Tropical Cyclone Yasi 2011

Post Cyclone Coastal Field Investigation

November 2012

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Executive Summary

In February 2011, North Queensland experienced its largest and most intense cyclone since 1918. Category 5 Tropical Cyclone Yasi crossed the coast near Mission Beach at approximately 00:30 AEST on 3 February 2011 with estimated wind gusts up to 285 km/hr and maximum recorded wind speed up to 185 km/hr. TC Yasi was 500 kilometres wide with an eye 30 kilometres across. The coastal communities in the direct path of TC Yasi – Tully, Mission Beach, Cardwell and Dunk Island suffered extensive damage to property and infrastructure costing $800 million (Source: http://statements.cabinet.qld.gov.au/MMS/StatementDisplaySingle.aspx?id=73637).

As TC Yasi approached the Queensland coast, members of the Queensland Climate Change Centre of Excellence's Coastal Impacts Unit were providing around the clock advice on potential storm surge heights to the State Disaster Coordination Centre. Using the Unit's extensive network of 25 storm tide gauges established along Queensland's coastline, real-time technical information was provided in support of the State's storm tide warning system. This highly technical and valuable information underpinned many of the State's disaster management decisions relating to the storm surge produced by TC Yasi. The small team of engineers, scientists and skilled technical staff operated wave and storm tide recording instruments and provided technical advice during a very difficult and high-pressure period. Their contribution was later recognised in the Queensland Parliament by (then) Premier Anna Bligh MP.

The storm tide gauges recorded a peak storm surge of 5.33 metres at Cardwell. Fortunately, TC Yasi crossed the coast during a falling tide, averting more serious inundation. Had it made landfall on high tide just four hours earlier the water level would have been almost 3 metres higher. Smaller storm surges were also recorded at Cairns (1.09 metres) and at Cape Ferguson, south of Townsville (2.01 metres). Historically the event ranks as the third-highest Queensland storm surge, behind Bathurst Bay, Cape York in 1899 (up to an estimated 14.6 metres) and Burketown, Gulf of Carpentaria in 1887 (5.5 metres).

Strong winds associated with TC Yasi created high-energy wave conditions, causing erosion along the coast from Cairns to Townsville. During the peak of the event, the Townsville wave gauge experienced technical problems due to the rolling of the Waverider buoy during wave breaking. Prior to the technical problems, the Townsville gauge recorded waves of up to 9.6 metres. It is likely that higher waves occurred during this time and before the landfall of TC Yasi.

In addition to collecting and processing information as TC Yasi unfolded, the Coastal Impacts Unit also visited the worst-affected areas immediately after the event to undertake field surveys and confirm measurements made by the recording network during the event, and to assess the magnitude of the damage to the coastline. Field investigations revealed varying degrees of damage to the natural and built environment, caused by a combination of high-energy wave conditions, strong winds, and storm tide inundation. As expected, communities located between Mission Beach to the north, and Cardwell to the south sustained the worst cyclone damage with significant damage to buildings, infrastructure and vegetation due to their being within the southern radius of maximum winds.

The information contained in this report is the result of the work performed by the Coastal Impacts Unit during and after TC Yasi. It provides an overview of the magnitude of the TC Yasi in relation to wave heights and the extent of damage resulting from the waves and storm surge.

The resulting information is used by coastal engineers to illustrate the relationship between inundation levels wrought upon the foreshore, and storm tide levels, which neglect to include the additional effects of wave run-up. Due to the narrow time window in which data must be retrieved, the unpredictable nature of such events and the scarcity of events to gather information from, this data is invaluable to further research and projects, including the Storm Tide Inundation Monitoring (Pilot) Project being undertaken by the Coastal Impacts Unit, which measured inundation levels during the same event. The insight provided from these studies will help Queensland communities to be more aware and resultantly, better prepared against the risk of inundation from storm tides in future events.

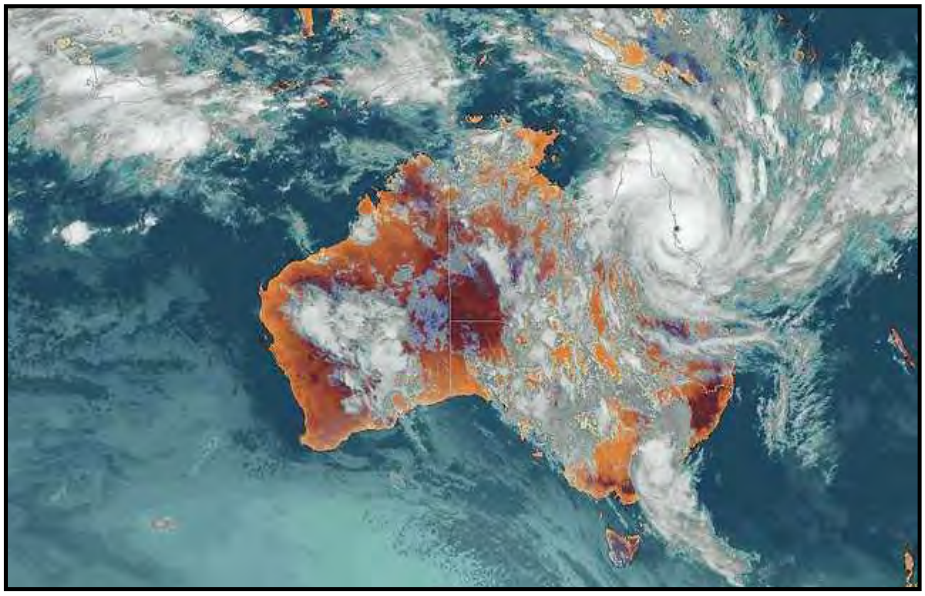


Figure 1: Satellite image of TC Yasi, 02 February 2011 (Source: Bureau of Meteorology, used with permission)

1 Introduction

Severe tropical cyclone Yasi (TC Yasi) formed northwest of Fiji in the Pacific Ocean on 29 January 2011 and made landfall near Mission Beach on the north Queensland coast between midnight and 01:00 Australian Eastern Standard Time (AEST) on 3 February 2011.

TC Yasi made landfall as a category 5 cyclonic system with such intensity that the system continued inland for over 500 kilometres before it weakened near Mt Isa. Whilst TC Yasi caused extensive wind/rain damage and resulted in storm tide inundation in several locations along Queensland's tropical coast, the system fortunately crossed the coastline during a falling tide, reducing the risk of more serious storm tide inundation which would have inevitably occurred on the high tide three to four hours earlier.

During the event, instrumentation established and managed by the Queensland Department of Science, Information Technology, Innovation and the Arts (DSITIA) measured wave and tide levels occurring along the Queensland coastline between Cairns and Cape Ferguson. DSITIA storm tide gauges recorded a maximum peak storm surge of 5.33 metres above the predicted tide at Cardwell, with smaller storm surges occurring at Clump Point (2.97 metres), Townsville (2.36 metres) and Cairns (1.09 metres). The maximum recorded wave height of 9.6 metres occurred at the Townsville wave buoy at 19:00 AEST on 2 February 2011, approximately 5.5 hours prior to the landfall of TC Yasi. This was the highest wave ever recorded at the Townsville wave buoy since commencement of operation in 1975. The previous highest maximum wave height recorded at the Townsville wave buoy was 6.6 metres at 07:30 AEST on 13 January 2009 during ex-tropical cyclone Charlotte.

Inundation levels at coastal communities most affected by TC Yasi were inspected in the week following landfall, namely: Bramston Beach; Etty Bay; Clump Point; Mission Beach; Hull Heads; Tully Heads; Cardwell; Lucinda; Forrest Beach; Balgal Beach; Saunders Beach; and Pallarenda, a northern suburb of Townsville. Although clean-up crews had removed much of the evidence of the storm surge from many of the areas inspected, assessments of storm surge heights were made using debris lines, water marks on buildings, debris retained in fences and trees, and also information obtained from local residents.

The high wave energy generated by TC Yasi resulted in beach erosion between Cairns and Townsville, and damage to infrastructure along the coastline between these two cities.

Erosion effects resulted in beach scarps between 0.5 to 2.0 metres in height with greater than 5 metres of preceding foredune reclaimed by the sea at unprotected locations (the worst of these being Tully Heads).

Unprecedented events were recorded at the Hinchinbrook Marina where multi-million dollar boats were piled on top of each other (Cover photograph - Source: Courier Mail).

2 Severe tropical cyclone Yasi

TC Yasi developed as a tropical low northwest of Fiji on 29 January and tracked on a general westward alignment, intensifying as it moved towards the Queensland coast. TC Yasi was upgraded to a Category 5 system at 04:30 AEST on 2 February, maintaining its intensity and accelerating towards the north Queensland coast until it made landfall near Mission Beach (138 kilometres south of Cairns) sometime between 00:00 and 01:00 AEST on Thursday 3 February 2011. Remarkably, TC Yasi continued inland on a westerly track through northern Queensland until it finally weakened to a tropical low near Mount Isa, over 500 kilometres inland, around 10:00 AEST on Thursday 3 February (Figure 2). TC Yasi was one of the most powerful cyclones to have affected Queensland since written records commenced. The Bureau of Meteorology (BoM) compares the intensity of TC Yasi to the likes of TC Mahina which crossed the Queensland coast at Princess Charlotte Bay in 1899 resulting in a storm surge of between 12–14.6 metres and 307 known fatalities.

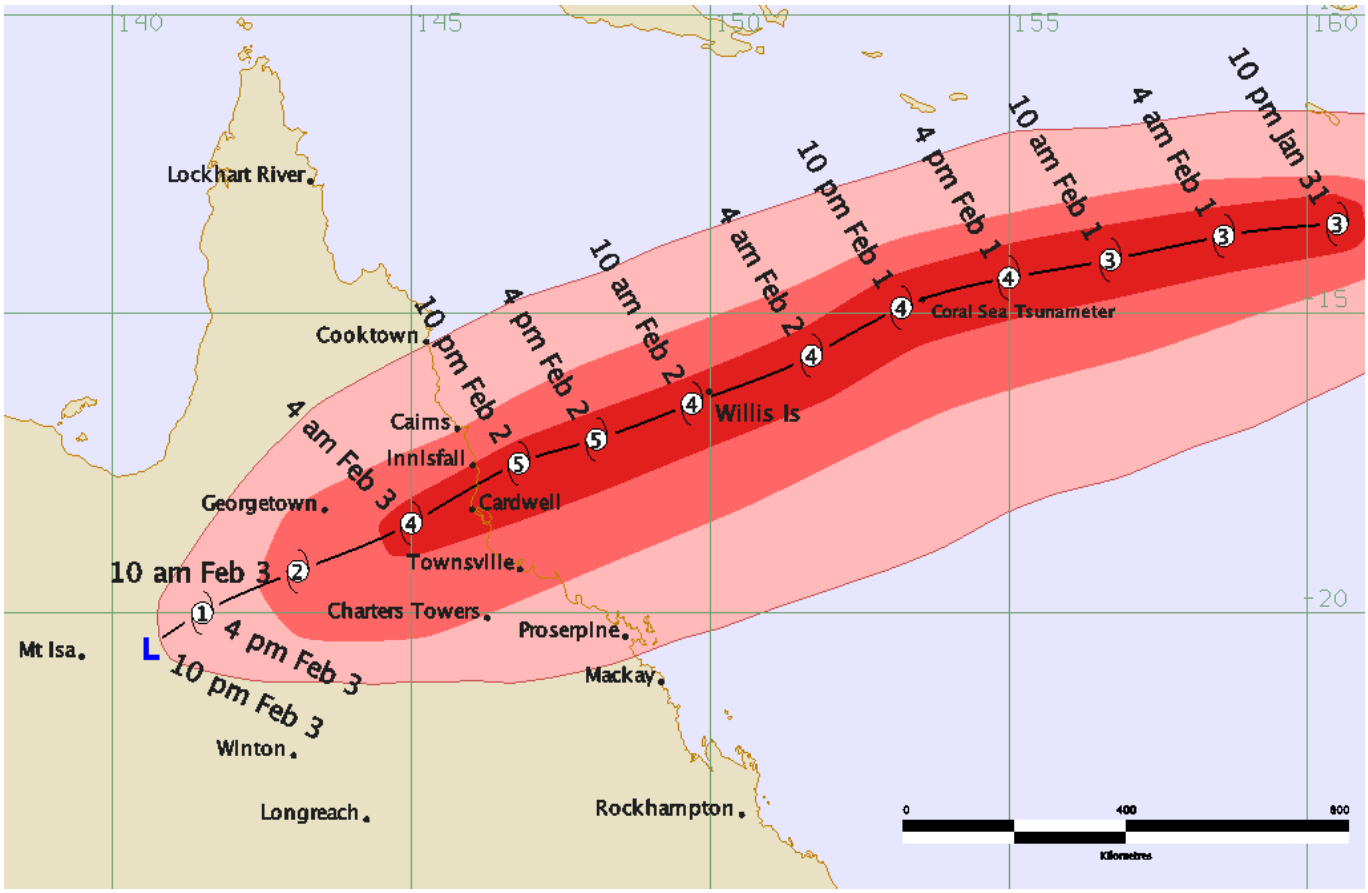


Figure 2: TC Yasi track map for Queensland coastline (Source: Bureau of Meteorology, used with permission)

TC Yasi crossed the Queensland coast sometime between 00:00 and 01:00 AEST on Thursday 3 February 2011 during a falling tide. As TC Yasi made landfall, a minimum central pressure of 929 hPa (Figure 3) was recorded at DSITIA's Clump Point storm tide gauge, with an estimated maximum wind gust of 285 km/hr offshore.

TC Yasi was 500 kilometres wide with an eye of 30 kilometres diameter and a recorded maximum sustained wind speed of 185 km/hr (estimated maximum sustained wind speed of 205 km/hr), resulting in significantly damaging winds between Innisfail and Townsville. Larger than normal

storm tides were experienced at a number of locations along the tropical coast, with a maximum storm surge of 5.33 metres (2.23 metres above Highest Astronomical Tide (HAT)) recorded at Cardwell at 01:20 AEST on 3 February, resulting in inundation in that region. Inundation also occurred 6–9 hours later on the mid-morning high tide following the crossing of TC Yasi at a number of coastal locations between Cairns and Townsville. Peak levels were measured at DSITIA's Townsville storm tide gauge 0.38 metres above HAT causing inundation of parts of the city. The 5.33 metres storm surge recorded at Cardwell during TC Yasi ranks as the third highest in Queensland’s written history, exceeded only by the storm surge events at Bathurst Bay, Cape York of between 12–14.6 metres in 1899 and Burketown, Gulf of Carpentaria in 1887 of 5.5 metres.

In the week following the event, DSITIA officers completed a field inspection of approximately 230 kilometres of coastline between Bramston Beach (south of Cairns) and Townsville. The objectives of the inspection were to:

- determine the extent of storm tide inundation estimated by surveyed heights of debris lines and water marks; and
- provide a record of coastal impacts such as beach erosion, infrastructure damage, and dune overtopping. Photographs and video were used to record the damage.

3 Recorded data

3.1 Storm Tide Data

A storm surge is a local rise in sea level caused by the combined action of severe winds and low-pressure systems on the ocean (such as that experienced during a tropical cyclone) causing large volumes of water to be pushed against the coast. When a storm surge is combined with normal astronomical tide and wave set-up, it creates a storm tide. The destructive capacity of a storm tide depends on the height of the tide at the time a cyclone crosses the coast. The higher the tide, the more likely it is that destructive flooding and erosion will take place. The inundation produced by a storm tide is exacerbated by wave run-up, wave overtopping and localised intense rainfall and can lead to coincident flooding if combined with the effects of riverine (freshwater) flooding.

DSITIA operates a storm tide monitoring network comprised of 25 tide gauges along the Queensland coastline (www.ehp.qld.gov.au/tides). This network allows near real-time access to tide data via the internet for use in monitoring storm surge and predicting storm tides along the coastline.

During TC Yasi tide data was obtained and analysed from the closest operating gauges including: Cairns; Mourilyan; and Clump Point gauges on the northern side of TC Yasi's path, and Cardwell and Townsville gauges to the south. Unfortunately, the Lucinda storm tide gauge was destroyed during the event, resulting in no records beyond 00:00 AEST on 3 February. Plots of the most affected sites at Clump Point, Cardwell and Townsville are shown in Figures 3-5. The peak storm surge (indicated by the green area graph) occurred not long after TC Yasi made landfall at each of the gauges. Note that the peak water level recorded at the Townsville gauge occurred 8–9 hours after TC Yasi made landfall. Figure 6 displays the storm surge measured at the storm tide gauges between Cairns and Townsville during the peak of the event.

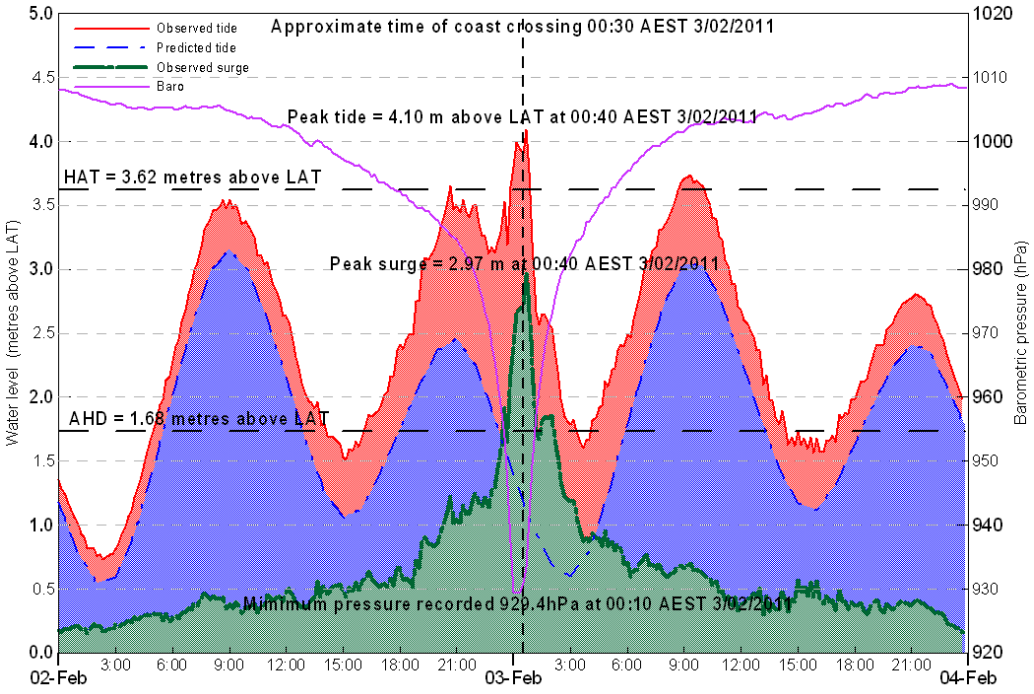


Figure 3: Plot of tides from Clump Point storm tide gauge 2–3 February 2011

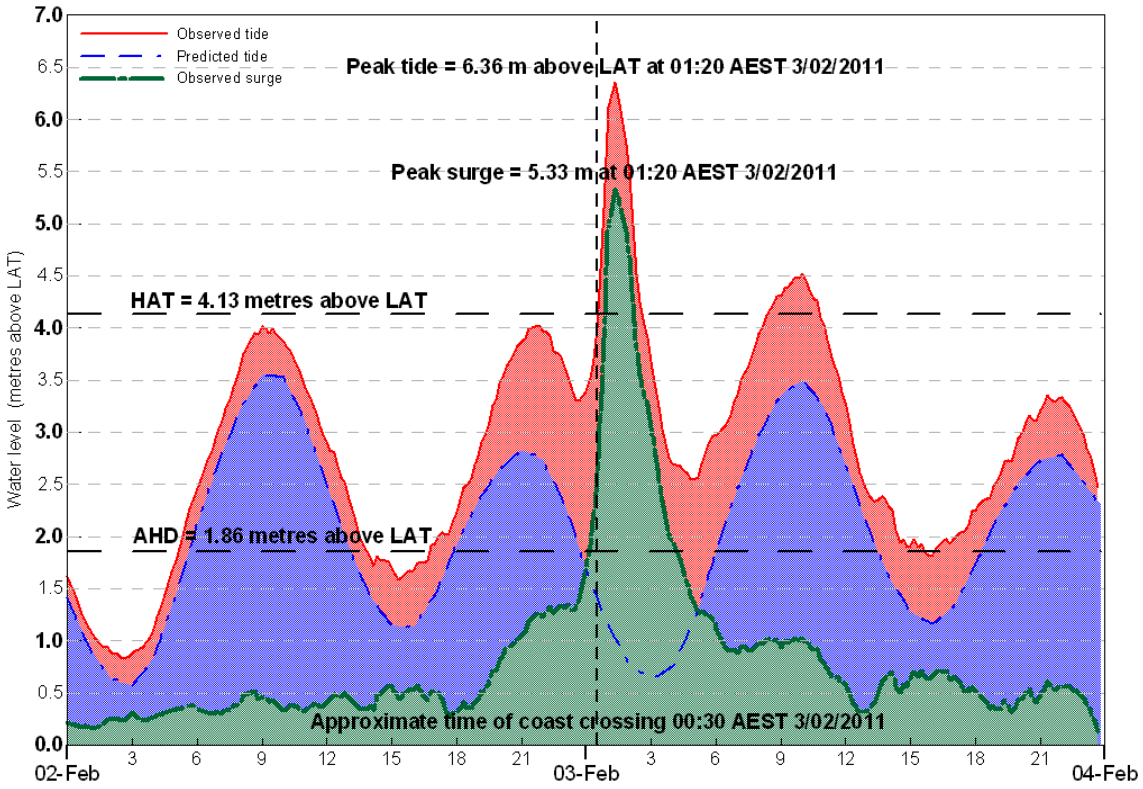


Figure 4: Plot of tides from Cardwell storm tide gauge 2–3 February 2011

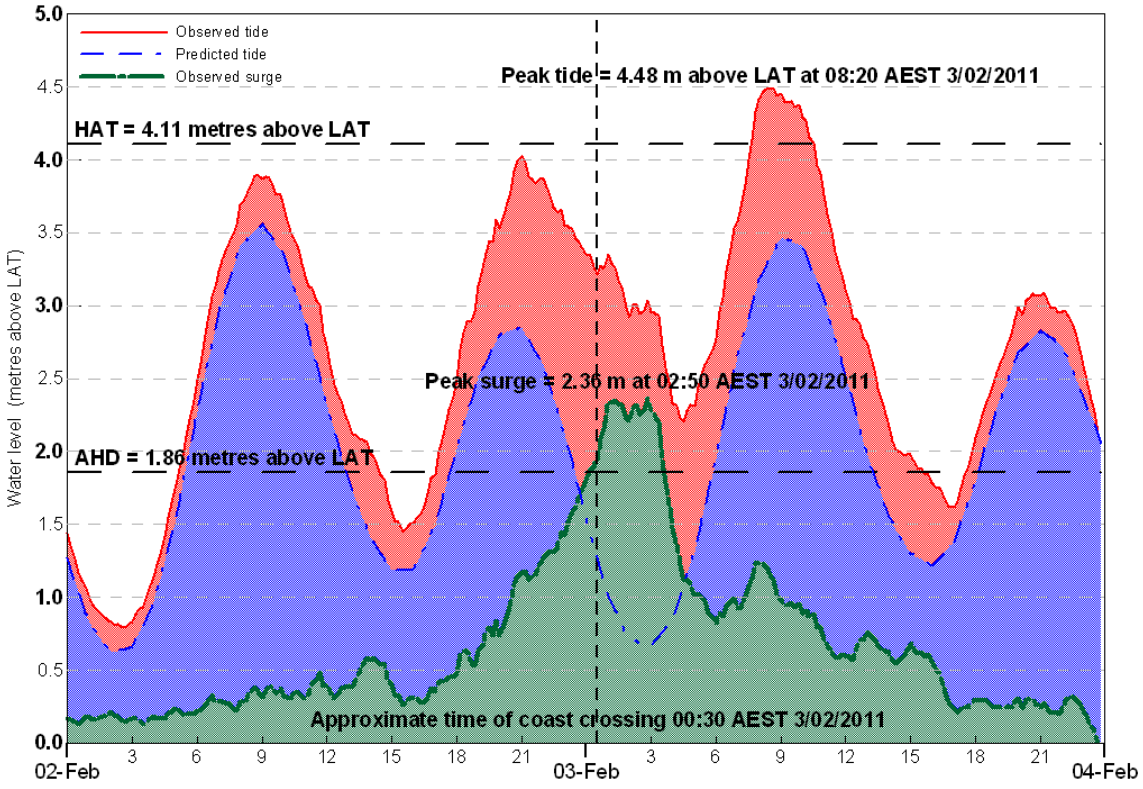


Figure 5: Plot of tides from Townsville storm tide gauge 2–3 February 2011

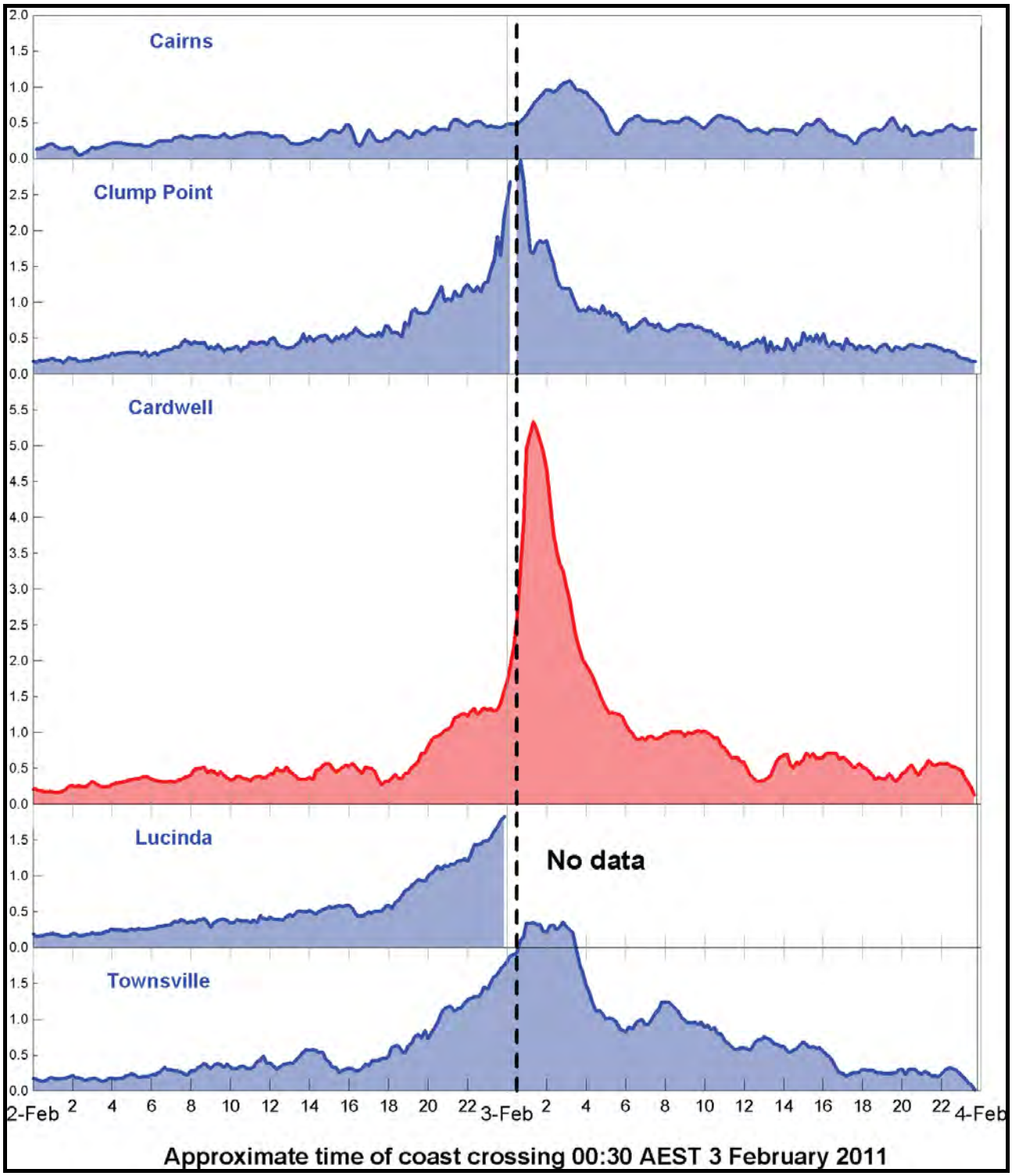


Figure 6: Storm surge (metres) recorded at DSITIA storm tide gauges

Table 1 displays the peak storm surge (water level above the predicted tide) recorded at the most affected operating storm tide gauges during the crossing of TC Yasi. The storm surges generally peaked between 0–3 hours after TC Yasi made landfall. The highest storm surge was recorded at the Cardwell gauge, 5.33 metres above the predicted tide.

Table 1: Peak recorded storm surges during TC Yasi

Storm Tide Gauge	Date (AEST)	Recorded peak storm surge (metres above predicted tide)
Cairns	03/02/2011 03:10	1.09
Mourilyan	03/02/2011 00:00	1.32
Clump Point	03/02/2011 00:40	2.97
Cardwell	03/02/2011 01:20	5.33
Townsville	03/02/2011 02:50	2.36
Cape Ferguson	03/02/2011 01:00	2.01

Table 2 displays the peak storm tide above Australian Height Datum (AHD) and HAT. The occurrence of the peak storm tide at each gauge varied, but generally coincided with the mid-morning predicted high tide, instead of during the peak storm surge which generally occurred 0–3 hours following the landfall of TC Yasi. The two exceptions to this observation were for the Clump Point and Cardwell storm tide gauges which experienced the largest storm surges.

Table 2: Maximum storm tide recorded during TC Yasi

Location	Date (AEST)	Peak water level (metres AHD)	Highest Astronomical Tide (metres AHD)	Peak water level above HAT (metres)
Cairns	03/02/2011 09:10	1.83	1.86	-0.03
Mourilyan	03/02/2011 09:36	1.79	1.77	0.02
Clump Point	03/02/2011 00:40	2.37	1.94	0.48
Cardwell	03/02/2011 01:20	4.50	2.27	2.23
Townsville	03/02/2011 08:40	2.63	2.25	0.38
Cape Ferguson	03/02/2011 09:20	2.41	2.15	0.26

Although the landfall of TC Yasi occurred near low tide, storm tides exceeding HAT were still experienced along the coastline between Cairns and Townsville (Photograph 1). The majority of storm tide gauges located between Cairns and Townsville recorded maximum water levels less than 0.5 metres above HAT, generally occurring 8–9 hours after TC Yasi made landfall. The key exception to this was the Cardwell gauge which recorded a peak water level of 2.23 metres above HAT shortly after the crossing of TC Yasi. The Clump Point gauge, which is located just north of where TC Yasi crossed the coast, also experienced a storm tide of 0.48 metres above HAT. Some significant storm tide inundation occurred on the late morning high tide on 3 February between Cairns (Photograph 2) and Townsville, with peak storm tide levels measured at the Townsville storm tide gauge at 0.38 metres above HAT, causing inundation in parts of the city.

The peak water level recorded at Cardwell was 4.50 metres AHD occurring at 1:20 AEST 3 February 2011, shortly after TC Yasi made landfall. The measured peak water level at Cardwell coincided with the peak recorded water level (5.33 metres above predicted tide), causing maximum storm tide inundation estimated at 6.88 metres above AHD based on surveyed debris lines along the Cardwell coast. Storm tide inundation is discussed in more detail in Section 4.

Photograph 1: (above) Cairns resident watching waves break along Cairns Esplanade during the secondary storm surge from TC Yasi (Source: News Limited)

Photograph 2: (left): Localised flooding at Hull Heads caused by storm tide inundation and heavy rainfall during TC Yasi (Source: News Limited)

Photograph 3: Coastal erosion and damage to buildings and infrastructure at Cardwell following TC Yasi (Source: News Limited)

3.2 Wave data

DSITIA operates a network of 14 wave monitoring stations along the Queensland coastline (Figure 9) (www.ehp.qld.gov.au/waves) utilising moored Waverider buoys manufactured by Datawell of Holland. During TC Yasi, the sites at Cairns and Townsville were actively monitored (Figures 7 and 8) to assist in storm tide monitoring along the coast.

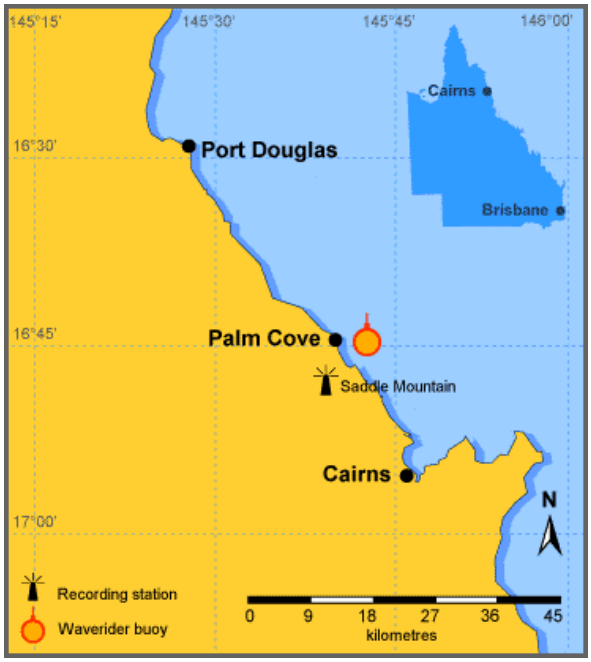


Figure 7: Cairns wave monitoring station location

Figure 8: Townsville wave monitoring station location

Figure 9: DSITIA wave monitoring stations

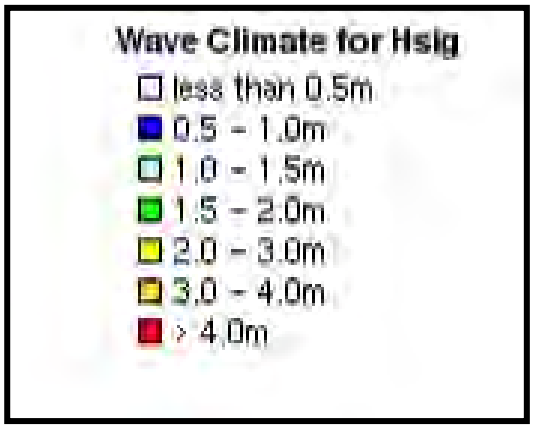
Peak significant (Hsig) and maximum (Hmax) wave heights recorded at these stations are shown in Table 3. The significant wave height (in metres) is defined as the average of the highest one-third of the zero up-crossing wave heights in a 26.6-minute wave record. Maximum wave height represents the maximum individual wave heights (Hmax) recorded at these stations during the event.

Table 3: Wave heights recorded during TC Yasi

Site	Hsig (metres)	Date AEST	Hmax (metres)	Date AEST
Townsville	4.73 (prior to gap)	02/02/2011 19:00	9.6 (prior to gap)	02/02/2011 19:00
Cairns	2.37	03/02/2011 03:30	4.06	03/02/2011 04:00

Figures 10 through 13 depict directional wave roses for the wave data recorded at the Townsville wave monitoring station during the approach, crossing and aftermath of TC Yasi on 1–4 February 2011 respectively. Each ring of the wave rose represents 5 per cent of the total wave period.

The wave heights recorded at the Townsville station between 00:00 and 23:50 AEST 1 February 2011 during the approach of TC Yasi display that the significant wave height remained below 1 metre and were predominantly from the easterly direction.



Closer to the landfall of TC Yasi, the Townsville station recorded significant wave heights of over 4 metres. During the peak of the event, the gauge experienced technical problems due to the rolling of the Waverider buoy during wave breaking. This resulted in a data gap between 19:00 AEST 2 February 2011 and 05:00 AEST 3 February 2011 during the peak wave heights (Figures 10 and 11). During the 24 hours prior to the landfall of TC Yasi, wave heights increased to above 4 metres. Prior to the technical problems, the Townsville gauge recorded a peak significant wave height of 9.6 metres at 19:00 AEST 2 February 2011. It is likely that higher waves occurred during this time and before the landfall of TC Yasi.

The peak significant wave heights were recorded on 3 February 2011, with over 40 per cent of significant wave heights above 3 metres. By 4 February 2011, significant wave heights had decreased significantly to below 1.5 metres.

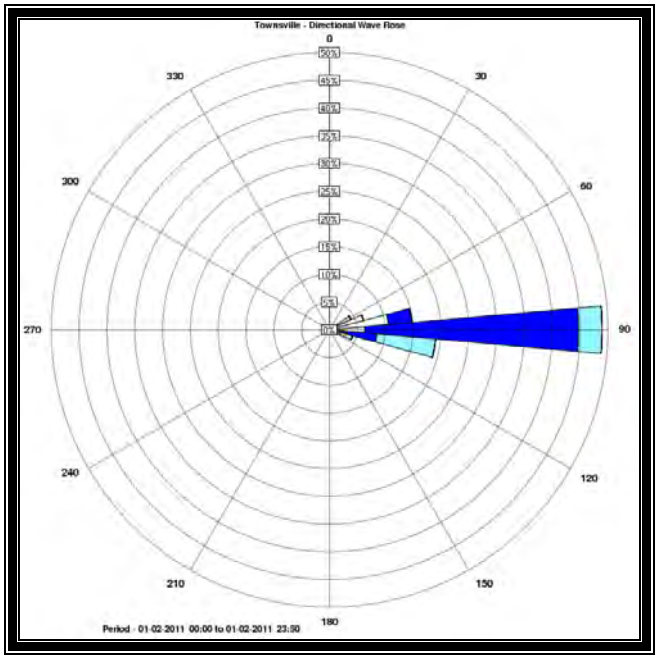


Figure 10: Townsville directional wave rose - peak wave height 01 February 2011 00:00-23:50 AEST

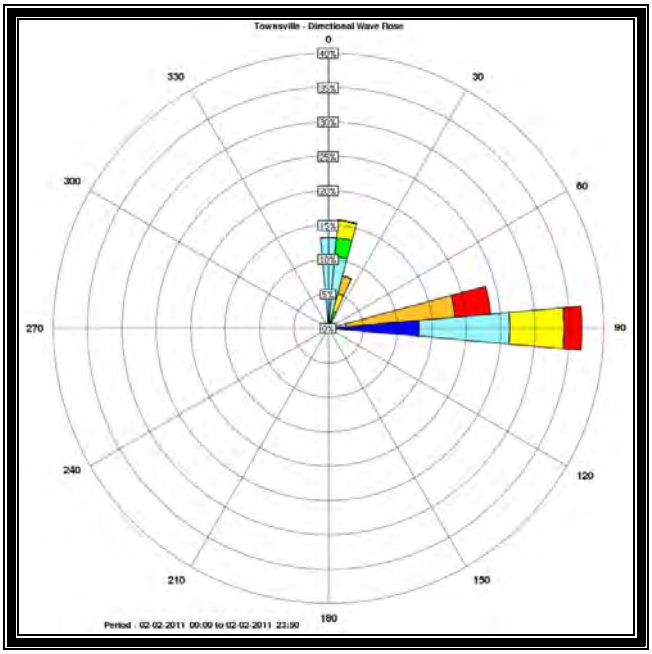


Figure 11: Townsville directional wave rose - peak wave height 02 February 2011 00:00-23:50 AEST

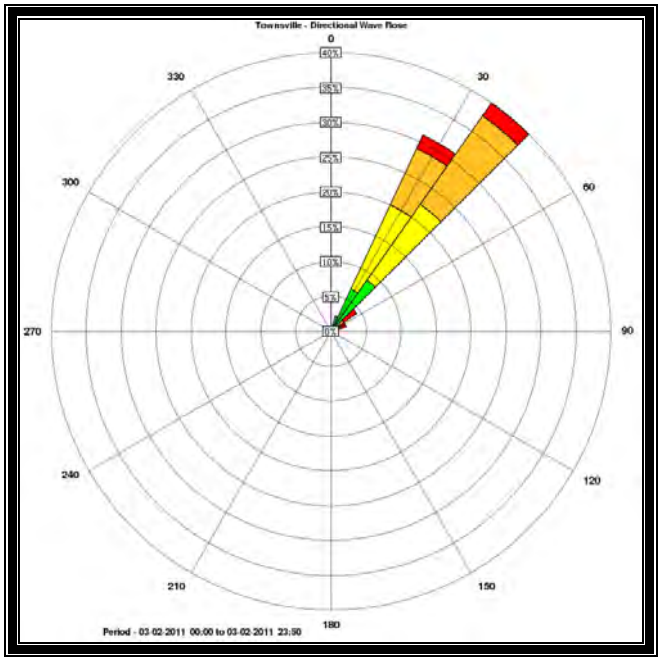


Figure 12: Townsville directional wave rose - peak wave height 03 February 2011 00:00-23:50 AEST

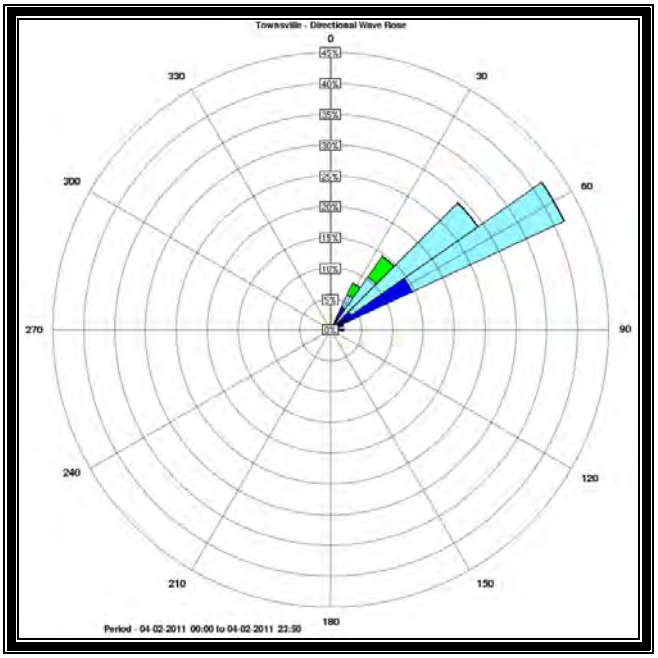


Figure 13: Townsville directional wave rose - peak wave height 04 February 2011 00:00-23:50 AEST

A time series plot of the wave height, period and direction recorded at the Townsville wave monitoring station for the period of 1–3 February 2011 is shown in Figure 14.

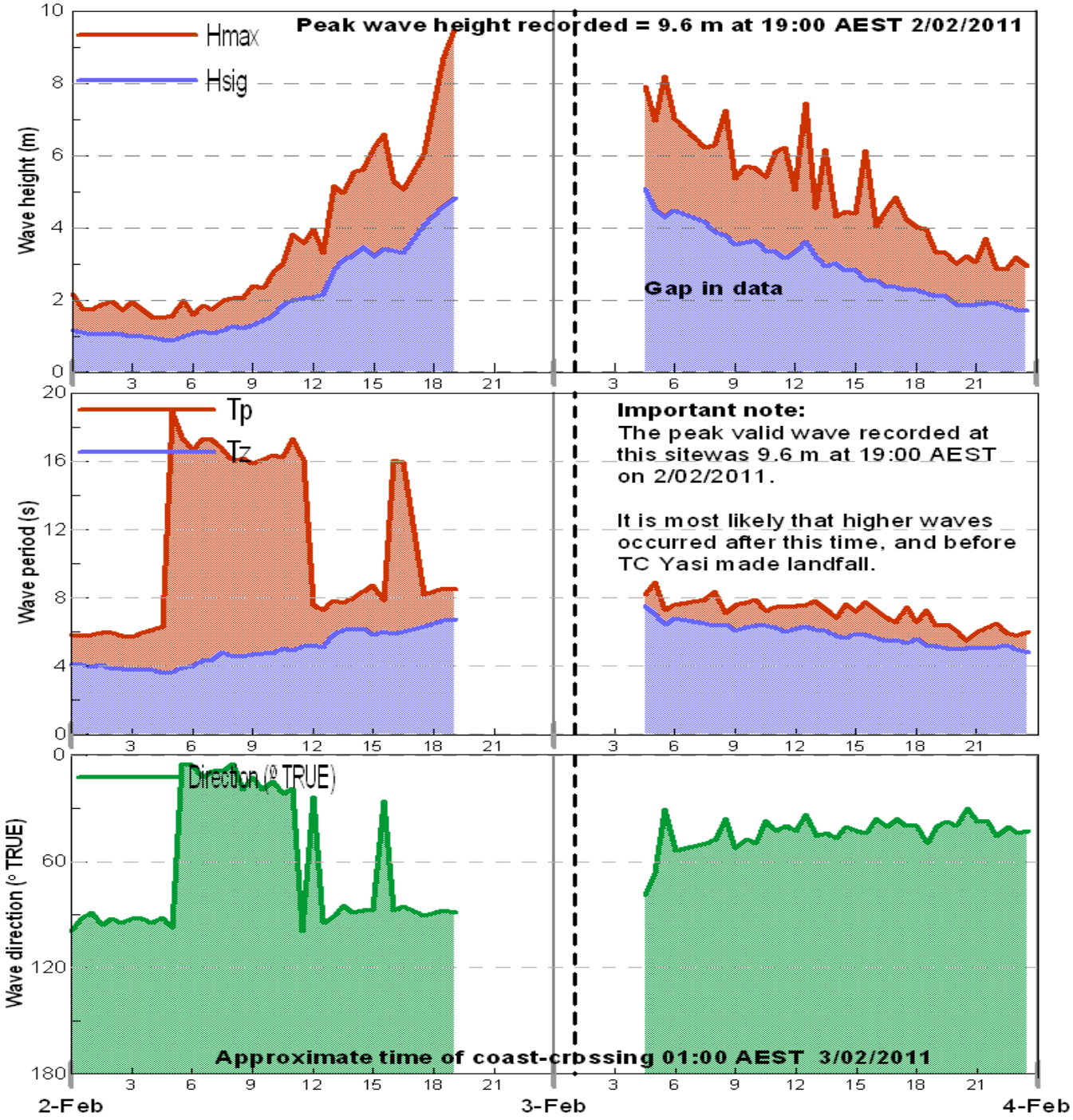


Figure 14: Time series plots of wave height, period, and direction recorded at Townsville during TC Yasi.

4 Post TC Yasi Inspection

4.1 Sequence of Inspection Activities

Four days after TC Yasi crossed the coast a field inspection was carried out by DSITIA officers to determine the extent of coastal impacts, and to survey storm tide inundation. Beaches located between Bramston Beach in the north and Townsville in the south were inspected between 7–11 February 2011 (approximately 230 kilometres of coastline). Although the inspection was undertaken only 4–7 days after TC Yasi crossed the coast, preliminary clean up work had already commenced, and debris lines left by the storm surge and wave run-up were sometimes difficult to make out (Photograph 4).

Photograph 4: Clean-up efforts commence in Cardwell following TC Yasi (Source: News Limited)

The inspection activities are summarised in chronological order in Table 4. The locality of the survey areas is provided in Figure 15. The following sections detail the findings of the inspection for each beach moving south from Bramston Beach, including photography, beach profile survey, debris line survey and inundation levels at each location. Photographs of each beach are provided.

Table 4: Post TC Yasi inspection activities during 07–10 February 2011

Location	Date	Remarks
Pallarenda Beach	08/02/2011	Beach profile x 3, debris line x 2, photography.
Saunders Beach	08/02/2011	Beach profile x 3, debris line x 2, photography.
Balgal Beach	07/02/2011	Beach profile x 4, debris line x 2, photography.
Forrest Beach (Ingham)	07/02/2011	Beach profile x 4, debris line x 1, photography.
Lucinda	07/02/2011	Beach profile x 2, debris line x 1, photography.
Cardwell	08/02/2011	Beach profile x 2, debris line x 1 photography.
Hull Heads	09/02/2011	Beach profile x 2, debris line x 1, photography.
Tully Heads	09/02/2011	Beach profile x 1, photography.
Clump Point	09/02/2011	Beach profile x 4, photography.
Bingil Bay	09/02/2011	Beach profile and debris lines taken.
Mission Beach	10/02/2011	Beach profile x 1, debris line x 1, photography.
Etty Bay (Innisfail)	10/02/2011	Beach profile x 1, debris line x 1, photography.
Bramston Beach	11/02/2011	Beach profile x 2, debris line x 1, photography.

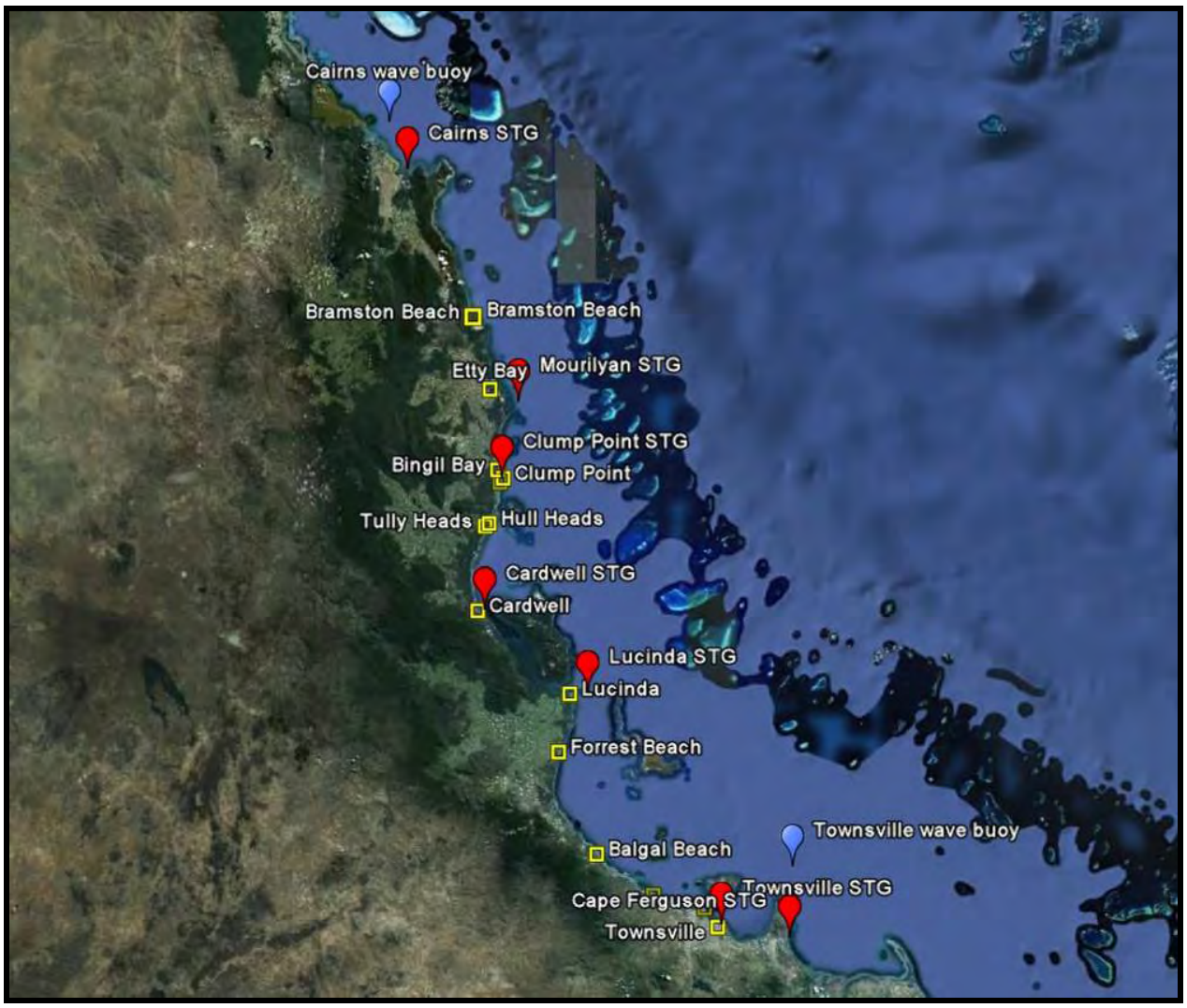


Figure 15: Areas surveyed post TC Yasi, and DSITIA monitoring instrument locations

4.2 Beach conditions

The communities located at beaches between Bramston Beach and Pallarenda were inspected from 7–11 February 2011. Debris deposits were located at many of the sites which allowed for an indication of the storm tide inundation, but due to the rapid response of volunteers, emergency crews and local residents carrying out clean up activities, some of the survey debris line data may be mistaken and interpretation of these lines should be treated with caution. The following sub-sections detail the findings made during each beach inspection, presented from north to south, starting at Bramston Beach.

As expected, the major impact from TC Yasi occurred to the coast on the southern side of its track (in the vicinity of the radius of maximum winds) for beaches facing an east to south-east direction, which were the areas of greatest exposure to onshore winds.

Bramston Beach

Location: Bramston Beach is located about 20 kilometres north of Innisfail, north of the where TC Yasi made landfall.

Orientation: The coastal alignment of the foreshore at Bramston Beach is northeast.

Cyclone impacts: Bramston Beach is located 60 kilometres north of where the eye of TC Yasi crossed the coastline resulting in comparatively minimal damage to this region. The inspection was carried out to the south and north of the groyne. Examination of the picnic area in the campgrounds to the south of the groyne indicated that the water level had overtopped the foredune and sand had been washed onto the grassed area some 10 metres behind the dune. There had also been some localised erosion on the northern side adjacent to the groyne, evident by fallen trees. Damage to the beach was minimal.

Debris Lines: Debris lines (predominantly pumice) indicative of inundation were found in the caravan park to the south of the groyne. Less convincing lines were found to the north of the groyne, but these were slightly lower than the height of the foredune which indicated these lines could have been from a high tide following TC Yasi.

Photograph 5: Minor damage - Caravan Park toilet block at Bramston Beach (Source: DSITIA)

Photograph 6: Debris and minor beach scarping at Bramston Beach (Source: DSITIA)

Figure 16: Bramston Beach surveyed beach profiles and debris lines (yellow triangles)

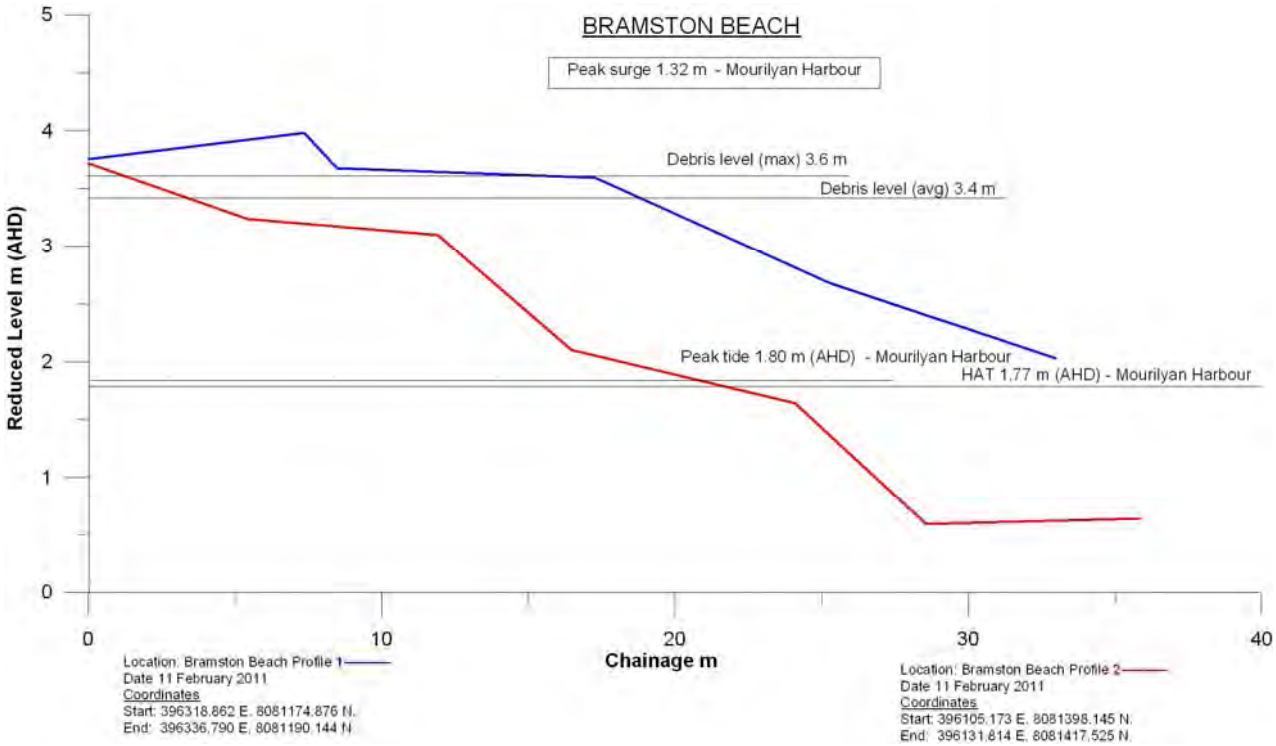


Figure 17: Beach profiles and debris levels surveyed at Bramston Beach

Etty Bay

Location: Etty Bay is located south of Innisfail, north of where TC Yasi made landfall. Etty Bay is characterised by a gentle sloping beach backed by a surf lifesaving clubhouse, a small caravan park and kiosk, and is encompassed by the Moresby Range.

Orientation: The coastal alignment of the foreshore at Etty Bay is northeast.

Cyclone impacts: Etty Bay is located 30 kilometres north of where the eye of TC Yasi crossed the coastline resulting in comparatively minimal damage to this region. In addition, Etty Bay was protected by the surrounding Moresby Range, buffering the full impact of westerly winds generated within the northern half of the cyclonic system. As a result, property and vegetation damage were minimal compared to other coastal locations to the south. The inspection found minimal beach erosion, with some sand having been washed over the foredune. The only road into Etty Bay suffered minor damage.

Debris Lines: There were two distinct debris lines detected at Etty Bay, one at the toe of the dune and across the road in front of the surf life saving club and the other on the lower beach which could have been corrupted by the rising tides over the high tides following the event.

Photograph 7: Damage caused by TC Yasi at Etty Bay (Source: DSITIA)

Figure 18: Etty Bay surveyed beach profiles and debris lines (yellow triangles)

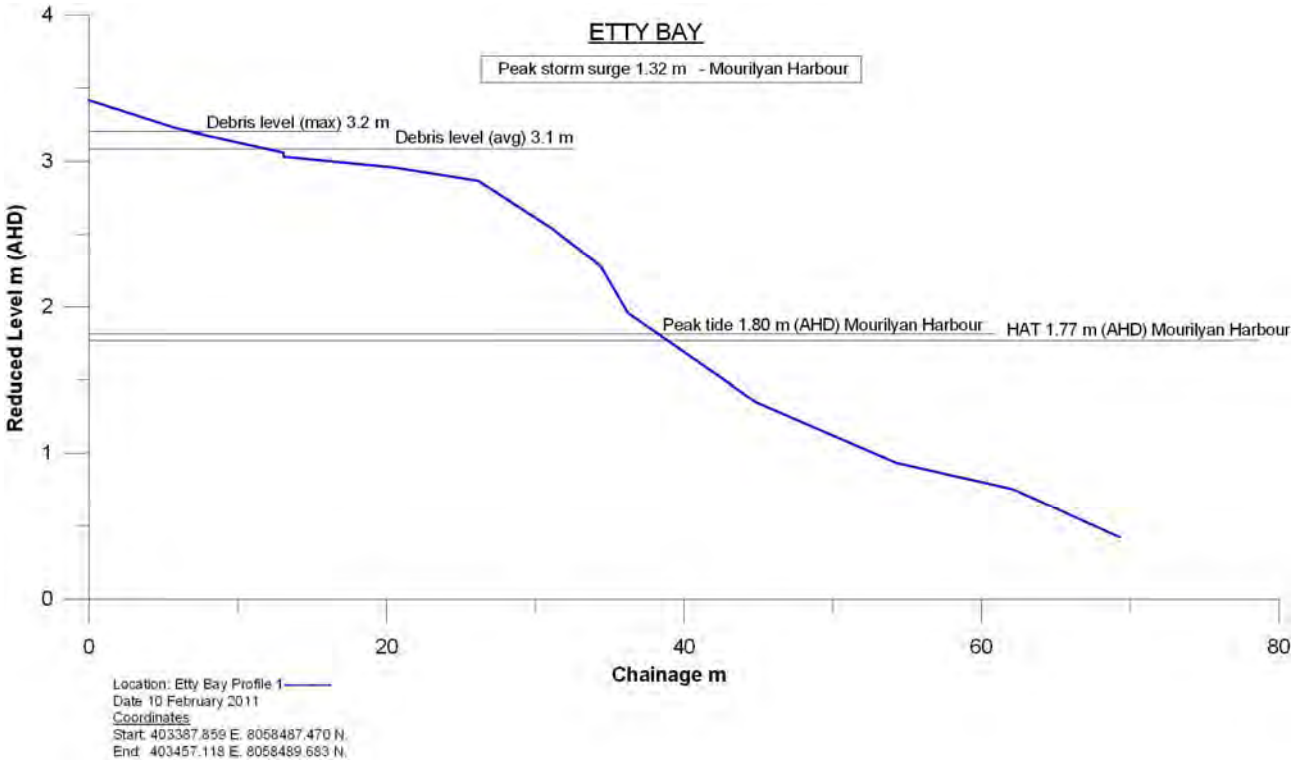


Figure 19: Beach profiles and debris levels surveyed at Etty Bay

Bingil Bay

Location: Bingil Bay is located approximately 33 kilometres south of Innisfail, just north of Mission Beach where TC Yasi made landfall. Bingil Bay is characteristic of many North Queensland beaches consisting of a moderately steep intertidal crest and trough system, with a slightly steeper narrow upper beach that meets a flat foredune.

Orientation: The coastal alignment of the foreshore at Bingil Bay is east-southeast. The sandy foreshore of the Bay is approximately 1 kilometre long and is bounded by headlands to the north and south.

Cyclone impacts: Evidence of TC Yasi's impacts to the Bingil Bay region included vegetation damage and damage to the road connecting Bingil Bay and Clump Point. Evidence of the damaged road and debris lines located between Clump Point and Bingil Bay are an indication of the storm surge in this area. A peak surge of 2.97 metres above the predicted astronomical tide was recorded at Clump Point (3 kilometres to the south). The surveyed beach profile lines at Bingil Bay (Figure 20) did not extend to the debris line.

Debris Lines: Maximum debris line levels were recorded at 4.8 metres AHD.

Photograph 8: Damage to road caused by TC Yasi between Clump Point and Bingil Bay (Source: DSITIA)

Photograph 9: Damage to road caused by TC Yasi between Clump Point and Bingil Bay (Source: DSITIA)

Photograph 10: Damage to coastal vegetation at Bingil Bay (Source: DSITIA)

Photograph 11: Damage to road caused by TC Yasi between Clump Point and Bingil Bay (Source: DSITIA)

Figure 20: Bingil Bay surveyed beach profiles and debris lines (yellow triangles)

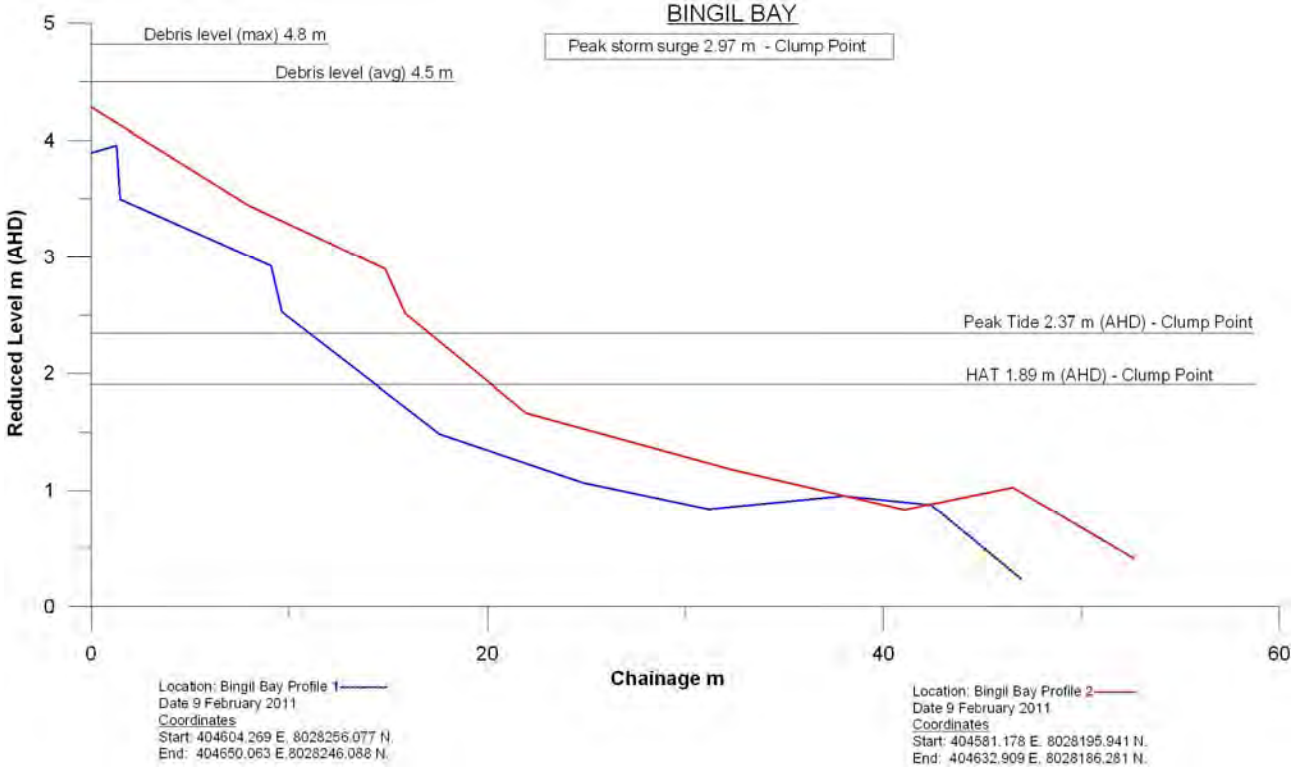


Figure 21: Beach profiles and debris levels surveyed at Bingil Bay

Clump Point

Location: Clump Point is located 110 kilometres south of Cairns and just north of Mission Beach where TC Yasi made landfall. Clump Point jetty is the location of one of DSITIA's storm tide gauges. This gauge has the ability to measure storm tide as well as barometric pressure and wind speed.

Orientation: The coastal alignment of the foreshore at Clump Point is just north of east

Cyclone impacts: The charter boat office adjacent to the jetty was extensively damaged with blown out roller doors and the walls completely destroyed, as well as holes and water damage to the lower sections of the internal cladding suggesting water depths of about 0.5 metres through the structure (about 3.5 metres AHD). The jetty had splintered decking and missing planks. It was evident that the repairs of the jetty carried out after TC Larry prevented more damage. The only evident damage to the storm tide gauge was the collapse of the anemometer. Although attempts are being made to retrieve some data from this device it appears the maximum wind speed was not captured. Clump Point storm tide gauge recorded peak water level at the 4.25 metres (LAT) compared to the jetty deck level of 4.27 metres (LAT). The water level recorded at the gauge does not include complete wave set-up or run-up and therefore the actual level may have been higher than the jetty itself, causing damage seen in the below photographs. The beach conditions do not appear to have been affected by TC Yasi. The approaches to the jetty had been undermined and electrical and water services had been severed to the jetty. Although generally a rocky beach, no apparent damage was evident.

Debris Lines: Debris lines were difficult to decipher at Clump Point jetty.

Photograph 12: Building and infrastructure damage caused by TC Yasi at Clump Point (Source: DSITIA)

Photograph 13: Damage to Clump Point jetty (Source: DSITIA)

Photograph 14: Damage to Clump Point jetty during TC Yasi (Source: DSITIA)

Photograph 15: Building damage caused by TC Yasi at Clump Point (Source: DSITIA)

Figure 22: Clump Point surveyed beach profiles

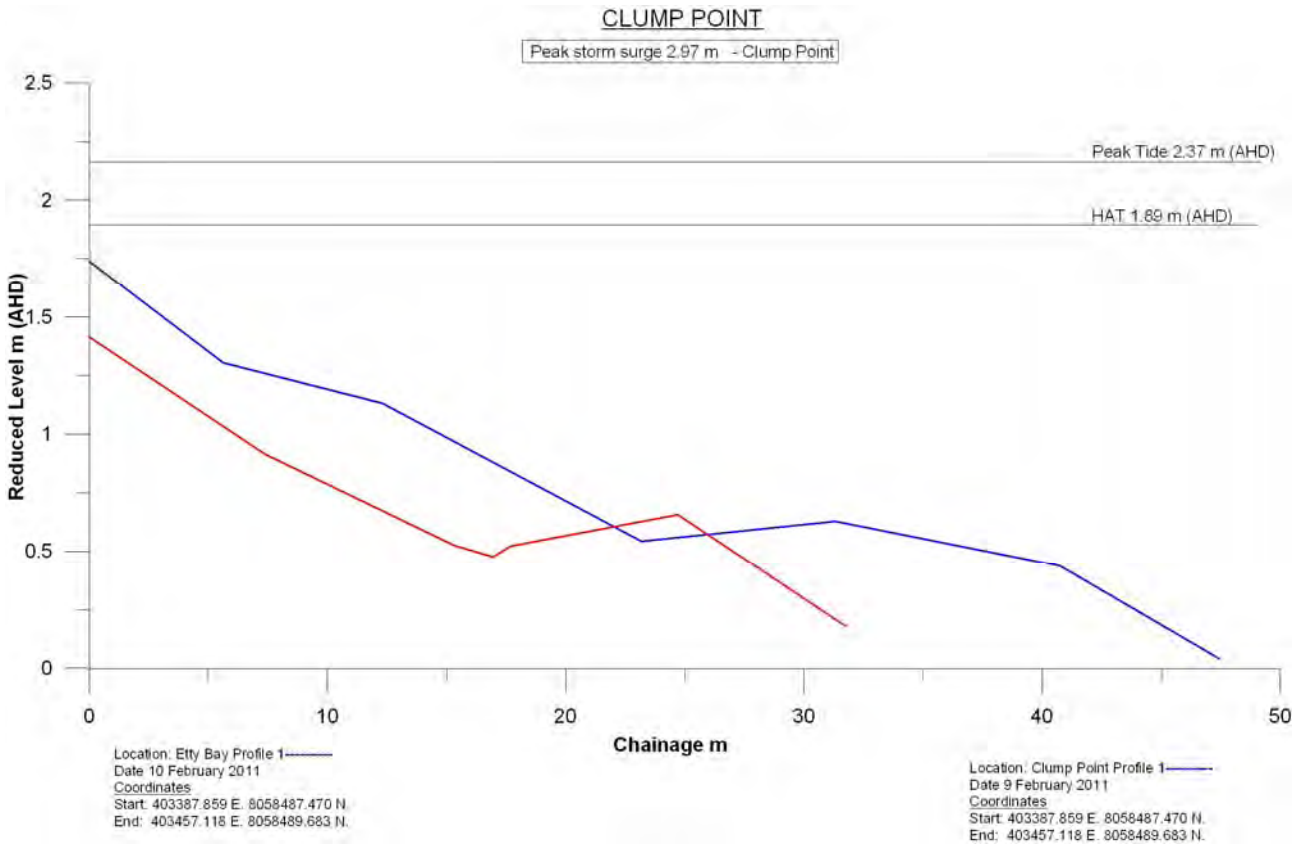


Figure 23: Beach profiles and debris levels surveyed at Clump Point

Mission Beach

Just south of Clump Point is the coastal settlement of Mission Beach. Mission Beach is a natural mid way point between Townsville and Cairns, and is made up of four beach villages linked by 14 kilometres of broad beach, a very popular place for visitors. Offshore are coral reefs and Dunk Island, which shelters the beaches. This is where TC Yasi crossed the coast. The beach escarpment lost approximately 5–10 metres, as evidenced by the number of coconut palms which had been uprooted or extensively undermined.

Orientation: Mission Beach is a gentle sloping dissipative beach facing east-southeast and has a wide intertidal zone sloping up to the vegetation line (mainly coconut palms) where it flattens out into the coastal ridge.

Cyclone impacts: TC Yasi caused widespread damage when it crossed at Mission Beach with a large destructive area that extended between Innisfail and Cardwell. Many communities in and around Mission Beach were left devastated, almost 1 month after TC Yasi hit, this area was still without power. Only the northern end of Mission Beach was inspected.

Debris Lines: Debris deposits of up to 1 metre high were found in low set beach front houses. Debris lines to a height of 3.5 metres AHD were recorded.

Photograph 16: Beach erosion caused by TC Yasi at Mission Beach (Source: DSITIA)

Photograph 17: Vegetation damage caused by TC Yasi (Source: DSITIA)

Photograph 18: Building damage caused by TC Yasi at Mission Beach (Source: DSITIA)

Photograph 19: Beach erosion and vegetation damage caused by TC Yasi at Mission Beach (Source: DSITIA)

Figure 24: Mission Beach surveyed beach profile and debris lines (yellow triangles)

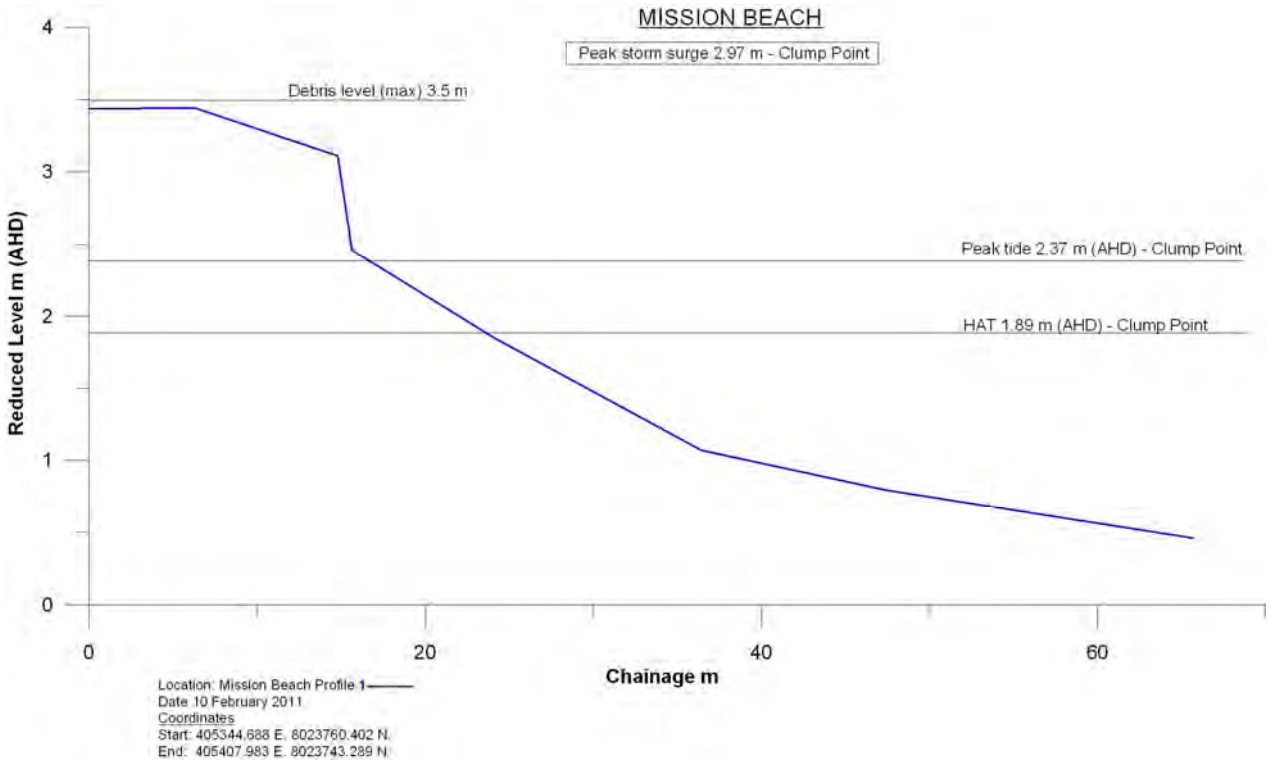


Figure 25: Beach profiles and debris levels surveyed at Mission Beach

Photograph 20: Coastal erosion at South Mission Beach following TC Yasi (Source: News Limited)

Hull Heads

Location: Hull Heads is located 55 kilometres south of Innisfail and approximately 5 kilometres from where TC Yasi made landfall at Mission Beach.

Orientation: The coastal alignment of the foreshore at Hull Heads is southeast. The settlement is bordered to the north by the Hull River. Bedarra Island sits approximately 8 kilometres due east of the Hull Heads settlement.

Cyclone impacts: Aerial photography shows the sand movement caused by the surge penetrated up to 100 metres from the foredune. Local residents reported the storm surge in this area to be the cause of far more damage than the high winds during TC Yasi. Some residents who sheltered upstairs in their homes watched as the storm surge washed through the downstairs of their homes, whilst other houses were completely washed away by the storm surge. It is not clear whether localised inundation in Hull Heads was caused by the storm surge or due to the influence of estuarine flooding caused by high rainfall. During the inspection, the Australian Volunteer Coast Guard (QF12) Flotilla Commander reported that 1.8 metres of water went through the Coast Guard building at the mouth of the Hull River. This would equate to a storm surge of 4.6 metres AHD (approximately 6.3 metres LAT) and would be consistent with storm surge levels recorded at the Cardwell storm tide gauge. A shipping container was moved 500–600 metres from the Hull Heads foreshore to the boat ramp downstream. Sand infiltrated extensively throughout the Hull Heads settlement.

Debris Lines: Debris lines were difficult to locate because (from interviews with local people) the storm surge continued east over the foredune, through the dwellings, meeting the rising waters from the Hull River coming from the west, leaving virtually no evidence of clear debris lines. The only debris lines recorded were inundation lines on properties and some debris left on fences and trees. The average height of the remaining debris was RL 4.3 metres AHD (approximately 6.0 metres LAT).

Photograph 21: Damage to Coast Guard building caused by TC Yasi at Hull Heads (Source: DSITIA)

Figure 26: Hull Heads surveyed beach profiles and debris lines (yellow triangles)

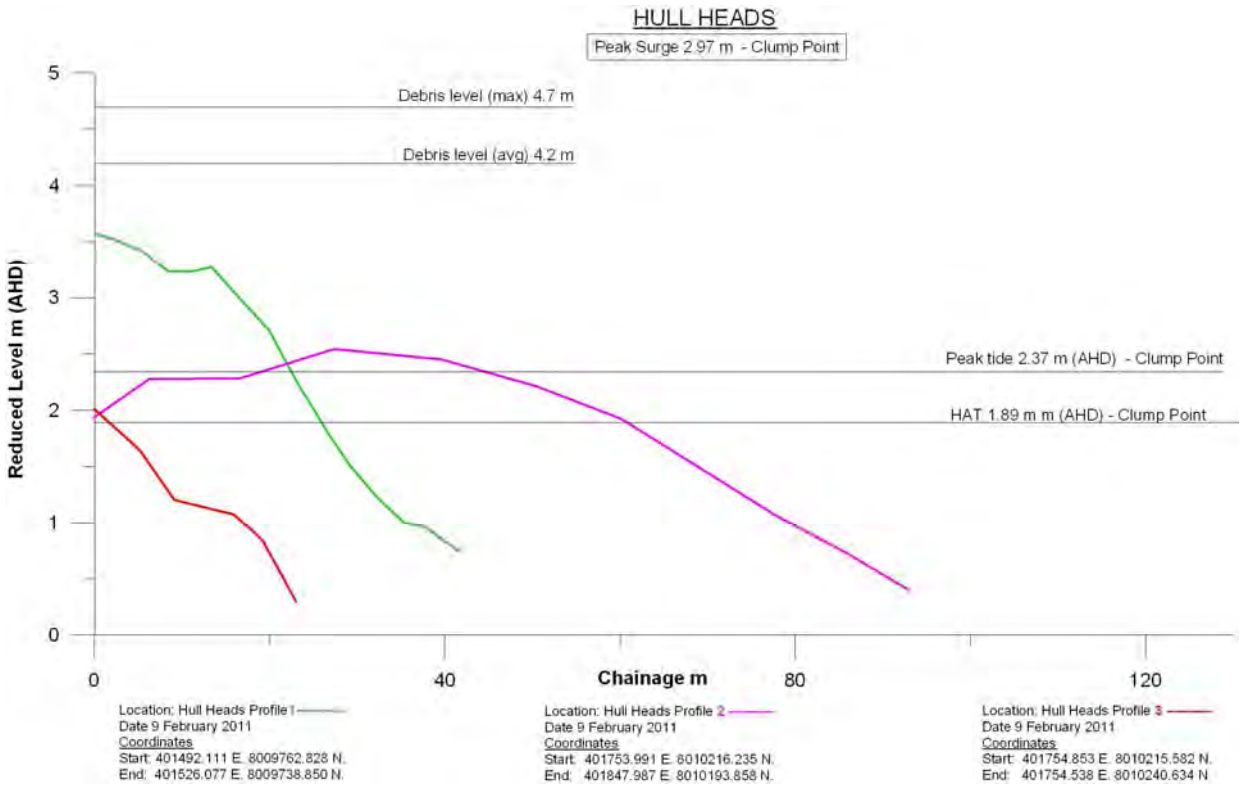


Figure 27: Beach profiles and debris levels surveyed at Hull Heads

Tully Heads

Location: Tully Heads is located 3 kilometres south of Hull Heads, approximately 20 kilometres south of where TC Yasi made landfall.

Orientation: The coastal alignment of the foreshore at Tully Heads is southeast.

Cyclone impacts: Being located only 3 kilometres south of Hull Heads, Tully Heads suffered similar devastation caused by the storm surge generated by TC Yasi. The esplanade road was severely damaged and large rocks were dislodged and moved inland from the foreshore revetment. The property damage at Hull Heads and Tully Heads was the worst seen throughout the surveyed area, due to the proximity of these two towns being located just south of the eye of TC Yasi as it crossed the coastline.

Severe damage was sustained to the existing rock wall at the southern end of Tully Heads. Soil erosion behind the crest of the rock wall as well as the inland movement of sand and rocks (up 0.5 metres diameter) indicated that there had been severe wave overtopping. Like Hull Heads, the storm surge at Tully Heads met the rising waters of the Tully River from the west. It was reported that more damage was done by the rising waters from the Tully River than by the storm surge over the fore dune. Containers at Tully Heads were also moved 300-400 metres (Photograph 23). Sand, pushed up by wind and the storm surge also inundated the properties as can be seen in Photograph 26. Erosion of the foreshore at Tully Heads has been an ongoing issue for many years. The continuous foreshore erosion was the primary reason the Bedarra View Caravan Park closed after TC Larry eroded the beach in 2006.

Debris lines: Like Hull Heads, debris lines were difficult to locate because (from local reports) the storm surge continued east over the foredune, through the dwellings, meeting the rising waters from the Tully River coming from the west, leaving virtually no evidence of clear debris lines. Recorded water marks on buildings and verbal accounts from local residents places the storm surge height above 4.6 metres AHD.

Photograph 22: Armour rocks from the seawall washed up by storm surge and increased wave energy during TC Yasi (Source: DSITIA)

Photograph 23: Building damage and relocation of shipping container during TC Yasi (Source: DSITIA)

Photograph 24: Building and vegetation damage caused by TC Yasi at Tully Heads (Source: DSITIA)

Photograph 25: Building and vegetation damage caused by TC Yasi at Tully Heads (Source: DSITIA)

Photograph 26: Sand intrusion and rock retaining wall destroyed by TC Yasi at Tully Heads (Source: DSITIA)

Photograph 27: Sand intrusion, vegetation damage and road destruction caused by TC Yasi at Tully Heads (Source: DSITIA)

Figure 28: Tully Heads surveyed beach profile

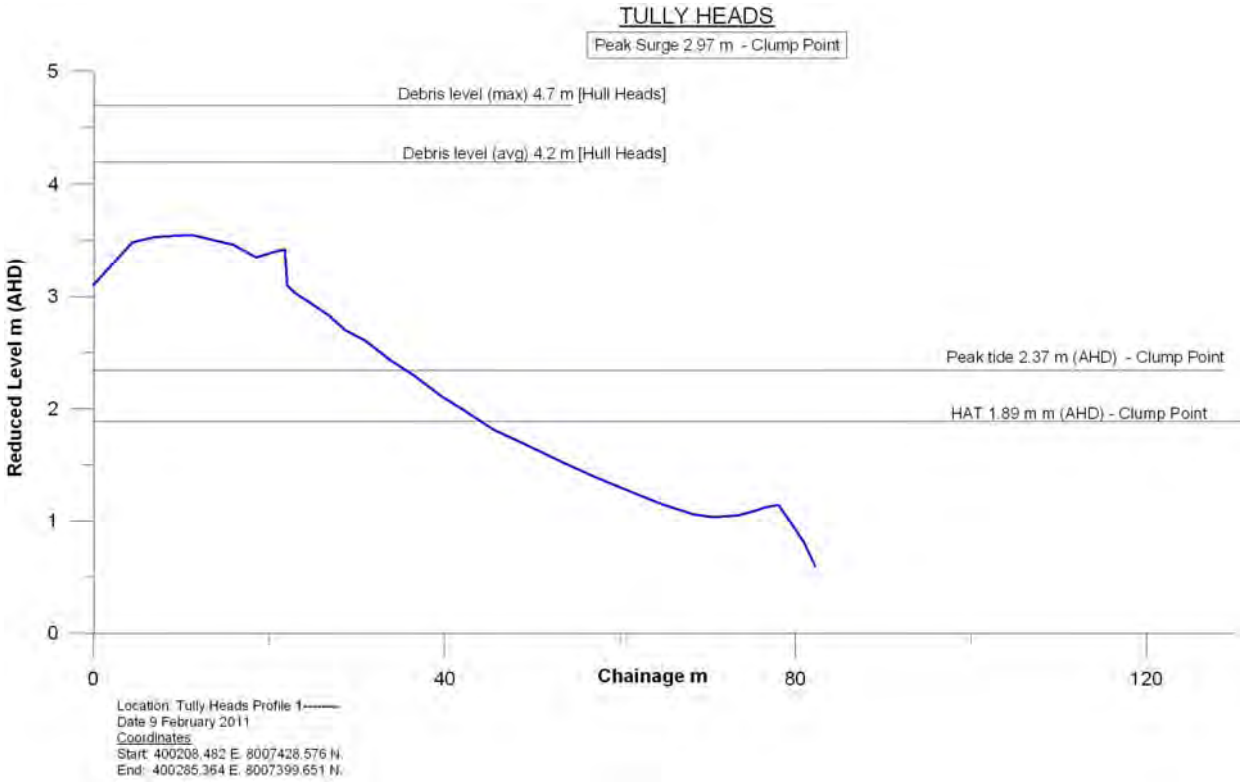


Figure 29: Beach profiles and debris levels surveyed at Tully Heads

Cardwell

Location: Cardwell is located approximately 45 kilometres south of Mission Beach where TC Yasi made landfall, placing Cardwell in the direct path of TC Yasi's damaging onshore winds and storm surge generated by the system.

Orientation: The coastal alignment of the foreshore at Cardwell is northeast.

Cyclone impacts: TC Yasi crossed the coast at Mission Beach 45 kilometres north of Cardwell, placing Cardwell on the southern side of TC Yasi's track and in the vicinity of the radius of maximum winds. TC Yasi caused wide spread devastation in Cardwell with damage to the highway and bringing power lines and vegetation down throughout the area. The trees lining the bank to the north of the jetty along Marine Parade were stripped of all foliage and the approaches to the jetty were destroyed. The Queensland Parks and Wildlife Service information building was damaged. The Port Hinchinbrook Marina, located just south of Cardwell was destroyed, with millions of dollars worth of yachts ripped apart and thrown inland due to the combined force of the storm surge and strong onshore winds.

Debris lines: Debris lines in this area were evident and widespread. Surveys of the debris lines extended landward of the main highway located adjacent to the foreshore.

Photograph 28: Damage to houses at Cardwell caused by TC Yasi (Source: News Limited)

Photograph 29: Jetty damaged by TC Yasi at Cardwell (Source: DSITIA)

Photograph 30: Damage to Port Hinchinbrook Marina, Cardwell, caused by TC Yasi (Source: News Limited)

Photograph 31: Coastal erosion and damage to buildings and infrastructure at Cardwell following TC Yasi (Source: News Limited)

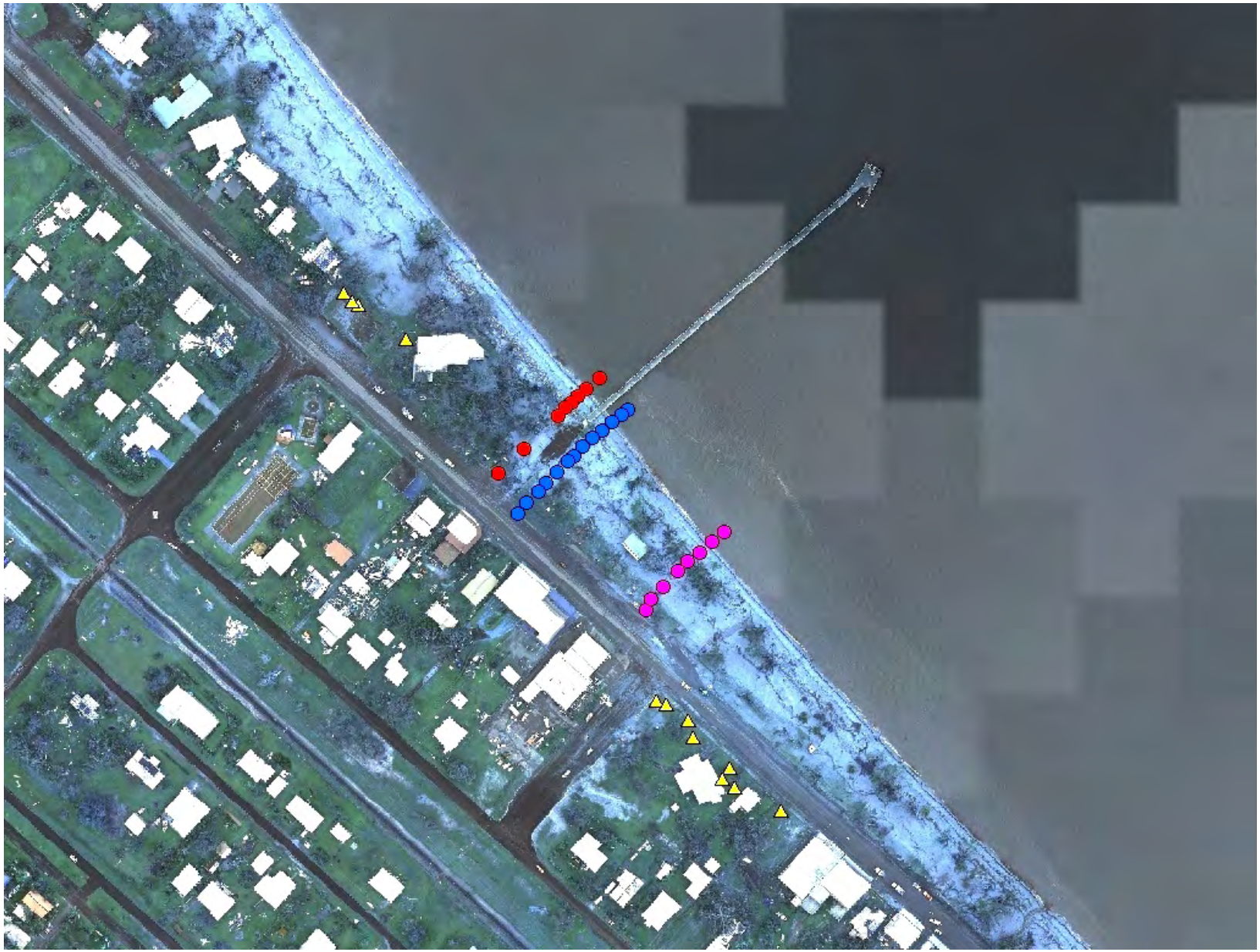


Figure 30: Cardwell surveyed beach profiles and debris lines (yellow triangles)

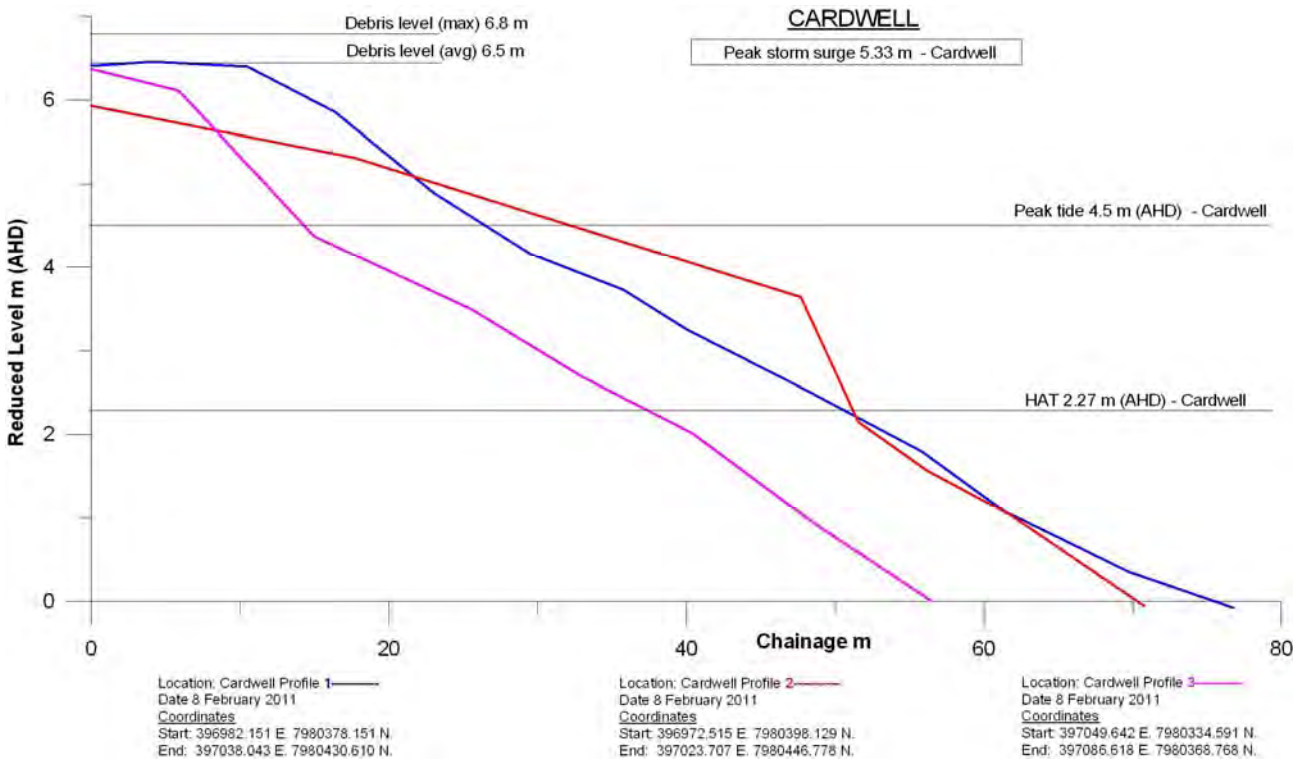


Figure 31: Beach profiles and debris levels surveyed at Cardwell

Lucinda

Location: Lucinda is located 115 kilometres northwest of Townsville and approximately 70 kilometres south where TC Yasi made landfall. Lucinda is home to an offshore sugar loading facility with a 5–6 kilometres long trestle extending from the mainland to the facility.

Orientation: The coastal alignment of the foreshore at Lucinda is north-northeast and east-northeast.

Cyclone impacts: Low lying areas of Lucinda were inundated and power was lost to the area for approximately 5 days. The beaches at Lucinda suffered only minimal damage. Several houses sustained damage; however the main damage caused by TC Yasi was to Lucinda's offshore sugar loading facility. Following TC Yasi, the regional harbour master declared an exclusion zone around the entire facility, including the 5–6 kilometres long trestle. During TC Yasi one of the department's storm tide gauges located offshore of Lucinda was completely destroyed (Photographs 32 and 33).

Debris lines: Debris lines were scarce due to the cleanup efforts of local residents and emergency workers. Pumice and debris lines were widespread in the park adjacent to the swimming enclosure and varied from 3.9 metres to 3.1 metres AHD. In hindsight, a check of the debris lines to the southern parts of Lucinda may have been a benefit but time did not allow for this.

Photograph 32: DSITIA's offshore storm tide gauge at Lucinda prior to TC Yasi (Source: DSITIA)

Photograph 33: DSITIA's offshore storm tide gauge at Lucinda - destroyed by TC Yasi (Source: DSITIA)

Photograph 34: Damage to Lucinda foreshore (Source: DSITIA)

Figure 32: Lucinda surveyed beach profiles and debris lines (yellow triangles)

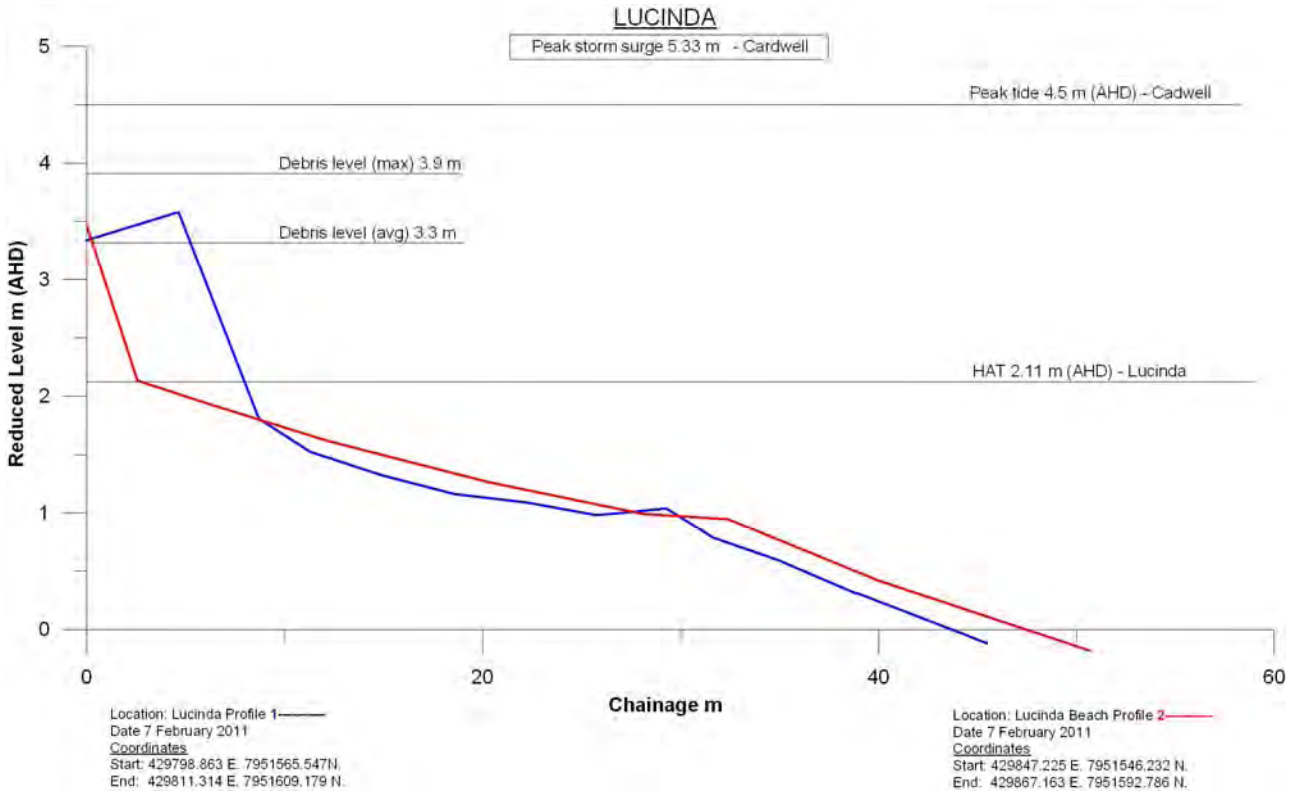


Figure 33: Beach profiles and debris levels surveyed at Lucinda

Forrest Beach (Allingham)

Location: Forrest Beach, also known as Allingham, is located approximately 15 kilometres south of Lucinda and 20 kilometres east of Ingham. Forrest Beach's coastal frontage comprises a 7 kilometres long sandy beach at the northern end of Halifax Bay, overlooking Orpheus Island and the Palm Island Group.

Orientation: The coastal alignment of the foreshore at Forrest Beach is southeast. Forrest Beach is bordered by the Palm Island Group approximately 20 kilometres due east.

Cyclone impacts: Forrest Beach suffered only minor erosion effects due to TC Yasi, most of the damage in the settlement was caused by falling vegetation and airborne debris. Although the storm surge reclaimed a significant volume of the upper beach, the foreshore of the settlement remained relatively intact.

Debris Lines: Pumice and debris lines were quite evident.

Photograph 35: Beach and dune erosion caused by increased wave action during TC Yasi at Forrest Beach (Source: DSITIA)

Photograph 36: Beach and dune erosion caused by increased wave action during TC Yasi at Forrest Beach (Source: DSITIA)

Figure 34: Forrest Beach surveyed beach profiles and debris lines (yellow triangles)

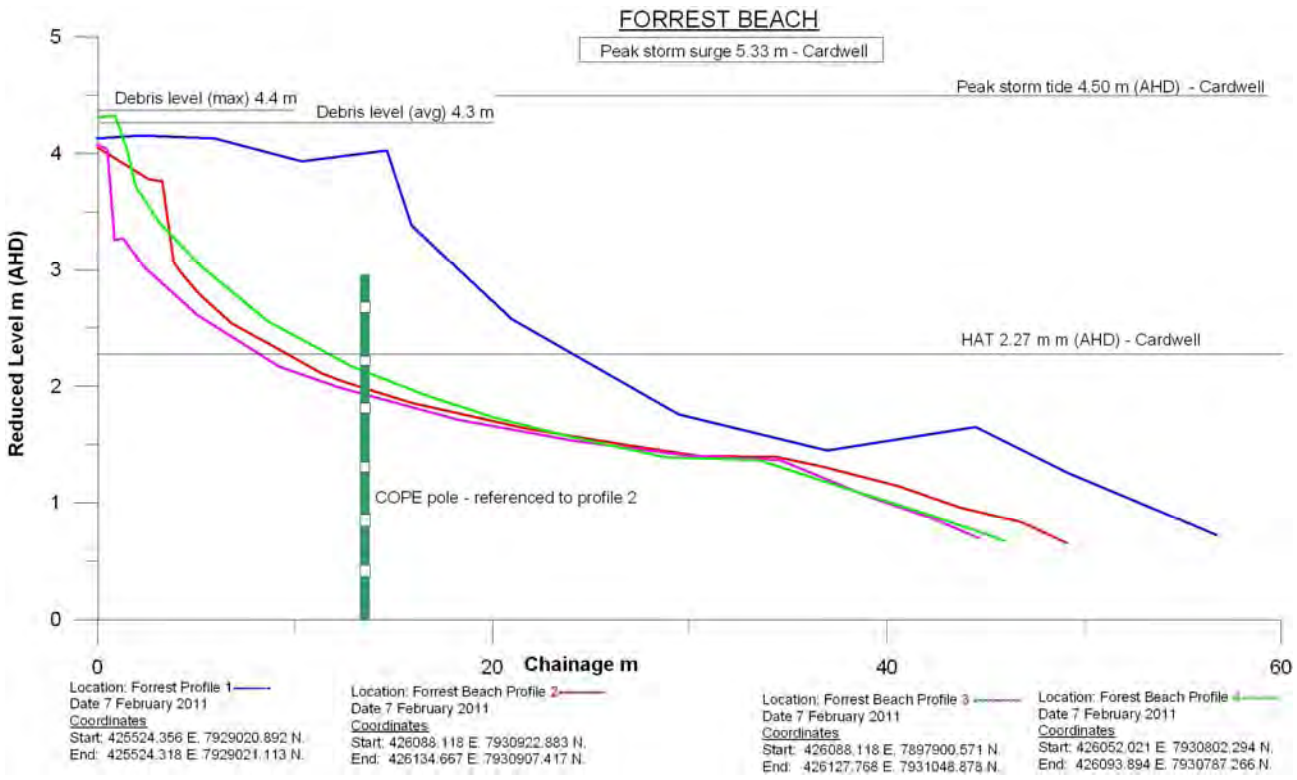


Figure 35: Forrest Beach surveyed beach profiles and debris (yellow)

Balgal Beach

Location: Balgal Beach is located 48 kilometres northwest of Townsville.

Orientation: The coastal alignment of the foreshore at Balgal Beach is northeast, the settlement lies on the western side of Halifax Bay. Approximately 20 kilometres due east lies Rattlesnake and Herald Island (on the eastern side of Halifax Bay).

Cyclone impacts: TC Yasi had little effect on infrastructure or property at Balgal Beach, except for superficial damage to the playground near Tooth Street. A significant volume of sand was eroded from the dune system on the foreshore, leaving a scarp which varied vertically from 0.5–1 metre.

Debris Lines: Due to the well developed, vegetated and steep backdune at Balgal Beach, debris lines were readily identifiable. The prominent debris line was situated approximately 0.5–1 metre higher than the top of the scarp.

Photograph 37: Dune erosion caused by increased wave action during TC Yasi at Balgal Beach (Source: DSITIA)

Figure 36: Balgal Beach surveyed beach profiles and debris lines (yellow triangles)

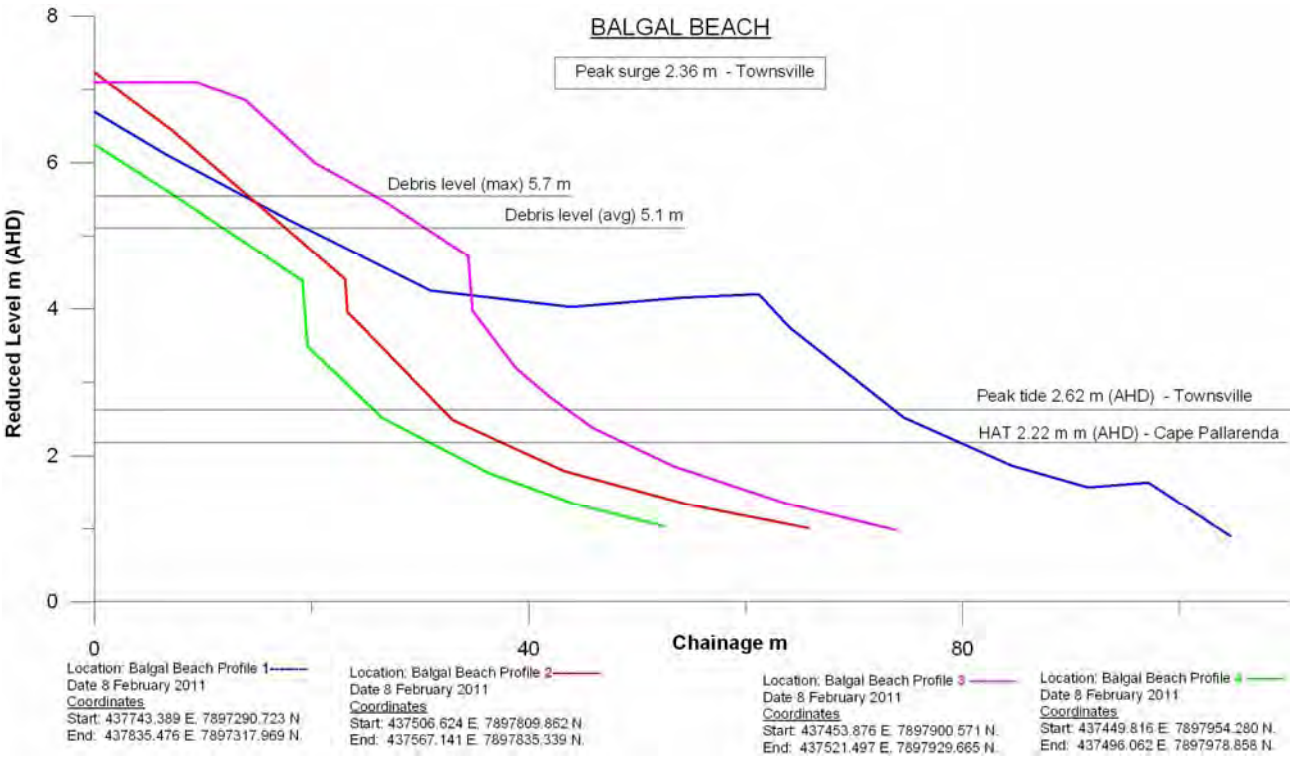


Figure 37: Beach profiles and debris levels surveyed at Balgal Beach

Saunders Beach

Location: Saunders beach is located 18 kilometres northwest of Townsville.

Orientation: The coastal alignment of the foreshore at Saunders Beach is northeast.

Cyclone impacts: The wind and storm surge associated with TC Yasi at Saunders Beach resulted in some sand infiltration across the foredune into the vegetated backdune, the foredune had also receded due to the storm activity between 2–10 metres. Approximately 50 per cent of the vegetation on the ocean-side of the foredune was undermined and ultimately collapsed due to the active sea state.

Debris Lines: Debris lines, composed typically of pumice and detritus, were distinct in steeper sloped backdune areas, as the slope of the backdune decreased, debris lines were harder to identify.

Photograph 38: Beach and Dune erosion caused by TC Yasi at Saunders Beach (Source: DSITIA)

Figure 38: Saunders Beach surveyed beach profiles and debris lines (yellow triangles)

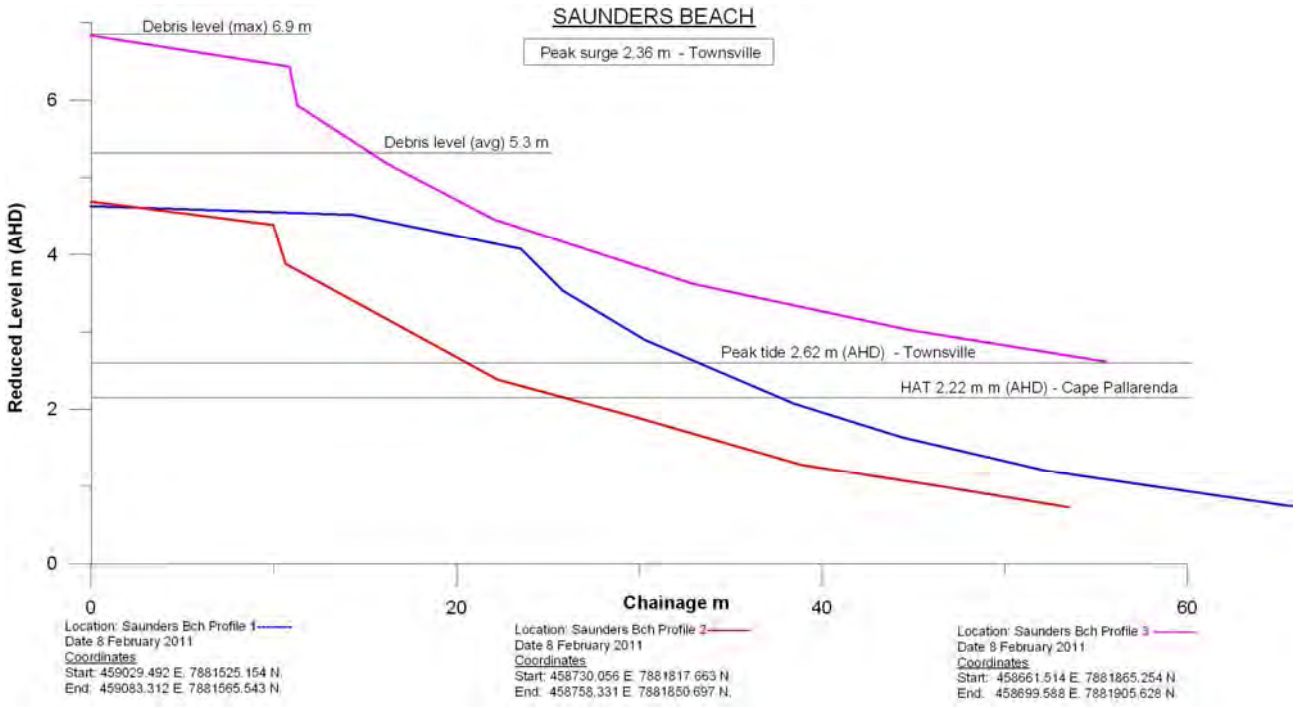


Figure 39: Beach profiles and debris levels surveyed at Saunders Beach

Pallarenda

Location: Pallarenda is located 8 kilometres northwest of Townsville.

Orientation: The coastal alignment of the foreshore at Pallarenda is easterly.

Cyclone impacts: Significant sand infiltration was notable at Pallarenda, but the rapid response of council made discerning the upper limits of the storm surge difficult. The previously intact swimming enclosure was destroyed and a yacht had been relocated to the foredune.

Debris Lines: Location of debris lines at Pallarenda was impeded by the swift clean-up response by council, emergency workers, and volunteers, although small distinct clusters of pumice and detritus were still identifiable in some locations.

Photograph 39: Damage to swimming enclosure caused by TC Yasi at Pallarenda (Source: DSITIA)

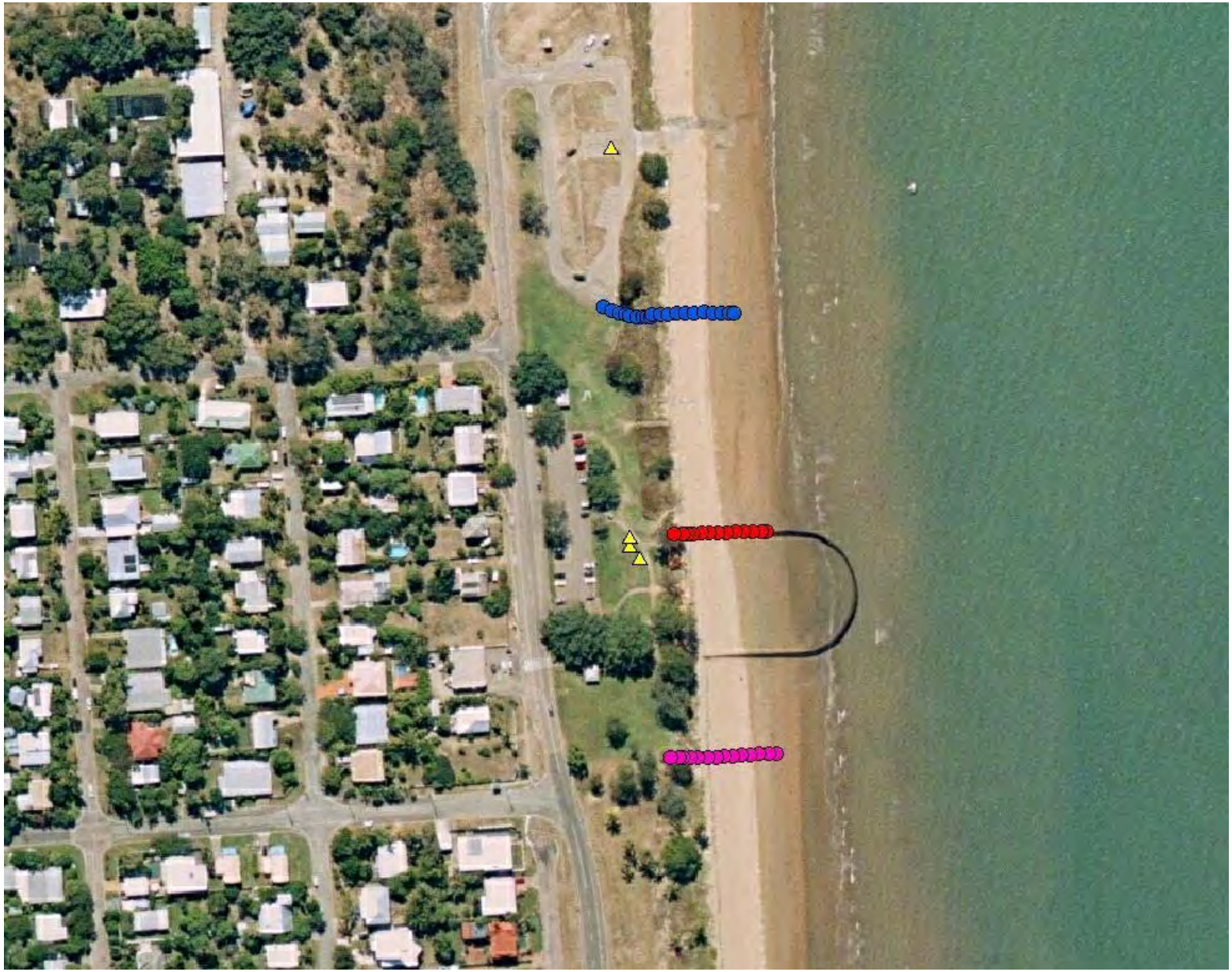


Figure 40: Pallarenda surveyed beach profiles and debris lines (yellow triangles)

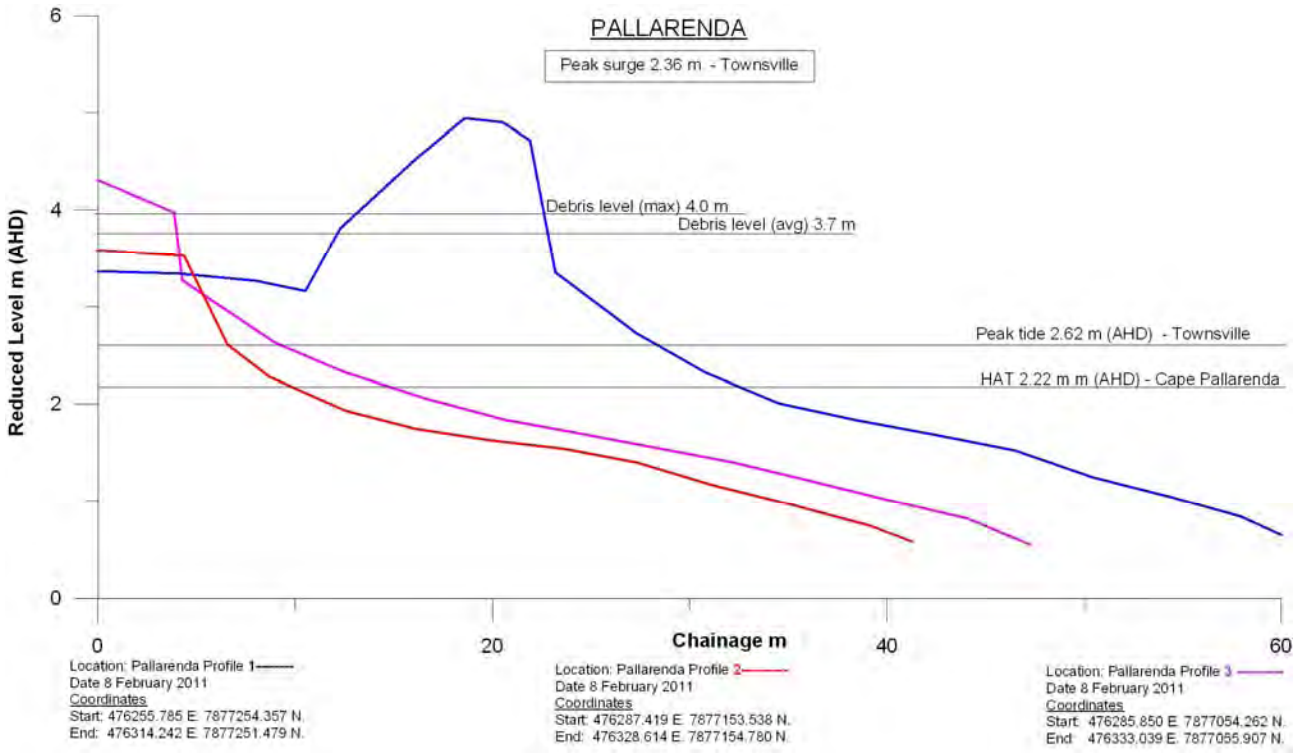


Figure 41: Beach profiles and debris levels surveyed at Pallarenda

5 Measured Inundation Levels

As noted in Section 2.1, during a tropical cyclone, the local rise in sea level is called a storm surge (Figure 42). When storm surge is combined with normal astronomical tide and wave set-up, it creates a storm tide. When a storm tide level is higher than the Highest Astronomical Tide (HAT), it is likely to cause inundation and flooding in coastal areas. The inundation level can thus be considered as the maximum water level reached, taking into consideration storm surge, wave set-up and wave run-up. As waves break on a beach, they raise the mean water level above the still water level of the sea, this is called a wave set-up. Wave run-up is the vertical distance above mean water level reached by the uprush of water from waves across a beach or up a structure. Wave run-up is a function of the beach steepness, wave height and wave period. When the storm surge combines with the normal astronomical tide and wave set-up and run-up, the resultant storm tide can cause damaging flooding in coastal areas.

The destructive capacity of a storm tide depends on the height of the tide at the time that the cyclone crosses the coast. The higher the tide, the more likely it is that destructive flooding and erosion will take place. The inundation produced by a storm tide is exacerbated by wave overtopping and localised intense rainfall and can lead to coincident flooding if combined with the effects of riverine (freshwater) flooding.

Photograph 40: The 5.33 metre storm surge during TC Yasi, 3 February 2011, damaged the Cardwell esplanade and deposited sand and debris above HAT (Source: News Limited).

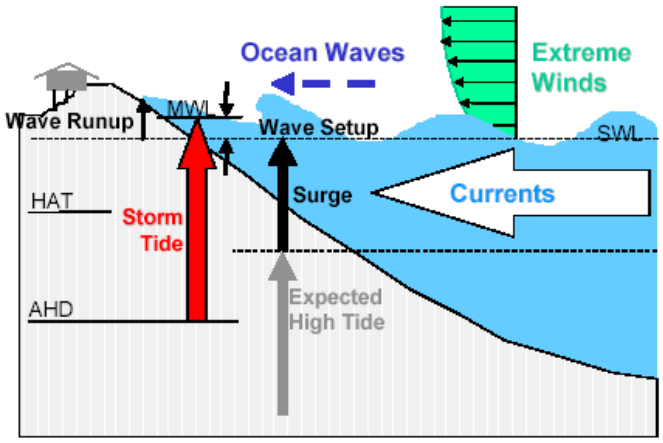


Figure 42: Water level components of a storm tide (Source: Dept of Natural Resources and Mines)

During the field inspection, debris lines were surveyed by the Coastal Impacts Unit at all locations identified in Section 3. The debris lines consisted mostly of pumice and vegetation as seen in photographs 41 and 42. Water marks on some structures (seawalls / public amenities) were also surveyed where relevant. A Real-Time-Kinematic (RTK) differential GPS system was used to measure (±0.02 metres) the elevation of the debris lines using known Permanent Survey Marks (PSMs) which relate the debris levels to Australian Height Datum (AHD). The surveyed inundation levels are presented in Table 5.

Photograph 41: Debris line used to survey storm tide inundation level (Source: DSITIA)

Photograph 42: Debris line used to survey storm tide inundation level (Source: DSITIA)

Table 5: Inundation levels surveyed during post-TC Yasi inspection

Inundation Levels (metres AHD)	Max value recorded	Average	Min value recorded	Standard Deviation	Vertical Range
Bramston Beach	3.65	3.43	3.00	0.20	0.66
Etty Bay	3.22	3.06	2.99	0.10	0.23
Clump Point	No debris located				
Bingil Bay	4.85	4.50	3.98	0.29	0.87
Mission Beach	3.54	3.48	3.41	0.04	0.12
Hull Heads	4.66	4.24	3.60	0.48	1.07
Tully Heads	No debris located				
Cardwell	6.88	6.53	5.96	0.26	0.92
Lucinda	3.89	3.31	2.89	0.31	0.99
Forrest Beach	4.42	4.31	4.08	0.09	0.33
Balgal Beach	5.66	5.08	4.05	0.50	1.61
Saunders Beach	6.95	5.29	4.44	1.04	2.52
Pallarenda	3.98	3.73	3.64	0.16	0.34

Table 6 presents data for the maximum measured inundation levels recorded at sites which are located in close proximity to DSITIA storm tide gauges. A comparison of the maximum inundation level (surveyed debris line) with the maximum recorded water level can provide an idea of the degree of wave set-up and run-up experienced along the shoreline in response to TC Yasi.

Table 6: Measured inundation levels and maximum recorded water levels

Location	Max recorded inundation level (metres AHD)	Max water level (metres above AHD) at closest operating storm tide gauge	Difference between max water levels and inundation (wave run-up)(metres)
Etty Bay	3.22	1.79 (Mourilyan)	1.43
Bingil Bay	4.85	2.37 (Clump)	2.48
Mission Beach	3.54	2.37 (Clump)	1.17
Cardwell	6.88	4.5 (Cardwell)	2.38

At Etty Bay, a maximum inundation level of 3.22 metres above AHD was surveyed during the field investigation. The maximum water level recorded at the nearby Mourilyan storm tide gauge was 1.79 metres. These results suggest that wave set-up and run-up processes were in the order of 1.43 metres.

At Cardwell, one of the worst affected regions during TC Yasi, a maximum inundation level of 6.88 metres above AHD was surveyed. The maximum water level recorded at the Cardwell storm tide gauge was 4.5 metres, suggesting that wave set-up and run-up processes were in the order of 2.38 metres.

Table 7 presents a comparison of inundation levels recorded at various locations during different cyclone events.

Table 7: inundation levels measured from previous cyclones compared with TC Yasi

Location	TC Winfred (metres AHD) 1986	TC Larry (metres AHD) 2006	TC Yasi (metres AHD) 2011
Etty Bay	3.7	4.5	3.2
Bingil Bay	–	5.2	4.9
Clump Point		3.9	–
Mission Beach	2.6	3.5	3.5
Hull / Tully Heads	–	3.2	4.7
Cardwell	–		6.9

This report has focused on surveys of the damage caused by TC Yasi to mainland coastal locations in Queensland. No attempt was made to investigate the effects on nearby islands, however Photographs 43 to 45 clearly show the extensive damage on Dunk Island. From the plotted peak storm surge heights shown on the right-hand side of Figure 43, it is clear that the peak of the storm surge caused by TC Yasi occurred over a swathe to the south of its path. Figure 43 also shows the small islands (of which Dunk Island is one) in this swathe where damage was known to have occurred, but where no survey information was collected for this report.

Photograph 43: Dunk Island Resort prior to TC Yasi (Source: News Limited)

Photograph 44: Dunk Island Resort following the destructive waves, storm surge and winds caused by TC Yasi (Source: News Limited)

Photograph 45: Damage and mass sand deposition at Dunk Island Resort caused by the several metre storm surge during TC Yasi (Source: News Limited).

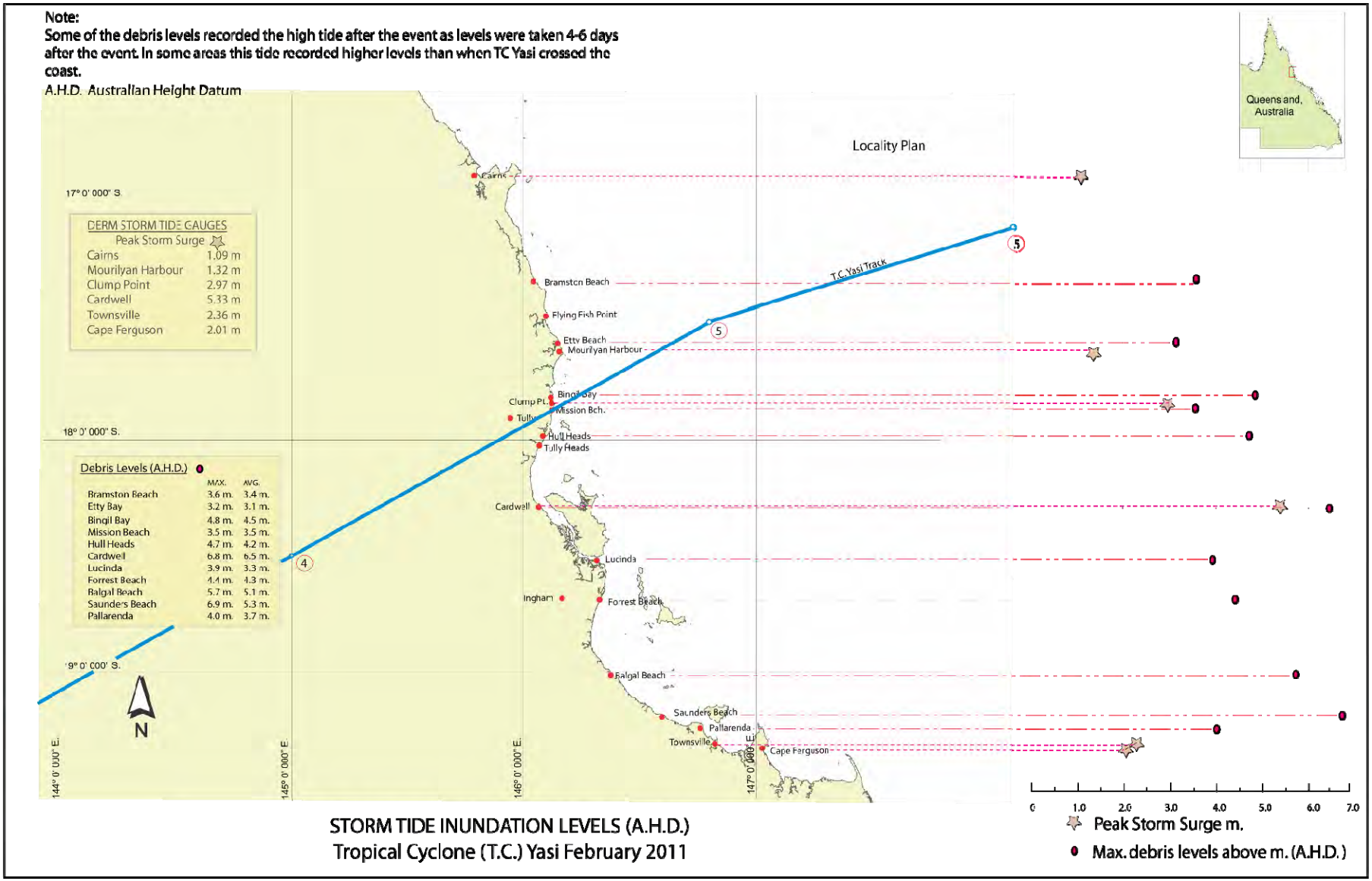


Figure 43: Storm tide inundation levels surveyed following TC Yasi