Review of Storm Tide Hazard at Selected East Coast Communities

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TABLE OF REVISIONS

Version	Status	Date	Prepared by	Approved by
C	Final	12/05/2017	B.A. Harper BE PhD CPEng PER RPEQ	B.A. Harper B A Harper

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ACKNOWLEDGEMENTS

The assistance of LGAQ Qcoast$_{2100}$ Program Coordinator Ms Subathra Ramachandram and DEHP Principal Coastal Scientist Mr Sel Sultmann is gratefully acknowledged, together with Mr Ross Fryar, GHD Principal - Water and Environment, for making available useful source material from GHD (2014).

LGAQ Queensland Government SEA

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EXECUTIVE SUMMARY

This report documents an assessment of the estimated storm tide hazard at a selection of east coast communities based on available published studies. Most of the communities are located north of Cairns and many are relatively small settlements in remote areas. Not all of these sites have been explicitly included in previous storm tide hazard studies but rather have been interpolated between relatively widely-spaced estimates that may not be appropriate for those specific sites.

Notwithstanding, a range of hazard metrics have been collated here, summarised by the 100 y, 1000 y and 10,000 y Average Recurrence Interval (ARI) and the Theoretical Maximum Storm Tide level (TMST).

Communities Having Assets Most at Risk by 2100

In order of decreasing exposure, these are deemed to comprise:

- Carmila Beach
- Clairview
- Ayton
- Yarrabah
- St Lawrence
- Ilbilbie
- Marton
- Lizard Island
- Palm Island
- Cooktown
- Cape Bedford
- Lockhart River
- Wujal
- Cape Flattery
- Port Stewart
- Portland Roads

Data Quality

Reference is made to previous reviews and ranking of the quality of the various hazard studies undertaken that limit the reliability of estimates in many areas.

Information Gaps

There are no detailed statistically-based storm tide hazard estimates available for:

- Portland Roads
- Port Stewart

Sites presently relying on relatively simple interpolation include:

- Lizard Island
- Cape Bedford
- Ayton / Wujal Wujal

Many sites do not contain estimates of breaking wave setup, which may be significant in some open coast environments and none include non-cyclonic water level events that often dominate below the 200 y ARI.

Sites on elevated sandy coasts that are potentially subject to significant coastal erosion, but have not been specifically assessed here include:

- Carmila Beach
- Clairview
- Cape Bedford
- Cape Flattery

Data Suitability for the QCoast_{2100} CHAS Process

Several matters have been considered in deciding if the available storm tide hazard data is suitable for a CHAS process, specifically:

- Exposure and Vulnerability
- Methodologies

Conclusion

The review has highlighted the fact that many of the sites being considered have relatively approximate storm tide hazard estimates, mainly because they have been previously regarded as remote or insignificant in the context of past scopes and budgets. None of the sites include non-cyclonic hazards and the necessary statistical blending with tropical cyclone events.

On this basis, the understanding and quantification of the storm tide hazard at most sites considered in this review would significantly benefit from more detailed site-specific studies. It can also be noted that existing models may already contain more reliable hazard estimates for some of these sites than was available at the time of the reference NDRP study in 2014.

To justify the need for further studies the present estimates can usefully be used to assess the basic criteria as to whether the hazard levels constitute, *prima facie*, a sufficient risk to each community in the long term to justify undertaking a formal CHAS process.

1. Introduction

This report documents a review of storm tide hazard information for the following Queensland coastal communities regarding potential application within the QCoast$_{2100}$ (2016) guidelines:

Table 1 Local Government Regions (North to South)

Local Government	Gazetted settlements
Cook Shire	Portland Roads, Port Stewart, Cape Flattery, Lizard Island, Cooktown, Marton, Rossville, Ayton
Lockhart River	Lockhart River
Hope Vale	Hope Vale, Cape Flattery, Cape Bedford
Wujal	Wujal Wujal
Yarrabah	Yarrabah
Palm Island	Great Palm Island (Bwgcolman)
Isaac	Cape Palmerston, Ilbilbie/Greenhill, Clairview, Carmila, St Lawrence

The detailed Scope of Work is included as Appendix A, summarised as follows:

- Collate and review all existing storm tide information for the above areas
- Identify (at a high level) localised areas with assets at risk
- Evaluate and assess data quality/accuracy.
- Identify any information gaps

The hazard is assessed in the context of the Average Recurrence Interval (ARI, or Return Period) event for a range of ocean water levels for each coastal LGA area. Readers are advised to appraise themselves of the interpretation of statistical storm tide risk levels as summarised in Appendix B.

Figure 1 presents a location map of the communities being assessed and Table 2 provides the geographic coordinates.

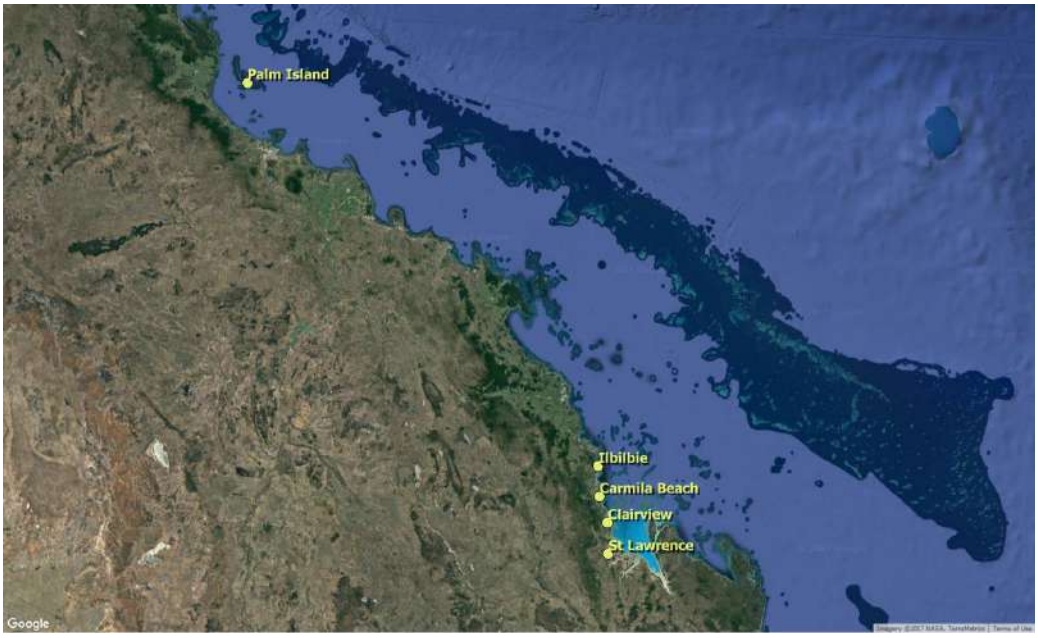

Figure 1 Assessed communities

Table 2 Assessed Communities (North to South)

Name	Longitude °	Latitude °
Portland Roads	143.4117	-12.5960
Lockhart River	143.3442	-12.7882
Port Stewart	143.6841	-14.0702
Lizard Island	145.4501	-14.6732
Cape Flattery	145.3097	-14.9623
Cape Bedford	145.3081	-15.2617
Hope Vale	145.1080	-15.2971
Marton	145.1909	-15.4605
Cooktown	145.2501	-15.4632
Rossville	145.2267	-15.6939
Ayton	145.3516	-15.9209
Wujal Wujal	145.3191	-15.9467
Yarrabah	145.8664	-16.9066
Palm Island	146.5776	-18.7339
Ilbilbie	149.4524	-21.6830
Carmila Beach	149.4634	-21.9114
Clairview	149.5299	-22.1108
St Lawrence	149.5356	-22.3462

2. Methodology Summary

This review relies on the examination of numerous public domain storm tide studies that have been undertaken by the State of Queensland, coastal Local Government authorities and some academic research, combined with available community land elevations provided by the Department of Environment and Heritage Protection. The communities under consideration are mainly remote and isolated and not all have been considered in previous studies.

The principal reference utilised here is GHD (2014), hereafter “NDRP report”, which was commissioned by the Department of Science, Information Technology, Innovation and the Arts (DSITIA) through the support of a Commonwealth Natural Disaster Resilience Program (NDRP) grant. The NDRP report sought to rationalise what had become, over time, a somewhat piecemeal collection of individual storm tide studies along the Queensland coast into a more consistent and informative understanding of the State-wide risk from extreme tropical cyclone storm tide as well as more frequent but more benign non-cyclonic influences.

The NDRP report approach was based on the following philosophy:

- Provide a statistically consistent set of ARI levels for the Queensland open coast as well as a derived Theoretical Maximum Storm Tide (TMST) level, using all available study information
- Follow the technical recommendations in:
  - Harper B.A. (ed.) (2001) Queensland climate change and community vulnerability to tropical cyclones - ocean hazards assessment - stage 1 (aka the “QCC” studies); and
  - GHD/SEA (2007) South east Queensland storm tide review – recommendations for modelling, risk assessment and mitigation strategies.
- Provide mapped risk summaries for selected locations along the east coast <u>for present climate conditions only</u>.

The following site-specific assessments have considered all the available NDRP study ARI and flooded extent imagery, plus DEHP-supplied elevation contours, together with:

- Satellite imagery[1]
- Highest Astronomical Tide (HAT)
- Estimated Lowest Habited Level (LHL)[2]

[1] Google Earth™

[2] This is simply based on a visual inspection of available built-imagery combined with land elevation contours and refers to a property ground level only.

- 10,000 y ARI Total Storm Tide extent (if available)
- Theoretical Maximum Storm Tide (TMST) level (refer Appendix C).

2.1 Cook Shire Council

2.1.1 Portland Roads

This is an isolated small coastal settlement accessible by road some 20 km NNE of Lockhart River, just north of Cape Weymouth (Figure 2).

This area is not covered by the NDRP study mapping and high resolution land elevations are not available but the TMST estimate is 5.5 m AHD. The immediate coastal environment appears elevated and the LHL is estimated to be around 10 m AHD. Haigh et al. (2012) suggest a regional 1000 y ARI level of about 2.5 m. It is reasonable to assume that the visible infrastructure will not be at significant risk from storm tide hazards.

2.1.2 Port Stewart

Accessible from Coen, Port Stewart is another very isolated small settlement just north of Princess Charlotte Bay, located at the navigable entrance of the Stewart River (Figure 3).

This area is not covered by the NDRP study mapping and high resolution land elevations are not available but the TMST estimate is 7.7 m. The immediate coastal environment appears low-lying and the LHL is estimated to be below 10 m AHD. Haigh et al. (2012) suggest a regional 1000 y ARI level of about 2.5 m.

The storm tide risk in the region is likely significant, given the broad continental shelf surrounding the shallow Princess Charlotte Bay, which provides a favourable storm surge environment.

2.1.3 Lizard Island

Located some 44 km NE of Cape Flattery within the Great Barrier lagoon, Lizard Island (Figure 4) is a mainland-associated island with tourism infrastructure and the Lizard Island Research Station (a division of the Australian Museum, Sydney). The island is serviced by boat and has an all-weather airstrip. Tropical Cyclone *Ita* in 2014 and *Nathan* in 2015 both impacted the island.

This area is covered by the NDRP study mapping and high resolution land elevations are available. The 10,000 y ARI inundation extent of about 2.5 m AHD is derived from interpolation of the Hardy et al. (2004) study. The TMST estimate is 5.5 m. The immediate coastal environment is not low-lying and the LHL is estimated to be above 6 m AHD in the tourist resort but 4 to 5 m AHD at the Research Station where the onshore slope is milder. The outer GBR barrier is some 20 km further to the east, water depths within the lagoon region are typically 15 to 20 m and the area has a moderately high tide range of order 3 m. Its location is not deemed especially susceptible to extreme storm tide.

Figure 2 Portland Roads

Figure 3 Port Stewart

Figure 4 Lizard Island showing 10,000 y ARI extent

2.1.4 Cooktown

The administrative centre of the Cook Shire, Cooktown and surrounds has a population of about 2000 and lies at the mouth of the Endeavour River. The nearshore lands vary between elevated in the east to very low-lying in the west, especially near the riverbanks, which are covered in mangrove forest.

This area is covered by the NDRP study mapping and high resolution land elevations are available. Most of the built environment is above 5 m AHD, except near the Charlotte Street waterfront and in Boundary Street. A WTP appears located at about 6 m AHD. The Cooktown Racecourse is as low as 2 m AHD.

The NDRP report mapping for this region is based on Hardy et al. (2004b), and shows that the extrapolated 10,000 y ARI extent reaches about 3.3 m AHD (Figure 5) and the estimated TMST is 7.6 m AHD, capable of encroaching over almost the entire community.

There is also some exposure of low lying housing on the southern entrance to Cooktown on the northern banks of the Annan River estuary, commencing at about 5m AHD.

The Cooktown community has a significant exposure to extreme storm tide impacts.

Figure 5 Cooktown region showing 10,000 y ARI extent

2.1.5 Marton

This low-lying community is about 5 km west of central Cooktown close to where the new (relocated) airport is situated. The airport is at an elevation of about 5 m AHD with many semi-rural areas around 3 to 4 m AHD, which are within reach of the 10,000 y ARI event and would be severely impacted by the TMST.

2.1.6 Rossville

This an elevated rural community more than 10 km inland and appears to have no coastal exposure. The immediate coastline has no sign of habitation and is not low-lying. Archer Point is connected by road some 15 km NE on the coast has signs of visitation but not habitation and is not low-lying. The interpolated hardy et al. (2004) 10,000 y ARI level is about 3.5 m AHD and the TMST is 6.3 m AHD.

No image is provided as there is apparently no community exposure to storm tide.

2.1.7 Ayton

This a small mainly semi-rural community in the Bloomfield River valley region (Figure 6) with exposure to the coast and the river mouth to the south, immediately adjacent to the Wujal Wujal Aboriginal Shire.

The Ayton area is covered by the NDRP study based on interpolated values from Hardy et al. (2004b), and high resolution land elevations are available but the hazard extent levels are very approximate as they are interpolated between only a few widely-separated points. The 10,000 ARI extent is assumed to be about 3.5 m AHD.

Most the built environment appears above 5 m AHD, but some eastern margins are below 3 m AHD. There is elevated land near the western margins.

The assessed TMST reaches about 7 m AHD and would impact about half of the community.

Figure 6 Ayton region showing 10,000 y ARI extent

2.2 Lockhart River Aboriginal Shire Council

2.2.1 Lockhart River

Lockhart River township (pop < 1000) is 2 km inland from the coast at an elevation of approximately 25 m AHD and is assessed as immune to storm tide hazards (Figure 7). Nearby Quintell Beach has a few isolated buildings evident from satellite images located at approximately 5 m AHD elevation.

The NDRP report mapping for this region is based on Hardy et al. (2004b), and shows that the extrapolated 10,000 y ARI extent reaches about 2.5 m AHD. The assessed TMST reaches about 7 m AHD and encompasses the few visible Quintell Beach buildings.

Figure 7 Lockhart River showing NDRP 10,000 y ARI extent; Inset: Quintell Beach

2.3 Hope Vale Aboriginal Shire Council

2.3.1 Hope Vale

Hope Vale community township is about 20 km inland from the coast at an elevation of approximately 50 m AHD and is therefore immune from storm tide hazards.

2.3.2 Cape Flattery

This small coastal township 45 km NE of Hope Vale (east of the original Hope Vale mission site at Elim) services the nearby silica mine and its associated export port (Figure **8**). The town is also serviced by ship and has an all-weather airstrip. Tropical Cyclone *Ita* in 2014 and *Nathan* in 2015 both impacted the area.

Storm tide levels are available from Hardy et al. (2004b) indicating a 10,000 ARI level of 2.32 m AHD but no NDRP flood extents or detailed land elevations were available for this review[3]. Using Google Maps™ the estimated LHL is between 5 to 10 m AHD. The TMST is 6.0 m.

The shallow continental shelf is approximately 20 km across to the outer barrier reef with shallow coastal margins in the embayment that may be susceptible to extreme storm tide impacts.

Figure 8 Cape Flattery

[3] This omission seems to be an oversight in the NDRP study scope.

2.3.3 Cape Bedford

This refers to a small collection of properties 22 km E of Hope Vale that are scattered over 5 km along the coastal foredune (Figure 9).

The NDRP report mapping for this region is based on interpolated Hardy et al. (2004b) levels between Cape Flattery and Cooktown only. The NDRP 10,000 y ARI extent reaches about 3.0 m AHD. The assessed TMST reaches about 6 m AHD.

No detailed land elevations were provided for this review. Using Google Maps™ the estimated LHL is between 5 to 10 m AHD. The TMST is 6.0 m.

Like Cape Flattery, the shallow continental shelf is approximately 20 km across to the outer barrier reef with shallow coastal margins in this large embayment that will be susceptible to extreme storm tide impacts.

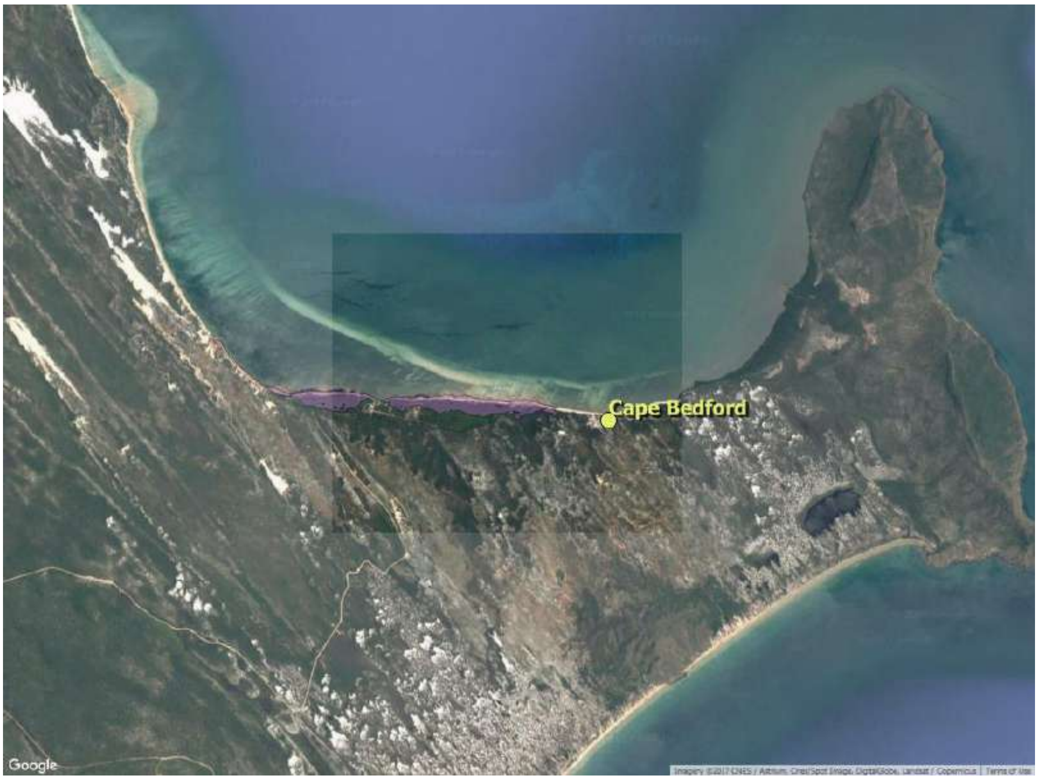

Figure 9 Cape Bedford

2.4 Wujal Wujal Aboriginal Shire Council

The aboriginal community of Wujal Wujal is concentrated on the northern bank of the Bloomfield River some 5 km upstream from its mouth near Ayton, although some generally elevate habitations extend along the southern bank of the river eastwards to the ocean.

The NDRP report mapping for this region (same as Ayton) is based on widely-interpolated estimates from Hardy et al. (2004b), and shows that the extrapolated 10,000 y ARI extent reaches about 3.5 m AHD.

Generally, all habitation appears to above 6 m AHD. The assessed TMST reaches about 7 m AHD and would only impact the community in a minor way.

Figure 10 Wujal Wujal region showing 10,000 y ARI extent

2.5 Yarrabah Aboriginal Shire Council

The beachside aboriginal community of Yarrabah (pop. 3000) is located about 10 km east of Cairns near Cape Grafton. Most of the community housing is located just above 3 m AHD but below 6 m AHD, although there is elevated land nearby that could provide retreat.

The NDRP report mapping for this region is based on Hardy et al. (2004b). Figure 11 shows that the estimated 10,000 y ARI extent of about 3.5 m AHD would impact the immediate coastal strip but spare most housing.

The assessed TMST reaches about 7 m AHD and that would impact the community in a major way.

Figure 11 Yarrabah community showing 10,000 y ARI extent

2.6 Palm Island Aboriginal Shire Council

The principal settlement is the beachside aboriginal community of Bwgcolman (pop. 5000) located on the south-western side of Great Palm Island, which is approximately 30 km offshore of the coast south of Lucinda. The coastal margins comprise sandy flats and fringing reefs.

Being a mainland island, the topography is generally elevated, with most of the built environment above 4 m AHD. The airstrip on the SW tip of the island is above 5 m AHD, as well as the nearby housing.

The NDRP report mapping for this region is based on Hardy et al. (2004b). Figure 12 shows that the estimated 10,000 y ARI extent of about 3.0 m AHD would only impact the immediate coastal strip.

The assessed TMST reaches 7.7 m AHD and would impact the community in a major way.

Figure 12 Palm Island community showing 10,000 y ARI extent

2.7 Isaac Regional Council

Isaac Shire has a relatively short coastal margin from south of Cape Palmerston to the Styx River just south of St Lawrence. However, the southernmost parts experience the highest tidal range in Queensland, which can reach up to 10 m within the coastal river systems.

2.7.1 Cape Palmerston

This review could not find any coastal settlements in this immediate vicinity.

2.7.2 Ilbilbie

Also known as Greenhill, this small beachside community of about 400 persons is a mixture of township and semi-rural properties. The township is located on a hill adjacent to the coastline, with no properties much below 10 m AHD. The semi-rural area is further inland with some properties at about 7 m AHD with connectivity to the sea via a creek on the northern limits.

The NDRP report mapping for this region is based on WS Group, CW and LT (2003). Figure 13 shows that the estimated 10,000 y ARI extent of about 6.0 m AHD would have little impact.

The assessed TMST reaches 12.3 m AHD and would impact the semi-rural community.

2.7.3 Carmila Beach

Located on the coast near Carmila, this very small beachside community comprises fewer than 20 properties, most located at about 7 m AHD along a sand ridge parallel to the beach but some as low as 5 m AHD in the back-beach area.

The NDRP report mapping for this region is based on WS Group, CW and LT (2003). Figure 14 shows that the estimated 10,000 y ARI extent of about 6.6 m AHD would have considerable impact on the area.

The assessed TMST reaches 13.8 m AHD and could extend up to 5 km inland, almost to Carmila township.

2.7.4 Clairview

Clairview is a small beachside community of about 75 properties spread out for some 4 km along the frontal beach ridge at an elevation of about 6 m AHD. The community is backed by the North Coast railway line and the Bruce Highway, with higher elevation immediately to the west. It is fronted by extensive tidal flats associated with the high tidal range.

Figure 13 Ilbilbie/Greenhill showing 10,000 y ARI extent

Figure 14 Carmila Beach showing 10,000 y ARI extent

Figure 15 Clairview showing 10,000 y ARI extent

Figure 16 St Lawrence showing 10,000 y ARI extent

The NDRP report mapping for this region is based on WS Group, CW and LT (2003). Figure 15 shows that the estimated 10,000 y ARI extent of about 7.2 m AHD could have considerable impact on the area.

The assessed TMST reaches almost 14 m AHD.

2.7.5 St Lawrence

St Lawrence is a small, historically significant semi-rural regional centre located on the navigable St Lawrence River some 10 km inland from its mouth, which is about midway along Broadsound. It lies north of the larger Styx River[4] some 23 km to the south and is one of the few areas that are significantly higher than 5 m AHD in this low-lying tidal region with a range of up to 10 m. The population is less than 500 and is bounded on the west by the North Coast railway line and the Bruce Highway.

The NDRP report mapping for this region is based on WS Group, CW and LT (2003). Figure 16 shows that the estimated 10,000 y ARI extent of about 7 m AHD would come close to some of the lowest properties in the town.

The assessed TMST reaches 14.7 m AHD, which would inundate the township and could extend storm tide levels up to 20 km inland.

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[4] The Styx River is known to experience a vigorous tidal bore on some king tide events and could behave similarly in a storm tide event.

3. Summary and Conclusions

This report documents an assessment of the estimated storm tide hazard at a selection of east coast communities based on available published studies as summarised in the NDRP study (GHD 2014) and the associated GIS datasets available online. Most of the communities are located north of Cairns and many are relatively small settlements in remote areas. Not all of these have been explicitly included in previous storm tide hazard studies and, accordingly, some of the information collected here is based on a simple linear spatial interpolation between relatively widely-spaced estimates that may not be appropriate for those specific sites.

A range of hazard metrics have been collated here, summarised by the 100 y, 1,000 y and 10,000 y ARI. It can be noted that these are the 1%, 0.1 % and 0.01% AEP (Annual Exceedance Probability) and, referring to Appendix B, the 40%, 5% and 0.5% Encounter Probability over any 50-year period.

The Theoretical Maximum Storm Tide level (TMST) is also included, the methodology for which is detailed in Appendix C. This considers what upper limit of storm surge magnitude might be physically possible through a combination of specifically extreme storm parameters. The resulting water level can then be regarded as representing a “theoretical upper limit” to possible storm tide levels and statistically approximates an infinitely long ARI estimate. It provides a relative ranking of overall susceptibility to storm tide.

Table 3 provides a summary of each community assessment under present climate conditions and attention is drawn (red) to situations where the estimated current LHL (Lowest Habited Level) of a property is deemed relatively low when compared with the 10,000 y ARI storm tide event and if there is no nearby access to higher ground.

Figure 17 shows the variation in assessed present climate storm tide hazard graphically including an allowance for a nominal 1 m Sea Level Rise (SLR) by 2100 to provide a simple future climate context.

The colour shading in Table 3 then follows the assessed assets-most-at-risk ranking by 2100 (refer below), which is based solely on the difference between the estimated 10,000 ARI level and the LHL. This will be different from a most-assets-at-risk ranking criteria, which would likely elevate the more developed communities having a higher population that have a direct exposure to a coast for commerce or community use and that show specific vulnerability to storm tide hazard and long-term SLR. This type of ranking would require a more detailed asset exposure and vulnerability analysis than possible during this review of hazard levels alone.

3.1 Communities Having Assets Most at Risk by 2100

In order of decreasing exposure, these comprise:

- Carmila Beach
- Clairview
- Ayton
- Yarrabah
- St Lawrence
- Ilbilbie
- Marton
- Lizard Island
- Palm Island
- Cooktown
- Cape Bedford
- Lockhart River
- Wujal Wujal
- Cape Flattery
- Port Stewart
- Portland Roads

3.2 Data Quality

Table 3 indicates the source of storm tide hazard estimates available for each community. The NDRP study included a review and scored the quality of all studies that were included in the interpolation analyses. Study 1 was scored very high with a score of ~ 50, while Study 2 and 4 were ranked ~ 25. Study 3 here refers to interpolating between relatively widely-spaced estimates from Study 1 that may not be appropriate for those specific sites.

3.3 Information Gaps

There are no detailed statistically-based storm tide hazard estimates available for:

- Portland Roads
- Port Stewart

although Haigh et al. (2012) suggests a 1000 y ARI level of about 2.5 m AHD in the region and the TMST analysis indicates potential for 6 to 8 m[5].

Elevation data was also not available in this review for these sites, although clearly Port Stewart, which does not have access nearby to higher ground, would be the more exposed. It is noted that the population at these locations is very small and the assets at risk appear minor.

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[5] In these areas, the 10,000 y ARI can be approximated as about 50% of the TMST.

Table 3 Summary Community Assessment (North to South) for Present Climate

Name	Lon	Lat	Comment	Est. Pop.	NDRP Mapping	LHL (m AHD)	LHL Ref	Higher Ground Access	Study Ref	100 y ARI (m AHD)	1000 y ARI (m AHD)	10000 y ARI (m AHD)	TMST (m AHD)
Portland Roads	143.41	-12.60	Small coastal settlement	30	no	~ 10	1	yes					5.5
Lockhart River	143.34	-12.79	Aboriginal community (beach)	1000	yes	5	2	yes	1	1.82	2.16	2.79	7.2
Port Stewart	143.68	-14.07	Small coastal settlement	20	no	~ 5	0	no					7.7
Lizard Island	145.45	-14.67	Offshore island	100	yes	4	2	yes	3			2.5	3.5
Cape Flattery	145.31	-14.96	Small coastal township	150	no	~ 5	0	yes	1	1.61	1.93	2.32	6.0
Cape Bedford	145.31	-15.26	Scattered coastal settlement	50	yes	~ 5	1	yes	3	1.74	2.23	2.81	6.0
Hope Vale	145.11	-15.30	Aboriginal community	1000	yes	n/a	2	yes					6.0
Marton	145.19	-15.46	Small coastal settlement	200	yes	4	2	yes	1	1.87	2.54	3.3	7.6
Cooktown	145.25	-15.46	Regional Centre	2000	yes	5	2	yes	1	1.87	2.54	3.3	7.6
Rossville	145.23	-15.69	Rural locality	100	yes	n/a	1	yes	3			3.5	6.3
Ayton	145.35	-15.92	Small coastal settlement	200	yes	3	2	yes	3			3.5	6.9
Wujal Wujal	145.32	-15.95	Aboriginal community	500	yes	6	2	yes	3			3.5	6.9
Yarrabah	145.87	-16.91	Aboriginal community	3000	yes	3	2	yes	1	1.93	2.46	3.5	5.9
Palm Island	146.58	-18.73	Aboriginal community	5000	yes	5	2	yes	4	2.59	3.02	3.43	7.7
Ilbilbie	149.45	-21.68	Small coastal settlement	400	yes	7	2	yes	2	4.62	5.4	6.63	12.3
Carmila Beach	149.46	-21.91	Small coastal settlement	50	yes	5	2	no	2	4.62	5.4	6.63	13.8
Clairview	149.53	-22.11	Small coastal settlement	150	yes	6	2	yes	2	5.20	5.97	7.18	13.9
St Lawrence	149.54	-22.35	Regional Centre	500	yes	7	2	yes	2	5.44	5.87	7.03	14.7

Hazard Ranking: 1, 2, 3, 4

LHL Ref: 0=guess, 1=Google, 2=DEHP

Study Ref: 1=Hardy et al. (2004b), 2=WS et al. (2003), 3=Hardy et al. (2004b) interpolated, 4=CW (2004b)

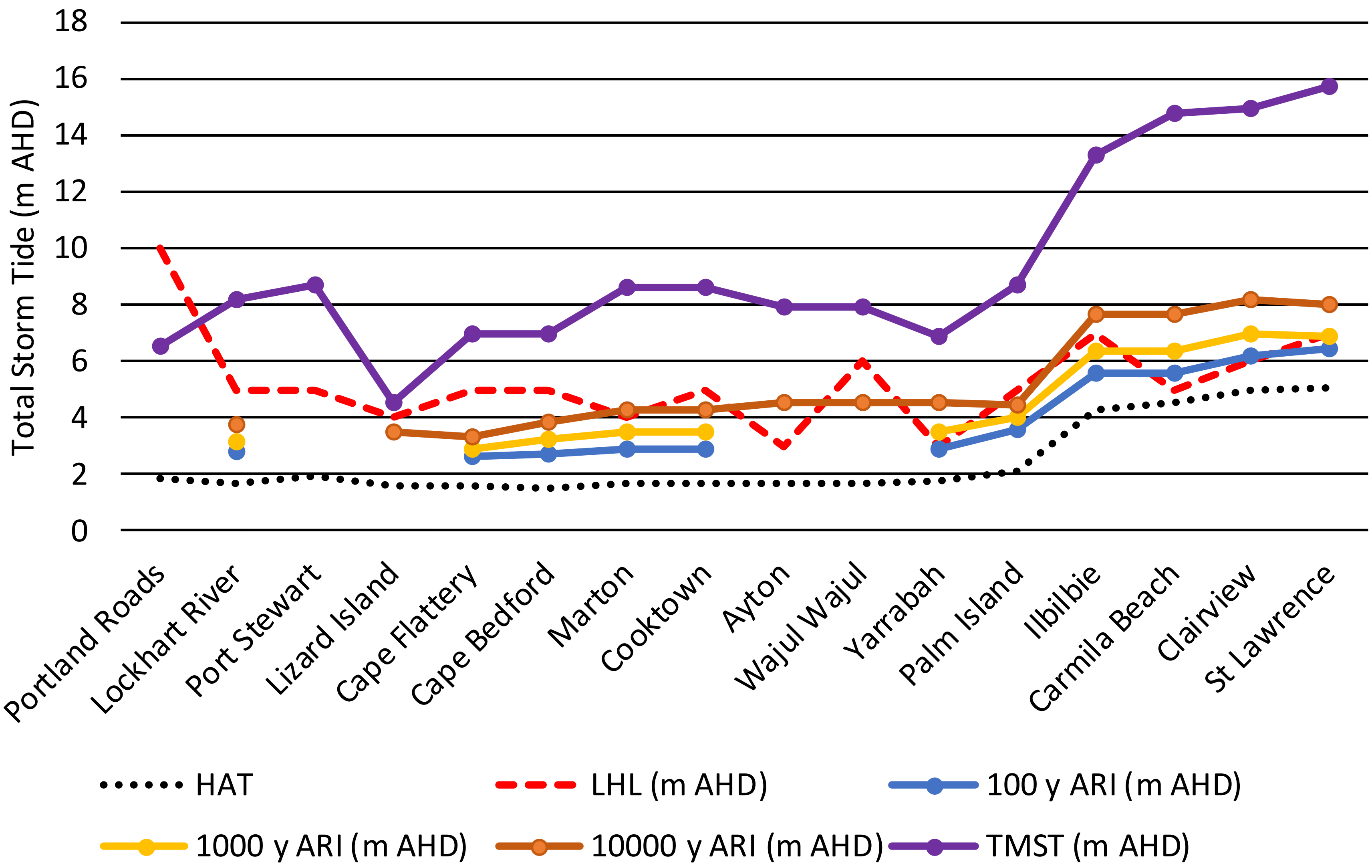

Figure 17 Storm Tide Hazard Summary in the context of a 1 m SLR by the Year 2100.

Sites where Study 3 is the reference should also be regarded as “gaps”, which includes:

- Lizard Island
- Cape Bedford
- Ayton / Wujal Wujal

All estimates derived from Study 1 and 3 do not contain estimates of breaking wave setup, which may be significant in some open coast environments. None of the sites include any estimate of the non-cyclonic water level hazard that can often dominate tropical cyclone impacts up until the 100 y ARI or even beyond and are important for coastal erosion studies. Freeboard allowances have not been nominated herein and may also be considered a data gap.

Sites on elevated sandy coasts that are potentially subject to significant coastal erosion, but have not been specifically assessed here include:

- Carmila Beach
- Clairview
- Cape Bedford
- Cape Flattery

Freeboard allowances are regarded as a management decision following a comprehensive risk analysis that convolves the hazard, the exposure and the vulnerability in the CHAS process.

3.4 Data Suitability for use in the QCoast_{2100} CHAS Program

There are several matters that should be considered when deciding if the available storm tide hazard data is suitable for a CHAS process.

3.4.1 Exposure and Vulnerability

Many of the sites considered herein are very small isolated settlements with relatively minor infrastructure. Whether there is a need for a specific CHAS approach for such situations is a matter for those Councils having jurisdiction on the one hand and responsibility to residents on the other. In many cases, it will be clear that a “forced retreat” will be the most practical long term option. A planning philosophy of “least regrets” based on the presently available information is then likely appropriate.

3.4.2 Methodologies

As highlighted by the NDRP study, there has been a degree of inconsistency between storm tide hazard studies along the coastline over past decades with a combination of State-initiated and LGA-initiated projects. At the State level, there has been a focus on ensuring that studies apply best practice in the various technical elements and follow minimum standards, but detailed site-specific analyses have generally been limited to major centres. At the

LGA level, the emphasis has been more on obtaining value-for-money detailed mapping products and less on the quality of the hazard estimates themselves.

As a result, not all studies can be considered as equally reliable, and this was quantified in the NDRP report scoring system. Also, some high scoring studies lack scope, such as inclusion of wave setup. Others lack an adequate consideration of projected climate change impacts or do not include the non-cyclonic water level hazard component that is important for coastal erosion studies.

Methodologies also continue to improve through adoption of new science, increasing climatic records, adoption of higher resolutions due to data availability and computational advances (e.g. Harper 2002 – 2016). Also, real event validations provide valuable quantification of hazard models that greatly increases confidence in the resulting estimates.

If a community is deemed to be at significant risk from long-term coastal hazards it will be critical that the hazard study information, which drives any quantitative economic decision-making analyses, is of the highest quality available at the time. Given that such studies will typically represent a very small proportion of the cost of projects that follow, having the most reliable hazard estimates available is highly desirable.

3.5 Conclusion

The review has highlighted the fact that many of the sites being considered here have relatively approximate storm tide hazard estimates, mainly because they have been previously regarded as remote or insignificant in the context of past scopes and budgets. None of the sites include non-cyclonic hazards and the necessary statistical blending with tropical cyclone events.

On this basis, the understanding and quantification of the storm tide hazard at most sites considered in this review would significantly benefit from more detailed site-specific studies. It can also be noted that existing models may already contain more reliable hazard estimates for some of these sites than was available at the time of the NDRP study in 2014.

To justify the need for further studies the present estimates can usefully be used to assess the basic criteria as to whether the hazard levels constitute, *prima facie*, a sufficient risk to each community in the long term to justify undertaking a formal CHAS process.

4. References

GHD/SEA (2007) South east Queensland storm tide review – recommendations for modelling, risk assessment and mitigation strategies. Prep. for Caboolture Shire Council on behalf of SEQDMAG by GHD Pty Ltd in assoc. with Systems Engineering Australia Pty Ltd, 99pp, Nov.

GHD (2014) NDRP storm tide hazard interpolation study. State of Queensland, Department of Science, Information Technology, Innovation and the Arts, Jun, 97pp. [Available online at: https://publications.qld.gov.au/dataset/ndrp-storm-tide-hazard-interpolation-study-report]

Harper B.A. (ed.) (2001) Queensland climate change and community vulnerability to tropical cyclones - ocean hazards assessment - stage 1, Report prep by Systems Engineering Australia Pty Ltd in association with James Cook University Marine Modelling Unit, Queensland Government, March, 375pp. [available from: http://www.longpaddock.qld.gov.au/about/publications/pdf/climatechange/vulnerabilitytotropicalcyclones/stage1/FullReportLowRes.pdf]

Harper B.A. (2002) Tropical cyclone parameter estimation in the Australian region: Wind-Pressure Relationships and Related Issues for Engineering Planning and Design, Systems Engineering Australia Pty Ltd for Woodside Energy Ltd, Perth, May, 83pp. [available from http://www.systemsengineeringaustralia.com.au/download/Wind-Pressure%20Discussion%20Paper%20Rev%20E.pdf]

Harper B.A. (2013) Best practice in tropical cyclone wind hazard modelling – in search of data and emptying the skeleton cupboard, Proc. 16th Australasian Wind Engineering Society Workshop, 18-19 July, Brisbane, pp1-10.

Harper B.A. and Mason L.B. (2016) A tropical cyclone wind event data set for Australia. Proc. 18th Australasian Wind Engineering Society Workshop, 6-8 July, McClaren Vale, SA.

Harper B., Kepert J. and Ginger J., (2010) Guidelines for converting between various wind averaging periods in tropical cyclone conditions. World Meteorological Organization, WMO/TD-No. 1555, 62pp.

QCoast_{2100} (2016) Developing a Coastal Hazard Adaptation Strategy: Minimum Standards and Guideline for Queensland Local Governments. Prepared by: The Local Government Association of Queensland and The Department of Environment and Heritage Protection, State of Queensland, Oct, 68 pp.

5. Accessible Storm Tide Information

Aurecon (2012) Sunshine Coast Storm Tide Study – Storm Tide Definition. Prepared for Sunshine Coast Regional Council, April, 21pp.

BMT WBM (2008) Cardwell Inundation Study, Final Report. Prepared for Cassowary Coast Regional Council, October, 176pp.

BMT WBM (2009) Cairns Region Storm Tide Study, Final Report. Prepared for Cairns Regional Council, September 86pp.

BMT WBM (2010) Bundaberg Coastal Storm Tide Study. Prepared for Bundaberg Regional Council, September, 106pp.

BMT WBM (2012) Mackay Region Storm Tide Study, Final Report. Prepared for Mackay Regional Council, November, 253pp.

BMT WBM (2013) Cairns Region Storm Tide Inundation Study, Final Report and Mapping. Prepared for Cairns Regional Council, Jan, 171pp.

Cardno Lawson Treloar (2009) Storm Tide Hazard Study. Prepared for Redland Shire and Logan City Councils, January, 287pp.

Cardno Lawson Treloar (2009) Storm Tide Hazard Study (Incorporating Caboolture, Pine Rivers and Redcliffe Councils). Prepared for Moreton Bay Regional Council, May, pp245.

Cook Shire Council (2017) Online storm tide maps:
http://www.cook.qld.gov.au/documents/12506/1130526/Bloomfield-Ayton%20storm%20tide%20mapping%202011-08.pdf
http://www.cook.qld.gov.au/documents/12506/1130526/Cooktown-Marton%20storm%20tide%20mapping%202011-08.pdf

CW (2003a) Caloundra City storm tide study – development report. Prepared for Caloundra City Council by Connell Wagner and Lawson & Treloar, Aug, 140pp.

CW (2003b) Caloundra City storm tide study – counter disaster planning report. Prepared for Caloundra City Council by Connell Wagner and Lawson & Treloar, Aug, 49pp.

CW (2003c) Capricorn Coast Storm Tide Hazard Investigation, Final Report. Prepared for Livingstone Shire Council, May, 53pp.

CW (2004a) Joint probability assessment storm tide and freshwater flooding – Stage 1a report - Caloundra City Council. Prepared by Connell Wagner, Mar, 20pp.

CW (2004b) Hinchinbrook Storm Surge Study, Final Report. Prepared for Hinchinbrook Shire Council, May, 85pp.

CW (2004c) Bowen Shire Storm Tide Study, Final Report. Prepared for Bowen Shire Council, September, 73pp.

CW (2005a) Maroochy Shire storm tide study – development report. Prepared for Caloundra City Council by Connell Wagner and Lawson & Treloar, Nov, 140pp.

CW (2005b) Maroochy Shire storm tide study – counter disaster planning report. Prepared for Caloundra City Council by Connell Wagner and Lawson & Treloar, Nov, 49pp.

CW (2005c) Stage 1b draft report - Joint probability assessment storm tide and freshwater flooding – Maroochy Shire Council. Prepared by Connell Wagner, Nov, 40pp.

GHD/SEA (2003) Storm tide modelling study of the Whitsunday coast and resort islands. Prep. for Whitsunday Shire Council by GHD Pty Ltd in assoc. with Systems Engineering Australia Pty Ltd, 166pp, November.

GHD/SEA (2007) Townsville – Thuringowa storm tide study. Prep. for Townsville City Council by GHD Pty Ltd in assoc. with Systems Engineering Australia Pty Ltd, 210pp, April.

GHD/SEA (2009) Cassowary Coast storm tide study. Prep. for Cassowary Coast Regional Council by GHD Pty Ltd in assoc. with Systems Engineering Australia Pty Ltd, 260pp, June.

GHD (2011) Storm Tide Risk Study – Great Sandy Strait Coastal Townships. Prepared for Fraser Coast Regional Council, August, 102pp.

GHD (2012) Gold Coast City Council Storm Tide Study, prepared by GHD, May, 176pp

GHD (2013) Gulf of Carpentaria storm tide and inundation study. Prepared by GHD Pty Ltd in association with the Australian Maritime College. State of Queensland, Department of Science, Information Technology, Innovation and the Arts, Mar, 456pp. [Available online at: http://qldgov.softlinkhosting.com.au/liberty/opac/search.do?limit=All&anonymous=true&highlightTerms=gulf&includeNonPhysicalItems=true&action=search&resourceCollection=All&branch=All&corporation=DERM&operator=AND&url=%2Fliberty%2Fopac%2Fsearch.do&queryTerm=storm+tide+inundation+gulf&mode=ADVANCED]

GHD/SEA (2007) Townsville - Thuringowa storm tide study, Final report. Prepared by GHD Pty Ltd in association with Systems Engineering Australia Pty Ltd, April, 210pp

Haigh I.D, Wijeratne E.M.S, MacPherson L.R, Mason M.S, Pattiaratchi C.B, Crompton R.P, George S. (2012) Estimating present data extreme total water level exceedance probabilities around the coastline of Australia, Prepared for the ACECRC 92pp.

Hardy T.A., Mason, L.B., Astorquia A. and Harper B.A. (2004a) Queensland climate change and community vulnerability to tropical cyclones - ocean hazards assessment - stage 2: tropical cyclone-induced water levels and waves: Hervey Bay and Sunshine Coast. Report prepared by James Cook University Marine Modelling Unit in association with Systems Engineering Australia Pty Ltd, Queensland Government, August, 115pp. [available from: http://www.longpaddock.qld.gov.au/about/publications/pdf/climatechange/vulnerabilitytotropicalcyclones/stage2/FullReportLowRes.pdf]

Hardy T.A., Mason L.B. and Astorquia A. (2004b) Queensland climate change and community vulnerability to tropical cyclones - ocean hazards assessment - stage 3: the frequency of surge plus tide during tropical cyclones for selected open coast locations along the Queensland east coast. Report prepared by James Cook University Marine Modelling Unit, Queensland Government, August, 61pp. [available from:

http://www.longpaddock.qld.gov.au/about/publications/pdf/climatechange/vulnerabilitytotropicalcyclones/stage3/FullReportLowRes.pdf]

Harper B.A. (2004) Queensland climate change and community vulnerability to tropical cyclones – ocean hazards assessment: synthesis report, Queensland Government, Aug, 38pp.

Lawson and Treloar (2001) Hervey Bay Storm Surge Study. Prepared for Hervey Bay City Council, October, 76pp.

Maunsell and DHI (2003) Burdekin Shire Storm Surge Study, Volume 1. Prepared for Burdekin Shire Council, July, 236pp

SEA (2011) Torres Strait extreme water level study. Prepared by Systems Engineering Australia Pty Ltd for the Torres Strait Regional Authority, July, 386pp. [Available at: http://www.tsra.gov.au/__data/assets/pdf_file/0009/3996/Torres-Strait-Extreme-Water-Level-Study-Dec.pdf]

WS Group, CW and LT (2003) Storm Tide Risk Management Study for Broadsound Shire Council and Sarina Shire Council, Final Report, March, 93pp.

Appendix A

Scope of Work

Contracted Services

Required of the Consultant:

- Undertake an assessment to review, collate and validate storm tide data/information for the following east coast councils:
    - ✓ Isaac Regional;
    - ✓ Palm Island Aboriginal Shire;
    - ✓ Yarrabah Aboriginal Shire;
    - ✓ Wujal Aboriginal Shire;
    - ✓ Hope Vale Aboriginal Shire;
    - ✓ Cook Shire; and
    - ✓ Lockhart River Aboriginal Shire.
- The scope of works includes:
    - ✓ Collate, review all existing storm tide assessments/studies/data available for the above areas. The LGAQ will provide GIS surfaces for coastal areas (if required) in a QGIS compatible format.
    - ✓ Identify (at a high level) localised areas with assets at risk i.e. residential, commercial, environmental & cultural values within the above LGs. The assessment must include all localities within the LGs that are subject to storm tide inundation, and as such there may be multiple storm tide values for a single LG.
    - ✓ Evaluate and assess if existing storm tide data available for the localised areas identified is reasonably defendable, and is of sufficient quality/accuracy for use as part of the QCoast_{2100} Program.
    - ✓ Identify any gaps in the existing information available:
        - Data is not of acceptable quality.
        - Resolution and level of detail available is not sufficient for the purpose of the Program and for use by Councils for proceeding phases of the CHAS.
        - No data is available.
    - ✓ Provide a concise report (using the LGAQ report template) including a tabulation of acceptable storm tide levels for a CHAS and any recommendations including for freeboard or wave setup. Where no recommendation can be made on water levels, provide a recommendation on acquiring the required information.
- The Program Coordinator will organise an inception meeting between the Consultant and representatives from the EHP and the LGAG following contract finalisation. The meeting will seek to identify DEM requirement in a QGIS compatible format and confirm project scope.

Appendix B

A Note on the Interpretation of Statistical Return Periods

B.1 General

This study has presented its analyses of hazard in terms of the so-called *Return Period* (or *Average Recurrence Interval ARI*). The Return Period is the “average” number of years between successive events of the same or greater magnitude. For example, if the 100-year Return Period wind speed level is 50 ms^{-1} then on average, a 50 ms^{-1} wind speed *or greater* will occur due to a single event once every 100 years, but sometimes it may occur more or less frequently than 100 years. It is important to note that in any “N”-year period, the “N”-year Return Period event has a 64% chance of being equalled or exceeded. This means that the example 50 ms^{-1} wind speed has a better-than-even chance of being exceeded by the end of any 100-year period. If the 100-year event were to occur, then there is still a finite possibility that it could occur again soon, even in the same year, or that the 1000-year event could occur, for example, next year. Clearly if such multiple events continue unchecked then the basis for the estimate of, say, the 100-year event might then need to be questioned, but statistically this type of behaviour can be expected.

The *Annual Exceedance Probability* (AEP) is also commonly used for expressing statistical risk, especially fluvial flooding, and is sometimes preferred. For “large” Return Periods (> 10 y) the AEP is simply the reciprocal of the ARI, such that a 100-year ARI is described as a 1 in 100 year AEP, or alternatively equals 0.01 or is the 1% exceedance event level.

A more consistent way of considering the above (NCCOE 2012) is to include the concepts of “design life” and “encounter probability” which, when linked with the Return Period, provide better insight into the problem and can better assist management risk decision making. These various elements are linked by the following formula (Borgman 1963):

$$T = - N / \ln [1 - p]$$

where p = encounter probability $0 \leq 1$

N = the design life (years)

T = the Return Period (years)

This equation describes the complete continuum of risk when considering the prospect of at least one event of interest occurring. More complex equations describe other possibilities such as the risk of only two events in a given period or only one event occurring.

Figure B.1 illustrates the above equation graphically. It presents the variation in probability of at least one event occurring (the encounter probability) versus the period of time considered (the design life or planning horizon). The intersection of any of these chosen variables leads to a particular Return Period (ARI) and a selection of common Return Periods is indicated. For example, this shows that the 200-year Return Period has a 40% chance of being equalled or exceeded in any 100-year period.

The level of risk acceptable in any situation is necessarily a corporate or business decision. Table B.1, based on Figure B.1, is provided to assist in this decision-making process by showing a selection of risk options. Using Table B.1, combinations of design life and a comfortable risk of occurrence over that design life can be used to yield the appropriate Return Period to consider. For example, accepting a 5% chance of occurrence in a design life of 50 years means that the 1000-year Return Period event should be considered. A similar level of risk is represented by a 1% chance in 10 years. By comparison, the 100-year Return Period is equivalent to about a 10% chance in 10 years. AS/NZS 1170.2 (Standards Australia 2011), for example, dictates a 10% chance in 50-years criteria or the 500-year Return Period as the minimum risk level for wind speed loadings on engineered structures and AS4055 also adopts this for residential housing.

B.2 References

NCCOE (2012) Guidelines for responding to the effects of climate change in coastal and ocean engineering – 3rd Edition May 2012. Engineers Australia, National Committee on Coastal and Ocean Engineering, EA Books, 74pp.

Borgman L. (1963) Risk Criteria. Journal of the Waterway, Port, Coastal and Ocean Division, ASCE, Vol 89, No. WW3, Aug, 1 - 35.

Standards Australia (2011) AS/NZS 1170.2:2011 : Structural design actions - Wind actions. 90pp, as amended.

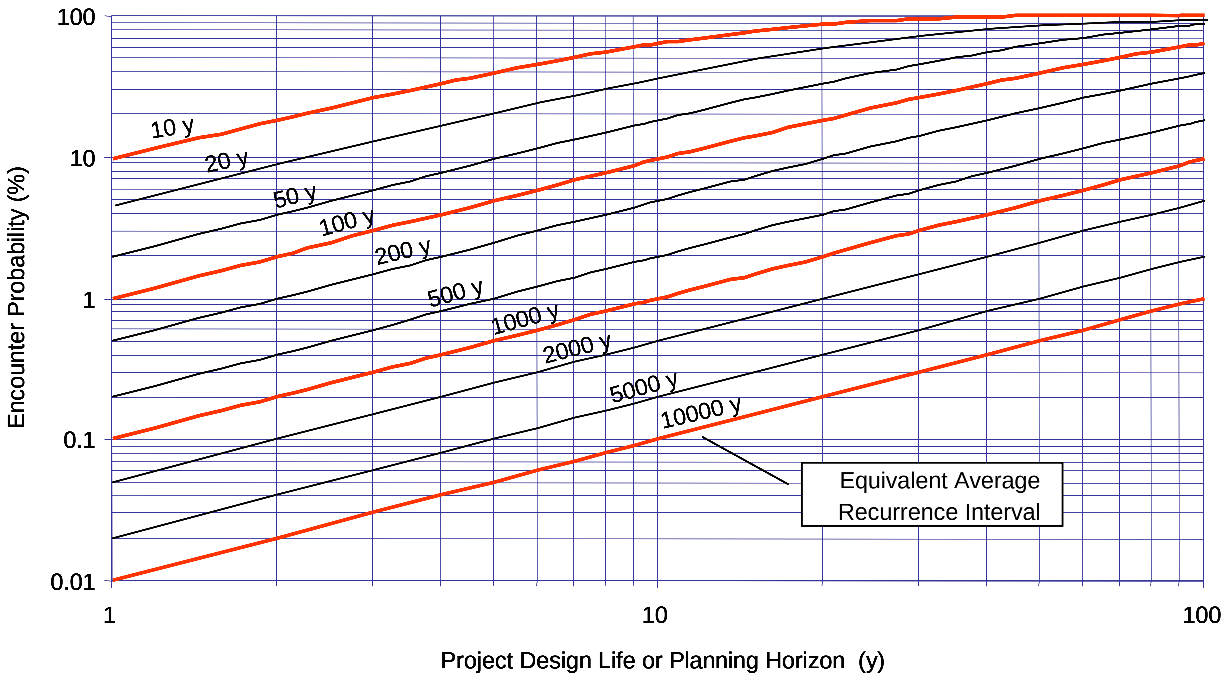

Figure B.1 Relationship between Return Period (or ARI) and Encounter probability

Table B.1 Risk selection based on encounter probability concepts.

Considered Design Life or Planning Horizon	Chosen Level of Risk of at Least One Event Occurring					
	% Chance					
y	1	2	5	10	20	30
	Equivalent Return Period or ARI (y)					
10	995	495	195	95	45	29
20	1990	990	390	190	90	57
30	2985	1485	585	285	135	85
40	3980	1980	780	380	180	113
50	4975	2475	975	475	225	141

Appendix C

The Theoretical Maximum Storm Tide (TMST) Level

C.1 General

The following description of this metric is from GHD (2014), where further details of the methodology are provided. The TMST provides a measure of whether a specific location of interest, as specified solely by its elevation, is potentially at any risk from TC storm tide, or not.

C.2 Definition

The "theoretical maximum storm tide" considers what upper limit of storm surge magnitude might be physically possible through a combination of specifically extreme storm parameters, without regard to their likely joint probability or overall probability of occurrence, and then combines that resulting magnitude with the Highest Astronomical Tide. The resulting water level can then be regarded as representing a "theoretical upper limit" to possible storm tide levels and statistically approximates an infinitely long ARI estimate. While this seems straightforward, the selection of the "extreme parameters" still requires significant subjective judgement. The parameters of interest in the context of a standard Holland parametric wind and pressure model, as described in Harper (2001), and their typical influence on the resulting storm surge magnitude are summarised in the following Table:

Parameter	Symbol	Indicative Range	Effect of Increasing |Latitude|	Impact Maximised When
Central Pressure	p_c	990 to 880 hPa	increases	lowest
Radius to Maximum Winds	R	5 to 100 km	increases	largest
Peakedness Parameter	B	0.8 to 2.5	decreases	largest[6]
Speed of Forward Movement	V_{fm}	0 to 10 m/s	increases	largest[7]
Track	θ_{fm}	180 to 290 deg	decreases	coast perpendicular (typically)

It can be noted that in the Queensland setting, all the above parameters exhibit a significant variation with latitude (assumed here increasing from north to south) and the likely ranges were investigated in Harper (2004a) in association with Bureau of Meteorology (BoM) personnel.

[6] This is a general statement that may not be the case in individual situations due to the relationship between B and R in the Holland model. This has been partly addressed here by adopting a more sophisticated "double Holland" wind field modelling approach.

[7] Typically, there will be a specifically resonant forward speed applicable to a particular situation and there are physical limits to the speed of a storm system and its ability to maintain intensity.

C.2 Methodology

The method involved undertaking a large number of discrete hydrodynamic model simulations of simplified tropical cyclone wind and pressure fields using the MMUSURGE hydrodynamic model. A series of hypothetical storm tracks were constructed, each of 36 h duration, approximately perpendicular to the coastline, spaced every 50 km apart from near Byron Bay in NSW and north to Torres Strait (being approximately 100 storm tracks). The highest peak storm surge values generated at each modelled location from all tracks on the adopted “B” grid resolution (2.8 km) were then been extracted and combined with the DSITIA-provided “HAT thread”. These were then merged with the Gulf of Carpentaria TMST estimates (GHD/AMC 2013), which have a similar basis, but were extracted from SATSIM parametric models rather than MMUSURGE simulations.

It can be noted that “breaking wave setup” is not specifically calculated in this assessment. Instead, the nominal recommendations of Harper (2007) for wave setup have been adopted with appropriate blending and interpolation. This has the effect of significantly increasing MMUSURGE-derived TMST levels only in those areas that are exposed to deepwater wave conditions (e.g. south of Hervey Bay). In other areas its impacts will generally be insignificant in situations where surge+tide inundation is the overwhelming impact.

C.3 References

GHD/AMC (2013) Gulf of Carpentaria Storm Tide and Inundation Study, prepared by GHD in association with Australian Maritime College, Mar, 454pp

GHD (2014) NDRP storm tide hazard interpolation study. State of Queensland, Department of Science, Information Technology, Innovation and the Arts, Jun, 97pp. [Available online at:
https://publications.qld.gov.au/dataset/ndrp-storm-tide-hazard-interpolation-study-report]

Harper B.A. (Ed.) (2001) Queensland climate change and community vulnerability to tropical cyclones: ocean hazards assessment - stage 1. Report prepared by Systems Engineering Australia Pty Ltd in conjunction with James Cook University Marine Modelling Unit, Queensland Government, March, 382pp.

Harper B.A. (2004a) Queensland climate change and community vulnerability to tropical cyclones – ocean hazards assessment: Stage 1a – Operational Manual, Queensland Government, Mar, 75pp.

Harper B.A (2007) Investigation into Maximum Storm Tide Inundation Levels along the Populated Queensland East Coast. Environmental Protection Agency (unpublished).