3.6.2 February 1999 Flood Event

The 1999 event was a larger multi-peak event, with major overtopping of creek banks. Although the peak flow for the 1999 event is not as large as the 2006 event, the extended duration of the 1999 event resulted in more substantial flooding in the lower catchment.

The hydrologic model provided a good representation of the 1999 event for Bolinda, Euramo and Upper Murray stream gauges, as seen in Figure 3-11 and Figure 3-12. All hydrographs are comparable to the recorded gauge flows. The only exception is found in the Upper Murray results which fails to represent the third peak of the event. Since the third peak is a only a minor peak in comparison with the first two peaks of the event this calibration is still considered sufficient.

Based on these results, the models representing the 1999 event have bee found to successfully simulate the major flood peaks, shape, timing and recession between peaks.

3.6.3 Calibrated Parameters

Three parameters were considered during URBS model calibration. A description of each of these is presented in Table 1-4.

The BoM provided additional assistance in recommending values for certain calibration parameters and for estimating typical values for others.

Table 3-4 Calibration Parameters

Parameter	Parameter Description	Tully River Model	Murray River Model	Kennedy/ Meunga Ck Model
β Catchment lag parameter	Represents storage within the sub-catchment. An increase in this parameter will attenuate flows within the catchment routing stage.	3	4	3.5
m Catchment non-linearity parameter	Power value of the storage-discharge relationship for catchment routing	0.8	0.8	0.8
α Channel lag parameter	Represents storage within the channel. A linear relationship between flow and storage is assumed for channel routing. An increase in α results in an increase in storage and therefore greater attenuation.	0.15	0.4	0.28

3.6.4 Rainfall Losses

As discussed in Section 3.3, a Uniform Continuing Loss Model was applied to the rainfall. Initial loss rates are determined during calibration by matching the rising limb of the predicted hydrograph to that of the recorded hydrograph. The continuing loss rate is then adjusted in conjunction with the calibration parameters discussed above to match the peak flood flows.

The initial and continuing loss rates determined for the above calibration events are presented in Table 3-5.

Table 3-5 Losses Applied to Calibration Events

Loss Type	Tully River Hydrology Model	Murray River Hydrology Model	Kennedy / Meunga Ck Hydrology Model
Initial Loss 2006 Event	50mm	0mm	25mm
Continuing Loss 2006 Event	3.5mm/h	3.5mm/h	3.5mm/h
Initial Loss 1999 Event	90mm	0mm	45mm
Continuing Loss 1999 Event	2mm/h	3.5mm/h	2.5mm/h

3.7 March 2006 Flood Hydraulic Model Calibration

The 2D/1D hydraulic model was initially calibrated to the 2006 flood event, which focussed on the roughness of the creek channel and the floodplain as moderate floodplain flow was experienced for this event.

3.7.1 Inflows and Tide Levels

The recorded stage hydrograph at Bolinda was converted into a flow hydrograph using the rating curve provided by the BoM. This was used as the inflow boundary for the Tully River at the upstream end of the hydraulic model. While the hydrologic model was found to simulate the event well, applying the recorded hydrograph ensures a more accurate boundary to the model, restricting external influences on hydraulic model calibration.

Tide levels for the Hull, Tully and Murray Rivers and Meunga Creek were obtained from the model results of the Coral Sea modelling. These head boundaries were applied as the downstream boundary conditions. Testing found the flood levels at the Murray Flats and Euramo stream gauge to be insensitive to these boundary conditions.

3.7.2 Manning's n Values

During the initial calibration process, it was found that the interactions between the Murray and Tully River in the vicinity of the Brick Creek had a major influence on the calibration of the Murray Flats gauge.

Survey information has shown that inaccuracies in the DEM ground elevations were on average around 0.6m less than actual ground elevations. However, maximum difference between ground surveyed levels and photogrammetry levels were as high as 2m in some places. This is probably due to the height and scale of the photography used to derive the photogrammetry.

Hence, the DEM is probably under-estimating ground levels in this area. This is consistent with the early model results, which showed too much flow passing from the Tully River to the Murray River upstream of the highway.

In order to appropriately match the flood levels recorded at the Murray Flats stream gauge, a high Manning's n value of 0.6 representing the sugar cane in the 2D areas of the model was required to account for the lower ground levels in the DEM. In other words, the over-estimation of flow due to the under-estimation of ground levels in this area is compensated in the model by using a high value of Manning's n for the sugar cane in this area.

This solution is not ideal, but necessary to achieve a suitable representation of flow transfer from the Tully River to the Murray River. Ground survey in this critical area (which is in the order of 20km^2) would be required to properly represent this important area.

Various combinations of Manning's 'n' values for other land uses were trialled. Values of Manning's 'n' that were found to produce the best results are presented in Table 3-6.

Table 3-6 Values of Manning's 'n' for March 2006 Event Calibration

Location	Manning's 'n'
Tully River downstream of the Echo Creek	0.045
Tully River upstream of the Echo Creek	0.05 – 0.06
Murray River downstream of the Bruce Highway	0.045
Murray River upstream of the Bruce Highway	0.045 – 0.06
Banyan Creek	0.045 – 0.07
Bulgan Creek	0.07
Sugar Cane/ Dense Crops	0.20
Sugar Cane between Tully and Murray River	0.60
Forest	0.20
Low Density Forest	0.09
Tributary Creeks	0.06
River Mouth	0.025
Parks	0.05
Pasture	0.07
Urban	0.3
Roads	0.02

3.7.3 Calibration Results

The recorded and modelled stage hydrographs using these values are presented in Figure 3-13 and Figure 3-14 for the gauges at Euramo (Tully River) and Murray Flats (Murray River) for the 2006 event.

Figure 3-13 shows the 2006 calibration hydrograph for Euramo (Tully River). The graph shows the following key features of the model representation of this flood event:

- The rising limb of the modelled Tully River flow is slightly advanced in comparison with the recorded values;
- From 50 hours through till 80 hours, however, comparison between the record and the modelled levels show an excellent match at the Euramo stream gauge. It is within this period that the peak flood level of the event occurs. At the Euramo gauge the peak flood level of 8.59 mAHD was

recorded during the 2006 event. In comparison, model results show a peak flood level of 8.53 mAHD.

- After the peak of the flood, the receding limb of the 2006 event is premature in the model results when compared with the recorded levels.
- Inaccuracies in the DEM information in the floodplain between the Murray and the Tully Rivers in the area around Brick Creek may have a major influence on the flood storage influencing the variation in levels for the falling limb of the flood. In addition, the inability of the URBS model to represent base flow after the flood event may also influence the variation in levels for the falling limb of the flood.

Figure 3-14 shows the 2006 calibration hydrograph for Murray Flats. The graph shows the following key features of the model representation of this flood event:

- The rising limb of the 2006 flood event matches well with the recorded gauge levels at the Murray Flats.
- The recorded peak flood level at the Murray Flats for the 2006 event was 8.08 mAHD. In comparison, the modelled peak flood level was found to be 8.13 mAHD.
- Similar to the Euramo calibration hydrograph, the Murray Flats gauge results show the receding limb of the hydrograph diverging from the recorded levels. For the receding limb of the flood, model results show the recorded gauge levels are greater than the modelled levels.

Currently, historical flood level information available for use in calibrating to the March 2006 event was restricted to the gauged hydrographs at Euramo and the Murray Flats and eight flood debris marks identified during the site visit shortly after the 2006 event. Council also provided two floodmarks from the 39 flood boards located across the catchment.

For the 2006 flood event, the difference between these recorded flood levels and those predicted by the hydraulic model are presented in Drawing 1 (see A3 Drawing Addendum).

The calibration to peak flood levels in the Tully-Murray area is good at five points (within 0.3m). However, for the point in the area between the Tully and Murray Rivers, the flood level predicted by the model is much higher than that recorded. This is probably due to the high Manning's n required in this area to obtain the observed flow distribution from the Tully River to the Murray River.

In the Kennedy – Meunga Ck area, the comparison with peak flood levels shows that the model is predicting levels within 0.3m for the all three of the points.

These calibration results indicate that the model adequately represents flooding behaviour for a small to moderate flood.

3.8 February 1999 Flood Hydraulic Model Verification

3.8.1 Inflows and Tide Levels

Using the identical topography and Manning's roughness coefficients to the model created for the 2006 calibration, the inflow boundaries conditions for the February 1999 were input into the model.

Similar to the 2006 flood event calibration, flows calculated from the Bolinda flood gauge were used as boundary condition inflows to remove any external differences in the hydraulic calibration process.

Tide levels for the Hull, Tully and Murray Rivers and Meunga Creek were obtained from the recorded levels at Clump Point. The cyclone associated with this flood event passed the coast a significant distance to the north of the study area. Hence, the local variations in storm surge magnitude and timing was assumed to be minor. These head boundaries were applied as the downstream boundary conditions.

3.8.2 Calibration Results

Figure 3-15 shows the 1999 calibration hydrograph for Euramo (Tully River). The graph shows the following key features of the model representation of this flood event:

- The rising limb of the modelled Tully River flow is slightly advanced in comparison with the recorded values;
- After the peak of the flood, the receding limb of the 1999 event is premature in the model results when compared with the recorded levels. This is similar to the model replication of the 2006 flood event.

For the 1999 flood event, the difference between these recorded flood levels and those predicted by the hydraulic model are presented in Drawing 2 (see A3 Drawing Addendum).

There are substantial differences in the comparisons between the recorded flood levels and those predicted by the flood model. Many of these differences could be due to errors in the flood level records. The data supplied by Council indicates the accuracy of the recorded flood levels sometimes $\pm$0.5m (or more in some instances).

The 1999 event, being a larger event than the 2006 event, verifies that the model is representing the floodplain flows to an appropriate level recognising the errors associated with the base DEM data.

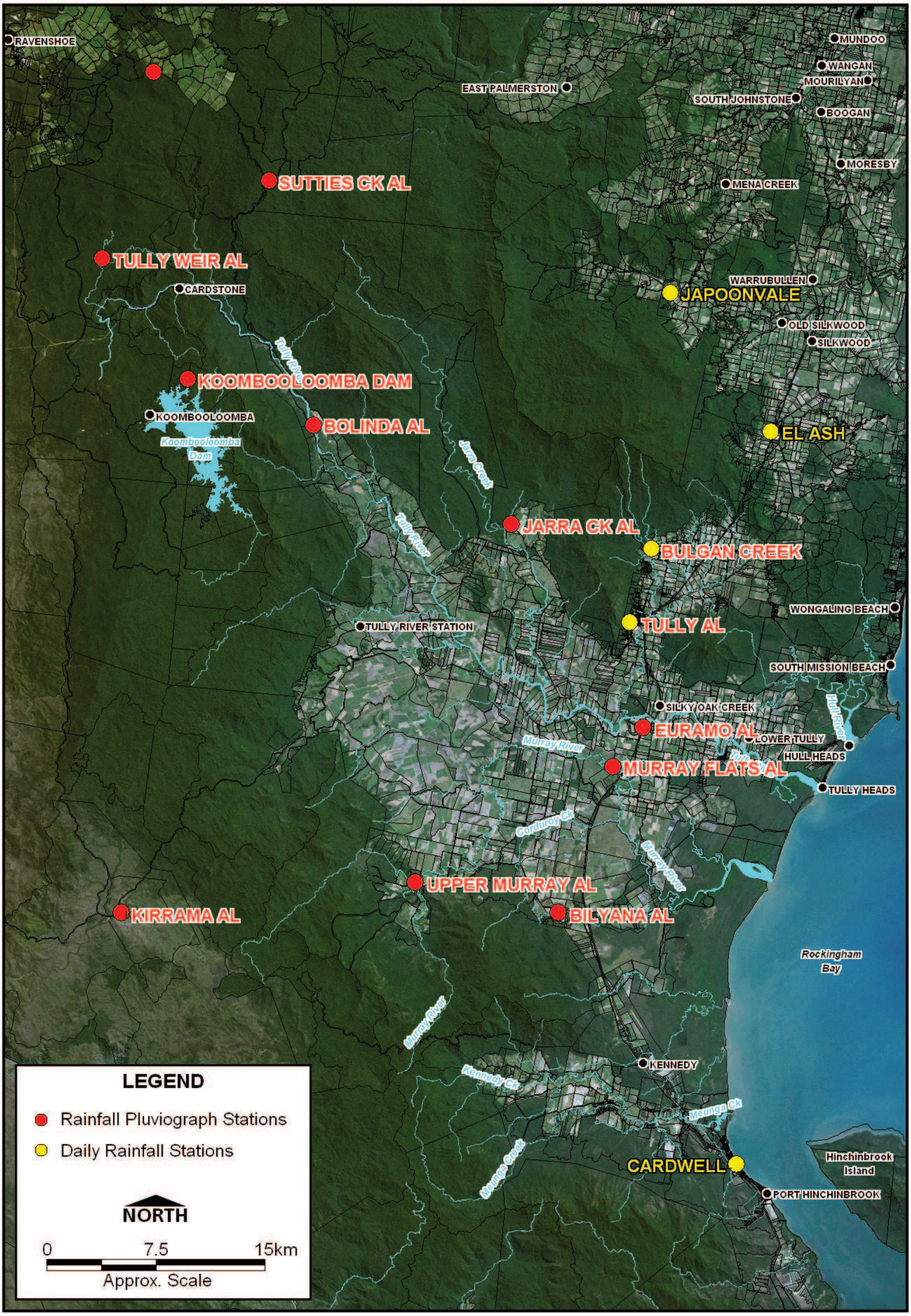
3.9 Conclusions on Calibration of Models

Hydrologic and hydraulic models have been developed for use in defining the existing flooding conditions in the study area. These models have been calibrated to the 2006 event and verified to the 1999 event.

Model results for the March 2006 event provide confidence that the model replicates in-bank and out-of-bank flood behaviour for a small to moderate size event. It was apparent from the calibration process that the accuracy of the DEM in the area between the Tully River and the Murray River upstream of the highway is critical to the accurate representation of flood behaviour. Unfortunately, this part of the DEM appears to be under-estimating ground levels. A high Manning's n value for sugar cane in this area was required to match the observed flooding behaviour.

Verification of the flood model using the 1999 event indicates that the model also has replicates the out of bank flow for a major event.

It is recommended that the model be adopted for design flood simulations (defining existing flood behaviour) and also for assessing the impacts and benefits of flood mitigation measures.



Pluviograph Data Received from BoM March 2006 Event

Figure 3-1

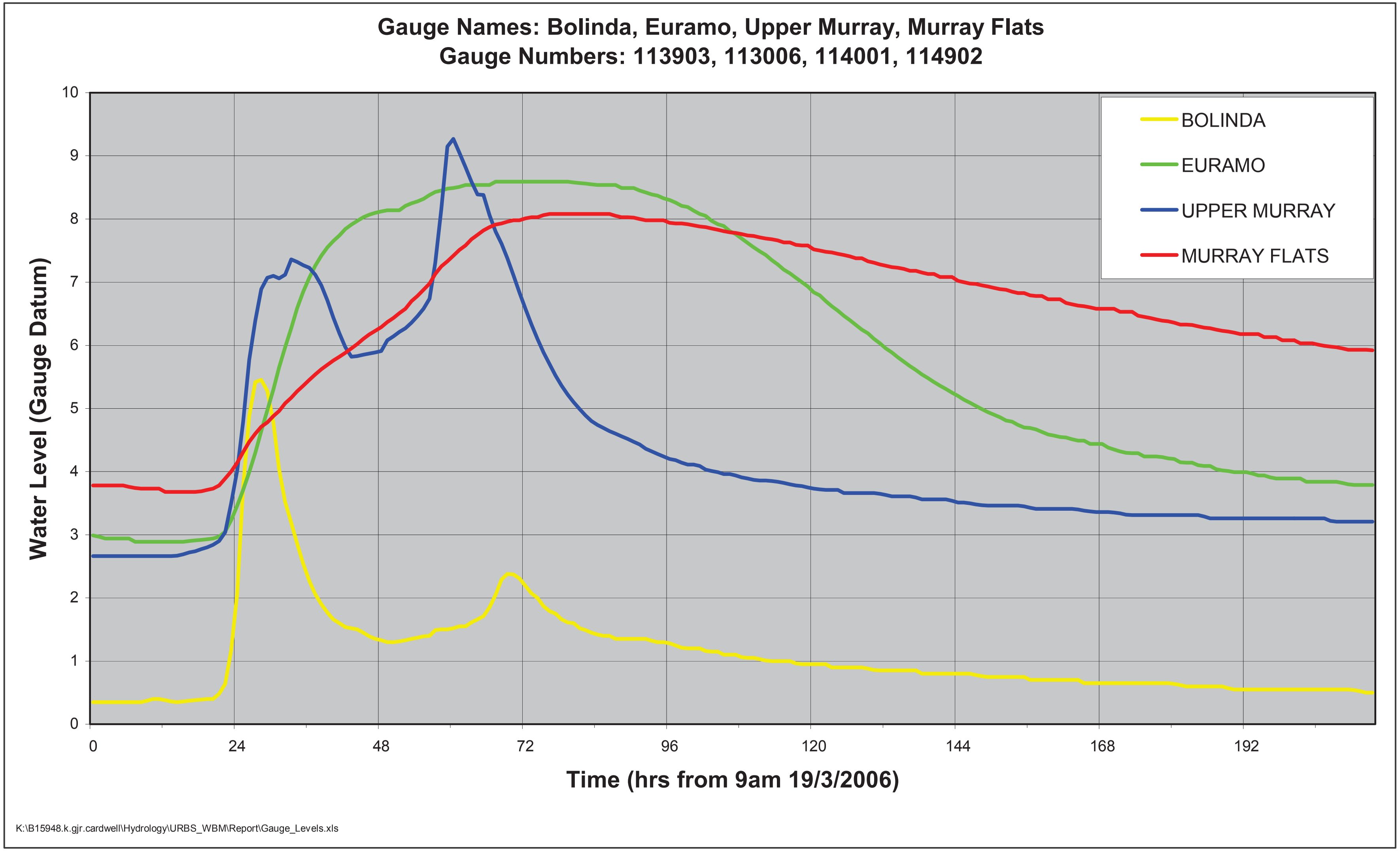
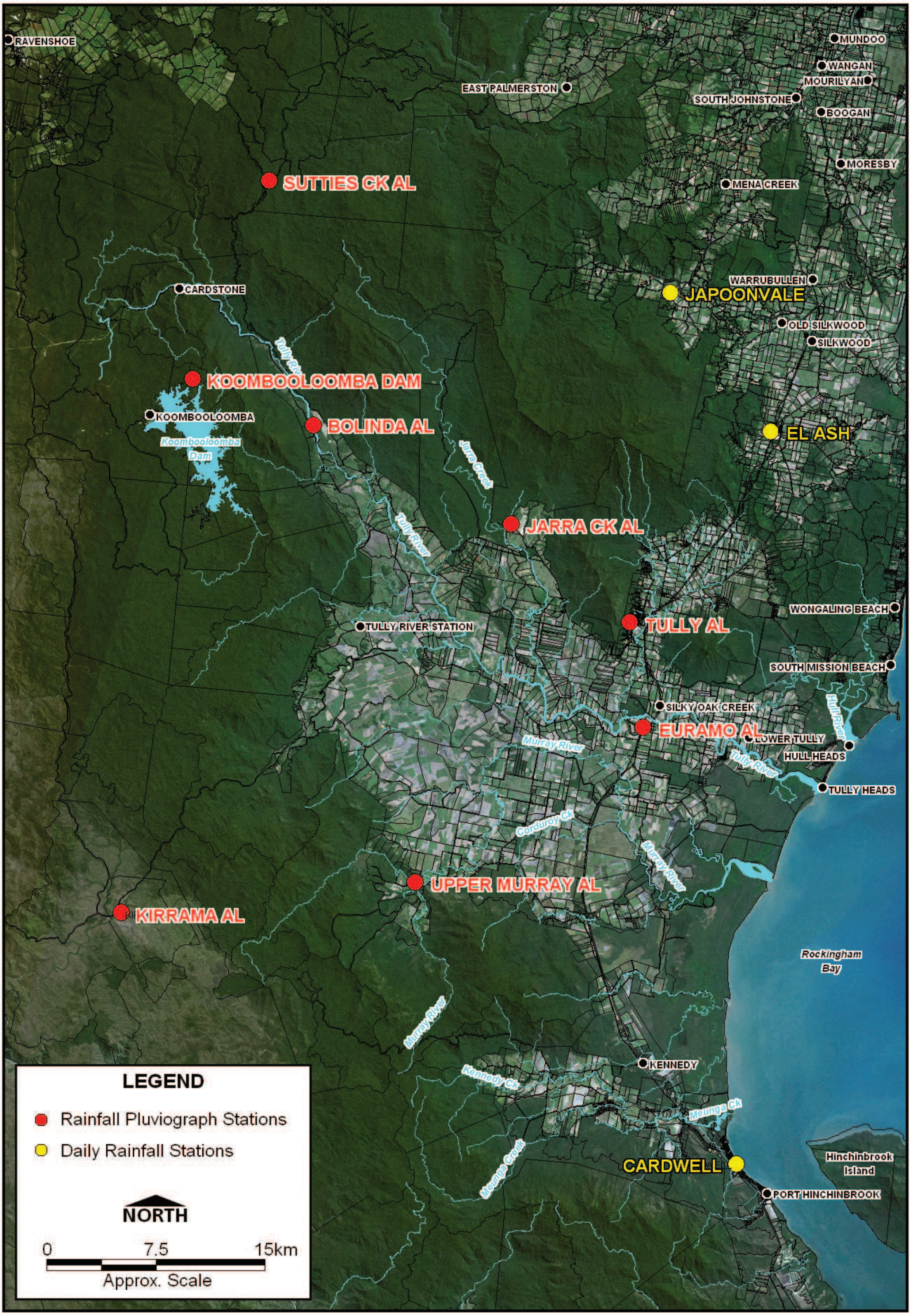


Figure 3-2 Stream Gauging Data Received from BoM – March 2006 Event



Pluviograph Data Received from BoM February 1999 Event

Figure 3-3

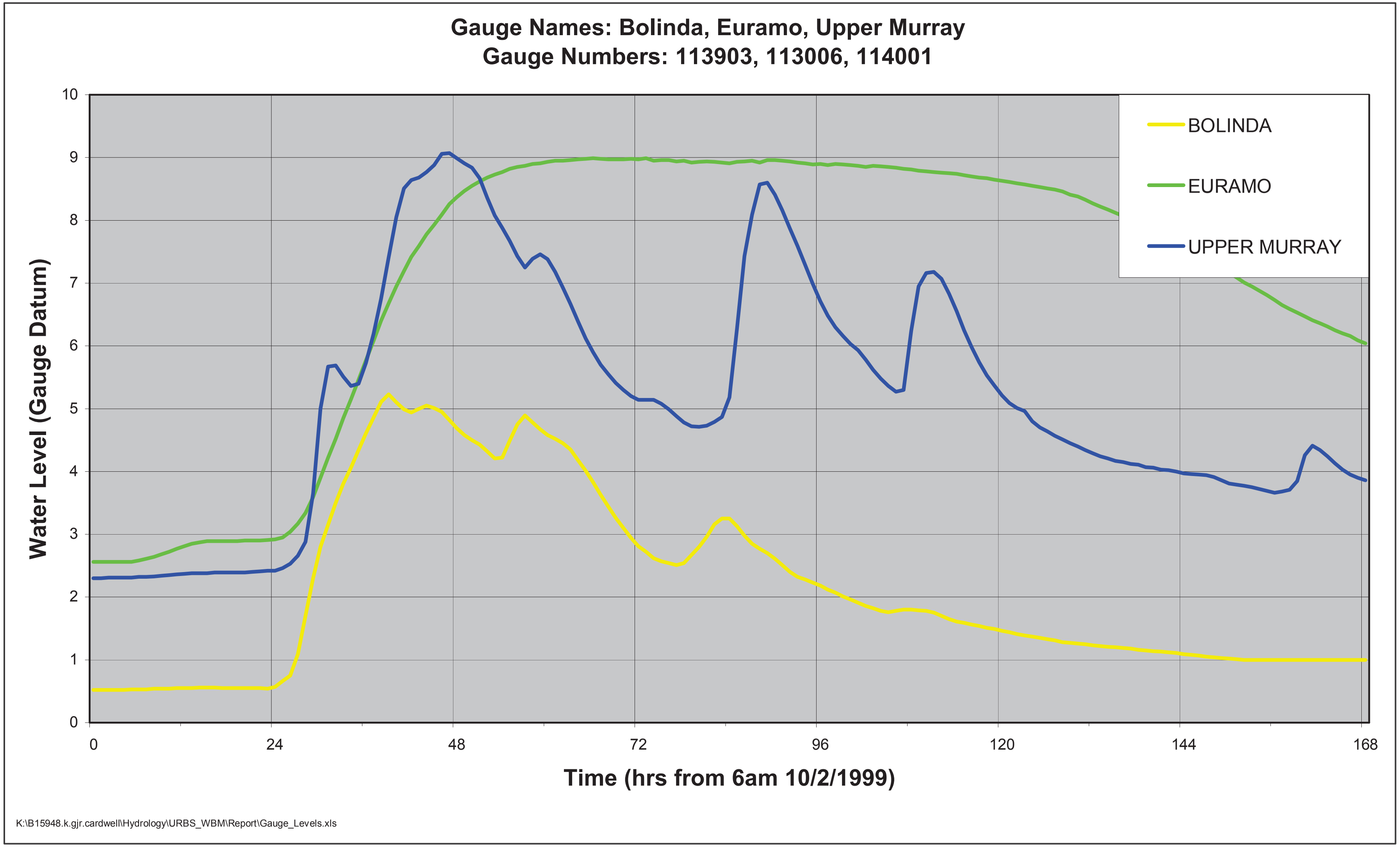
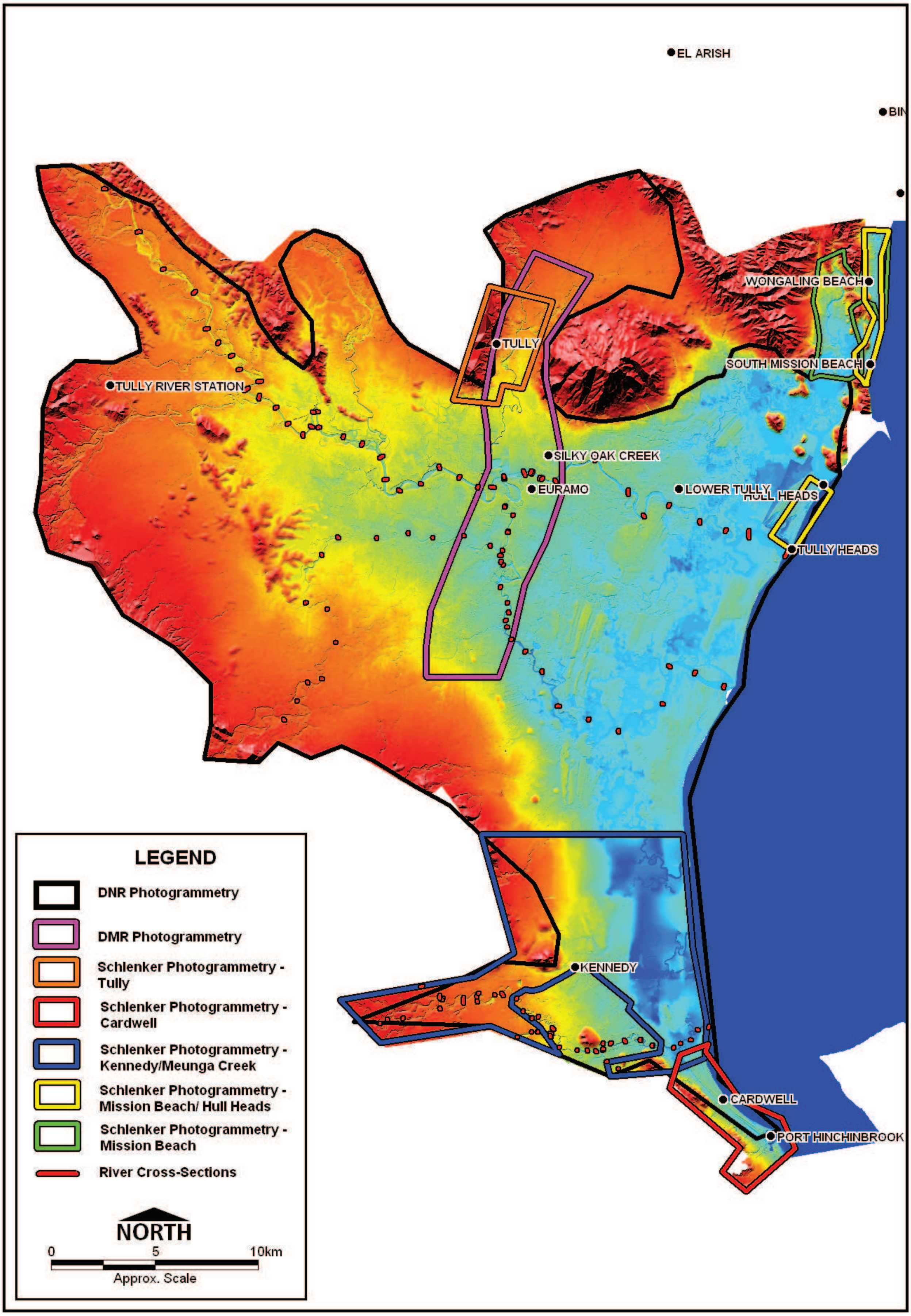
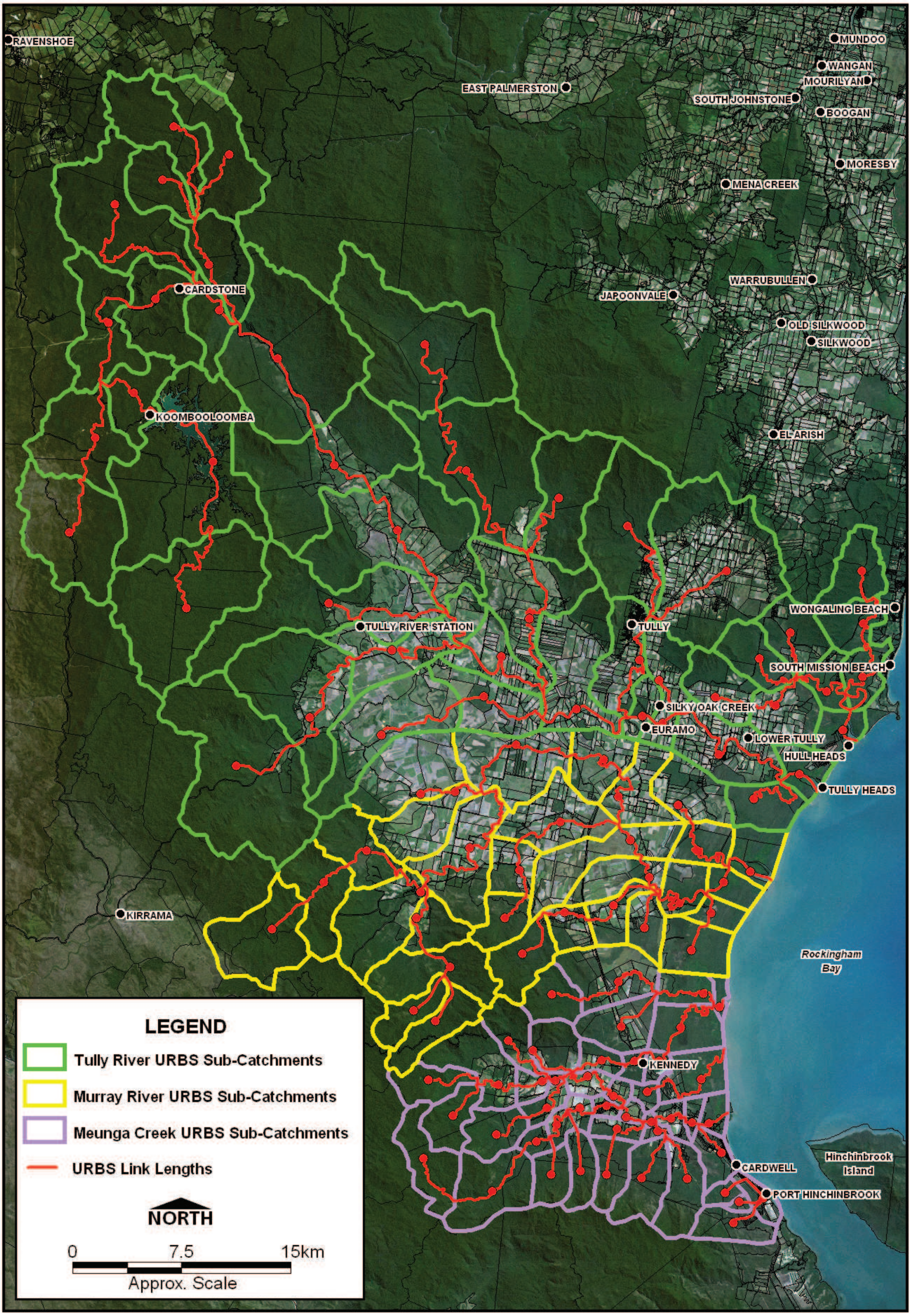


Figure 3-4 Stream Gauging Data Received from BoM – February 1999 Event



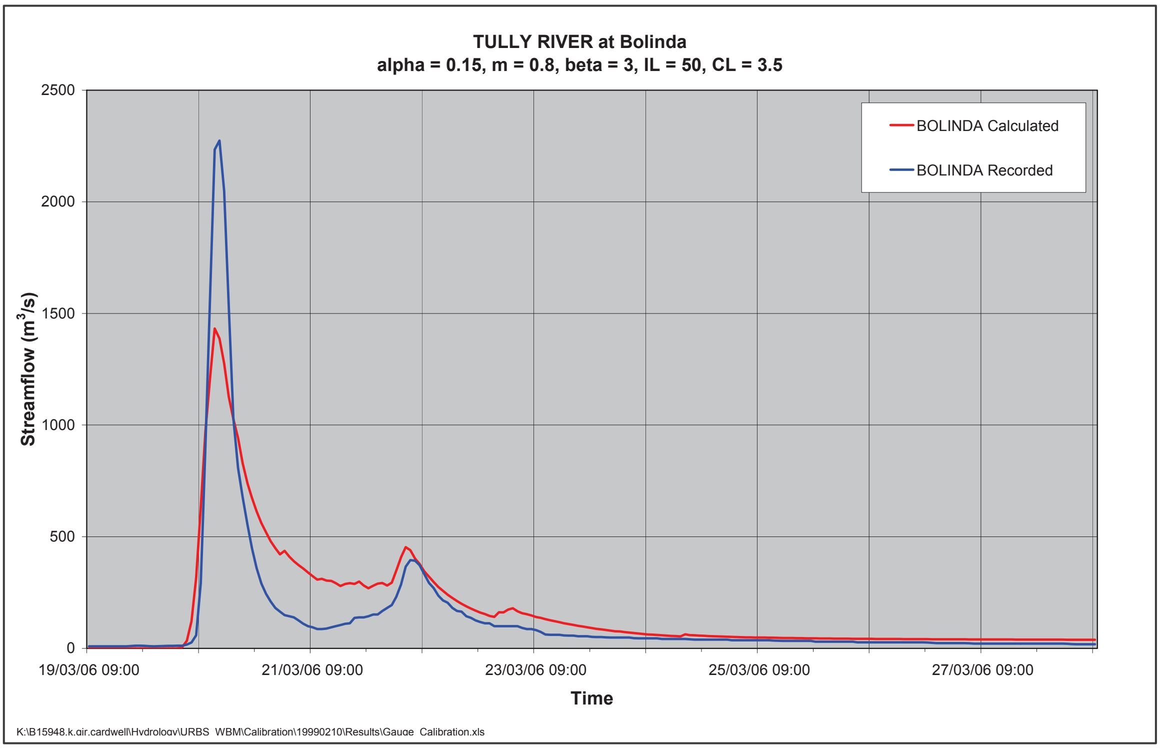
Topographic Data **Figure 3-5**



URBS Catchment Discretisation Figure 3-6

Extent of TUFLOW 2D Hydraulic Model **Figure 3-7**

Inflow Boundaries for 2D Hydraulic Model **Figure 3-8**



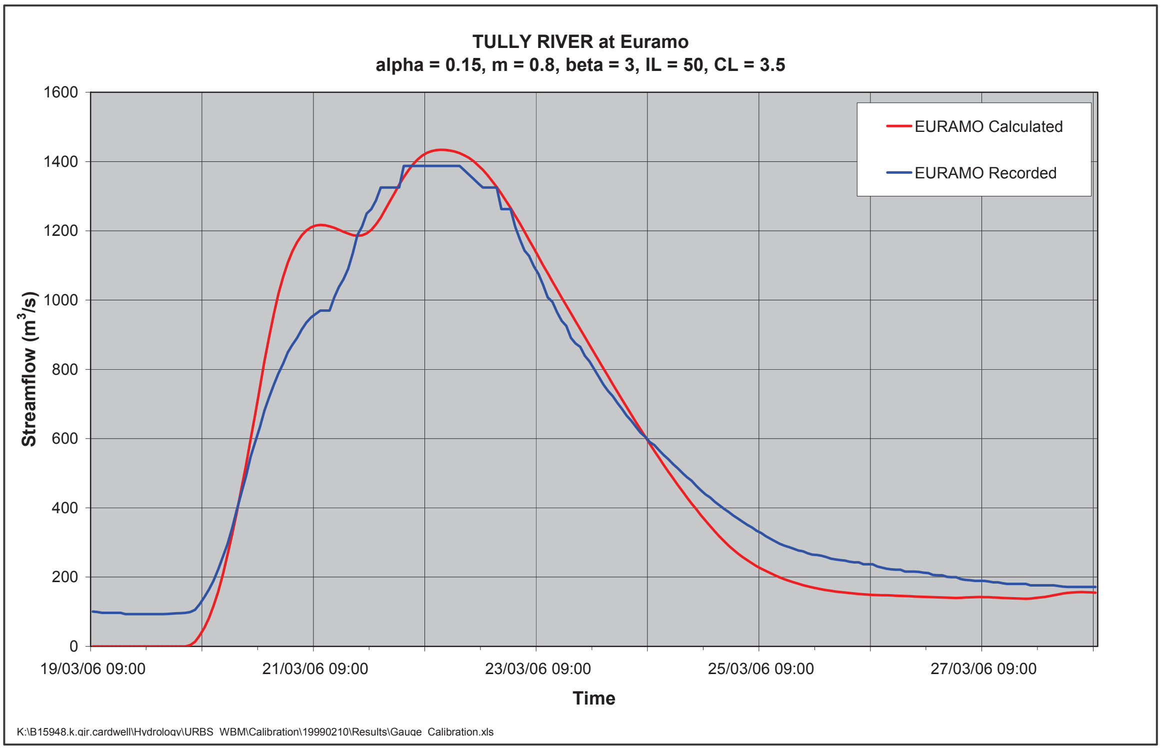
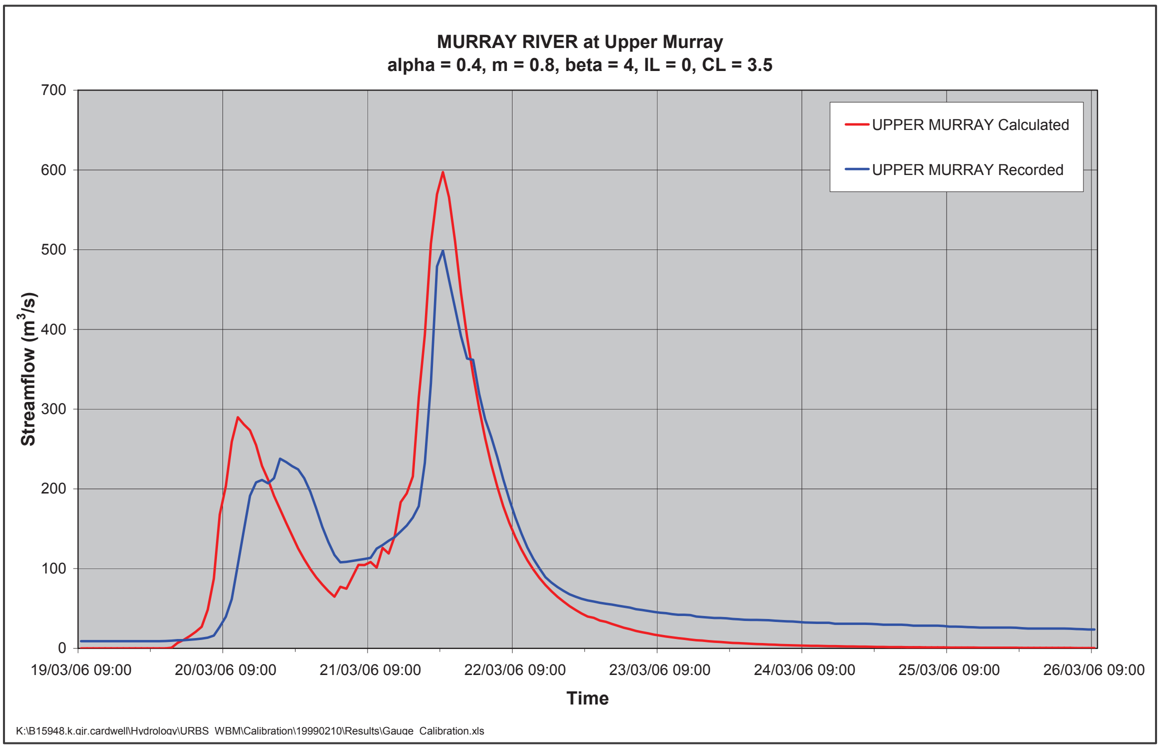


Figure 3-9 Hydrologic Calibration Results – March 2006 Event (Tully River)



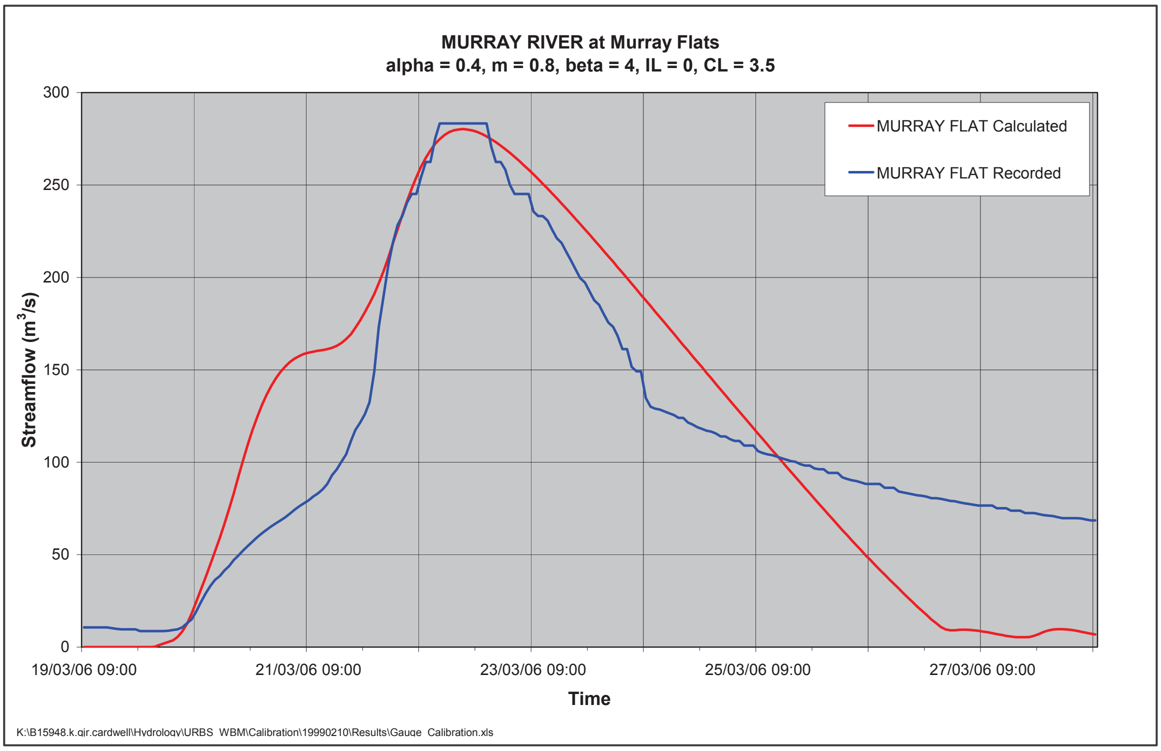
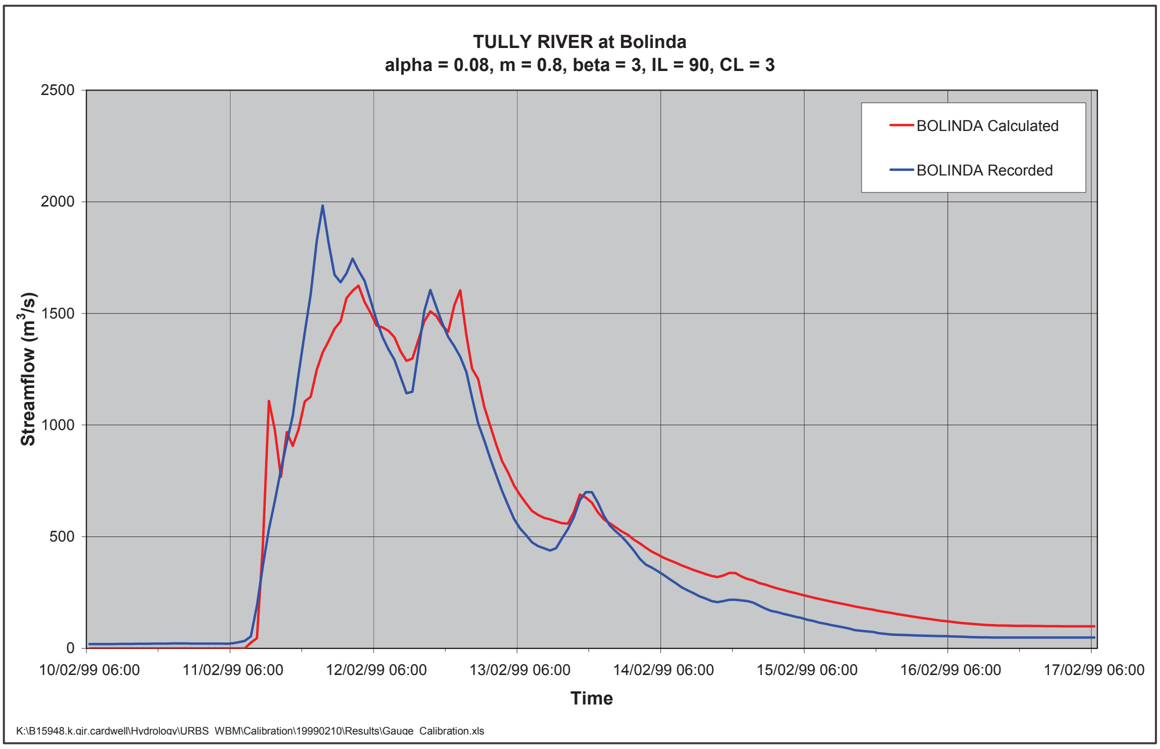


Figure 3-10 Hydrologic Calibration Results – March 2006 Event (Murray River)



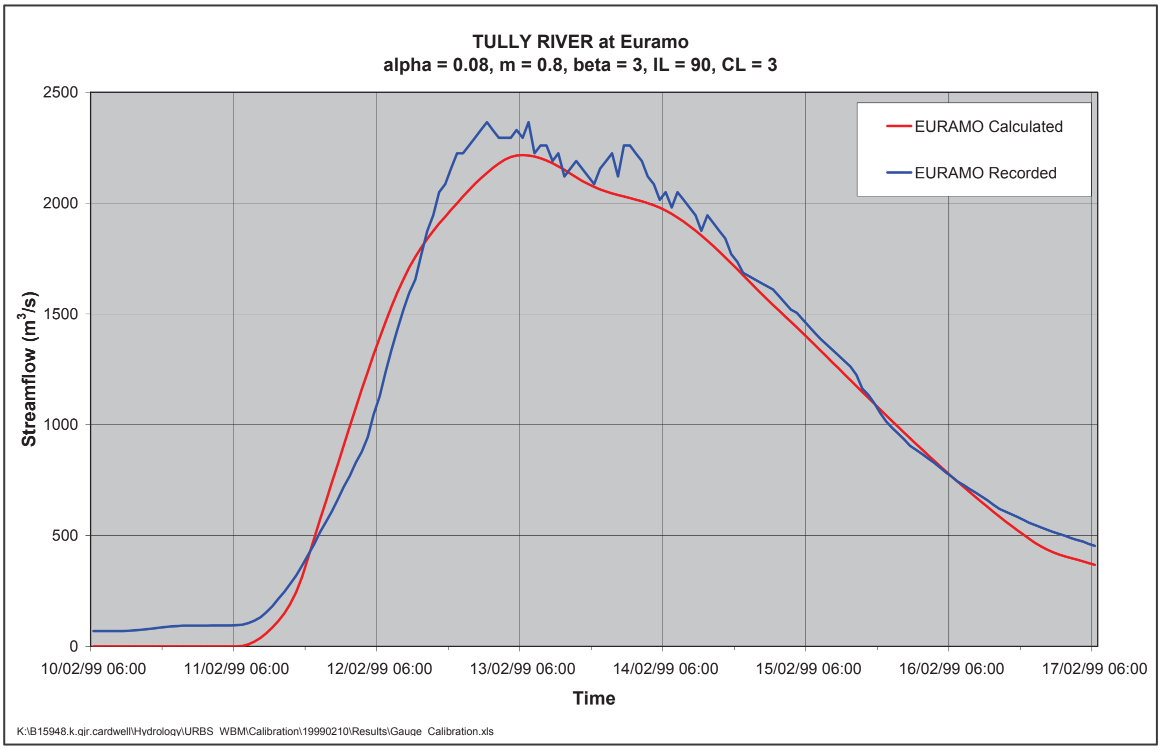


Figure 3-11 Hydrologic Calibration Results – Feburary 1999 Event (Tully River)

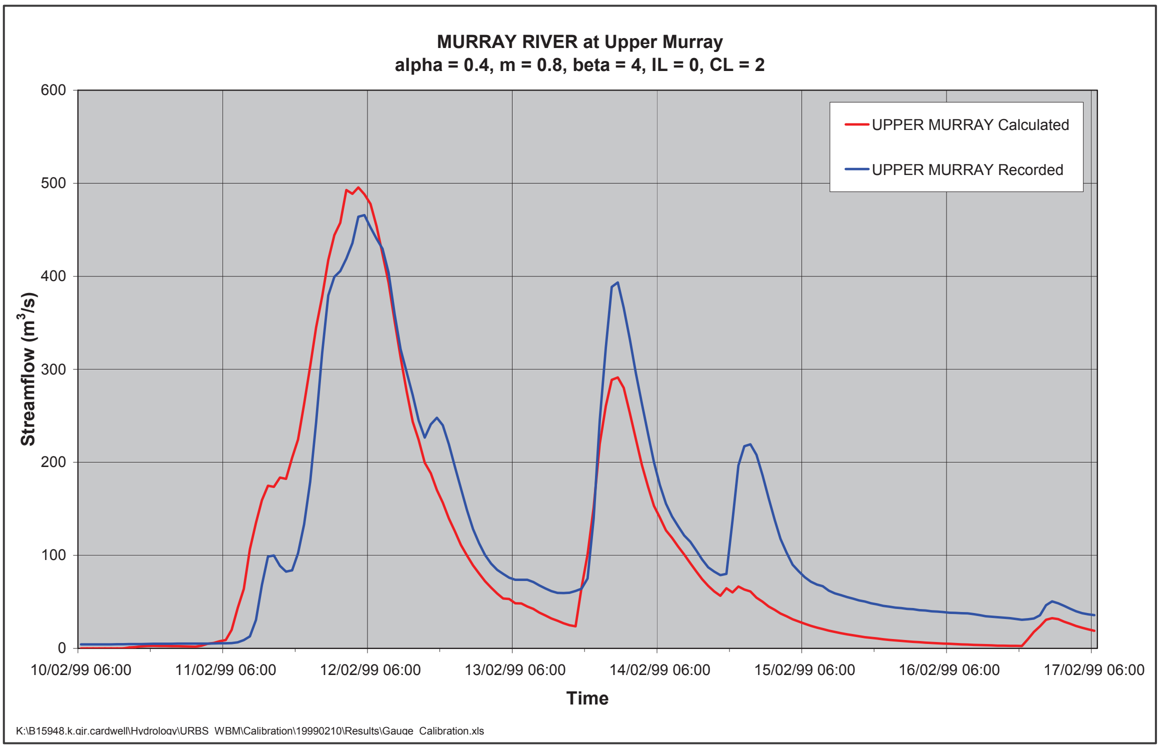


Figure 3-12 Hydrologic Calibration Results – Feburary 1999 Event (Murray River)

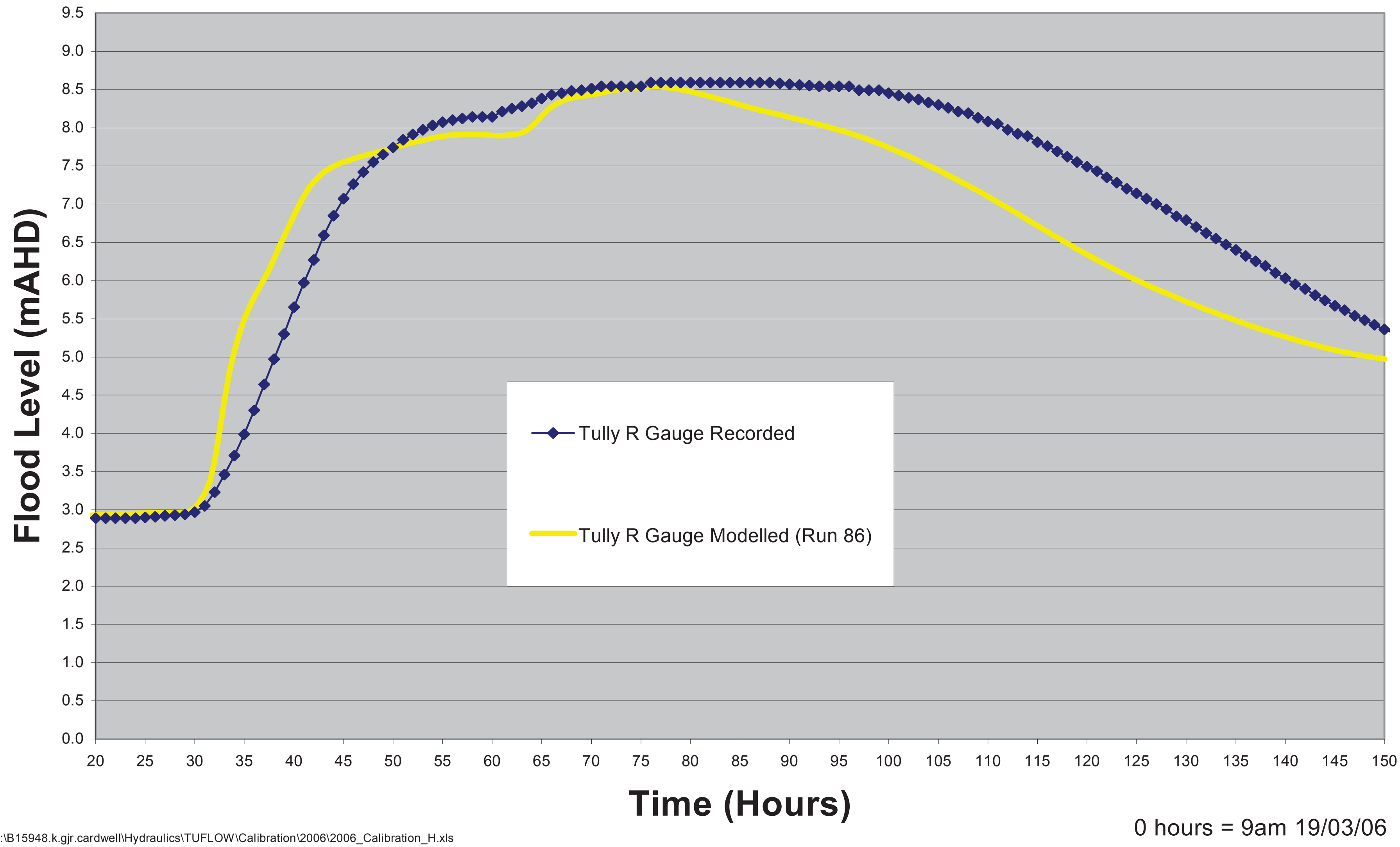


Figure 3-13 March 2006 Flood Model Calibration at Euramo

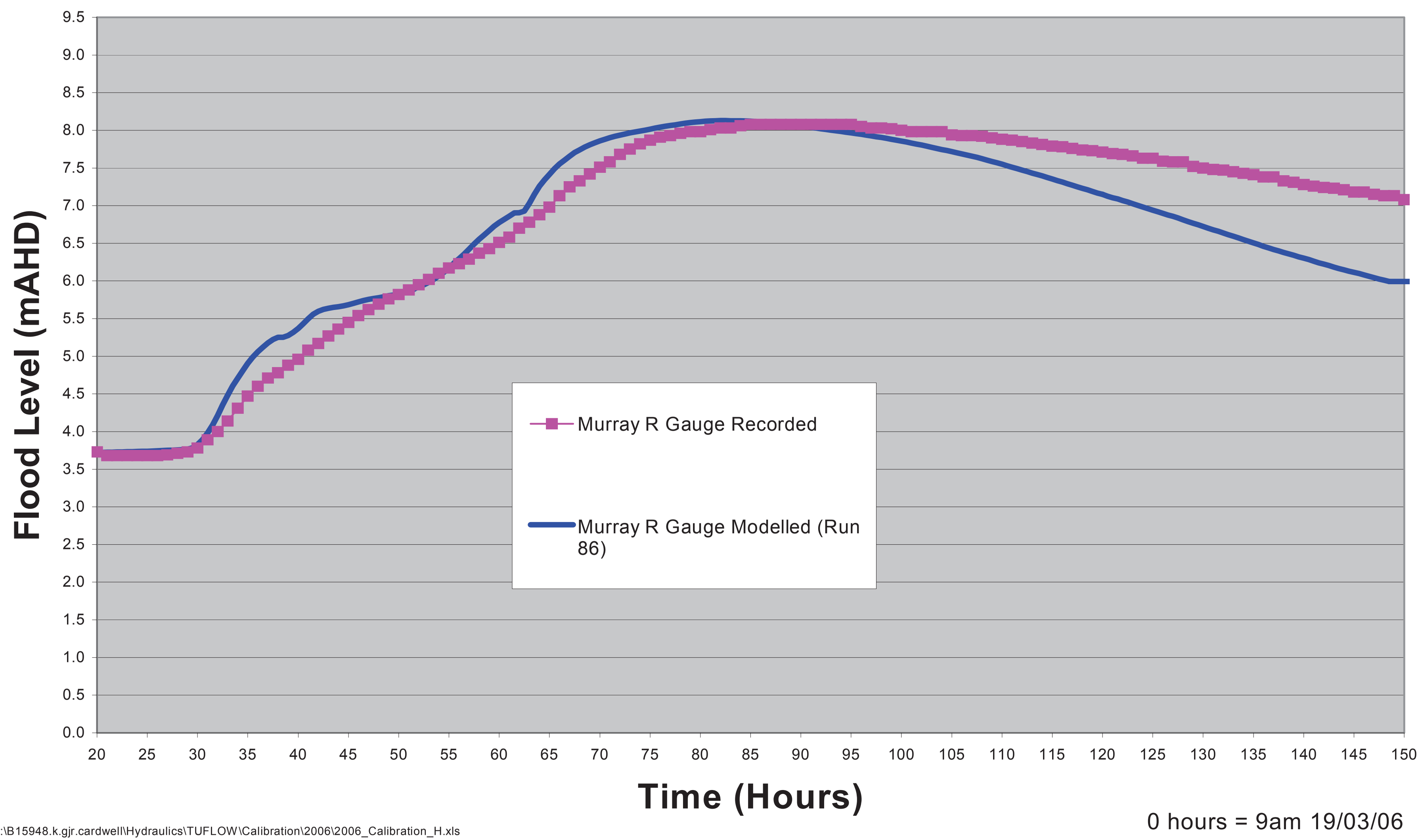
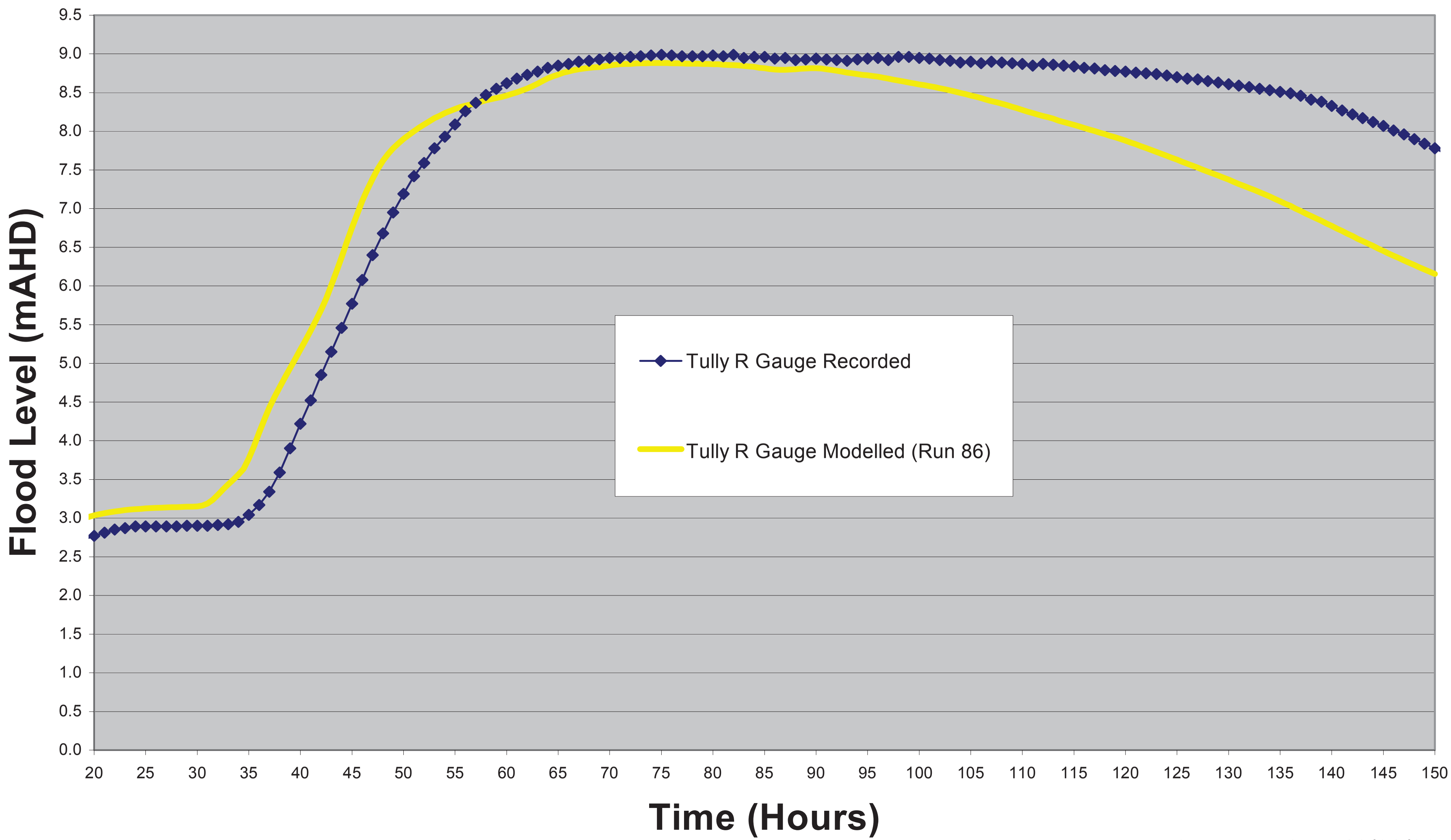


Figure 3-14 March 2006 Flood Model Calibration at Murray Flats



0 hours = 6am 10/02/99

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Figure 3-15 Feburary 1999 Flood Model Calibration at Euramo

4 FLOOD AND STORM SURGE INUNDATION MODELLING

4.1 Flood Modelling of Design Events

4.1.1 Introduction

Chapter 3 described the development of the hydrologic and hydraulic models developed for the Cardwell Inundation Study. The calibration and verification of these models to actual flood events was also discussed. This paper describes the next phase in the study, the development of design floods. The design hydrologic and hydraulic models are described and preliminary flood maps of the design floods are presented.

The terminology used throughout this report to discuss design events is that of Annual Exceedance Probability or AEP. For example, a flood event with a 1% probability (or a chance of 1 in 100) of being exceeded in any one year is referred to as the 1% AEP flood event. This is commonly referred to as the 100 year ARI (Average Recurrence Interval) flood. The term Average Recurrence Interval is deemed to be somewhat misleading as it may imply that the period between 100 year ARI flood events is likely to be 100 years. It is more accurate to use the AEP terminology as it provides a direct reference to the risk / probability of occurrence or exceedance in any year.

To assist in the use of this terminology, the following conversion from AEP to ARI is provided for the events (both flooding and storm surge) considered in this study:

10% AEP	=>	10 year ARI
2% AEP	=>	50 year ARI
1% AEP	=>	100 year ARI
0.5% AEP	=>	200 year ARI
0.01% AEP	=>	10,000 year ARI

4.1.2 Design Rainfall Estimates

In order to simulate design storm events, estimates of design rainfall depths are required. As well, the temporal and spatial variation of these rainfall depths requires estimation.

This study used the CRCFORGE method to calculate these rainfall events. The CRCFORGE method is a regional analytical method for developing point rainfall estimates at rare risk levels (i.e. AEP's much less than 1%) from data records of less than 100 years duration on average. The method is a development of the FORGE method (UK) by the Cooperative Research Centre for Catchment Hydrology.

Applying this approach to the Tully / Murray River catchments and the Kennedy Area catchments resulted in the rainfall totals (averaged over the catchment) as shown in Table 4-1 and Table 4-2. The rainfall depths varied spatially over the catchments with the rainfall depths along the coastline approximately 30 % to 45% higher than those in the higher / western parts of the catchment.

Temporal patterns for these events were derived from Australian Rainfall and Runoff (IEAust, 2000).

Preliminary simulations of the Tully / Murray River 2D/1D flood model was carried out for a range of storm durations for the 1% AEP flood event. These simulations indicated that the 72 hour duration was the critical duration for this catchment. A similar approach was adopted for the Kennedy Area catchments that indicated the 12 hour duration was the critical duration for this catchment.

Table 4-1 Design Rainfall Depths for Tully – Murray Catchment (mm)

Duration	10 % AEP	2% AEP	1% AEP	0.5% AEP
15 min	31	40	45	50
30 min	45	59	66	74
1 hour	64	84	94	105
3 hours	113	151	170	190
6 hours	159	217	245	274
12 hours	226	314	354	395
18 hours	276	384	433	484
24 hours	319	443	500	558
48 hours	476	662	759	864
72 hours	585	813	946	1097
96 hours	657	913	1063	1233
120 hours	708	984	1144	1326

Table 4-2 Design Rainfall Depths for Kennedy Area Catchments (mm)

Duration	10 % AEP	2% AEP	1% AEP	0.5% AEP
15 min	31	42	47	52
30 min	47	62	70	78
1 hour	68	90	101	113
3 hours	117	160	181	202
6 hours	166	229	259	289
12 hours	234	329	371	415
18 hours	284	400	451	504
24 hours	325	458	517	578
48 hours	466	656	751	854
72 hours	538	758	880	1021
96 hours	579	815	949	1104
120 hours	611	859	999	1162

A log-normal probability approach was used to extend the CRCFORGE estimates (available up to the 0.05% probability) to estimate the 0.01% AEP rainfall depths.

As well, an estimate of the Probable Maximum Precipitation (PMP) rainfall was made for the purposes of simulating the Probable Maximum Flood (PMF). The PMF is the largest flood that could reasonably be expected to occur on a catchment. There have been a number of advances in the estimate of extreme floods in the past decade. There now exists a quick method for obtaining PMP estimates derived from the latest edition of Australian Rainfall and Runoff (IEAust, 2000). The estimate uses an empirical equation involving basic catchment parameters (area, latitude, etc) and the 50 year ARI 72 hour rainfall intensity.

The results for the 0.01% AEP rainfall and the PMP for the Tully / Murray River catchments and the Kennedy Area catchments are presented in Table 4-3.

Table 4-3 Extreme Event Design Rainfall Depths (mm)

Duration	Tully – Murray Catchments		Kennedy Area Catchments	
	0.01 % AEP	PMP	0.01 % AEP	PMP
12 hours	700	971		
72 hours			2150	2234

4.1.3 Design Event Hydrological Modelling

The URBS model of the Tully, Murray and other catchments was simulated for the 10%, 2%, 1%, 0.5% and 0.01% AEP rainfall events as well as the PMP. Inflows for the 2D/1D hydraulic model were derived from these simulations.

The hydrological model parameters used in the design flood simulations are presented in Table 4-4.

Table 4-4 Hydrological Modelling Parameters

Parameter	Parameter Description	Tully River Model	Murray River Model	Kennedy/ Meunga Ck Model
β Catchment lag parameter	Represents storage within the sub-catchment. An increase in this parameter will attenuate flows within the catchment routing stage.	2.8	3.4	3.0
m Catchment non-linearity parameter	Power value of the storage-discharge relationship for catchment routing	0.8	0.8	0.8
α Channel lag parameter	Represents storage within the channel. A linear relationship between flow and storage is assumed for channel routing. An increase in α results in an increase in storage and therefore greater attenuation.	0.134	0.3	0.13

An initial loss of 0mm and continuing loss of 2.5 mm/h were used for all hydrologic design runs. These values are conservative and within industry standards for the durations investigated and consistent with the losses used in the calibration events. The value of initial loss would have little bearing on peak flood behaviour for a 72 hour duration event.

4.1.4 Design Event 2D/1D Hydraulic Modelling

The calibrated TUFLOW hydraulic model described in Chapter 3 was modified to include the proposed upgrade of the Bruce Highway. This involved the representation of approximately 60 individual culvert ands bridge structures along the route. As well, the road surface was represented by 3D breaklines. This data was provided by Connell Hatch.

The 2D/1D flood model was then used to simulate the 10%, 2%, 1%, 0.5% and 0.01% AEP flood events as well as the PMF. The Mannings n values listed in Table 3-6 were adopted for the design simulations.

Sensitivity analyses of the assumed downstream water level at the mouth of the rivers and creeks indicated that the flood gradients and levels are relatively insensitive to this assumption. The exception is the area in the immediate vicinity of the river mouths. However, planning levels are likely to be dictated by storm tide considerations rather than flood levels.

The Drawing Addendum contains a full set of maps for these flood events including maps of peak levels, depths, velocities and velocity-depth products for all six flood events (a total of 24 maps - see Drawings 3 to 26 in the A3 Drawing Addendum). All of these data will also be provided to Council as digital GIS data.

4.1.5 Discussion of Design Event Flood Behaviour

It should be noted in this discussion that the behaviour observed is derived from simulation of a ‘design’ flood event of 72 hours for the Tully-Murray area, 18 hours for the Tully township area and 12 hours for the Meunga Creek area. It is recognised that all flood events are different in nature with varying durations, rainfall patterns, antecedent moisture conditions and storm surge conditions.

The results of the flood modelling indicate the following general behaviour:

- As common with most river systems, the Tully and Murray Rivers break their banks with relatively frequent flood events (probably in the order of the 50% AEP flood event although this has not been quantified);
- Even for relatively frequent flood events (e.g. 10% AEP flood event), there is considerable flow from the Tully River system into the Murray River system upstream of the Bruce Highway;
- Peak flood levels at Tully (at the Banyan Creek bridge) are 17.2mAHD for the 1% AEP flood, with the 10% AEP flood level at 16.7mAHD and the PMF flood level at 18.7mAHD;
- Peak flood levels at the Tully River Bruce Highway bridge are 9.9mAHD for the 1% AEP flood, with the 10% AEP flood level at 9.1mAHD and the PMF flood level at 12.1mAHD;
- Peak flood levels at the Murray River Bruce Highway bridge are 9.1mAHD for the 1% AEP flood, with the 10% AEP flood level at 8.6mAHD and the PMF flood level at 11.0mAHD;
- The peak levels in the upper Tully River system occur 30h to 40h into the flood event;
- The peak levels upstream of the Bruce Highway occur 40h to 45h into the flood event;
- The peak levels downstream of the Bruce Highway occur 45h to 55h into the flood event;
- The peak levels near the coast occur 55h to 60h into the flood event;
- Total peak inflows to the Tully River system for the 1% AEP flood event are in the order of 7,000 m^3/s. However, due to cross-flow into the Murray River system and retardation on the floodplain, the peak flow in the Tully River at the Bruce Highway bridge is only 1,600 m^3/s.

4.1.6 Sensitivity Analysis: Assumed Ocean Levels

In order to test the sensitivity of flood behaviour to the assumed water levels in the ocean at the time of a flood event, three simulations were carried out:

- 1% AEP Flood & Mean Spring Tide (peaking at 1.0mAHD)

- 1% AEP Flood & 1% AEP Storm Tide (peaking at 2.88mAHD) with likely timing (i.e. peak at start of flood)
- 1% AEP Flood & 1% AEP Storm Tide (peaking at 2.88mAHD) with worst timing (i.e. peak at peak of flood)

The time-varying boundary conditions for these three flood events are presented graphically in Figure 4-1.

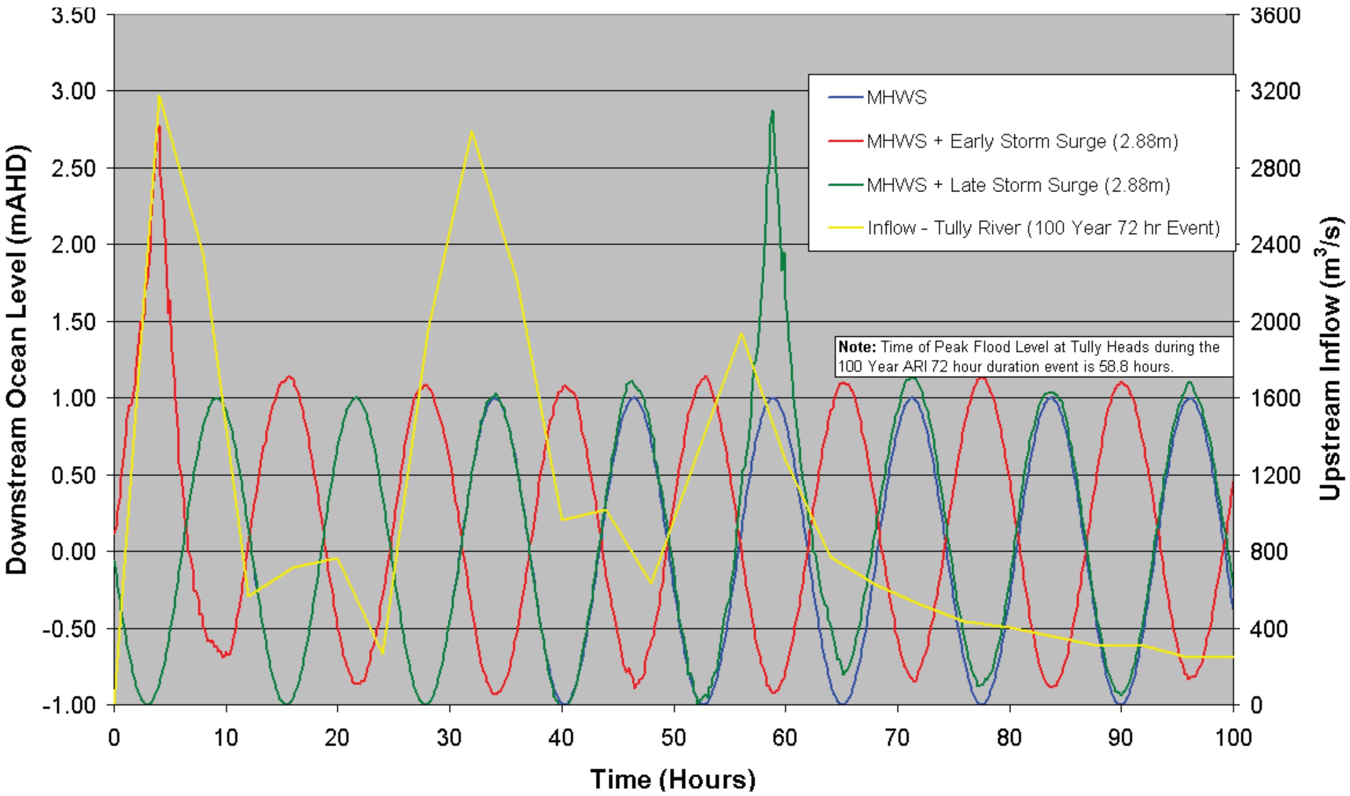

Figure 4-1 Sensitivity Analysis Boundary Conditions

The peak flood levels from these three simulations were compared. The differences are presented in Figure 4-2 and Figure 4-3. Yellow areas depict areas with impacts between 50mm and 100mm, orange areas depict areas with impacts of between 100mm and 150mm, red areas depict areas with impacts of between 150mm and 200mm and purple areas depict areas with impacts greater than 200mmm.

Figure 4-2 Sensitivity Analysis Results for Ocean Levels (Whole Floodplain)

Figure 4-3 Sensitivity Analysis Results for Ocean Levels (Coastal Areas)

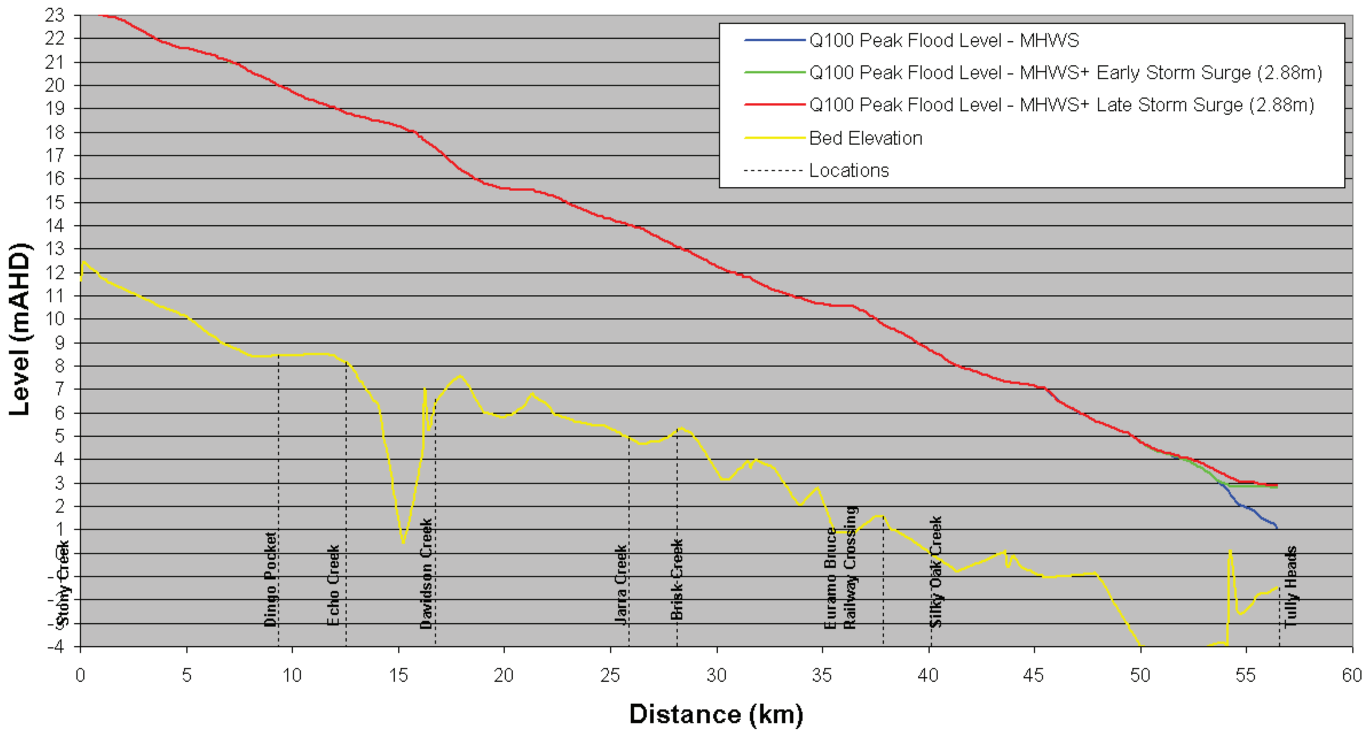

Figure 4-4 Sensitivity Analysis Results (Long Section)

It is apparent from analysing the results presented in these figures that the choice of ocean water level (both in magnitude and timing) has little impact on flood levels upstream of the river mouths.

Hence, it was decided that the six design flood events would be simulated with a constant water level of 0.0mAHD.

4.1.7 Sensitivity Analysis: Mannings n Between Tully and Murray Rivers

During the calibration process, it was identified that the accuracy of the survey data for the critical area between the Tully and Murray River floodplains (upstream of the highway) was poor. Furthermore, it was demonstrated during the calibration stage that too much flow was passing from the Tully floodplain to the Murray River floodplain. Hence, the best calibration was achieved by increasing the Mannings n of this critical area by a factor of 3 (i.e. sugar cane increased from 0.2 to 0.6). This adjustment was made to counteract the effect that ground levels (assumed to be too low) have on allowing too much flow to pass from the Tully floodplain to the Murray River floodplain.

In order to assess the impact of this assumption on peak flood levels, the Mannings n of this critical area was reduced back to 0.2 for the 1% AEP flood event and compared with the design flood levels for the 1% AEP flood event. This comparison is presented in Drawing 27 (see A3 Drawing Addendum).

This comparison indicates that this assumption (i.e. ground levels are too low in the flood model for this area) results in conservative flood levels along the Tully River floodplain (by approximately 400mm to 600mm). For the Murray River floodplain, this assumption results in a possible under-estimation of flood levels by approximately 150mm.

4.2 Storm Surge Modelling of Design Events

4.2.1 Introduction

Chapter 2 described the development of the offshore cyclone windfield, hydrodynamic and wave models for the Cardwell Inundation Study. The calibration and verification of these models to actual tropical cyclone events was also discussed. This chapter describes the next phase in the study, the development of design estimates of tropical cyclone storm surge inundation for the study area. The procedure involved in making these estimates included the following components:

- Derivation of historical cyclone climatology (statistics);
- Simulation of 112 representative cyclone events;
- Development of storm surge and wave parametric models;
- Simulation of 50,000 years of cyclone activity (Monte Carlo simulation);
- Statistical interpretation and mapping of results.

4.2.2 Cyclone Climatology

The purpose of the cyclone climatology analysis is to derive a statistical description of historical tropical cyclone activity of relevance to the study area. The BOM tropical cyclone database was the basis of this analysis. The statistical analysis relies primarily upon data from post 1959 as this is more reliable than pre-1959 data due to the advent of weather radar. An exception to this is the inclusion of the most severe recorded event, the1918 "Innisfail" cyclone (estimated Central Pressure (CP) of 926 hPa), in our statistical population as censored data.

A "Zone Of Influence" (ZOI) extending 350 km north of Tully Heads, 250 km south and 500 km offshore was constructed and any cyclones entering this domain were included in the population analysed. The ZOI is shown in Figure 4-5 along with the 75 cyclones that have crossed the coast since 1959.

Individual North Queensland tropical cyclones can belong to the following classes;

- Cyclones that form in the Coral Sea and then cross the Queensland coast;
- Cyclones that form in the Gulf of Carpentaria and then cross Cape York into the Coral Sea before continuing east or adopting a southerly track parallel to the coast;
- Cyclones that form in the Coral Sea and then track roughly parallel with the Queensland coast or with a more easterly track taking them away from the coast.

The first class poses the highest storm surge risk. For the purposes of the cyclone climatology analysis tropical cyclones have been assumed to belong to two distinct statistical populations;

1. Coral Sea coast crossing cyclones, which account for 40% of the occurrences;
2. Coast parallel cyclones (which have formed in either the Gulf of Carpentaria or the Coral Sea). These account for the remaining 60% of occurrences since 1959/60.

The historical cyclone track data have been analysed in order to characterise the tropical cyclone climatology for the study area. The following characteristics have been evaluated for each TC within the ZOI;

- Minimum distance of track to Tully Heads;
- Average track bearing;
- Average forward velocity;
- Minimum central pressure.

The empirical statistical distributions of the first three of these cyclone parameters are shown in Figure 4-6 to Figure 4-8. The distributions have been evaluated for all post-1959/60 cyclones as well as individually for the coast-crossing and coast-parallel populations.

The primary parameter governing/defining the “severity” of a cyclone is its Central Pressure (CP). Coming up with a distribution to model extreme values of the cyclone central pressure is an important part of the long-term cyclone storm surge simulation. Results of the long-term storm surge risk assessment are expected to be sensitive to the adopted central pressure distribution.

Extreme value analysis is the means of estimating/extrapolating such a distribution. In this study the Generalised Pareto (GP) distribution has been fitted to CPs less than a prescribed threshold. The GP distributions have been fitted to the available data using the method of Maximum Likelihood Estimation. This method has various advantages over alternative fitting techniques in dealing with low outliers and censored data (prior to systematic or reliable recording), (Teakle, 2004).

There exists a physical limitation to how low the central pressure can fall in a particular region. For tropical cyclones in North Queensland, this “Maximum Possible Intensity” (minimum possible central pressure) has been estimated to be 895 hPa (Ocean Hazards Assessment – Stage 1, 2001). Extrapolation of the extreme value distributions to very low probabilities (> 100 year ARI event) can be problematic with limited datasets. In fitting the GP distribution the knowledge of a MPI has been used to stipulate the upper limit of the fitted distributions (effectively removing a degree-of-freedom from the optimisation process). It is believed that this procedure provides the most reliable extrapolation of the available central pressure dataset (47 years of systematic data) to the very low probabilities that will be required for the long-term (50,000 year) cyclone storm surge simulation.

The GP distributions have been fitted to the entire population of post 1959/60 cyclones, as well as to the coast crossing and coast parallel populations. The 1918 “Innisfail” cyclone has been included in the fitting process as censored data (pre-systematic-recording). Table 3-4 lists all of the cyclones used in the extreme value analysis, their central pressures and which sub-population they belong to (coast crossing or coast parallel). Any cyclone with a minimum central pressure of greater than 1000 hPa was discarded from the analysis (and hasn’t been included in Table 3-4).

The fitted GP distributions are shown in Figure 4-9 to Figure 4-11, and a summary of the central pressure AEPs is given in Table 4-6.

Table 4-5 Tropical Cyclones Used in the Climatology Analysis

Season	Name	Central Pressure (hPa)	Population
1917/18		926	Crossing
1959/60		995	Parallel
1960/61		997	Parallel
1960/61		990	Parallel
1963/64	GERTIE	999	Crossing
1964/65	FLORA	996	Parallel
1964/65	JUDY	993	Parallel
1966/67	ELAINE	996	Parallel
1969/70	DAWN	994	Parallel
1970/71	GERTIE	988	Parallel
1971/72	ALTHEA	952	Crossing
1971/72	FAITH	990	Parallel
1972/73	MADGE	998	Crossing
1973/74	UNA	985	Crossing
1973/74	VERA	996	Parallel
1973/74	YVONNE	995	Crossing
1974/75	GLORIA	986	Parallel
1975/76	ALAN	994	Crossing
1975/76	BETH	990	Parallel
1975/76	DAWN	995	Crossing
1975/76	WATOREA	970	Parallel
1976/77	KEITH	992	Crossing
1976/77	LILY	999	Parallel
1976/77	NANCY	998	Crossing
1976/77	OTTO	987	Parallel
1977/78	HAL	994	Parallel
1978/79	PETER	992	Parallel
1978/79	KERRY	993	Parallel
1980/81	EDDIE	992	Crossing
1980/81	FREDA	984	Parallel
1981/82	DOMINIC	998	Crossing
1982/83	DES	999	Parallel
1982/83	ELINOR	988	Parallel
1983/84	GRACE	995	Parallel
1983/84	INGRID	995	Parallel
1984/85	MONICA	997	Parallel
1984/85	ODETTE	998	Parallel
1984/85	PIERRE	986	Parallel
1984/85	TANYA	986	Parallel
1985/86	VERNON	991	Parallel
1985/86	WINIFRED	957	Crossing
1985/86	MANU	974	Crossing
1987/88	CHARLIE	972	Crossing
1988/89	DELILAH	997	Parallel
1988/89	AIVU	935	Crossing
1989/90	FELICITY	993	Parallel
1989/90	IVOR	971	Parallel
1990/91	JOY	940	Crossing
1990/91	KELVIN	980	Parallel
1992/93	NINA	990	Parallel
1995/96	CELESTE	985	Parallel
1995/96	DENNIS	990	Parallel
1996/97	GILLIAN	995	Crossing
1996/97	ITA	994	Crossing
1996/97	JUSTIN	990	Crossing
1997/98	KATRINA	940	Parallel
1997/98	NATHAN	990	Parallel
1998/99	PETE	991	Parallel
1998/99	RONA	970	Crossing
1999/00	STEVE	975	Crossing
1999/00	TESSI	980	Crossing
1999/00	VAUGHAN	975	Parallel
2000/01	ABIGAIL	992	Crossing
2003/04	GRACE	992	Parallel
2004/05	INGRID	940	Crossing
2005/06	LARRY	935	Crossing

Table 4-6 Central Pressure AEPs

AEP (%)	Cyclone central pressure (hPa)		
	All	Crossing	Parallel
10	954	958	978
1	923	922	959
0.5	917	916	955
0.2	911	910	949
0.1	908	906	945
0.01	899	898	927

4.2.3 Parametric Models Derivation

In order to be in a position to undertake the long term (50,000 year) simulation of tropical cyclone activity it was necessary to derive computationally efficient models of the storm surge and wave response along the study area coastline to a given tropical cyclone track. The storm surge and wave parametric models were derived from the simulation results of 112 cyclone tracks using the TUFLOW and SWAN models detailed in Chapter 2.

The coast-crossing population of cyclones was represented by the following combination of parameters;

- Central Pressure: 895, 920, 950, 980 hPa;
- Distance from Tully Heads: -50, -25 0, 25, 50 75 km;
- Bearing: 225, 270 degrees true;
- Forward Velocity: 3, 7 m/s;
- Radius to Maximum Winds: 25 km.

This amounted to 4x6x2x2x1 = 96 simulations of coast crossing tropical cyclones.

The coast-parallel population of cyclones was represented by the following combination of parameters;

- Central Pressure: 920, 940, 960, 980 hPa;
- Distance from Tully Heads: 50, 100 km;
- Bearing: 165 degrees true;
- Forward Velocity; 3, 7 m/s;
- Radius to Maximum Winds: 25 km.

This was a further 4x2x1x2x1 = 16 simulations of coast parallel tropical cyclones.

The TUFLOW and SWAN model results from these 112 cases were stored and processed to derive the storm surge and wave parametric models that were subsequently used in the 50,000 year Monte Carlo simulation. The parametric model derivation from model results followed the procedures outlined in Ocean Hazards Assessment – Stage 1a, 2004.

4.2.4 Astronomic Tide Calculation

Storm tides result from the superposition of tropical cyclone induced storm surge with an underlying astronomic tide. The prediction of astronomic tide for a given tropical cyclone event is therefore an important component of the long-term Monte Carlo simulation.

The astronomic tide component have been calculated using standard tide prediction procedures (Pawlowicz et al. 2002) and tidal harmonic constituents derived by Queensland Transport for the Clump Point and Cardwell storm tide warning gauges. Linear interpolation of the tidal harmonic amplitudes and phases has been used at locations along the study area coastline between these two gauges. The linear interpolation assumption was shown to be reasonable from analysis of the TUFLOW model tide predictions along the study area coastline.

4.2.5 Monte Carlo Simulation

The 50,000 year simulation of tropical cyclone generated storm tides and waves involved the following steps:

1 Random generation of tropical cyclone parameters based upon distributions derived during the cyclone climatology analysis;

2 Calculation of the resulting storm surge and wave time-series response using the derived parametric models;

3 Random generation of the coast crossing date of the tropical cyclone;

4 Prediction of the astronomic tide variation during this period;

5 Superposition of the calculated storm surge and astronomic tide to calculate the resulting storm tide;

6 Calculation of wave setup and runup contributions (see details in Section 4.2.6 below);

These calculations were performed for 93 locations at approximately 500 m centres along the study area coastline.

For each simulated event during the 50,000 year period, parameters such as the peak storm surge, peak wave height and peak storm tide level were extracted and subsequently ranked in order that the corresponding Annual Exceedance Probabilities could be derived. A summary of Storm Surge and Wave Height AEPs are given in Table 4-7 and Table 4-8. Storm Tide AEPs and those including wave setup and runup allowances are summarised in Sections 4.2.7 and 4.2.8 respectively.

A qualitative discussion and interpretation of the results is provided in Section 0.

Table 4-7 Storm Surge AEPs at Major Locations

	Peak Storm Surge (m)					
Location / AEP	**1%**	**0.5%**	**0.2%**	**0.1%**	**0.01%**	**PME**
Port Hinchinbrook	2.13	2.65	3.29	3.73	4.61	6.90
Cardwell	2.32	2.89	3.61	4.07	5.01	7.69
Tully Heads	1.99	2.48	3.06	3.42	4.21	5.73
Hull Heads	2.00	2.50	3.07	3.42	4.19	5.74
South Mission Beach	1.69	2.10	2.61	2.92	3.72	5.38
Wongaling Beach	1.56	1.95	2.42	2.70	3.54	5.04

Table 4-8 Offshore Storm Wave Height AEPs at Major Locations

	Peak Significant Wave Height (m).				
Location / AEP	**1%**	**0.5%**	**0.2%**	**0.1%**	**0.01%**
Port Hinchinbrook	2.33	2.48	2.66	2.77	2.96
Cardwell	2.61	2.74	2.86	2.93	3.06
Tully Heads	3.42	3.52	3.58	3.60	3.66
Hull Heads	3.45	3.56	3.63	3.67	3.74
South Mission Beach	3.03	3.16	3.27	3.36	3.48
Wongaling Beach	3.82	3.95	4.03	4.07	4.14

4.2.6 Wave Setup and Runup Calculation

Wave setup is an elevation of the mean (time-averaged) water surface due to the pumping effect of waves. Wave setup has the potential to cause a small to moderate increase in the water levels in the coastal waterways and floodplains. The wave setup contribution to mean water levels has been estimated as 10% of the offshore wave height (m) i.e. 0.2–0.4 m. The wave setup contribution to the mean water level along the exposed ocean shoreline can be much larger than this, however the wave runup process defines the maximum extent of inundation at such locations.

Wave runup is the intermittent process of advancement and retreat of the instantaneous shoreline on a time-scale that is of the order of the incoming wave period (~10s). Along the exposed ocean shoreline wave runup can be a significant contributor to the peak inundation levels. Furthermore the large quantity of energy contained in individual wave runup or swash events can pose a serious risk to any structures within the wave runup zone.

The wave runup contribution to shoreline water levels has been estimated using an empirical formulation of Stockdon et al (2006). The runup height predicted with this formula is the level above the offshore mean water level that is exceeded by 2% of swash events. This formulation was demonstrated to provide robust estimates of debris levels for both the TC Winifred and TC Larry calibration events.

An important parameter in the wave runup formula is the foreshore beach slope. The upper foredune beach slope has been estimated where sufficiently accurate survey data exists at locations along the study area shoreline. This estimate of beach slope provides an upper-bound (conservative) estimate of beach slope during a storm tide event. For situations where the foredune is overtopped by the combination of storm tide and wave runup, this estimate of the effective beach slope will be too large and the wave runup height will consequently be overestimated. More detailed modelling of the wave runup process would be required to account for the reduced wave runup potential when the foredune is overtopped.

4.2.7 Design Storm Tide Levels

A summary of peak storm tide AEPs at major centres in the study area is provided in Table 4-9. These estimates do not include an allowance for wave setup or runup, nor do they include an allowance for global warming induced sea level rise.

Table 4-9 Peak Storm Tide AEPs at Major Locations

	Peak Storm Tide Level (m AHD)					
Location / AEP	**1%**	**0.5%**	**0.2%**	**0.1%**	**0.01%**	**PME***
Port Hinchinbrook	2.61	3.05	3.77	4.21	5.20	9.09
Cardwell	2.74	3.21	4.02	4.49	5.65	9.86
Tully Heads	2.35	2.83	3.40	3.84	4.86	7.74
Hull Heads	2.35	2.82	3.42	3.86	4.84	7.74
South Mission Beach	2.07	2.45	3.00	3.33	4.22	7.34
Wongaling Beach	1.97	2.31	2.81	3.20	4.29	6.97

* *The PME levels correspond to a maximum possible storm surge (from an 895 hPa cyclone) coinciding with a HAT astronomic tide level. This probability of this event occurring is many times less than the 0.01% AEP.*

4.2.8 Design Storm Tide Levels Including Wave Setup and Runup

Table 4-10 summarises the peak storm tide AEPs including an allowance for wave setup (refer Section 4.2.6). These levels can be assumed to apply at any location not within the zone exposed to wave runup (approximately 150m inland of the shoreline). These levels do not include an allowance for climate change induced sea level rise.

Table 4-10 Peak Inundation Levels (Including Wave Setup) AEPs

	Peak Storm Tide Level including Wave Setup (m).				
Location / AEP	**1%**	**0.5%**	**0.2%**	**0.1%**	**0.01%**
Port Hinchinbrook	2.85	3.30	4.04	4.49	5.49
Cardwell	3.00	3.48	4.31	4.78	5.95
Tully Heads	2.69	3.18	3.76	4.20	5.23
Hull Heads	2.70	3.17	3.79	4.23	5.21
South Mission Beach	2.38	2.76	3.33	3.67	4.57
Wongaling Beach	2.35	2.70	3.22	3.61	4.71

Table 4-11 summarises the peak storm tide AEPs including an allowance for potential wave runup (refer Section 4.2.6). These levels will apply in the zone exposed to wave attack, which has been assumed to extend approximately 150m inland of the HAT shoreline. These levels do not include an allowance for climate change induced sea level rise.

Table 4-11 Peak Inundation Levels (Including Wave Runup Potential) AEPs**

	Peak Storm Tide Level including Wave Runup Potential (m).				
Location / AEP	**1%**	**0.5%**	**0.2%**	**0.1%**	**0.01%**
Port Hinchinbrook	3.67	4.21	4.99	5.44	6.56
Cardwell	5.08	5.70	6.63	7.17	8.48
Tully Heads	5.15	5.76	6.44	6.91	7.97
Hull Heads	3.99	4.57	5.21	5.71	6.73
South Mission Beach	3.80	4.28	4.92	5.34	6.30
Wongaling Beach	3.94	4.41	4.98	5.36	6.59

** *These levels represent the potential height exceeded by 2% of wave runup events. The upper foredune slope is used in the wave runup height calculation. For situations where the frontal dune is overtopped this estimate of the effective slope will produce conservative (upper-bound) estimates of the runup height and peak inundation levels.*

The extent of inundation of the coastal areas and the resulting peak depths expected (based on the levels listed above) are presented for the 5 storm surge events (i.e. 1%, 0.5%, 0.2%, 0.1% and 0.01% events) in Drawings 28 to 37 (see A3 Drawing Addendum). These drawings show both cases of with wave runup and without wave runup.

4.2.9 Discussion

This section provides a qualitative discussion and interpretation of the results from the 50,000 year Monte Carlo simulation.

With reference to Table 4-7 it can be seen that the 1% AEP storm surge height varies from around 1.6 m at the northern end of the study area to around 2.3 m at Cardwell. This is a consequence of the varying offshore bathymetry between the northern and southern extents of the study area. At the northern end the offshore bathymetry has a moderate slope, whereas at the southern end the offshore slope is relatively flat. This relatively shallow extent of water within Rockingham Bay means that the southern end of the study area is more prone to onshore-wind induced storm surge. The funnel shape of the mainland coastline and Hinchinbrook Island also contributes to surge and tide amplification at Cardwell relative to the northern end of the study area.

Storm surge heights at the 0.01% AEP level are seen to be more than double those at the 1% AEP level. The PME estimate of storm surge corresponds to a worst possible situation of an 895 hPa cyclone induced storm surge coincident with a HAT tide level. The probability of this event is many times less than the 0.01% AEP.

With reference to Table 4-8 it can be seen that the 1% AEP offshore storm wave height varies from around 3.8 m at Wongaling Beach to 2.3m at Port Hinchinbrook. The sheltering of South Mission Beach by Dunk Island is reflected in the lower wave climate than at Wongaling and Hull Heads. Wave heights can be seen to only increase marginally for the lower AEP's.

With reference to Table 4-9 the peak storm tide levels (not including wave runup, setup or greenhouse allowances) increase from approximately 2.0 m AHD at Wongaling Beach to 2.7 m AHD at Cardwell. This is a consequence of both the larger tides and larger storm surges that can be experienced at the southern end of the study area. Peak storm tide levels at the lower AEPs are seen to be significantly higher than the 1% AEP, with the 0.01% AEP levels being 2.3–3.0m higher. The PME storm tide levels are much higher again, but represent an absolute worst possible situation of an 895 hPa cyclone induced storm surge coincident with a HAT tide level.

With reference to Table 4-11 there is seen to be a great deal of variability in the storm tide estimates including wave runup potential. This variability arises from the strong shoreface slope dependence of the wave runup process. Locations with receding shorelines such as Cardwell and Tully Heads have significantly steeper foredune slopes (due to the erosion scarp) than locations with stable or accreting shorelines such as Wongaling Beach, South Mission Beach and Hull Heads. A doubling of the foredune slope approximately translates to a doubling of the wave runup potential.

As discussed earlier once the frontal dune is overtopped the peak storm tide levels including wave runup potential reported in Table 4-11 correspond to an upper-bound (conservative) estimate of the inundation.

The uncertainty associated with the estimates derived in this report is believed to come largely from the following two sources. The first source of uncertainty arises from fitting and extrapolating statistical distributions to a limited (50 year) historic dataset. An estimate of the resulting error in storm tide predictions that might occur from this source is beyond the scope of this study. Another source of uncertainty arises from the ability of the numerical models used in this study to represent real tropical cyclones. It is our experience from the model calibration phase that representation of real tropical cyclones with a simple parametric windfield model has its limitations due to real-life windfield complexities, such as strong asymmetries and sub scale features such as meso-vortices. The limitations of the windfield model directly translate into the ability of the hydrodynamic model to predict storm surge heights. An approximate estimate of the rms error in surge predictions that might occur from this source of uncertainty is around $\pm$0.3 m.

4.2.10 Global Warming

An allowance for global warming induced sea level rise has not been included in the above design storm tide levels. The level of future sea level rise that is accommodated in these estimates is 0.3m. This is based on the IPCC 2001 upper bound of the 50-year sea level rise. This increase is consistent with other studies along the Queensland and NSW coastlines and EPA recommendations for shoreline erosion assessments.

A sensitivity analysis was conducted regarding the implications of future changes to cyclone frequency and intensity to the estimates listed above.

The cyclone intensity was increased by 10% such that a 930hPa cyclone was re-assessed as a 923hPa cyclone (i.e. 10% increase in the 70hPa lowering from the normal pressure of 1000hPa). The cyclone frequency was increased by 10% from 1.38 cyclones per year (for the broader study area known as the Zone of Influence) to 1.58 cyclones per year.

The sensitivity analyses indicated that the change in the frequency of cyclones does not substantially increase storm tide levels. The majority of the increase is associated with increased cyclone intensity.

The combined impacts of the increase in cyclone intensity and frequency are presented in Table 4-12 below for a number of critical locations along the coastline. It can be seen from these results that the impact of such increases on cyclone intensity and frequency is in the order of 0.17m to 0.24m for the 1% AEP storm tide levels. This impact increases to approximately 0.50m for the 0.01% AEP storm tide levels. This is a significant increase in levels and is of a similar magnitude to that used for expected sea level rise (i.e. 0.3m).

Table 4-12 Impact of Increased Cyclone Intensity and Frequency on Storm Tide Levels (m)

Location	Increase in Storm Tide (m)				
	1%	0.5%	0.2%	0.1%	0.01%
Cardwell	0.24	0.35	0.23	0.27	0.63
Tully Heads	0.22	0.24	0.33	0.36	0.39
Wongaling Beach	0.17	0.24	0.23	0.20	0.29

4.3 Combined Flood and Storm Surge Modelling

One of the main objectives of this study is to assess the vulnerability of the community to flooding and storm surges. There is a possibility that both of these types of events could occur at or near the same time. This section documents the attempts to quantify the additional risk to the community resulting from combined events of storm surge and flooding.

However, it is important to note in these assessments that the probability of combined storm surge and flooding events is considerably less than the probability of each event (but more probable than the multiplied probabilities). For example, the probability of a 1% AEP flood occurring at the same general time (leaving aside the issue of exact timings) as a 1% AEP storm tide is less than 1%. However, the probability of this event is greater than 0.01% (i.e. the multiplied probabilities) due to the inter-dependence of the two phenomena.

Essentially, there are two possibilities for a combined storm surge and flooding event.

Firstly, a severe tropical cyclone could cross the coast in or just to the north of the study area. This could result in a large storm tide. The cyclone could then move inland and develop into a tropical low (more slow moving) that could result in high intensity rainfall on the catchment. This would result in flooding of the rivers and floodplains. This scenario is, for the purposes of this discussion, termed "Storm Tide Preceding Flood Event".

Secondly, a flood may result in the study area due to high intensity rainfall on the catchment. This event could be followed by a somewhat independent severe tropical cyclone crossing the coast in or just to the north of the study area. This scenario is, for the purposes of this discussion, termed "Flood Preceding Storm Tide Event".

In order to determine the effects of these combinations on inundation behaviour in the study area (specifically the eastern / coastal parts of the study area), two scenarios were assessed in detail:

- ***Flood Preceding Storm Tide Event:*** 1% AEP flood (72h) with a 1% AEP storm surge approximately 12 hours after the peak flood flow at the river mouths;
- ***Storm Tide Preceding Flood Event:*** 1% AEP flood (72h) with a 1% AEP storm surge at the start of the flood.

The results of these two scenarios will be used in the Community Vulnerability Assessment to assess the impacts of combined storm surge and flood events on issues such as:

- Evacuation routes
- Warning times
- Duration of inundation.

4.4 Dune Breach Assessment

A potential threat to low-lying areas with a coastline consisting of dune systems is the development of breaches in the dune system during coastal inundation events. These breaches in the dune system may develop as a consequence of hydrodynamic loading during or directly following storm surge events.

In order to assess the flooding hazard associated with the development of a breach in the dune system within the study area, a Dune Breach Assessment was undertaken.

The Dune Breach Assessment has focussed on the dune systems at the following six communities within the study area:

- Cardwell Township;
- Tully Heads and Hull Heads;
- South Mission Beach;
- Wongaling Beach;
- Tully Township;
- Floodplain areas.

The flooding hazards associated with breaching of the dune system are largely dependent on the significance of flood protection of the dune system and the elevation of land behind the dune. At the six communities considered in the Dune Breach Assessment, the dunes are approximately at the same level as the ground levels behind the dune system. Therefore, the potential for impoundment of water behind the dune is limited and the potential for this to breach the dune system is small.

It is, therefore, concluded that the inundation hazards associated with dune breaching is considered to be low in the study area.

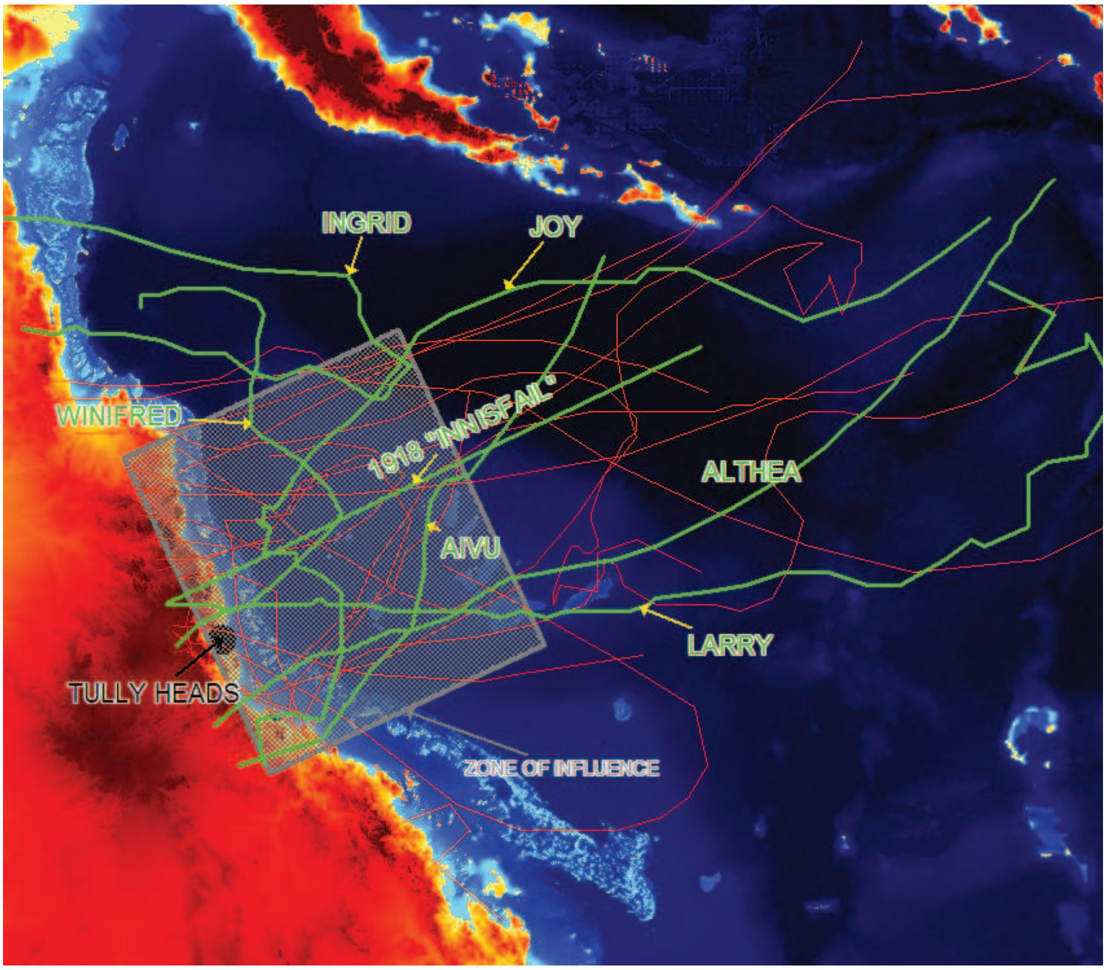

Figure 4-5 Cyclone Climatology Zone of Influence and Coast Crossing Cyclones

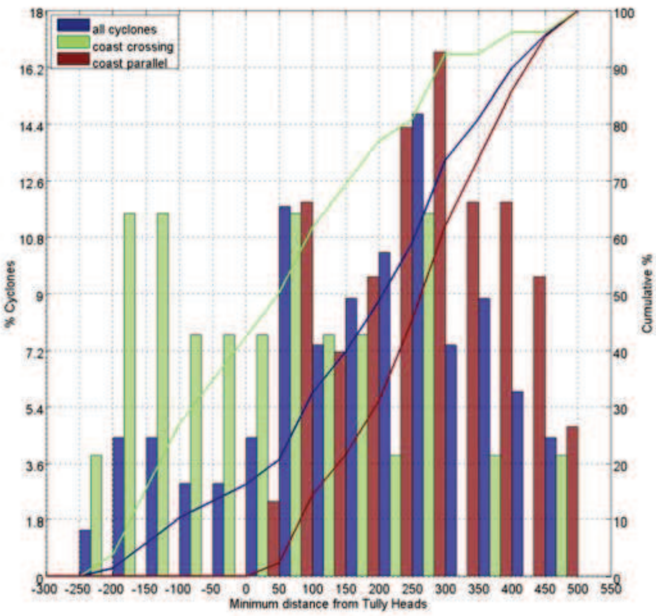

Figure 4-6 Distribution of Post-1959/60 Minimum Track Distance from Tully

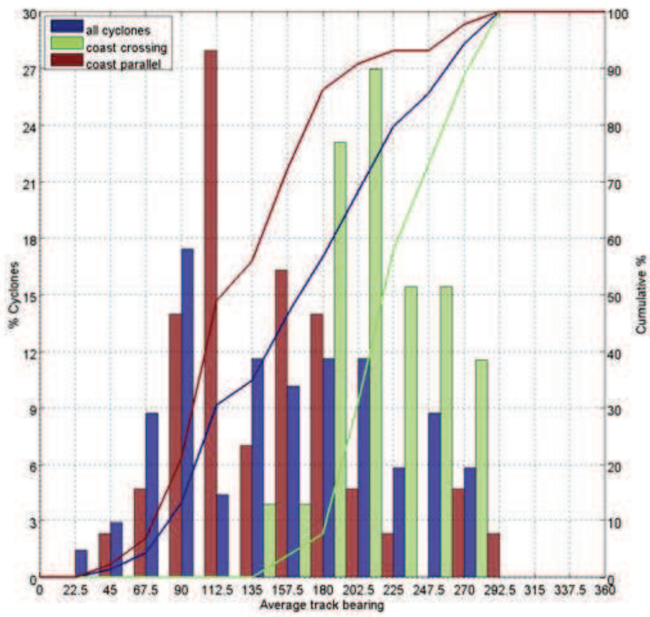

Figure 4-7 Distribution of post-1959/60 Average Track Bearings

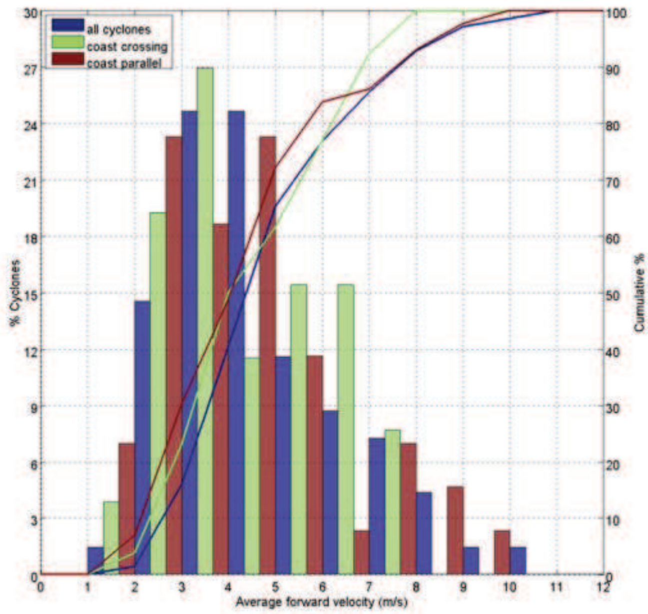

Figure 4-8 Distribution of Post-1959/60 Average Track Forward Velocities

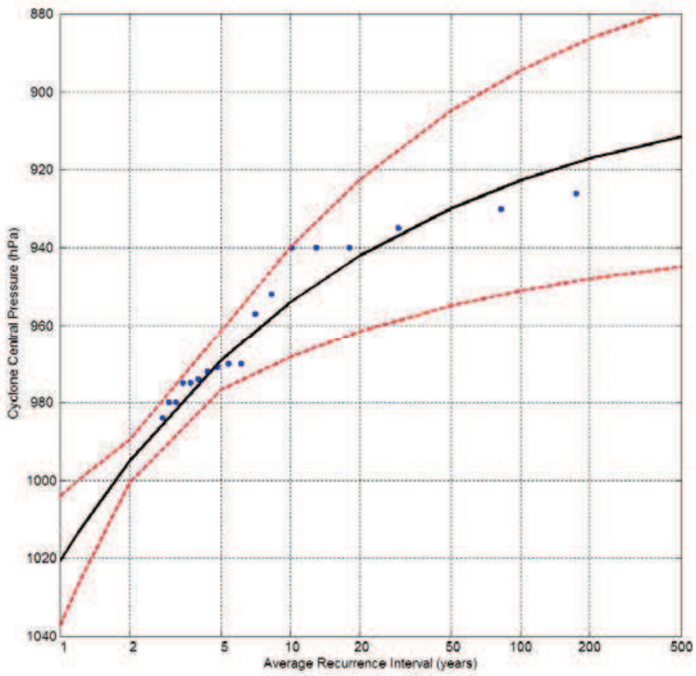

Figure 4-9 GP Distribution Fitted to All ZOI Tropical Cyclone Central Pressures

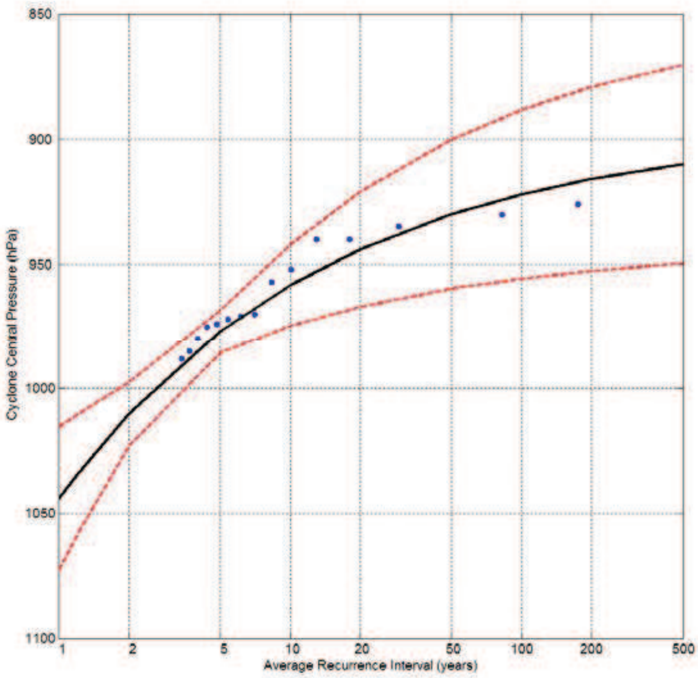

Figure 4-10 GP Distribution Fitted to Coast-Crossing Tropical Cyclone Central Pressures

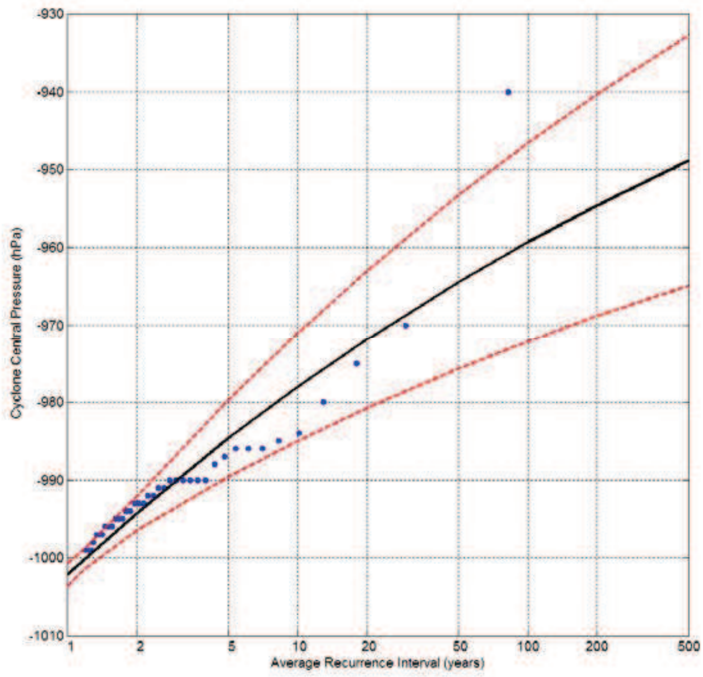

Figure 4-11 GP Distribution Fitted to Coast-Parallel Tropical Cyclone Central Pressures

5 COMMUNITY VULNERABILITY

5.1 Introduction

This chapter describes the vulnerability of the various communities in the study area to the risks of flooding and storm surge inundation. This Community Vulnerability Assessment is based on the results of the flood and storm surge modelling as well as profiles of the various communities.

A good definition of Community Vulnerability, in regard to natural hazards, is provided in Zamecka and Buchanan:

> *"Susceptibility and resilience to hazards determine vulnerability of the community. In other words, vulnerability can be described by a measure of the exposure of a person or group to the effects of hazards and the degree to which that person or group can anticipate, cope, resist and recover from the impact of the hazards. Vulnerability is dependant upon the capacity of physical, social, economic and political structures to resist hazardous events."*

5.2 Approach to Community Vulnerability Assessment

5.2.1 Scope of Community Vulnerability Assessment

In the context described above, this Community Vulnerability Assessment has focussed on the following six communities:

- Cardwell Township
- Tully Heads and Hull Heads
- South Mission Beach
- Wongaling Beach
- Tully Township
- Floodplain areas

Further, this Community Vulnerability Assessment has focussed only on the effects of flooding and storm surge inundation. It does not consider the effects of wind damage from cyclonic events. The analysis and quantification of the effects of flooding and storm surge inundation relied heavily upon an assessment of damages accruing from such events.

5.2.2 Sources of Data

In order to gain an understanding of the essential demographics of the communities and risk elements, various sources of data were reviewed. These included Cardwell Shire Socio Economic Profile (CSIRO, 2006) and other data provided by Council (e.g. GIS layers of essential infrastructure).

However, the most valuable source of data was the Australian Bureau of Statistics (ABS). Much of the data used was either sourced from the ABS web-site (e.g. summaries of the 2001 census) or sourced directly from the ABS. While the 2006 census was held before this Community Vulnerability

Assessment was carried out, the data was only available in short summary form at the time of analysis. Hence, the more complete data from the 2001 census was used.

A number of other sources of data were pursued (e.g. Office of Economic and Statistical Research). However, they indicated that nearly all of the raw data is also sourced from the ABS.

5.3 Damages Assessment

5.3.1 Types of Damages Assessments

To assist in the Community Vulnerability Assessment, damages from flood and coastal inundation need to be quantified. These damages establish the socio-economic costs to society and assist in determining the relative vulnerabilities of the communities. They can also be used to help quantify the benefits of certain mitigation measures.

Flood damages are classified as tangible or intangible, reflecting the ability to assign monetary values. Intangible damages arise from adverse social and environmental effects caused by flooding, including factors such as loss of life and limb, stress and anxiety. Tangible damages are monetary losses directly attributable to flooding. They may occur as direct or indirect flood damages. Direct flood damages result from the actions of floodwaters, inundation and flow, on property and structures. Indirect damages arise from the disruptions to physical and economic activities caused by flooding. Examples are the loss of sales, reduced productivity and the cost of alternative travel if road and rail links are broken.

For the purposes of this assessment, flood damages are classified into the following categories:

- Tangible:
  - Rural Damages;
  - Urban Damages (residential, commercial and industrial); and
  - Infrastructure Damages.
- Intangible Damages.

The flood damages assessment drew upon:

- The flood modelling results;
- Ground level data of the study area;
- Aerial photography to ascertain land use;
- Damages assessments completed for other flood studies.

The elements and their interaction is presented in Figure 5-1.

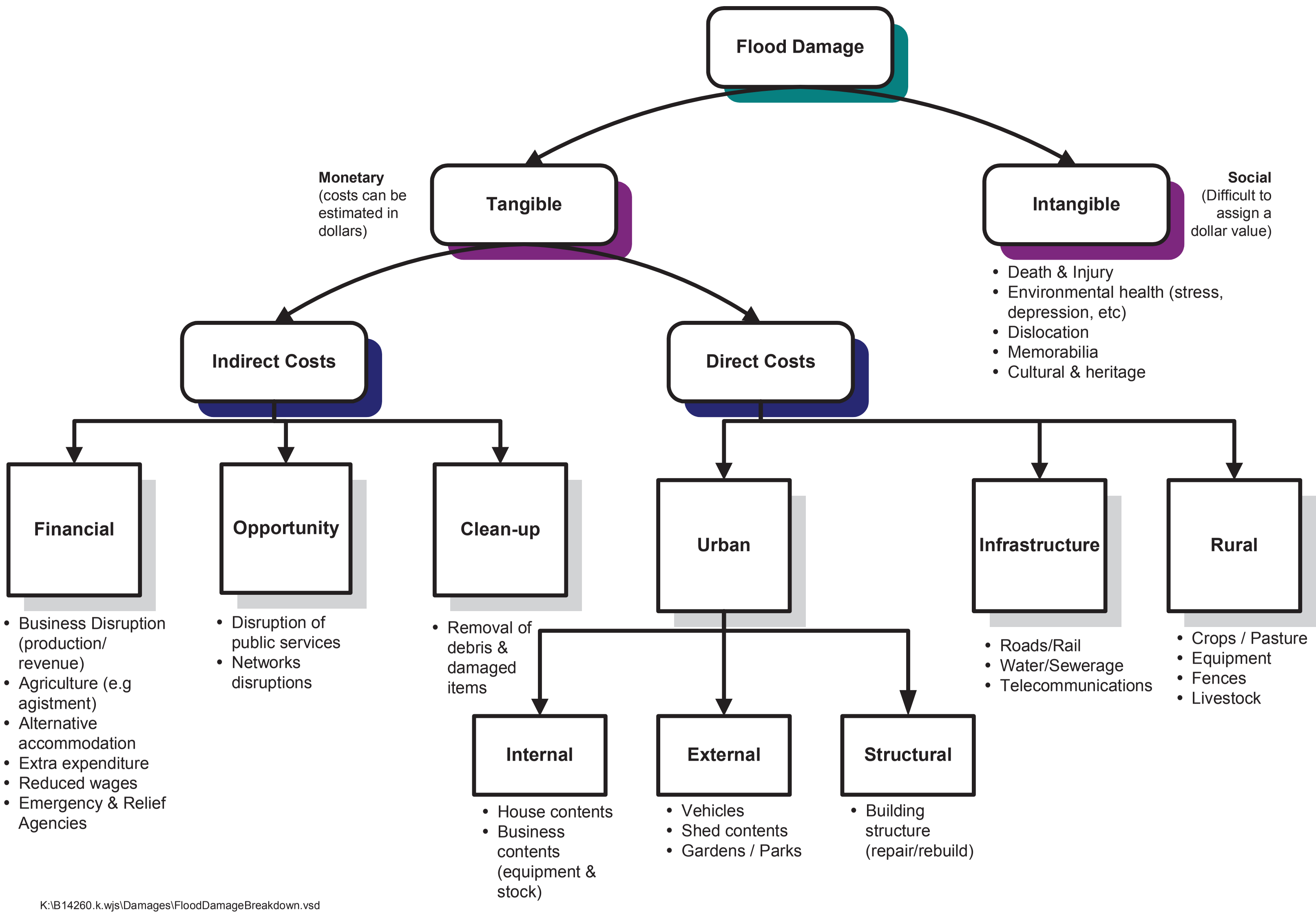

Figure 5-1 Elements of Flood Damages Assessment

5.3.2 Approach to Inundation Damages Assessment

It has been assumed that the majority of inundation damages in the study area would occur in the townships. Due to a lack of data, this analysis does not include damage to residential properties outside of these townships.

The damage to urban areas is principally to property and can be categorised into residential, commercial / industrial sectors. However, as there is not a database of floor levels, structure types (eg house or commercial) or structure values, this assessment is limited to an assumption that all structures identified on aerial photos are houses.

The derivation of urban damages has utilised stage-damage relationships developed by the Centre for Resource and Environmental Studies (Australian National University), 1992, ANUFLOOD.

The procedure for these calculations is provided below:

- Determine the damages due to a particular flood/coastal event using the assumed floor levels of dwellings that are potentially inundation-affected.
- Calculate the depth of inundation within each dwelling for each ARI event.
- Prepare stage-damage relationships for residential properties. These relationships will account for such factors as the relative degree of flood preparedness of the community ("stage" is another way of referring to depth).
- Produce total inundation damages for a range of flood events for residential properties.
- Sum damages for all dwellings for each ARI event and present the results in a probability-damage graph.
- Calculate the average annual damages using the area under the graph.

Floor Levels

In order to accurately determine damages due to flooding, it is necessary to determine at what level floodwaters are able to enter buildings. An accurate floor level survey is usually used for this purpose. However, this study has used a more approximate approach and has assumed that all houses have floor levels equal to the level derived from the Digital Terrain Model (DTM). While this approach is not completely accurate, it allows a relative assessment of the damages at each town as the same methodology is used for all areas.

A GIS layer was created that identified each habitable property, including ground level for each house. Over 2,700 houses were identified from aerial photography.

Floor levels (based on ground levels from the Digital Terrain Model) were used in conjunction with the predicted flood levels for each ARI event to determine whether floodwaters enter the building and, if so, to what depth.

Flood Inundation Stage-Damage Relationship

Stage-damage relationships (or “curves”) are used to determine the flood damage sustained by a particular property based on the depth of flooding. For example, if floodwaters entered a house to a depth of say 1m, the stage-damage curves would be used to determine the average damage in dollars that water of depth 1m would cause.

As explained in Section 5.3.1, total damages consist of direct and indirect costs. Direct damages include damage to the actual building and damage to contents (such as carpets and televisions in the case of a residential property or stock in the case of a commercial property). Indirect costs include loss of business due to time for floodwaters to subside and for cleaning up to be completed. In this investigation, total damages have been used. However, as discussed above, due to a lack of data, there was no assessment of commercial properties and, hence, no assessment of lost business costs.

Stage-damage curves are critical in the calculation of damages and benefit-cost ratios. The derivation of these curves is a complex and time-consuming process. It requires surveys to be undertaken of houses, businesses and contents in the region to determine the relationship between depth of flooding and potential damage. Surveys of this type allow the development of potential stage-damage curves. Potential curves represent the maximum damage that would occur if there were no actions by residents to move material items out of reach of floodwaters. As residents usually do take some action in times of flood, actual damages are usually less than potential damages. The amount by which actual damages are less than potential is a function of warning time, flood preparedness and depth of flooding. For example, with no warning time a resident would be unable to move many belongings to a higher area but the number of belongings moved to a safe position would increase with the increase in warning time. Alternatively, a resident may be unprepared for flooding. They may expect to be affected by a flood and so may not move any belongings regardless of warning time as they do not realise that they are threatened.

Stage-damage relationships for this study were adopted from curves presented in ‘Guidance on the Assessment of Tangible Flood Damages’ (NRM, 2002) based on ANUFLOOD.

ANUFLOOD residential stage-damage curves do not account for damages below floor level. Damages sustained to gardens, garden equipment and storages below floor level are assumed to increase linearly from zero at ground level to $1000 at floor level. EM (1999) also used this assumption for the Lismore Levee Investigations. It was assumed that all houses were of medium size. The ANUFLOOD stage damage relationship used is shown in Table 5-1.

Table 5-1 Stage-Damage Relationship for Medium Residential Properties (CPI factored from ANUFLOOD, 1992)

Depth over Floor Level	Medium House ($2007)
0 m	$ 5,402
0.1 m	$ 10,807
0.6 m	$ 29,535
1.5 m	$ 39,266
1.8 m	$ 39,864

Coastal Inundation Stage-Damage Relationship

Stage-damage relationships for coastal inundation are more complex due to the uncertainty in the type of inundation that could occur during a storm surge event. Flood inundation of houses / buildings is usually characterised by slow rising floodwaters with low velocities. The principal mechanisms for damage is the actual inundation / wetting of the structure and contents.

Inundation of houses / buildings during storm surge events is generally characterised by inundation of waves with high velocities and considerable energy. This can lead to significant damage to properties if sustained over a period of time. While there is little in the way of statistics and reliable estimates on this issue, an estimate of damages resulting from storm surge inundation is required for this study.

In order to derive damage estimates that are both conservative and consistent across the study area, it was decided that any house identified to be inundated by storm surge was assumed to be largely destroyed. An estimate of damage to the structure and contents of $ 250,000 was used in the absence of any other reliable figures.

5.3.3 Flood Inundation Damages Assessment

The peak depth of flooding was determined at each dwelling for the 10, 50, 100, 200 and 10,000 year ARI and PMF event and the associated cost extracted from the stage-damage relationships. Total damages for each flood event were determined by summing the predicted damages for each individual dwelling. If floodwaters did not enter a particular dwelling but inundated a portion of the property, damages to the grounds of the property was assumed to increase linearly from zero at ground level to $1,000 at floor level as for residential properties.

The numbers of properties inundated were calculated for four township areas. There were no properties found to be inundated from regional Tully / Murray River flooding at Wongaling Beach. The Average annual damages were determined by calculating the area under the curve plotted from these values. A summary of the numbers of properties inundated and the accruing damages for the four township areas are presented in Table 5-2 to Table 5-5.

Table 5-2 Tully Township – Flood Damages Summary

ARI (years)	AEP	Number Prop.	Damage	Average Damage / Property	External Damage	Structural Damage	Infrastructure Damage	Total Damages
PMF	0.00%	156	$5,505,374	$35,291	$1,212,432	$960,000	$1,043,957	$8,721,763
10000y	0.01%	143	$5,125,168	$35,840	$1,111,396	$880,000	$967,210	$8,083,773
200y	0.50%	85	$2,598,392	$30,569	$660,620	$40,000	$444,014	$3,743,026
100y	1.00%	78	$2,249,252	$28,837	$606,216	$ 0	$384,313	$3,239,781
50y	2.00%	70	$1,894,248	$27,061	$544,040	$ 0	$328,682	$2,766,969
10y	10.00%	42	$1,118,336	$26,627	$326,424	$ 0	$194,834	$1,639,594

Table 5-3 Cardwell Township – Flood Damages Summary

ARI (years)	AEP	Number Prop.	Damage	Average Damage / Property	External Damage	Structural Damage	Infrastructure Damage	Total Damages
PMF	0.00%	106	$3,010,142	$28,398	$823,832	$140,000	$537,202	$4,511,177
10000y	0.01%	89	$2,405,645	$27,030	$691,708	$100,000	$432,536	$3,629,889
200y	0.50%	75	$1,573,282	$20,977	$582,900	$ 0	$292,646	$2,448,828
100y	1.00%	64	$1,305,777	$20,403	$497,408	$ 0	$244,930	$2,048,114
50y	2.00%	57	$1,118,329	$19,620	$443,004	$ 0	$212,320	$1,773,653
10y	10.00%	45	$863,086	$19,180	$349,740	$ 0	$165,037	$1,377,864

Table 5-4 Tully Heads / Hull Heads – Flood Damages Summary

ARI (years)	AEP	Number Prop.	Damage	Average Damage / Property	External Damage	Structural Damage	Infrastructure Damage	Total Damages
PMF	0.00%	151	$3,144,606	$20,825	$1,173,572	$120,000	$604,202	$5,042,379
10000y	0.01%	136	$2,779,631	$20,438	$1,056,992	$80,000	$533,109	$4,449,732
200y	0.50%	7	$151,860	$21,694	$54,404	$ 0	$27,968	$234,232
100y	1.00%	3	$89,934	$29,978	$23,316	$ 0	$15,228	$128,478
50y	2.00%	3	$75,727	$25,242	$23,316	$ 0	$13,375	$112,417
10y	10.00%	2	$15,934	$7,967	$15,544	$ 0	$4,410	$35,888

Table 5-5 South Mission Beach – Flood Damages Summary

ARI (years)	AEP	Number Prop.	Damage	Average Damage / Property	External Damage	Structural Damage	Infrastructure Damage	Total Damages
PMF	0.00%	5	$197,586	$39,517	$38,860	$60,000	$40,601	$337,047
10000y	0.01%	5	$196,318	$39,264	$38,860	$60,000	$40,436	$335,613
200y	0.50%	5	$139,049	$27,810	$38,860	$ 0	$23,966	$201,875
100y	1.00%	3	$67,645	$22,548	$23,316	$ 0	$12,321	$103,281
50y	2.00%	2	$52,939	$26,470	$15,544	$ 0	$9,237	$77,720
10y	10.00%	0	$ 0	-	$ 0	$ 0	$ 0	$ 0

A summary of the Average Annual Flood Damages for each of the four townships is provided below:

- Tully Township $ 250,000
- South Mission $ 6,000
- Tully Heads / Hull Head s $ 20,000
- Cardwell Town $ 170,000
- ***TOTAL*** ***$ 446,000***

As seen from this summary, the majority of the flood damages for the shire occur in Tully and Cardwell. The following should be noted in consideration of these damages estimates.

- The Average Annual Damages for Cardwell town are probably over-estimated as they are influenced by inundation of properties along One Mile Creek. The flood model resolution is too large (40m grid) to accurately represent the hydraulic features of this creek. Hence, it is expected that a more detailed flood assessment of One Mile Creek would yield lower flood levels and less damages.
- As discussed above, this assessment does not include damages to commercial / industrial properties. The magnitude of indirect damages to commercial properties due to loss trade can be a substantial part of flood damages. Hence, it is assumed that the damages presented above are an under-estimate of the actual damages.

5.3.4 Coastal Inundation Damages Assessment

As described above, the coastal damages assessment was limited to an assessment of the number of properties expected to be inundated due to storm surge events and then multiplying that total by $250,000 per house. The resulting damages using this approach are presented for the four coastal townships in Table 5-6 to Table 5-9.

Table 5-6 Cardwell Town – Storm Surge Damages Summary

ARI (years)	AEP	Number of Inundated Properties	Total Damages
100y	1.00%	68	$17,000,000
200y	0.50%	133	$33,250,000
500y	0.20%	257	$64,250,000
1,000y	0.1%	325	$81,250,000
2,000y	0.05%	410	$102,500,000
5,000y	0.02%	509	$127,250,000
10,000y	0.01%	534	$133,500,000
PME	0.00%	577	$144,250,000

Table 5-7 Tully Heads / Hull Heads – Storm Surge Damages Summary

ARI (years)	AEP	Number of Inundated Properties	Total Damages
100y	1.00%	108	$27,000,000
200y	0.50%	122	$30,500,000
500y	0.20%	152	$38,000,000
1,000y	0.1%	180	$45,000,000
2,000y	0.05%	205	$51,250,000
5,000y	0.02%	230	$57,500,000
10,000y	0.01%	235	$58,750,000
PME	0.00%	244	$61,000,000

Table 5-8 South Mission Beach – Storm Surge Damages Summary

ARI (years)	AEP	Number of Inundated Properties	Total Damages
100y	1.00%	8	$2,000,000
200y	0.50%	27	$6,750,000
500y	0.20%	89	$22,250,000
1,000y	0.1%	121	$30,250,000
2,000y	0.05%	147	$36,750,000
5,000y	0.02%	157	$39,250,000
10,000y	0.01%	160	$40,000,000
PME	0.00%	191	$47,750,000

Table 5-9 Wongaling Beach – Storm Surge Damages Summary

ARI (years)	AEP	Number of Inundated Properties	Total Damages
100y	1.00%	77	$19,250,000
200y	0.50%	103	$25,750,000
500y	0.20%	133	$33,250,000
1,000y	0.1%	181	$45,250,000
2,000y	0.05%	228	$57,000,000
5,000y	0.02%	245	$61,250,000
10,000y	0.01%	260	$65,000,000
PME	0.00%	337	$84,250,000

A summary of the Average Annual Coastal Damages for each of the four townships is provided below:

- Cardwell Town $ 540,000
- Tully Heads / Hull Heads $ 475,000
- South Mission $ 135,000
- Wongaling Beach $ 490,000
- ***TOTAL*** ***$1,640,000***

The following should be noted in consideration of these damages estimates:

- This total average annual damage from coastal inundation for the shire is about four times that expected from flood damages;
- The accuracy of the total damages is not high due to the lack of an accurate stage-damages curve. Furthermore, the inundation levels are those derived from a conservative extrapolation of the wave-runup over the coastal dune system.

5.3.5 Intangible Damages

There are a number of intangible costs of flood and coastal inundation to the community including the following:

- Loss of life and limb;

- Preparedness (cost of flood warning, planning, community education);
- Inconvenience;
- Isolation/evacuation;
- Stress and anxiety;
- Disruption; and
- Health issues.

These intangible damages are not easily quantifiable and have not been included in the monetary assessment of flood damages.

5.4 Inundation of Emergency Services

An assessment of the potential for inundation of Emergency Services (e.g. Police or Fire Stations) was made based on GIS data provided by Council. The floor levels of the Emergency Services buildings were based on an interrogation of the Digital Terrain Model.

The depths of over floor flooding / coastal inundation were assessed for the complete range of flood / storm surge events. The figures below provide a summary of this assessment for the three areas identified with Emergency Services.

The results of this assessment were then used in the overall vulnerability assessment of each area.

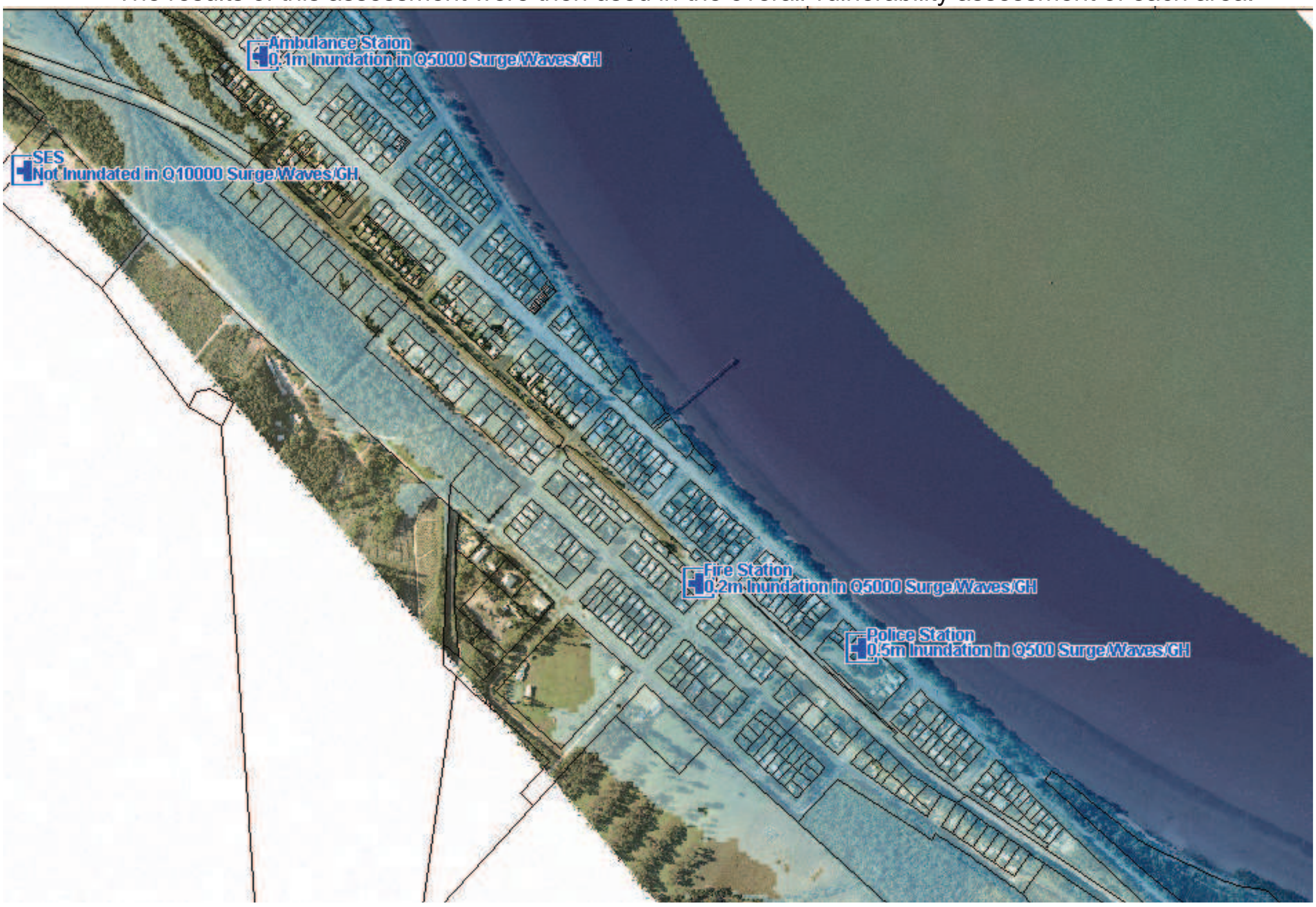

Figure 5-2 Inundation of Emergency Services: Cardwell

Figure 5-3 Inundation of Emergency Services: Wongaling Beach

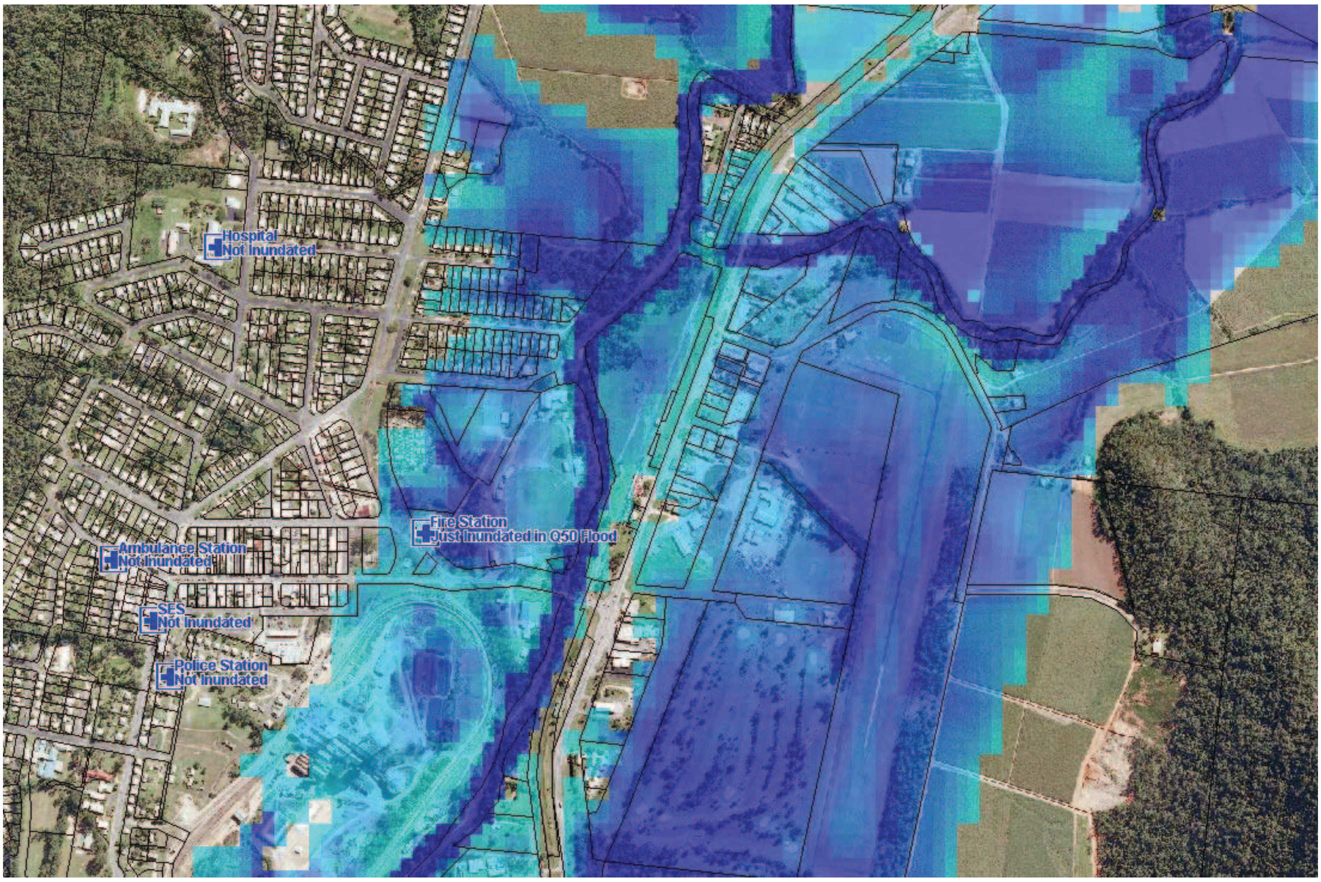

Figure 5-4 Inundation of Emergency Services: Tully

5.5 Inundation of Evacuation Centres

An assessment of the potential for inundation of evacuation centres was made based on GIS data provided by Council. The floor levels of the evacuation centres were based on an interrogation of the Digital Terrain Model.

The depths of over floor flooding / coastal inundation were assessed for the complete range of flood / storm surge events. The figures below provide a summary of this assessment for the four areas identified with evacuation centres.

The results of this assessment were then used in the overall vulnerability assessment of each area.

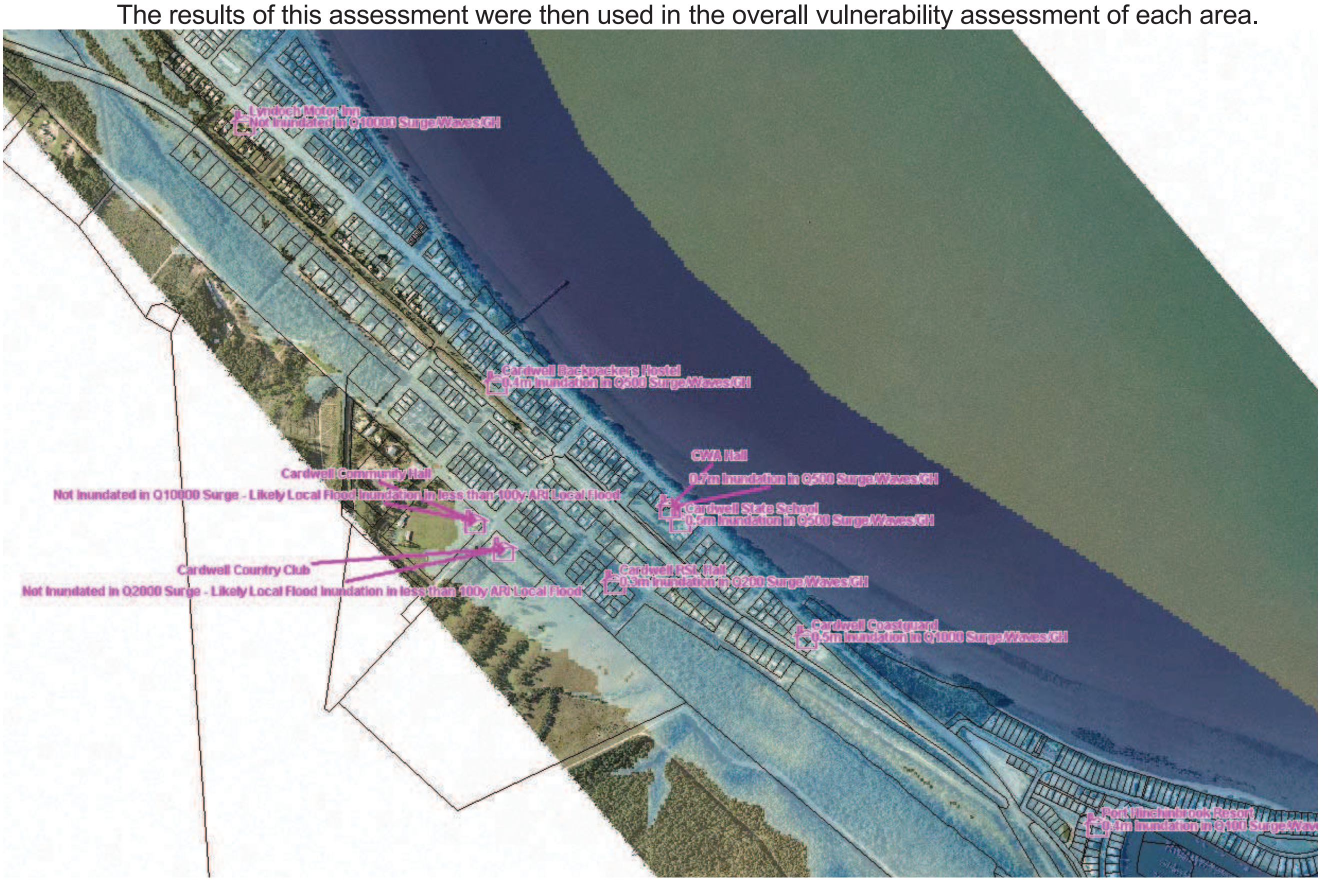

Figure 5-5 Inundation of Evacuation Centres: Cardwell

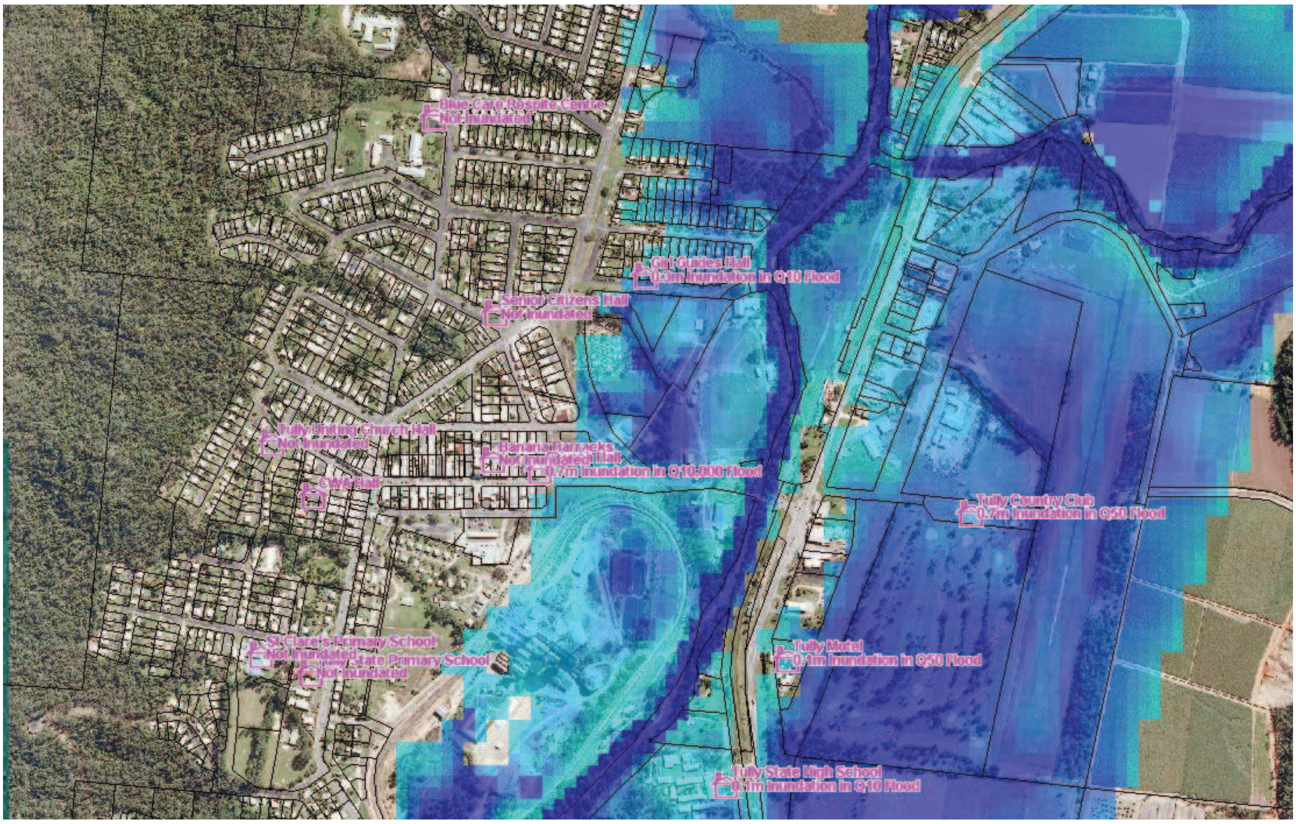

Figure 5-6 Inundation of Evacuation Centres: Tully

Figure 5-7 Inundation of Evacuation Centres: Wongaling Beach

Figure 5-8 Inundation of Evacuation Centres: South Mission Beach

5.6 Inundation of Critical Infrastructure

An assessment of the potential for inundation of critical infrastructure (e.g. sewerage pump stations) was made based on GIS data provided by Council. The floor levels of the critical infrastructure were based on an interrogation of the Digital Terrain Model.

The depths of over floor flooding / coastal inundation were assessed for the complete range of flood / storm surge events. The figures below provide a summary of this assessment for the three areas identified with critical infrastructure.

The results of this assessment were then used in the overall vulnerability assessment of each area.

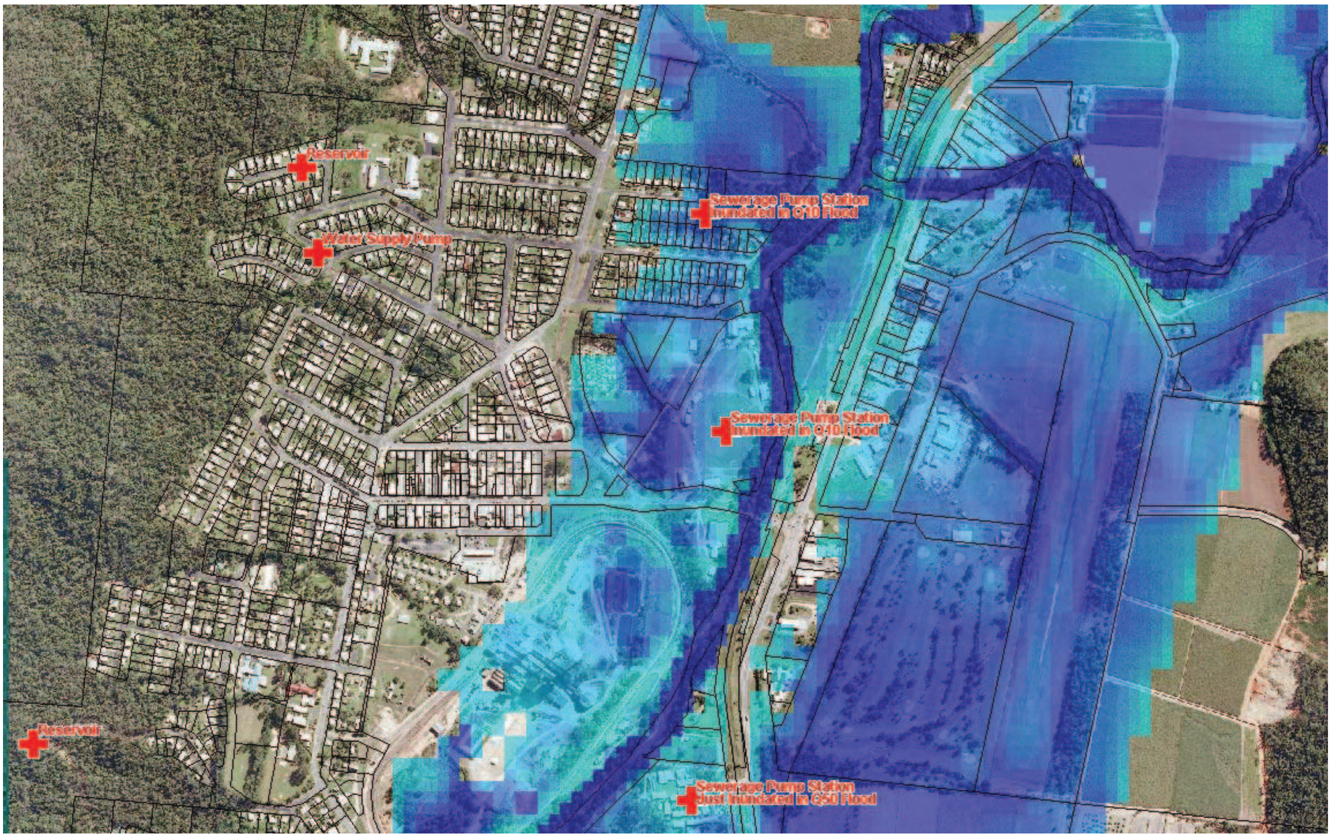

Figure 5-9 Inundation of Critical Infrastructure: Tully

Figure 5-10 Inundation of Critical Infrastructure: South Mission Beach

Figure 5-11 Inundation of Critical Infrastructure: Wongaling Beach

5.7 Community Vulnerability Assessment: Townships

5.7.1 Overview

The Community Vulnerability Assessment relied upon the following factors:

- Estimates of average annual flood and coastal inundation damages (see above);
- ABS data on the profile of the communities
- Risks of inundation of critical infrastructure, essential services and evacuation centres.

A fully quantitative analysis was not possible due to the intangible nature of some of these elements.

5.7.2 Cardwell Township

Age of Community: The ABS data has indicated that 27% of the Cardwell population is aged over 65 years. This is a relatively high percentage and, hence, implies that there is a high proportion of the community that is highly vulnerable in responding to the requirements of evacuation and recovery.

Structural Integrity of Housing: This assessment has not included an assessment of the structural integrity of houses in the area. Rather, it focuses on the percentage of the population living in what could be determined as structures that are vulnerable in a cyclonic event. The ABS data has indicated that 27% of the Cardwell population lived (at the time of the 2001 census) in caravans or tents. This is a relatively high proportion and indicates that a significant part of the community would need assistance in accommodation following a storm surge inundation event.

Mobility of Community: The ABS data has indicated that 16% of the Cardwell population does not have access to a car or motorbike. This is a relatively high proportion and indicates a section of the community is vulnerable to responding to evacuations.

Income of Community: The ABS data has indicated that 44% of the Cardwell population has a combined household income of less than $ 25,000. This would indicate that a significant proportion of the population would be somewhat limited in their preparation (e.g. excess income for stored food) and could also be vulnerable in the recovery stage of an event.

Experience of Previous Flood / Cyclone Events: The ABS data has indicated that 35% of the Cardwell population has moved to Cardwell from outside of North Queensland in the last five years. This would indicate that a significant proportion of the population would not have experienced a cyclone or flood event. Hence, the ability of this proportion of the community to effectively respond to warnings may be hampered by a lack of experience or an understanding of the consequences.

Summary: The following is a summary of the Vulnerability Assessment for the Cardwell township.

- 27% Population > 65 years old = High
- 27% Caravan / Tent Dwellings = High
- 16% with no vehicle = High
- 44% Household Income < $ 25,000 = High
- 35% Moved from non FNQ (in 5y) = High
- Inundation Risk: Evacuation Centres = Moderate
- Inundation Risk: Crit. Infrastructure = None / Low
- Inundation Risk: Emergency Services = Low
- ***Summary: Highly Vulnerable Community***

5.7.3 Tully Heads and Hull Heads

Age of Community: The ABS data has indicated that 20% of the Tully Heads and Hull Heads population is aged over 65 years. This is a relatively high percentage and, hence, implies that there is a moderate to high proportion of the community that is highly vulnerable in responding to the requirements of evacuation and recovery.

Structural Integrity of Housing: This assessment has not included an assessment of the structural integrity of houses in the area. Rather, it focuses on the percentage of the population living in what could be determined as structures that are vulnerable in a cyclonic event. The ABS data has indicated that 26% of the Tully Heads and Hull Heads population lived (at the time of the 2001 census) in caravans or tents. This is a relatively high proportion and indicates that a significant part of the community would need assistance in accommodation following a storm surge inundation event.

Mobility of Community: The ABS data has indicated that 9% of the Tully Heads and Hull Heads population does not have access to a car or motorbike. This is not a high proportion and indicates a small section of the community is vulnerable to responding to evacuations.

Income of Community: The ABS data has indicated that 45% of the Tully Heads and Hull Heads population has a combined household income of less than $ 25,000. This would indicate that a significant proportion of the population would be somewhat limited in their preparation (e.g. excess income for stored food) and could also be vulnerable in the recovery stage of an event.

Experience of Previous Flood / Cyclone Events: The ABS data has indicated that 37% of the population has moved to Tully Heads and Hull Heads from outside of North Queensland in the last five years. This would indicate that a significant proportion of the population would not have experienced a cyclone or flood event. Hence, the ability of this proportion of the community to effectively respond to warnings may be hampered by a lack of experience or an understanding of the consequences.

Summary: The following is a summary of the Vulnerability Assessment for the Tully Heads and Hull Heads townships.

- 20% Population > 65 years old = Mod/High
- 26% Caravan / Tent Dwellings = High
- 9% with no vehicle = Moderate
- 45% Household Income < $ 25,000 = High
- 37% Moved from non FNQ (in 5y) = High
- Inundation Risk : Evacuation Centres = Moderate
- Inundation Risk : Crit. Infrastructure = None / Low
- Inundation Risk : Emergency Services = None / High
- ***Summary: Highly Vulnerable Community***

5.7.4 South Mission Beach

Age of Community: The ABS data has indicated that 17% of the South Mission Beach population is aged over 65 years. This is a moderate percentage and, hence, implies that there is a moderate proportion of the community that is highly vulnerable in responding to the requirements of evacuation and recovery.

Structural Integrity of Housing: This assessment has not included an assessment of the structural integrity of houses in the area. Rather, it focuses on the percentage of the population living in what could be determined as structures that are vulnerable in a cyclonic event. The ABS data has indicated that 48% of the South Mission Beach population lived (at the time of the 2001 census) in caravans or tents. This is a very high proportion and indicates that a significant part of the community would need assistance in accommodation following a storm surge inundation event. However, it is assumed that the census data for this area is somewhat over-estimating this proportion, as it is likely to be based on the available tent and caravan sites in the area. High tourist season does not overlap with the cyclone season to any great degree. Hence, it is likely that the proportion of the population in caravans or tents during a cyclone event would be significantly less than the stated 48%.

Mobility of Community: The ABS data has indicated that 8% of the South Mission Beach population does not have access to a car or motorbike. This is not a high proportion and indicates a small section of the community is vulnerable to responding to evacuations.

Income of Community: The ABS data has indicated that 27% of the South Mission Beach population has a combined household income of less than $ 25,000. This would indicate that a moderate proportion of the population would be somewhat limited in their preparation (e.g. excess income for stored food) and could also be vulnerable in the recovery stage of an event.

Experience of Previous Flood / Cyclone Events: The ABS data has indicated that 43% of the South Mission Beach population has moved to South Mission Beach from outside of North Queensland in the last five years. This would indicate that a significant proportion of the population would not have experienced a cyclone or flood event. Hence, the ability of this proportion of the community to effectively respond to warnings may be hampered by a lack of experience or an understanding of the consequences.

Summary: The following is a summary of the Vulnerability Assessment for South Mission Beach.

- 17% Population > 65 years old = Moderate
- 48% Caravan / Tent Dwellings = High*
- 8% with no vehicle = Moderate
- 27% Household Income < $ 25,000 = Moderate
- 43% Moved from non FNQ (in 5y) = High
- Inundation Risk : Evacuation Centres = Moderate
- Inundation Risk : Crit. Infrastructure = Moderate
- Inundation Risk : Emergency Services = None / Low (see WB)
- ***Summary: Moderately Vulnerable Community***

5.7.5 Wongaling Beach

Age of Community: The ABS data has indicated that 16% of the Wongaling Beach population is aged over 65 years. This is a moderate percentage and, hence, implies that there is a moderate proportion of the community that is highly vulnerable in responding to the requirements of evacuation and recovery.

Structural Integrity of Housing: This assessment has not included an assessment of the structural integrity of houses in the area. Rather, it focuses on the percentage of the population living in what could be determined as structures that are vulnerable in a cyclonic event. The ABS data has indicated that 36% of the Wongaling Beach population lived (at the time of the 2001 census) in caravans or tents. This is a very high proportion and indicates that a significant part of the community would need assistance in accommodation following a storm surge inundation event. However, it is assumed that the census data for this area is somewhat over-estimating this proportion, as it is likely to be based on the available tent and caravan sites in the area. High tourist season does not overlap with the cyclone season to any great degree. Hence, it is likely that the proportion of the population in caravans or tents during a cyclone event would be significantly less than the stated 36%.

Mobility of Community: The ABS data has indicated that 14% of the Wongaling Beach population does not have access to a car or motorbike. This is not a high proportion and indicates a moderate section of the community is vulnerable to responding to evacuations.

Income of Community: The ABS data has indicated that 36% of the Wongaling Beach population has a combined household income of less than $ 25,000. This would indicate that a high proportion of the population would be somewhat limited in their preparation (e.g. excess income for stored food) and could also be vulnerable in the recovery stage of an event.

Experience of Previous Flood / Cyclone Events: The ABS data has indicated that 49% of the Wongaling Beach population has moved to Wongaling Beach from outside of North Queensland in the last five years. This would indicate that a significant proportion of the population would not have experienced a cyclone or flood event. Hence, the ability of this proportion of the community to effectively respond to warnings may be hampered by a lack of experience or an understanding of the consequences.

Summary: The following is a summary of the Vulnerability Assessment for Wongaling Beach.

- 16% Population > 65 years old = Moderate
- 36% Caravan / Tent Dwellings = High
- 14% with no vehicle = Moderate
- 36% Household Income < $ 25,000 = High
- 49% Moved from non FNQ (in 5y) = High
- Inundation Risk : Evacuation Centres = Low
- Inundation Risk : Crit. Infrastructure = High
- Inundation Risk : Emergency Services = Low
- ***Summary: Moderately Vulnerable Community***

5.7.6 Tully Township

Age of Community: The ABS data has indicated that 14% of the Tully population is aged over 65 years. This is a moderate percentage and, hence, implies that there is a moderate proportion of the community that is highly vulnerable in responding to the requirements of evacuation and recovery.

Structural Integrity of Housing: This assessment has not included an assessment of the structural integrity of houses in the area. Rather, it focuses on the percentage of the population living in what could be determined as structures that are vulnerable in a cyclonic event. The ABS data has indicated that 8% of the Tully population lived (at the time of the 2001 census) in caravans or tents. This is a low proportion and indicates that a small part of the community would need assistance in accommodation following a storm surge inundation event.

Mobility of Community: The ABS data has indicated that 18% of the Tully population does not have access to a car or motorbike. This is not a high proportion and indicates a moderate proportion of the community is vulnerable to responding to evacuations.

Income of Community: The ABS data has indicated that 32% of the Tully population has a combined household income of less than $ 25,000. This would indicate that a moderate to high proportion of the population would be somewhat limited in their preparation (e.g. excess income for stored food) and could also be vulnerable in the recovery stage of an event.

Experience of Previous Flood / Cyclone Events: The ABS data has indicated that 20% of the Tully population has moved to Tully from outside of North Queensland in the last five years. This would indicate that a moderate proportion of the population would not have experienced a cyclone or flood event. Hence, the ability of this proportion of the community to effectively respond to warnings may be hampered by a lack of experience or an understanding of the consequences.

Summary: The following is a summary of the Vulnerability Assessment for Tully.

- 14% Population > 65 years old = Moderate
- 8% Caravan / Tent Dwellings = Low
- 18% with no vehicle = Mod/High
- 32% Household Income < $ 25,000 = Mod/High
- 20% Moved from non FNQ (in 5y) = Moderate
- Inundation Risk : Evacuation Centres = Low
- Inundation Risk : Crit. Infrastructure = Moderate
- Inundation Risk : Emergency Services = Low
- ***Summary: Low / Mod Vulnerable Community***

5.8 Summary of Community Risk Levels

In the context of this study, risk can be considered to be a measure of the combination of the hazard exposure of the community and the vulnerability of the community. Based on the individual assessments of community vulnerability carried out for each township, a matrix of hazard exposure against community vulnerability is presented in Table 5-10.

Table 5-10 Summary of Community Risk Levels

Hazard Exposure	Vulnerability of Community		
	Low	***Moderate***	***High***
Low		South Mission Beach	
Moderate	Tully	Wongaling Beach	Cardwell
High			Tully Heads / Hull Heads

It is apparent from the matrix presented above that the Tully Heads / Hull Heads township has a high exposure to hazards (primarily from coastal / storm surge inundation) and a highly vulnerable community. This equates to a high risk area in regard to storm surge events.

The matrix also identifies that Cardwell township is an area with a moderate exposure to hazard but has a highly vulnerable community. This equates to a moderate to high risk area in regard to storm surge events.

The Wongaling Beach area has a moderate exposure to hazard and a moderately vulnerable community. This equates to a moderate risk area in regard to storm surge events.

Both Tully and South Mission Beach have a low to moderate risk.

Hence, it is recommended that the efforts for addressing a reducing these risks be focussed on the areas of Tully Heads / Hull Heads and then Cardwell.

6 MANAGEMENT MEASURES

6.1 Introduction

A range of management measures have been identified in this study that are aimed to reduce the risk to the local communities associated with flooding and storm surge. Generally, these measures fall into the following three categories:

- Property Modification Measures: Non-structural (eg. planning, house raising)
- Response Modification Measures: Improved Emergency Response / Recovery
- Flood / Coast Modification Measures: Structural Management Measures

There were not any viable Flood / Coast Modification Measures identified in the course of this study. Section 6.5.5 provides further discussion on this matter.

This chapter reviews the available options for Non-structural Measures (such as modification to properties, development and building controls, land use planning controls) and Response Modification Measures (e.g. flood emergency measures). However, before these controls can be developed it is necessary to define the flood hazard on the floodplain.

6.2 Flood Hazard Assessment

6.2.1 Overview

Integral to the development of a Flood and Coastal Inundation Management Plan is the definition of flood hazard over the floodplains. This section discusses the different approaches available for defining flood hazard. The Queensland Department of Natural Resources and Water is currently developing a flood risk policy for Queensland, which will address the development of floodplain management plans. Hence, in the absence of this completed policy, the discussion in this section relies on the Australian and NSW guidelines and floodplain management plans prepared for catchments in NSW.

Flood hazard is the term used to describe the potential risk to life and limb and potential damage to property resulting from flooding. The degree of flood hazard varies both in time and place across the floodplain. Floodwaters are deep and fast flowing in some areas, whilst at other locations they are shallow and slow moving. It is important to determine and understand the variation of degree of hazard and flood behaviour across the floodplain over the full range of potential floods.

6.2.2 Flood Hazard Categorisation

A review of the methodology in CSIRO (2000), DLWC (2001) and previous floodplain management plans for the categorisation of flood hazard is undertaken and a methodology is recommended for the Tully / Murray Floodplain.

CSIRO (2000)

It is necessary to divide the floodplain into flood hazard categories that reflect the flood behaviour across the floodplain. CSIRO (2000) refers to the degree of flood hazard as being a function of:

- The size (magnitude) of flooding;
- Depth and velocity (speed of flowing water);
- Rate of floodwater rise;
- Duration of flooding;
- Evacuation problems;
- Effective flood access;
- Size of population at risk;
- Land use;
- Flood awareness/readiness; AND
- Effective flood warning time.

CSIRO (2000) suggests four degrees of hazard: low, medium, high and extreme. The categorisation of the floodplain is largely qualitative using the above factors. For example, medium hazard is where adults could wade safely, but children and elderly may have difficulty, evacuation is possible by a sedan, there is ample time for flood warning and evacuation and evacuation routes remain trafficable for at least twice as long for the required evacuation time.

A key factor in the ease of evacuation from an area is the water depth and the velocity along the evacuation route, i.e., the stability of pedestrians wading through flood waters or vehicles driving along flooded roads. CSIRO (2000) notes that there are estimation procedures available for stability estimation, but considers that further research is required across a broader range of conditions and so does not recommend a procedure for hazard categorisation on this basis.

DLWC (2001)

DLWC (2001) identifies similar contributing factors to flood hazard as identified in CSIRO (2000). However, in recognition of the need to incorporate floodplain risk management into statutory planning instruments, DLWC (2001) recommends that land-use categorisation in flood prone areas be based on two categories, 'hydraulic' and 'hazard'. Hydraulic categories "*reflect the impact of development activity on flood behaviour"*, and hazard categories reflect "*the impact of flooding on development and people.*" Three hydraulic categories are identified – fringe flooding, flood storage and floodway – and two hazard categories – high and low resulting in the following categories:

1. Low Hazard – Flood Fringe;
2. Low Hazard – Flood Storage;
3. Low Hazard – Floodway;
4. High Hazard – Flood Fringe;
5. High Hazard – Flood Storage; and
6. High Hazard – Floodway.

A definition of the hydraulic and hazard categories is given in Table 6-1.

Table 6-1 Definition of Hydraulic and Hazard Categories

Category	Definition
Hydraulic	
Flood Fringe	The remaining area of flood prone land after floodway and flood storage have been defined. Development in this area would not have any significant effect on the pattern of flood flow and/or flood levels.
Flood Storage	Those parts of the floodplain that are important for the temporary storage of floodwater during the passage of a flood. A substantial reduction of the capacity of the flood storage would increase nearby flood levels, re-distribute flows and increase flows downstream.
Floodway	Those areas where a significant volume of water flows during floods and are often associated with natural channels. If they are even only partially blocked, there will be a significant increase in flood levels and possibly a re-distribution of flows resulting in impacts elsewhere.
Hazard	
Low	People and possessions could be evacuated by trucks and/or wading. The risk to life is considered to be low.
High	Evacuation by trucks would be difficult, able-bodied adults would have difficulty wading to safety, possible danger to personal safety and structural damage buildings is possible.

DLWC (2001) recommends that the definition of hazard initially be undertaken using relationships between depth (D) and velocity (V) of floodwater, i.e., using hydraulic principles, and then the categorisation should be refined using the other contributing factors to hazard noted in Section 0.

The consideration of depth and velocity is based on curves presented in the manual and shown in Figure 6-1 and Figure 6-2. In basic terms, the first of these curves shows high hazard for:

- Depths greater than 1m;
- Velocities greater than 2 m/s; and
- $D + 0.3 \times V > 1.0$ (where D=Depth, V=Velocity).

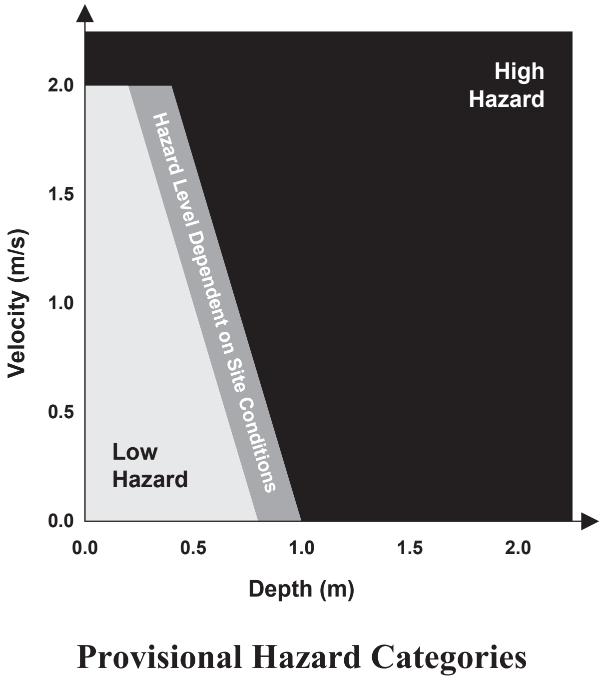

Figure 6-1 NSW Floodplain Management Manual Hazard Categories

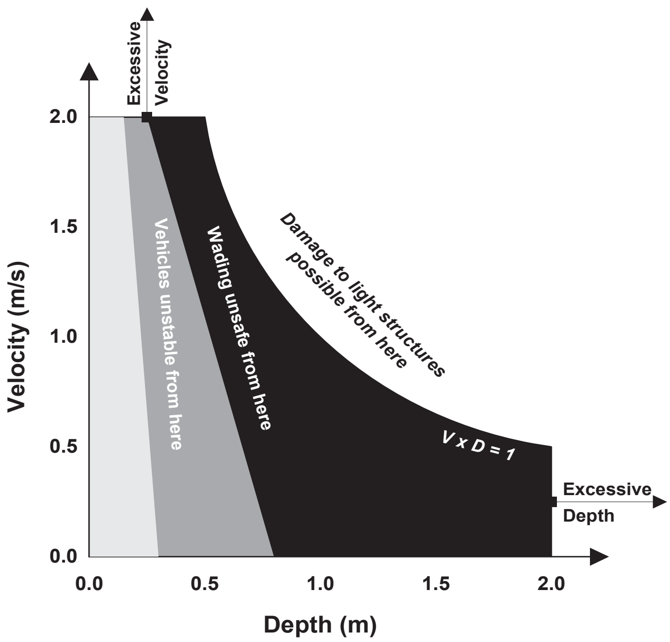

Figure 6-2 Velocity and Depth Relationships

Varying Hazard (Lismore, Mid-Richmond)

A modified approach to hazard definition using a wider range of flood hazard categories was applied to the Lismore floodplain by Patterson Britton and Partners (PBP) and in WBM (2002). The categorisation involves the four categories described in Table 6-2. This method has a shortfall in that it does not categorise areas where V x D is > 1.0, but D < 1 m.

Table 6-2 Flood Hazard Categories for Lismore Floodplain

Hazard Category	Depth	V x D	Other Characteristics
Low	< 1m	< 1.0	Adults can wade.
High	> 1m	< 1.0	Wading not possible, risk of drowning, damage only to building contents, large trucks able to evacuate.
Very High	> 1m	> 1.0 < 2.0	Truck evacuation not possible, structural damage to light framed houses, high risk to life.
Extreme	> 1m	> 2.0	All buildings likely to be destroyed, high probability of death.

6.2.3 Recommended Approach for Consideration

In considering the application of these issues to the specific flood characteristics of the Tully / Murray Floodplain, it is noted that:

- Duration of flooding is long (in the order of days) across the floodplain;
- Warning times are not long;
- Rates of floodwater rise are relatively slow; and
- Flood awareness is moderately high and does not vary significantly across the floodplain.

The above four parameters are not significantly variable to warrant specific treatment and are therefore not used to define variations in the flood hazard, but will be built into the development control measures. The flood hazard is therefore defined on the remaining, varying characteristics of:

- The size of the flood;
- Depth and velocity of floodwaters; and
- Evacuation and access.

On this basis it recommended that the following hazard categories be adopted for the Tully / Murray Floodplain and that they be defined in accordance with the criteria in Figure 6-3, which combines Figure 6-1 and Figure 6-2.

1 Low Hazard;

2 High Hazard – Depth;

3 High Hazard – Floodway (VxD > 1 and/or V > 2m/s).

The High Hazard – Wading category is not used in this study.

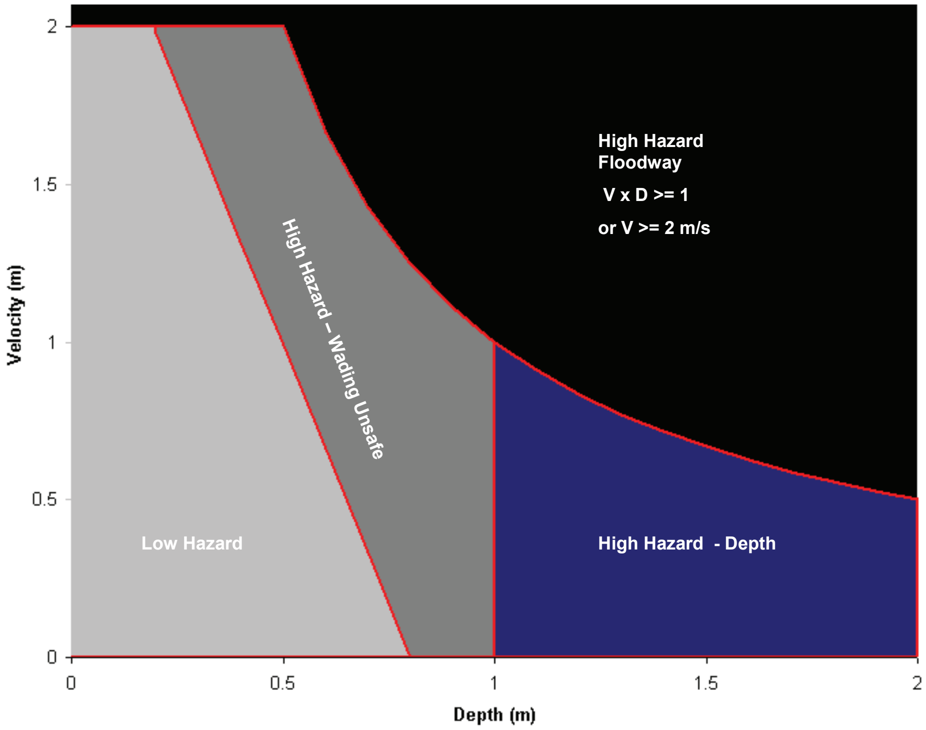

Figure 6-3 Definition of Recommended Flood Hazard Categories

6.2.4 Flood Hazard Maps

Using the Flood Hazard categorisation described in the previous section, flood hazards have been determined for the entire floodplain for all design events and are presented in Drawings 38 to 43 (see A3 Drawing Addendum) for the six flood events assessed.

With regard to the State Planning Policy 1/03 (Mitigating the Adverse Impacts of Flood, Bushfire and Landslide), Council and the Committee has chosen the 1% AEP as the Defined Flood Event (DFE). Hence, Drawing 40 is most relevant as it presents the flood hazards for the DFE.

6.3 Coastal Hazard Assessment

6.3.1 Overview

Integral to the development of a Flood and Coastal Inundation Management Plan is the definition of hazard along the coastline of the study area arising from storm surge inundation. This section discusses the different approaches available for defining this hazard.

The State Coastal Management Plan – Queensland's Coastal Policy (State Coastal Plan) has an associated guideline "Mitigating the Adverse Impacts of Storm Tide Inundation". This document gives guidance to Councils to ensure that storm tide inundation is adequately considered:

- when decisions are made about development, particularly in the making or amending of local government planning schemes;
- when assessing development applications; and

- when land is designated for community infrastructure under the Integrated Planning Act 1997 (IPA)..

As defined in the guideline, *"storm tide is a coastal hazard that can cause dangerous levels of inundation to coastal areas, over and above the risks associated with overland flooding from high rainfall."*

6.3.2 Coastal Hazard Categorisation and Maps

The 'natural hazard management area for storm tide' is the area of coast inundated by the Defined Storm Tide Event (DSTE). The default Defined Storm Tide Event (DSTE) level is the Highest Astronomical Tide (HAT) level plus 1.5 m. however, this study has allowed a more accurate determination of the DTSE levels along the coastline.

The following relevant sections of the "Mitigating the Adverse Impacts of Storm Tide Inundation" guideline are reproduced below:

> ***A2.8*** *"The management of storm tide risk is distinctly different to the management of flooding primarily because storm tide inundation occurs during the peak of a storm at the same time a severe wind hazard is also occurring and an evacuation response is unlikely possible. It therefore could be argued that the preferred basis for determining the DSTE should be a less frequent event than the 1 percent AEP event, which is commonly adopted for flood risk management. Local governments should consider defining a natural hazard management area (storm tide) based on a DSTE corresponding to an event with a lower probability (ie. more extreme) than the 1 percent AEP. In each case, the determination of the DSTE should be based on a rational appraisal of the impacts of storm tide inundation and the social and economic benefits of development."*
>
> ***A2.9*** *"Within the natural hazard management area (storm tide), low and high hazard severity zones should also be defined. The intent of defining the high hazard zone is to recognise the increased threat to public safety and the potential for loss or damage to property and structures caused by wave impacts and/or high velocity flows. The high hazard zone is where a significant discharge of water and/or dangerous breaking waves occur during the DSTE. Determination of the high hazard zone requires considerable detailed information on the predicted characteristics and likely effects of a storm tide inundation event within a particular locality. Further guidance to enable the delineation of the various levels of hazard severity is provided in later sections."*
>
> ***A2.33*** *"The approach given in the SCARM report is not entirely appropriate to the assessment of storm tide hazard, as it is unlikely that people or vehicles would be attempting evacuation during the peak storm conditions. The severity level for a storm tide hazard should instead focus on the effects of high flow velocities and breaking waves on the stability of structures. Suggested storm tide hazard severity zones are defined as follows:*
>
> - *Low – The inundation depth is less than 1m with wave heights less than 0.9m, and the product of depth x velocity is less than 0.3m^2/s.*
> - *High – Most residential structures will incur moderate to severe damage. The inundation depth is 1m or more with breaking waves of 0.9m or higher, and/or peak flows with a product of depth x velocity of 0.3m^2/s or greater."*

A2.40 *"In many cases detailed information on storm wave conditions and wave propagation across affected areas may not be available. In these cases, as a first approximation, the extent of the wave zone can be estimated as the area in which the depth of inundation at the DSTE exceeds 1m and is directly adjacent to the open coast. A consideration of potential dune breach and erosion processes, including potential failure of existing coastal protection structures, should also be taken into account."*

In regard to the excerpts from the guideline above, the following comments are made in regard to the application to this study area:

- With regard to Section A2.8 of the guideline, Council and the Committee has chosen the 1% AEP as the Defined Storm Tide Event (DSTE);
- With regard to Sections A2.9 and A2.33 of the guideline, it is not possible to determine velocity-depth products resulting from wave overtopping of the coastal dune due to the complex hydraulic behaviour of breaking waves. Furthermore, it is not possible to determine velocity-depth products resulting from storm surge levels (without waves) due to the strong influence of localised features such as houses.
- For these reasons, the following approach to defining high and low hazard areas has been adopted:
  - High Hazard Coastal Inundation: Area where inundation depth for 1% AEP event including wave runup, wave setup and climate change allowance is greater than 1.0m;
  - High Hazard Coastal Wave Zone: Area where inundation depth for 1% AEP event including wave runup, wave setup and climate change allowance is greater than 0.0m and within 150m of the coast (defined by MHWS) and linearly decreasing to a depth of 1.0m over the next 50m (i.e. 200m from the coast);
  - Low Hazard Coastal: Area where inundation depth for 1% AEP event including wave runup, wave setup and climate change allowance is greater than 0.0m and less than 1.0m;

Based on the criteria listed above, a Coastal Hazard map is presented in Drawing 44.

In accordance with the guidelines, a matrix approach is proposed for defining suitable uses for land within the high and low hazard zones. The matrix for the development control over coastal hazard areas has been incorporated into the matrix for the flood hazard areas.

Of note is the classification of all coastal high hazard areas in the same category as the high hazard floodway areas (as distinct from the high hazard flood depth areas). This classification recognises the difference between inundation of floodwaters with slow moving velocity and slow rates of rise compared to that of coastal inundation with little warning time.

6.4 Non-Structural Measures: Property Modification

The aim of property modification measures is to reduce the number of buildings that are inundated in a particular design flood or coastal inundation event. This can be achieved by: (i) purchasing flood-prone buildings and re-locating or removing them; (ii) raising the floor level of existing buildings; and/or (iii) imposition of controls on property and infrastructure development. The following property modification measures are discussed below:

- **Voluntary House Purchase**
  Purchasing houses that are located within a High Hazard Floodway or Coastal Inundation area. There are not any houses that have been identified in the High Hazard Floodway areas on the floodplains. Hence, it is not discussed in detail in this report. There may be houses located in a Coastal Inundation high hazard zone. However, this study has not identified such zones due to a lack of understanding of the expected depths and localised velocities resulting from storm surge events.

- **Voluntary House Raising**
  Raising the floor level of individual houses to a specified level. Thus, the number of houses that are inundated during flooding or coastal inundation events may be reduced. Criteria will need to be defined (e.g. buildings that are inundated in the 20 year design flood) for selecting those buildings to be considered for house raising (following a floor level survey).

- **Development Controls**
  The imposition of controls on property and infrastructure development. For example, setting the minimum habitable floor level for new houses based on the design flood or coastal inundation levels.

6.4.1 Voluntary House Raising

House raising is aimed at reducing the flood damage to houses by raising the floor level of individual buildings to a specified level. Thus, the number of houses that are inundated during flooding or coastal inundation events may be reduced. Such measures can only be undertaken on a voluntary basis.

The reduction in damages achieved by raising a building is determined using an estimate of the building floor level, and stage damage relationships as discussed in Section 5.3. No floor level or building type data is available for the study. Hence, it is assumed that all buildings with floor levels (below a defined threshold) could be raised.

A basic procedure for calculating reduction in flood damage is as follows:

- Calculate the existing annual average damages;
- Define a criteria for selecting those buildings to be considered for house raising (e.g. all houses with floor levels below the 20 year ARI flood levels);
- Calculate the annual average damages after raising those houses that satisfy the defined criteria;
- Estimate the cost of raising the houses; and
- Determine a monetary benefit-cost ratio for each scenario.

6.5 Non-Structural Measures: Development Control

6.5.1 Background

In recent years, floodplain and coastal inundation management has placed increasing emphasis on non-structural solutions. In particular, the use of town planning controls, which relate to a number of different non-structural management measures including floor level controls, warning and evacuation, building design, voluntary house purchase, distribution of appropriate land-uses etc.

Traditional floodplain and coastline planning has relied almost entirely on the definition of a single flood standard, which has usually been based on the 100 year ARI flood event. Overall, this approach has worked satisfactorily. However, it is now viewed as simplistic and inappropriate in certain situations. In particular, it has failed to comprehensively consider the varying land uses and flood risks on the floodplain.

A number of new approaches have emerged from Floodplain Management Studies completed in regions of NSW, which provide a transitional level of control based on flood hazard and the sensitivity of the possible range of land-uses to the flood risk. As noted earlier, DLWC (2001) reflects this new approach to floodplain planning.

This section reviews the planning tools available to town planners in floodplain management, the traditional approach to floodplain management, new planning approaches that have emerged and recommends an appropriate approach for CCRC.

The ‘Traditional Approach’ to planning (which is somewhat reflected in the State Planning Policy 1/03) involves:

- Consideration of a range of events to select a ‘Defined Flood Event’ of DFE, typically the 1 in 100 year ARI event or a known historical flood, irrespective of land-use; and
- Adoption of the ‘Defined Flood Event’ to define flood liable land, above which flood planning is not considered and below which development control occurs.

The Traditional Approach to floodplain planning results in restricted development on a merit basis below the Flood Standard and most development above the flood standard. This also reinforced the community belief that there is no flood hazard above the standard.

In general, this approach has worked well, but has led to a number of problems including (Bewsher and Grech, 1997):

- Creation of a ‘hard edge’ to development at the DFE Level;
- Distribution of development within the floodplain in a manner which does not recognise the risks to life or the economic costs of flood damage;
- Unnecessary restriction of some land uses from occurring below the DFE Level, while allowing other inappropriate land uses to occur immediately above the DFE Level;
- Polarisation of the floodplain into perceived ‘flood prone’ and ‘flood free’ areas;
- Lack of recognition of the significant flood hazard that may exist above the DFE Level (and as a result, there are very few measures in place to manage the consequences of flooding above the DFE Level); and
- Creation of a political climate where the redefinition of the DFE Level (due to the availability of more accurate flood behaviour data, or for other reason) is fiercely opposed by some parts of the community, due to concern about significant impacts on land values ie. land which was previously perceived to be ‘flood free’ will now be made ‘flood prone’ (despite the likelihood that such impacts may only be short term).

Therefore, a number of councils in NSW have considered it inappropriate to adopt a single 'Defined Flood Event'.

A number of new planning approaches have emerged from Floodplain Management Studies completed in regions of NSW (Hunter, Hawkesbury, and Paterson) that provide a transitional level of control based on flood hazard and the sensitivity of the possible range of land-uses to the flood risk. This approach is incorporated into CSIRO (2000) and DLWC (2001). In DLWC (2001) the following changes have been implemented.

- The term Flood Liable Land is replaced by the term Flood Prone Land and is to be defined as land inundated by the Probable Maximum Flood (PMF).
- The focus on the PMF changes from considering "if" it happens to "when" it happens. That is, the probability of a PMF is extremely small but real and therefore requires consideration in the Floodplain Management process (this has been driven by the recent occurrence of floods exceeding the 100 year ARI event).
- It reinforces the need to manage the floodplain through assessment of a range of design floods rather than a selected standard flood.
- The Flood Standard is to be replaced by Flood Planning Levels (FPL's), which indicates that a range of planning levels may be used. This is one of the most crucial changes in that it reinforces an approach of matching FPL's with different land-uses and using the FPL's as planning control mechanisms. Many different factors are to be considered in the selection of appropriate FPL's.
- The adoption of the varying FPL's is promoted in the available planning tools.
- There is reinforcement of the links required between the Floodplain Management Plan and the emergency management.
- Other issues are also introduced or further reinforced such as Ecologically Sustainable Development, Total Catchment Management, Community Consultation, climate change and riverine environment enhancement.

With the release of the State Planning Policy Guidelines for Mitigating the Adverse Impacts of Flood, Bushfire and Landslide (DLGP/DES, 2003) and the Guidelines for Mitigating the Adverse Impacts of Storm Tide Inundation, new approaches have emerged. These approaches provide a transitional level of control based on flood and coastal inundation hazard and the sensitivity of the possible range of land-uses to the risk. Careful matching of land use to hazard maximises the benefit of using the floodplain and coastline as well as minimises the risk of inundation.

An approach is outlined in DLWC (2001) that:

- ➢ promotes the definition of varying hazard across the floodplain;
- ➢ defines appropriate land-uses with the hazard zones; and
- ➢ provides adequate development controls for the relevant land-use and hazard.

Figure 6-4 illustrates the general approach to planning promoted in DLWC (2001).

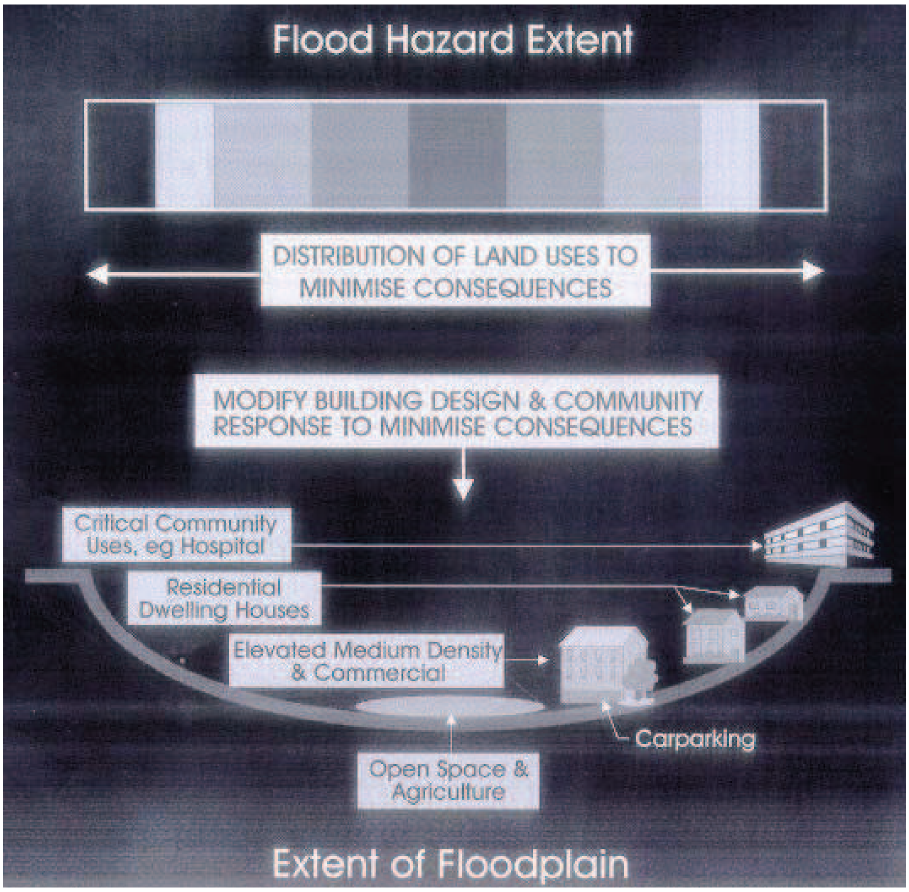

Figure 6-4 Flood Hazard Extent: NSW Floodplain Management Manual (DLWC, 2001)

6.5.2 Review of Approaches

The following sections provide a summary of the various approaches with a recommended approach outlined in Section 6.5.3. Issues that must be considered in the development of a code-assessable scheme are listed below.

- Land-use categories.
- Floodplain planning controls will be developed through the Floodplain Management Study.
- Flood hazard categorisation must be completed at the commencement of the process using methods approved by the SAG.
- Floodplain Characteristics:
    - Extent and depth of flooding and hazard can be mapped reasonably accurately as a result of the modelling undertaken as part of this study;
    - A major proportion of the flood prone land is rural land-use;
    - Major concern is the management of flooding in the urban centres; and
    - There are a large number of residential properties that would be inundated in a 100 year ARI flood event
- Community tolerance and acceptance of the level of flood inconvenience.

Traditional Approach

The Traditional Approach to floodplain planning has been described and reviewed in Section 6.5.1. The approach has been adopted by many councils throughout Queensland, but has been found to be inadequate in areas that have experienced flooding larger than the DFE Level. Also this approach is not in line with current developments in floodplain management such as detailed in the NSW Floodplain Management Manual (DLWC, 2001). BMT WBM recommends that this approach is not adopted for planning in the study area.

Planning MATRIX

An approach initially developed for the Blacktown Floodplain Management Study in NSW by Bewsher Consulting, and adopted by a number of other councils, is the Planning MATRIX Approach. The approach distributes land-uses within the floodplain and coastal areas and controls development to minimise the inundation damages as illustrated in Figure 6-4.

Steps involved in developing a Planning MATRIX follow:

- Categorising the Floodplain and Coastal areas - divide the floodplain and coastline into areas of differing hazard.
- Prioritising Land Uses - review all land-uses used by council and divide into discreet categories of land uses with similar levels of sensitivity to the flood and coastal hazard. The categories are then listed under each hazard band in the planning matrix in priority of land use.
- List Planning Controls (Building and Community Response) - assign different planning controls to modify building form and the ability of the community to respond in times of inundation, depending on type of land use and location.

The MATRIX can be adopted by Council as a code assessable scheme to cover development applications on the floodplain and coastal area.

6.5.3 Recommended Approach for Consideration

Future planning schemes should account for land-use, flood hazard and/or coastal hazard and then recommend appropriate control measures. Based on the review outlined above, it is recommended that the following approach be adopted:

- For each Land-use Category, develop a Flood / Coastal Planning Matrix. When applications are being processed, Council staff will source the appropriate matrix to specify any control measures related to flooding;
- Identification of the appropriate flood hazard category(ies) applicable to a property will be made through a flood hazard map and/or coastal hazard map; and
- The system proposed has been designed to be performed using hardcopy plans or interactively carried out on a computer using Council's GIS.

The planning scheme would be adopted by Council to cover applications for development on the floodplain and coastal areas.

6.5.4 Development and Use of Planning Matrices

Preliminary planning matrices developed for the study area are presented in Drawings 44 to 46 (see A3 Drawing Addendum) for each of the discrete land use categories.

It is intended that the planning matrix be utilised by those Council officers assessing or advising on development applications. The procedure used by officers follows these steps:

- Identify the land use of the site under consideration;
- Identify the flood hazard and/or coastal hazard category applicable to the site under consideration again by either visual inspection of hardcopy plans or by interrogation of a GIS layer; and
- Use the matrices presented in Section 6.5.4 to determine the controls relating to the site based on land use and flood hazard and/or coastal hazard category.

There is the potential for a significant advantage in being able to access the land-use and flood or coastal hazard category from a GIS database as both items are able to be provided with one on-screen query. The data has been developed with this in mind.

An example of the application of the matrix approach to determining a floor level in a High Hazard Depth area is presented below in Figure 6-5.

DEVELOPMENT WITHIN A RESIDENTIAL AREA				
		100 Year Hazard		
Controls	**Development Type**	**Low Hazard**	**High (Depth) Hazard**	**High (Floodway) Hazard**
Fill Level	New Development	No Min	No Min	
	Emergency Services	PMF Flood Level		
Floor Level	Habitable Building	100y level +0.5m	100y level +0.5m	
	Ancillary Building (eg shed)	10y level +0.3m	10y level +0.3m	
	Emergency Services	PMF Level		

Figure 6-5 Example Use of Matrix for Habitable Building in High Hazard Depth Area

Another example of the application of the matrix approach is presented below in Figure 6-6 to determining a floor level of an Emergency Services building in a Low Hazard area.

DEVELOPMENT WITHIN A RESIDENTIAL AREA				
		100 Year Hazard		
Controls	Development Type	Low Hazard	High (Depth) Hazard	High (Floodway) Hazard
Fill Level	New Development	No Min	No Min	
	Emergency Services	PMF Flood Level		
Floor Level	Habitable Building	100y level +0.5m	100y level +0.5m	
	Ancillary Building (eg shed)	10y level +0.3m	10y level +0.3m	
	Emergency Services	PMF Level		

Figure 6-6 Example Use of Matrix for Emergency Services in Low Hazard Area

6.5.5 Benefits of Improved Development Control

An estimate was made of the financial benefits that could accrue from improved development control (as a result of implementing the recommended approach listed above). This estimate was based on the following approach / assumptions.

- It is assumed that CCRC population will grow over the next 50 years at 1.7% per annum (Cardwell Shire: Socio-Economic Profile ,CSIRO 2006). This will result in a 130% increase in the population over 50 years;
- It was assumed that all of the 130% of new development (houses, shops etc) would be constructed above the 1% AEP planning levels as identified by this study. It was also assumed that this 130% of new development is equal to 1.3 times the current value of the shire development (i.e. same rate / value of development);
- It was also conservatively assumed that this development would be coastal-based development;
- The current Average Annual Damages (for coastal areas) are estimated to be $ 1.6 million per year.
- If no development controls were introduced (i.e. the 'Do Nothing' case), the Average Annual Damages would increase to $ 3.8 million per year.
- If development controls as outlined in this report were introduced (i.e. ensuring that all building are built above the 1% AEP inundation levels), the Average Annual Damages would increase to $ 3.0 million per year.
- This represents a difference of $ 800,000/a in damages. This annual saving in damages has a Net Present Worth to the community of $ 11 million (approximately 14 times the annual savings).

It is recognised that the estimate of benefits relies upon a number of assumptions and possibly conservative estimates. However, the order of the savings to the community is still expected to be at least $ 3 million.

The cost of this study and implementation of the planning controls would be in the order of $ 350,000. Hence, this exercise demonstrates that the study and proposed approach represents a considerable benefit for the community for a relatively small cost.

6.6 Response Modification: Warning & Emergency Planning

6.6.1 Background

Response modification measures are aimed at increasing the ability of people to respond appropriately in times of flood / storm surge and/or enhancing the warning and evacuation procedures in an area. The following response modification measures have been investigated:

- **Warning & Emergency Planning**
  An effective flood and/or storm surge warning system, in combination with a high level of community awareness, is invaluable in minimising the inundation damages and trauma associated with flood and/or storm surge inundation. An accurate, prompt warning system ensures that residents are given the best opportunity to react appropriately. Comprehensive emergency planning ensures that no time is wasted in the event of a flood and/or storm surge and response measures are implemented efficiently.
- **Raising Community Awareness**
  As the community becomes more aware of the potential for flooding and/or storm surge, it is less likely that people will experience health and psychological trauma following a flood and/or storm surge. Also, the community will be more likely to respond effectively to warnings and to remove possessions and themselves from the dangers of inundation.

Most of the information presented in this section has been derived from the current Cardwell Shire Council Disaster Management Plan and the draft review of that document.

6.6.2 Flood / Storm Surge Warning & Emergency Planning

Under Queensland legislation, the primary responsibility for emergency response in the study area rests with the Council's Local Counter Disaster Committee, which is chaired by the Mayor of CCRC. The SES acts under the direction of this Committee. The role of this committee is to:

- Prepare and maintain a Local Counter Disaster Plan for the Shire of Cardwell; and
- Coordinate for Counter Disaster purposes all resources available within the Shire.

There are many factors which determine the success or otherwise of the warnings and assistance that the SES are able to provide. These factors may be divided into the four main groupings of:

1 Community ***awareness***.

2 Quality of flood information ***received*** by the SES from other sources.

3 Ability of the SES to ***interpret*** this information.

4 Ability of the SES to ***respond*** to their assessment by providing advice and assistance to the community.

Some of these key areas are discussed in detail in the following sections.

6.6.3 Community Awareness

Community awareness and preparedness is an important factor in determining the success of flood / storm surge warnings and response. An aware community is able to understand warnings, how they relate to their particular situation and to respond appropriately. Raising community awareness is an important component of this study and is referred to again in Section 6.6.4. It is important to note that community awareness and flood / storm surge warning are strongly linked.

The following recommendations for are made for further consideration by Council:

Public Education Brochure

It is recommended that the public education program be expanded to address the issues identified in this study. This could include a letterbox drop at the start of the wet / cyclone season. This flyer could include contact details and helpful tips on what to do in a flood / storm surge situation.

Educational DVD / Video

The use of a professionally made DVD to educate the community on this issue is seen as a valuable and useful tool. It is thought that the DVD would be relatively short (in the order of 10 to 20 minutes long) and be presented in an easily understood manner. The presenter would need to be chosen well to increase the credibility of the content (e.g. now retired General Peter Cosgrove AC MC).

It is envisaged that the DVD would cover the following critical topics:

- Storm surge threat
- Areas of high risk
- Coincident threat from cyclonic winds
- Coincident / subsequent threat from floodplain inundation
- Preparations / Awareness
- Warning System
- Response to Warnings
- Evacuations
- Recovery

It is expected that the cost to prepare such a DVD would be in the order of $ 50,000.

6.6.4 Response: Interpretation of Warnings

Through discussions with local SES volunteers at Cardwell, it became apparent that the SES relies upon relatively inaccurate maps of ground level and expected inundation. These maps currently form part of the basis for decisions on evacuation procedures.

This study has involved the collation of relatively high quality ground level data for the populated town centres. It is proposed that best use be made of this data to produce hard-copy maps at a suitable scale for SES use in the planning phase and operationally. These topographical maps should include colour-coded contours at a relatively fine vertical interval (say 0.2m).

Council is also now in receipt of high-resolution aerial photography (geographically registered) taken in August 2006 that would provide an important background to these maps.

These maps could also be supplemented with expected inundation extents for a range of probabilities. Decisions on whether to include an allowance for climate change and/or wave runup will need to be made to ensure the usefulness of the maps.

6.6.5 Evacuation Refuge for Tully Heads / Hull Heads

The Community Vulnerability Assessment highlighted the high level of risk that the Tully Heads and Hull Heads areas are exposed to during a large storm surge event. In summary, this high level of risk is based on the following findings:

- The area is exposed to significant areas of inundation in even a 1% AEP storm surge event (with an allowance for sea level rise and wave runup effects);
- It is possible that the road routes to the area could be severed by minor to moderate flooding preceding a storm surge event;
- There are not any evacuation centres located in the area;
- The community is highly vulnerable due to the high number of low-income households (45%) and the high number of residents that have recently moved to Far North Queensland (37%).

All of the above points to a reasonable probability of a storm surge occurring within the next 50 years that would inundate a large number of houses. Assuming effective evacuation planning and effective warnings and response, these residents would have been encouraged to evacuate prior to the storm surge inundation. However, if the roads to the west are cut due to preceding flooding, this could result in a very unsafe situation for those residents.

Figure 6-7 Possible Location for Tully Heads / Hull Heads Evacuation Refuge

This study has also assessed the extent of inundation for very rare storm surge events. The mapping has indicated that the land to the western portion of Tully Heads is relatively high and above the 0.1% AEP storm surge levels (with an allowance for sea level rise). Furthermore, there are small parts of this area not inundated in a 0.01% AEP event.

It would be feasible to construct a community evacuation centre on this area. Much of the land that is not inundated in the 0.1% AEP storm surge (see Figure 6-7) would be suitable and require minimal filling (in the order of 0.5m) to raise the floor level above the 0.01% AEP storm surge levels.

6.7 Structural Management Measures

Throughout this study, there have been invitations at numerus public forums to provide any suggestions for management measures. Only one structural flood management measure was suggested in these forums by a resident on the Murray River floodplain. That suggestion was for a dam to be constructed on the upper reaches of the Murray River. It was further suggested that this dam could be used to supply water to drier catchments on the other side of the Cardwell Range possibly as part of a broader scheme to pump water over the Great Dividing Range.

This study cannot provide any comment on the feasibility of such a dam for the purposes of water supply. However, it is considered unlikely that the dam would have any significant benefit for flooding on the Tully / Murray floodplain as it is likely that the dam would be full during the wet season, thus reducing its detention capacity. Furthermore, the costs of such a dam are likely to significantly outweigh any benefits accruing from reduced flooding on a rural floodplain.

7 RECOMMENDATIONS, LIMITATIONS AND CONCLUSIONS

7.1 Recommendations

The following measures are recommended for further consideration. Further details of these measures are presented in Section 6.

1 It is considered that the adoption of a planning matrix is fundamental and that integration of the planning matrix into the Town Plan should occur. A decision is required from CCRC (possibly via the SAG) as to whether the Planning Matrix should be adopted in principle and which hazard categories should be incorporated.

2 The development of public education tools such as regular brochures and a DVD should be considered for further action;

3 Improved maps for use by the local SES would assist in the planning and operational phases of evacuations. It is recommended that this element be properly scoped (through discussions with the local SES) to develop topographical and inundation maps.

4 It is considered important to coordinate the outcomes of this study with the outcomes of Johnstone Storm Surge Study (currently being completed by GHD). This coordination is more pertinent since the creation of the merged council area in 2008.

A number of additional studies and tasks are recommended below to add to the value of this study.

Flood / Drainage Study of One Mile Creek (Cardwell Town):
Following an assessment of the western parts of Cardwell town, it would appear that much of the flood inundation experienced in this area results from relatively short duration rainfall events in the One Mile Creek catchment. The drainage network of One Mile Creek is somewhat complex with flow possibly moving north and south depending on the size of the rainfall / flood event.

Further, it has been postulated by members of the community that the culvert under the Bruce Highway to the south of town (prior to discharging through Port Hinchinbrook) could be under-sized or too high. It is recommended that a local drainage / creek study be carried out for One Mile Creek which would focus on these issues. The relevance to this study is that the inundation from One Mile Creek can jeopardies the access to the main evacuation centre for Cardwell (at the Cardwell Community Centre).

Future Topographical Survey:
It has been identified that the modelling tasks in this study could be improved through the acquisition of more accurate survey over the floodplain. As well, a floor level survey (possibly targeted on those houses expected to be inundated) would assist in the quantification of flood and coastal inundation damages.

7.2 Study Limitations

The following limitations on the findings of this study are discussed below:

- The interaction of floodwaters between the Tully and Murray River floodplains is complex and can only be properly represented in a numerical model based on highly accurate ground survey and calibration to a large flood event;
- The ability of the numerical coastal storm surge models to represent wind and waves accurately is limited to the ability to represent the cyclones using the Holland Wind Field (which assumes a circular shape of the wind field);
- The ability to predict wave runup over and beyond the sloping beach profile (into the residential / populated areas) is limited to relatively conservative extrapolations of the wave runup profile on the sloping beach profile.
- The risks to the community from inundation are dominated by storm surge inundation, especially in the areas of Tully Heads and Hull Heads,
- The estimate of flood and coastal damages is limited by an assumption that the floor level of houses is at the ground level derived from the aerial photogrammetry Digital Elevation Model. Further, the damages assessments assumed all structures identified from aerial photography are medium size houses and did not rely upon detailed field-based inspections of structure type (residential or commercial), size or value;

7.3 Conclusions

The study has concluded the following:

- The coastal areas of Tully Heads and Hull Heads are High Risk areas with regard to storm surge inundation;
- The mapping of storm surge inundation and flood inundation will enable Council to better manage the risks associated with this type of natural hazard;
- If development controls as outlined in this report are introduced, there is the potential for considerable long-term savings to the community through reduced inundation damages.

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