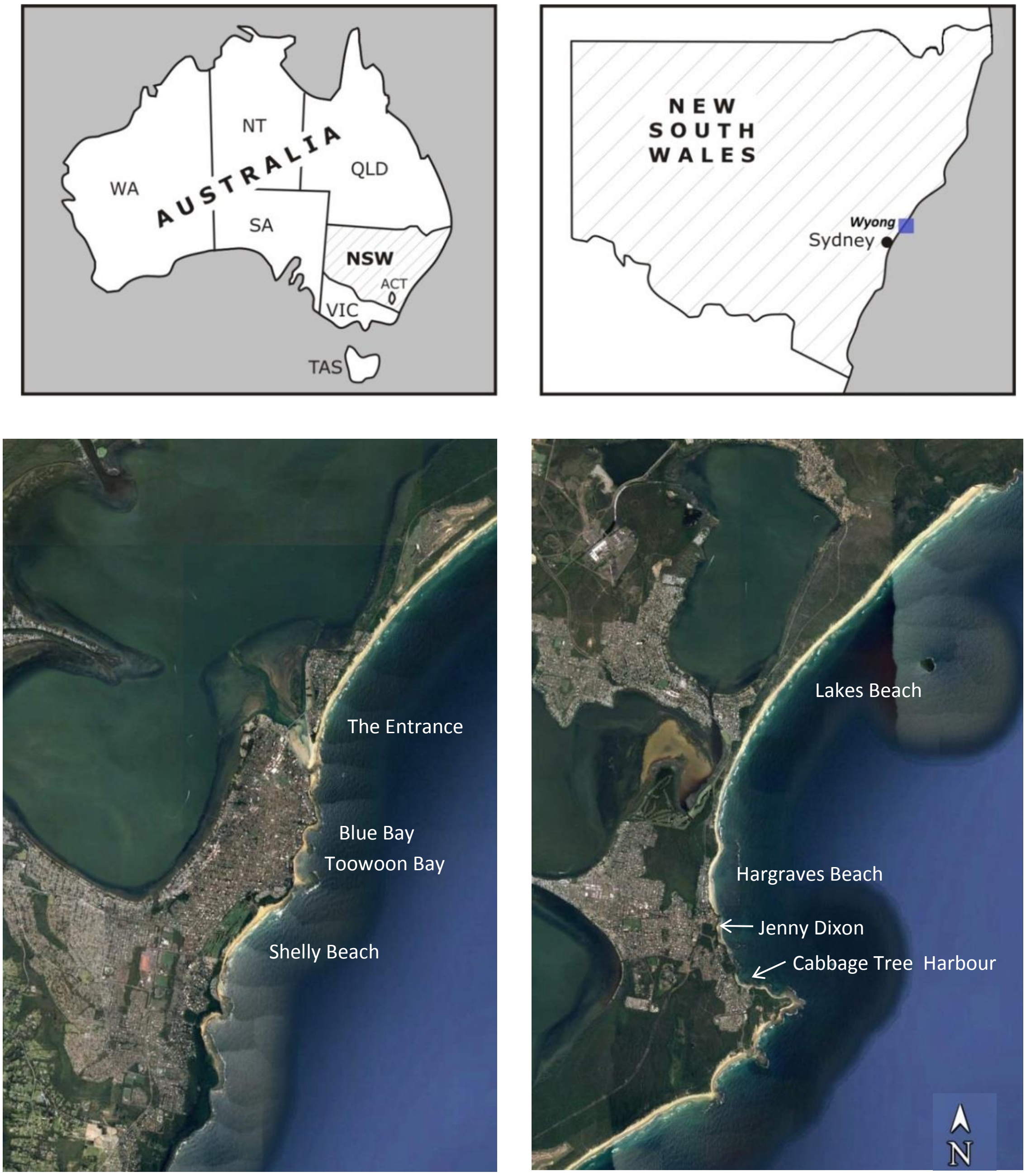



**Figure 2-1: Overview of survey locations**

# 3. Background Information

This section provides a summary of the background information and concepts underlying WRL's analysis of the effect of the June 2016 storm on Wyong's beaches. It includes a discussion of the wave climate during the June 2016 storm, however, it does not detail the incident wave conditions for the pre-storm surveying in September – November 2015. This can be found in WRL's previous Technical Report (Drummond *et al.*, 2016).

## 3.1 Incident Wave Conditions

The Wyong coastline experiences an average significant wave height of 1.5 m from the south-south-east superimposed on a highly variable wind wave climate (Shand et al., 2010). Due to this prevailing wave direction, the southern extent of beaches in this region usually have some degree of protection from storm erosion with exposure increasing to the north of each embayment. Figure 3-1 shows the wave heights between November 2015 and the start of June 2016 from the Manly Hydraulics Laboratory (MHL) wave buoy located offshore in 90 m water depth. WRL is awaiting receipt of QA controlled data from MHL of wave heights during the June 2016 ECL storm event, however wave heights reported online from Sydney Port Authority (buoy located offshore of Botany Bay in approximately 92 m water depth showed water heights up 7 m from an easterly direction in this period.

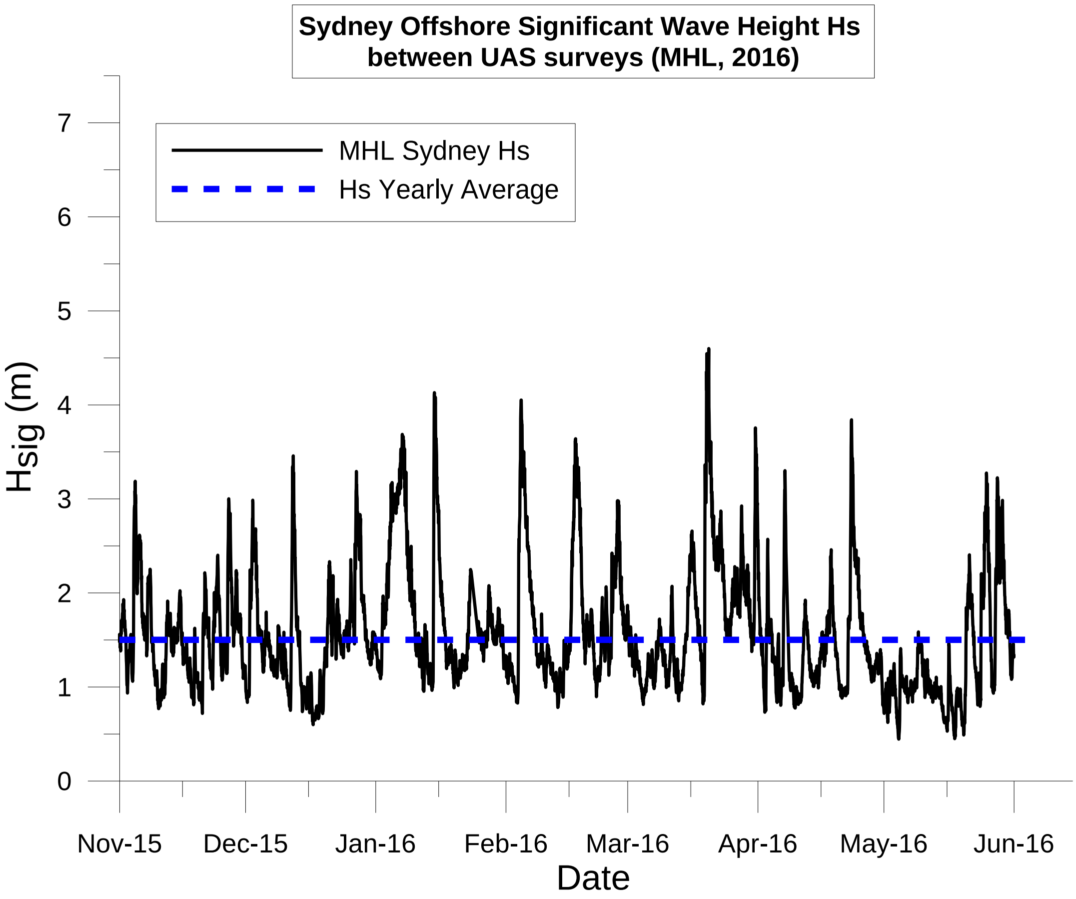



**Figure 3-1: Sydney offshore wave height between survey dates**

## 3.2 Profile Locations

For the purposes of volumetric analysis, four (4) profiles have been established for each beach, uniformly distributed alongshore, in order to give a representation of each section of the beach. UAV survey data was extracted at each profile location. In cases where the UAV derived data did not extend to 0 m AHD due to interference from wave run-up, a representative beach slope was identified and used as a basis for extrapolation to the 0 m AHD contour.

## 3.3 Beach Volume Change

This report includes analysis of the change in the volume of sand buffer above 0 m AHD at each analysis profile between November 2015 and June 2016. This is calculated by comparing the initial volume of sand at a number of different profiles during the 2015 surveying campaign with the remaining volume available after the storm. This can be used as a measure of the beach volume change between surveys, and provides an indicator of the erosive effect of the storm on each beach location.

As the initial survey was completed in October – November 2015, rather than immediately prior to the June 2016 storm, there is no way of isolating the effect of the storm on the beach from longer term changes in the beach. Therefore the volume changes presented in this report do not represent the 'storm demand', but instead a volume change between two points in time.

## 3.4 Erosion Intensity Maps

For each beach, an intensity map of erosion has been provided. The intensity map directly compares the two surveys (pre- and post-storm) to show the change in elevation along the beach. Intensity maps are only provided in the active beach zone and where survey data was collected for both surveys. No extrapolation is performed, so the intensity maps do not infer information in the wave run-up zone.

In addition to erosion intensity maps, approximate beach volume change at profiles at 100 m intervals are also presented for The Entrance, Blue Bay and Toowoon Bay and Shelly Beach. These beach volume change calculations include an extrapolation down to 0 m AHD. Due to the lack of data approaching the 0 m AHD contour, automated volume calculations were not considered appropriate for Hargraves Beach and Lakes Beach. Volume change at these locations is instead presented on the erosion intensity map to give an indication of the spatial distribution of change.

# 4. Survey and Analysis

## 4.1 Overview

Analysis at each beach location is based on two survey dates, one prior to the June 2016 ECL storm event and one immediately after. The dates of each survey are shown in Table 4.1.

**Table 4.1: Survey Dates**

| Location | Pre-Storm 2015 Survey Date | Post-Storm 2016 Survey Date |
|---|---|---|
| Lakes Beach | 24/11/15 | 17/06/16 |
| Hargraves Beach | 24/11/15 | 17/06/16 |
| Cabbage Tree Bay | 19/11/15 | 30/06/16 |
| The Entrance – The Entrance North | 28/10/15 | 10-13/06/16 |
| Blue Bay – Toowoon Bay | 10/11/15 | 13/06/16 |
| Shelly Beach | 10/11/15 | 14/06/16 |

At each beach location four (4) analysis profiles were taken in representative locations along the beach. Table 4.3 summarises the volume change at each profile and a comparison with the BMT WBM (2015) design storm erosion. At Cabbage Tree Bay and Jenny Dixon, the presence of rock platforms and very narrow beach width meant that volume calculations were considered an inappropriate measure of beach profile change in these locations. Table 4.2 shows the sand buffer volume during both surveys for four key locations.

Selected profiles are presented throughout this section to illustrate the difference between the beach profile in November 2015 and June 2016. However, for a full compilation of all profiles, see Appendix A. In addition to the profiles, ortho-mosaic aerial imagery of each beach can be found in Appendix B. Imagery includes both pre-storm (November 2015) and post-storm (June 2016) for the purpose of comparison.

**Table 4.2: Volume of Sand Buffer above 0 m AHD at Key Locations**

| Location | Approximate volume above 0 m AHD ($m^3/m$) | |
|---|---|---|
| | November, 2015 | June, 2016 |
| The Entrance North Profile Curtis Pde | 147 | 73 |
| Hargraves Beach Profile 2 Beach Centre | 156 | 133 |
| Lakes Beach Profile 1 SLSC | 312 | 282 |
| Shelly Beach Profile 2 SLSC | 218 | 243 |

**Table 4.3: Beach Change Summary**

| Location | Profile ID | Movement of 2 m AHD Contour (m) (negative: landward, positive: seaward) | Volume Change (m3/m) above 0 m AHD Nov 2015 - June 2016 | BMT WBM (2015) Design Storm Erosion (m3/m) Relative to ~2007 Conditions | Percentage of Design Storm Erosion |
|---|---|---|---|---|---|
| Lakes Beach | Profile 1 | -8 | -30 | 150 | 20% |
| | Profile 2 | +2 | -33 | 150 | 22% |
| | Profile 3 | -18 | -94 | 150 | 63% |
| | Profile 4 | 0 | -30 | 150 | 20% |
| Hargraves Beach | Jenny Dixon | -1 | N/A* | N/A* | N/A* |
| | Profile 1 | 7 | +67 (Accreted) | 180 | N/A |
| | Profile 2 | -15 | -23 | 180 | 13% |
| | Profile 3 | -7 | -4 | 180 | 2% |
| Cabbage Tree Bay | Profile 1 | 0 | N/A* | N/A* | N/A* |
| | Profile 2 | 0 | N/A* | N/A* | N/A* |
| | Profile 3 | 0 | N/A* | N/A* | N/A* |
| | Profile 4 | +3 | N/A* | N/A* | N/A* |
| The Entrance | Entrance South | +6 | +22 (Accreted) | 170 | N/A |
| | Entrance Profile 1 | -16 | -69 | 170 | 41% |
| | Entrance Profile 2 | -26 | -86 | 170 | 51% |
| | Entrance North | -16 | -72 | 170 | 42% |
| Blue Bay - Toowoon Bay | Blue Bay 1 | -7 | -10 | 115 | 9% |
| | Blue Bay 2 | +2 | +9 (Accreted) | 115 | N/A |
| | Toowoon Bay 1 | -15 | -30 | 75 | 40% |
| | Toowoon Bay 2 | 0 | -14 | 75 | 19% |
| Shelly Beach | Profile 1 | +4 | +6 (Accreted) | 290 | N/A |
| | Profile 2 | +2 | +25 (Accreted) | 290 | N/A |
| | Profile 3 | 0 | -2 | 290 | 1% |
| | Profile 4 | -17 | -52 | 290 | 18% |

*Volume change not calculated due to the presence of rock.

## 4.2 Lakes Beach

The erosion intensity map at Lakes Beach (Figure 4-3) indicates that this area lost a significant amount of sand near the scarp along the whole length of the beach. The storm primarily removed sand from the face of the dune. Three (3) of the four (4) profiles showed a relatively consistent volume loss of approximately 30 $m^3$/m, the exception to which is Lakes Beach Profile 3 (Figure 4-1), that had significantly more erosion (94 $m^3$/m). However, most of this eroded volume is accounted by the area below the 2 m AHD contour, where the beach profile had to be extrapolated. There is therefore more uncertainty in this region, and it is possible that at this profile the volume change may be over stated by the analysis.

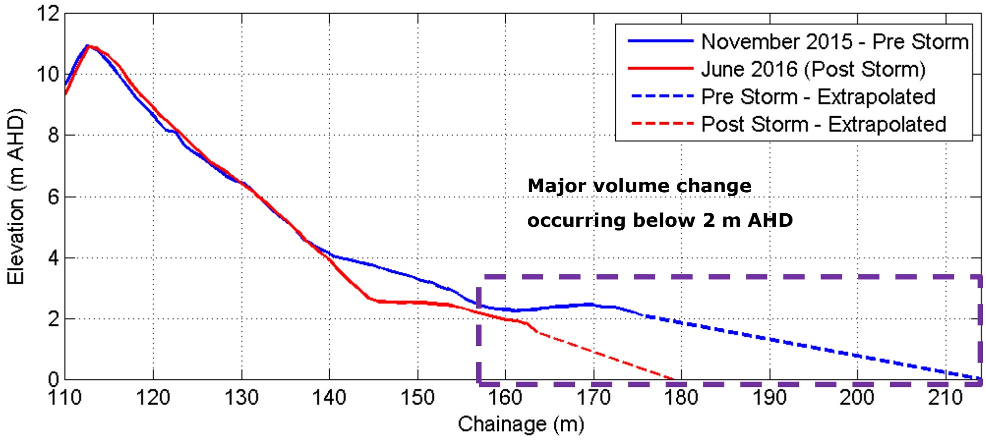



**Figure 4-1: Lakes Beach Profile 3 (ΔV = -94 $m^3$/m)**

Figure 4-3 shows the beach response was relatively uniform along Lakes Beach, most likely due to the relatively straight longshore profile. The most significant infrastructure on Lakes Beach is the Surf Life Saving Club at the southern end of the beach (at Profile 1, Figure 4-2). There was a volume loss of 33 $m^3$/m at this location and a beach retreat of approximately 8 m at the 2 m AHD contour between November 2015 and June 2016. It is not considered to have caused threat to the SLSC. In front of the SLSC, there is still a sand buffer of over 280 $m^3$/m, significantly larger than the design storm demand described in BMT WBM (2015) of 150 $m^3$/m.

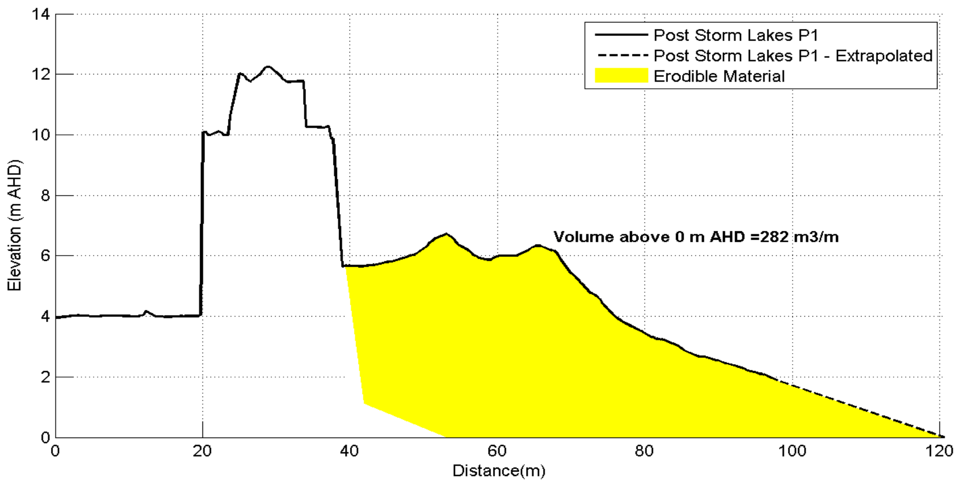



**Figure 4-2: Lakes Beach Profile 1 (Lakes Beach SLSC), Post Storm**

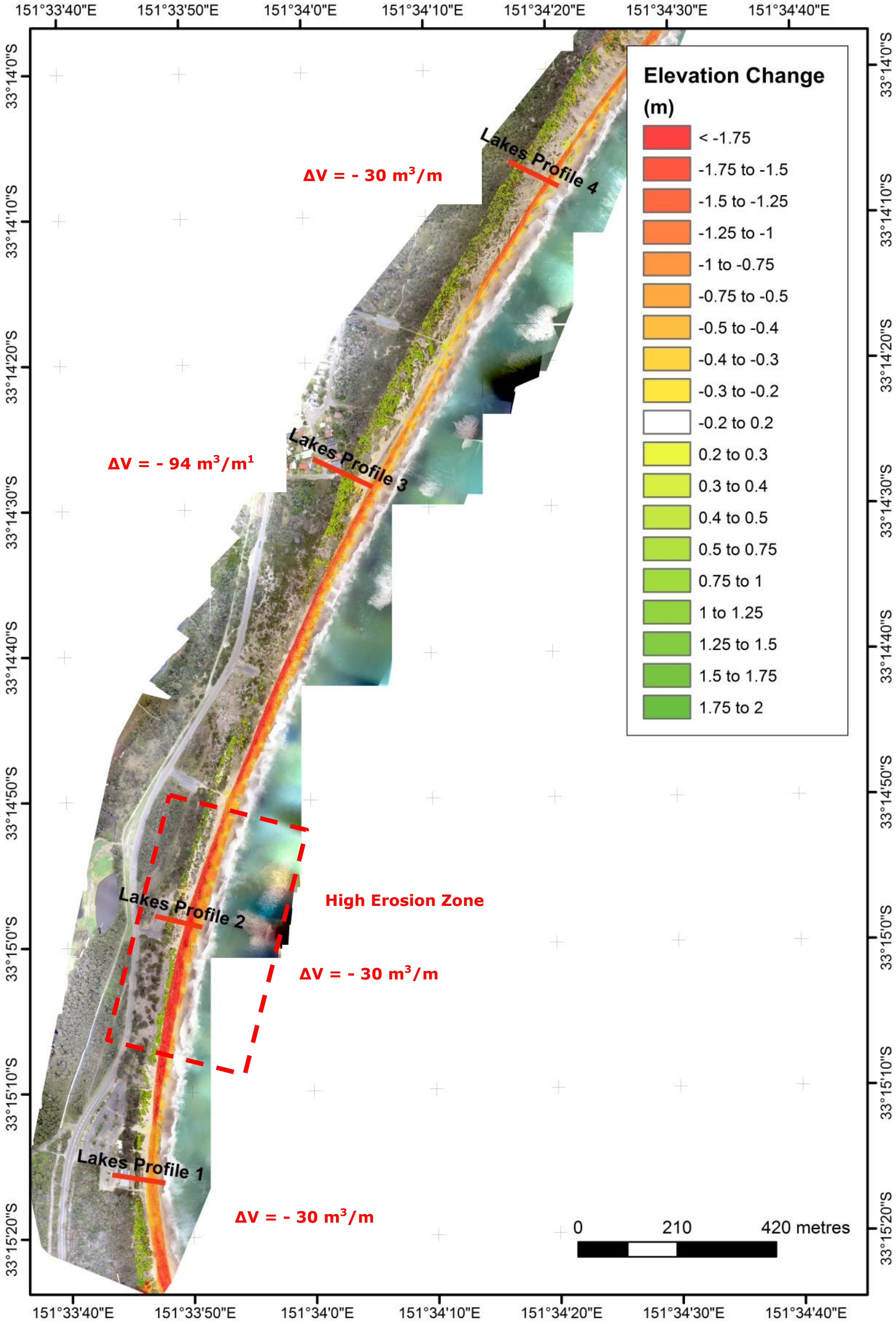



**Figure 4-3: Lakes Beach erosion intensity map**

[1] The majority of erosion at this profile occurred in the extrapolated zone below 2 m AHD (see Figure 4-1).

## 4.3 Hargraves Beach

The erosion intensity map for Hargraves Beach (Figure 4-7) shows that volume change along the beach was highly variable. The southern end of the beach shows significant accretion, with the volume change at Profile 1 exhibiting an accretion of 67 $m^3$/m in sand volume. As the two surveys are separated by 7 months, it is unclear whether this accretion was a gradual change occurring between November 2015 and June 2016, or a representation of longshore movement of sand or beach rotation during the recent large storms. Sediment transport and response to storm events at this location is complicated by the presence of submerged offshore reefs.

The central beach shows some significant movement of the scarp. Profile 2 showed a 15 m landward movement of the 2 m AHD contour and shows significant erosion occurring up to 50 m landward of the 0 m AHD contour. Similar beach retreat was observed at Profile 3, although significantly less volume change was observed at this location. This section of Hargraves Beach is densely populated with many residential buildings behind a low vegetated dune. Dramatic loss of beach volume puts these structures at greater risk of coastal inundation and structural damage if another similar storm event occurs before the beach has time to recover. The erosion from the June 2016 storm did not significantly threaten these houses, but did reduce the storm buffer available for subsequent storms. The volume of sand buffer remaining at Hargraves Beach Profile 2 is just over 130 $m^3$/m, smaller the design storm erosion of 150 $m^3$/m (BMT WBM, 2015).

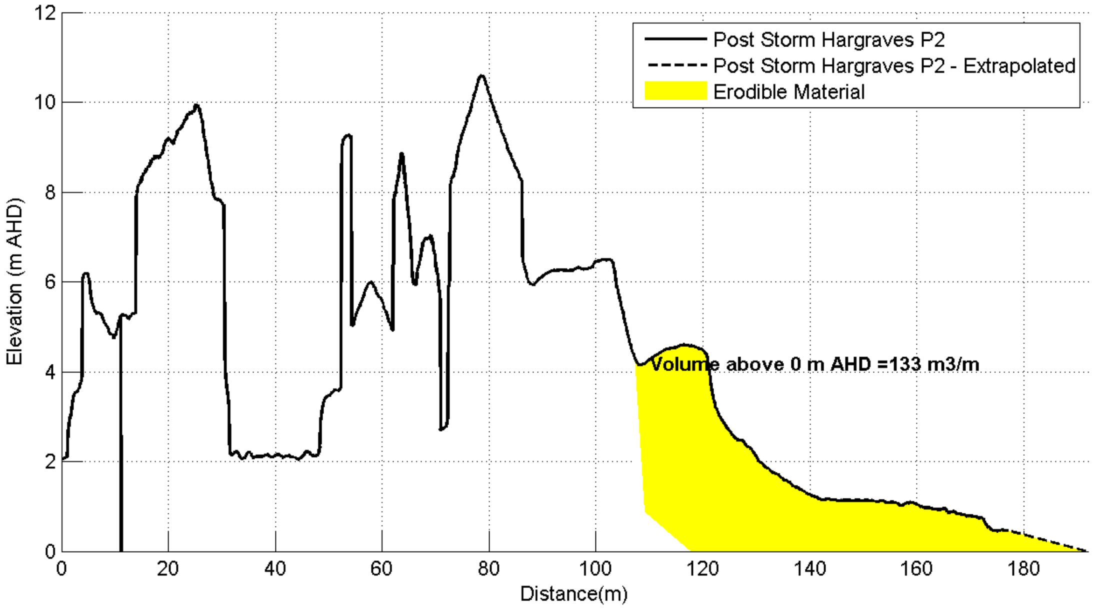



**Figure 4-4: Hargraves Beach Profile 2, Post Storm**

The undeveloped northern end of Hargraves Beach experienced the most erosion of all areas along the beach. Erosion occurred for all areas below the vegetation line. As this section of the beach has no significant infrastructure put at risk by storm erosion, no profiles were closely examined in this area. However, elevation changes of greater than 1.75 m were observed between November 2015 and June 2016.

Jenny Dixon has significant rock outcrops present along the beach and the beach width was not considered adequate to perform any accurate beach volume change calculations. Inspection of the two ortho-mosaic images indicated that previously buried bed rock was exposed in the June 2016 survey. Anecdotal reports by local residents suggested that the erosion occurred following the ECL event, but that significant sand volumes had returned to the beach between the storm (4$^{th}$ June) and the UAV survey undertaken on the 17$^{th}$ June. This may have contributed to the minimal change in the beach profile at Jenny Dixon as shown in Figure 4-5 and Figure 4-6.

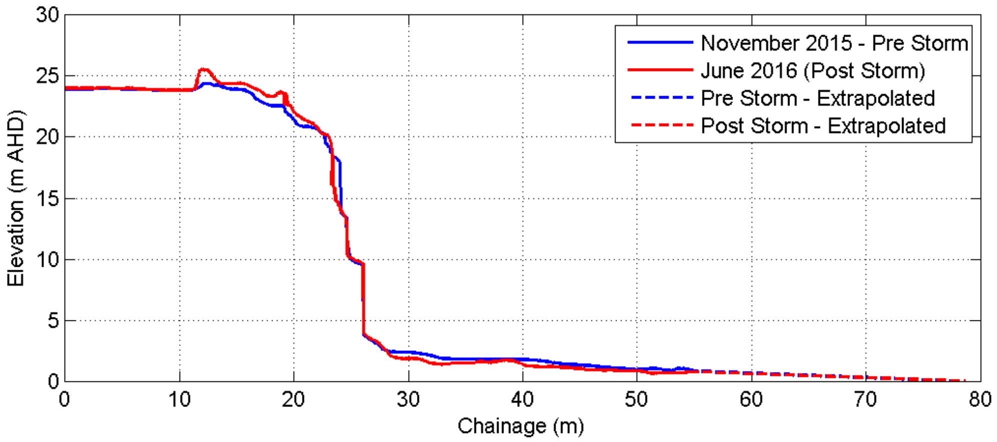



**Figure 4-5: Jenny Dixon Profile**


**Figure 4-6 Jenny Dixon Post Storm aerial image (17/06/2016)**

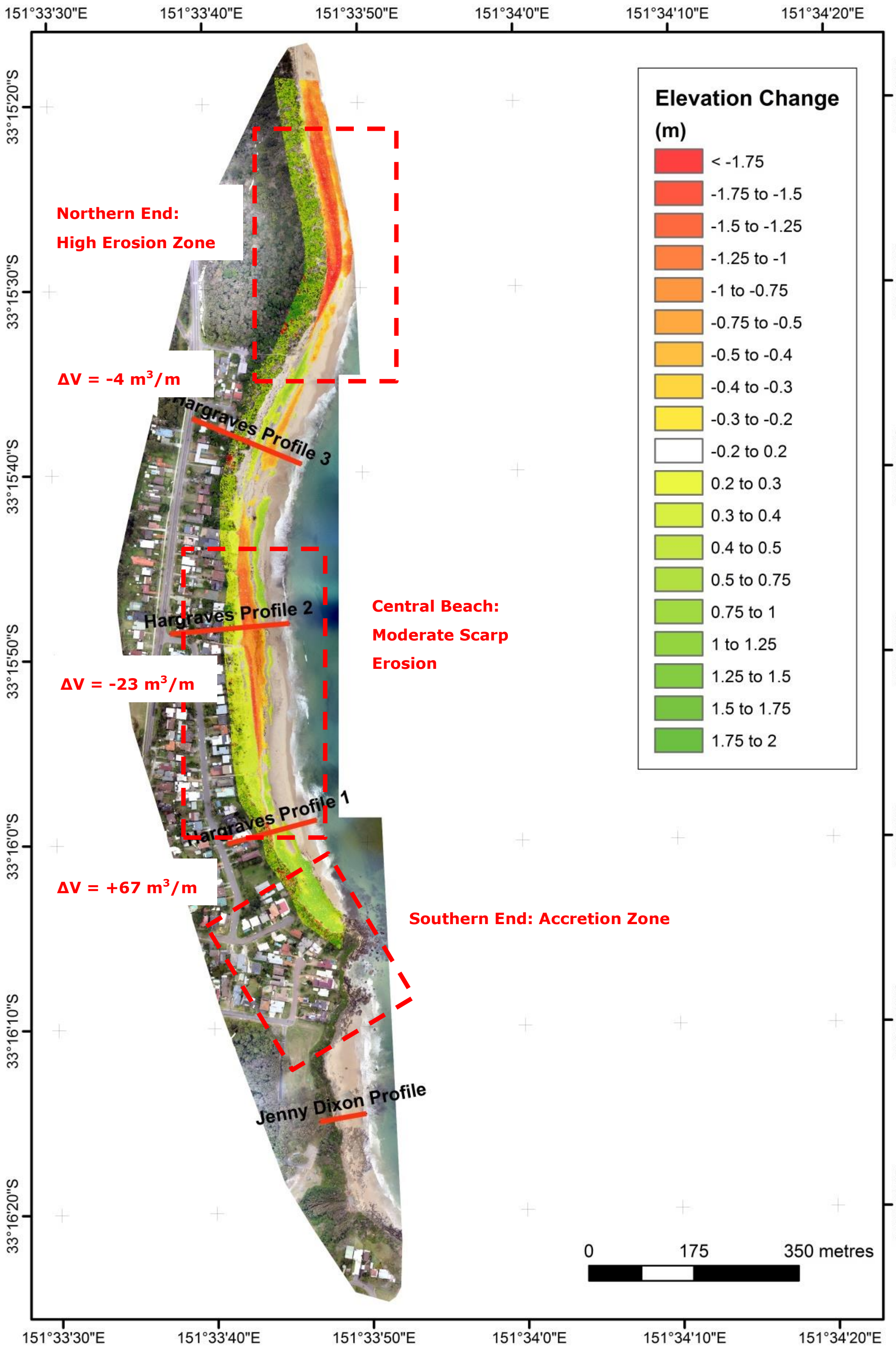



**Figure 4-7: Hargraves Beach erosion intensity map**

## 4.4 Cabbage Tree Bay

Cabbage Tree Bay is protected by nearshore reefs and rock platforms. At the time of surveying in June 2016, there was very little beach width, as the wave runup was exceeding 2 m AHD. While extrapolations to 0 m AHD can be made, the available data is not considered to have a sufficient extent to analyse volume changes at each profile, or to develop a correct erosion intensity map.

However, during the survey, WRL identified the collapse of a cliff located near Profile 3 (Figure 4-10). Figure 4-9, Figure 4-11 and Figure 4-12 show 3D imagery of the cliff from November 2015 and June 2016 respectively. These figures clearly show the extent of the partial cliff collapse and the complete removal of vegetation at the base of the cliff. The Wyong Coastal Zone Management Plan (BMT WBM, 2015) identifies the cliff at Cabbage Tree Bay constituted by indurated sands (commonly known as coffee rock) that likely undermined during the June 2016 wave event due to direct wave attack and the loss of vegetation. A preliminary analysis of the UAV survey data estimates the total volume of material collapsed from the cliff is in excess of 90 $m^3$. Figure 4-8 shows the profile taken through the region of the cliff collapse. The cliff has significantly steepened, which may lead to further geotechnical instability.

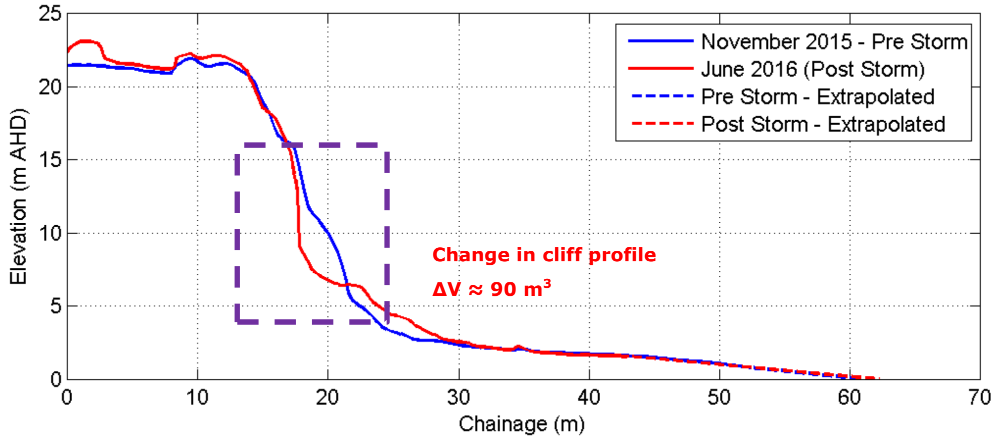



**Figure 4-8: Cabbage Tree Bay Profile 3 - cliff collapse**

**Figure 4-9: Photo of partial cliff collapse**

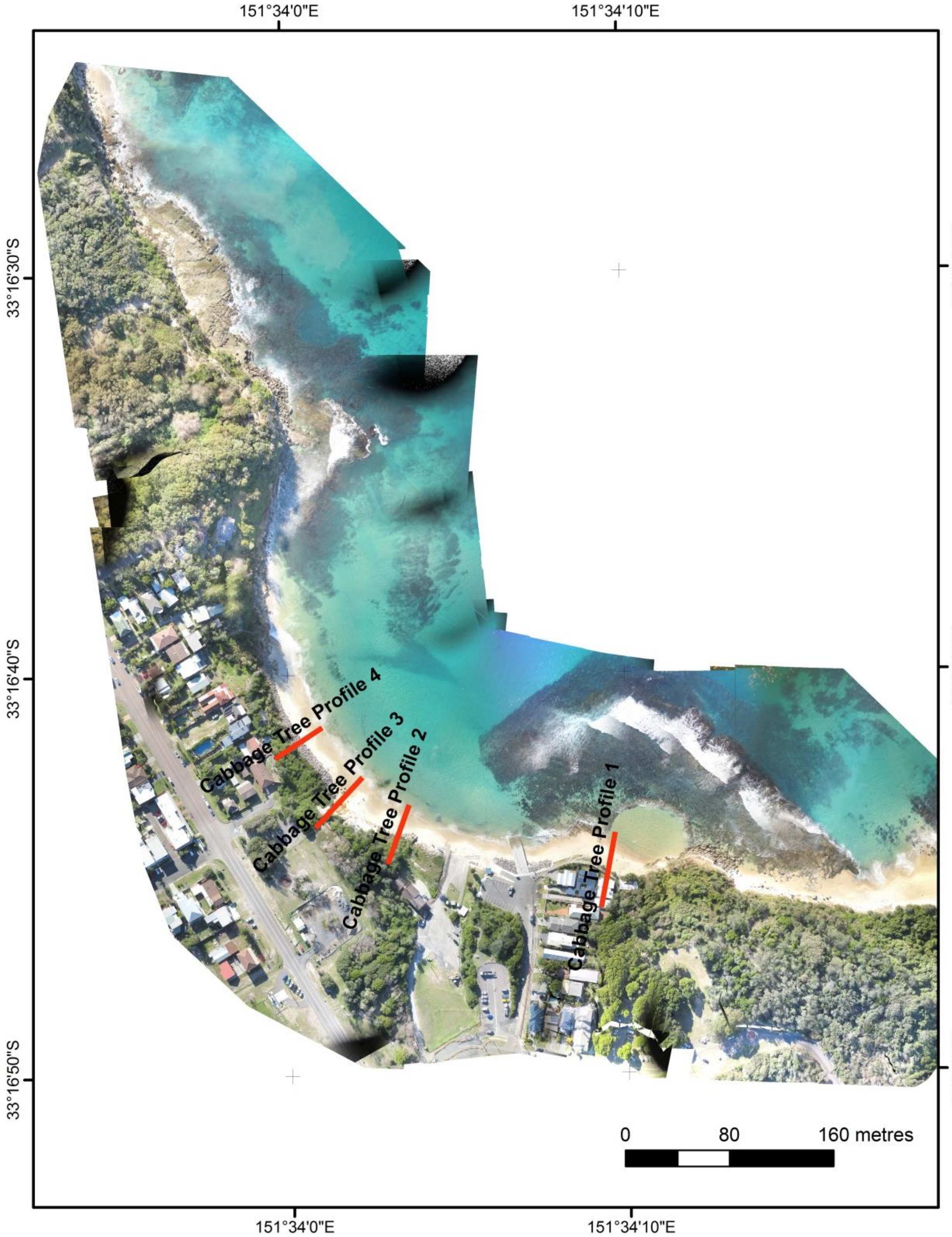



**Figure 4-10: Cabbage Tree Bay aerial image (30/06/2016)**

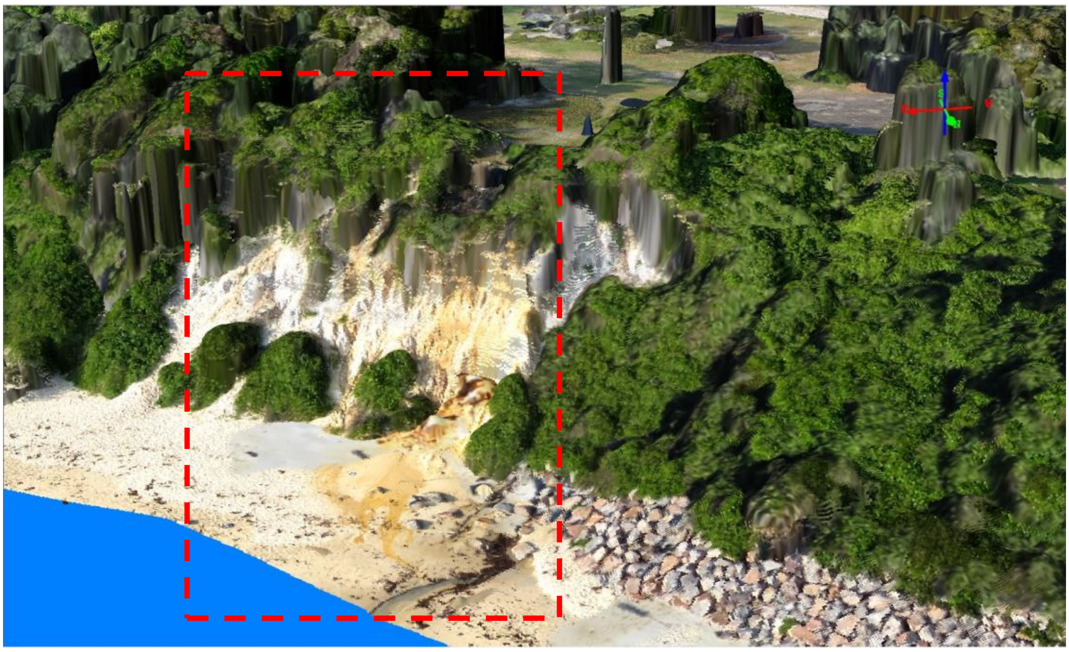


**Figure 4-11: 3D Imagery of cliff, November 2015**

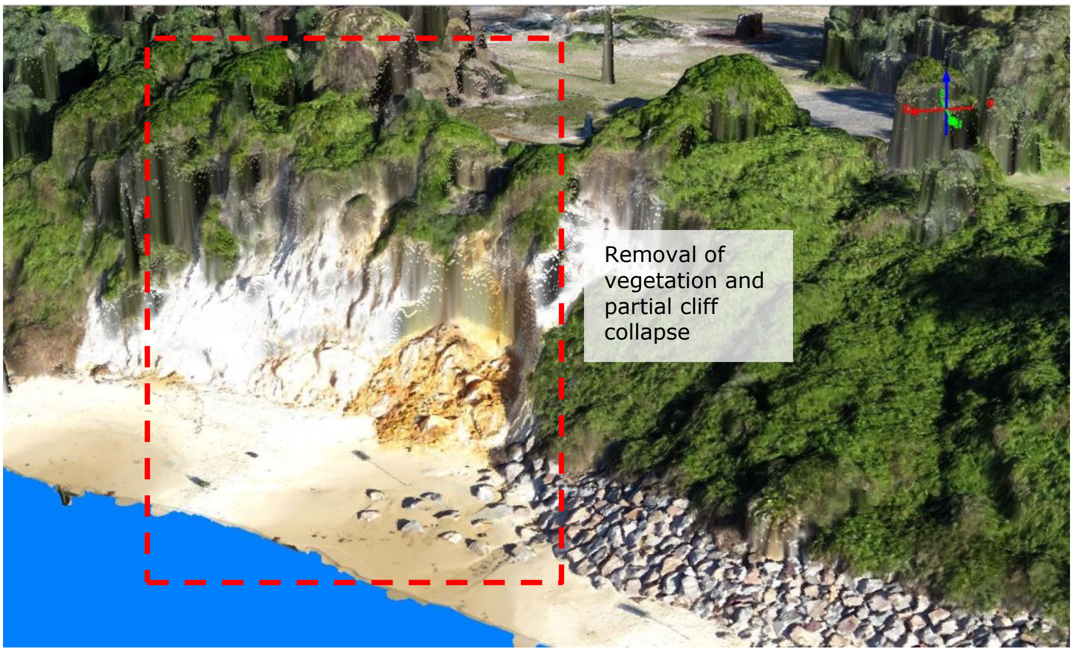



**Figure 4-12: 3D Imagery of cliff, June 2016**

## 4.5 The Entrance to The Entrance North

The Entrance and the Entrance North experienced significant changes in beach profile between November 2015 and June 2016. Similar to other beaches along the Wyong coastline, the southern end of this beach experienced moderate accretion (Figure 4-14), but north of the Tuggerah Lake entrance all the way north of Curtis Parade showed significant, relatively consistent erosion (shown in Figure 4-15). The entrance to the lake itself showed significant bathymetric changes, evident in aerial imagery (Figure 4-16), with the emergence of a second outlet channel forming on the beach.

The majority of The Entrance is highly developed close to the active beach. The erosion north of the Tuggerah Lake entrance was between 50 – 130 $m^3$/m at all the profiles considered (Figure 4-15). This is between 30 – 75 % of the stated design storm demand of 170 $m^3$/m (BMT WBM, 2015). Two of the profile locations have significant residential infrastructure located near the beach; Hutton Rd near Hargraves St (The Entrance Profile 1) and Curtis Pde (Entrance North Profile). As shown in the erosion intensity map (Figure 4-14) both of these locations have been substantially eroded between the two survey dates. At the two profiles, the 2 m AHD contour moved landward by approximately 15 m and at both locations erosion proceeded landward to the vegetated dunes. The erosion extent reached approximately 60 m landward of the 0 m AHD contour. The remaining sand buffer at The Entrance North Profile (near Curtis Pde) is approximately 70 $m^3$/m, significantly less than the design storm demand of 170 $m^3$/m (BMT WBM, 2015). If a storm of a similar intensity and wave direction of the June ECL occurs before the beach has time to recover, then there is significant potential for increased risk to residential infrastructure.

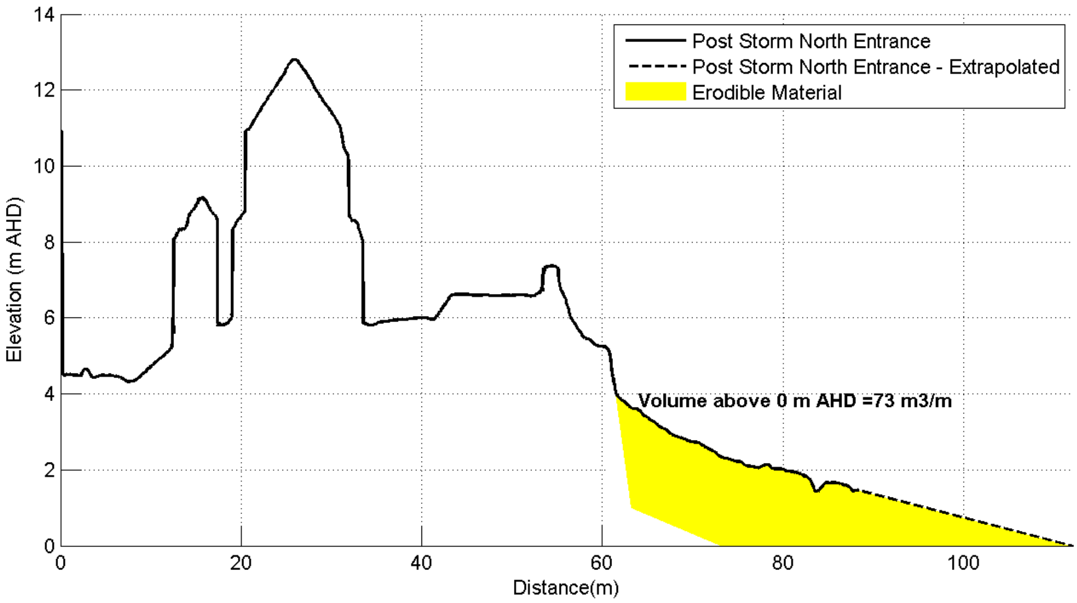



**Figure 4-13: The Entrance North Profile (near Curtis Pde), Post Storm**

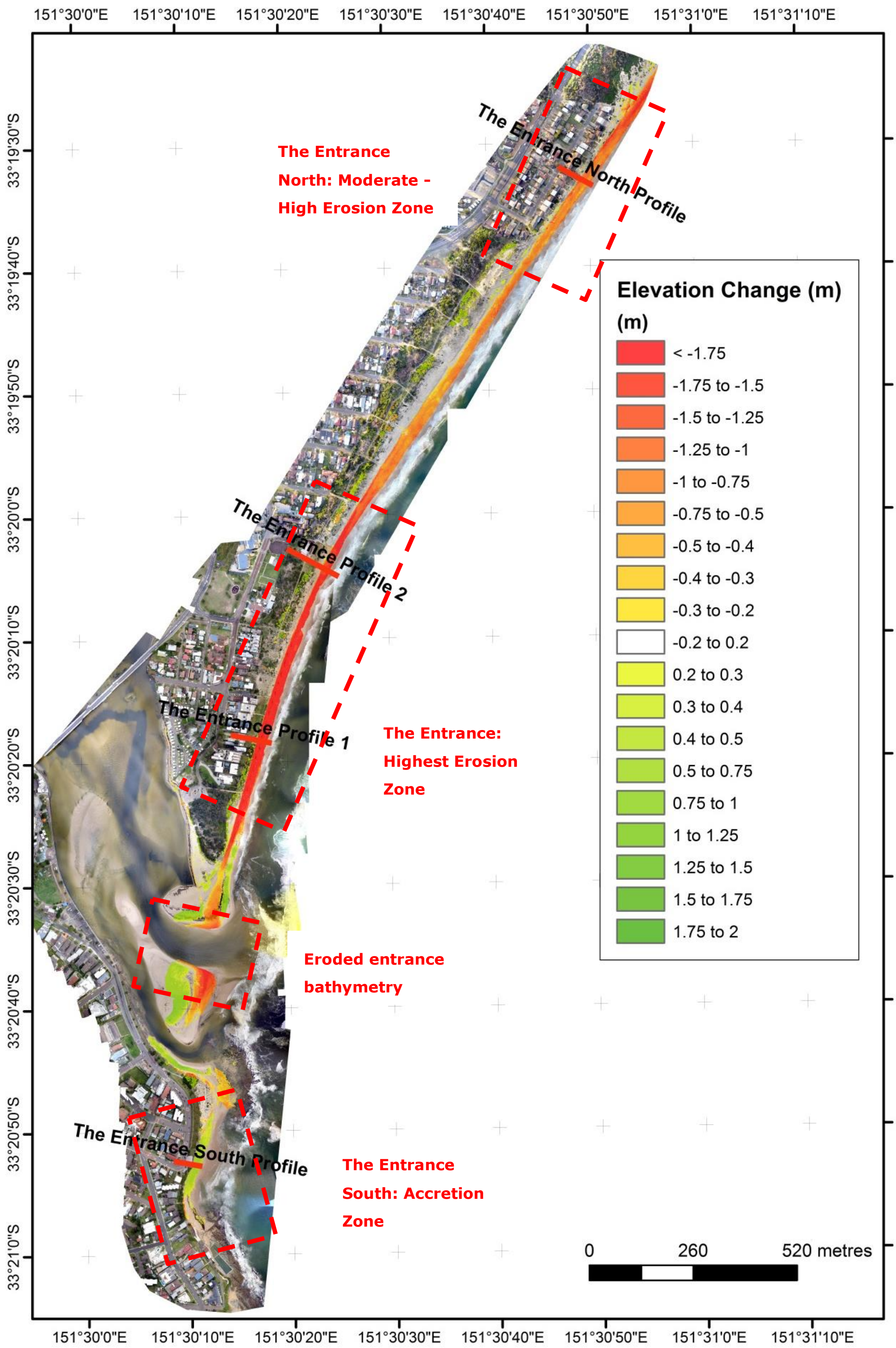
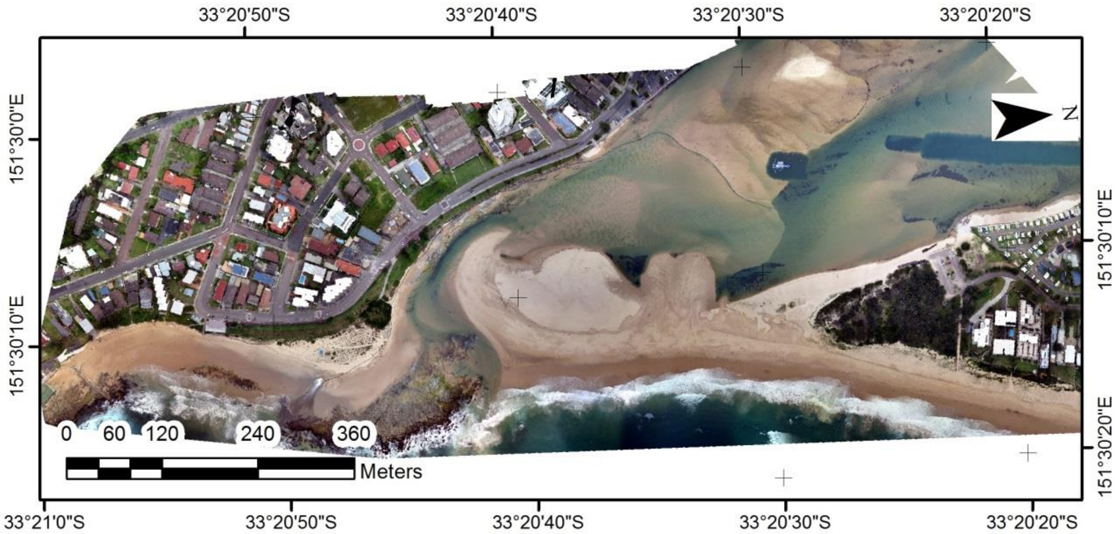



**Figure 4-14: The Entrance erosion intensity map**


**Figure 4-15: The Entrance volume change at profiles along the beach**



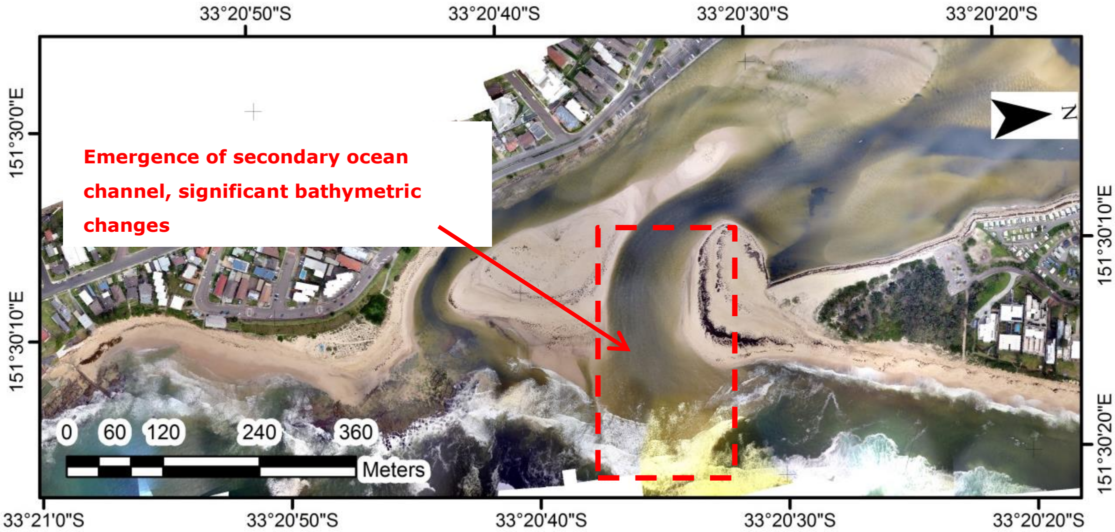




**Figure 4-16: Bathymetric changes at The Entrance**
**Top: Pre-storm 28/10/2015, Bottom: Post-storm 13/06/2016**

## 4.6 Blue Bay – Toowoon Bay

Blue Bay and Toowoon Bay are protected by rock platforms and offshore reefs from the north and south which dissipate wave energy. As a result, the volumetric and beach profile changes were much less significant at these beaches than most other analysed locations. While erosion did occur along the beach (shown in the erosion intensity map in Figure 4-18 and the volumetric change map in Figure 4-19), the erosion is unlikely to have caused any significant concern to the residential buildings along the beach. A maximum volume loss of approximately 30 $m^3$/m was observed. The accretion and erosion were not uniform along the beach, as shown in Figure 4-19. It is unclear whether the inconsistency in beach change was a result of the beaches' response to the June 2016 storm, or as a result of long term changes occurring between November 2015 and June 2016.

The only major erosion zone identified by the erosion intensity map occurred at the salient that separates Blue Bay and Toowoon Bay (Figure 4-17), which showed elevation changes of up to -1.5 m. It is unclear whether this is erosion caused by the June 2016 storm or long term temporal changes in the salient profile that occurred over the 7 months between the surveys. It is possible, however, that the long wave period, large waves heights and north-easterly direction associated with the June 2016 ECL event allowed waves to refract and propagate into the usually low wave energy zone around the salient. The erosion occurred at least 30 m seaward of any infrastructure. In comparison, the salient on the southern end of Toowoon Bay accreted between November 2015 and June 2016.

A number of narrow accretion zones were identified along the beach. Through examination of the aerial imagery, WRL concluded that these areas represent the infilling of a number of storm water outlet channels that are located along the beach. These are marked in Figure 4-18.

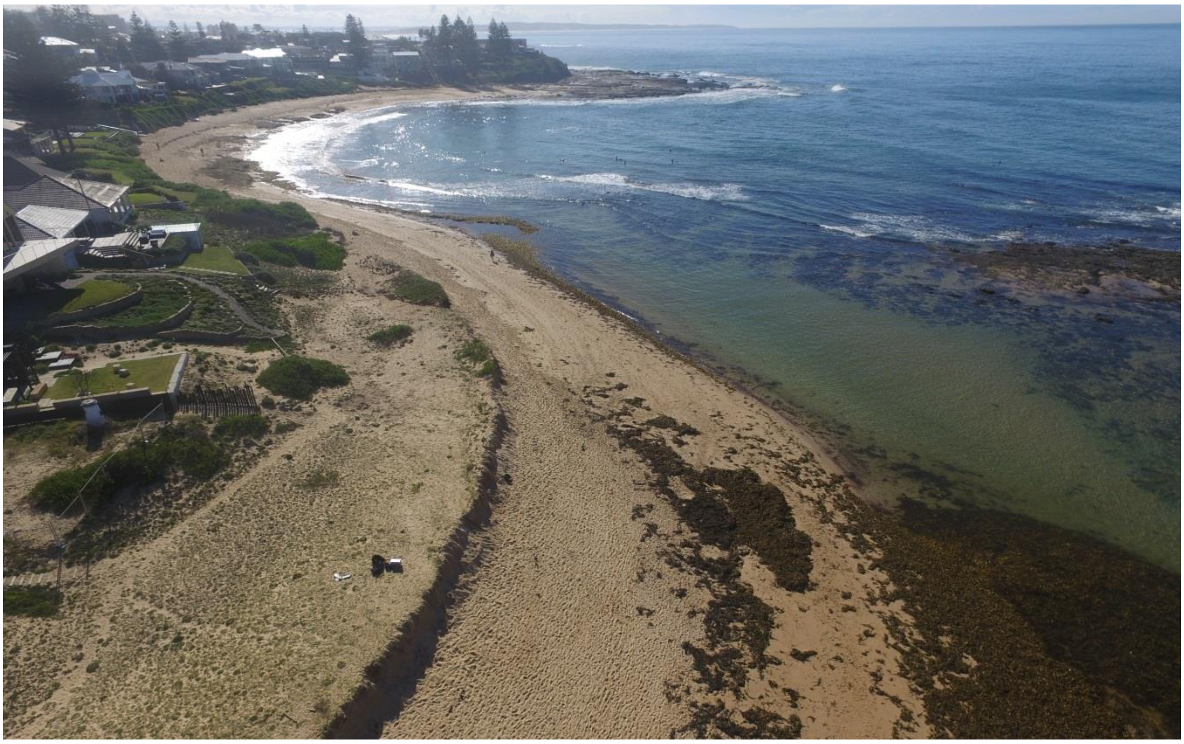


**Figure 4-17: Blue Bay salient looking north. Note the significant weed build-up and dune scarp**

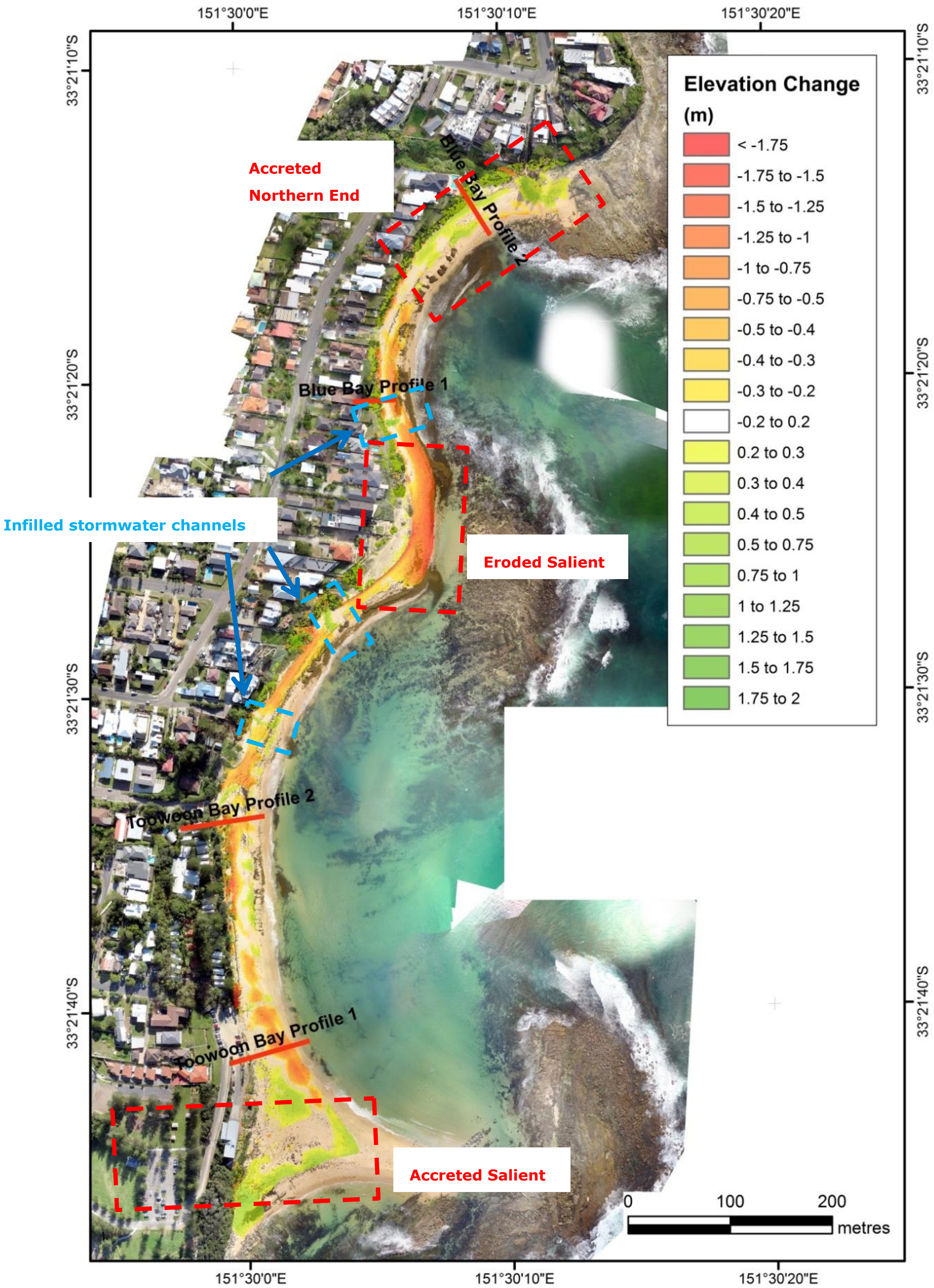



**Figure 4-18: Blue Bay and Toowoon Bay erosion intensity map**


**Figure 4-19: Blue Bay and Toowoon Bay volume change along the beach**

## 4.7 Shelly Beach

Shelly Beach erosion intensity map (Figure 4-21) and the volume change along the beach (Figure 4-22) show two very distinct changes along the beach. The southern end accreted significantly, while the northern end experienced considerable erosion. The area in front of the SLSC (Shelly Beach Profile 2) and caravan park (Shelly Beach Profile 1) accreted over the time period under investigation. While the impact of the storm cannot be separated from long term accretion and erosion trends, it is unlikely the June 2016 storm caused significant erosion at the southern end of beach. Even with the accretion between the two survey dates, the sand buffer in front of Shelly SLSC is approximately 240 $m^3$/m, less than the design storm demand of 290 $m^3$/m.

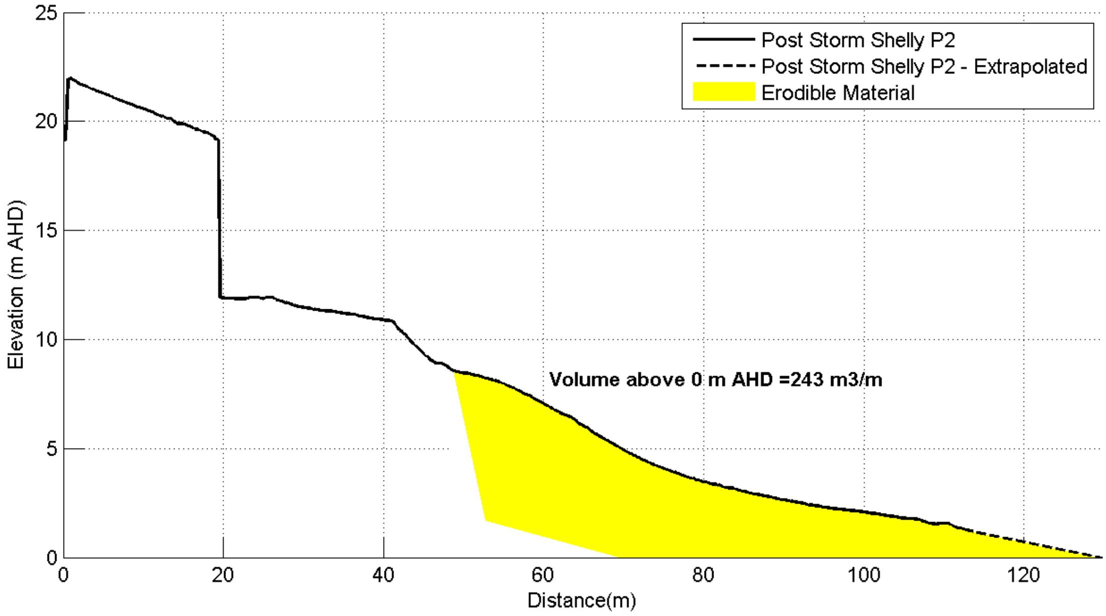



**Figure 4-20: Shelly Beach Profile 2 (SLSC), Post Storm**

Conversely, the northern end of the beach exhibited substantial erosion between November 2015 and June 2016. However, as there is no significant infrastructure near the eroded beach, the erosion is unlikely to have caused significant concern. Erosion mainly occurred near the beach scarp seaward of the vegetation line, within approximately 50 m of the wave run-up zone during average wave conditions. Profile 4 showed approximately 12 m of landward movement of the 2 m AHD contour.

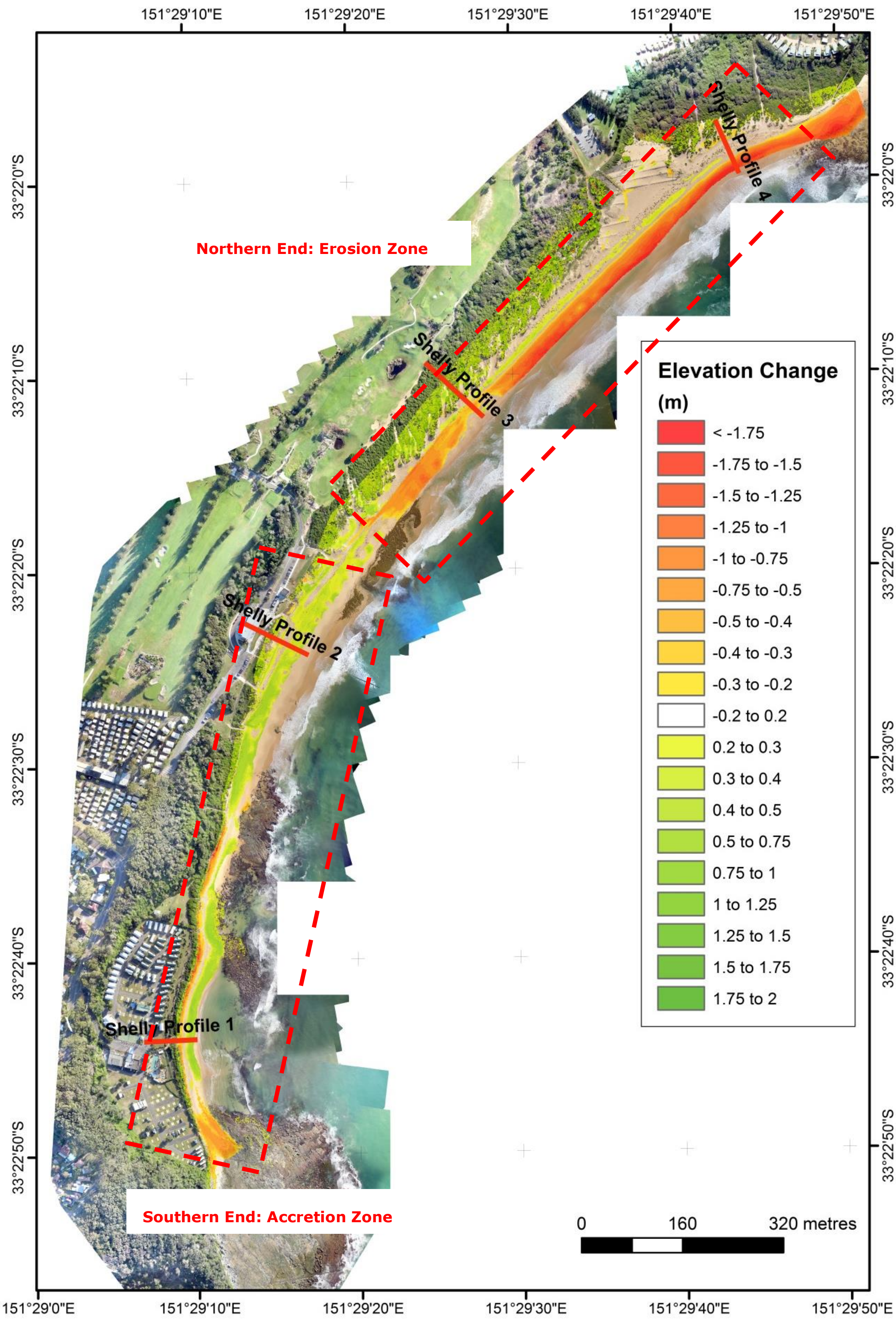



**Figure 4-21: Shelly Beach erosion intensity map**


**Figure 4-22: Volume change at Shelly Beach along several beach profiles**

# 5. Summary

This report summarises the differences observed in UAV survey data collected in November 2015 and June 2016 at six (6) beaches along the Wyong coastline. The intervening time period between surveys included the June 2016 storm. Sydney Offshore Wave Buoy data indicated that significant wave heights during the June 2016 storm were up to 7 m. Furthermore, the easterly wave direction of this event and spring high tide water levels allowed large waves to propagate into usually sheltered areas of the coastline. As the 'pre-storm' survey occurred approximately seven (7) months prior to the storm, it is not possible to completely attribute beach changes to the June 2016 storm, versus response to longer term processes.

Lakes Beach showed relatively uniform erosion along the whole longshore section of beach surveyed. Typical changes in sand volume along the beach were approximately -30 $m^3$/m. There is little development along Lakes Beach, apart from the SLSC, which did not experience sufficient sand erosion to significantly threaten the infrastructure.

Hargraves Beach exhibited large spatial variation in profile changes along the beach. The southern end of the beach showed moderate accretion, the centre experienced moderate erosion and the northern section showed more significant erosion. However, the northern section of Hargraves Beach is undeveloped close to the active beach zone, so the threat to infrastructure as a result of erosion during the June 2016 ECL is considered minimal.

The most significant change observed at Cabbage Tree Bay was the partial cliff collapse at the centre of the cliff region, with substantial vegetation removed from the foot of the cliff. It is understood that this cliff collapse occurred as a direct result of the June 2016 storm.

The Entrance and the Entrance North showed some of the most extreme changes in beach profiles observed at the Wyong beaches. The Entrance South accreted moderately, but the dune north of the Tuggerah Lakes entrance experienced volume losses of 50 to 130 $m^3$/m between November 2015 and June 2016. Significant residential infrastructure on Hutton Rd and Curtis Pde maintained adequate dune buffers to prevent infrastructure damage during the storm. The remaining sand buffer at Curtis Pde is approximately 70 $m^3$/m, which is significantly less than the design storm demand of 170 $m^3$/m (BMT WBM, 2015).

Blue Bay and Toowoon Bay are relatively well protected by rock platforms and offshore reefs from the north and south. Beach profile changes along the beach were highly variable, but generally consisted of minimal volume movement compared to observations at The Entrance or Hargraves Beach.

Shelly Beach showed two (2) very distinct zones of beach change between the two (2) surveys. The southern end of the beach accreted, where the SLSC and caravan park is located, while the largely undeveloped northern end showed substantial erosion.

# 6. References


BMT WBM (2015), "Wyong Coastal Zone Management Plan draft report", pp 5, 16, 17, extract received via email from Wyong Council on 17/02/2016.

Drummond, C. D. and Cullen, J. G. (2016) "UAV Surveying of Wyong Coastline – November 2015" WRL Technical Report, WRL, Sydney.

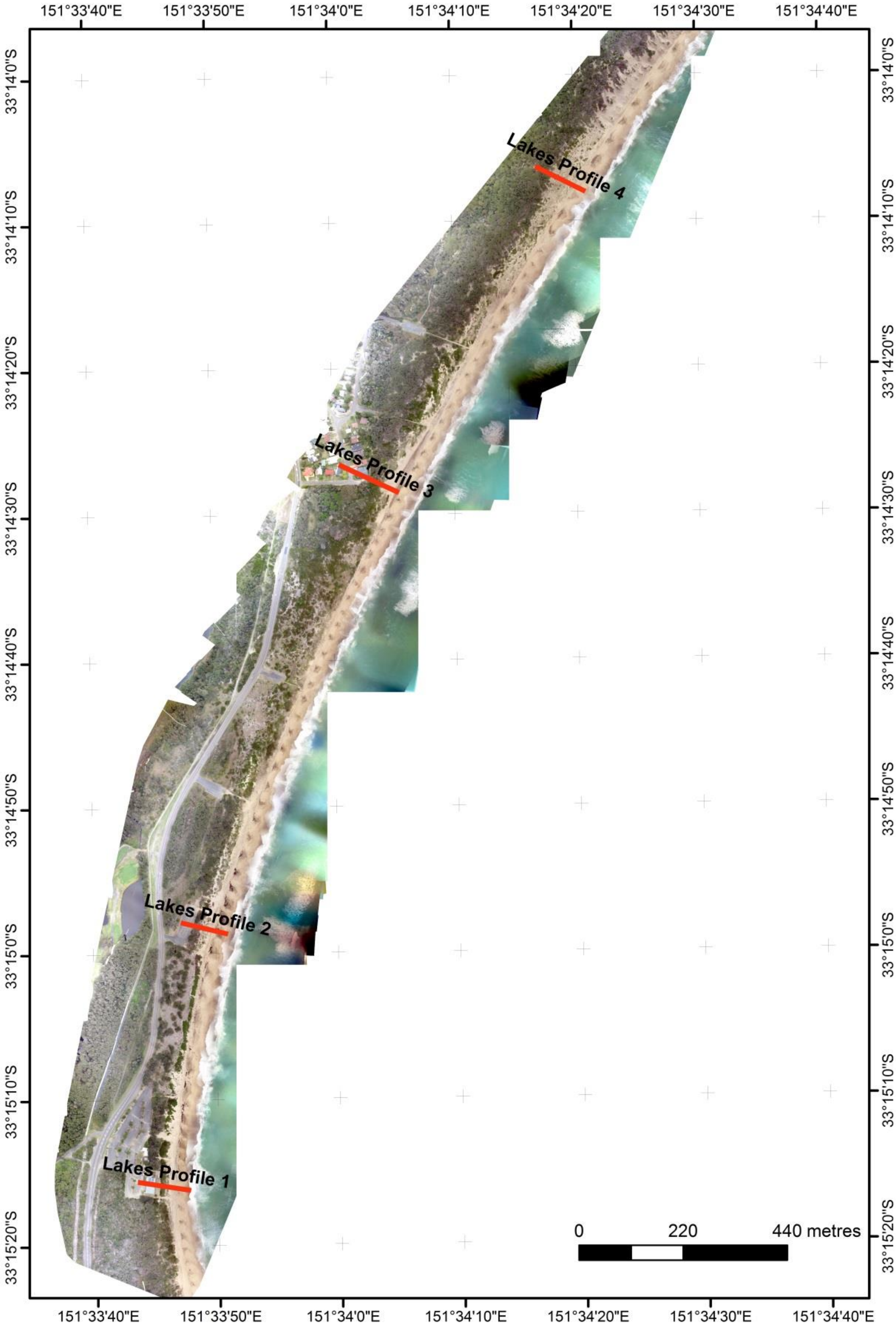
Shand, T. D., Goodwin, I. D., Mole, M. A., Carley, J. T., Browning, S., Coghlan, I. R., Harley, M. D., and Peirson, W. L. (2010), "NSW Coastal Storms and Extreme Waves", The 19th Coastal Conference, Batemans Bay, NSW, Australia.

Turner, I. L., Harley, M. D. and Drummond, C. D. (2016) "UAVs for coastal surveying" *Coastal Engineering*, *114*, pp.19-24.

# 1. Appendix A – Beach Profiles

Appendix A presents each of the profiles extracted at the six (6) survey locations. Profiles were typically taken to show the infrastructure behind the beach (where infrastructure existed). The change in volume of sand however was only calculated using the active beach zone. Changes in vegetation height, or small changes in the exact location of vertical walls (which the UAV typically does not capture as accurately from the aerial perspective) between the surveys are therefore not included in the volume change estimates.

**Lakes Beach**


151°33'40"E
151°33'50"E
151°34'0"E
151°34'10"E
151°34'20"E
151°34'30"E
151°34'40"E
33°14'0"S
33°14'10"S
33°14'20"S
33°14'30"S
33°14'40"S
33°14'50"S
33°15'0"S
33°15'10"S
33°15'20"S
Lakes Profile 4
Lakes Profile 3
Lakes Profile 2
Lakes Profile 1
0
220
440 metres

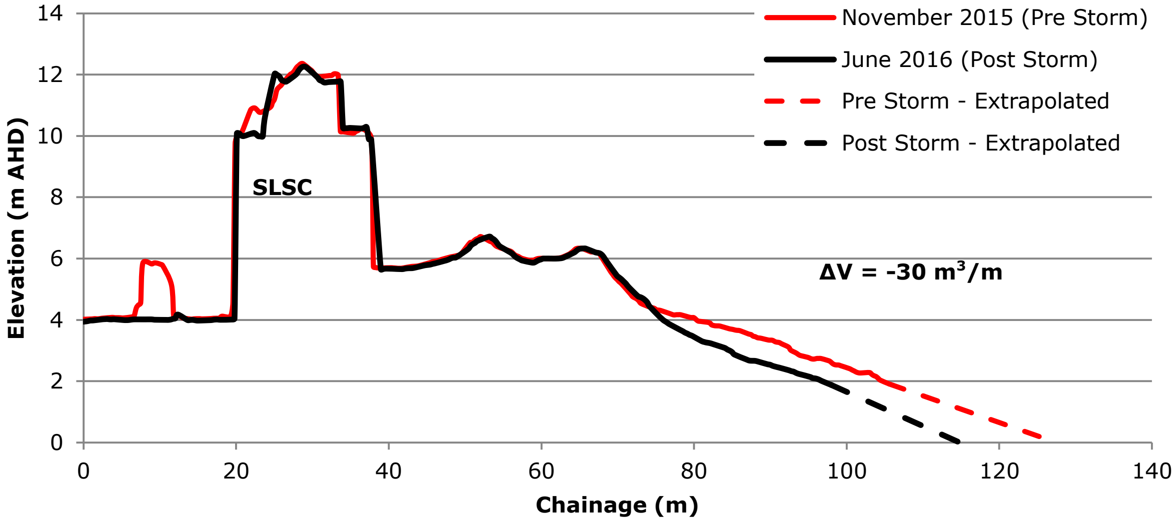



**Figure A 1: Lakes Beach Profile 1**

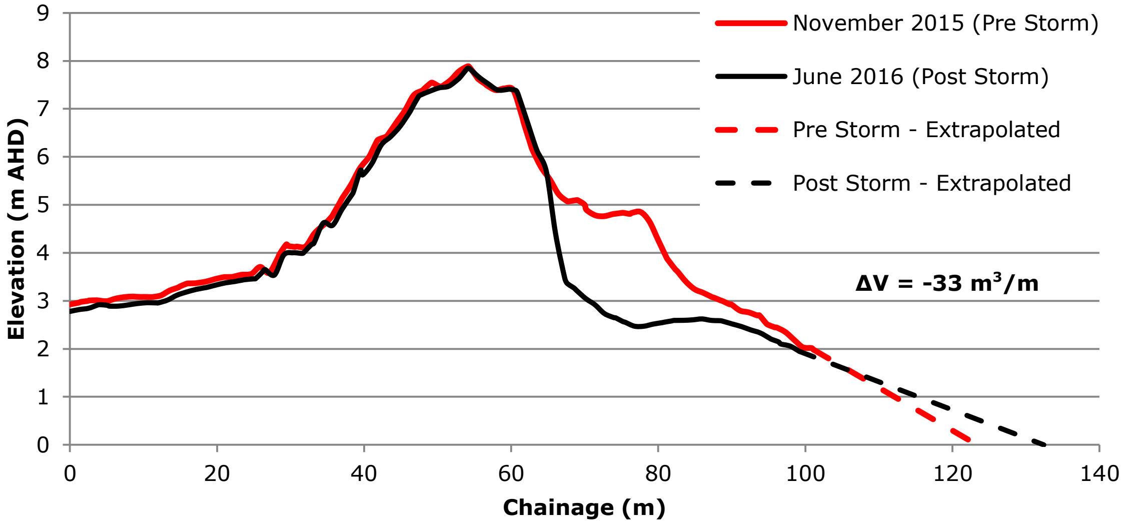



**Figure A 2: Lakes Beach Profile 2**

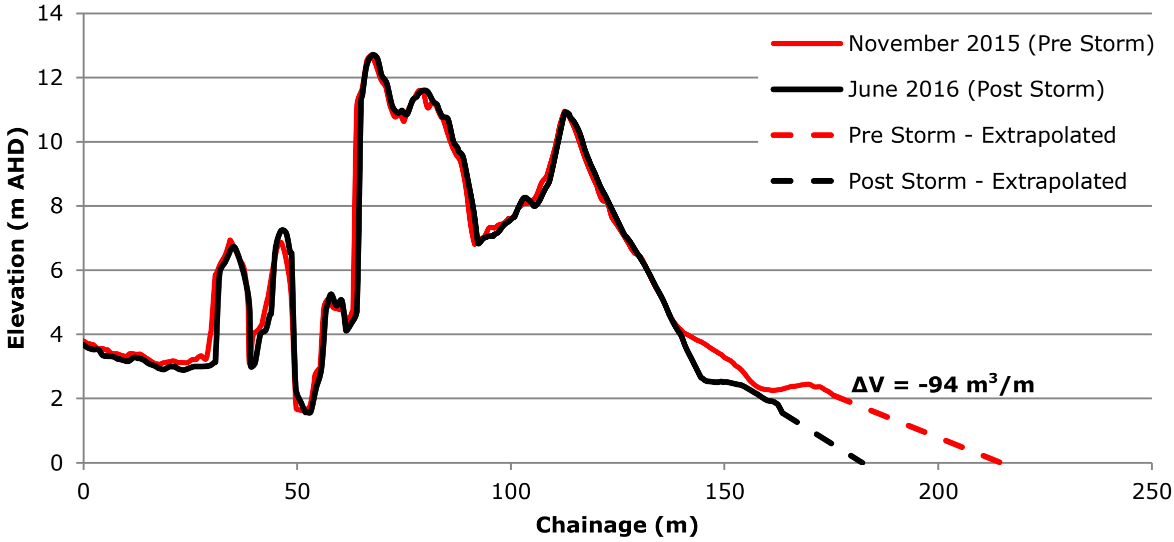



**Figure A 3: Lakes Beach Profile 3**

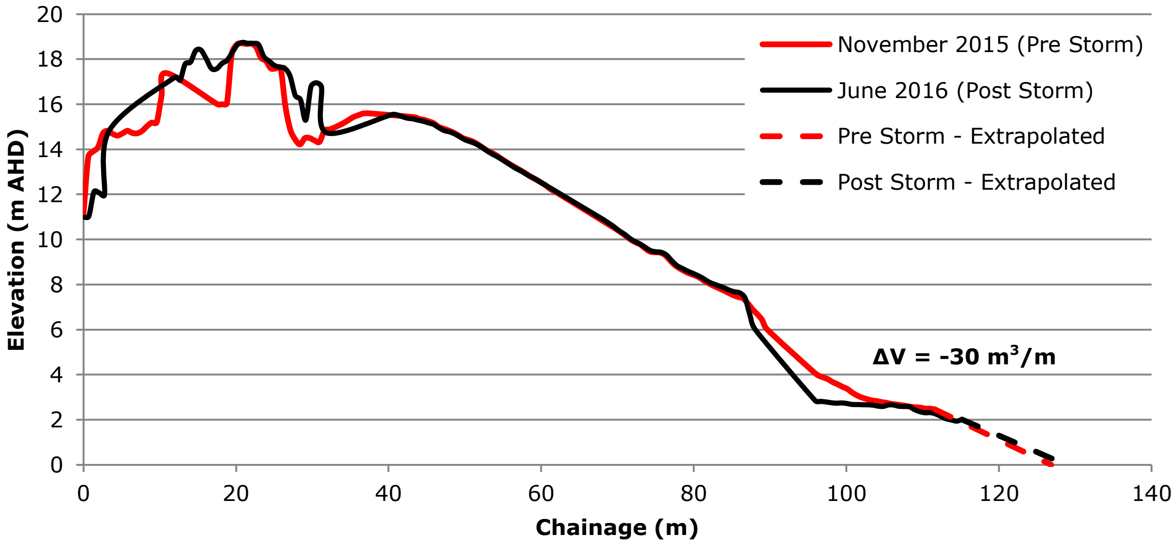
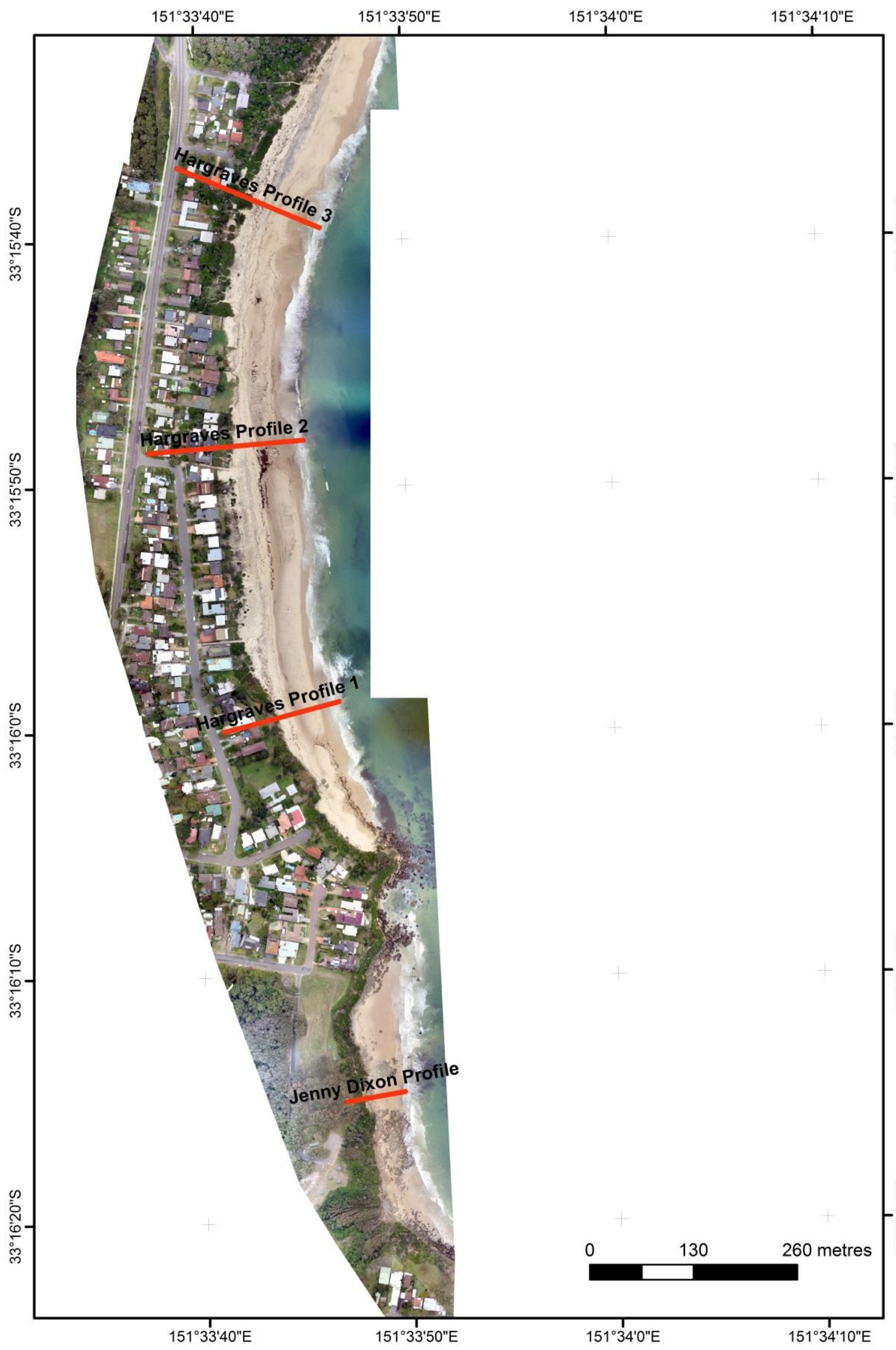



**Figure A 4: Lakes Beach Profile 4**

**Hargraves and Jenny Dixon**



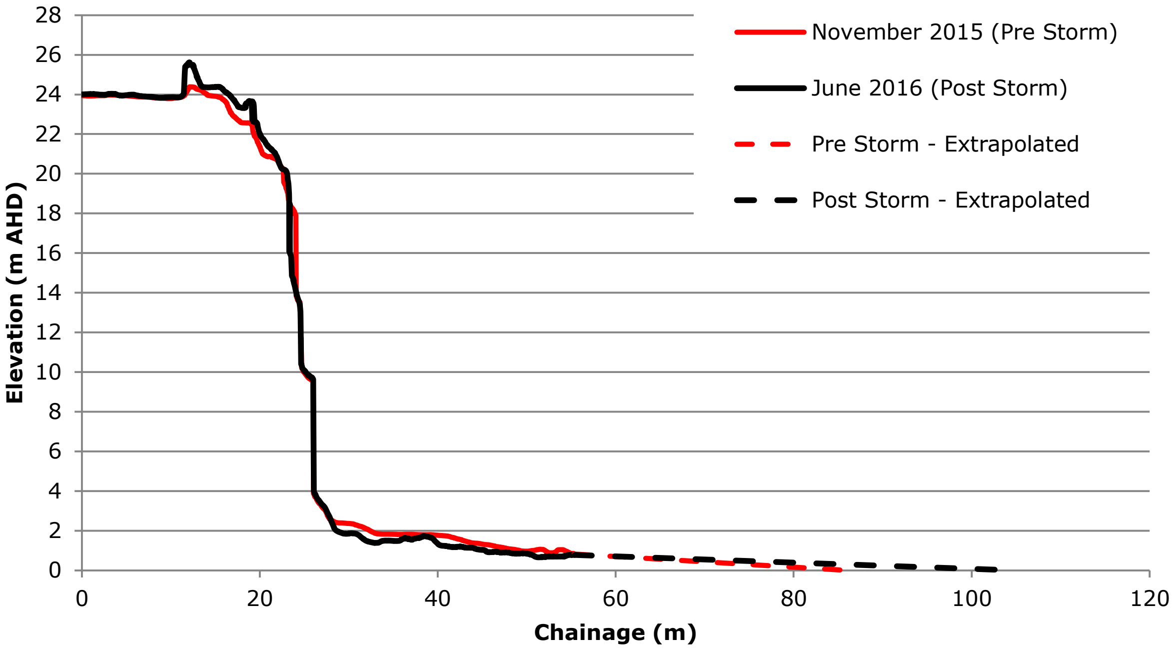



**Figure A 5: Jenny Dixon Profile**

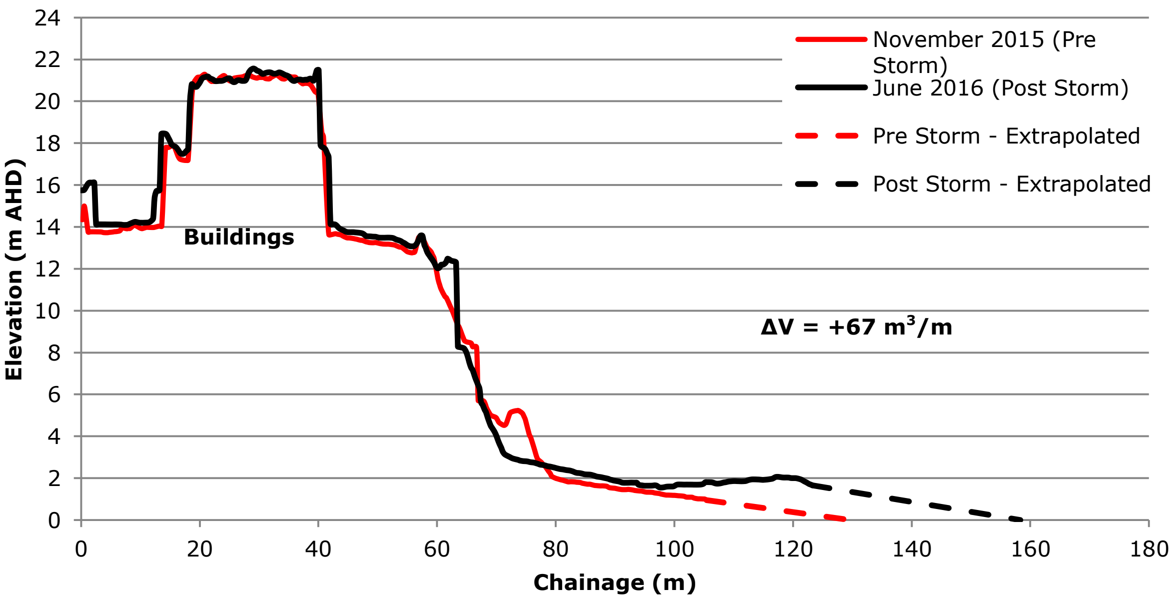



**Figure A 6: Hargraves Beach Profile 1**

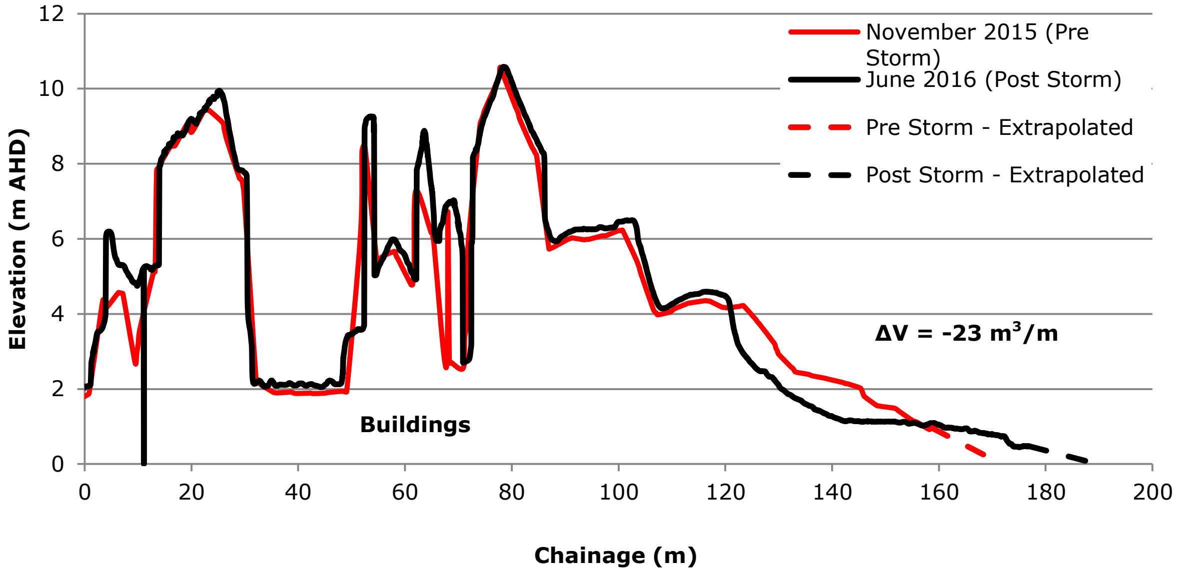



**Figure A 7: Hargraves Beach Profile 2**

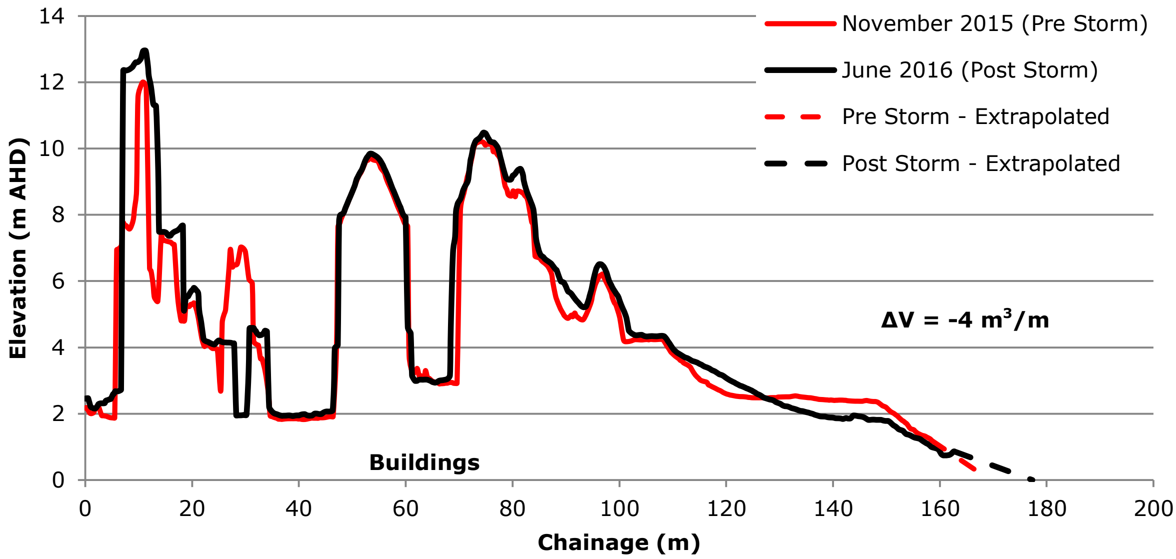
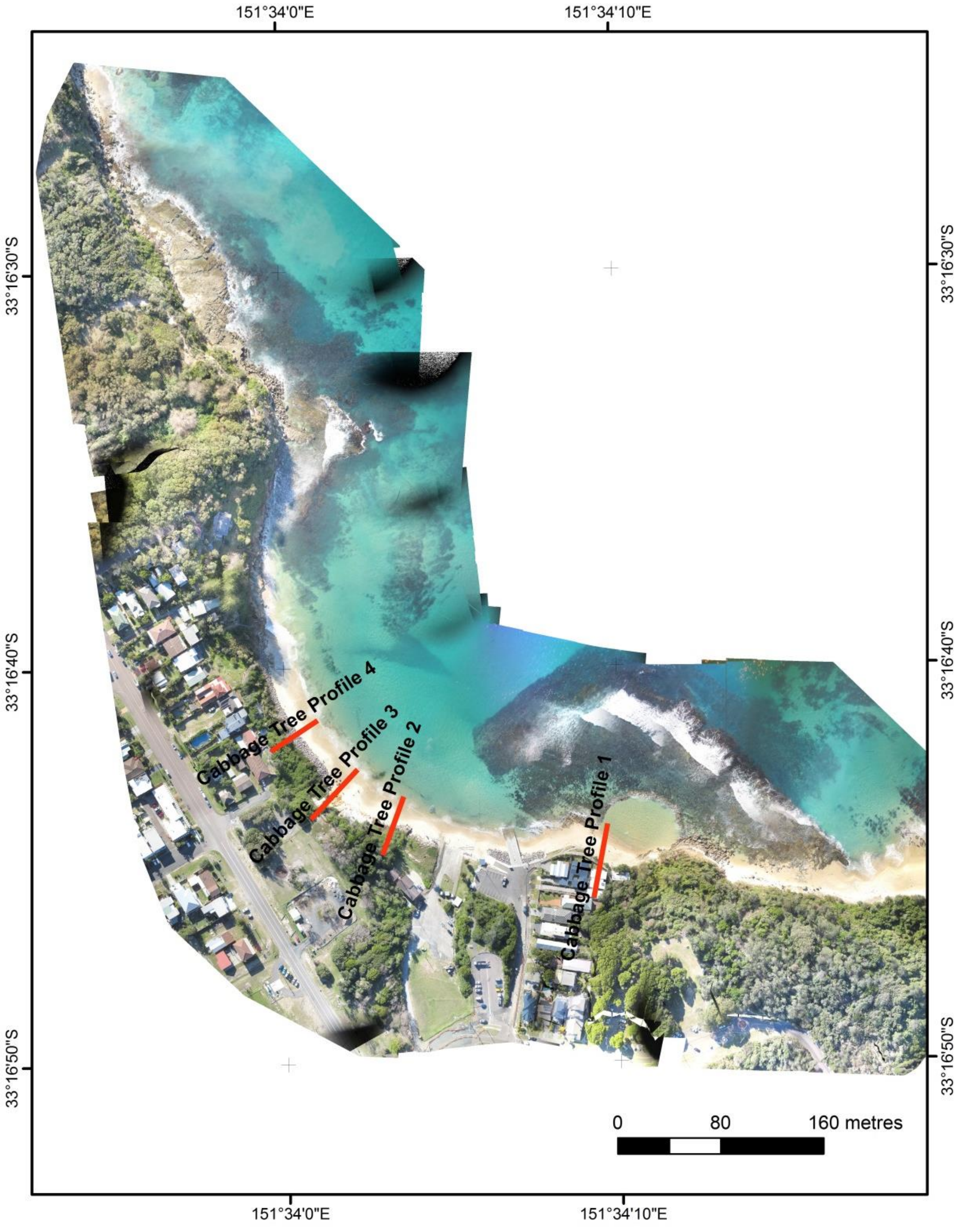



**Figure A 8: Hargraves Beach Profile 3**

**Cabbage Tree Bay**



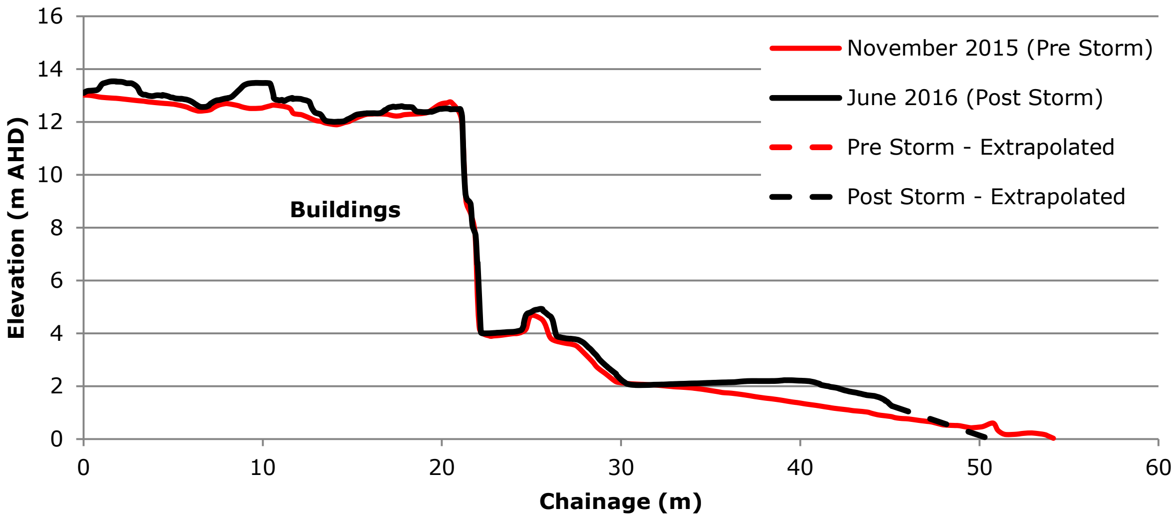



**Figure A 9: Cabbage Tree Bay Profile 1**

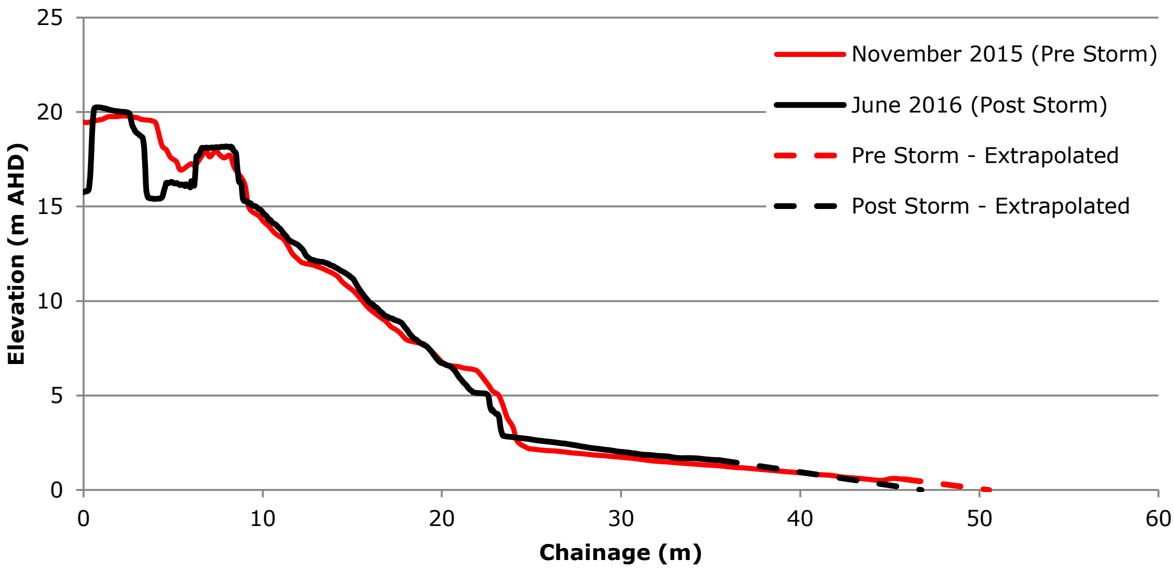



**Figure A 10: Cabbage Tree Bay Profile 2**

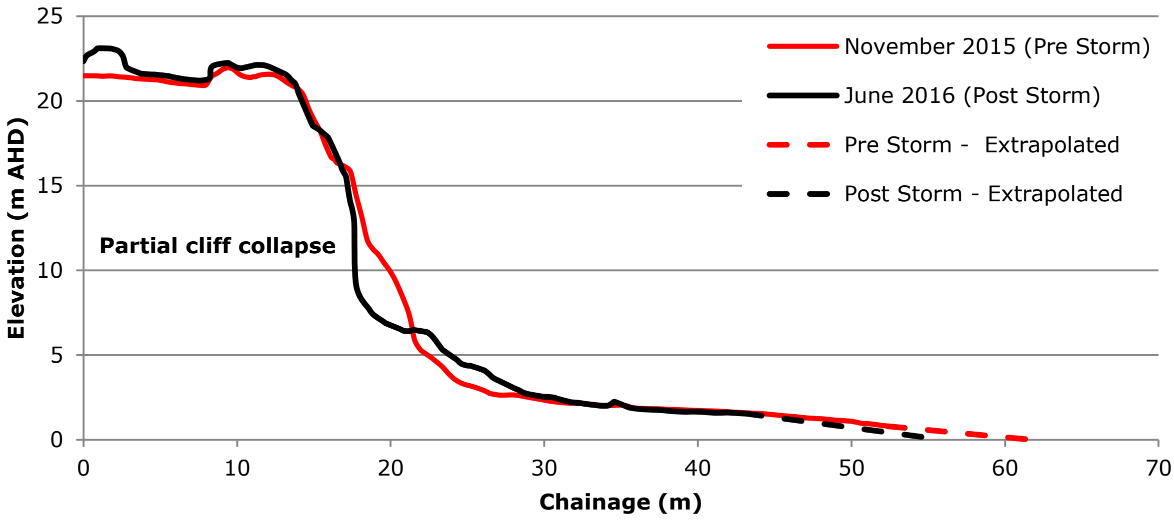



**Figure A 11: Cabbage Tree Bay Profile 3 (landslide)**

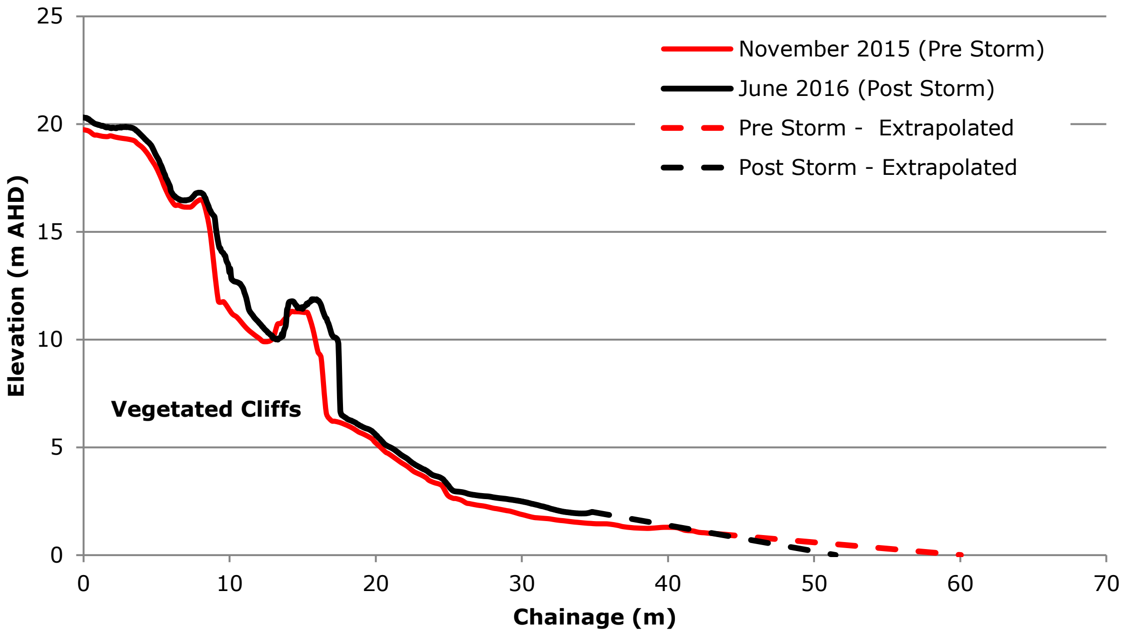
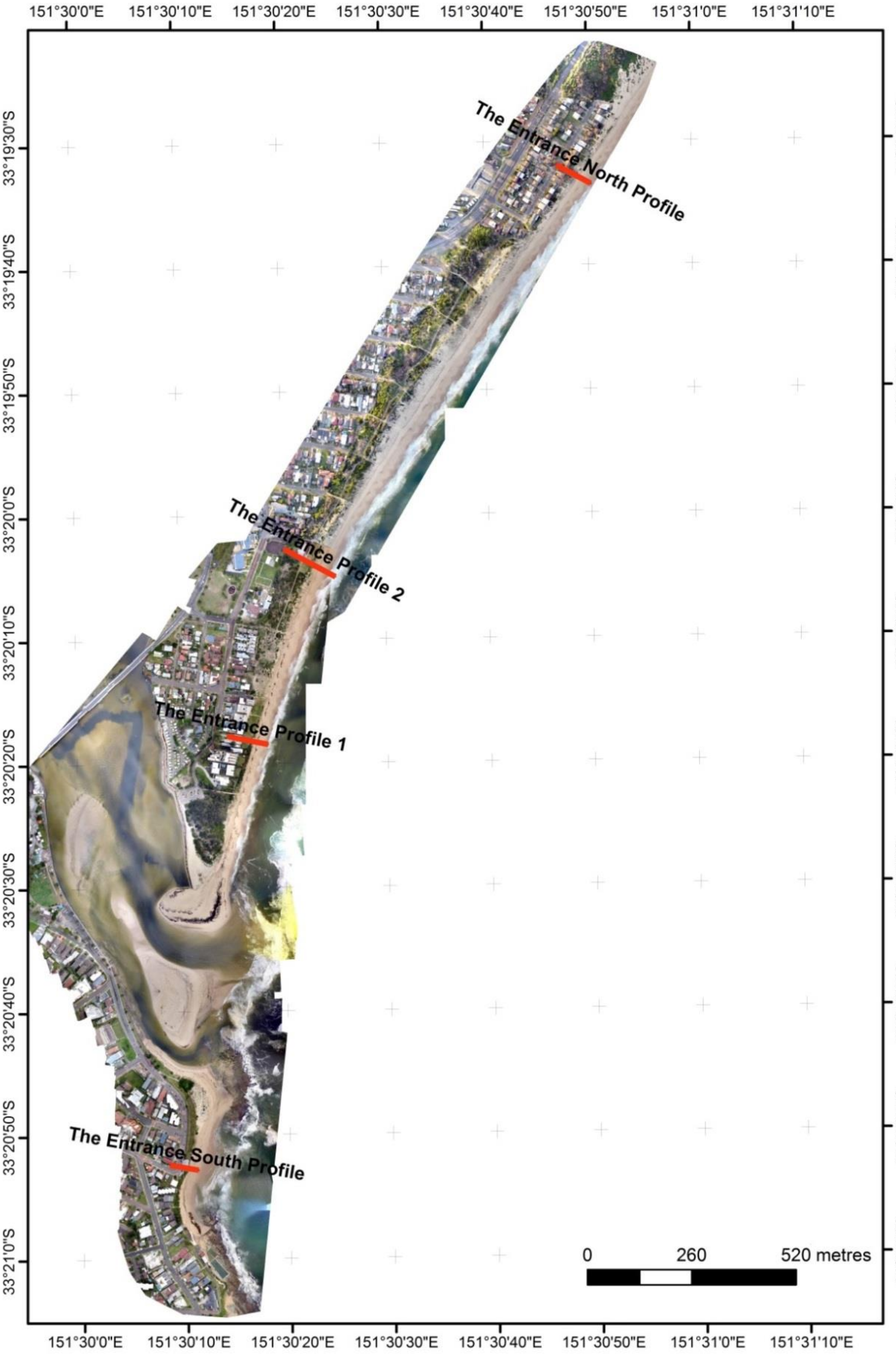



**Figure A 12: Cabbage Tree Bay Profile 4**

**The Entrance**



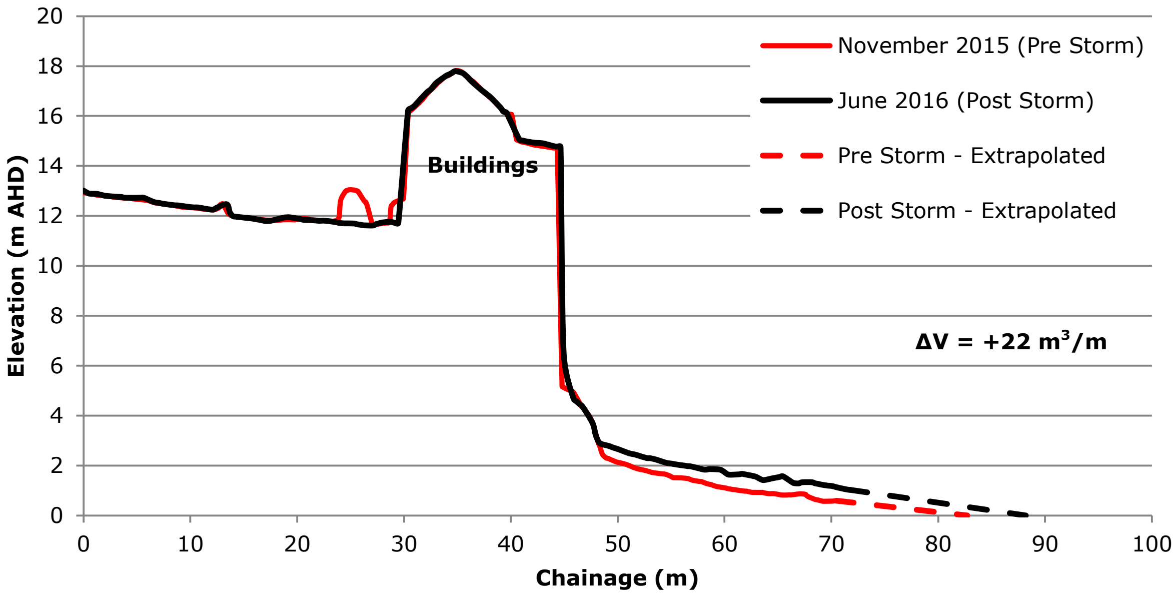



**Figure A 13: The Entrance South Profile**

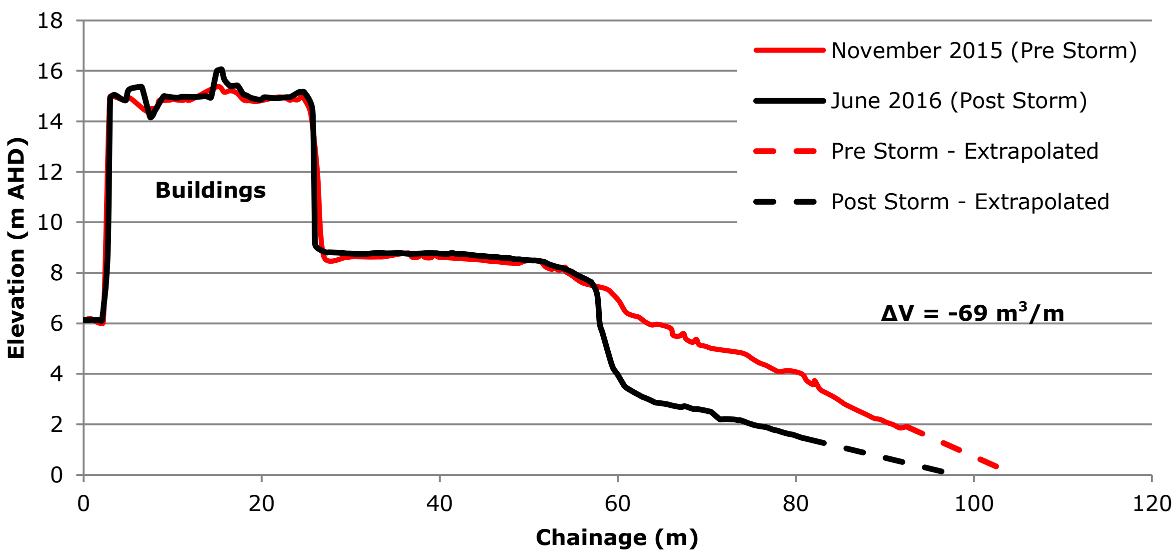



**Figure A 14: The Entrance Profile 1**

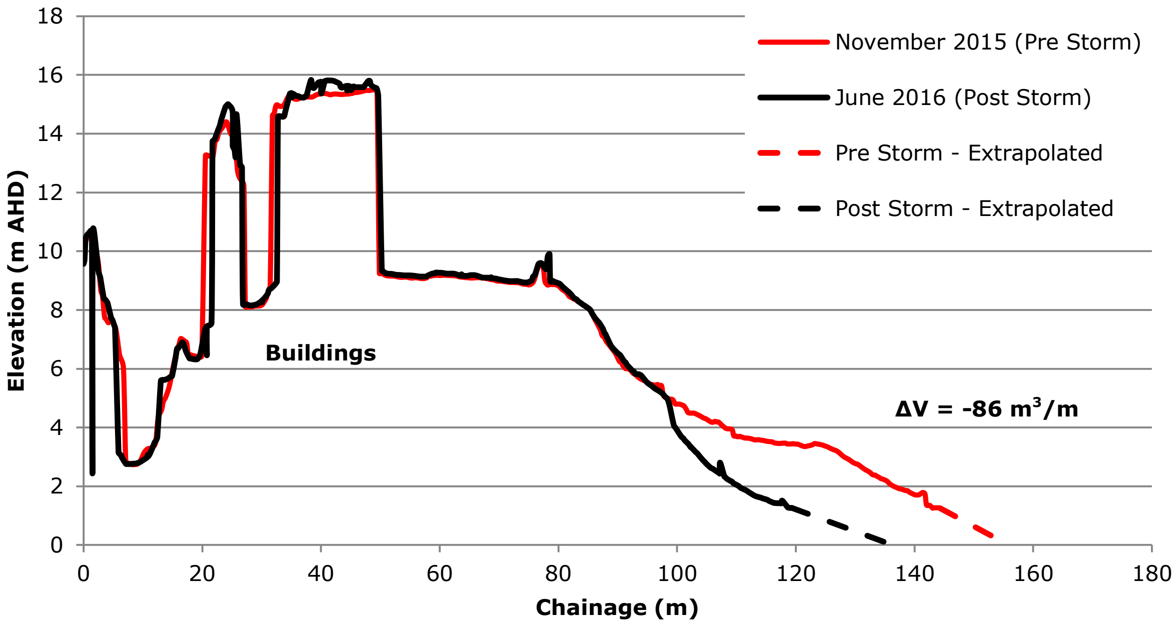



**Figure A 15: The Entrance Profile 2**

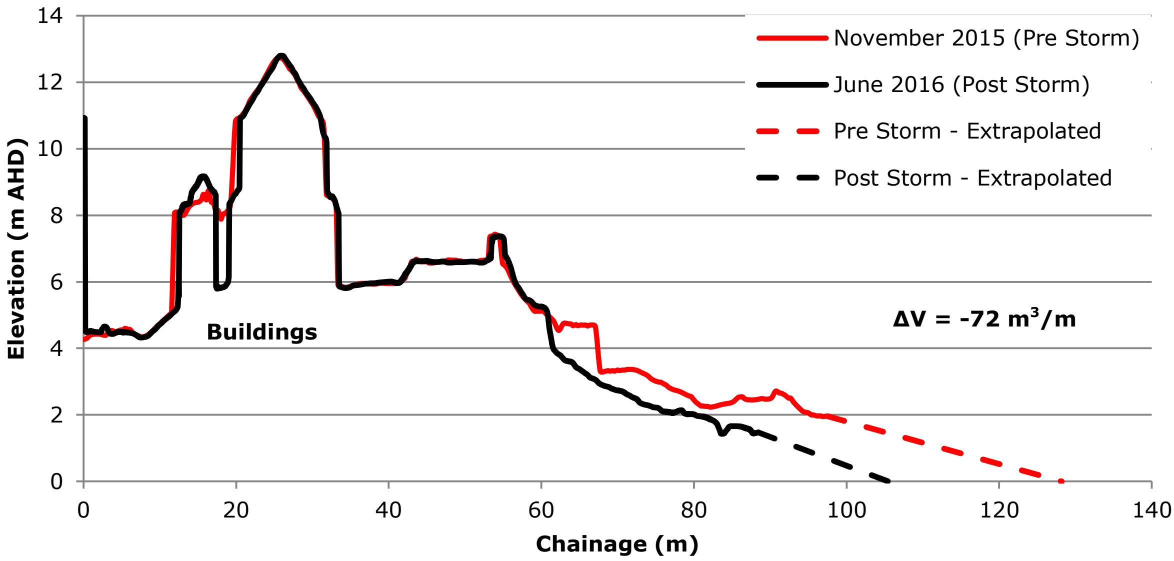
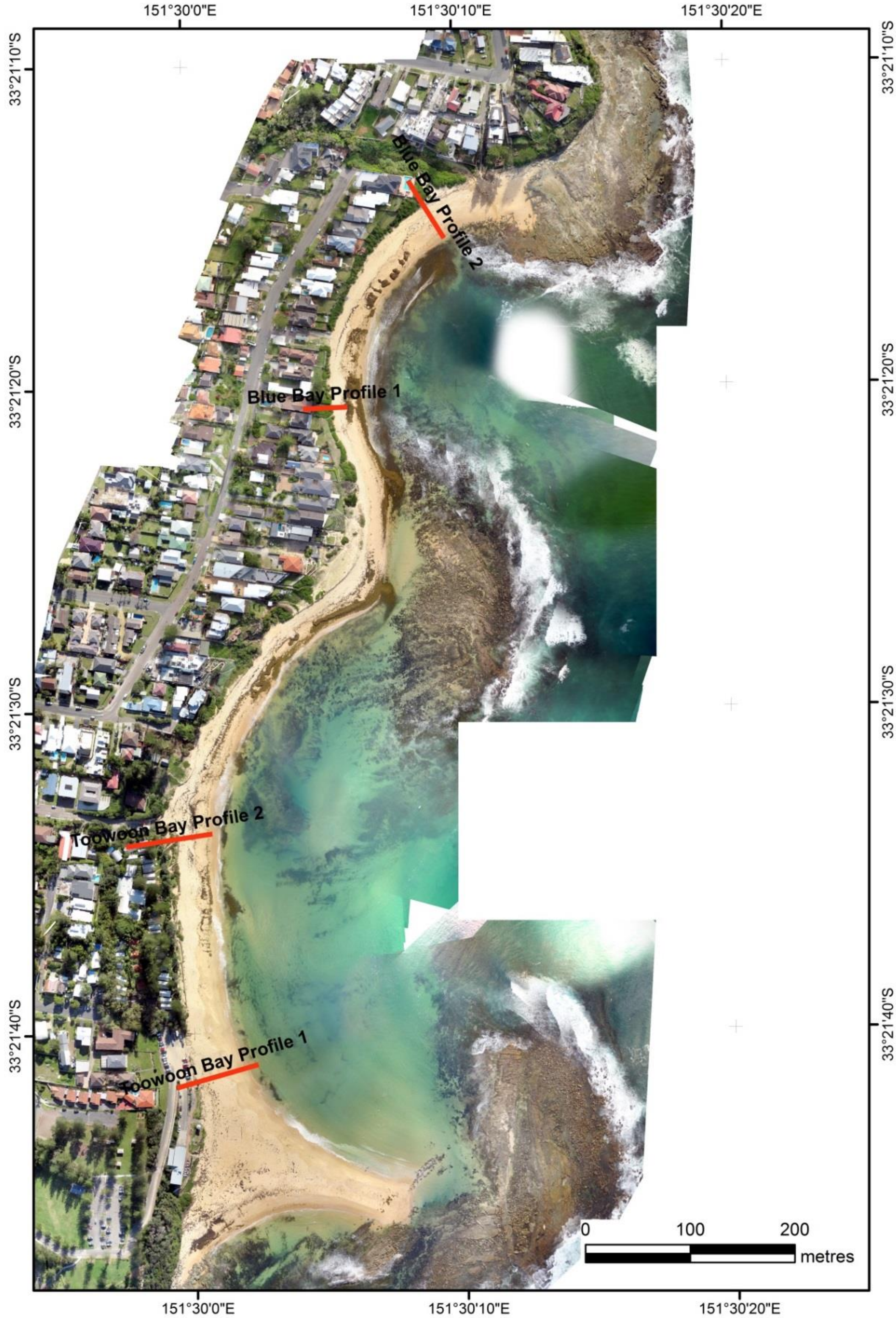



**Figure A 16: The Entrance North Profile**

**Blue Bay – Toowoon Bay**



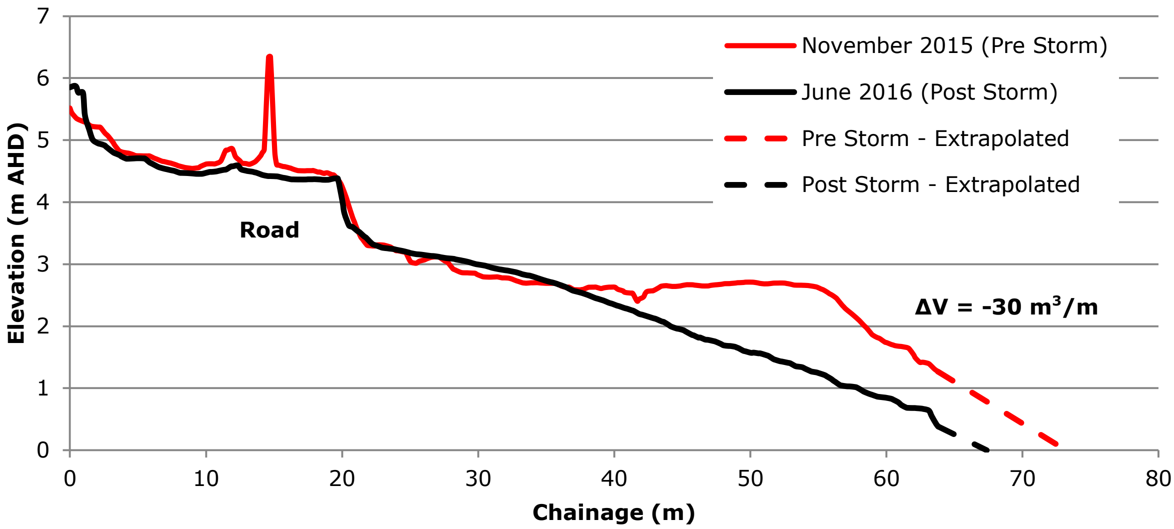



**Figure A 17: Toowoon Bay Profile 1**

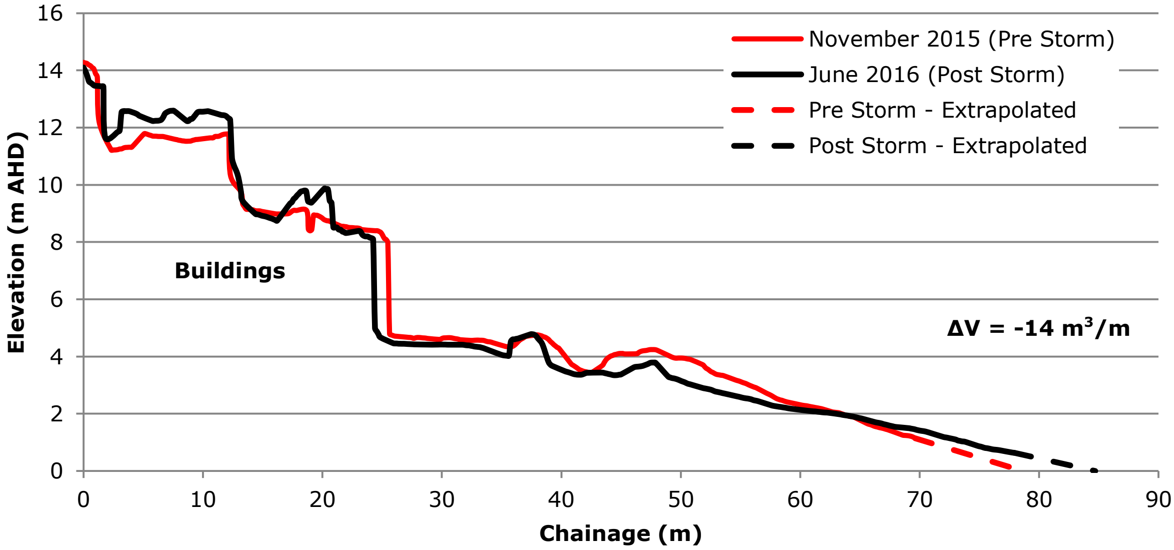



**Figure A 18: Toowoon Bay Profile 2**

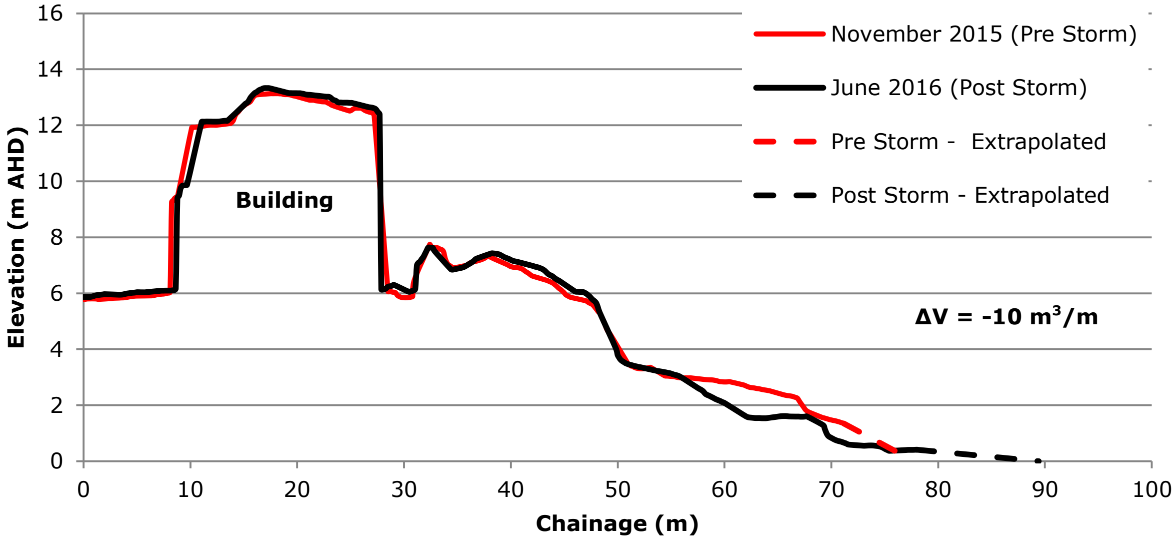



**Figure A 19: Blue Bay Profile 1**

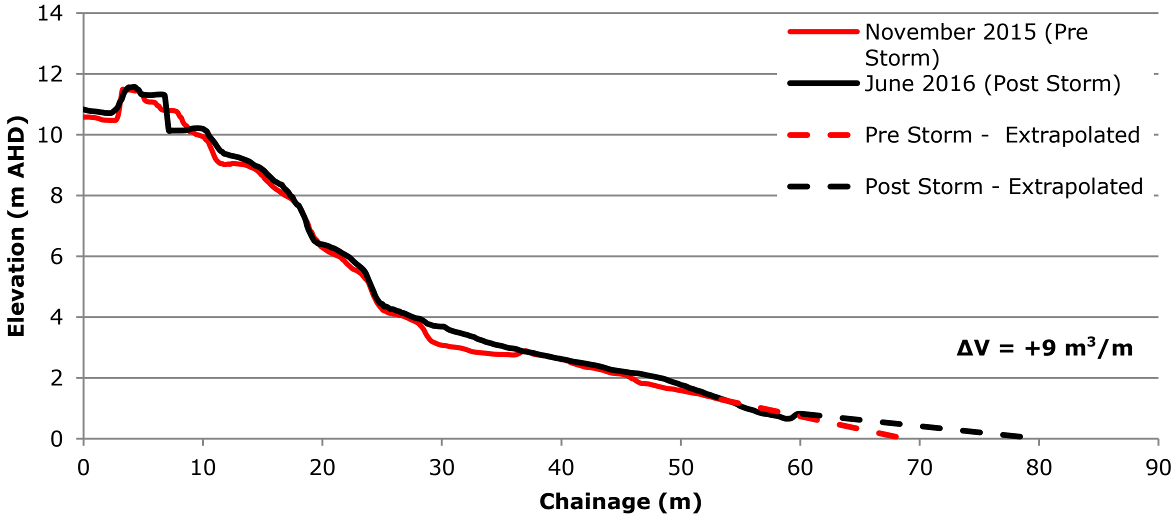



**Figure A 20: Blue Bay Profile 2**

**Shelly Beach**

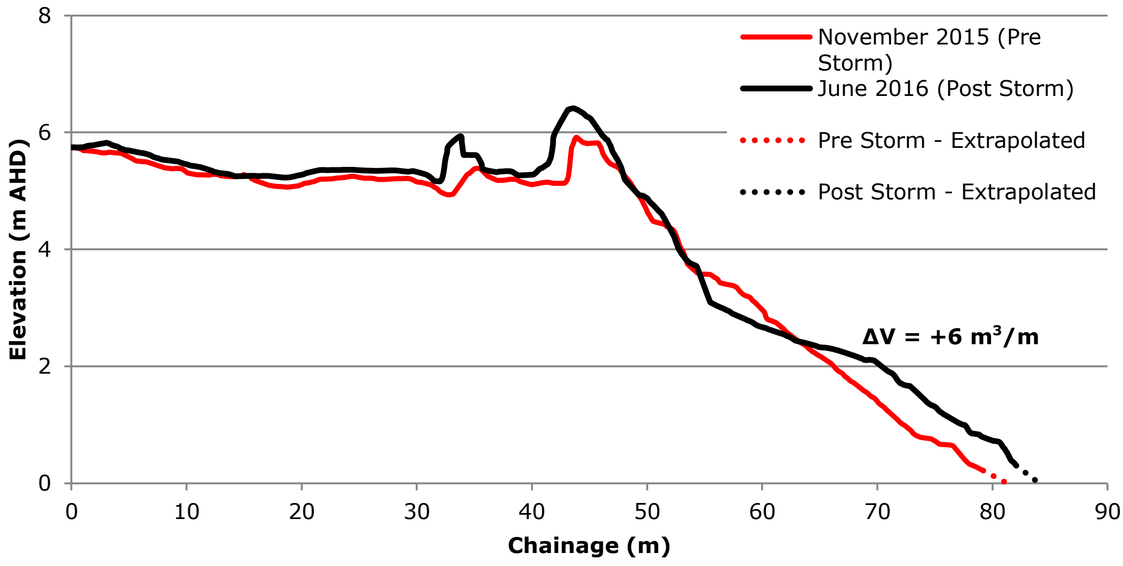



**Figure A 21: Shelly Beach Profile 1**

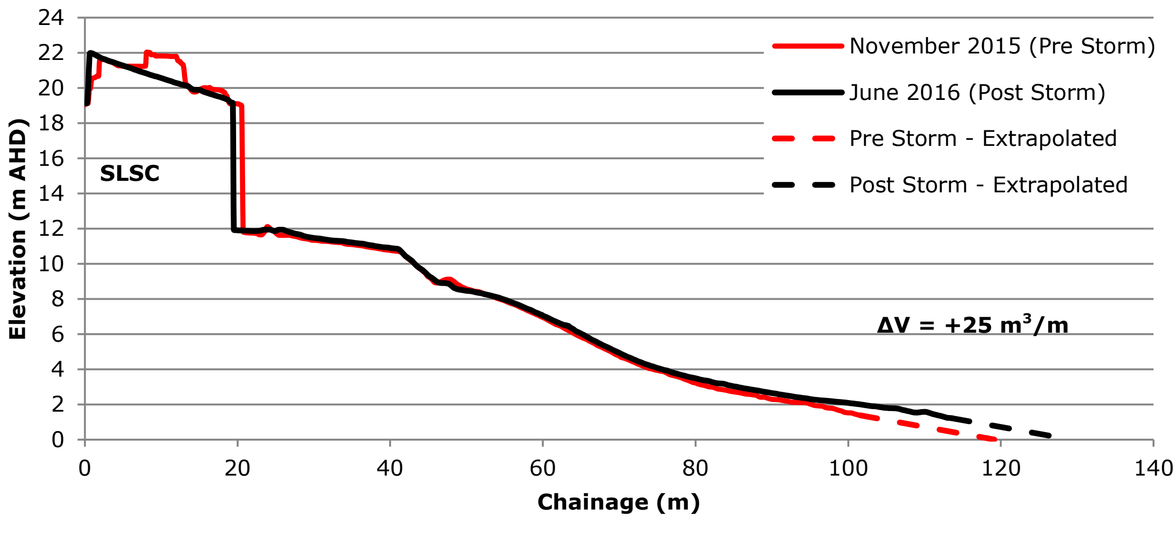



**Figure A 22: Shelly Beach Profile 2**

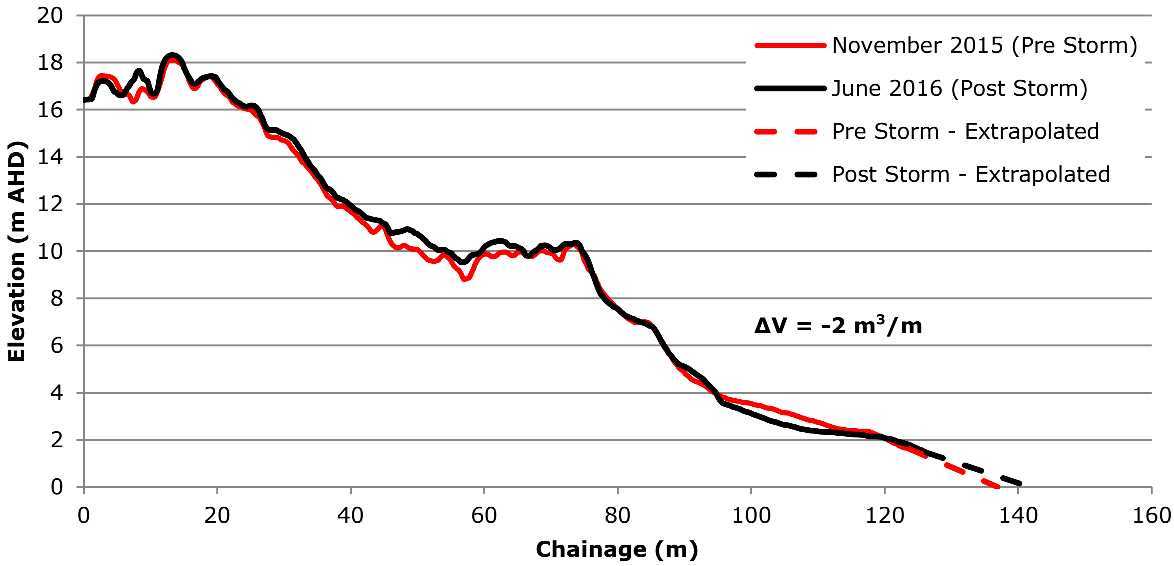



**Figure A 23: Shelly Beach Profile 3**

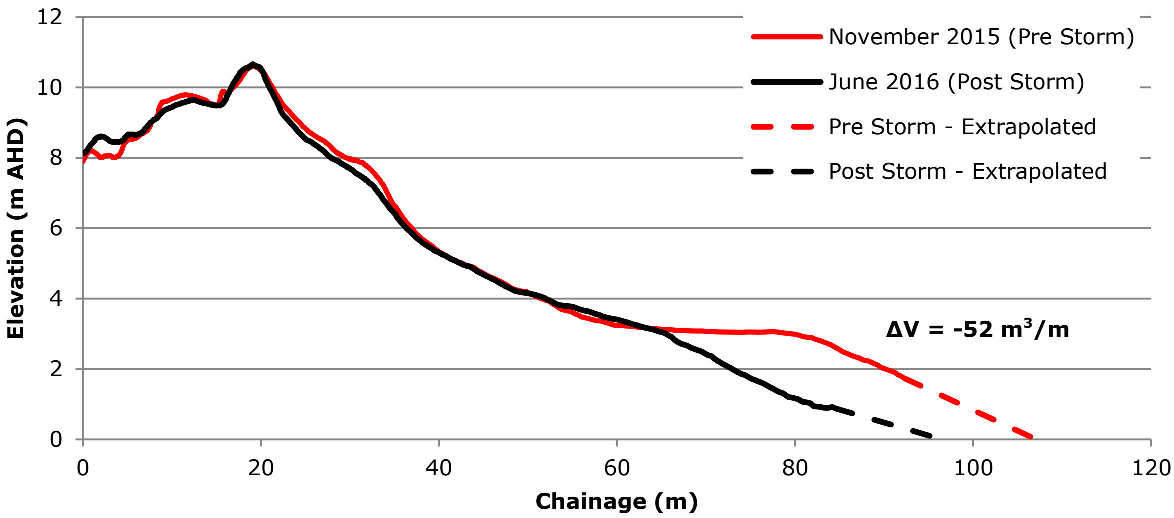
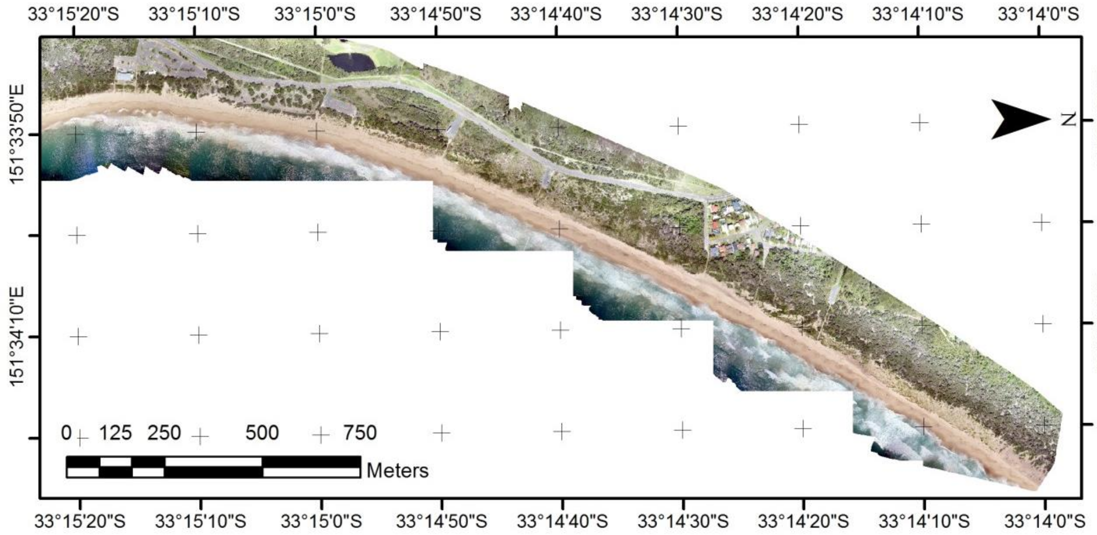



**Figure A 24: Shelly Beach Profile 4**

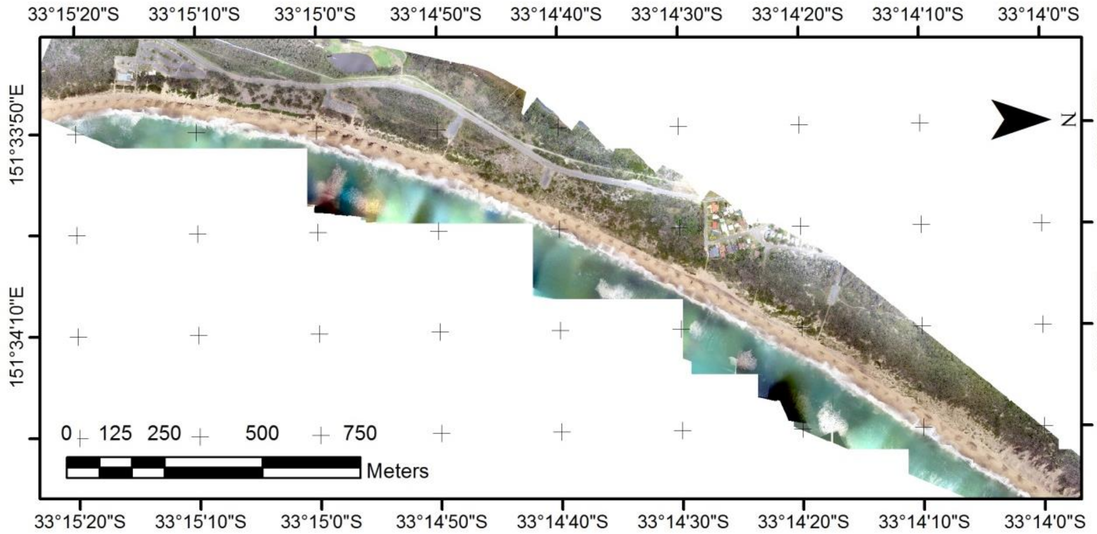
## 2. Appendix B – Aerial Imagery

**Location 1: Lakes Beach**

**Lakes Beach – Pre Storm 24/11/2016**

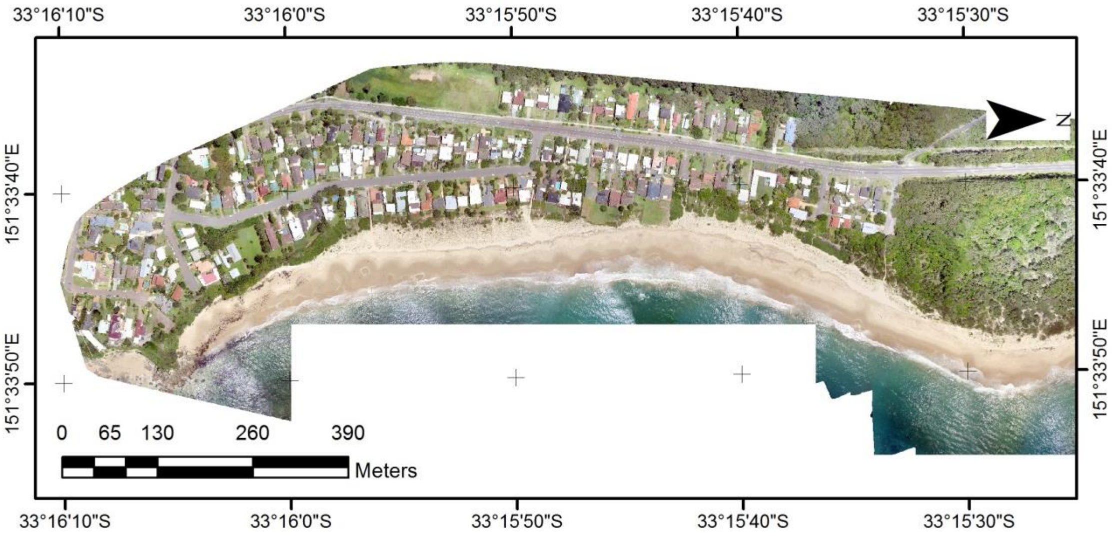



**Lakes Beach – Post Storm 17/06/2016**

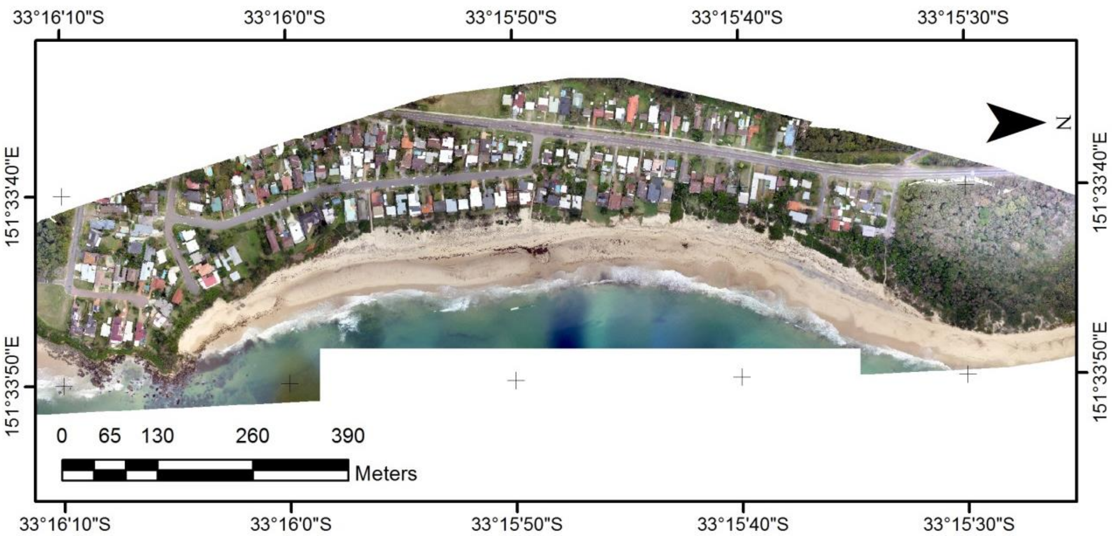


## Location 2: Hargraves Beach and Jenny Dixon

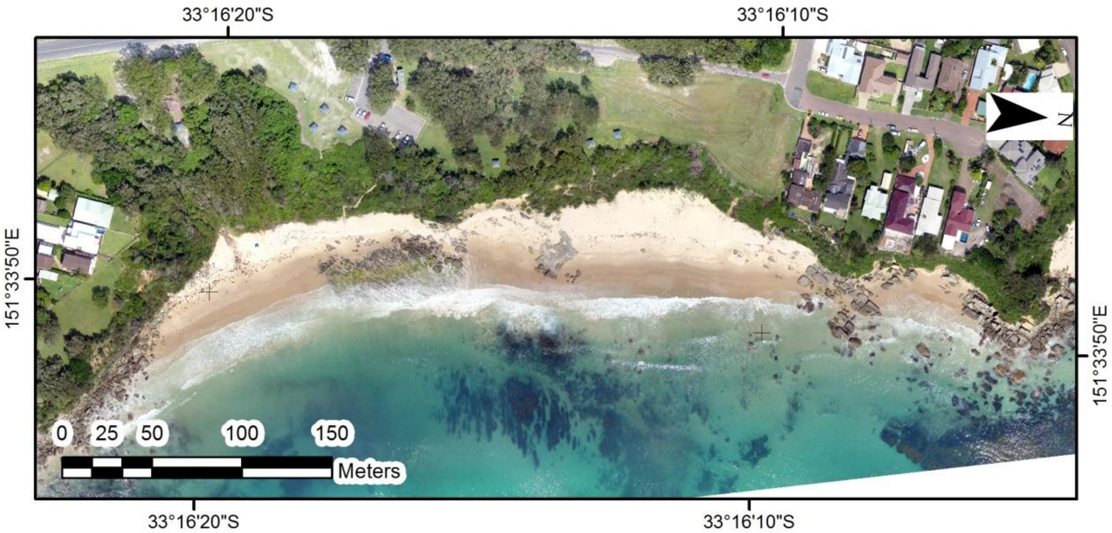
**Hargraves Beach – Pre Storm 24/11/2015**



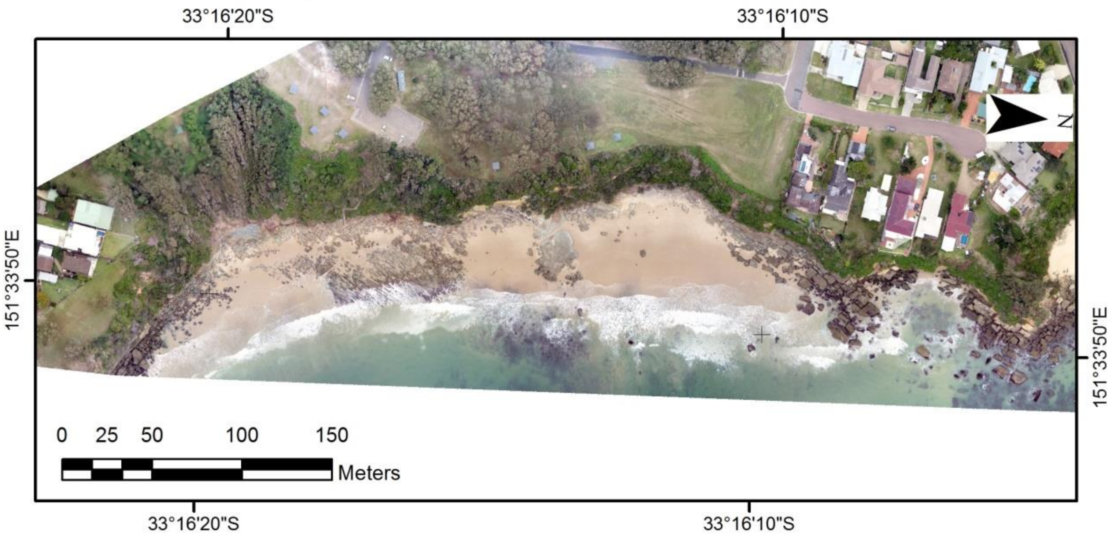

**Hargraves Beach – Post Storm 17/06/2016**



**Jenny Dixon – Pre Storm 24/11/2015**

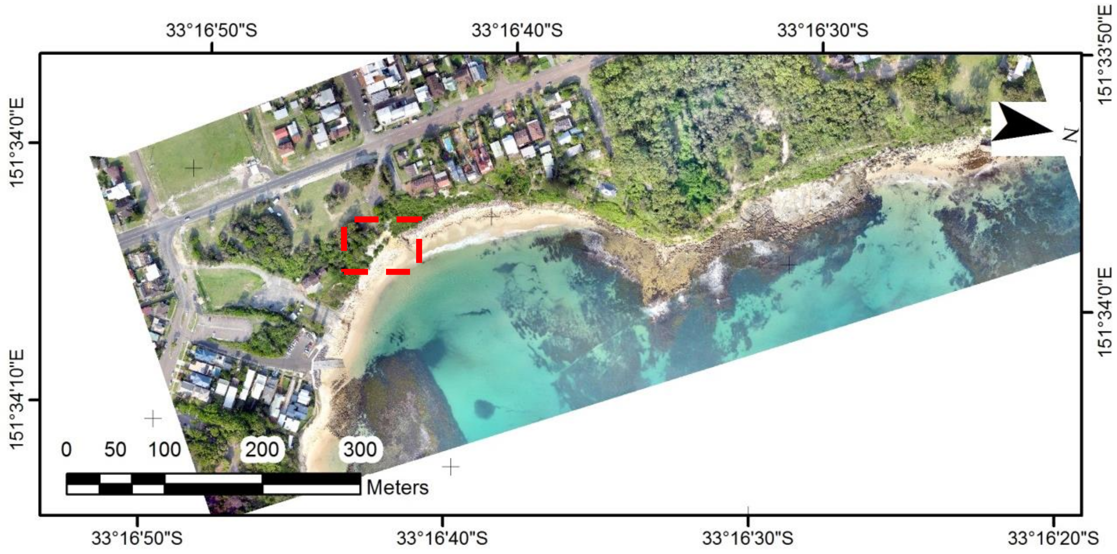



**Jenny Dixon – Post Storm 17/06/2016**

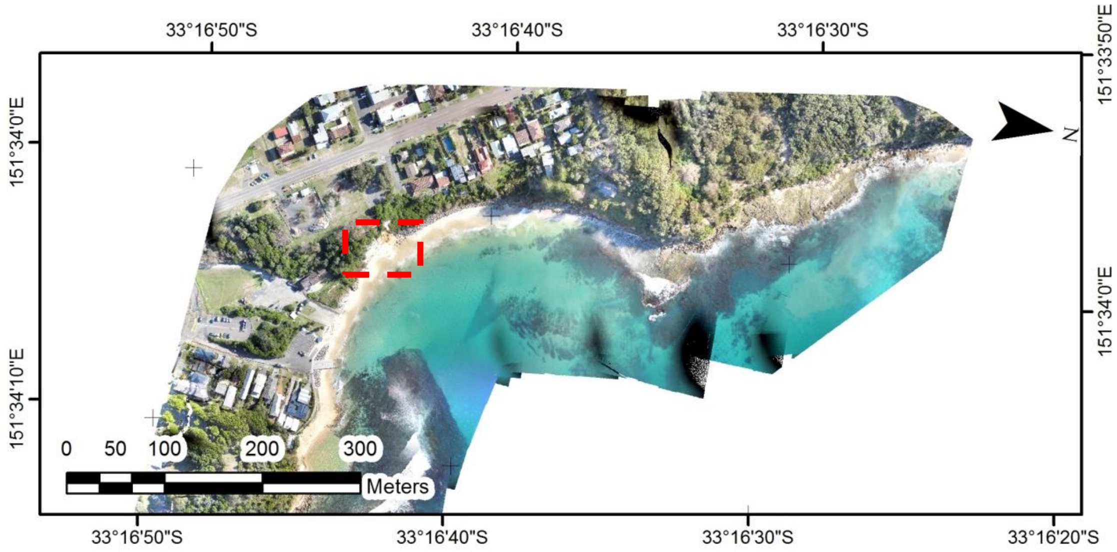


## Location 3: Cabbage Tree Harbour

**Cabbage Tree Harbour – Pre Storm 19/11/2015**



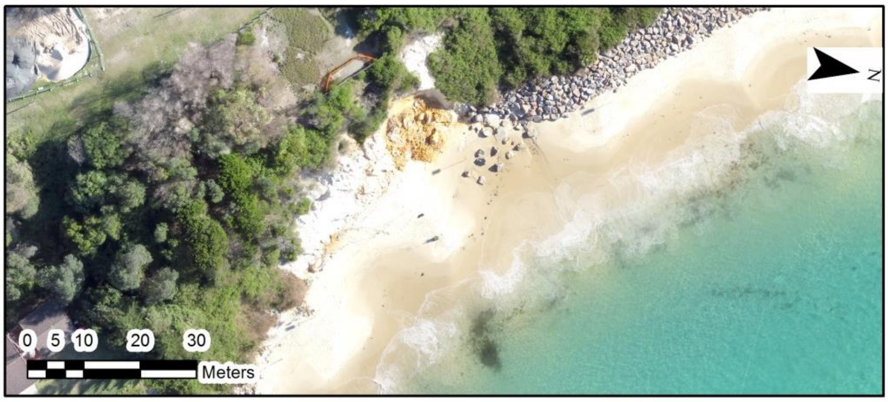

**Cabbage Tree Harbour – Post Storm 30/06/2016**




**See zoomed extent for further detail in the red box.**

**Cabbage Tree Harbour – Pre Storm 19/11/2015**
**Zoomed Extent**

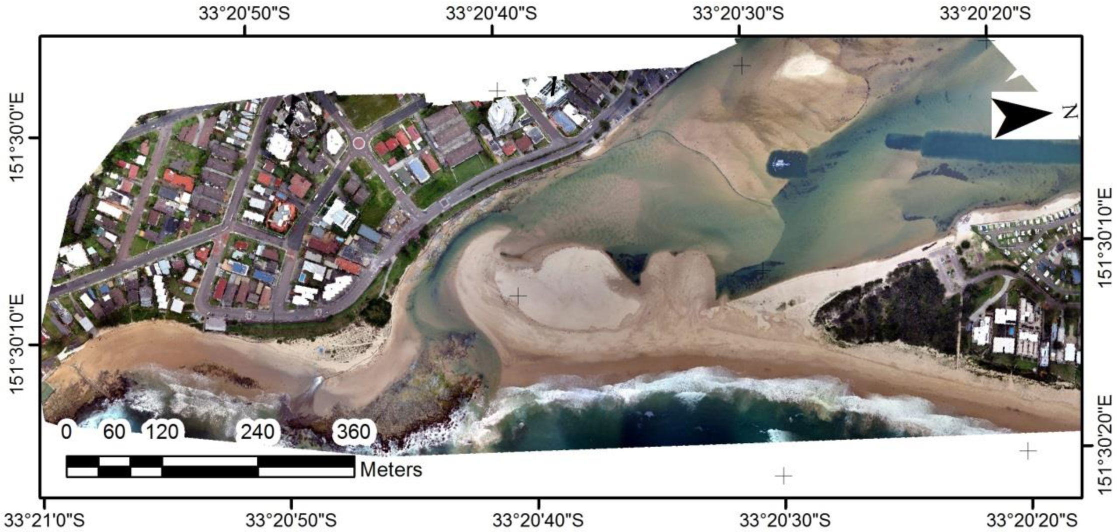

**Cabbage Tree Harbour – Post Storm 30/06/2016**
**Zoomed Extent**



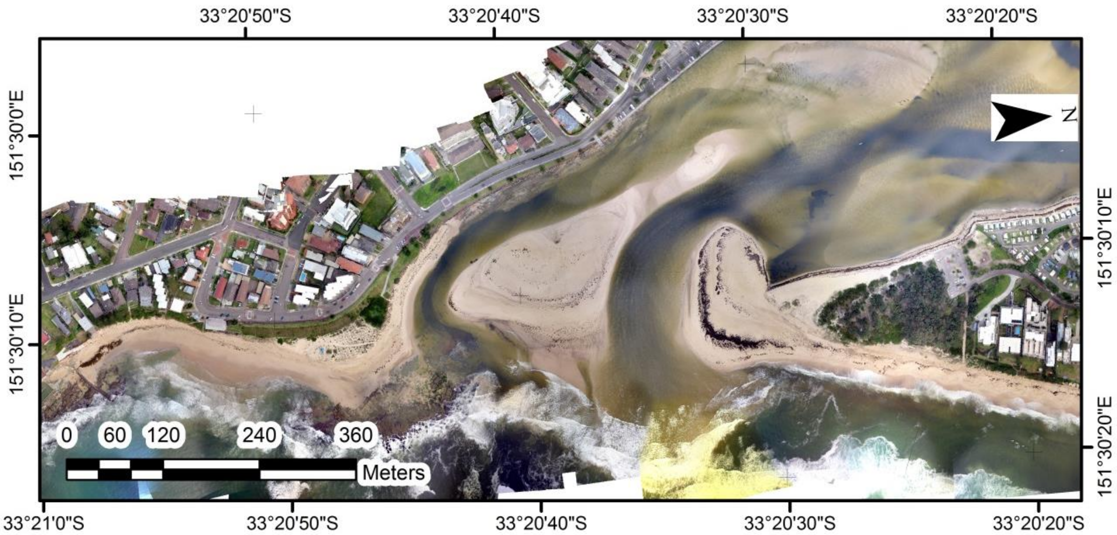

**Partial Cliff Collapse Region**

## Location 4: The Entrance and The Entrance North

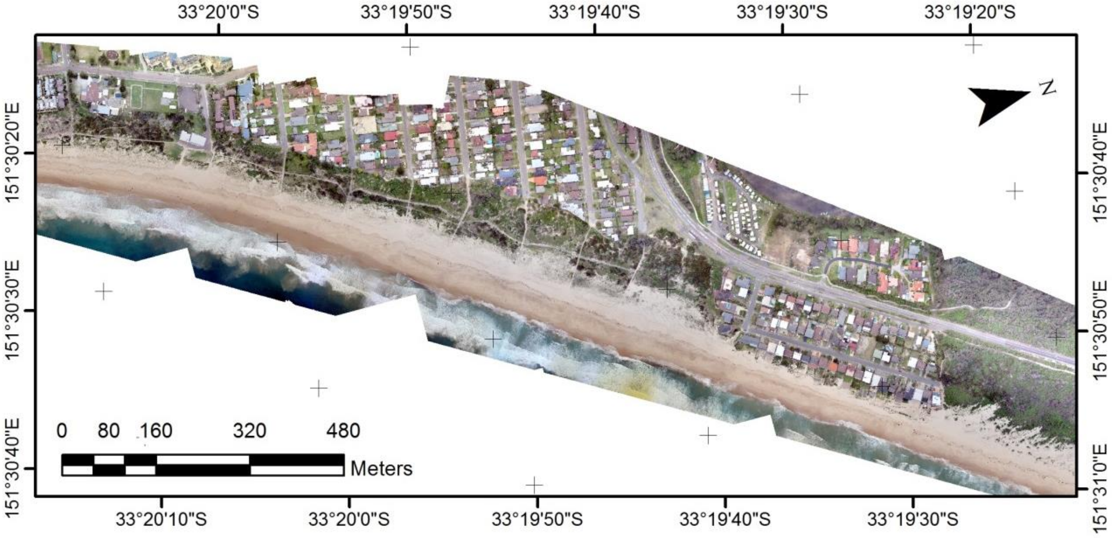
**The Entrance – Pre Storm 28/10/2015**



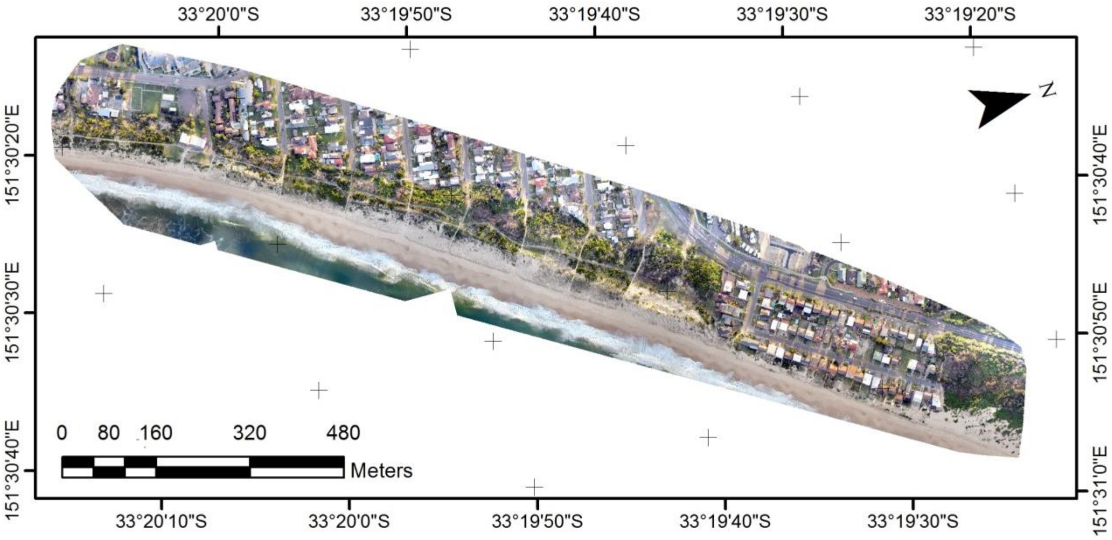

**The Entrance – Post Storm 13/06/2016**



**The Entrance North – Pre Storm 28/10/2015**

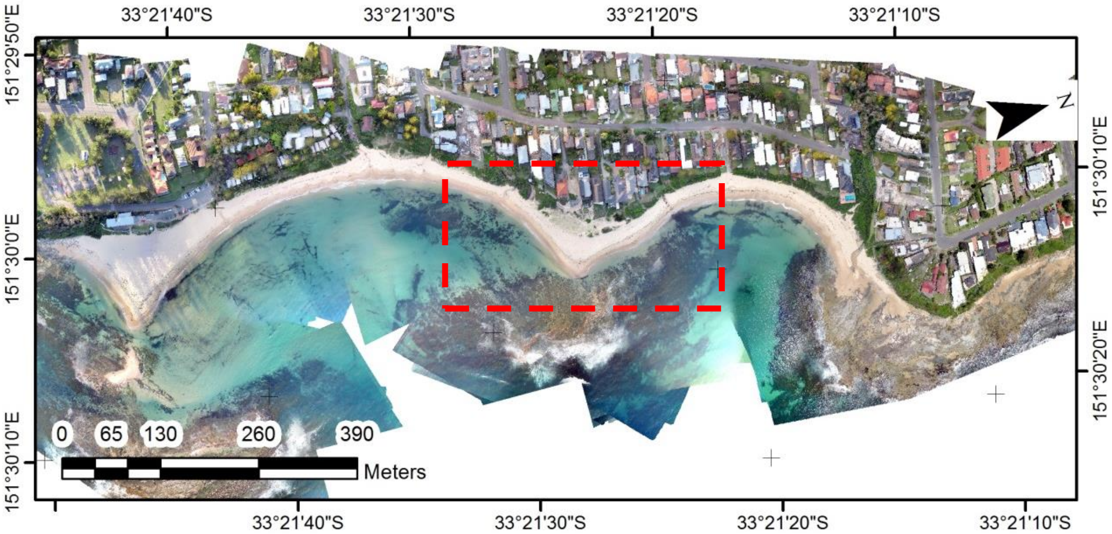



**The Entrance North – Post Storm 10/06/2016**

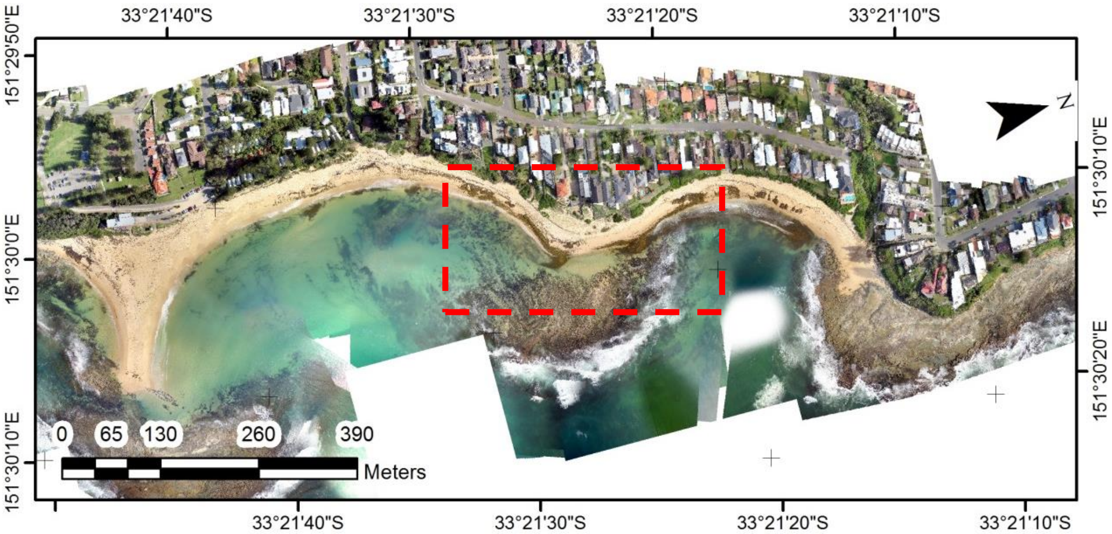


**Location 5: Blue Bay and Toowoon Bay**

**Toowoon Bay to Blue Bay – Pre Storm 10/11/2015**




**Toowoon Bay to Blue Bay – Post Storm 13/06/2016**



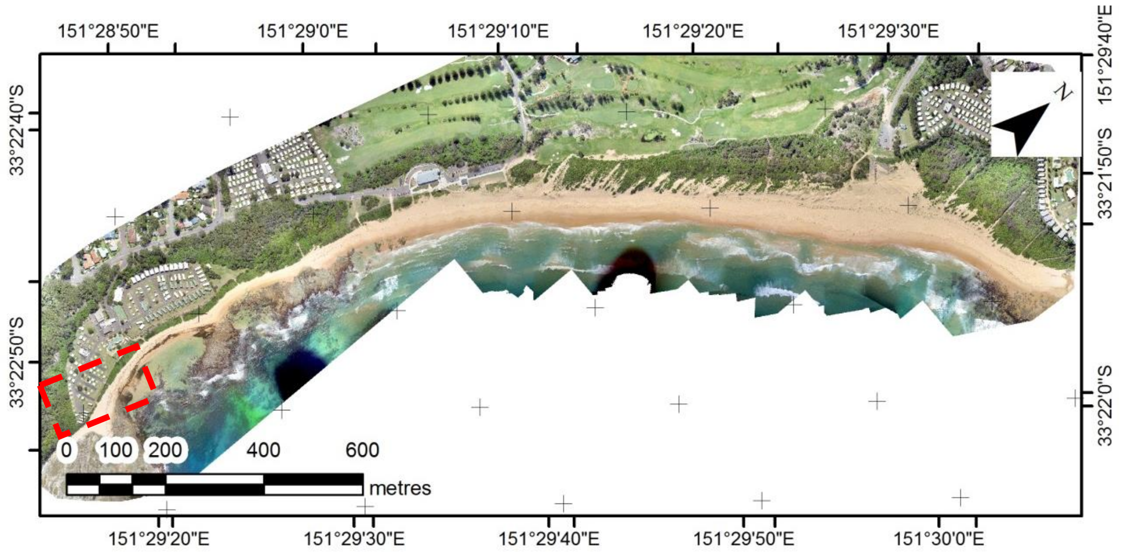

**See zoomed extent for further detail in the red box.**

**Toowoon Bay to Blue Bay – Pre Storm 10/11/2015**
**Zoomed Extents**

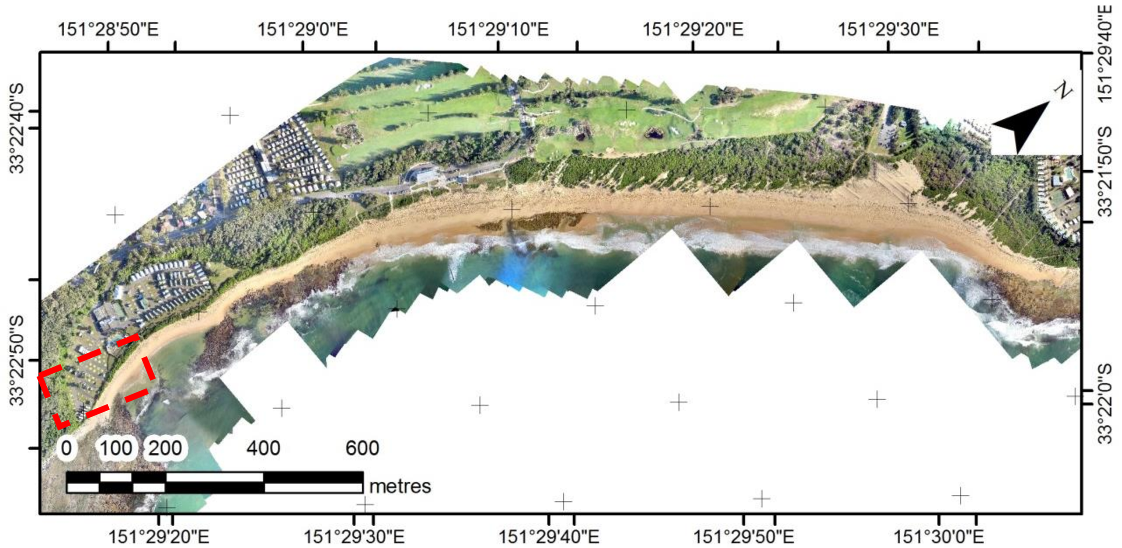

**Toowoon Bay to Blue Bay – Post Storm 13/06/2016**
**Zoomed Extents**

## Location 6: Shelly Beach

**Shelly Beach – Pre Storm 10/11/2015**




**Shelly Beach – Pre Storm 14/06/2016**




**See zoomed extent for further detail in the red box.**

**Shelly Beach – Pre Storm 10/11/2015**
**Zoomed Extents**


**Shelly Beach – Post Storm 14/06/2016**
**Zoomed Extents**