Tropical Cyclone Larry
Post Cyclone Coastal Field Investigation

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Queensland Government
Environmental Protection Agency

Coastal Sciences technical report

April 2007

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1. Introduction

Tropical Cyclone (TC) Larry crossed the coast near Innisfail, north Queensland between the coastal communities of Etty Bay and Mourilyan on Monday, 20 March between 6:20 and 7:20am during a neap tide (refer Figure 1). A 915hPa central pressure was estimated from satellite imagery at the time of crossing with accompanying wind gusts up to 290km/h. TC Larry was a fast moving intense cyclone with a 20 to 30km radius to maximum winds. The Queensland Premier and the Minister for Emergency Services signed a Disaster Declaration (Disaster Management Act, 2003 Section 69 – Subdivision 2) on Sunday afternoon (19 March 2006).

This event occurs only 12 months after TC Ingrid, a category 5 “midget” cyclone, crossed the east coast of north Queensland just north of Cape Sidmouth on 10 March 2005 between 5 and 7am (EPA, 2005). However, the last cyclone to cross the coast near Innisfail was TC Winifred. TC Winifred was a category 3 cyclone (central pressure of 957hPa) that crossed the coast at low tide just south of Mourilyan Harbour on the 1 February 1986 (BPA, 1986). Though not as intense as TC Larry, TC Winifred was a larger cyclone (40 to 50km radius to maximum winds) which travelled southwards parallel to the coast for a number of days, initially as a low, prior to tracking landwards on 31 Jan 1986 (refer Figure 2).

Before TC Larry crossed the coast, Queensland Environmental Protection Agency (EPA) staff were working together with the Commonwealth Bureau of Meteorology (BoM) and Department of Emergency Services (DES) personnel to provide storm tide level warnings and advices for the threatened coastal communities. This included monitoring measured storm tide levels, being the cumulative water level arising from the tide, surge, and wave set-up, through the EPA storm tide network.

Following the event, officers from EPA, including Queensland Parks and Wildlife Service (QPWS), and BoM completed a field investigation in March 2006. The objectives of the inspection were to determine the extent of storm tide inundation by preliminary estimates of the height of observed debris lines and watermarks, and the impact of TC Larry on coastal communities between Bramston Beach to the north and Cardwell to the south. Photographs and video were used to record the damage.

This report summarises the results of the March 2006 field investigation in terms of coastal impacts, recorded storm tide levels and surveyed inundation levels. The report also incorporates the additional survey analysis undertaken in August 2006 (Cleaves et al, 2007), to provide a complete assessment of inundation levels following TC Larry. Some comparisons are also provided in relation to TC Winifred.

2. Recorded data

2.1. Storm tide data

The EPA operates a storm tide system comprising 22 tide gauges along the Queensland coastline (refer www.epa.qld.gov.au/tides). This allows near real-time access to tide data via the public telephone network during events to monitor the effects of coastal flooding from tidal surge.

For this event, tide data was obtained from the Townsville, Lucinda, Cardwell, Clump Point, Mourilyan and Cairns gauges. Plots of the records for the most affected sites at Cardwell, Clump Point and Mourilyan are shown in Figure 3 (refer EPA, 2006). Table 1 shows a list of the maximum storm tides recorded at each of the storm tide gauges. Although high storm tides were experienced at some sites, TC Larry crossed on a neap tide resulting in total water levels that were less than 1m above the Highest Astronomical Tide (HAT).

Table 1. *Recorded storm tide levels on 20 March 2006*

Location	Time	Surge + Setup (m)	Storm Tide (m AHD)	HAT (m AHD)
Cairns	09:00am	0.51	0.87	1.78
Mourilyan	07:30am	1.34	1.56	1.65
Clump Point	07:00am	2.30	2.57	1.91
Cardwell	08:10am	1.76	2.17	2.20
Lucinda	08:00am	0.86	1.15	2.05
Townsville	10:00am	0.77	1.19	2.15

The recorded water level at Mourilyan during the peak of the storm tide was approximately 0.1m below HAT. The measured peak surge was 2.30m at Clump Point, causing a storm tide that was 0.66m above HAT. This compares with the measured peak surge of 1.8m at Clump Point during TC Winifred (BPA, 1986). The total

storm tide levels on the shoreline may be in the order of 0.5m higher than the levels provided in Table 1 owing to additional wave set-up.

Although about 77km south of the crossing point of the cyclone, Cardwell also recorded elevated water levels just below HAT.

2.2. Wave data

The EPA operates a network of wave monitoring stations along the Queensland coastline (refer www.epa.qld.gov.au/waves). Sites at Mackay, Townsville and Cairns were monitored during this event (Figure 2). Unfortunately, there are no wave sites within close proximity of the affected area.

Peak significant wave heights recorded at these stations are shown in Table 2 along with respective wave height rankings compared to the total record of wave data for each site. The significant wave height is defined as the average of the highest one third of the zero up-crossing wave heights in a 26.6 minute wave record.

Table 2. *Recorded significant wave heights.*

Site	Hsig (m)	Date / Time	Rank
Mackay	3.2	21/03/2006 21:00	13
Townsville	2.9	20/03/2006 08:00	3
Cairns	1.4	20/03/2006 09:00	12

Table 3 shows the maximum individual wave heights (Hmax) recorded at these stations during the event.

Table 3. *Maximum recorded individual wave heights.*

Site	Hmax (m)	Date / Time	Rank
Mackay	6.8	19/03/2006 19:00	5
Townsville	5.3	20/03/2006 08:00	3
Cairns	2.7	20/03/2006 10:00	14

The cyclone was quite fast moving and crossed the coast in a location where the Great Barrier Reef (GBR) is in the order of 30km from land. These factors together with the shallow depth of the GBR lagoon would have combined to limit the wave conditions. To assess the potential wave heights within the study area, simple wave hindcasting methods (USACE, 2003) were adopted for a shallow restricted wind fetch bound by the GBR. The peak significant wave heights in the GBR lagoon are estimated to range up to 6m with peak periods up to 8s. In the Kurrimine to Mission Beach area, waves are further depth limited and are likely to be no more than 2 to 4m. Debris on the Clump Point jetty railing (Photo 28) suggests wave heights in the order of 1 to 2m (given the measured peak storm tide was at deck level).

This is further supported by the work undertaken by James Cook University (JCU), where they developed an Atlas of Tropical Cyclone Waves in the Great Barrier Reef using an in-house modified wave model based on WAM Cycle 4 (JCU, 2004). For a location within the GBR lagoon and offshore of Dunk Island the significant wave height ranges from 4 to 5.8m for a 1 in 20 yr to 1 in 50 yr event respectively.

Further south, the Townsville region experienced gale force winds for around 12 to 16 hours. The Cape Cleveland wave recording station recorded peak waves of 2.9m (Hsig) at around the time of the cyclone landfall. For Mackay, the peak Hmax of 6.8m during this event is the fifth largest recorded by the EPA at this site since recordings commenced there in November 1977. Plots of wave heights and periods from the Mackay, Townsville and Cairns wave recording stations are shown in Figure 4. Peak wave directions are also shown for Mackay.

3. Sequence of inspection activities

Visual inspections of the affected coastal areas were undertaken by staff from Regional and Central Office EPA, and BoM on 26-28 March 2006. Central Office EPA, QPWS, and BoM officers were also involved with topographic surveys of the inundation levels and beach profile surveys of the most eroded beaches on 28-30 March 2006. Staff from Johnstone Shire Council (JSC) attended beach and rock wall inspections from Flying Fish Point to Kurrimine on 27 March 2006. A chronology of the inspection activities is summarised below in Table 4. The locality of these beaches is provided in Figure 1.

A subsequent field inspection was undertaken in August 2006 to collect further survey data in support of the findings from the March inspection. Details of the August inspection can be found in Cleaves et al (2007).

Table 4. *Inspection activities during 26 to 30 March 2006.*

#	Date	Time	Location	Remarks
1	26/3/06	3:30pm	Bramston Beach	Inundation water line and beach erosion (video and still photography).
2	27/3/06	9:00am	Innisfail	Met with JSC at the Works depot. Council officers accompanied for inspections from Flying Fish Point to Kurrimine.
3	27/3/06	9:30am	Flying Fish Point	Inspected rock wall and beach near public toilet block (video and still photography).
4	27/3/06	11:55 am	Etty Bay	Inundation level recorded (video and still photography).
5	27/3/06	12:30pm	Mourilyan Harbour	Checked water level to verify storm tide gauge readings (still photography).
6	27/3/06	1:24pm	Cowley Beach	Inundation level, beach erosion and boat ramp inspected (video and still photography).
7	27/3/06	2:48pm	Kurrimine	Inundation level, beach erosion and boat ramp inspected (video and still photography).
8	27/3/06	5:30pm	Cardwell and Port Hinchinbrook	Beach erosion and inspection of rock wall (video and still photography).
9	28/3/06	7:30am	Cardwell jetty and storm tide gauge	Inspection of storm tide gauge.
10	28/3/06	9:00am	Tully Heads / Bedarra View caravan park	Inundation level, beach erosion and rock wall inspected (video and still photography).
11	28/3/06	10:05am	Hull Heads	Beach inspection (still photography).
12	28/3/06	10:55am	South Mission Beach.	Inundation level and beach erosion (video and still photography).
13	28/3/06	11:56am	Wongaling Beach	Inundation level and beach erosion (video and still photography).
14	28/3/06	12:45pm	Mission Beach	Inundation level and beach erosion (video and still photography).
15	28/3/06	1:38pm	Clump Point	Inspect damage to jetty and storm tide gauge. Retrieve data from the storm tide gauge and replace the memory card.
16	28/3/06	3:00pm	Garners Beach	Inspect inundation level (video and still photography).
17	28/3/06	3:40pm	Bingil Bay	Inspect inundation level (video and still photography).
21	28/3/06 to 30/3/06		Tully Heads to Flying Fish Point	Topographic survey of inundation levels and survey of a beach profile at Bingil Bay.

4. Beach conditions

The beaches from Bramston Beach to Cardwell were inspected from Sunday 26 March to Tuesday 28 March 2006 (approximately 100km stretch of coastline), a week after the event. The tides over this period were increasing into spring tides, which would have corrupted debris lines on the foreshore for locations where there was no overtopping of the beach ridge or dune system. The following sections detail the findings of the inspection for each beach moving south from Bramston Beach. Photographs of each beach are provided in appendix B. For completeness, the beach profiles surveyed in August 2006 are also included in appendix A. A description of the rate of beach recovery observed during the August 2006 inspection can be found in Cleaves et al (2007).

It is expected that the major impact from TC Larry would occur on the southern side of the cyclone track in the vicinity of the radius of maximum winds (i.e. between Cowley beach and Clump Point) for beaches facing a more east to south-east direction, as this would be the region of maximum onshore winds.

4.1. Bramston Beach

Bramston beach is located about 20km north of Innisfail. The inspection was to the direct south and north of the groyne. Examination of the picnic area to the north of the groyne indicates that the water levels just overtopped the foredune and beach sand had been washed over onto the grassed area some 10m behind the dune. There had also been some localised erosion on the northern side adjacent to the groyne.

4.2. Flying Fish Point

Flying Fish Point is situated just north of Innisfail and the Johnstone River. The southern beach area had beach sand washed over the foredune to the edge of the road. Abrasion on a tree trunk indicates that the water level overtopped the dune by less than 0.1m. To the north, a rock wall protects residential development. The rock wall experienced some damage with exposure of the geotextile membrane under the primary armour layer, and also undermining of the concrete capping behind the rock wall crest. Debris lines in the backyards of houses, undermining of the concrete capping, and inshore movement of smaller rocks (diameter about 0.4m) indicates that wave overtopping occurred.

4.3. Etty Bay

Etty Bay is located just south of Innisfail and in close proximity to where TC Larry crossed the coast. The bay is the surfing beach for Innisfail and is characterised by a gentle sloping beach backed by a surf life saving building, a small caravan park, and then the Moresby Range. There is no sign of any erosion of the beach, rather it appears that sand has been washed over the foredunes. There are two distinct debris lines – at the toe of the dune and across the road in front of the surf life saving club. The lower beach debris line could have been corrupted by the rising tides over the week following the event.

4.4. Mourilyan Harbour

Mourliyan Harbour was visited to inspect the integrity of the storm tide gauge. There was no apparent sign of any damage to the housing structure. At the head of the rock wall, there are signs of wave run-up and minor overtopping with a line of smaller grade rocks (less than 0.2m in diameter) washed inland about 10m.

4.5. Cowley Beach

Cowley beach is about 19km south of Innisfail, which is getting towards the region of maximum onshore winds to the south of the cyclone track. The area inspected was in the vicinity of the boat ramp. Cowley beach is a moderately steep beach with a developed offshore bar. There was no noticeable erosion scarp along the beach. Instead the foredunes were moderately sloped inshore and bare for 5 to 10m inland. There was extensive damage to the foredune vegetation, particularly uprooted trees as a result of sand loss and strong onshore winds. The exposed roots and positioning of the remaining palm trees indicates a possible 10m horizontal loss (0.2m vertical loss) of the foredune.

The concrete capping for the abutment of the boat ramp had been undermined from erosion of the soil beneath it by wave action. Clumps of bitumen from the boat ramp access road had been moved about 10m inshore. Sand had been washed over the esplanade road and there was debris (consisting mostly of pumice stone) along residential property boundaries (about 20m inshore of the foredunes).

Local residents provided anecdotal advice of storm tide levels about 0.2m over the esplanade road.

4.6. Kurrimine

Kurrimine beach is located about 28km south of Innisfail and is in the vicinity of the maximum onshore winds to the south of the cyclone track. The area inspected was the northern end of Kurrimine near the boat ramp off Bramble St. Adjacent to the boat ramp to the north is a small caravan park, which is bound to the north by a creek bordered by mangroves. Further north of the creek is more mangroves and Murdering Point. The beach has a relatively steep upper face with exposed tidal flats at low tide. Further offshore are the King Reefs.

The caravan park was extensively damaged by the cyclone with some caravans totally destroyed. A water line inside one of the remaining caravans indicated a water depth of 0.56m, corresponding to an inundation level of 3.5m (AHD). Substantial quantities of sand and debris had been washed through the caravan park into the back vegetation. Seaweed caught in the mangroves to the north and fallen trees on the beach further supported the surveyed inundation level. A 3m slab of concrete was moved some 30m inland from near the boat ramp.

The foredune in front of the caravan park has eroded about 10m in the horizontal causing cusping between the palm trees. A concrete caravan base was situated on the beach. In general, Kurrimine beach had 0.2 to 0.5m high erosion scarps along the foredune.

4.7. Garners Beach

Garners beach is about 31km south of Innisfail and is a shallow northeast facing embayment with a wide tidal flat zone at low tide, and a moderately steep and narrow upper beach. Further offshore is coral reef. Behind the beach is three houses and 60m high headlands.

The orientation and shallow nature of the beach would have sheltered it from large wave action. There were 0.3 to 0.5m high erosion scarps along the foredune and extensive fallen defoliated trees. On the day of the inspection, the sand was damp up to the fallen vegetation, indicating no useable beach on a high spring tide.

There was no distinguishable inundation line. Local residents at the southern end of Garners beach indicated that the water level reached about 0.4m on a house stump, however this level appeared lower than the frontal dunes. Further inspection of seaweed caught in the frontal vegetation suggests that the water level may have only been 0.1 to 0.2m above the frontal dune.

4.8. Bingil Bay

Bingil Bay is approximately 33km south of Innisfail, facing east. The beach at low tide consists of a moderately steep intertidal crest and trough system, with a slightly steeper narrow upper beach that meets the flat foredune. It is possible that the intertidal crest has accreted as a result of the surge from TC Larry.

To the north, there is a small creek that cuts across the beach. To the south, there is up to a 0.5m scarp in front of the foredune. Sand has been washed over the dunes onto Alexander Drive and there is a pumice stone debris line about 10m landward of the road that is in the order of 5cm thick. At the southern end, a rock revetment protecting Alexander Drive around the headland has slipped.

4.9. Clump Point

Clump Point was visited to inspect the integrity of the storm tide gauge. Although there was no apparent sign of any damage to the storm tide gauge and housing structure, the jetty structure and ancillaries were damaged. Seaweed on the lower rail and uplift of the timber decking on the jetty indicated that the combined storm tide and wave action exceeded the deck level. The recorded peak still water level at the Clump Point storm tide gauge of 4.25m (LAT) compared to the jetty deck level of 4.27m (LAT) still further supports this.

The charter boat office next to the jetty was extensively damaged with blown out roller doors, as well as holes and water damage to the lower sections of the internal cladding suggesting water depths of about 0.5m through the structure (about 3.5m AHD).

4.10. Mission / Wongaling / South Mission

The 10km easterly facing stretch of coastline between Clump Point and Tam-O'Shanter Point includes Mission beach to the north, Wongaling, and South Mission beach to the south. Offshore are coral reefs and Dunk Island, which shelters the beaches.

(i) Mission Beach

Mission beach is 2km south of the Clump Point jetty and is the southern limit of notable large-scale defoliation of vegetation. This gentle sloping dissipative beach faces east of southeast and has a wide intertidal zone sloping up to the vegetation line (mainly coconut palms) where it flattens out into the coastal ridge. At the time of the inspection (ie ebbing tide from a high spring tide close to HAT), the sand was moist up to the limit of the vegetation. In the vicinity of Castaways Resort there are up to 0.5m erosion scarps with recession between the coconut palms of up to 5m.

Inundation level assessments were hindered by recovery works that already had commenced in the area. Debris lines within the grounds of the resort suggest moderate wave overtopping of the beach ridge.

(ii) Wongaling Beach

Wongaling beach is situated 40km south of Innisfail and faces east. The beach exhibits a concave profile with a steeper upper beach and gently sloping low tide beach. The intertidal beach is narrower than Mission beach and there is an erosion scarp ranging from 0.2m to 1m. The high tide water line on the day of the inspection suggests the scarp at the vegetation line would be at or slightly higher than HAT. In the park area behind the beach there is an overflow of sand some 20m inshore from the beach.

A number of inundation levels were identified including:

- Debris lines near the back fences of residential housing to the south at Wheatley Creek.
- Water marks in the park public toilet block behind the beach that were 0.5m above ground level.
- Debris lines to the north on a sloping vacant lot on the inland side of Banfield Parade.

All these levels indicate the water level from the storm tide reached about 0.5m above the foredune.

(iii) South Mission Beach

South Mission beach is located about 44km south of Innisfail, facing southeast. The southern end of South Mission beach has been slowly eroding for the past 30 years and has been the subject of a coastal erosion

investigation and management options study (EPA, 2005). The beach inspection was undertaken at about mid-tide over a 2km stretch of coastline along Kennedy Esplanade north of the boat ramp.

The beach profile is similar to Wongaling beach, with a steep upper beach and gently sloping low tide beach. As with Wongaling, the high tide water line on the day of the inspection suggests the toe of the erosion scarp at the vegetation line would be at or slightly higher than HAT. There were about 0.5m high erosion scarps along the beach with erosion between the coconut palms. The beaches were in a similar state to the May 2004 condition detailed in EPA (2005).

Beach sand had washed over onto Kennedy Esplanade and a clear debris line was visible on the hill across the road. By the time of the inspection, most of the sand had already been cleaned up and dumped into the eroded areas between the coconut trees. The water level reached about 0.5m above ground level at the public toilet block towards the southern end.

4.11. Tully Heads

Tully Heads is located 55km south of Innisfail and faces southeast. The foreshore in front of the Bedarra View caravan park has retreated approximately 10m inshore such that coconut palms and a picnic table were now located on the beach. The erosion of this beach has been an ongoing issue for many years. At the time of the inspection (about one hour after peak high tide), the water line was close to the toe of the small erosion scarp (about 0.1m high) and there are a number of fallen coconut palms. Unconfirmed advice from local residents suggests the storm tide reached a depth of 0.7m at a house in the caravan park. There was also an influx of sand about 20m inshore of the foredune.

Some damage was sustained to the existing rock wall at the southern end of Tully Heads beach with slumping and exposure of the underlying geotextile fabric. Soil erosion behind the crest of the rock wall as well as the inland movement of sand and rocks (up 0.3m diameter) indicates there had been wave overtopping.
recede

4.12. Cardwell and Oyster Point

Cardwell is well away from the cyclone crossing location (about 80km south of Innisfail) but still experienced a substantial surge. Anecdotal advice suggests that the storm tide and wave action just came over the deck of the Cardwell jetty. However there was no sign of any damage to either the jetty or the storm tide gauge and housing. In between the trees that line the bank to the north of the jetty along Marine Parade, there are 0.5m high erosion scarps. A debris line just inshore of the bank suggests minor wave overtopping.

At Port Hinchinbrook (Oyster Point) there was failure of a rock wall along Keith Williams Drive with slumping and exposure of the underlying geotextile layer. Advice from local residents suggests the storm tide was lower than a king tide and that the storm tide, reached the top of the rock wall. It was also advised that the majority of the damage to the rock wall occurred as the storm tide receded, with anecdotal advice that the water level dropped 0.5m in 12 minutes.

5. Measured inundation levels

Debris lines comprising vegetation and pumice were surveyed at a number of locations by QPWS on behalf of the EPA and BoM on 28 to 30 March 2006, to quantify the inundation levels. Water level marks on structures were also recorded and surveyed where available. The inundation level can be considered as the maximum water level reached taking into consideration storm tide and wave run-up.

A total station theodolite was used to measure (within a centimetre) the elevation of the debris lines using known permanent survey marks to relate the levels to Australian Height Datum (AHD). Difficulties were encountered at some locations (such as South Mission Beach) with locating suitable permanent survey marks. For these locations, temporary survey marks were installed to be surveyed in to permanent marks at a later stage. The permanent survey mark adopted for Etty Bay was levelled to State Datum (SD) rather than AHD, producing problems comparing levels with other locations.

In August 2006, EPA staff conducted an additional field trip (Cleaves et al, 2007) in conjunction with Cardwell and Johnstone Shire Council surveyors to address the issues identified above, to collect additional information related to inundation levels, and to survey beach profiles in the affected areas. The analysed inundation levels were then assessed where multiple levels were collected at each location to determine a single representative inundation level for each beach.

The resulting inundation levels are presented in Figure 5 and Table 5. The inundation levels were generally in the order of 3.5m above AHD or about 1.5m above HAT. For most beaches, this equates to overtopping of the

beach ridge/dune in the order of 0.5m. The highest inundation level of 5.2m AHD (3.3m above HAT) occurred at Bingil Bay, about 30 kilometres south of the cyclone track. Etty Bay also recorded a relatively large inundation level of 4.5m AHD (or 2.6m above HAT). This location was in close vicinity to the landfall location.

The major identified difference between these two bays and the other locations inspected was the topography above HAT. Figure 6 highlights the differences by plotting a number of profiles at various locations against an arbitrary chainage. Typically the open beach profiles, such as Flying Fish Point, Kurrimine and Mission Beach, flatten out at the beach ridge around 3.0m AHD. Etty Bay and Bingil Bay continue to slope up inland of the dune into the ranges surrounding these bays. Also, the overall beach slope is more uniform than the other beaches which exhibit a more concave profile.

At Clump Point, an inundation level of 3.9m AHD was surveyed just south of the jetty. This correlates with the level of water damage within the charter boat office of about 3.9m AHD. These results together with the measured peak storm tide level at the Clump Point storm tide gauge suggest that wave setup and run-up processes were of the order of 1.3m in the vertical.

The inundation levels are comparable with the inundation levels that were measured following TC Winifred (BPA, 1986). Table 6 shows the comparison of measured inundation levels following these two cyclones.

Unfortunately no inundation level was recorded for Bingil Bay following TC Winifred. However, table 4 shows that for the sites available for comparison, Etty Bay recorded the highest inundation for both events. For TC Winifred, Etty Bay was situated about 10km north of landfall.

Table 5. *Measured inundation levels following TC Larry.*

Location	Inundation (m above AHD)	HAT (m above AHD)
Flying Fish Point	3.5	1.7
Etty Bay	4.5	1.7*
Cowley Beach	3.7	1.6
Kurrimine	3.5	1.9
Bingil Bay	5.2	1.9*
Clump Point	3.9	1.9*
Mission Beach	3.5	1.9*
Wongaling Beach	3.4	1.9
South Mission Beach	3.1	1.9*
Tully Heads	3.2	1.8

**denotes inferred HAT levels based on known HAT levels in surrounding areas.*

Table 6. *Inundation levels following TC Larry and TC Winifred.*

Location	TC Larry (m AHD)	TC Winifred (m AHD)
Etty Bay	4.50	3.70
Cowley Beach	3.70	3.20
Kurrimine	3.50	2.80
Mission Beach	3.50	2.60

6. Coastal hazard rating

Tropical cyclones have the potential to make substantial morphological changes to the coastline because of the wave energy dissipated along the shoreline as the water level increases. These changes depend on many things besides the magnitude of the waves and wind associated with the cyclone, such as the initial beach profile, whether a dune is present, and if so, what type of vegetation is established on it. A scale has been developed by the United States Geological Survey (USGS, 2001) to describe, in a simple way, the net erosion or accretion occurring at the coastline.

For a natural beach system the USGS Inundation Hazard Scale applied to the Tropical Cyclone Larry event would be rated at Impact Level 3 (Overwash Regime) described in Figure 7.

The Impact Level 3 coastal hazard depicts a situation in which the wave run-up exceeds the elevation of the dune, or in the absence of a dune, the beach berm. In this instance the system will be overtopped, transporting sand landward. This is a net change contributing to the migration of the foredune landward.

7. Conclusions

Although TC Larry was a significant event, its compact size and rapid movement resulted in minor erosion from Cowley Beach to Tully Heads with erosion scarps typically less than 0.5m in height.

The inundation levels were mostly in the order of 3.5m above AHD or about 1.5m above HAT. The maximum inundation levels surveyed at Bingil Bay and Etty Bay are difficult to fully explain given the complexity of this event. A full understanding of the processes affecting the inundation levels at these locations will require further analysis of the complex wind field as well as detailed bathymetric and topographic information in the vicinity of these bays.

Based on the observations and surveyed debris lines, the water depth over the beach ridge/dune would have been less than 0.5m in depth for most locations. If the storm surge had occurred on the peak of a spring tide, as was the case a week later, then the inundation levels would have been about 1.5m higher.

8. Acknowledgements

The authors wish to acknowledge the following organisations and their staff who provided time and resources to collect the data presented in this report:

- The Australian Bureau of Meteorology for resources provided to this investigation.
- Queensland Parks and Wildlife Service, Northern Region for providing survey assistance.
- Marine Safety Queensland for predicted tidal levels.
- Queensland Department of Emergency Services for resources provided to this investigation.
- Cardwell Shire Council for assistance with additional inundation and beach profile surveys from Tully Heads to Wongaling beach in August 2006.
- Johnstone Shire Council for assistance with additional inundation and beach profile surveys from Bingil Bay to Flying Fish Point in August 2006.

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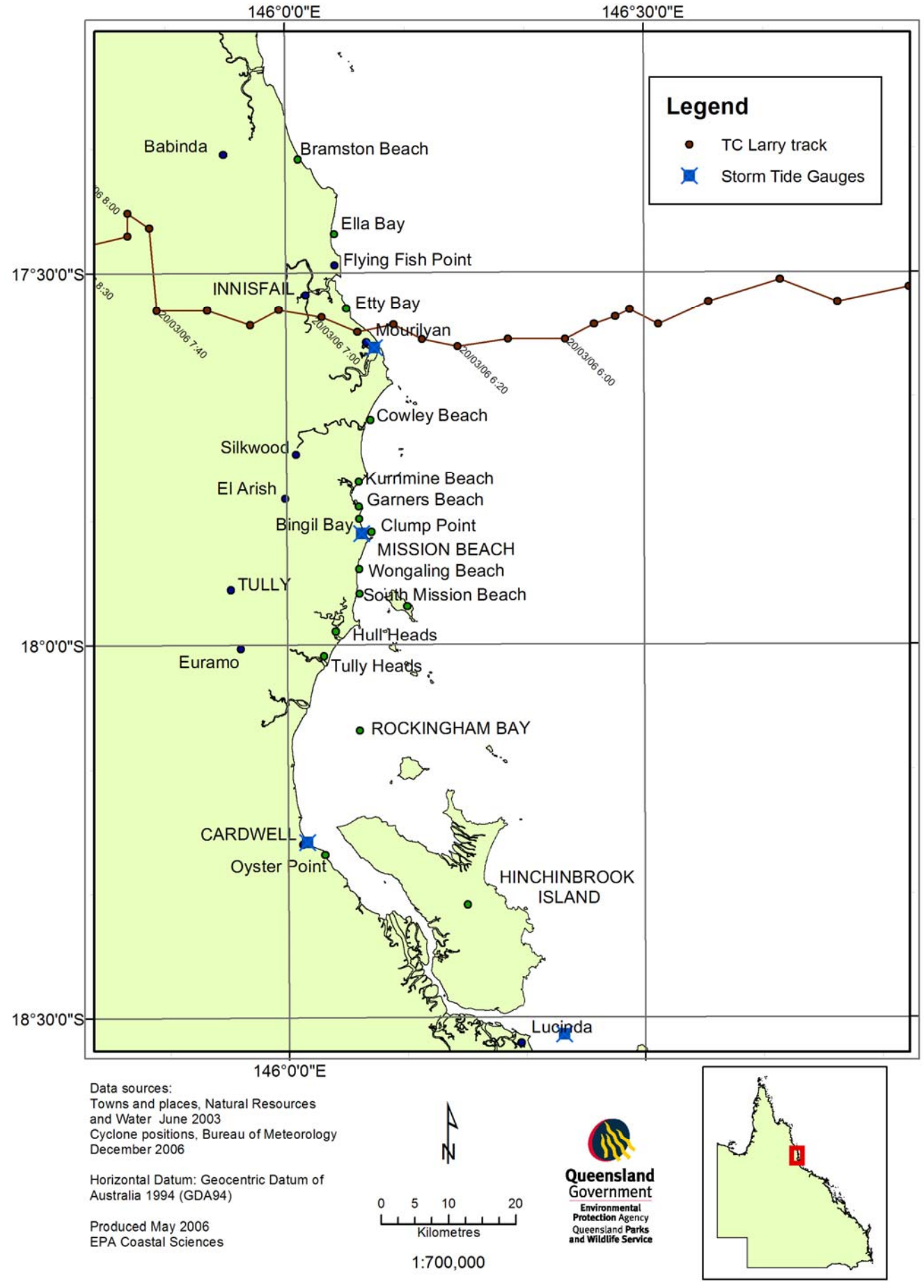


Figure 1. *Locality of post tropical cyclone Larry field inspection.*

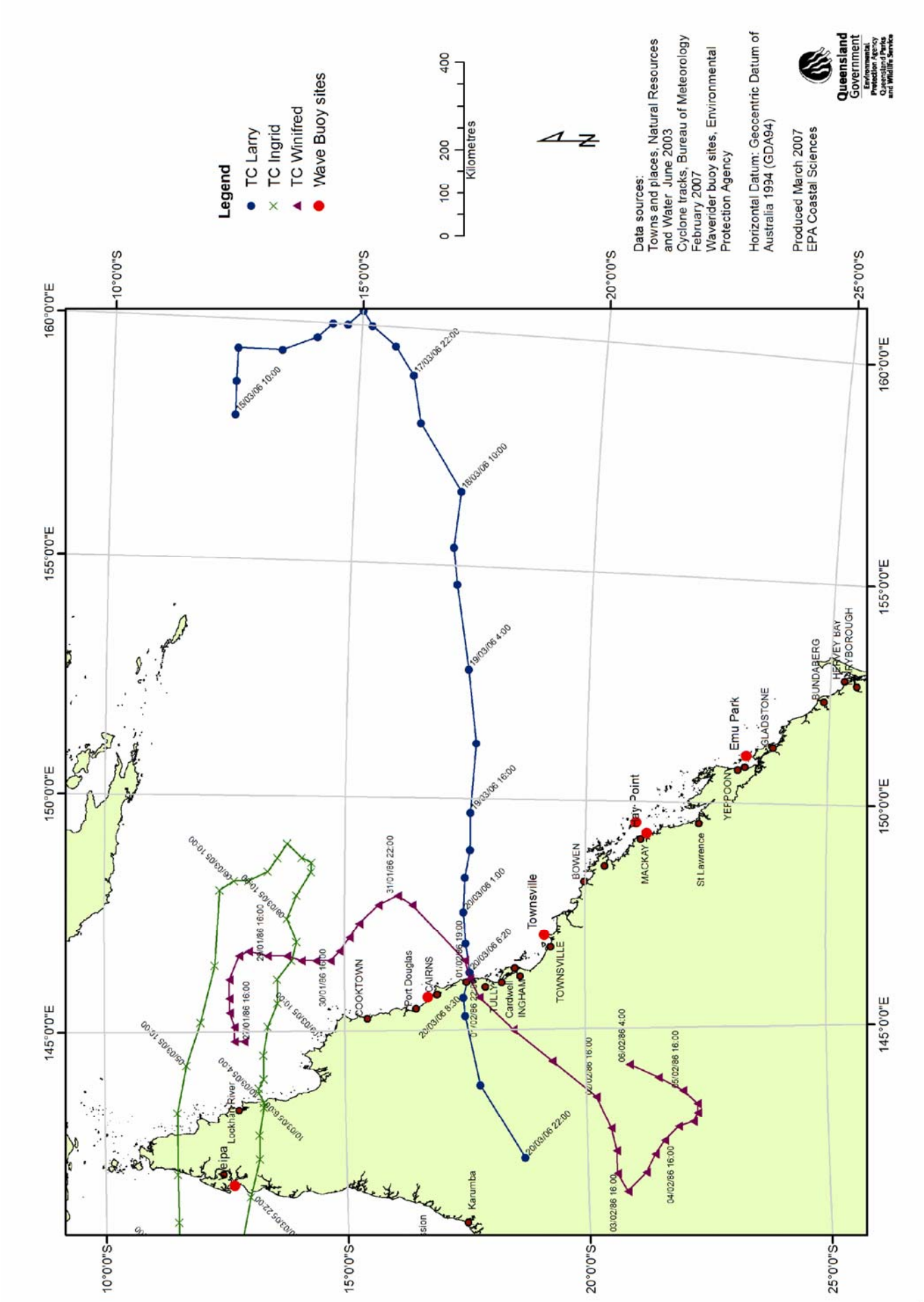


Figure 2. *Cyclone tracks.*

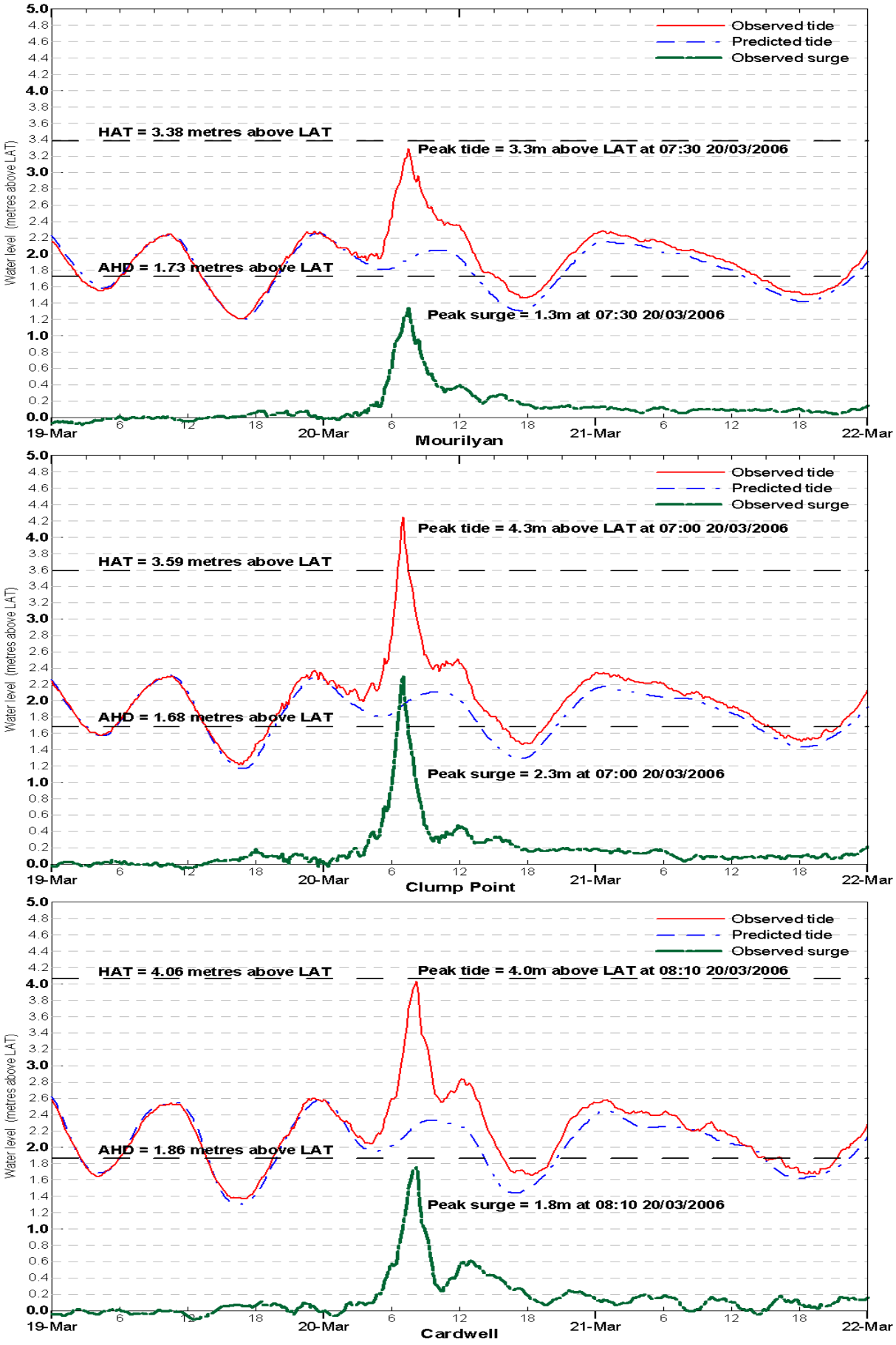


Figure 3. *Recorded storm tide levels.*

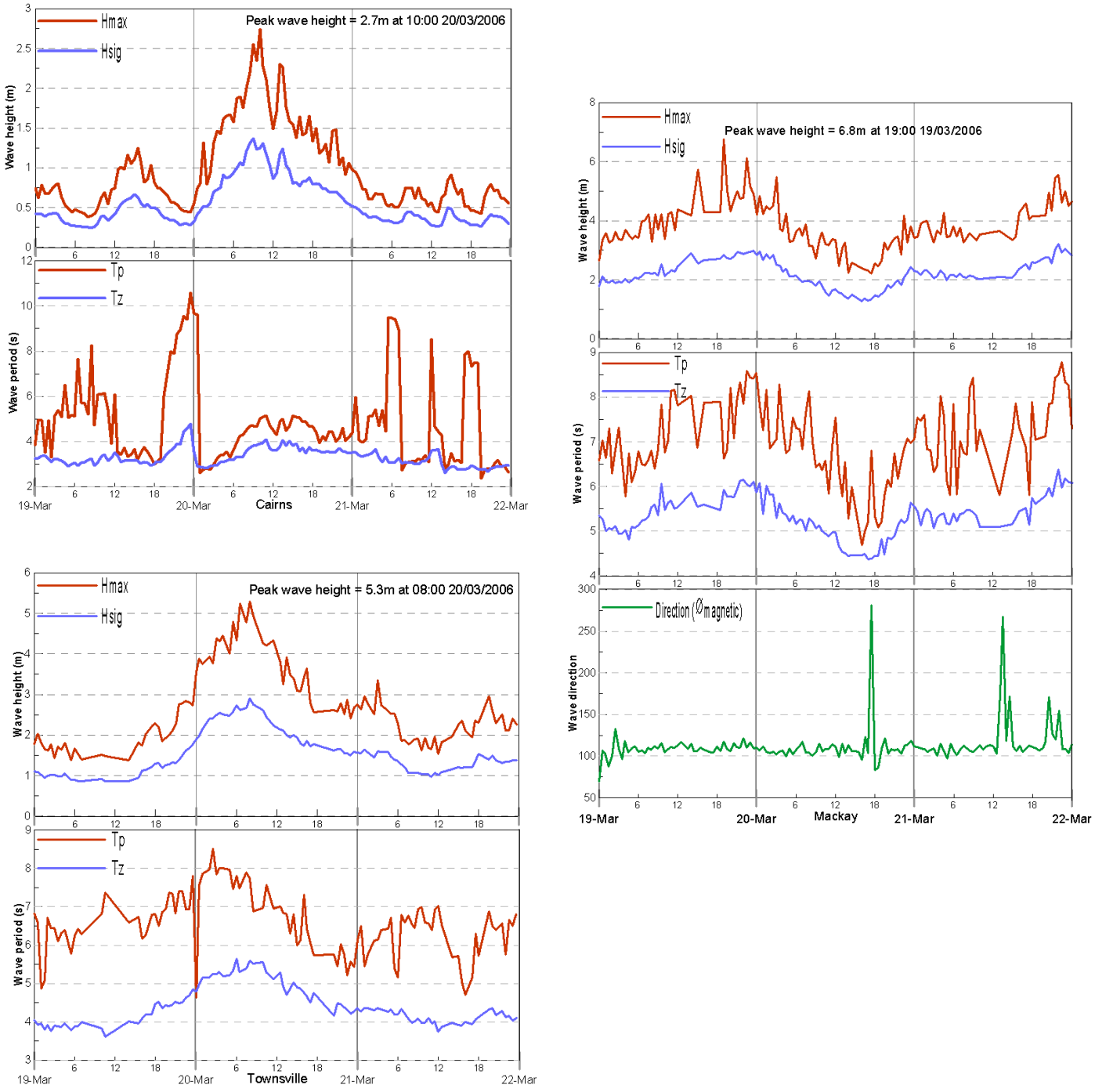


Figure 4. *Wave conditions during Tropical Cyclone Larry (data 19–21 March 2006) for Cairns, Townsville and Mackay wave sites.*

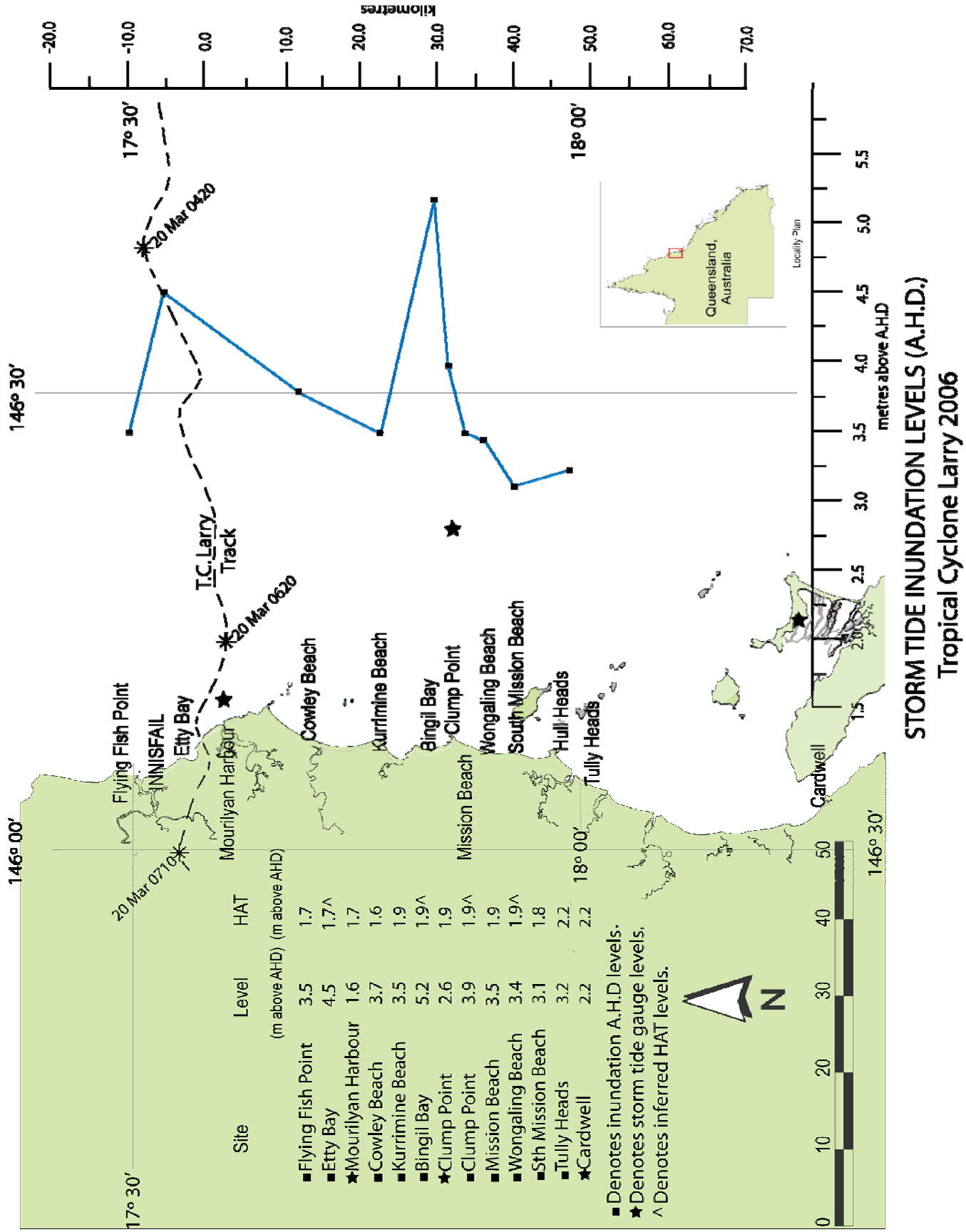


Figure 5. *Surveyed inundation levels.*

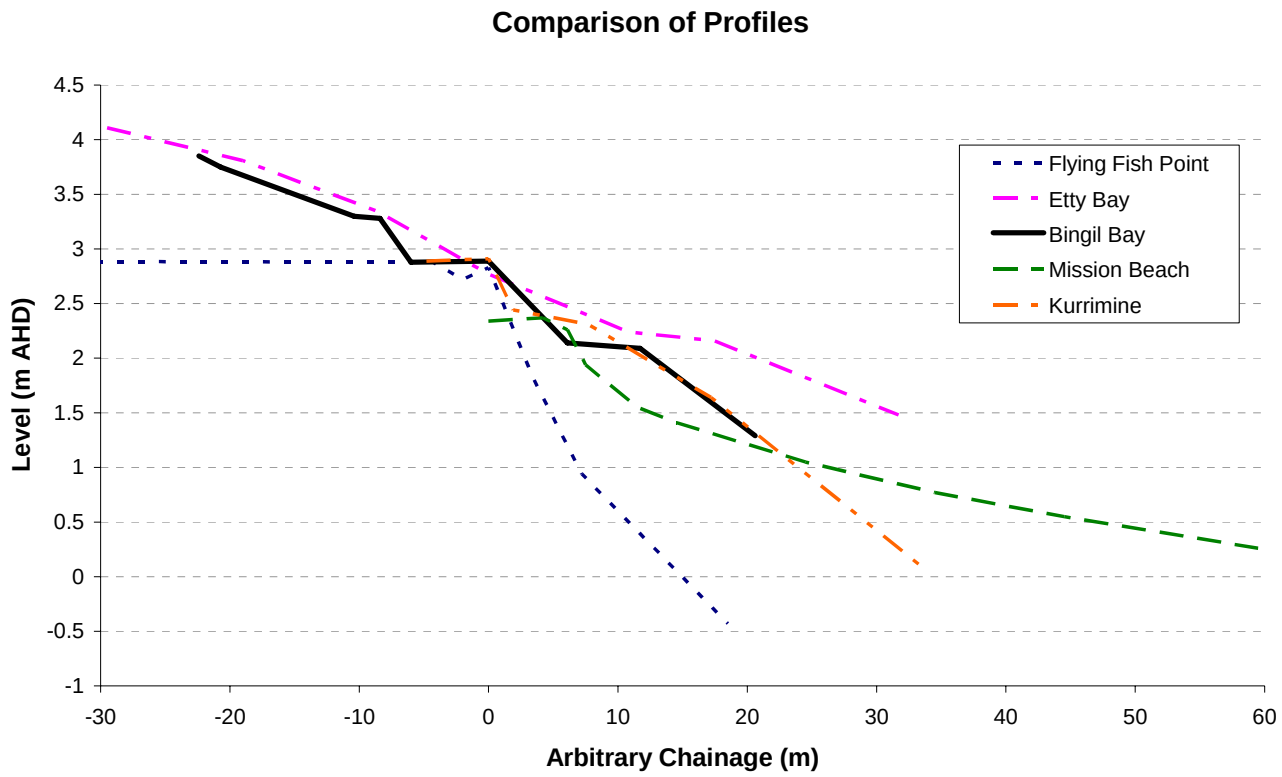
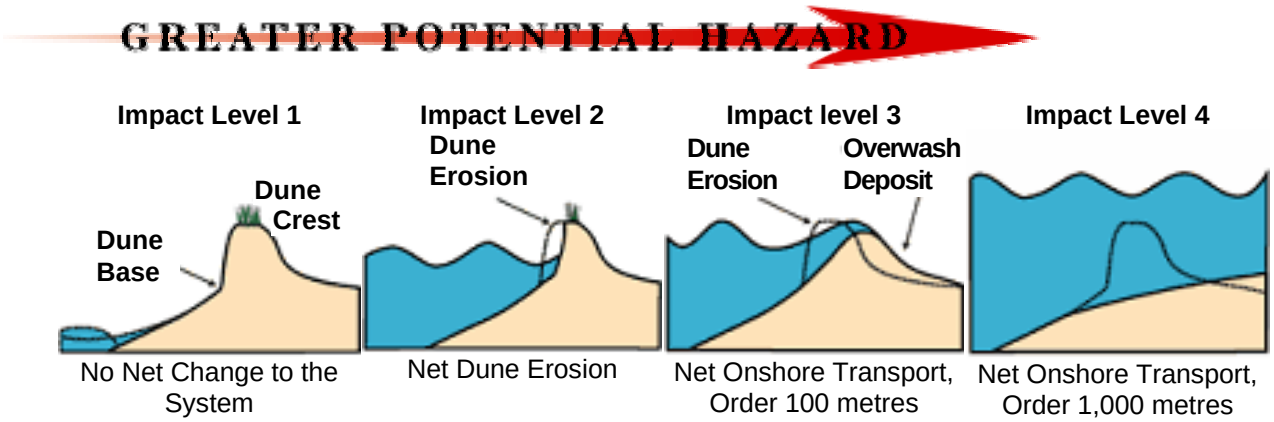


Figure 6. *Comparison of beach profiles post TC Larry.*



Images from USGS web site http://coastal.er.usgs.gov/hurricanes/mappingchange/scale.html

Figure 7. *USGS Inundation Hazard Scale.*

Appendix A.

Beach Profiles surveyed

23 to 25 August 2006

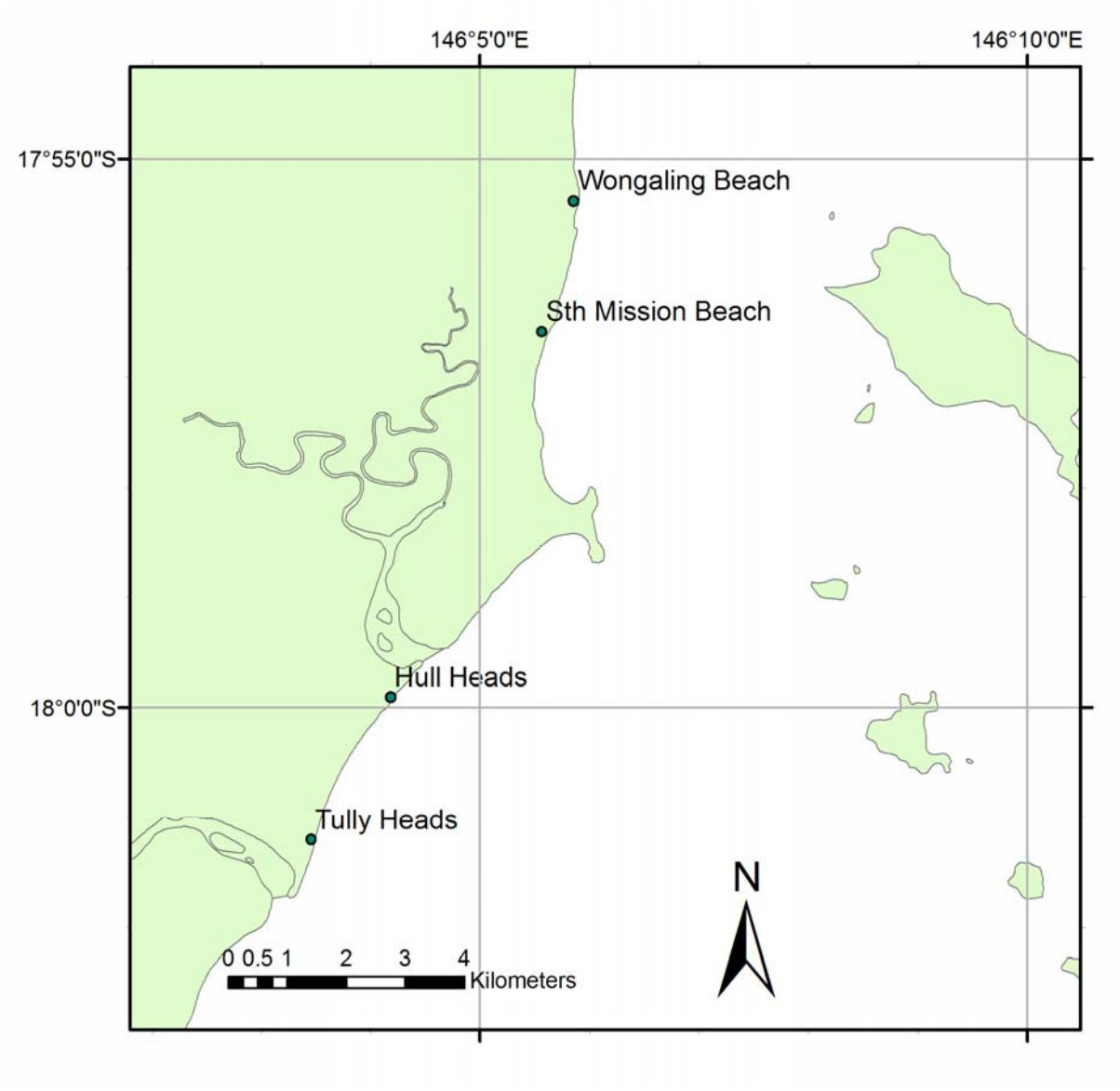
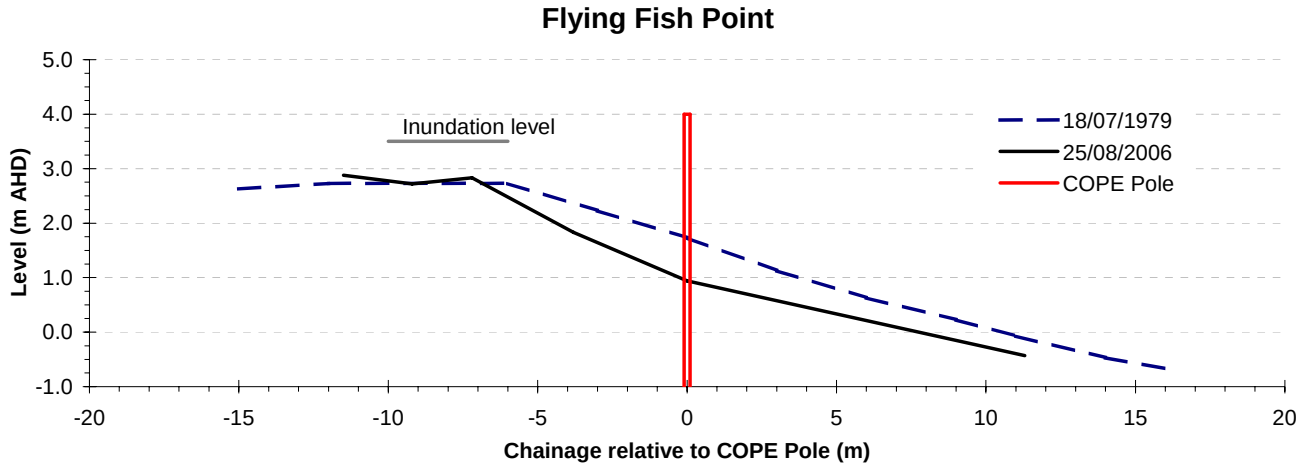
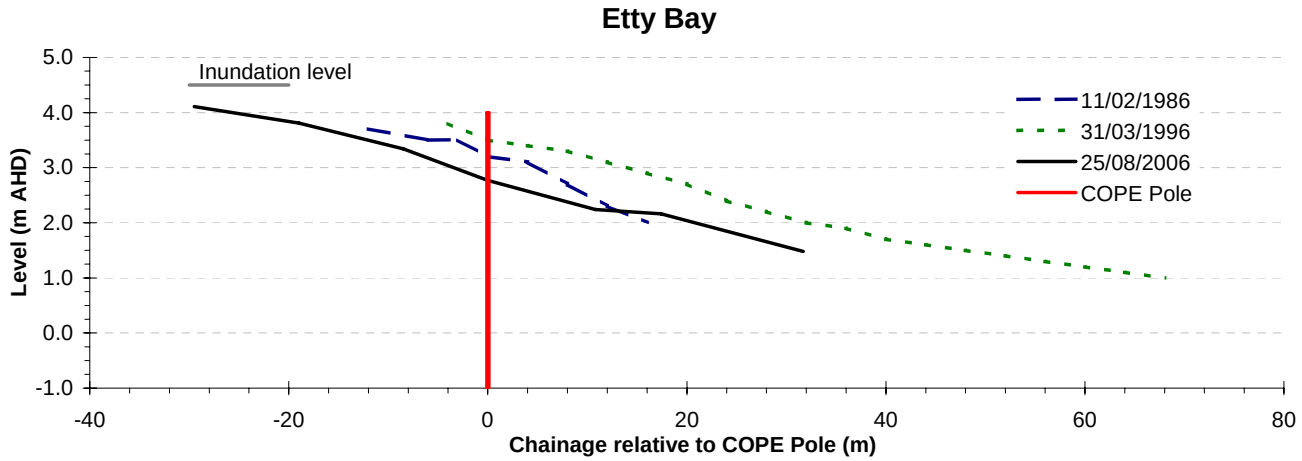
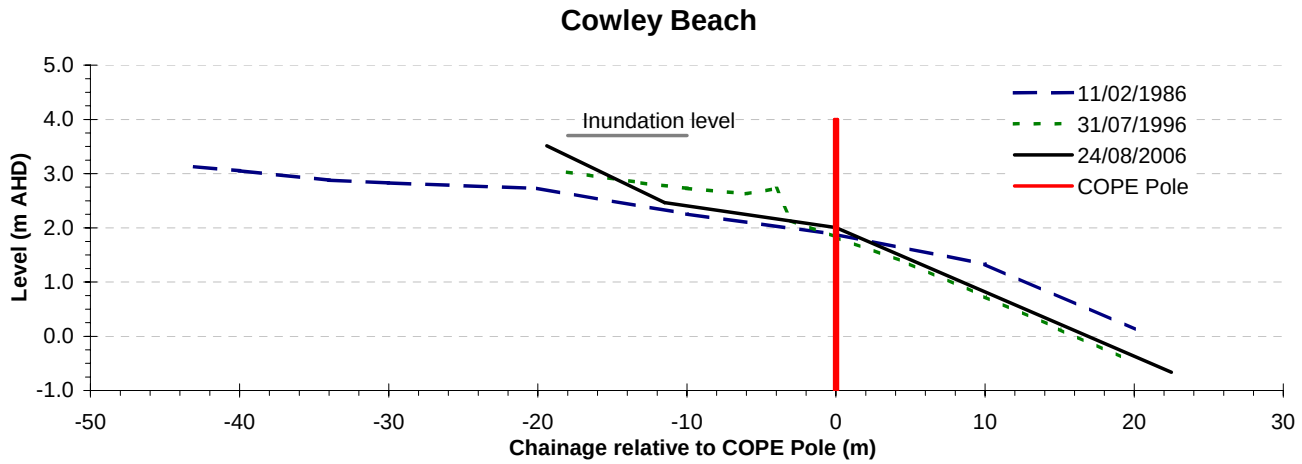


Figure A- 1. *Indicative location of surveyed profiles within Cardwell Shire.*

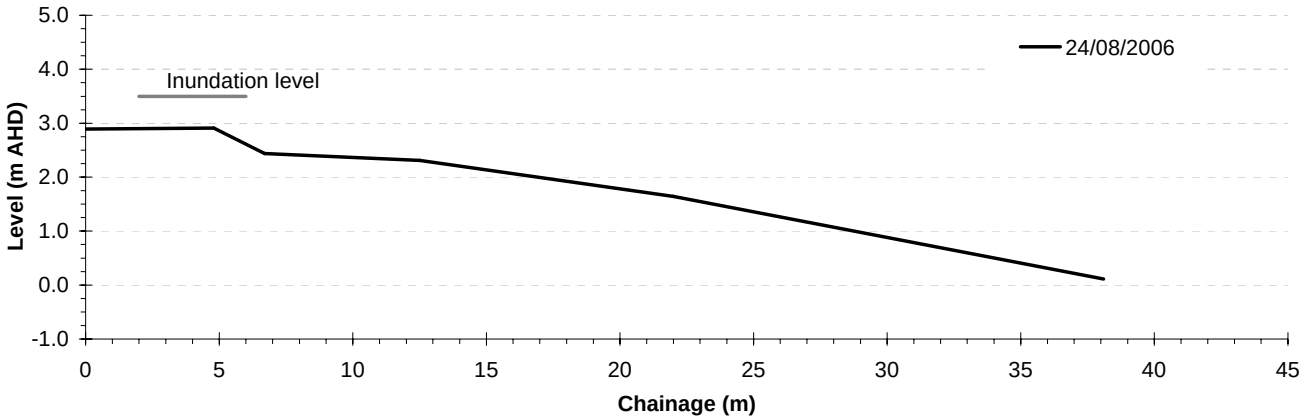
Figure A- 2. *Indicative location of surveyed profiles within Johnstone Shire.*


Flying Fish Point
Inundation level
18/07/1979
25/08/2006
COPE Pole
Level (m AHD)
Chainage relative to COPE Pole (m)

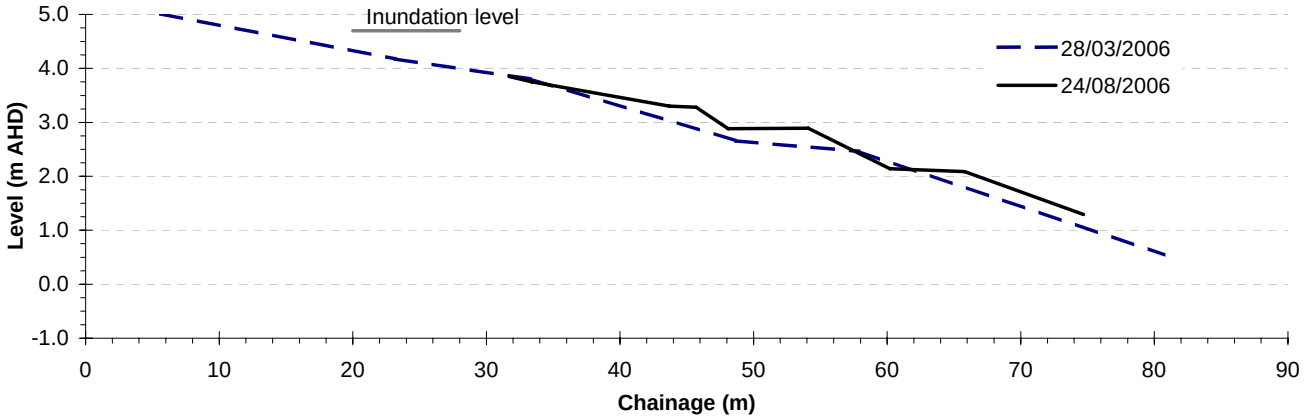

Etty Bay
Inundation level
11/02/1986
31/03/1996
25/08/2006
COPE Pole
Level (m AHD)
Chainage relative to COPE Pole (m)


Cowley Beach
Inundation level
11/02/1986
31/07/1996
24/08/2006
COPE Pole
Level (m AHD)
Chainage relative to COPE Pole (m)

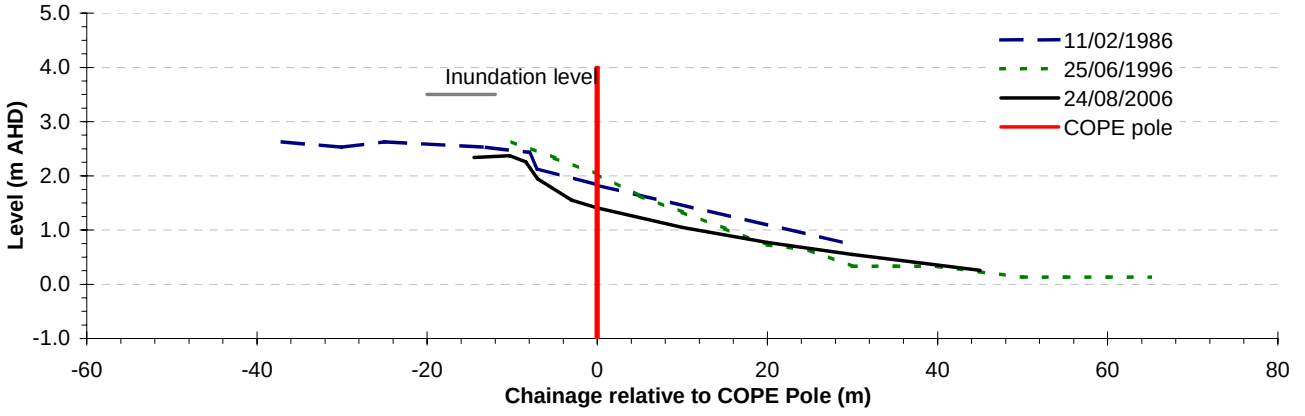
Kurrimine



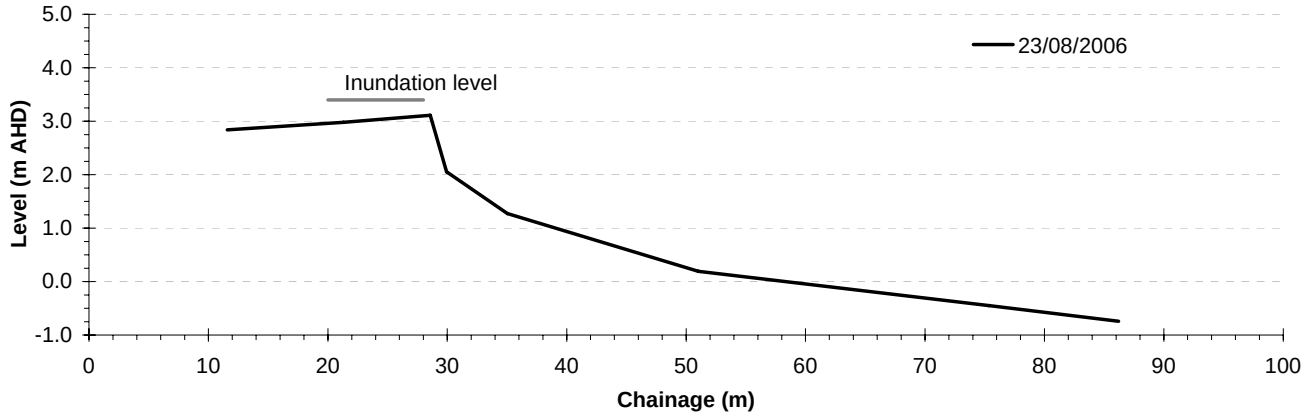
Bingil Bay



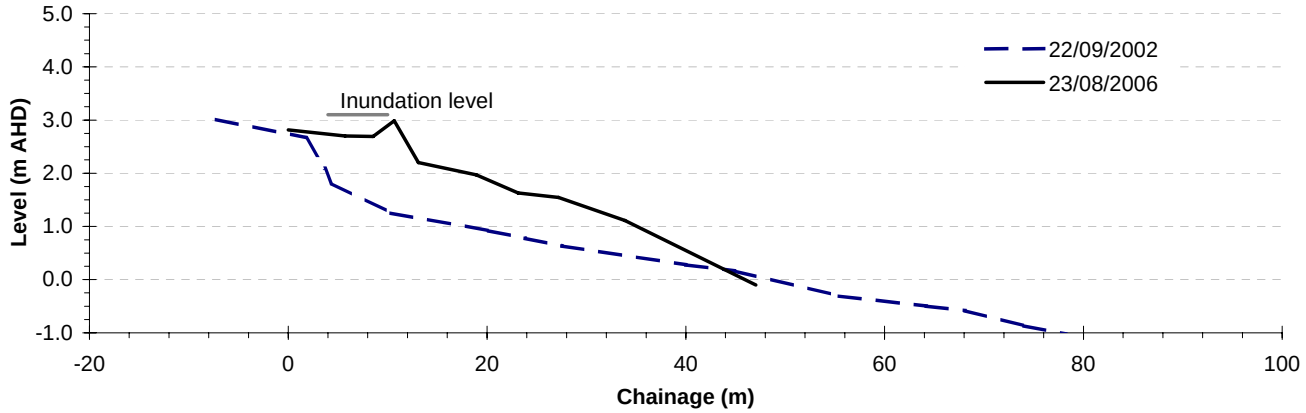
Mission Beach



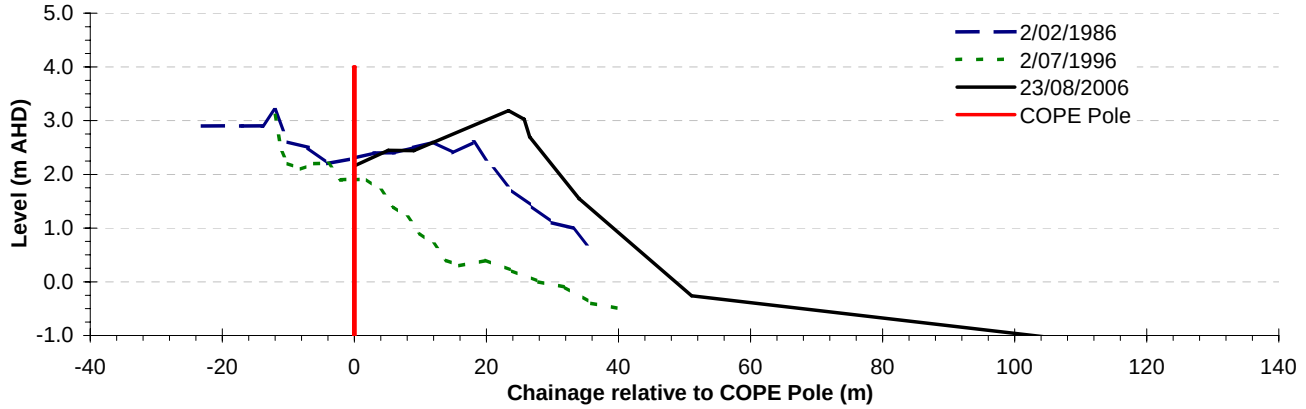
Wongaling Beach

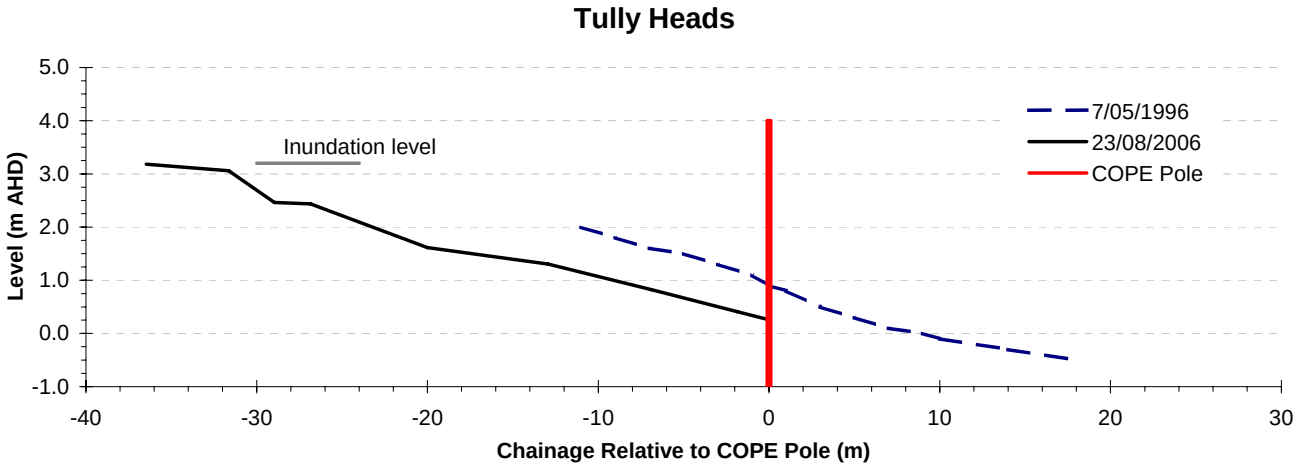


South Mission Beach



Hull Heads




Tully Heads
5.0
4.0
3.0
2.0
1.0
0.0
-1.0
Level (m AHD)
Inundation level
7/05/1996
23/08/2006
COPE Pole
-40
-30
-20
-10
0
10
20
30
Chainage Relative to COPE Pole (m)

Appendix B.

Photography captured during field investigation

26 to 28 March 2006

Photo 1. *Bramston beach looking north of the groyne, showing minor inundation over the dune.*

Photo 2. *South beach at Flying Fish Point.*

Photo 3. *Abrasion marks on a tree at Flying Fish Point.*

Photo 4. *Beach sand washed across the park area at Flying Fish Point.*

Photo 5. *Undermining of rock wall at Flying Fish Point.*

Photo 6. *Etty Bay towards the south.*

Photo 7. *Debris line landward of pole at Etty Bay.*

Photo 8. *Storm tide gauge at Mourilyan harbour.*

Photo 9. *Erosion at Mourilyan harbour.*

Photo 10. *Fallen trees and exposed roots at Cowley beach (viewed to the north).*

Photo 11. *Boat ramp on Cowley beach (viewed to the south).*

Photo 12. *Eroded access road to the boat ramp at Cowley beach, undermined by wave action*

Photo 13. *Debris lines along property boundaries at Cowley beach.*

Photo 14. *Pumice debris lines along Cowley beach road. The road slopes downward from the beach.*

Photo 15. *Kurrimine beach viewed to the north of the boat ramp. Caravan park is to the left of the photo.*

Photo 16. *Kurrimine beach to the south, showing erosion of vegetation in the vicinity of the boat ramp.*

Photo 17. *Debris lines along Bramble Street, looking towards the caravan park at Kurrimine.*

Photo 18. *Seaweed amongst the roots of a fallen tree on Kurrimine beach indicates the storm tide level.*

Photo 19. *Beach sand was washes some 20m inland of Kurrimine beach at the caravan park.*

Photo 20. *A concrete slab was moved from near the boat ramp by the storm tide. Also pictured is a boulder from the rock wall.*

Photo 21. *Garners beach viewed to the north, showing a wide intertidal zone.*

Photo 22. *Fallen trees along the vegetation line at Garners beach.*

Photo 23. *Bingil Bay showing the small creek to the north.*

Photo 24. *Bingil Bay viewed to the south, demonstrating the intertidal crest and trough system.*

Photo 25. *Erosion around the coconut palms at Bingil Bay.*

Photo 26. *Beach sand washed some 20m inshore across Alexander Drive at Bingil Bay.*

Photo 27. *A rock wall protecting the road around Clump Mountain failed (south of Bingil Bay).*

Photo 28. *Clump Point jetty and storm tide gauge showing lifted timber decking and seaweed on the railing as a result of wave action.*

Photo 29. *The storm tide caused structural damage to "Quick Cat Cruises" offices at Clump Point.*

Photo 30. *View of the interior damage to the building at Clump Point (picture taken from the ocean side of the building).*

Photo 31. *Mission beach viewed to the south near Castaways resort.*

Photo 32. *Castaways resort, Mission Beach.*

Photo 33. *Debris lines at Wongaling beach near Wheatley Creek.*

Photo 34. *Beach sand washed inshore across the park area at the northern end of Wongaling beach.*

Photo 35. *The highest erosion scarps were observed at Wongaling beach.*

Photo 36. *Inundation water levels within a public toilet block at Wongaling.*

Photo 37. *Debris lines inland of Banfield Parade located just north of Wongaling beach.*

Photo 38. *A public toilet block situated at the southern end of South Mission beach, which has since been demolished.*

Photo 39. *Inundation water levels within the public toilet block at South Mission beach.*

Photo 40. *Erosion scarps at South Mission beach. Beach sand that had washed over the esplanade, had been piled between the palms.*

Photo 41. *Inundation debris line at South Mission beach.*

Photo 42. *Beach erosion at Tully Heads (viewed to the south).*

Photo 43. *Beach sand was washed about 20m inland at Tully Heads.*

Photo 44. *Slumping of the rock wall at Tully heads, exposing the underlying geotextile layer.*

Photo 45. *Sand and rocks washed inshore of the rock wall at Tully Heads by wave overtopping.*

Photo 46. *Debris line at Cardwell indicates slight overtopping of the dune.*

Photo 47. *Erosion scarp along Marine Parade at Cardwell.*

Photo 48. *Cardwell storm tide gauge.*