BUNDABERG FLOODS – THE SCIENCE BEHIND THE STORY

Dwayne Honor, Email: dwayne.honor@bundaberg.qld.gov.au
Manager Design, Bundaberg Regional Council, Queensland, Australia

Ben Regan, Email: ben.regan@ghd.com
Senior Engineer, GHD Pty Ltd, Queensland, Australia

Abstract

On Saturday the 26th of January 2013, ex-Tropical Cyclone Oswald crossed the Burnett River catchment causing a series of natural disasters to occur in the vicinity of Bundaberg, Queensland. A total of five (5) tornadoes struck the coastal fringe to the east of the city causing damage to the adjacent townships of Bargara and Burnett Heads. On Sunday the 27th of January, following significant rainfall across the catchment - the Burnett River broke its banks and the city of Bundaberg began to experience its largest flood in recorded history.

The events of January 2013 were preceded by moderate levels of flooding in the city of Bundaberg during December 2010 and January 2011. As a result of these events, Bundaberg Regional Council (BRC) undertook a review of its Local Disaster Management Plan and importantly commissioned a comprehensive flood study of the lower Burnett River. This included the development of a calibrated flood model. The timing of this study was fortuitous as the outputs of the model were used to inform emergency management decisions during the 2013 event. This highlighted the need for the floodplain risk management process to be underpinned by good science and sound engineering.

This paper summarises the nature and impact of the 2013 flood and describes how flood model outputs were used during the event. The paper also provides an overview of post flood activities that have been undertaken to improve community resilience to flooding, and provides some key learning's for emergency response, recovery and floodplain risk management activities.

Key Words: Ex-Tropical Cyclone Oswald, Bundaberg Floods, Burnett River, Flood Modelling, Floodplain Risk Management.

Introduction

On the afternoon of Saturday 26th January 2013, when most people around the country would have been celebrating Australia Day with friends and family, the people of Bundaberg and surrounds were battling a series of five (5) devastating tornadoes.

With Council efforts focussed on emergency response and recovery from these events, it was only the beginning of a series of much larger natural disasters. Following severe weather warnings from the Bureau of Meteorology (the Bureau), ex-Tropical Cyclone Oswald began to deliver extreme rainfall across inland areas of the Bundaberg region. On Councils northern borders, rainfall from the Gladstone area started to head in a southerly direction across the catchments of Baffle Creek, Kolan River, Gin Gin Creek and ultimately the Burnett River. A track of ex-Tropical Cyclone Oswald is provided in Appendix A.

With the Burnett River rising to record flood levels, mass self evacuation of North Bundaberg was ordered followed by a mandatory evacuation.

Prior to the event, Council had almost completed comprehensive hydrologic modelling of the Burnett River catchment and hydraulic modelling of the lower Burnett River reach located between Paradise Dam (approximately 130km upstream of Bundaberg) to the river mouth (located 10km downstream of Bundaberg). The outputs of these models were used to assist the decision making process and to improve the understanding of flood behaviour amongst a wide range of emergency response personnel as the event unfolded.

Bundaberg Flood History

The city of Bundaberg and surrounding areas have been subject to a number of moderate to large flood events that have adversely affected local residents, businesses, land owners and infrastructure.

During the last 135 years, major floods have occurred in 1875, 1890, 1893, 1942, 2010 and most recently in 2013. Other minor to moderate flood events occurred in 1971, 1974, 1983, 1989, 1992, 1996 and 2011. Figure 1 illustrates the timing and magnitude of historical flood peaks at the Bundaberg Gauge.

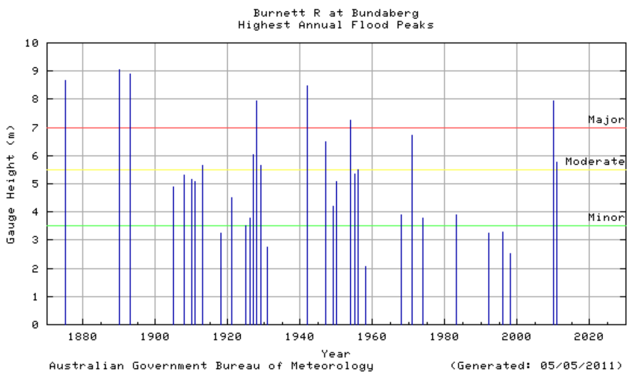


Figure 1 – Graph of Burnett River Historical Floods Events, Bundaberg.

Burnett Catchment Overview

The Burnett River catchment is one of the largest catchments in Queensland. At Bundaberg, the upstream catchment area is approximately 32,820 km². Figure 2 illustrates the location and extent of the catchment.

The Burnett River originates in the Dawes Range to the north of Monto and flows in a southerly direction through Eidsvold and Mundubbera.

Upstream of Mundubbera, the Burnett River is joined by the Nogo and Auburn Rivers which drain large areas of the western part of the catchment, and the Boyne River which drains the basin area to the south. Downstream of Mundubbera, the Burnett River flows in a north-easterly direction towards the coast. Between Gayndah and Mt Lawless the Barker-Barambah Creek system joins the Burnett River.

There are a number of dams in the Burnett River catchment with the larger dams including Cania Dam, Wuruma Dam, Boondoonba Dam, Bjelke-Peterson Dam and Paradise Dam.

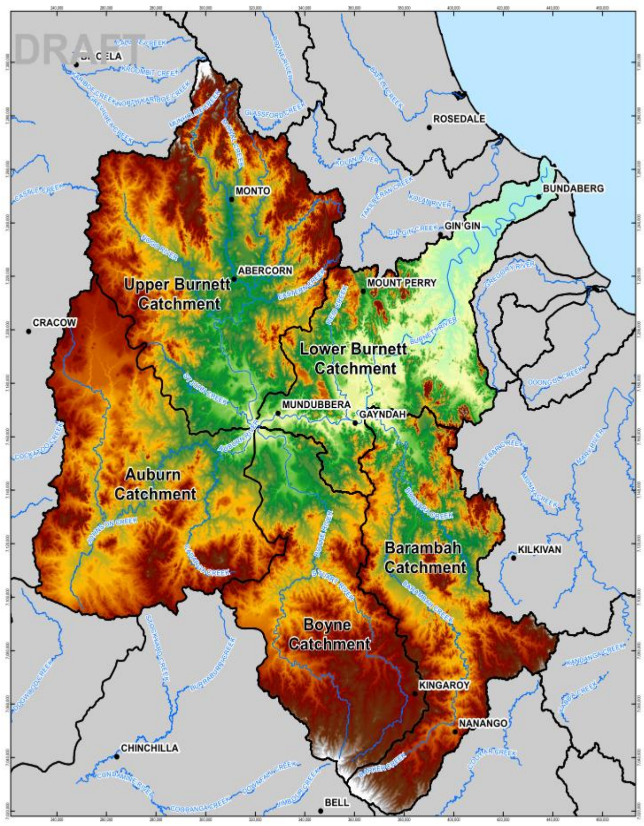


Figure 2 – Burnett River Catchment

Lead up to the January 2013 Flood Event

While flooding is not new to Bundaberg there were a unique set of events leading up to the January floods that were significant in their own right.

Preceding the Australia day long weekend, the Bureau was issuing weather warnings for destructive winds and heavy rainfall, abnormally high tides and dangerous surf conditions.

Starting with tornadoes, the first struck at Bargara causing damage to around 60 houses, many sheds and fences. Figure 3 highlights some of the damage. The second touched down at Burnett Heads, destroying 2 houses and damaging another 55. The third struck at Coonarr, damaging 1 home. The fourth again hit Burnett Heads, with the fifth striking the Avondale area with damage only to bushland. A disaster declaration was made and an Evacuation Centre was activated in Bundaberg.

Figure 3 – Tornado Damage, Bargara, January 2013 (wooden stake through door)

Catchment Rainfall and Records

With the cleanup of the tornadoes continuing, significant rainfalls were experienced in all major river catchments that discharge through the Bundaberg Regional Council area including Baffle Creek, Kolan River, Gin Gin Creek and the Burnett River.

The Bureau's Special Climate Statement 44 (2013) provides a concise analysis of the extreme rainfall that resulted from Oswald. The statement indicates:

- A total of 26 sites with 80 years or more of data set all time daily rainfall records, with another 28 setting January records;

- Extreme single and multi day rainfall fell across the Burnett catchment. Most exceptionally, the catchment average of 206.8mm on 27th January exceeded the previous record (123.6mm on 20th January 1929) by nearly 70 per cent;

- The Burnett catchment also set records by large margins for highest 2-, 3- and 4-day timescales;

- Bundaberg recorded 252mm of rainfall on 27th January;

- In the upper Burnett catchment conditions were particularly extreme with flood peaks exceeding previous records by several metres (5.86m margin at Eidsvold from January 2010); and

- Bundaberg's peak flood height of 9.53m set on 29th January broke the previous record set in 1890 by 0.49m. Refer to Figure 4 showing aerial photography of the flood extents.

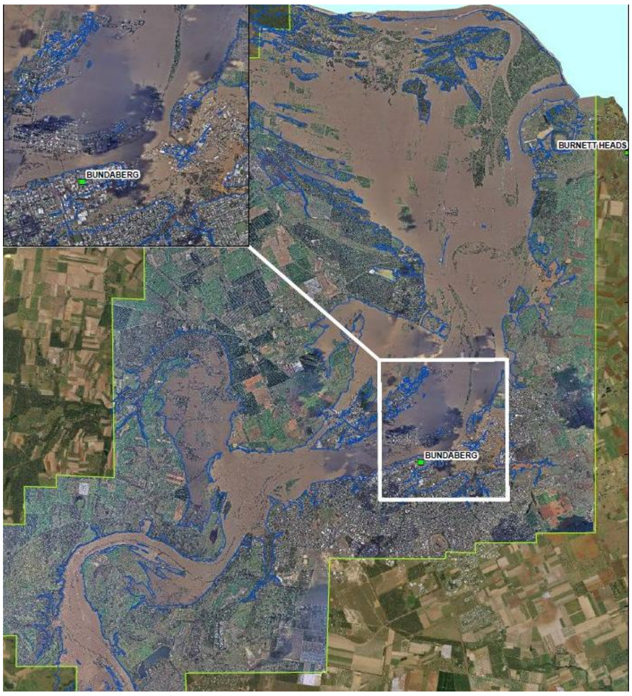


Figure 4 – Aerial Photography showing extents of peak flooding in Bundaberg, Jan 2013

Aside from the problems occurring in the Burnett catchment, Council were also faced with similar rainfall and extreme flooding in the Kolan River system which experienced its highest catchment averaged rainfalls for 1-, 2-, 3- and 4-day timescales (breaking the previous records from 1913).

Storm Surge Impacts

In addition to the high rainfall and resultant flooding in the Burnett River, the Bureau was also providing storm surge predictions of approximately 1.0m above normal tide conditions. The Department of Science, Information Technology, Innovation and the Arts (DSITIA) operates a network of 25 storm tide gauges along the Queensland coastline (DSITIA 2013). Tidal residuals (being the non-tidal part of sea level measurement) for Burnett Heads at the Burnett River mouth recorded about 0.75m of storm surge on the 27th January. The storm surge combined with the high Burnett River flows to exacerbate flooding on the lower Burnett River floodplain.

Evacuations of Bundaberg

On the 27th of January, severe weather warnings were already in place before a voluntary mass evacuation of north and east Bundaberg commenced. At this time, swift water rescue crews from the Qld Fire and Rescue Service were operating around the city. Emergency air support requests were also being made in preparation for the floods including a helicopter fleet of Australian Defence Force (ADF) Blackhawk helicopters and other aircraft.

With the Burnett River continuing to rise to unprecedented levels, a mandatory evacuation of North Bundaberg was ordered on the 28th January. Several retirement villages were evacuated while the largest air evacuation in Australia’s history was in full swing. A total of 24 helicopters were involved with approximately 850 people rescued or evacuated by air over a 48hr period. In a single 12hr shift, one Emergency Management Queensland helicopter rescued 50 people (Bruce 2013).

In total there were approximately 7,000 displaced persons with some 1400 people residing at evacuation centres. As described by Keast (2013) the Bundaberg Base Hospital evacuated 131 patients, including 10 critical patients on January 29 via two RAAF Hercules C-130 aircraft, a Beechcraft King Air B200 twin-turboprop and a Lear jet. Patients were transported to the Royal Brisbane and Women’s Hospital, Princess Alexandra Hospital, Prince Charles Hospital, Mater Mother’s Private, Brisbane Private Hospital and Logan Hospital.

Summary of Flood Magnitude

The January 2013 flood event has been estimated to be similar in magnitude to a 1% AEP design event with:

- Approximately 16,500m^3/s flowing from Paradise Dam;
- Flood depths of up to 27m above ground level downstream of the Wallaville township, with deeper levels measured from the river bed;
- Flood inundation footprint of approximately 275km^2 downstream of Paradise Dam within the BRC area alone;
- Velocity*Depth values (Hazard) reaching a maximum of 12m^2/s in North Bundaberg, and between 4 and 6 m^2/s in some of the hardest hit residential areas;
- 19 hectares of rural residential properties completely inundated to depths between 5.5 and 25m with no ability to raise these homes above such levels; and
- Property devaluations of approximately 30% based on post flood sales.

The Burnett River Flood Model

Following the flood events of December 2010 and January 2011, Bundaberg Regional Council (BRC) commissioned GHD to prepare an updated flood study of the Burnett River. The study superseded an existing 2004 study and was initiated to inform a new regional planning scheme and to provide a sound basis for future planning decisions.

As part of the study, a detailed (360-sub-catchment) hydrologic model (URBS) of the Burnett River catchment was developed to simulate the rainfall-runoff process and estimate discharge hydrographs at key locations. In order to simulate the propagation of floodwater across the floodplain, an integrated 1D/2D Tuflow hydraulic model was also developed for the river reach located between Paradise Dam (AMTD 130km) and the river mouth. The hydraulic model was developed with a 15m cell size using recently obtained topographic and bathymetric survey. Finer scale hydraulic models were also nested within the model domain to assess local flooding behaviour. The extent of the hydraulic model is provided in Figure 5.

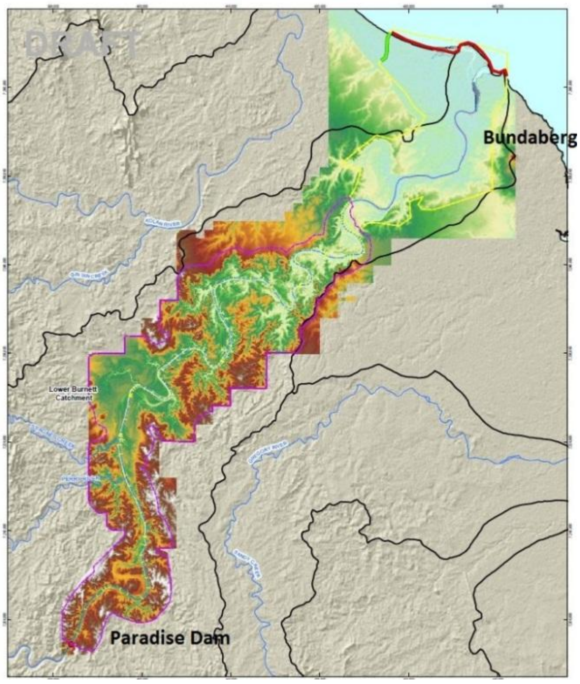


Figure 5 – Burnett River 2D Hydraulic Model Extent

The hydrologic and hydraulic models were calibrated to a range of historic flood events including those occurring in 1942, 1971, 2010, 2011 and 2013. Overall, a good level of calibration was achieved with the hydrologic model able to reproduce the magnitude, volume and timing of historic flood hydrographs to an acceptable standard, and the hydraulic model able to accurately replicate the level and extent of historic floods. For the January 2013 event, the models simulated the peak flood level at the Bundaberg flood gauge to within 0.04m, and 90% of modelled levels were simulated to within ±0.3m of the flood levels recorded on the floodplain. Figure 6 provides a comparison of modelled and recorded flood levels at the Bundaberg flood gauge and illustrates the excellent level of calibration achieved.

Once calibrated, the flood models were used to assess the behaviour of flooding for design flood events ranging in size from the 2% AEP to the probable maximum flood (PMF). A sensitivity analysis was also undertaken to assess the impact of key model parameters and environmental factors such as spatial rainfall patterns, antecedent soil conditions, initial dam levels, floodplain roughness, river bed levels, tide conditions and climate change.

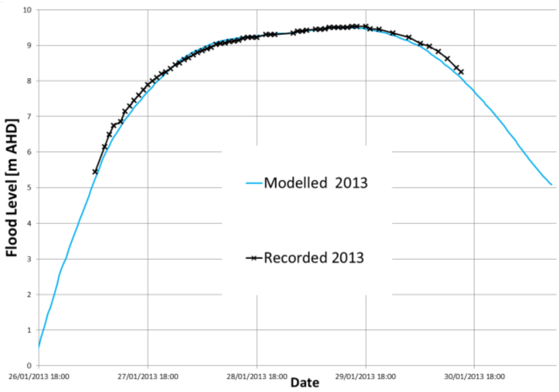


Figure 6 - Flood Model Calibration at Bundaberg Flood Gauge, January 2013.

In addition to the calibrated hydrologic and hydraulic models, key outputs from the flood study included:

- A flood frequency analysis of historic flood events;
- Local and regional flood level, depth, velocity and hazard inundation maps for historic and design flood events (refer Figure 7);
- Identification and description of river breakout locations, active conveyance zones, regions of flood storage and backwater areas.

- Incremental flood emergency mapping for inundation tied to key river gauges (a key learning from the 2010/11 events);
- Digital flood animations;
- An assessment of the potential for flooding due to extreme rainfall across local catchments;
- A general relationship between peak flood levels in Bundaberg and peak flood levels at upstream flood gauges; and
- Sensitivity analysis maps illustrating potential flood impacts including changes in flood levels, extents and velocities.

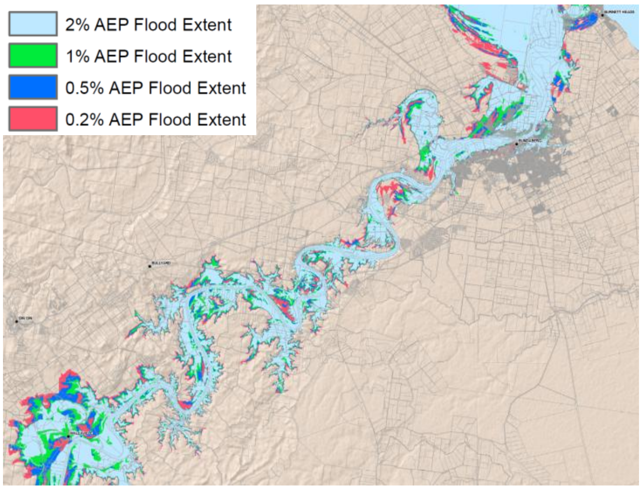


Figure 7 – Example Burnett River Regional Flood Extent Map

Model use during the Flood Event

Throughout the January 2013 flood event, Council relied upon the Bureau's flood warning predictions (river level and timing). However, in order to better understand the potential behaviour and extent of Burnett River flooding, Council also made use of key flood study outputs including:

- General relationships between flood levels (and flows) at upstream gauges (Paradise Dam & Walla) and flood levels in Bundaberg.
- Flood inundation maps at incremental flood gauge heights; and
- Digital flood animations.

During the event, council were able to:

- Use the flood levels predicted by the Bureau in conjunction with the flood study maps to estimate likely inundation extents;
- Use the relationship between actual Paradise Dam outflow rates and flood levels in Bundaberg in conjunction with flood study maps to estimate likely inundation extents (refer Figure 8); and
- Use the relationship between flood levels at the Walla flood gauge and flood levels in Bundaberg in conjunction with flood study maps to estimate likely inundation extents.

It is noted that the flood travel time between Paradise Dam and Bundaberg is typically in the order of 24 hours, and the travel time between Walla and Bundaberg 17 hours. This provides an opportunity for early flood warning.

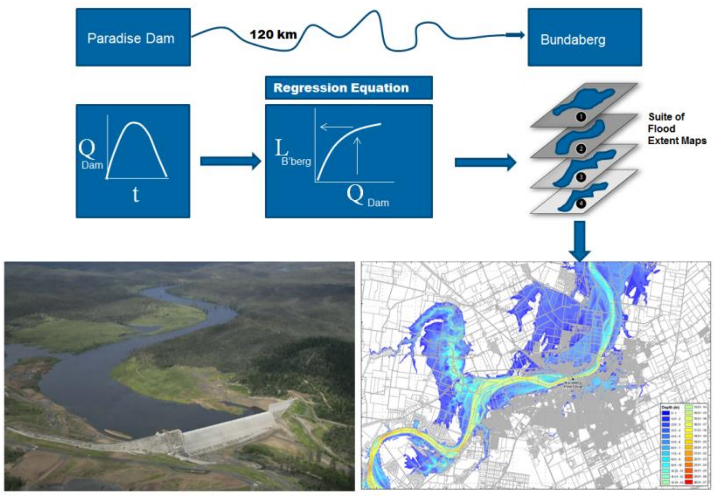
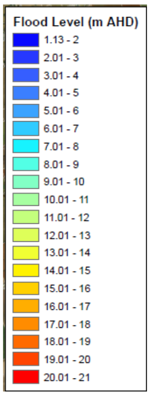


Figure 8 – Estimation of likely flood extents during 2013 event

During the event, flood inundation maps were also provided to disaster coordinators to provide an understanding of predicted inundation extents in Bundaberg for a given gauge level. The maps were in 0.5m gauge increments up to the 1% AEP with additional maps available for larger events. Figure 9 provides an example of an incremental gauge map which includes a table indicating the location of critical infrastructure.

ID	Description
1	Bundaberg Administration Centre
4	Quay Street Administration Centre:
6	Bundaberg Operations Centre:
7	Bundaberg Civic Centre
8	Kalkie Depot
11	Millbank Waste Water Treatment Plant
15	Bundaberg East Wastewater Treatment Plant
16	North Waste Water Treatment Plant
17	Thebeban Waste Water Treatment Plant
18	Bourbong Street Water Tower
19	Mt Perry Road Water Tower
20	Sussex St Water Tower
21	The Hummock
22	Turner Street Water Tower



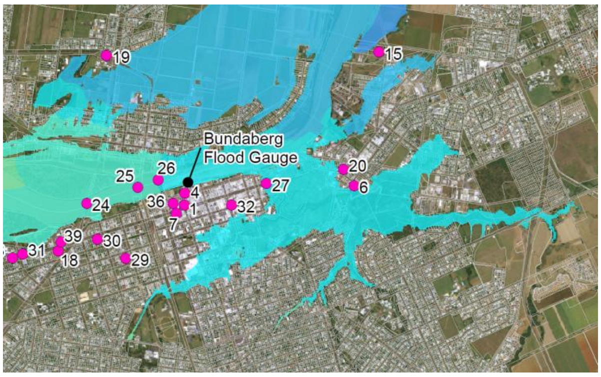


Figure 9 – Example of the incremental mapping from the Flood Model.

Through these maps it was apparent that between 7.0m and 9.0m on the Bundaberg Gauge, significant inundation would be experienced across North Bundaberg leading to complete isolation, inundation depths of several metres and extreme velocity which would not be navigable.

The hazard (V*D) and velocity information from the model also highlighted the risks to residential housing and potential for significant damage. This information proved invaluable to disaster coordinators and heavily informed decisions on mandatory evacuation.

Model use in Flood Recovery

The outputs of the flood model were also useful during the receding phase of the flood.

Flood animations clearly showed those areas of the floodplain that would first recede and those areas that would take longer to recede.

During the event, Council also used the incremental gauge maps from the hydraulic model to quickly develop a map that provided an overview of the likely water recession (refer Appendix B). The map was pivotal to the logistical recovery effort during the recession of flood water and included:

- A table of the estimated date/time of predicted flood levels at the Bundaberg Gauge as the flood waters receded. This gave the recovery effort an understanding of how long the flood waters would remain;
- Three zones of inundation duration being long, medium and short term labelled with their respective level ranges at the gauge. Recovery personnel could also use actual gauge recordings to understand flood water recession across the City;
- Urban Search and Rescue (USAR) zones of interest to allocate search parties and inspection teams; and
- Road names, building footprints, locality names and cadastral boundaries to assist external agencies in basic navigation.

A snap shot of the map is provided in Figures 10 and 11 below.

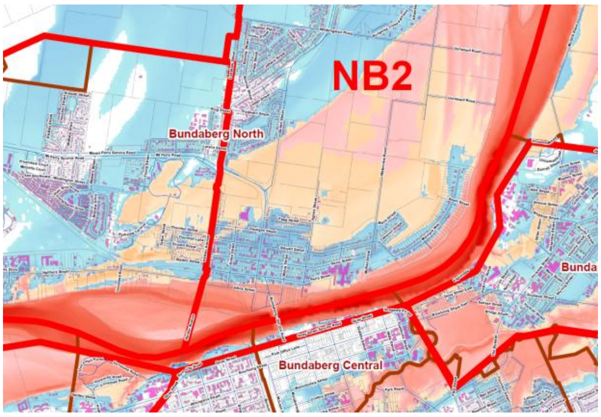


Figure 10 – Snap shot of the inundation recession map used in the January 2013 flood

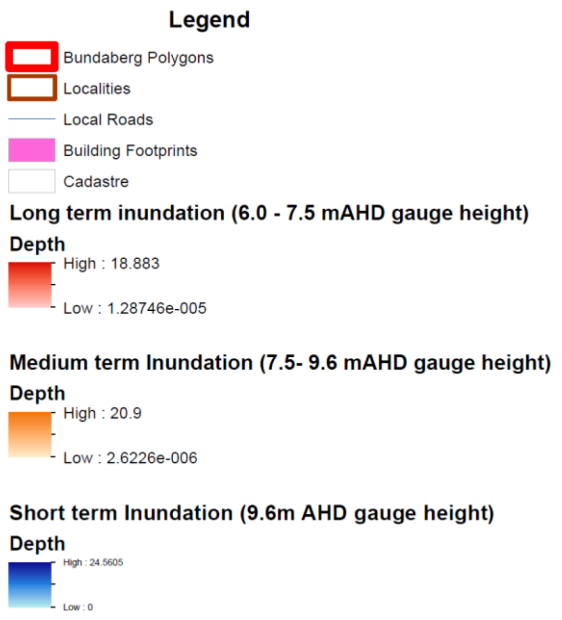


Figure 11 – Legend from the map showing zones of inundation based on gauge heights.

Mapping Products and Navigation

Another important facet of the flood emergency was the need for navigable mapping products for airborne assets. Council staff working with military personnel quickly realised that helicopters require grids of latitude, longitude on maps for navigation and as a result developed maps to cater for such purposes. This should be a key consideration in development of emergency mapping products.

Early Flood Warning System Upgrade

Following the flood disaster and analysis of rainfall records, an upgrade to the existing Lower Burnett River Flood Warning Network is being implemented. Funding of $205,000 from the Cyclone and Flood Warning Subsidy has been provided by the Department of Local Government, Community Recovery and Resilience. In a partnership between the Bureau and Council, upgrades will be made to existing gauging stations.

Existing gauges rely solely on the Telstra network. The upgrade will involve the addition of a VHF radio network to the Bureau's ALERT technology with new repeater stations sited at Mt. Goonaneman and Mt. Watalgan adding redundancy and reliability to the current network. A map of the proposed upgrade is provided in Appendix C.

The existing network of river gauging stations will be further enhanced with an additional six (6) rainfall only stations. These will be installed to help cover an ungauged area located between Mt. Perry and Walla. During the January 2013 event, extreme rainfall over this area generated local runoff that influenced the rising limb of the Burnett River hydrograph extending the duration of flood inundation.

The upgraded gauging stations will transmit real-time data to a base station located at the Bundaberg Regional Council's main administration centre. This will lead to increased situational awareness of rainfall conditions across the catchment and the potential for flooding.

Community Impacts and Loss of Life

Throughout the flood events of January 2013, the primary focus was preservation of human life. Wherever possible, decisions were being informed by the best available science including preliminary outputs from the flood model to improve the understanding of flood behaviour.

Tragically, one (1) human life was lost as a result of the Bundaberg floods.

The community impacts have been severe and many residents have been left traumatised. In such circumstances, the difficulties of gathering technical data post flood and sourcing data from some of the hardest hit areas of the community should never be underestimated. Emotional support should be provided to personnel involved in recovery efforts along with a basic understanding of common post flood behaviours.

The Australian Centre for Posttraumatic Mental Health (2011) describes what people may experience after a flood event:

- Shock and disbelief at what happened;

- Fear and apprehension that it might happen again;

- Anger at the unfairness and senselessness of it all; and

- Shame and guilt for not having acted differently and somehow feeling that they are to blame.

These behaviours have commonly been observed throughout communities living adjacent to the Burnett River.

Property and Infrastructure Damage

Following recession of flood waters, North Bundaberg was declared an exclusion zone to control people movements in the area. The damage sustained was extreme and became a high risk environment. Figures 12 - 14 below highlight some of the damage sustained to property and the road network.

Figure 12 – Property damage resulting from flood induced scour

Figure 13 – Road infrastructure damage, Kolan Street, North Bundaberg.

Figure 14 – Residential Property Destroyed by Flood Waters, Hinkler Avenue, North Bundaberg.

Appendix D provides a map of the Rapid Damage Assessments (RDA) that was undertaken by Urban Search and Rescue (USAR) personnel immediately after the flood waters receded. It provides a snapshot of the level of damage experienced to property across Bundaberg. Table 1 below indicates the extent of damage sustained.

Category	Houses Affected
Total	**50**
Severe	**448**
Medium	882
Minor	837
Undamaged	819

Table 1 – Rapid Damage Assessments of Bundaberg, post flood January 2013.

Approximately 4,040 houses were directly affected by the floods across the Bundaberg region. Over 600 businesses were also affected with the entire Hinkler Central Shopping Centre being inundated.

Flood Induced Scour

During the January 2013 flood, a number of properties in North Bundaberg experienced significant structural damage which was exacerbated by flood induced scour of alluvial soils due to high local flow velocities around building foundations. Anecdotal evidence also indicates that this phenomenon also occurred during the 1890 flood.

In order to better understand the factors contributing to scour, local “nested’ 2D hydraulic models were developed to simulate the impact of local features such as buildings and fences on local flow patterns and velocities; and a soil investigation by Coffey Geotechnics was also undertaken.

Figure 15 provides an example of the output from one of the nested hydraulic models, and Table 2 illustrates the relatively high local flow velocities estimated by the model.

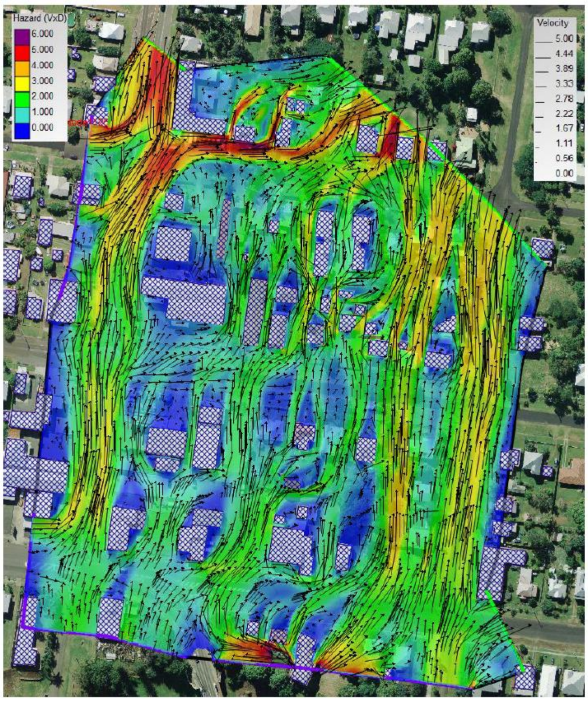


Figure 15 – Local Flow Patterns in North Bundaberg.

Description	Velocity
Property Maximum Velocity Mean	**3.46 m/s**
Property Maximum Velocity Std Dev	**0.95 m/s**
Lowest Property Maximum Velocity	**1.82 m/s**
Highest Property Maximum Velocity	**5.77 m/s**
1sigma	**4.41 m/s**
2sigma	**5.35 m/s**

Table 2 – Statistical Analysis of Flood Velocities, North Bundaberg, January 2013

These high flow velocities combined with the alluvial soils found in the North Bundaberg floodplain explain the significant depths of scour (up to 3m) experienced around several dwellings in this area.

New Guideline for Flood Induced Scour

In order to improve the structural resilience of buildings to flooding, BRC and GHD have developed a new guideline to assist building designers and owners to improve the resilience of dwellings to flood induced scour. The guideline provides a number of alternative designs including foundation protection methods and can be viewed on Councils website.

Conclusion

The events of January 2013 in Bundaberg clearly highlight the value a comprehensive flood study can bring to the decision making process during a large flood event, how the outputs of flood models can be used to improve the flood resilience of communities and the need for effective floodplain risk management planning.

Underpinned by science, as Dr Graeme Edwards famously quoted, ‘It’s not the plan that’s important… it’s the planning’ (Leflar et al. 2013).

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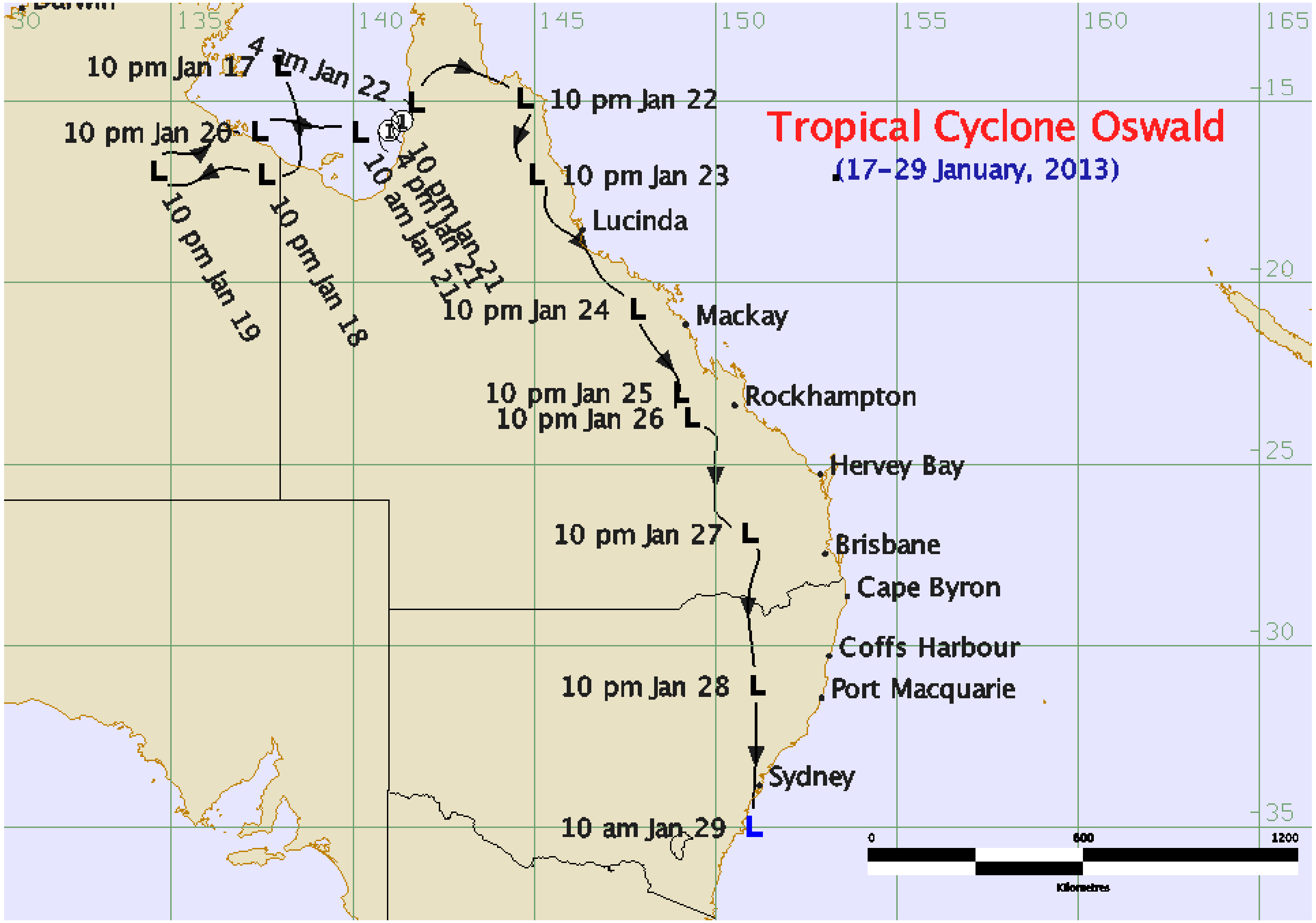
Appendix A

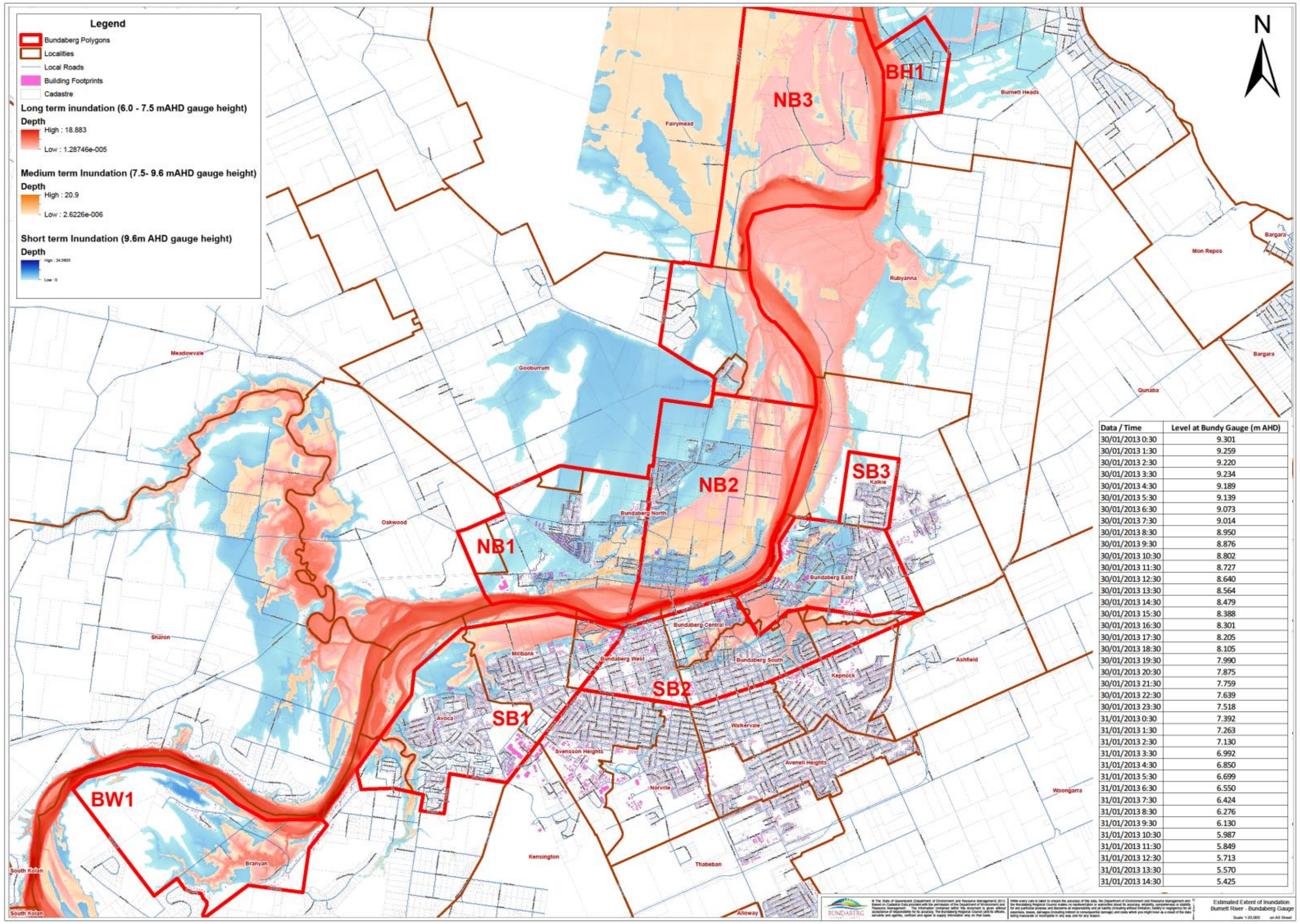
Tracking map of Ex-Tropical Cyclone Oswald



Source: Bureau of Meteorology (2013)

Appendix B

Map of estimated recession of Burnett River flood waters, Bundaberg



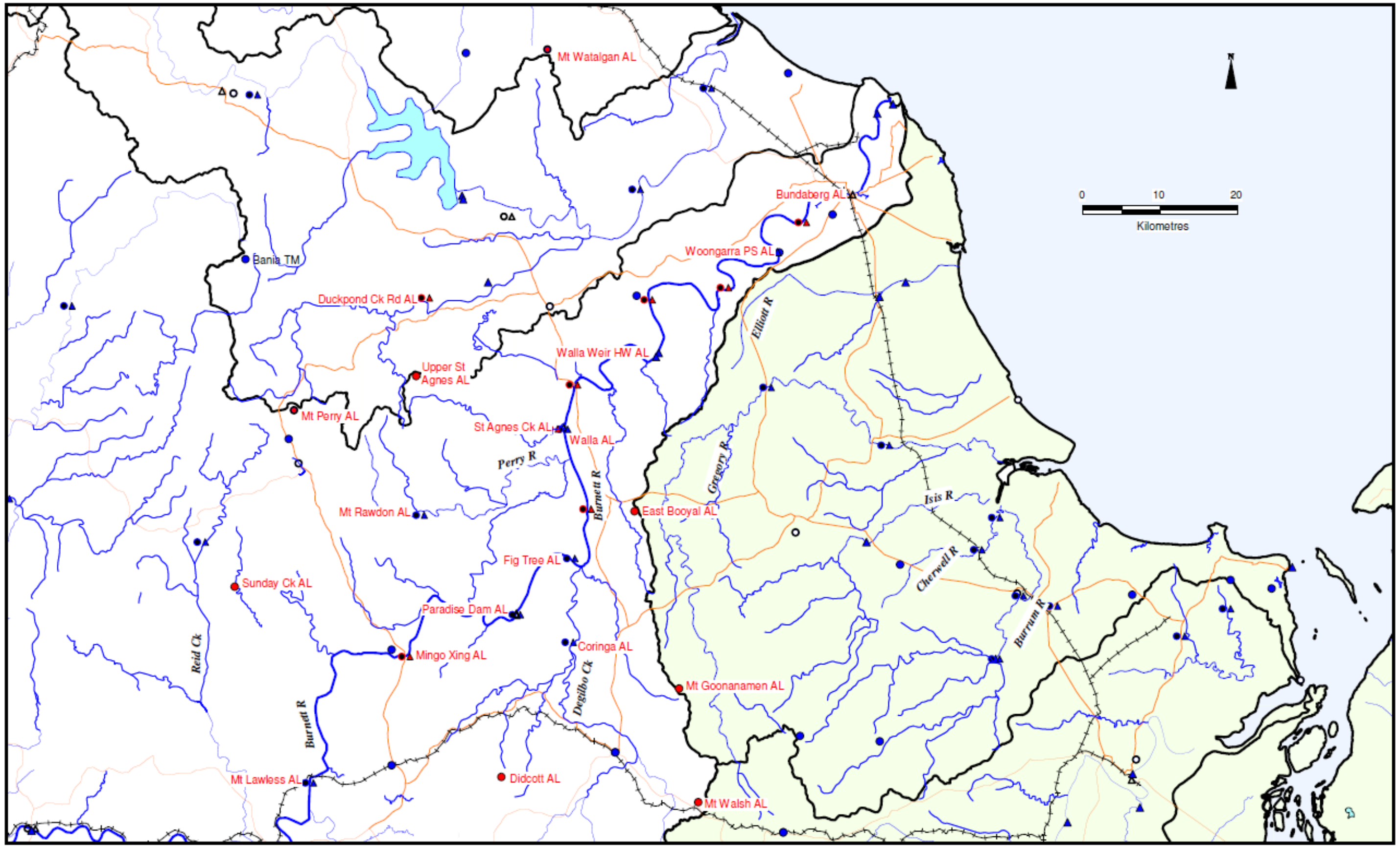
Data / Time	Level at Bundy Gauge (m AHD)
30/01/2013 0:30	9.301
30/01/2013 1:30	9.259
30/01/2013 2:30	9.220
30/01/2013 3:30	9.234
30/01/2013 4:30	9.189
30/01/2013 5:30	9.139
30/01/2013 6:30	9.073
30/01/2013 7:30	9.014
30/01/2013 8:30	8.950
30/01/2013 9:30	8.876
30/01/2013 10:30	8.802
30/01/2013 11:30	8.727
30/01/2013 12:30	8.640
30/01/2013 13:30	8.564
30/01/2013 14:30	8.479
30/01/2013 15:30	8.388
30/01/2013 16:30	8.301
30/01/2013 17:30	8.205
30/01/2013 18:30	8.105
30/01/2013 19:30	7.990
30/01/2013 20:30	7.875
30/01/2013 21:30	7.759
30/01/2013 22:30	7.639
30/01/2013 23:30	7.518
31/01/2013 0:30	7.392
31/01/2013 1:30	7.263
31/01/2013 2:30	7.130
31/01/2013 3:30	6.992
31/01/2013 4:30	6.850
31/01/2013 5:30	6.699
31/01/2013 6:30	6.550
31/01/2013 7:30	6.424
31/01/2013 8:30	6.276
31/01/2013 9:30	6.130
31/01/2013 10:30	5.987
31/01/2013 11:30	5.849
31/01/2013 12:30	5.713
31/01/2013 13:30	5.570
31/01/2013 14:30	5.425

Appendix C

Map of proposed upgrade to the Lower Burnett River Flood Warning Network.

Australian Government
Bureau of Meteorology

MAP 136.2



- Manual Heavy Rainfall Station
- Daily Reporting Rainfall Station
- Manual River Station
- Telemetry Rainfall Station
- Telemetry River Station

LOWER BURNETT RIVER
PROPOSED ALERT FLOOD WARNING NETWORK

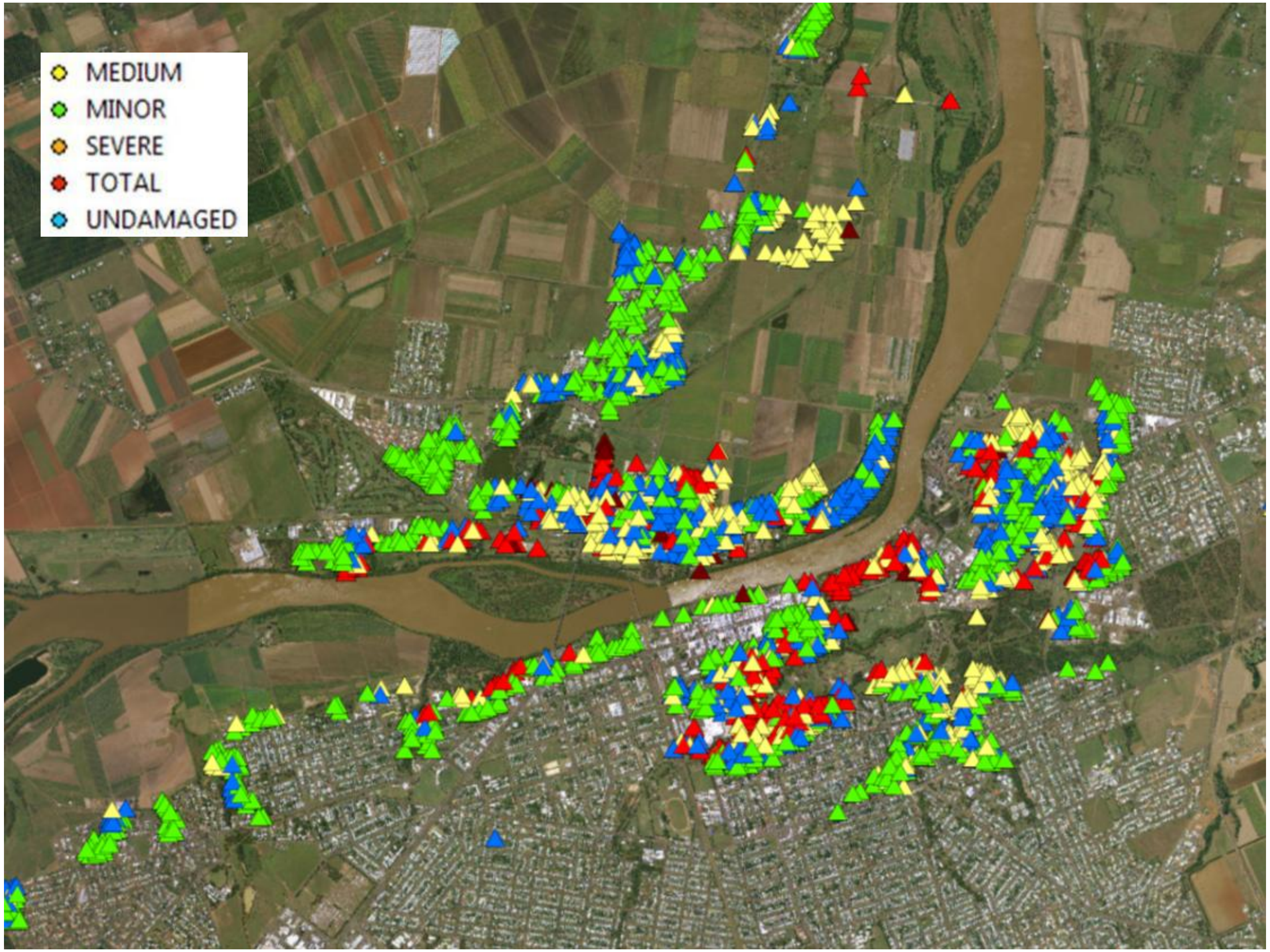
Major Roads
Railway

Revised: June 2013

r/pub/maps/map06/map136_2.wor

Appendix D

Map of Rapid Damage Assessments (RDA) of Bundaberg immediately following flood waters recession.



Source: Department of Community Safety (2013)

Author Biographies

Dwayne Honor is the Design Manager for the Bundaberg Regional Council and has been working in local government over the last 10 years.

In preparation for a new regional planning scheme he is the Project Manager for the Burnett & Kolan River Flood studies and the Burnett River Floodplain Risk Management Study. He was working out of the Local Disaster Coordination Centre for ten days assisting in planning and logistics while supporting Urban Search and Rescue (USAR) teams during the January 2013 floods. Dwayne is deeply entrenched in recovery projects for the foreseeable future to assist the Bundaberg regions flood recovery.

Educated at Central Queensland University (Rockhampton), he has degrees with Distinction in Engineering Technology and Business Administration and is a committee member of the Central Queensland Branch, Queensland Division, Institute of Public Works Engineering Australasia (IPWEA).

Postal Address: Dwayne Honor, Manager Design

Bundaberg Regional Council

PO Box 3130, Bundaberg Qld 4670

E-mail: dwayne.honor@bundaberg.qld.gov.au

Ben Regan is a senior engineer at GHD Pty Ltd. Ben has over 13 years experience in the delivery of flood related projects to private and public sector clients. Ben was the project director for the Burnett River and Kolan River Flood Studies and assisted Council during the January 2013 event. Ben's qualifications include a Bachelor of Engineering (Hons), Master of Applied Finance, and a Master of Business Administration from the University of Queensland.

Postal Address: Ben Regan, Senior Engineer GHD Pty Ltd

GPO Box 668 Brisbane QLD 4001

E-mail: ben.regan@ghd.com