*Connell Wagner Pty Ltd*
*ABN 54 005 139 873*
*433 Boundary Street*
*Spring Hill*
*Queensland 4004 Australia*

*Telephone: +61 7 3246 1000*
*Facsimile: +61 7 3246 1001*
*Email: cwbne@conwag.com*
*www.conwag.com*

# *Capricorn Coast*
# *Storm Tide Hazard Investigation*
# *For Livingstone Shire Council*
# *Final Report*

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Connell Wagner

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# *Glossary*

| | | |
|---|---|---|
| AHD | – | Australian Height Datum |
| AEP | – | Annual Exceedance Probability |
| BPA | – | Beach Protection Authority |
| CL | – | Confidence Limits |
| CP | – | Central Pressure (hPa) |
| DCDB | – | Digital Cadastral DataBase |
| DoE | – | Department of Environment (now the Environmental Protection Agency) |
| HAT | – | Highest Astronomical Tide |
| $H_{max}$ | | Maximum wave height observed in a wave record |
| $H_s$ | – | Significant Wave Height |
| PSM | – | Permanent Survey Mark |
| RL | – | Reduced Level |
| $R_m$ | | Radius to maximum cyclone wind speed |
| $R_2$ | | Wave Run-up Height not exceeded by more than 2% of waves |
| Tp | – | Peak Spectral Period |
| $V_f$ | – | Cyclone Forward Speed |

# 1. Introduction

Livingstone Shire Council obtained funding from the Federal and Queensland State Governments to undertake a Storm Tide Hazard Assessment of the Capricorn Coast. The funding was made available through the Natural Disaster Risk Management Studies Program, administered in Queensland by the Department of Emergency Services.

The stated aim of the Storm Tide Hazard Assessment was to identify and quantify areas of risk associated with storm surges which impact on the coastal communities of Livingstone Shire Council, in particular at Yeppoon, Emu Park and Keppel Sands.

Connell Wagner was commissioned by Livingstone Shire Council on 7 January 2002 to undertake the Storm Surge Study. The specific objectives of the Study were to identify the true risk of storm surge inundation along the coastal region extending from Joskeleigh/Keppel Sands in the south to Bangalee in the north of the Shire. This was undertaken by predicting extreme water levels, and the effects of actual storm surge inundation combined with wave penetration across the specific coastal areas.

The Study has included the following tasks:

- Predicting extreme water levels for the Livingstone Shire Council coastline jurisdictions, using official cyclone records;
- Modelling actual storm surge inundation using state of the art (improved) wind field models and site specific numerical hydrodynamic modelling, which represent the coastlines offshore features and shape of coastline;
- Determining combined wave penetration using estimates of extreme wave conditions to improve the original calculation of wave setup effects across specific coastal areas;
- Identifying critical areas of concern arising from climatic changes, expanding coastal development, increasing population areas and the effects to essential services and Council infrastructure; and
- Mapping the storm surge inundation by preparing storm surge and hazard mapping indicating the extreme water levels for all affected areas.

As this study's results are important for counter-disaster planning, it was important to include prediction of 'extreme' water levels. In a freshwater flooding context, predictions usually include up to the so-called "Probable Maximum Flood" (PMF), although in the coastal context, PMF has no meaning. For this Study the extreme event that has been adopted will be referred to as the "Probable Maximum Storm Tide".

An important exclusion from this study is the issue of freshwater flooding, and its joint occurrence with storm surge. This issue is discussed further in Section 15.

Connell Wagner commissioned Lawson & Treloar as specialist sub-consultants to undertake the storm surge and wave numerical modelling, followed by the Monte Carlo analyses.

# 2. Study Area

The Storm Surge Study includes all coastline areas within Livingstone Shire Council. The Study Area extends from the mouth of Pumpkin Creek, near Joskeleigh in the south to the mouth of Barwells Creek in the north. This includes the communities of Keppel Sands, Emu Park and Yeppoon. Figures 1 and 2 present the study area and some of the key features of the area.

Several creek systems discharge along this stretch of coastline including:

- Pumpkin Creek;
- Cawarral Creek;
- Kinka Creek;
- Causeway Lake;
- Williamson Creek;
- Ross Creek; and
- Barwells Creek.

The Study Area is predominantly formed of open coast beaches that are provided with some protection by offshore islands and reefs. The beach faces are typically flat with extensive inter-tidal zones that are exposed at low tide. The back-beach area is generally low and may be protected by a low frontal dune, for example, but in some locations, as is the case at Yeppoon, there is no dune and some form of coast protection works have been built to prevent shoreline recession and to protect public and private property. Where dunes occur, the dune system generally does not extend landward more than the frontal dune itself. The Shire also includes some significant coastal lagoons such as Cawarral Creek, Ross Creek and Corio Bay, which is north of the designated study area.

The Shire has experienced some damage from cyclone surge, apart from wind, wave and rainfall effects, which are more common. Notable amongst these is Cyclone David which occurred in January, 1976. At the peak of the storm tide, ocean water overtopped the back-beach area near Council Chambers in Yeppoon, thereby requiring evacuation of the nearby hospital. Land levels in this area are in the order of 3m AHD. This event provides some indication of the extent of impact that has been experienced.

Further south, marina facilities at Rosslyn Bay were damaged severely. Storm tide penetration into major waterways will have provided the possibility of significant penetration of ocean water behind the coastal beach front and the opportunity for those high waters to inundate parts of the hinterland. However, cyclones such as Fran in March, 1992, which caused winds up to 76 knots on Great Keppel Island, are not reported to have caused a significant storm tide in the area. A review of the Cyclone Impacts report prepared by the Brisbane office of the Bureau of Meteorology shows no other severe storm tide events since about 1950.

It is possible that the very severe cyclone of January, 1918, which crossed the Queensland coast near Mackay, caused some surge in this region. A surge in excess of 3m was reported at Mackay during that event.

# 3. Previous Studies

Several studies have documented the existence of storm surges within the Capricorn Coast area. The *Impacts Report* prepared within the Brisbane office of the Bureau of Meteorology by Mr J Callaghan presents descriptive accounts of historical cyclone impacts. Significant storm surge/cyclone events are detailed in Table 1.

**Table 1– Historical Cyclonic Events**

| Cyclonic Event | Impact |
|---|---|
| 1 Feb 1893 | A tropical cyclone crossed the coast near Yeppoon smashing buildings and uprooting trees. |
| *David*<br>19 January 1976 | *David* crossed to the north of St Lawrence. It passed over Gannet Cay. Winds unroofed 30 buildings in Yeppoon. The breakwater at Rosslyn Bay was destroyed along with yachts and trawlers. Wave recording stations at Yeppoon recorded a peak wave height ($H_{max}$) of 7.6m. |
| *Elinor*<br>3-4 March 1983 | *Elinor* crossed the coast near Carmila. Heavy rain and minor damage in the Yeppoon area. |
| *Fran*<br>16 March 1992 | *Fran* caused considerable property damage along the coast of Queensland. Maximum wind gust of 76 knots recorded on Great Keppel Island. |
| *Rewa*<br>20 January 1994 | *Rewa* came within 100km of the east coast of Queensland. Floodwaters caused damage to approximately 100 homes. Two men were rescued from a fishing trawler off the coast of Yeppoon. |

The 1979 Beach Protection Authority Publication, *Capricorn Coast Beaches* provided a detailed study of coastline behaviour along the Capricorn Coast including storm surge. Storm surge was analysed using a simplistic, empirical model to represent surges. The model was also limited in scope and only being able to accurately model storm surge probabilities in the area between Yeppoon and Emu Park.

There were also a number of studies that occurred in the wake of cyclone David, such as the *Rosslyn Bay Boat Harbour Surge Investigations* by James Cook University and *Storm Surge Flooding at Farnborough Resort* by Cameron, McNamara and Partners. However, these studies have generally been narrow in focus and have not attempted to quantify the risk or consequences arising from storm surge events across the whole of the Capricorn Coast.

Previous cyclone storm tide investigations for the Yeppoon area are reported in Blain, Bremmer & Williams (1977). The study approach adopted at that time was similar to the one followed in this study. However, this study has been able to use much finer grid resolution, a 3D model and a much larger set of basic cyclone simulations to provide input to the Monte Carlo analysis. These changes were possible because of the much increased computing power that is now available. Another issue to be considered is that at that time no Greenhouse related climate changes were considered.

# 4. Available Data

A range of data items were required to undertake the Storm Surge Study including:

- Data to set up and calibrate the numerical storm surge model;
- Data to establish a numerical wave model; and
- Data to allow the preparation of inundation maps for affected coastal areas.

The following sections detail the data collected and used on this project.

## 4.1 Bathymetric Data

Bathymetric data is required to describe the topography of the seabed and coastline over the area of the proposed numerical model system. Charts 818, 819, 820, 822 and 4602 were used. This data was digitised to provide a digital terrain model from which the numerical surge and wave model grids were prepared.

Additionally, Council provided land survey charts to describe land levels in the low lying coastal and estuarine regions of the study area. The storm surge model depths were modified in the areas using this data to describe low lying areas such as Cawarral Creek.

## 4.2 Tidal Information

Tides in this region are predominantly semi-diurnal. Therefore there are two high and two low tides each day. The most representative site is Rosslyn Bay, for which tidal planes are presented in Table 2.

**Table 2 – Tidal Information**

| Tide | Tidal Level (m LAT) |
|---|---|
| Highest Astronomical Tide (HAT) | 4.94m |
| Mean High Water Springs (MHWS) | 4.12m |
| Mean High Water Neaps (MHWN) | 3.22m |
| Mean Sea Level (MSL) | 2.36m |
| Mean Low Water Neaps (MLWN) | 1.61m |
| Mean Low Water Springs (MLWS) | 0.72m |

This information is presented in The Official Tide Tables & Boating Safety Guide (2001), prepared by the Department of Transport, Queensland. All data is to Chart Datum which is Lowest Astronomical Tide (LAT). Datum AHD is 2.36m above Chart Datum.

## 4.3 Wave Data

The Beach Protection Authority (BPA) recorded wave data at their Yeppoon site between November 1974 and April 1978 in a depth of 25m at 23°7'S; 151°, 4'E. The highest wave height ($H_s$) recorded at this installation was 3.9m during cyclone David in January, 1976. In general, two readings, each of 20 minutes duration, were made in analogue form. Hence it is possible that peak storm wave conditions were not recorded.

The second highest wave condition ($H_s$ = 3.5m) occurred during cyclone Otto, which crossed the Queensland coast near Bowen in March, 1977. This cyclone, though not intense, caused large waves as far south as Double Island Point.

### 4.4 Cyclone Data

Cyclone track data was required to describe the characteristics of historical cyclones that have affected the Livingstone Shire Coast region. Although some data was held in L&T archives, the Bureau of Meteorology advised that all data is now available from their web site in digital form. This data was downloaded for this study. Additionally, cyclone impacts have been discussed with Mr Jim Davidson and Mr Jeff Callaghan of the Bureau of Meteorology and data presented in the Bureau's Impacts report has been provided and assisted this study.

Generally, cyclone track data has improved in quality since about 1960 when satellite imagery and over-the-horizon radar sampling provided better records of important parameters. However, events occurring since 1955, and which have had a significant effect in the study area, have been included.

Table 3 lists all cyclones included in this investigation that have occurred since 1955, and which have passed close by the study area. Those cyclone tracks are plotted in Figure 3.

**Table 3 – Cyclones Affecting Livingstone Shire Coast Since 1955**

| No | Cyclone Number | Cyclone Name | 1st Day Cyclone is in Zone of Influence | Representative Central Pressure in Zone of Influence (hPA) | Distance of Simplified Track to Site (km) | Average Forward Velocity of Simplified Cyclone Track (m/s) |
|---|---|---|---|---|---|---|
| *South East Population Cyclones* | | | | | | |
| 1 | 248 | | 20/01/56 | 1001 | -290 | 16.7 |
| 2 | 260 | | 22/12/56 | 998 | 255 | 6.1 |
| 3 | 262 | | 10/01/57 | 994 | 240 | 17.5 |
| 4 | 280 | | 16/02/59 | 975 | -180 | 7.5 |
| 5 | 293 | | 03/01/61 | 996 | 208 | 9.4 |
| 6 | 304 | | 23/12/61 | 1000 | 280 | 9.2 |
| 7 | 334 | Gertie | 16/03/64 | 1004 | 360 | 2.2 |
| 8 | 396 | Dora | 10/02/71 | 1000 | 385 | 5.4 |
| 9 | 399 | Fiona | 20/02/71 | 995 | 5 | 5.1 |
| 10 | 405 | Althea | 26/12/71 | 990 | -290 | 9.0 |
| 11 | 431 | Una | 19/12/73 | 1001 | -227 | 5.2 |
| 12 | 640 | | 10/01/75 | 994 | 236 | 15.1 |
| 13 | 468 | Dawn | 04/03/76 | 990 | 30 | 9.4 |
| 14 | 470 | Watorea | 28/04/76 | 980 | 195 | 11.5 |
| 15 | 523 | Freda | 27/02/81 | 977 | 390 | 5.7 |
| 16 | 700 | Grace | 15/01/84 | 975 | 385 | 4.8 |
| 17 | 706 | Lance | 07/04/84 | 995 | 249 | 6.1 |
| 18 | 735 | Pierre | 21/02/85 | 990 | 23 | 5.4 |

| No | Cyclone Number | Cyclone Name | 1st Day Cyclone is in Zone of Influence | Representative Central Pressure in Zone of Influence (hPA) | Distance of Simplified Track to Site (km) | Average Forward Velocity of Simplified Cyclone Track (m/s) |
|---|---|---|---|---|---|---|
| 19 | 817 | Rewa | 18/01/94 | 970 | 140 | 5.0 |
| 20 | 842 | Gertie | 23/12/95 | 994 | 217 | 12.2 |
| 21 | 897 | Paul | 16/01/80 | 990 | 68 | 11.5 |
| *South West Population Cyclones* | | | | | | |
| 22 | 243 | | 06/03/55 | 965 | 154 | 5.8 |
| 23 | 244 | | 25/03/55 | 985 | -199 | 4.9 |
| 24 | 253 | | 04/03/56 | 974 | 290 | 5.0 |
| 25 | 597 | | 17/03/56 | 996 | -349 | 5.3 |
| 26 | 600 | | 21/03/57 | 1005 | -122 | 4.0 |
| 27 | 310 | | 31/12/62 | 985 | 340 | 6.5 |
| 28 | 357 | Dinah | 27/01/67 | 948 | -208 | 4.6 |
| 29 | 383 | Ada | 17/01/70 | 970 | 322 | 1.8 |
| 30 | 397 | Gertie | 13/02/71 | 983 | 236 | 3.1 |
| 31 | 409 | Daisy | 11/02/72 | 970 | -315 | 4.2 |
| 32 | 414 | Emily | 01/04/72 | 965 | -86 | 5.4 |
| 33 | 435 | Wanda | 24/01/74 | 998 | -299 | 5.5 |
| 34 | 461 | David | 18/01/76 | 964 | 127 | 6.8 |
| 35 | 464 | Beth | 21/02/76 | 994 | -220 | 2.4 |
| 36 | 482 | Otto | 09/03/77 | 990 | 385 | 5.1 |
| 37 | 496 | Kerry | 27/02/79 | 994 | 310 | 3.1 |
| 38 | 521 | Cliff | 14/02/81 | 990 | -217 | 9.4 |
| 39 | 721 | Elinor | 01/03/83 | 985 | 110 | 1.9 |
| 40 | 762 | Charlie | 01/03/88 | 993 | 408 | 3.6 |
| 41 | 806 | Fran | 15/03/92 | 980 | -127 | 3.9 |
| 42 | 899 | Simon | 23/02/80 | 960 | 5 | 3.5 |

### 4.5 Storm Surge Data

Calibration of the proposed storm surge model provides confidence in simulated storm surge results. Only one severe event (Cyclone David) was identified in this area since 1955. Prior to this time data is less reliable. However, cyclone Fran, which occurred in March 1992, caused a storm surge of 0.7m at Gladstone (Auckland Point) to the south of the Livingstone Shire. Therefore the surge model was developed to include Gladstone, with sufficient model extent to the south to ensure physically realistic surge development at Gladstone. Recorded water levels and predicted tide data for these events are presented in Figures 4 and 5.

This data was provided by the Department of Transport, Queensland and was used for model calibration/verification. Note that although the Rosslyn Bay water level recorder (cyclone David) did malfunction for part of that event, fortunately the surge at the peak of the event was available.

### 4.6 On-Shore Survey Data

The following survey data was used during the study for on-shore areas:

- **Beach dune survey from the BPA**
  Topographic details of frontal beach dunes along the Capricorn Coast were included in the contour maps used for the storm surge and inundation modelling.

- **Topographic and infrastructure details from Council**
  Council supplied details of the major infrastructure within the shire including roads, water and sewer mains, cadastral boundaries and aerial photographs. As well being used to in the risk assessment on-site work this data was also used to verify levels and assess potential areas of flood inundation.

- **Road and structure details from Main Roads**
  The Rockhampton Office of the Department of Main Roads supplied road and structure drawings for numerous sections of road within Livingstone Shire. These road and structure details were used to represent several of the structures within the MIKE 11 and MIKE 21 models.

- **Detailed survey by Finch Consultants**
  Details for several roads and structures could not be obtained from the information received from Council and Main Roads. Finch Consultants were engaged to provide survey of roads and structures as well as provide cross-sections for the 5 creeks that were modelled using MIKE 11.

### 4.7 Other Data

Information was also obtained from previous scientific studies of the area. A number of these previous reports are discussed in Section 3. Local newspaper articles and souvenir information also assisted in gaining an important historical perspective on past cyclone events.

Mr Chris Russell and Dr Doug Treloar conducted a site visit on 10 and 11 January 2002 where they visited Council, investigated the study area and spoke to local residents. Some of the key activities that were undertaken during this site visit included:

- SAG Meeting with Council employees and representatives to ascertain what Council expected from the study and determine what data Council had available for use in the study;
- Thorough inspection of all of the areas at risk with Mr John Watkins of Council; and
- Meeting with Council SES Controller Mr Bob Jeacocke who provided information on his experiences with cyclone events in the area and provided contacts of other people who may have additional information.

In addition local residents were contacted for anecdotal information on previous cyclonic events. Mr Mike Prior was contacted, as he was the Rosslyn Bay charter boat operator at the time of Cyclone David. Mr Prior recalled the impact of Cyclone David which created 3m high waves over the top of the Yeppoon Seawall and shifted boulders upwards of 1 cubic metre in size. His main concern was that because historically storm surges in the area have not occurred in conjunction with a large tide residents may have become complacent regarding the potential impacts of storm surges.

Numerous attempts were made to contact Mr Keith Sleeman but he was unobtainable.

# 5. Approach

The purpose of this study was to develop detailed storm tide statistics at selected sites within Council's area of responsibility. These sites were:

- Bangalee;
- Barwells Creek;
- Causeway Creek;
- Cawarral Creek;
- Emu Park;
- Joskeleigh;
- Keppel Sands;
- Kinka Creek;
- Ross Creek;
- Rosslyn Bay;
- Williamson Creek; and
- Yeppoon.

There are two basic approaches that can be adopted. They are:

- Hindcast historical cyclone events using actual cyclone tracks and tides; or

- Analyse the historical cyclone track data to develop a parametric description of variables such as central pressure, track direction and distance from the Yeppoon area in terms of probabilities of occurrence. This task is followed by a series of cyclone simulations that provide basic time series of surge, wave and wind data. These time series are then used in a Monte Carlo analysis in which cyclones are generated according to the parameterised cyclone wave climate. Estimated parameters for each simulated cyclone event are determined by interpolation/extrapolation from the base simulation results.

Both approaches produce time series of parameters that are subjected to extremal and correlation analyses. However, the Monte Carlo approach lends itself to the preparation of data covering much longer periods of time, and because AEP up to about the 1 in 10,000 years were required for this study, the Monte Carlo procedure was adopted. All water level recurrence statistics were based on a 10,000 years period of simulations.

# 6. Cyclone Data Analysis

## 6.1 General

The Monte Carlo procedure required that a range of cyclone simulations be undertaken to provide basic time series input data for interpolation/extrapolation. As part of this process it was necessary to describe each simulated cyclone in a general way, choosing the principal parameters - track direction, distance from the Yeppoon area, central pressure and forward speed, based on historical cyclone data. These events and parameters are presented in Table 3.

In this analysis only those cyclones affecting the area over the 45 years period from 1955 to 2001 were considered. Based on previous experience, only those cyclones passing within a defined zone of influence were included in parameter analyses. This zone of influence was chosen on the basis of those cyclone tracks that might produce the highest storm surges along the Livingstone Shire coast. For this study the zone of influence was defined as being the area between latitudes 20.1°S and 26.1°S and longitudes 147.5°E and 153.5°E. Yeppoon is located at 23°8'S; 150°45'E.

## 6.2 Track Direction

An inspection of the available cyclone track data led to the decision to adopt two direction categories:

- From north-east to south-west (south-westward); and
- From north-west to south-east (south-eastward).

These are generally equivalent to coast crossing and coast parallel tracks, respectively. The selection basis is related to cyclone track direction in the Capricorn Coast region. Although many cyclones do not wholly fit these descriptions, each of the 42 identified cyclones could be placed satisfactorily in one of these two direction categories.

On this basis, (21/42) 50% of cyclones were classified as south-westward and (21/42) 50% south-eastward.

## 6.3 Track Distance

Due to the clockwise rotating windfield structure of a cyclone, track location relative to the coastline is an important issue when determining the impact a cyclone will have on a coastal location. For example, a south-westward moving cyclone that crosses the coast to the north of this region will cause a strong storm surge to occur due to onshore winds as the cyclone crosses the coast, whereas a south-westward tracking cyclone crossing to the south of the site will cause offshore winds that push water away from the coastline. For cyclones of similar central pressure and forward speed, the inverse barometer effect and the strength of the cyclonic winds in the study region are proportional to the distance the cyclone is from the site. Wind direction is also dependent on track location and for cyclones that pass within approximately 30km of the site, full reversal of wind direction will occur as the cyclone passes the site.

This parameter is more complex than one might expect because it is interlinked with central pressure and location north or south, east or west of the Livingstone Shire. This issue is also related to the clockwise rotating windfield structure of cyclones. For example, within the adopted 6° of latitude/longitude extent from the Livingstone Shire region, the lowest central pressure may not occur when the cyclone is closest to the Livingstone Shire. Second, a cyclone passing 100km north of the Livingstone Shire region may cause greater surge in the study region than a similar cyclone passing 100km to the south. The differences in outcome also depend on seabed topography.

For this study, track distance was defined by simplifying each cyclone track into a linear track and determining the radial distance from this track to Yeppoon. If a cyclone significantly changed intensity as it passed through the selected zone of influence, the distance to the most intense section of the cyclone track was chosen.

For shore crossing (south-westward) cyclones, tracks that passed north of the site were defined as positive distances; those that crossed to the south were defined with negative track distances. Similarly, for shore parallel (south-eastward) cyclone tracks, those that passed offshore of the site were defined as being positive while those that travelled over land (west of the coastline) were defined as being negative.

These parameters are described in Appendix A.

### 6.4 Forward Speed

Forward speed ($V_f$) may influence cyclone surge in two ways. First, the cyclonic winds may be increased by this speed on the south-eastern side of the cyclone and decreased on the north-western side. Second, when forward speed is close to the celerity of long waves $(\sqrt{gd})$, a resonance state can develop which causes an increased surge. Windfield changes would also affect waves near the Capricorn Coast.

Average forward speeds were estimated in the region near the Livingstone Shire. The results are presented in Appendix A, separately for south-westward and south-eastward tracking cyclones.

### 6.5 Cyclone Central Pressure

Central pressure is the cyclone parameter that has the dominant impact on wind speed. Representative cyclone central pressures that were assessed to have had the most significant impact on the site were determined in the Livingstone Shire region and analysed separately for all cyclones and also for the south-westward and south-eastward tracking cyclones. Results are presented in Table 4.

**Table 4 – Analysis of Cyclone Central Pressures for Selected Populations of Historical Cyclones**

| AEP (years) | SW Population | | SE Population | | All Cyclones Since 1955 | |
|---|---|---|---|---|---|---|
| | CP (hPa) | 95% CL (hPa) | CP (hPa) | 95% CL (hPa) | CP (hPa) | 95% CL (hPa) |
| 1 in 5 | 980 | 7 | 991 | 5 | 976 | 7 |
| 1 in 10 | 971 | 10 | 985 | 7 | 968 | 9 |
| 1 in 20 | 963 | 13 | 980 | 9 | 961 | 12 |
| 1 in 50 | 952 | 18 | 973 | 12 | 952 | 15 |
| 1 in 100 | 945 | 22 | 968 | 15 | 944 | 18 |
| 1 in 500 | 927 | 30 | 956 | 20 | 928 | 23 |
| | | | | | | |
| **Data Points** | 21 | | 21 | | 42 | |
| **Years of Analysis** | 45 | | 45 | | 45 | |

The results show that south-westward tracking cyclones (coast crossing) are generally more severe than coast parallel cyclones. Note that Walsh and Ryan (2000) advise that current climate change investigations show that there is unlikely to be an increase in coast crossing cyclone severity.

These parameters were used to define 54 basic cyclone simulations used to prepare time series data for the Monte Carlo analyses. They are presented in Table 5. Six additional cyclones were included to describe the effect of the radius to maximum winds and astronomical tide level.

**Table 5 – Parameters Adopted for Basic Cyclone Runs**

| Run No | Track Direction | Track Distance (km) | Vf (m/s) | CP (hPa) |
|---|---|---|---|---|
| 1 | SW | 150 | 4 | 950 |
| 2 | SW | 150 | 4 | 970 |
| 3 | SW | 150 | 4 | 990 |
| 4 | SW | 150 | 8 | 950 |
| 5 | SW | 150 | 8 | 970 |
| 6 | SW | 150 | 8 | 990 |
| 7 | SW | 75 | 4 | 950 |
| 8 | SW | 75 | 4 | 970 |
| 9 | SW | 75 | 4 | 990 |
| 10 | SW | 75 | 8 | 950 |
| 11 | SW | 75 | 8 | 970 |
| 12 | SW | 75 | 8 | 990 |
| 13 | SW | -75 | 4 | 950 |
| 14 | SW | -75 | 4 | 970 |
| 15 | SW | -75 | 4 | 990 |
| 16 | SW | -75 | 8 | 950 |
| 17 | SW | -75 | 8 | 970 |
| 18 | SW | -75 | 8 | 990 |
| 19 | SW | -150 | 4 | 950 |
| 20 | SW | -150 | 4 | 970 |
| 21 | SW | -150 | 4 | 990 |
| 22 | SW | -150 | 8 | 950 |
| 23 | SW | -150 | 8 | 970 |
| 24 | SW | -150 | 8 | 990 |
| | | | | |
| 25 | SE | 150 | 6 | 950 |
| 26 | SE | 150 | 6 | 970 |
| 27 | SE | 150 | 6 | 990 |
| 28 | SE | 150 | 12 | 950 |
| 29 | SE | 150 | 12 | 970 |

| Run No | Track Direction | Track Distance (km) | Vf (m/s) | CP (hPa) | |
|---|---|---|---|---|---|
| 30 | SE | 150 | 12 | 990 | |
| 31 | SE | 75 | 6 | 950 | |
| 32 | SE | 75 | 6 | 970 | |
| 33 | SE | 75 | 6 | 990 | |
| 34 | SE | 75 | 12 | 950 | |
| 35 | SE | 75 | 12 | 970 | |
| 36 | SE | 75 | 12 | 990 | |
| 37 | SE | -75 | 6 | 950 | |
| 38 | SE | -75 | 6 | 970 | |
| 39 | SE | -75 | 6 | 990 | |
| 40 | SE | -75 | 12 | 950 | |
| 41 | SE | -75 | 12 | 970 | |
| 42 | SE | -75 | 12 | 990 | |
| 43 | SE | -150 | 6 | 950 | |
| 44 | SE | -150 | 6 | 970 | |
| 45 | SE | -150 | 6 | 990 | |
| 46 | SE | -150 | 12 | 950 | |
| 47 | SE | -150 | 12 | 970 | |
| 48 | SE | -150 | 12 | 990 | |
| 49 | SE | 0 | 6 | 950 | |
| 50 | SE | 0 | 6 | 970 | |
| 51 | SE | 0 | 6 | 990 | |
| 52 | SE | 0 | 12 | 950 | |
| 53 | SE | 0 | 12 | 970 | |
| 54 | SE | 0 | 12 | 990 | |
| 55 | SE | 0 | 6 | 950 | Radius to Max. Winds = 30km |
| 56 | SE | 0 | 6 | 950 | Radius to Max. Winds = 20km |
| 57 | SE | 0 | 6 | 950 | Radius to Max. Winds = 10km |
| 58 | SE | 0 | 6 | 970 | Water Level = MSL |
| 59 | SE | 0 | 6 | 970 | Water Level = MSL+1.0m |
| 60 | SE | 0 | 6 | 970 | Water Level = MSL-1.0m |

The basis for selection of these simulation cyclones was their overall representation of severe, but not extremely rare cyclones. Because of the limited number of these basic runs, it was important that a reliable basis for describing the parameters of the greatest number of simulated cyclones was developed.

## 6.6 Greenhouse Related Climate Change Issues

At the commencement of the study, two documents provided the information most relevant to this matter. They were:

- Climate Change in Queensland under Enhanced Greenhouse Conditions, Second Annual Report (1998-1999) prepared by CSIRO Atmospheric Research; and
- Walsh, K.J.E. and Ryan, B.F (2000): Tropical cyclone intensity increase near Australia as a result of climate change. Journal of Climate, Vol.13.

The (1998-1999) CSIRO report is now superseded by the (1999-2000) report.

The main issues are:

- What is the likely magnitude of change, if any, in MSL over a 50 years planning period (say)?
- What is the likely change in cyclone occurrence frequency, if any?
- What is the likely change in cyclone intensity, if any?

### *6.6.1 MSL Rise*

The issue of MSL rise is addressed by Walsh and Ryan (2000). Walsh is also an author of the CSIRO reports and this matter does not appear to be addressed in the (1999-2000) CSIRO report. The increase in MSL advised is 0.2m over 50 years. A range of 0.1m to 0.4m was advised in the CSIRO (1998-1999) report as part of discussions on storm surge analyses for Cairns.

We understand that Council have adopted for planning purposes an increase of 0.3m. Further discussions with Council need to be undertaken to confirm this value. This parameter would need to be re-assessed on a decadal basis, or as substantial new information became available. This is consistent with basic hydrodynamics and recommendations in CSIRO (1999-2000).

### *6.6.2 Cyclogenesis Changes*

Section 3 of CSIRO (1999-2000) addresses the likely (though not definite) changes in cyclone activity in the Queensland region. This CSIRO report also discusses the Monte Carlo procedure, which is consistent with the overall study approach adopted for this study.

Parameters proposed by CSIRO for inclusion in the Monte Carlo analysis are central pressure, radius to maximum winds, forward speed and coast parallel and coast crossing cyclones. CSIRO have analysed data for the Hervey Bay region using a regional extent similar, but not identical, to that adopted for this study. There is no definitive basis for this choice, both are realistic; the basic assumption being that cyclone parameters within the adopted region are similar throughout the adopted region. Note that CSIRO's main purpose in their Section 3 was to examine design wind speeds over land and cyclone filling was also considered by them.

### *6.6.3 Extreme Event Analysis*

Although CSIRO discuss frequency of cyclone occurrence on the basis of coast parallel and coast crossing cyclones, they do not appear to describe cyclone intensity recurrence in terms of these separate populations, see Figure 3.5 of CSIRO (1999-2000).

CSIRO (1999-2000) adopt the Generalised Pareto Distribution (GPD) to describe the frequency of recurrence of cyclones with specific central pressures. CSIRO choose the GPD rather than the more common Extreme Value Type 1 (EXV1) distribution (termed Gumbel by CSIRO) because the GPD has an upper limit extreme value. They also state, incorrectly in our view, *'. . . that the GPD also has an advantage over the Gumbel distribution in that all available data are used to fit the distribution rather than just the extreme value within a specified time interval.'*

That statement is correct only when annual minimum central pressures are used, for example, in a Gumbel analysis procedure. Using the EXV1 (same theoretical formulation as Gumbel) though, all data is used in either the Method of Moments, Least Squares or Maximum Likelihood Method. Moreover, there is the issue of adopting a physically realistic minimum central pressure. CSIRO do not specify how this should be done, or whether they did for the CSIRO (1999-2000) report. However, their Figure 3.5 implies a minimum central pressure of about 940hPa for the Hervey Bay region.

For this study a minimum central pressure of 920hPa was adopted for present day cyclone simulations.

#### *6.6.4 Forward Speed*

This study has analysed cyclone forward speed in a manner very similar to that applied by CSIRO. However, the parameters have been developed separately for coast parallel and coast crossing cyclones for this study. The probability density function was described as a cumulative frequency distribution, see Appendix A, and sampled using random numbers within the Monte Carlo analysis.

#### *6.6.5 Radius to Maximum Winds (Rm)*

CSIRO (1999-2000) propose 30km. Note that cyclone Dinah probably had an Rm closer to 40km. A radius of 30km was used for this study. Additionally, the sensitivity of the results to choice of Rm was examined.

#### *6.6.6 Direction of Approach*

A similar procedure has been followed in this study. However, a theoretical distribution was not fitted to the data, as was adopted by CSIRO, but rather a cumulative probability distribution based on the actual occurrences was used, see Appendix A.

Distance from the Yeppoon area was also included in this study using a statistical description.

#### *6.6.7 Changes in Cyclogenesis*

Estimated changes in cyclone intensity are summarised in Table 3.4 of CSIRO (1999-2000). For the Queensland region cyclone central pressures are likely to reduce by 5hPa, on average, over the next 50 years.

The CSIRO (1999-2000) report discusses the point that cyclones with central pressures greater than 985hPa may not change, whereas cyclones more intense than 985hPa may increase in intensity by more than the average 5hPa.

For this study, two Monte Carlo analyses were undertaken. They were:

- An analysis based on existing cyclone data, to which could be added 0.3m (to be confirmed) for projected MSL rise over the next 50 years. Plans prepared from this investigation exclude any Greenhouse related rise in MSL, but include a note that 0.3m is to be adopted; and

- An analysis based on an average increase in cyclone intensity of 5hPa, to which could be added 0.3m for projected MSL rise over the next 50 years.

# 7. Storm Surge Modelling

## 7.1 Model Setup

The numerical current and storm surge model applied to this investigation was the Delft3d hydrodynamic modelling system. This system provides a third order finite difference solution to the equations of mass and momentum conservation. It uses an alternating direction, implicit solution scheme.

The model has been applied to many investigations throughout Australia. It includes tidal and wind forcing, wetting and drying and turbulence model eddy viscosity terms. The model also includes spatially variable bed friction. Roughness height was set to be 0.03m in the sea and 0.1m on land. The model also has a range of other modules, such as an advection-dispersion module, which can be operated in parallel with the hydrodynamic module.

Wind setup develops across the nearshore area as the result of interfacial shear between the wind and sea surface and the consequent onshore currents. The Coriolis acceleration acting on northward flowing currents may also cause a storm surge component. Setup is inversely proportional to water depth, directly proportional to fetch and proportional to the square of wind speed. A large area model was established to ensure physically realistic development of these currents and setup. This model area extended north to Townshend Island, south to Bustard Head and seaward beyond the 200m depth. Grid sizes vary from about 75m near the coastline to 500m offshore and at the northern and southern ends of the model.

Two other features of the model were important to this study. First, the model has an advanced curvilinear grid system. This grid system enables preparation of a grid which better follows the natural curvature of waterways such as The Narrows between Curtis Island and the mainland to the south of the immediate study area. Preparation of the grid in curvilinear form reduces the so-called stair-case problem of fixed grid size rectangular grids, which tend to falsify bed friction along narrow waterways that are not closely aligned with the grid. It also allows fine grid resolution in these narrow waterways and near the coastline, whilst allowing a coarser grid further away where high resolution is not required.

Second, a cyclone passing to the north of Yeppoon will drive water southward into the Port Alma area where some flow constriction will occur. When this happens there will be a natural tendency for some back-flow near the seabed to occur, as well as horizontally at different locations. This flow structure can be described better by three dimensional modelling, which also allows better application of wind stress to the water column. Horizontal grid sizes down to about 75m were used in The Narrows and near the shoreline. Three vertical layers were used.

Wind fields were computed from the available historical cyclone track data for model calibration/verification and from idealised cyclone track data for the basic Monte Carlo simulations. The wind and pressure fields were prepared using the Holland wind model developed for the Bureau of Meteorology. This model is considered to provide the most realistic description of cyclonic windfields for the Australian region.

## 7.2 Model Verification

Two cyclones were selected for model verification. They were Cyclone David in 1976 and Cyclone Fran in 1992. Peak surge for Cyclone David was about 1.5m at Rosslyn Bay, occurring at a lower high tide. A slightly higher storm tide occurred at the following higher high tide, though the surge then had reduced to 1m. For Fran, peak surge was about 0.8m.at Auckland Point in Gladstone and occurred near MSL. Water levels were elevated for a few days during those events.

Figures 6 and 7 show that the modelled surge peak was reproduced well for both cyclones. Figure 8 shows the extent of storm surge in the Capricorn Coast region near the time of peak surge.

This outcome shows that the model system can be used confidently to predict cyclone surge in the Capricorn Coast region.

# 8. Monte Carlo Analysis

## 8.1 Analysis Processes

Previous sections have discussed the fifty-four basic model cyclone surge simulations that were undertaken. These results provided time series of cyclone surge over 72 hour periods at intervals of 0.5 hours.

In reality cyclone central pressures will vary considerably and coastline crossing may be any distance from the Capricorn Coast, or cyclones may run parallel to the coast, offshore or inland of the Capricorn Coast region. Furthermore, the phases of peak surge relative to high and low water of the astronomical tides will be random. Extreme water levels could be determined from very long term tidal records, which would include cyclone occurrences, but these are not available for the Capricorn Coast. A practical alternative is to perform a Monte Carlo modelling exercise.

Monte Carlo modelling requires the generation of a large number of simulated cyclone events. These simulated cyclones are generated by randomly selecting parameters from distributions created by analysing historical cyclones, which have affected the area (as described in Section ). Because the historical data showed that south-westward tracking cyclones exhibited different characteristics to the south-eastward moving cyclones, they were considered separately. Distributions of historical cyclone parameters for characteristics including distance to landfall, forward speed and central pressure were developed for both cyclone data populations, see Appendix A and Table 4.

Forty-two cyclones were defined as being significant cyclonic events occurring in the region since 1955. This means that the average inter-arrival time of cyclones that affect the Capricorn Coast is 0.91 years. Of these, 50% will be coast-crossing (south-westward) while 50% will be coast-parallel (south-eastward) tracking cyclones. Coast crossing cyclones are normally more severe than coast parallel cyclones in this region.

Once track direction has been selected, a simulated cyclone is then given other cyclone parameters. Track distance from the Capricorn Coast and forward speed were selected using random numbers to select values from the distribution of cyclone parameters, see Appendix A.

Central pressures were determined independently by sampling randomly and fulfilling the central pressure versus probability of non-exceedance distributions determined from the cyclone data. This was done using the analytical expressions (Extreme Value Type 1) representing the best fit to the data. They are:

- South-westward Cyclones
  $0.0955 \times (p - 985.9) = \ln(-\ln P)$
  $P = 1-1/\lambda R$
  $\lambda = 0.467$

- South-eastward Cyclones
  $0.1482 \times (p - 994.6) = \ln(-\ln P)$
  $P = 1-1/\lambda R$
  $\lambda = 0.467$

where

R is average recurrence interval (years)
$\lambda$ is average number of cyclones per year
p is cyclone central pressure
P is probability of non-exceedance

Central pressures higher than 1001hPa were discarded and another choice made. These events were not considered to be cyclones. Similarly, central pressures lower than 920hPa were discarded. This is a slightly arbitrary choice, but is lower than any cyclone that has affected the area and recognises that sea temperatures limit the possible minimum central pressure. These modelling processes were checked by calculating the average recurrence interval relationship(s) of simulated central pressures. The agreement was good. Long term mean atmospheric pressure was adopted to be 1010hPa.

Because the hydrodynamic model was setup to calculate storm surge only, suitable time-series of tide elevations were required to allow the calculation of total water elevations (storm tide) during the simulated cyclones. Nineteen years of astronomical tides at half-hourly intervals were predicted using the so-called Canadian tidal package (Foremann, 1977) and tidal constants for Rosslyn Bay provided in Australian National Tide Tables, 2001. This period of time allows for recession of the lunar nodes along the plane of the ecliptic and the associated changes in tidal range.

Random numbers were used to select a time series of tidal levels from any one of the nineteen years and any of the months between December and May, the typical cyclone season for this area. In this manner the correct arrival time structure was formed and cyclone arrival times and tides varied randomly.

Random numbers were used to select other cyclone parameters based on distributions of historical cyclones in the region of influence, see Appendix A. Once all the parameters (track direction, minimum track distance to site, forward speed and central pressure) of each simulated cyclone were determined, time series of storm surge were interpolated from the fifty-four base simulation runs. Total water level (storm tide) for the event was then calculated by adding the storm surge time-series to the time series of randomly selected tidal levels.

In addition to the basic fifty-four simulations undertaken to provide input to the Monte Carlo analyses, it was important to test the sensitivity of the analyses to astronomical tide levels and radius to maximum wind speed. Wind set-up is inversely proportional to water depth.

Figure 9 compares the results for three values of Rm - 10km, 20km and 30km. The track selected for this comparison was SE with 0km track distance from the coastline. This track will typically cause the greatest storm surge in the Capricorn Coast region. The simulation was undertaken with a central pressure of 950hPa. The results show that for this site Rm can be important. The greatest surge was caused by an Rm of 30km, which was adopted for this study.

Storm surge (wind setup component) is dependent on water depth. Therefore in the very nearshore region, where tide range has a significant influence on water depth, it is an important issue. However, in the Monte Carlo based analysis the basic simulations were undertaken at MSL, the most common tide level. This means, in a simple topographical region, that surges occurring at high tide are over-estimated, whereas those occurring near low tide would be underestimated to some extent. Figure 10 compares surge time series at Yeppoon for three tide levels adopted for describing the effect of tide level on storm surge – MSL-1.0m, MSL and MSL+1.0m. The result is consistent with the concepts discussed above and shows that the effect is in the order of 10%. Those results were applied on a site specific basis to the Monte Carlo procedure.

### 8.2 Results

Simulations of 10,000 years were undertaken and the simulated time series of results stored. Monte Carlo simulation results were analysed by ranking them in terms of peak event storm tide and then undertaking an Extreme Value Type 1 Analysis using the method of moments.

The outcome of the analyses is presented in Table 6 in terms of datum AHD. Water levels are presented for the AEP 1 in 50 years and longer. Time series plots of combined astronomical tide and storm surge water level for the selected AEP are presented in Figure 11. These time series provide a basis for assessment of inundation times and for assessment of inland flows. Storm tide is dominated by the astronomical tide and peak water levels caused by cyclone surge will persist only for durations up to six hours.

**Table 6 – Peak Storm Tide at Selected Locations Excluding Greenhouse Related Climate Changes**

| Location | AEP Water Levels (m AHD) | | | | | |
|---|---|---|---|---|---|---|
| | 1 in 50 | 1 in 100 | 1 in 500 | 1 in 1,000 | 1 in 10,000 | PMS |
| Bangalee | 3.16 | 3.47 | 4.11 | 4.37 | 5.24 | 5.47 |
| Barwell Creek | 3.25 | 3.59 | 4.28 | 4.57 | 5.51 | 5.68 |
| Causeway Lake | 3.17 | 3.55 | 4.31 | 4.63 | 5.68 | 6.08 |
| Cawarral Creek | 3.36 | 3.68 | 4.34 | 4.62 | 5.52 | 5.65 |
| Emu Park | 3.11 | 3.39 | 3.96 | 4.20 | 4.98 | 5.23 |
| Joskeleigh | 3.27 | 3.58 | 4.23 | 4.49 | 5.37 | 5.52 |
| Keppel Sands | 3.26 | 3.57 | 4.20 | 4.47 | 5.34 | 5.44 |
| Kinka Creek | 3.15 | 3.45 | 4.05 | 4.30 | 5.12 | 5.24 |
| Ross Creek | 3.27 | 3.60 | 4.28 | 4.56 | 5.48 | 5.59 |
| Williamson Creek | 3.23 | 3.55 | 4.21 | 4.49 | 5.38 | 5.55 |
| Rosslyn Bay | 3.16 | 3.46 | 4.09 | 4.35 | 5.20 | 5.50 |
| Yeppoon | 3.27 | 3.61 | 4.30 | 4.58 | 5.52 | 5.66 |

Previous studies have shown that at more frequent AEP (eg 1 in 20 years), high water levels are more likely to be produced by high astronomical tides together with other meteorological events such as east coast lows, rather than cyclone storm surge.

The highest storm tides generally occur at Causeway Lake and Cawarral Creek and there are significant variations in water levels amongst the sites within the study area.

Table 7 presents equivalent results for the case where central pressures have been reduced by 5hPa in order to represent possible Greenhouse related climate change cyclonic response. No MSL rise has been included.

**Table 7 – Peak Storm Tide at Selected Locations Including Greenhouse Related Climate Change to Cyclone Central Pressure, But Not to MSL**

| Location | AEP Water Levels (m AHD) | | | | |
|---|---|---|---|---|---|
| | 1 in 50 | 1 in 100 | 1 in 500 | 1 in 1,000 | 1 in 10,000 |
| Bangalee | 3.34 | 3.67 | 4.35 | 4.63 | 5.54 |
| Barwell Creek | 3.46 | 3.81 | 4.53 | 4.83 | 5.80 |
| Causeway Lake | 3.38 | 3.78 | 4.60 | 4.94 | 6.05 |
| Cawarral Creek | 3.55 | 3.87 | 4.52 | 4.79 | 5.68 |
| Emu Park | 3.28 | 3.56 | 4.16 | 4.40 | 5.21 |
| Joskeleigh | 3.45 | 3.77 | 4.41 | 4.67 | 5.54 |
| Keppel Sands | 3.44 | 3.75 | 4.39 | 4.65 | 5.52 |
| Kinka Creek | 3.31 | 3.62 | 4.24 | 4.50 | 5.36 |
| Ross Creek | 3.46 | 3.80 | 4.50 | 4.78 | 5.73 |
| Williamson Creek | 3.42 | 3.75 | 4.43 | 4.71 | 5.63 |
| Rosslyn Bay | 3.33 | 3.65 | 4.31 | 4.58 | 5.47 |
| Yeppoon | 3.47 | 3.82 | 4.53 | 4.83 | 5.80 |

# 9. Wave Setup

## 9.1 General

Wave setup is caused by the conservation of wave momentum flux in the surf zone, Goda (2000). The shoreward decrease in wave height in the breaker zone leads to a gradient in wave radiation stresses and a consequent increase in the 'still water level' in the shoreward direction. Wave grouping causes some fluctuations in this still water level. At the breaker line there is a setdown.

This shoreward increase in water level is called wave setup and it increases non-linearly in the shoreward direction. It is greatest at the shoreline and is additional to storm tide.

Wave setup depends upon 'nearshore' wave height. Five historical cyclone events were selected for this investigation. They were:

- David (1976);
- Dinah (1967);
- Emily (1972);
- Rewa (1994); and
- Simon (1980).

These cases were selected because offshore wave heights were expected to be high and they represented different offshore wave directions.

## 9.2 Wave Modelling

The first step in this investigation was to set up an offshore wind/wave model based on the second generation wind/wave modelling system, ADFA1, developed by Dr Ian Young of the Australian Defence Force Academy. The model is based on a numerical solution of the Radiative Transfer Equation and is applicable in water of any depth. It predicts the evolution of the directional wave energy spectrum as a result of the processes of wind energy transfer, propagation, refraction, shoaling, bed friction, white capping, nonlinear wave-wave inter-action and depth limited wave breaking. Output from the model includes significant wave height, dominant wave direction and spectral peak wave period at selected grid points. The wind/wave model was established on a 5km computational grid with an origin at $26^0$ S:$152^0$52' E.

The model extended northward to approximately $20^0$ S and eastward to approximately $154^0$ E. A time step of 7.5 minutes was adopted to ensure physically realistic wave propagation and growth. The frequencies selected for spectral description ranged from 0.03Hz to 0.423Hz - a total of fifteen frequencies being used. Directional resolution was based on sixteen divisions of the compass. The Holland wind model, developed by the Australian Bureau of Meteorology for tropical regions of Australia, was used to calculate cyclone wind fields from the cyclone track parameters. The model extent and spatial resolution are considered more than adequate for the description of peak storm wave conditions arising from tropical cyclones. Generally, little wave energy propagates through the Great Barrier Reef and wave generation occurs within the reef lagoon for waves affecting this shoreline.

In addition to this regional model, a finer grid (140m) SWAN wave model was established for the inshore area. The SWAN model is part of the Delft3d system and was developed at the Delft Technical University. It includes natural bathymetry, offshore wave input (parametric or spectral), wind input, refraction, shoaling, bed friction, full frequency-direction wave propagation, white-capping, wave/current interaction and solutions to $3^{rd}$ order. Fine grids can be nested within coarser outer grids. The model system is considered to be one of the most reliable. Output from the ADFA model was used as boundary input data for the SWAN wave propagation model, which transferred offshore waves to the nearshore region extending along the coastline from Bangalee to Joskeleigh.

Output locations from the SWAN model were located in approximately 6m of water depth at each of the study sites. Figure 12 shows the SWAN model for the study area, together with example output for cyclone Dinah.

Using a surf zone model with beach profiles provided by the EPA, wave setup was calculated using SWAN model output as input in water depths of about 6m, where wave setup is negligible. Wave setup was calculated following the procedures developed by Goda (2000). In general, wave setup is 10% of the nearshore significant wave height at this site. The relationship depends on seabed slopes and wave period.

### 9.3 Model Verification

In order to verify the ADFA wave model, output for Cyclone David was compared to peak wave conditions recorded at the Yeppoon Waverider Buoy and provided by the EPA. Additionally, the daily synoptic charts prepared by the Bureau of Meteorology were inspected to estimate offshore wave direction. Peak recorded conditions occurred on 20 January, 1976. They were:

- $H_s$ = 3.9 m;
- $T_p$ = 9.65 s; and
- Direction ESE (estimated by EPA).

Modelled results for Cyclone David were as follows:

- $H_s$ = 3.8 m;
- $T_p$ = 9.66 s; and
- Direction = $99^0$.

This verification indicates good agreement between modelled results and recorded data for this event and gives confidence in the modelling system to predict wave parameters reliably for this location.

### 9.4 Results

Results from the wave modelling, as described above, are presented in Table 8. As can be seen from these results, the nearshore wave height (6m depth) is typically only 2m with wave direction between $45^0$ and $90^0$ at peak wave conditions in this study area. This seems low, but is the outcome of wave propagation across extensive, shallow seabed areas.

**Table 8 – Wave Modelling Results at Surf Zone**

| Cyclone Event | Wave Model (offshore) Output | | | Inshore Location | SWAN (inshore) output | | |
|---|---|---|---|---|---|---|---|
| | $H_s$ (m) | $T_p$ (s) | Direction ($^0$) | | $H_s$ (m) | $T_p$ (s) | Direction ($^0$) |
| David | 3.8 | 9.66 | 99 | Bangalee | 2.0 | 9.5 | 91 |
| | | | | Barwell Creek | 1.9 | 9.5 | 96 |
| | | | | Causeway Lake | 1.9 | 9.5 | 87 |
| | | | | Cawarral Creek | 2.0 | 9.5 | 91 |
| | | | | Emu Park | 2.0 | 9.5 | 94 |
| | | | | Joskeleigh | 2.0 | 9.5 | 80 |
| | | | | Keppel Sands | 2.0 | 9.5 | 94 |
| | | | | Kinka Creek | 1.8 | 9.5 | 74 |
| | | | | Ross Creek | 1.8 | 9.5 | 77 |
| | | | | Williamson Creek | 1.7 | 9.5 | 68 |
| | | | | Rosslyn Bay | 1.8 | 9.5 | 73 |
| | | | | Yeppoon | 2.0 | 9.5 | 88 |
| Dinah | 4.4 | 10.9 | 24 | Bangalee | 1.8 | 10.7 | 45 |
| | | | | Barwell Creek | 1.6 | 10.7 | 52 |
| | | | | Causeway Lake | 1.9 | 10.7 | 40 |
| | | | | Cawarral Creek | 1.5 | 10.7 | 57 |
| | | | | Emu Park | 1.7 | 10.7 | 46 |
| | | | | Joskeleigh | 1.8 | 10.7 | 47 |
| | | | | Keppel Sands | 1.6 | 10.7 | 58 |
| | | | | Kinka Creek | 1.9 | 10.7 | 35 |
| | | | | Ross Creek | 1.9 | 10.7 | 35 |
| | | | | Williamson Creek | 2.0 | 10.7 | 35 |
| | | | | Rosslyn Bay | 2.0 | 10.7 | 37 |
| | | | | Yeppoon | 2.0 | 10.7 | 36 |
| Emily | 3.6 | 9.8 | 73 | Bangalee | 2.0 | 9.5 | 70 |
| | | | | Barwell Creek | 1.8 | 9.5 | 76 |
| | | | | Causeway Lake | 1.8 | 9.5 | 70 |
| | | | | Cawarral Creek | 1.9 | 9.5 | 84 |
| | | | | Emu Park | 2.0 | 9.5 | 83 |
| | | | | Joskeleigh | 2.0 | 9.5 | 72 |
| | | | | Keppel Sands | 1.9 | 9.5 | 86 |
| | | | | Kinka Creek | 1.8 | 9.5 | 61 |
| | | | | Ross Creek | 1.9 | 9.5 | 63 |
| | | | | Williamson Creek | 1.9 | 9.5 | 58 |
| | | | | Rosslyn Bay | 2.0 | 9.5 | 62 |
| | | | | Yeppoon | 2.0 | 9.5 | 69 |

| Cyclone Event | Wave Model (offshore) Output | | | Inshore Location | SWAN (inshore) output | | |
|---|---|---|---|---|---|---|---|
| | $H_s$ (m) | $T_p$ (s) | Direction ($^0$) | | $H_s$ (m) | $T_p$ (s) | Direction ($^0$) |
| Rewa | 3.3 | 9.6 | 101 | Bangalee | 1.9 | 9.5 | 90 |
| | | | | Barwell Creek | 1.8 | 9.5 | 94 |
| | | | | Causeway Lake | 1.8 | 9.5 | 85 |
| | | | | Cawarral Creek | 2.0 | 9.5 | 91 |
| | | | | Emu Park | 2.0 | 9.5 | 94 |
| | | | | Joskeleigh | 1.9 | 9.5 | 78 |
| | | | | Keppel Sands | 1.9 | 9.5 | 94 |
| | | | | Kinka Creek | 1.8 | 9.5 | 72 |
| | | | | Ross Creek | 1.8 | 9.5 | 75 |
| | | | | Williamson Creek | 1.7 | 9.5 | 66 |
| | | | | Rosslyn Bay | 1.8 | 9.5 | 71 |
| | | | | Yeppoon | 2.0 | 9.5 | 86 |
| Simon | 3.3 | 7.8 | 26 | Bangalee | 1.7 | 7.4 | 44 |
| | | | | Barwell Creek | 1.5 | 7.4 | 52 |
| | | | | Causeway Lake | 1.7 | 7.4 | 38 |
| | | | | Cawarral Creek | 1.2 | 5.0 | 55 |
| | | | | Emu Park | 1.4 | 5.7 | 44 |
| | | | | Joskeleigh | 1.5 | 5.7 | 45 |
| | | | | Keppel Sands | 1.4 | 5.7 | 55 |
| | | | | Kinka Creek | 1.7 | 7.4 | 35 |
| | | | | Ross Creek | 1.7 | 7.4 | 34 |
| | | | | Williamson Creek | 1.8 | 7.4 | 34 |
| | | | | Rosslyn Bay | 1.8 | 7.4 | 35 |
| | | | | Yeppoon | 1.8 | 7.4 | 35 |

Wave setup analysis for these peak inshore wave conditions and subsequent extremal analysis leads to the following setup heights:

- AEP 1 in 50 year = 0.2m;
- AEP 1 in 100 year = 0.3m; and
- > AEP 1 in 100 year = 0.4m.

These are the wave setup heights occurring jointly with storm tide at the specified AEP.

### 9.5 Inclusion Of Wave Setup In Water Level Statistics

In order to include wave setup in total water level in a manner that is fully physically realistic, it would be necessary to undertake a detailed joint occurrence study of cyclone surge and wave setup so that relative phasing and duration were explicitly included. Such a study would also be best undertaken together with rainfall/runoff modelling so that fresh water flows in the principal estuaries were included also.

This study has shown that offshore wave direction does not have a major influence on nearshore wave heights and setup, at least over the commonly occurring wave directions. Wave setup heights are to be added to the storm tide statistics of Tables 4 and 5 at the specified AEP.

Note that peak storm wave heights for storms of AEP 1 in 20 years or more will not vary greatly and that peak wave setup for those events will be similar. It is also unlikely that peak wave setup will occur at the same time as peak storm tide. The wave setup heights presented in Section 9.4 reflect that characteristic.

# 10. Property Design Water Levels

With respect to suitable design water levels for coastal properties in the study area, it is recommended that the AEP 1 in 100 years storm tide is the appropriate design level. This level should include the possible Greenhouse related MSL rise (exact amount to be confirmed by Council), ie the Greenhouse related MSL rise should be added to the levels provided in Table 6.

For coastal sites it is also necessary to include wave runup for habitable and commercial floor levels of buildings in order to prevent ocean inundation. Wave runup is difficult to assess because it depends on seabed slope near the breaker line. Based on survey profiles provided by the EPA, the foreshore slope at this point, including the design storm tide, is about 1:25. However, it could be steeper if wave action causes rapid sand transport offshore and an erosion escarpment forms in the back-beach area.

Previous studies have found the relationship of Holman (1986) to be realistic for runup calculation on natural and near natural shoreline areas. It is:

- $R_2 = (5.2\beta + 0.2)H_s$

  where $R_2$ is the wave runup height exceeded by only 2% of waves
  $\beta$ is bottom slope near the Still Water Line.
  $H_s$ is significant wave height in 6m depth

From Section 9.4 the nearshore wave height (6m depth) is typically only 2m at peak wave conditions in this study area. The outcome then is that a realistic 'estimate' of $R_2$ is 1m. This includes wave setup implicitly. Note that:

- Wave setup is manifested as a relatively steady increase in water level that occurs at the coastline and can propagate into bays and creeks. It varies over times in the order of hours. Hence it should be included in the boundary time series input to inundation modelling; and

- Wave runup is what one sees at the beach when a wave breaks and rushes up the beach face. It varies metres over times of a few seconds. It is only important at the coastline, unless it causes significant overtopping and filling of the area behind the beach. This can lead to a drainage problem if the water can not escape back to the beach.

On this basis, floor levels for coastline sites should be set at 1m above the AEP 1 in 100 year water level, plus 0.5m freeboard (including 0.2m Greenhouse MSL rise), for the specific locations indicated in Table 6. The definition of a coastline site is a little unclear, but applies to all properties on the frontal dune. An example of this calculation is provided below:

- **For Yeppoon coastline area**
  - AEP 1 in 100 year storm tide level = 3.6m AHD
  - Freeboard = 0.5m
  - Wave Runup (includes wave setup) = 1.0m
  - Minimum Floor Level = 5.1m AHD

Where properties are 'back' from the shoreline, waves may overtop the back beach area and propagate in-land, for an unspecified distance, but in the order of 100m. Therefore for a property about 100m inland, built on a land level of 3.2m AHD, at Yeppoon, storm tide would lead to a water depth of 0.6m (3.8-3.2m AHD). Wave heights at the site might then be 0.6 x water depth ≅ 0.4m (based on work by Nelson (1983) on depth limited waves with flat bed slopes) with wave runup of 0.4m. Floor levels would then need to be at 4.5m AHD to prevent inundation, (including a freeboard of 0.5m). This calculation is dependant on the ground levels in the area under consideration and is summarised below:

- **For Yeppoon back beach area (if overtopping of the frontal dune occurs)**
  - AEP 1 in 100 year storm tide level = 3.6m AHD
  - Wave Runup (including wave setup) = 0.4m
  - Freeboard = 0.5m
  - Minimum Floor Level = 4.5m AHD

*(Note: This result/example assumes a land level of 3.2m AHD)*

Further inland where hinterland modelling shows that the coastline storm tide level remains applicable, the floor levels should be set to the storm tide level plus wave setup and freeboard, as demonstrated below:

- **For Yeppoon inland area**
  - AEP 1 in 100 year storm tide level = 3.6m AHD
  - Wave Setup = 0.3m
  - Freeboard = 0.5m
  - Minimum Floor Level = 4.4m AHD

The freeboard allowance includes uncertainties and potential MSL rise caused by possible Greenhouse related climate change. Coastal Councils in NSW use 0.5m freeboard (including 0.2m for possible Greenhouse related MSL rise) and this has been adopted here. This freeboard component is a consistent value applied in all areas.

**Table 9** presents the results of similar floor level calculations for the remaining sites included in the scope of this study. Note that in areas where overtopping of the frontal dune is possible, the recommended floor levels in this inundated area are dependant on the ground level and therefore have not been documented in

**Table 9**.

**Table 9 – Floors Levels for Properties Affected by Storm Surge**

| Location | Recommended Floor Levels (m AHD) | |
|---|---|---|
| | Coastal Site | Inland Site |
| Bangalee | 5.00 | 4.30 |
| Barwells Creek | 5.10 | 4.40 |
| Causeway Lake | 5.05 | 4.35 |
| Cawarral Creek | 5.20 | 4.50 |
| Emu Park | 4.90 | 4.20 |
| Joskeleigh | 5.10 | 4.40 |

| Location | Recommended Floor Levels (m AHD) | |
|---|---|---|
| | Coastal Site | Inland Site |
| Keppel Sands | 5.10 | 4.40 |
| Kinka Creek | 4.95 | 4.25 |
| Ross Creek | 5.10 | 4.40 |
| Williamson Creek | 5.05 | 4.35 |
| Rosslyn Bay | 4.95 | 4.30 |
| Yeppoon | 5.10 | 4.40 |

# 11. Storm Surge Inundation

Having predicted storm tide levels and wave setup along the coastline, it was then appropriate to determine resulting inundation of inland areas. In general, this is not simply a matter of adopting the storm tide level at the coast and projecting it inland at a constant level. There are numerous physical features that would influence the inland propagation of an elevated storm tide, and it was important to take these into consideration.

To assist in the prediction of inland inundation, five one-dimensional MIKE 11 and one two-dimensional MIKE 21 hydrodynamic models were developed as detailed in Table 10.

**Table 10 – Details of Hydraulic Models**

| Location | Model Type |
|---|---|
| Pumpkin Creek | MIKE 11 |
| Cawarral Creek | MIKE 11 |
| Kinka Creek | MIKE 11 |
| Causeway Lake | MIKE 11 |
| Ross Creek | MIKE 21 |
| Barwells Creek | MIKE 11 |

The MIKE 11 models were used in the areas where flow is likely to be more channelised and hence can be realistically modelled using a one-dimensional network. The area surrounding Ross Creek is more low-lying with a number of small channels. Therefore, two-dimensional modelling using MIKE 21 was deemed more appropriate for accurately determining flood inundation. The creek systems listed in Table 10 were considered to require modelling due to either restrictions at the mouth or in downstream reaches that may limit storm tide penetration and/or significant storage that may attenuate upstream water levels.

For all models the downstream boundary condition consisted of the storm tide levels plus the wave setup data. All storm surge levels were calculated as a time series for a period of 72 hours. Wave setup values were added to the storm surge levels in these time series. Wave setup rises from 0m at 0 hours and peaks at the time of the storm tide, then decays to 0m at 72 hours. The wave setup data detailed in Table 11 was applied to the downstream boundary of all models.

**Table 11 – Wave Setup Estimates**

| Annual Exceedance Probability | Wave Setup (m) |
|---|---|
| 1 in 50 years | 0.2 |
| 1 in 100 years | 0.3 |
| Greater than 1 in 100 years | 0.4 |

For each of the models sufficient creek cross-sections were applied to realistically represent inundation. Cross-sections were taken at narrow creek locations that could potentially act as a controlling point and flood storage areas were added to a number of cross-sections.

Inundation Plans have been prepared for the following AEP:

- 1 in 50 years;
- 1 in 100 years;
- 1 in 500 years;
- 1 in 1,000 years; and
- Probable Maximum Surge.

A series of plans have been prepared presenting the estimated inundation associated with each of these events. A series of three base plans have been produced covering Yeppoon, Emu Park and Keppel Sands. Two sets of inundation plans have been prepared using these base plans.

Figures 13, 14 and 15 present the AEP 1 in 50, 1 in 100 and 1 in 500 year storm surge inundation and Figures 16, 17 and 18 present the estimated inundation under the AEP 1 in 1,000 year and Probable Maximum Surge event.

The potential impact on population and infrastructure is discussed in detail in the following sections.

# 12. Factors Affecting Flood Hazard

As discussed in SCARM (2000), factors affecting flood hazard can be grouped into four broad categories:

- Flood behaviour (ie severity, depth, velocity, rate of rise, duration);
- Topography (ie evacuation routes, islands);
- Population at risk (ie number of people and developments, type of land use, flood awareness); and
- Emergency management (ie forecasting/warning, response plans, evacuation plans, recovery plans).

It is appropriate to make comment upon all of these issues in general terms, before proceeding on to the specific hazard assessment.

## 12.1 Flood Behaviour

In accordance with risk management guidelines, this study has assessed and quantified the full range of potential storm tides, from the AEP 1 in 50 year event to the extreme AEP 1 in 10,000 year event (Probable Maximum Surge).

The rate of rise of ocean level associated with a storm surge is dependant on many factors, as discussed in Sections 6 and 9. Irish (1977) reported an indicative storm surge hydrograph based on Queensland data. Close to landfall or close to the coast water levels gradually increase, followed by a rapid rise to peak water level and an equally rapid fall, and then gradual decay. However, storm tide is dominated by the astronomical tide and peak water levels caused by cyclone surge will persist only for durations up to six hours.

The total time of inundation of any particular area is not only dependant on the time the peak surge is sustained, but on the local drainage features once the ocean level has dropped. For example, in many of the residential areas, the inundation time will be dictated by the time the local underground pipe network takes to drain the excess water. It is considered reasonable therefore to assume a total time of inundation of somewhere between 12 and 24 hours.

The hazard posed by the flood waters themselves is directly related to the depth of storm tide flooding and the velocity of the flow. SCARM (2000) presents a series of hazard categories related to the depth and velocity of flow, and the relative evacuation time. Whilst the latter factor will only be known by the counter-disaster managers, this report assigns an initial hazard assessment based on the first two factors, with the understanding that this will be adjusted at a later time. Depth of inundation maps have been prepared in critical areas, based on the following depth ranges:

- 0 to 0.3m (nominal low hazard);
- 0.3 to 0.6m (nominal medium hazard);
- 0.6 to 1.2m (nominal high hazard); and
- >1.2m (nominal extreme hazard).

Adjustments based on velocity of flow are made in individual locations as appropriate.

Hazard maps have been prepared for the Capricorn Coast under the AEP 1 in 100 year Storm Surge event and the Probable Maximum Surge event. These are presented in Figures 19, 20 and 21 for the AEP 1 in 100 year event and Figures 22, 23 and 24 for the Probable Maximum Surge event for the areas of Yeppoon, Emu Park and Keppel Sands respectively.

## 12.2 Topography

The availability of effective access routes from flood-prone areas and developments can directly influence the resulting hazard when a flood occurs. Specific comment on access and evacuation are provided in Section 13.

## 12.3 Population at Risk

The degree of hazard and social disruption varies with the size of the population at risk. An estimate of the total population at risk (PAR) at critical locations has been made (refer Section 13).

The flood awareness of the population is typically related to past experiences with flooding, and regular public awareness campaigns.

# 13. Risk to Population and Infrastructure

## 13.1 Population at Risk

For the purposes of this risk/hazard assessment, all critical areas (ie areas inundated under the Probable Maximum Surge event) have been examined. Note that some inundated areas have been excluded from consideration, including:

- Land currently undeveloped, hence not filled to above flood level; and
- Parks and environmental areas.

An attempt has been made to quantify the potential population at risk (PAR) within each zone, based on recent aerial photography supplied by Council (exact date unknown), DCDB and Australian Bureau of Statistics 1996 Census data. The methodology involved a count of all properties (residential and commercial/industrial) from the DCDB, cross-checked against aerial photography, to provide the basis number of properties affected. The ABS data was used to provide average numbers of persons per household. The combination of these two figures provides an indicative population figure for each zone. Table 12 below provides a summary of this data and the PAR.

**Table 12 – PAR Per Zone**

| Area | Approximate No of Properties[1] | Ave Household Size[2] | Estimated PAR[3] |
|---|---|---|---|
| Yeppoon | 790 Residential<br>62 Commercial/Industrial | 2.7 | 2133 |
| Emu Park | 49 Residential<br>6 Commercial/Industrial | 2.7 | 133 |
| Keppel Sands | 200 Residential<br>19 Commercial/Industrial | 2.7 | 540 |
| Kinka Beach | 195 Residential<br>3 Commercial/Industrial | 2.7 | 527 |
| Causeway Lake | 55 Residential<br>1 Commercial/Industrial | 2.7 | 149 |
| | | **Total Population At Risk** | **3482** |

*Notes 1. Count based on DCDB and aerial photography where available (not verified on site).*
*2. Source – Australian Bureau of Statistics – 1996 Census data.*
*3. Estimated PAR based on residential dwellings only.*
*4. Does not include persons residing in units.*
*5. Does not include persons residing in units or shops.*

## 13.2 Risk to Infrastructure

### *13.2.1 General*

Keppel Sands and Joskeleigh may become completely isolated during a storm surge, due to inundation of the Keppel Sands Road. These communities could not expect external assistance during an event and would need to be evacuated before significant sea level rise occurred as all of Joskeleigh and much of Keppel Sands may become inundated, and southern part of Keppel Sands is at risk from Pumpkin Creek breaking out (and wave break in over the seawall).

**Plate 1 – Seawall at low tide, south end at Keppel Sands beach.**


**Plate 2 – Pumpkin Creek at low tide, south end of Keppel Sands** (Note - One block inland from area in centre of Plate 1)

The urban area along the coast may become fragmented with storm surge sea level rise potentially (depending on height of rise) cutting the Scenic Highway along the Coast at following locations:

- Ross Creek (also affects Tanby Road and Tarranganba Road);
- Cooee Bay (extreme events only);
- Lammermoor Beach;
- Statute Bay;
- Causeway; and
- Kinka Creek.

The Rockhampton - Emu Park Road (Hill Street) is likely to be affected by surge in Cawarral Creek.

**Plate 3 – Low point on Scenic Hwy at Statute Bay.** (Note – Potential breakthrough point to Causeway tidal system)

**Plate 4 – Low point on Scenic Highway at Lammermoor Beach.**


As a result of coincident stormwater runoff severing alternative inland access (where this access exists) areas likely to be isolated include:

- Emu Park and Zilzie;
- Kinka Beach;
- Residential area north of the Causeway;
- Rosslyn Bay and part of Statute Bay;
- South end of Lammermoor Beach and northern end of Statute bay;
- Tarranganba, south end of Cooee Bay , and north end of Lammermoor beach; and
- North End of Cooee Bay.

Access to areas north of Yeppoon may become affected by storm surge and (particularly) wave action cutting the Yeppoon Byfield Road near Farnborough Beach, and storm surge (in Probable Maximum Surge case) affecting bridges across Barlows Creek.

Other access issues arise with the bottom end of Pinnacle Street being very low (currently street kerb and channel is affected by HAT), the only vehicular access path into this cul-de-sac. During a storm surge this access would be rapidly blocked to conventional vehicles.

### *13.2.2 Roads*

Inundation of roads is most likely to occur as a result of backflow of tidal water through the existing open and underground stormwater drainage networks. Flow velocities are expected to be minimal, possibly in the order of 0.5m/s, and scour of road pavements or footpaths is therefore unlikely to be a source of major road infrastructure damage. Long term inundation of roads and footpaths (approximately 12 hours) may allow the underlying road pavements and subgrade to become waterlogged, resulting in a softening of the pavement structure. The pavement should return to pre-inundation strengths when the underlying pavement and subgrade has sufficiently dried. This may take some time after the surface water has receded.

When the inundation has receded it is recommended that vehicular use on recently inundated roads be restricted to single axle vehicles and emergency vehicles. Heavy or commercial vehicles, not required for emergency access, should be prevented from travelling on the affected roads until the pavements have regained sufficient strength. This time can vary considerably and is particularly dependent on the type of subgrade material. It is therefore recommended that Council engineers be consulted before unrestricted access is permitted.

### *13.2.3 Sewer*

During wet weather, sewerage inflows tend to increase dramatically due to illegal stormwater connections and groundwater ingress. It could be expected that this would also be the case during periods of surge inundation.

Areas south of Rosslyn Bay and north of Emu Park and Keppel Sands are not sewered. Some damage to individual septic systems due to seawater ingress or floatation of septic tanks can be expected. Seawater ingress would stop or hinder treatment of sewage in the tank, and result in release of essentially untreated waste into adsorption trenches in saturated ground. Septic systems are typically private infrastructure (except for public toilets) but release of sewage has major public health implications.

The sewage treatment plants at Yeppoon and Emu Park should be sufficiently elevated to remove risk of inundation except from extreme (PMF) events. The Yeppoon STP is programmed for relocation inland by 2005.

Of more concern would be the numerous sewerage pump/lift stations throughout the lower lying areas subject to inundation. The main lift pump stations into these STP's are (off Charles Street and Rockhampton – Emu Park Road respectively) are at significant risk of inundation. Other small pump stations at high risk of inundation are at Rosslyn Street, Stature Bay, and Lyndall Street at Williamson Creek (see Plate 5 below).

**Plate 5 – Rosslyn Street Pump station** (Note salt pan in background)

**Plate 6 – Lyndall St Pump Station** (Note Mangroves on two sides)

The pump station overflow systems would also be inundated, allowing salt water to enter the pump well. If the pumps remain in service, the shock loading from salt water influx could result in a complete loss of biological treatment performance at the sewage treatment plant. Following this shock loading, the quality of treatment plant outfall would initially have pathogen and pollutant levels similar to that of raw sewage. This would gradually return to normal levels after treatment bacteria have fully re-established, ie perhaps after six to twelve weeks of operation.

The pumps rely on electrical power, which may be interrupted during the inundation and could result in the overflow of raw sewage into waterways. Power supply to the pump stations is sourced via overhead transformers and is no greater risk from inundation than general power supply failure (see Section 13.2.5). Switch boards and motor control cabinets are generally located at or near ground level and may require maintenance or replacement following seawater inundation.

#### *13.2.4 Water Supply*

The water supply system is typically located on elevated ground and or sealed underground infrastructure. Some above ground creek crossings may be at risk.

**Plate 7 – Water supply across Kinka Creek.**


### *13.2.5 Electrical and Communications*

**General**

The electrical infrastructure in the areas includes overhead and underground reticulation owned by Ergon to provide electricity supply and underground reticulation owned by Telstra to provide communications and phone services.

**Communications**

The Telstra infrastructure is all underground reticulation. The system is therefore designed and installed to be robust against the ingress of water. The pit and conduit system is regularly inundated with water as part of the natural storm water dissipation. The cables and cable joints used are grease filled which can be submerged in low level water with no adverse affects. The cable connection pillars, which are located above ground, are also sealed and positively pressurised to prevent the ingress of water, however are not submersible.

The weak links are Telstra RIM's and exchanges. The RIM's are electronic devices installed in suburban areas in a weatherproof housing. The housings are not generally located above the storm surge level and are not designed for submersion.

The loss of a RIM will cause a local loss of communications restricted to the general area of the RIM. The loss of an exchange will cause a loss of all communications connected to the exchange. This will have affect a larger area of population and rectification will not be possible until the water level returns to normal. There are no life threatening implications associated with communications other than disconnection of local electrical power supplies.

In the Yeppoon area, there are no RIMs located within surge areas, however there is an exchange which may be at risk from an AEP 1 in 1,000 year surge inundation.

In the Emu Park region, there is an exchange and RIM which may be at risk from an AEP 1 in 1,000 year surge inundation.

The exchange located in the Keppel Sands area is at a slight risk from an AEP 1 in 100 year inundation and at high risk from an AEP 1 in 1,000 year surge. The depth of the inundation due to the AEP 1 in 1,000 year surge is estimated to be between 0.6m and 1.2m.

**Electrical Supply**

The Ergon infrastructure is a combination of overhead and underground reticulation. 11kV and 415V services are reticulated to all areas. The overhead reticulation is suitably segregated from the rising water by virtue of being located well above ground level. The poles supporting the cables are able to withstand minor water flow around the base of the pole. Susceptible points in this system are locations where overhead and underground reticulation is joined at connection boxes. The location and height above ground of connection boxes is currently under review by Ergon.

The underground reticulation is robust against water due to the inherent resistance required for underground installations. The weak points are ground mounted and low level equipment, which is not water proof. These include house meter panels, distribution pillars, padmount transformers and 11kV Ring Main Units (RMU). Ergon has a series of cascading protection, which includes meter panels protected at distribution pillars protected at the transformer protected at the RMU protected at the zone substation. As the protection trip proceeds from meter panel to substation a greater area is affected by a loss of power. Power will not be able to be returned until the water level lowers and new equipment is installed. In the case of transformers and RMU's this may take 2 to 3 weeks for supply and installation.

In the Yeppoon region, two underground high voltage padmount sites are at risk from AEP 1 in 50, 1 in 100, 1 in 500 and 1 in 1,000 year surges. These are estimated to be up to and over 1.2m underwater.

One underground high voltage padmount site in the Emu Park region is also at risk from all estimated surges. The depth of these surges at the sites are also estimated to be up to and over 1.2m.

There are no essential Ergon installations within the Keppel Sands region.

There is potential loss of life situations if the electricity is not shut off prior to water levels rising. The speed at which water rises and warnings, which may be available, will play an important role in assisting Ergon in the maintenance and safety of the network. However, the protection settings are generally set to provide power shutoff in less than 1 second.

### *13.2.6 Other Infrastructure*

Public buildings at risk from inundation include Livingstone Shire Council offices, hospital and ambulance buildings at Anzac Parade at Yeppoon (particularly due to wave action on top of surge) and Keppel Sands State School.

**Plate 8 – Keppel Sands State School** (Note Mangroves on right hand side)


### 13.3 Risk Assessment

As outlined in Section 12, depth of inundation maps have been prepared for critical areas, based on increments outlined in SCARM (2000). Figures 13 to 18 present the inundation mapping for the full range of storm tide events considered. Figures 19 to 21 present the depth mapping for the AEP 1 in 100 year storm surge event and Figures 22 to 24 present the depth mapping for the Probable Maximum Surge event. A review of hazard at each of the communities is provided below:

**Yeppoon**

Under the AEP 1 in 100 year event, the lower reaches of Ross Creek and Fig Tree Creek are substantially inundated. Properties in that border on to Ross Creek may experience some minor inundation, however the main area of concern is along Fig Tree Creek. In particular, Whitman Street, Industrial Avenue, Charles Street and Burnett Street are subject to substantial inundation (greater than 1.2m). There is also the possibility of the area surrounding Cordingley Street becoming an isolated area.

Under the Probable Maximum Surge event, inundation along Fig Tree Creek extends into William Street and the area surrounding the junction of Cordingley and Shaw Streets becomes completely isolated. The Yeppoon-Rockhampton Road is also cut by deep water (>1.2m). Properties along Anzac Parade and into Normanby Street are also inundated. Isolation occurs for properties located on Wattle Grove, the area between Ocean Parade and Poplar Street, and Seahorse Crescent/Scenic Highway.

**Emu Park**

Under the AEP 1 in 100 year storm surge event, inundation along Kennedy Street and Reef Street may occur. Svendsen Road, near the junction with Hartley Street, may be cut as may Emu Park Road near Brown Street, although alternative access routes are dry. In general the area appears to be above the inundation levels and access into and out of the area is possible.

Under the Probable Maximum Surge event, the situation has not worsening substantially. Inundation of some properties along Claude, Kennedy, Arthur, George and Wilbraham Streets will occur.

Properties between Hartley Street and Warlock Street may also be inundated. Svendsen and Emu Park Road are cut although alternative access into and out of the area is available.

**Keppel Sands**
Under the AEP 1 in 100 year Storm Surge event, inundation of properties along Schofield Parade and Carlo Court occurs. A portion of the Keppel Sands Road appears to be inundated by deep water (>1.2m) limiting access in and out of the area.

Under the Probable Maximum Surge event, the community of Keppel Sands is completely isolated and surrounded by deep water (> 1.2m). Inundation of properties along Schofield Parade and Carlo Court has worsened and new areas are inundated including Meadow Street, Taylor Street, Horne Twiner Street, Limpus Avenue, Roden Street, Dingwall Street and Chishom Lane.

**Kinka Beach**
Under the AEP 1 in 100 year Storm Surge event, the properties in Kina Beach do not appear to be affected by inundation and access is maintained to the township.

Under the Probable Maximum Surge event, the majority of properties are inundated by up to 1.2 metres of water and access into and out of the area is blocked.

**Causeway Lake Area**
Under the AEP 1 in 100 year Storm Surge event, properties located on the north-western bank of the Lake are subject to inundation of up to 1.2 metres. Access into and out of this area is still feasible.

Under the Probable Maximum Surge event, the majority of properties are inundated by over 1.2 metres of water. Access away from the inundation area is feasible to higher ground but it should be noted that this higher ground is isolated by flood waters.

**Summary**
A summary of the hazard ratings for each area and AEP is provided in Table 13. The worst hazard rating for each area has been used.

**Table 13 – Initial Hazard Estimates**

| Area | Storm Tide AEP | |
|---|---|---|
| | 1 in 100 year | Probable Maximum Surge |
| Yeppoon | High | Extreme |
| Emu Park | Low* | Medium |
| Keppel Sands | Extreme | Extreme |
| Kinka Beach | Low | High |
| Causeway Lake | High | Extreme |

** Indicates hazard would be negligible once alternative flood free access is open*

It should be noted that the hazard estimates presented in Table 13 are initial estimates only based on the mapping produced. The hazard classifications should be confirmed by the counter-disaster managers, taking into account local knowledge and emergency procedures.

# 14. Emergency Management

General advice was obtained from the Bureau of Meteorology on the existing cyclone/storm tide warning system currently in place throughout Queensland. A summary of the procedure is as follows:

- Preliminary Advice – given 30 hours prior to cyclone landfall. There are no specific water level predictions available with this first warning, but advice is provided that there is a high likelihood of further warnings. Voluntary evacuations are possible at this time, for areas at high risk;
- Storm Tide Warning – given 18 hours prior to cyclone landfall. At this stage, a predicted peak storm tide level is provided (in metres AHD). Evacuations would commence immediately after this warning if appropriate; and
- Follow-up Warnings – issued every 3 hours thereafter.

Evacuations should commence as early as possible as cyclone landfall also coincides with the most destructive winds, and it is difficult to evacuate during such conditions.

Hence approximately 18 hours of warning time should be available for counter disaster managers to facilitate evacuations of critical areas.

It is understood that DES have issued advice regarding appropriate colour schemes to be used on Emergency Planning Mapping (ie Evacuation Plans) and the format of these drawings. These drawings will present storm tide inundation in 0.5m intervals and take into account knowledge of local Counter Disaster personnel (eg isolated areas that need to be evacuated early etc). It is therefore recommended that these drawings be adopted and used during a cyclonic event to assess the areas likely to require evacuation based on the Bureau of Meteorology warnings.

# 15. Recommended Further Work

This Study has quantified and highlighted the risks posed to the Capricorn Coast from storm surge flooding, however there are some critical issues that remain outstanding, including:

- The need to for more accurate survey information to be obtained to enable further review/refinement of the inundation mapping;
- The need for preparation of an evacuation plan for the communities of Yeppoon, Emu Park and Keppel Sands;
- The need for the initial hazard estimates presented in Table 13 to be reviewed by counter-disaster managers and adjusted based on evacuation times;
- The need for consideration of freshwater flooding occurring jointly with storm surge; and
- The need for consideration for treatment options.

As discussed in SCARM (2000), the study area is subjected to both rainfall and storm surge flooding, and both these flood-producing mechanisms can and do occur at the same time. If flooding is caused by heavy rainfall and storm surge combined, the question arises of how severe will be the resultant flood for example, for rainfall severity of AEP 1 in 100 years and storm surge severity of AEP 1 in 20 years. If both effects are caused by the same storm, the more extreme severity is chosen as representative of the resultant flood severity (ie AEP 1 in 100 years for the above example). However, heavy rainfalls and storm surge may not be generated by the same storm, and even if they are, the relative severity of each effect may be independent of the other.

A review of the typical time of concentration for catchments along the Capricorn Coast indicated that the response time for the coastal creeks was short and therefore it is feasible that freshwater peak discharges could coincide with peak storm surge levels.

Due to the amount of inundation predicted to occur under the action of storm surge alone, it is recommended that Council's consider a joint probability study to actually quantify this critical issue. An arbitrary choice of combination of freshwater events and storm surge events would produce results of unknown quality, hence an unknown impact on Council's counter-disaster plans. This study should also examine the joint probability of wave setup with surge, to allow more realistic combination estimates to be made. Once this study is completed, inundation plans and the hazard assessment would need to be reviewed.

This report has focussed on analysing and evaluating risks posed to the Capricorn Coast from storm surge, but has not considered any risk treatment options. Council will need to review all possible treatment options in the light of this report. It may be that some relatively simple structural measures could remove flood risk in some areas (eg flood flaps on stormwater outlets to prevent surge inundation of local roads, raising of some low points on access roads etc).

In addition, the information collected in this report should be used to update or produce evacuation plans for the townships of Yeppoon, Emu Park, Keppel Sands, Kinka Beach and Causeway Lake.

A final issue to note is the impact that sea-level rise would have on the existing inundation plans. Council's should closely monitor predictions of sea-level rise with time, and review the impacts on the inundation plans accordingly.

# 16. Conclusions

This report describes the data, methods and results of an investigation of storm tide levels in the nominated Livingstone Shire Council storm tide hazard Study Area situated on the Capricorn Coast of Queensland.

An analysis of historical cyclones that have affected the area was undertaken. Only cyclones recorded since 1955 were included. That data was analysed to provide statistical descriptions of the principal cyclone parameters. Numerical storm surge and wave models were set up using bathymetric data prepared from available charts. The surge model was validated using historical storm surge data provided by the Department of Transport.

Numerical simulations of fifty-four selected base cyclones were undertaken. A further six sensitivity simulations were undertaken to describe the effects of tide level and radius to maximum winds. They provided time series of storm surge over periods of seventy-two hours at half hourly intervals. Those simulations provided basic data for cyclone surge descriptions used in a Monte Carlo analysis, together with the analysed historical data.

Cyclones and astronomical tides over a period of ten thousand years were simulated. The resulting storm tide time series were analysed using the Extreme Value Type 1 distribution to provide peak storm tide levels at selected average recurrence intervals. Other meteorological events such as East Coast lows may also cause elevated ocean levels.

Wave setup was also investigated and likely water level increments determined. In addition, wave runup heights, which implicitly include wave setup, was determined specifically for locations along the beach frontal dune. Design levels for different locations in the coastal region that might be affected by storm tide have been provided for an example site. A procedure for undertaking similar calculations for other sites has been prepared.

The peak storm tide levels presented in Table 6 do not include an increment for possible MSL rise caused by Climate Change. This may be 0.2m by 2048 (CSIRO, 2000). Wave setup increments are to be added to peak storm design surge levels, other than for frontal dune sites where wave runup is to be included.

This study has quantified the storm surge risk along the Capricorn Coast and assessed potential impacts in terms of flood inundation and flood hazard.

In summary, the overall risks appear manageable with good counter disaster planning. There are a couple of areas that would require evacuation under the more extreme storm tides, however the majority of coast is generally immune from surges up to AEP 1 in 100 years (ie typical flood immunity standards), with localised inundation of some areas. Isolation of areas, such as Keppel Sands, would need to be specifically addressed. Approximately 18 hours advanced warning would be given by BoM to allow time for evacuation.

It is important for Council to obtain an accurate picture of the joint probability of flooding combined with storm surge.

# 17. References

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# *Figures*

# Appendix A

***Analysed Historical Cyclone Data***

# *Part 1 – General*

# *Part 2 – Prediction of Storm Tide*

# *Part 3 – Hazard Assessment*

# *Part 4 – Study Conclusions*