FLOOD FORECAST MAPPING SANS MODELLING

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Abstract

The 2012 Queensland Floods Commission of Inquiry recommendations reiterated the requirement for local Councils to be responsible for flash flood warnings. Given that a flash flood is defined by a 6 hour response time, a method of providing flooding intelligence (by way of mapping) that is both rapid and simple, is essential. Existing methods utilising waterRIDE™ software connected to a Flood Warning System, such as Enviromon or TARDIS, generally provide forecast capabilities by means of additional modelling (such as real-time hydrologic modelling), which necessarily adds complexity to the system. Depending on the sophistication of the modelling approach, the time required for this extra step can significantly reduce the available time to respond and compromise an effective disaster management response. Sunshine Coast Council is prototyping a new method of flood forecasting, in partnership with Reliant Systems (TARDIS) and WorleyParsons (waterRIDE™). This paper provides detail on how these two systems are combined to rapidly deliver regional flood forecast mapping directly from catchment average rainfall IFD information without the need for additional hydrologic or hydraulic modelling.

Introduction

In January 2014 Sunshine Coast Council installed TARDIS flood warning system (FWS) management software to integrate with Enviromon and provide Local Disaster Coordination Centre (LDCC) hydrologists with a means of accessing FWS rainfall and river level information remotely on mobile devices. This system provided Intensity-Frequency-Duration (IFD) functionality at rain gauges. It was desirable to have the same functionality at locations within the catchment, that accounted for average rainfall of the contributing catchment.

Stream Point IFD

Reliant Systems were engaged to deliver this functionality, which was called Stream Point ARIs. For each stream point a polygon and a catchment area was provided to

TARDIS. Stream Point catchment rainfall was calculated using Thiessen Polygon methodology used to determine weightings to apply at nearby gauges. These weightings were also applied to the design rainfall information of the same gauges and multiplied by an areal reduction factor. This is shown in Figure 1.

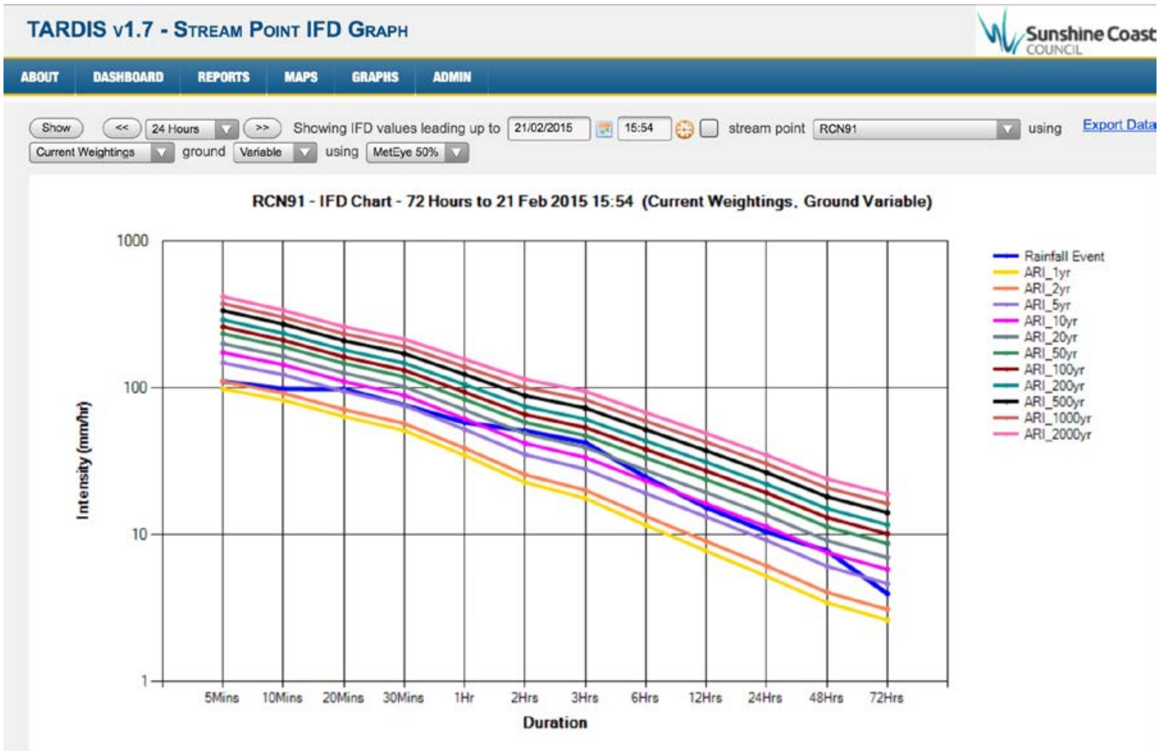

Figure 1 Stream Point IFD graph, Glass House Mountains post Ex TC Marcia

It was then desirable to be able to quote an Average Recurrence Interval (ARI) for the likely flooding that would be associated with such rainfall. This requires Annual Exceedance Probability (AEP) neutral assumptions to be applied to all other dependant factors, most notably catchment losses, in order for the probability of flooding to be derived from rainfall.

Losses

The method relies on AEP neutral assumptions to determine the probability of flooding. The Antecedent Precipitation Index (API) is calculated by TARDIS on a six hourly basis for each regional catchment within the Sunshine Coast Local Government Area (LGA). Thiessen Polygons are again used to determine an average rainfall for each of the regional catchments.

Data was provided by Seqwater for Queenland Catchments showing API and Initial Loss. This is shown in Figure 2. TARDIS applies loss to the Stream Point IFD as Continuing Loss. The Seqwater relationship was used to determine API values representing four catchment saturation categories based points of inflection in the polynomial relationships. Table 1 shows the API values adopted. The continuing loss values for the saturation categories were notionally determined by SCC hydrologists based on engineering judgement and experience. Whilst four categories have been applied at SCC, TARDIS allows for up to 11 saturation categories.

Table 1 Loss Categories

Saturation Category	API	Continuing Loss (mm/hr)
Very Dry	0	10
Dry	30	5
Wet	100	2.5
Very Wet	160	0

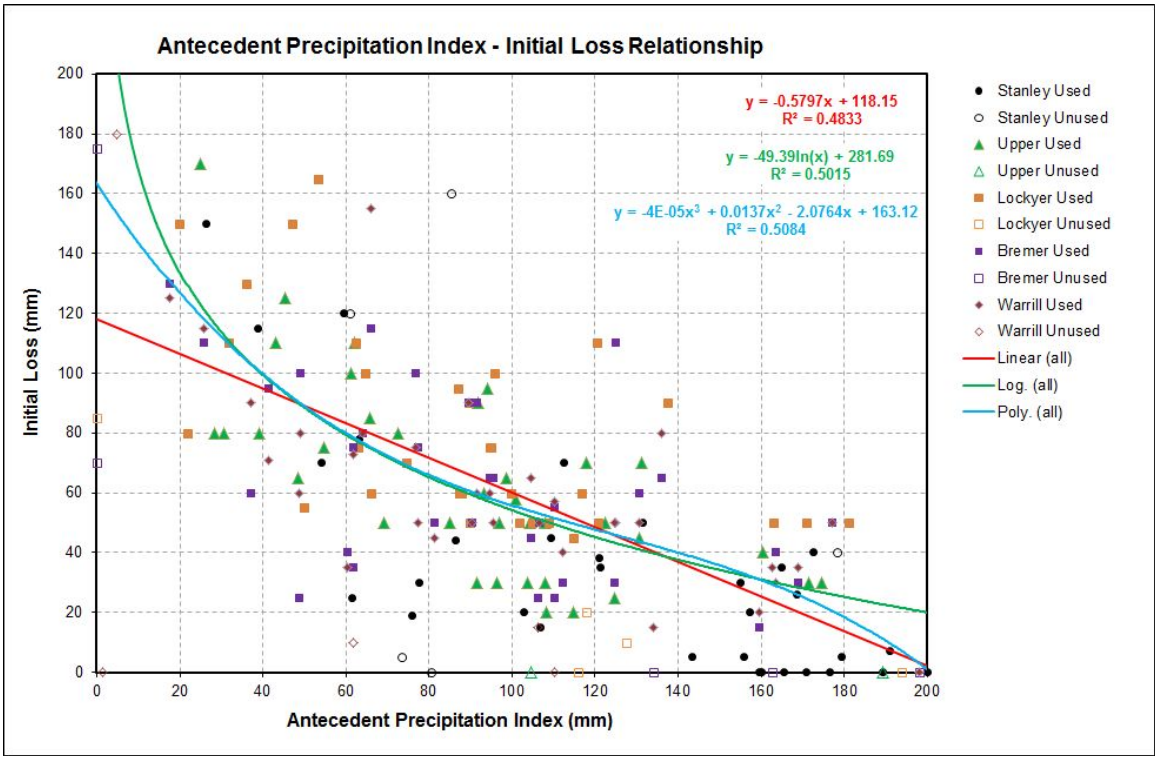

Figure 2 Seqwater data on API vs Initial Loss

Time of Concentration

It also required a Time of Concentration (Tc) to be determined that represents the duration of rainfall with intensity that produces the peak flood flow for the location. This is considered to be equivalent to the definition of Tc required for the rational method.

Tc methods of Australian Rainfall and Runoff (ARR, 1999) and the Queensland Urban Drainage Manual (QUDM, 2013) were investigated, including the Bransby-Williams' equation, the Main Roads Department Rational Method (QLD) and the Eastern NSW rational method. ARI estimates were derived from the Stream Point IFDs at ARR derived Tc values and compared to flood frequency estimates for available historic events (generally less than Q10 as the analysis was limited to recent record given the installation dates of available stream gauges). The comparison was not favourable and it was concluded that ARR Tc estimation methods were either not suitable or were too difficult to accurately derive required parameters.

A new relationship was determined for the Sunshine Coast Council LGA. This was done by estimating the Tc values required from Stream Point IFD curves to match the ARI from flood frequency analyses. This relationship is shown in Figure 3. It was discovered that area (in km^2) with a variable exponent was a good determinant of Tc.

The variable exponent (m) is presumed to relate to the stream geomorphology and hence conveyance characteristics. Within the Sunshine Coast Council LGA it was observed that m values varied between 0.65 (incised catchments with better conveyance) to 1.05 (flat catchments with meandering channels and lower conveyance). It was also observed that on approach to the river mouth, where the waterways opened (representative of a large catchment area to stream length ratio) the value of the m exponent reduced below 1 indicating improved conveyance characteristics and a reduction in run time (relative to an equivalent area catchment).

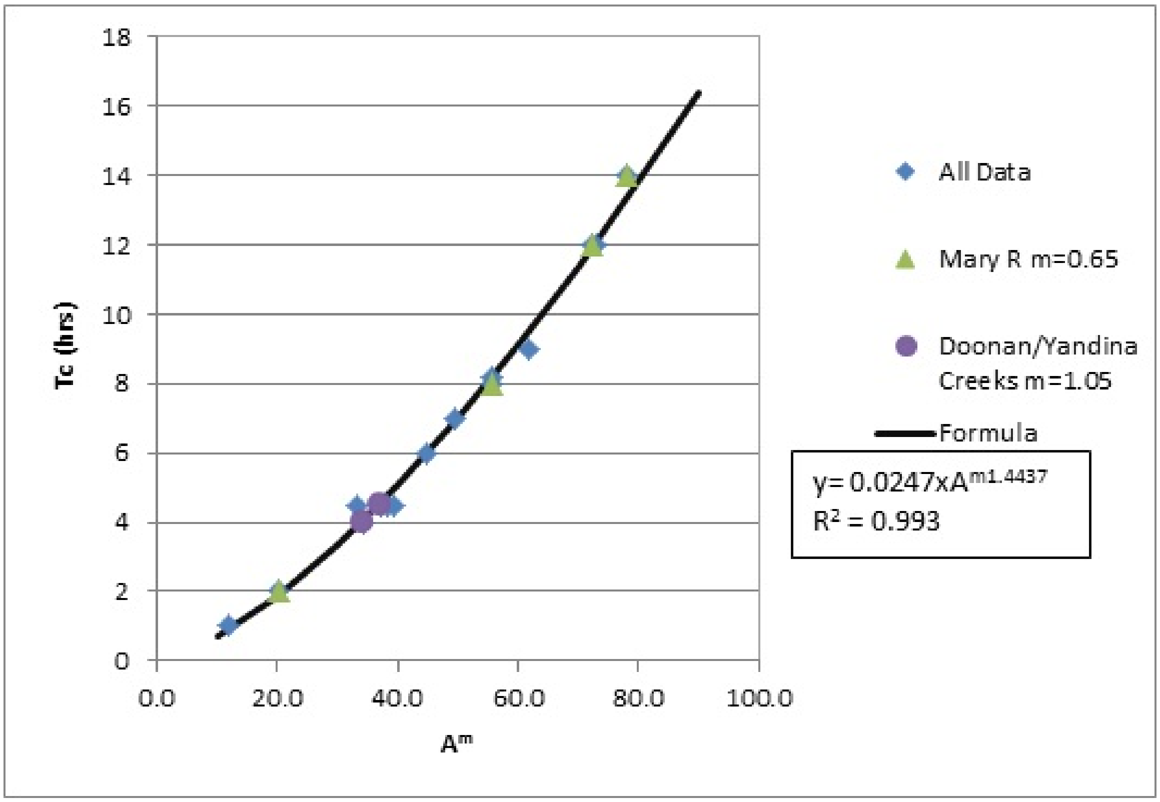

Figure 3 Sunshine Coast Time of Concentration Relationship

For natural catchment areas below $25km^2$, the following adjustment is recommended:

$$Tc_i = Tc \times \frac{A_i}{25}$$

Tc values are rounded to 15 minute values when entered to TARDIS. This simplification allows for TARDIS to perform IFD calculations much faster.

The Stream Point ARI map shows the ARI, derived from the Stream Point IFD at the Tc. It colour codes minor (yellow), moderate (orange) and major (red) flooding. This is shown in Figure 4.

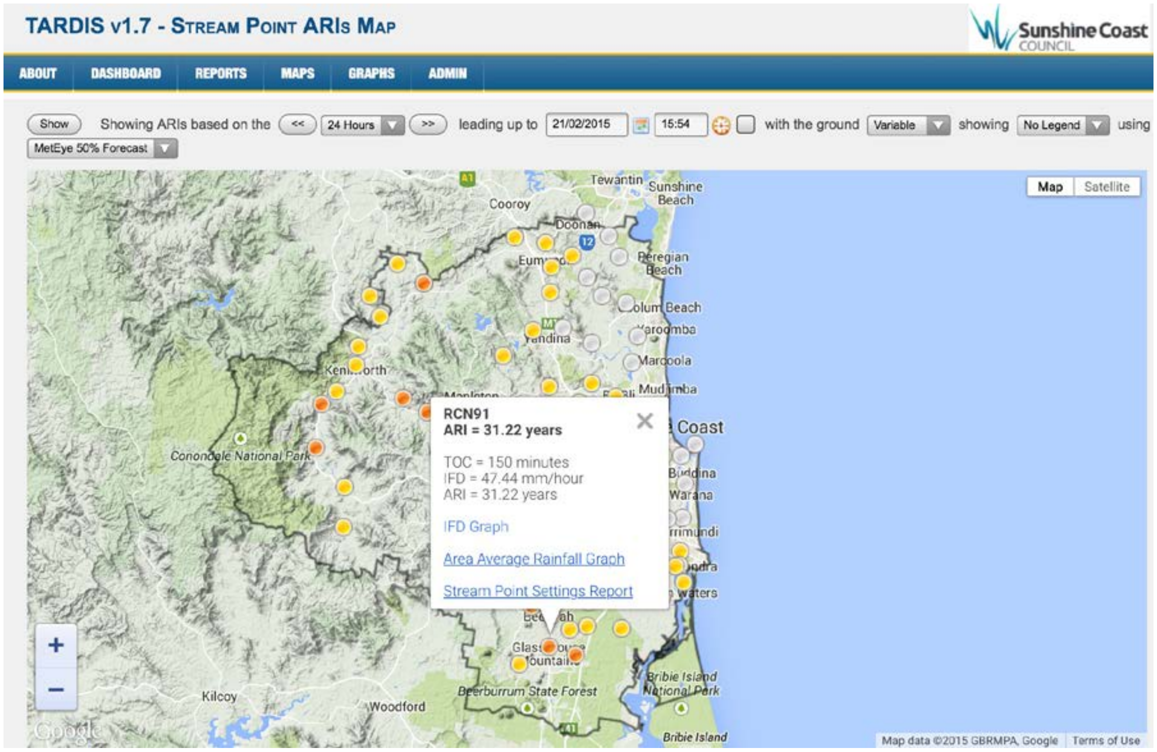

Figure 4 Stream Point ARI map showing ARI at a selected Stream Point

Forecast Rainfall

Sunshine Coast Council subscribes to Bureau of Meteorology ADFD rainfall forecasts, as seen on MetEye (BoM, 2013). This provides up to 48 hours of 3 hourly interval forecast rainfall, with 3 forecast scenarios (50%, 25% and 10%). Each scenario representing the percentage chance of exceeding the magnitude provided in the interval. TARDIS automatically retrieves these forecasts and archives them. It then interpolates the forecast rainfall at each of the active FWS rain gauges. When the TARDIS date and time is set into the future, forecast rainfall is seamlessly applied. Thus when a TARDIS Stream Point ARI map is prepared with the time set 6 hours into the future and a 48 hour duration of analysis, the analysis uses 42 hours of actual rainfall in the IFD analysis of event rainfall data.

waterRIDE^{TM} Integration

WorleyParsons created a waterRIDE^{TM} forecast project using 76 TARDIS Stream Points for the entire Sunshine Coast LGA.

Figure 5 shows the zones of influence created for Stream Points. A reasonably detailed representation has been adopted for the SCC LGA and this directly affects the run-time of the waterRIDE^{TM} calculations (ref Table 2). The degree of detail in the zones of influence is a critical determinant in the overall precision versus run-time consideration.

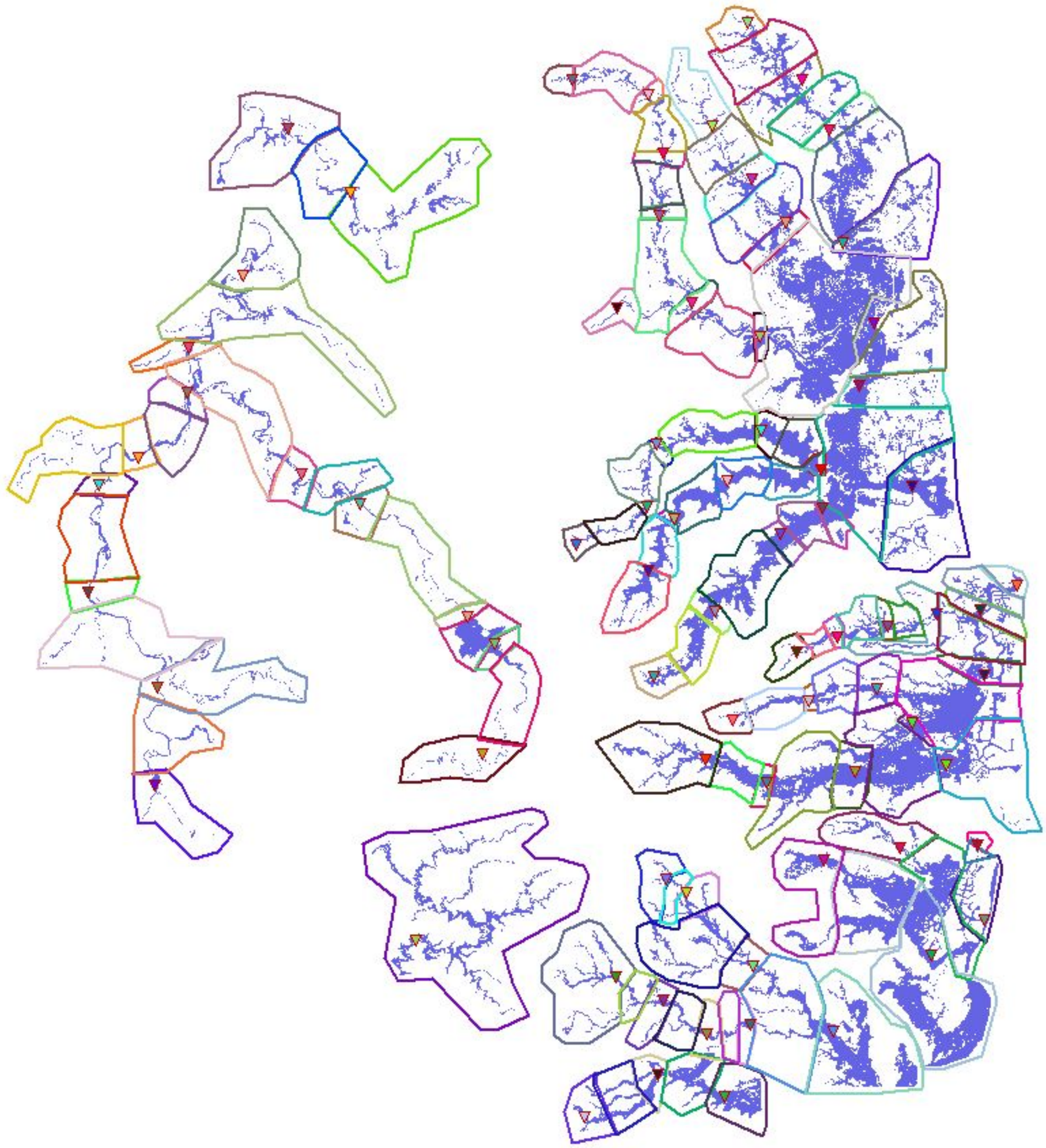

Figure 5 waterRIDE^{TM} Zones of Influence polygons for SCC LGA

WorleyParsons also updated waterRIDE^{TM} to allow ARI values to be imported rather than water level. On import to waterRIDE^{TM} the ARI values are converted to water level using the multiple ARI mapping layers already available to waterRIDE^{TM}.

There are two ways of importing the ARI values. Manually this can be imported indirectly through a CSV file. This also allows for the analysis of historic events. Automatically waterRIDE™ can import the ARI values at each of the 76 Stream Points using a TARDIS stored procedure to query the SQL tables of the TARDIS database.

Once converted to water level, waterRIDE™ is then able to undertake its established methods for interpolating an event map from the multiple ARI mapping layers available. This process is shown conceptually in Figure 6.

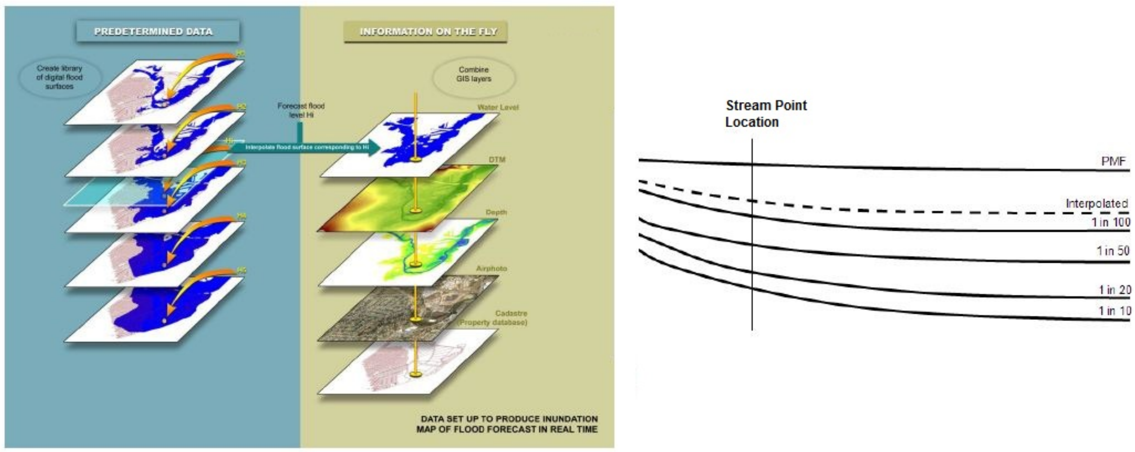

Figure 6 wateRide™ Interpolation Process

The waterRIDE™ application first computes a surface interpolation. It then publishes the map as a gridded water level and depth information as well as a shape file. All of these published formats are ready for import into a GIS for flood consequence analysis. The gridded product is preferred as it computationally easier to create and therefore provides a faster disaster management product.

Performance

The run time performance of the TARDIS and waterRIDE™ components of the system is provided in Table 2.

Table 2 Component Run Time

Predictive Component	**Time**
TARDIS (Stream Point ARIs)	<5 seconds
waterRIDE™ (Surface Interpolation and grid extractions for mapping)	~6 minutes (Server) ~13 minutes (Laptop)

The performance of the system to accurately predict flood extents was tested against a historic event for which flood mapping existed. This event occurred in Nambour on the 24th January 2012. The catchment area to this location is $38km^2$ and the resultant Tc is 4.75 hours, confirming the location as subject to flash flooding. The mapping from waterRIDE™ was compared with mapping produced by a GIS Analyst from peak water levels extracted from the FWS stream gauge and maximum height gauges. This flood extent took several hours to produce following collection of levels from the maximum height gauges.

It is considered that the agreement between the forecast flood extent and the flood event estimated using post event data, is excellent. It is therefore concluded that this method of flood extent estimation is appropriate for informing local disaster coordination centre operations during an event.

The peak water occurred at 21:25 with the minor flooding threshold exceeded at 20:00. The TARDIS lead time on predicting the peak and the threshold exceedance of the minor flood level was 1 hour (without forecast rainfall). This is considered reasonable lead time performance. With automated waterRIDE™ mapping it is possible to understand the extent of flooding approximately 55 minutes prior to the peak occurring. Traditional method of forecasting, where a hydrological model is utilised, would require extra time to complete the intermediate calculations prior to mapping, with the extra complexity introducing the potential for increased uncertainty or process failure in the estimation of the peak.

It is possible for the run time performance of the waterRIDE™ mapping to be improved based upon a simplification of the zones of influence and number of adopted Stream Points used for mapping. WorleyParsons have provided simplified zones of influence however the testing of precision vs run time has not yet been undertaken, in part because the current system performance is considered acceptable.

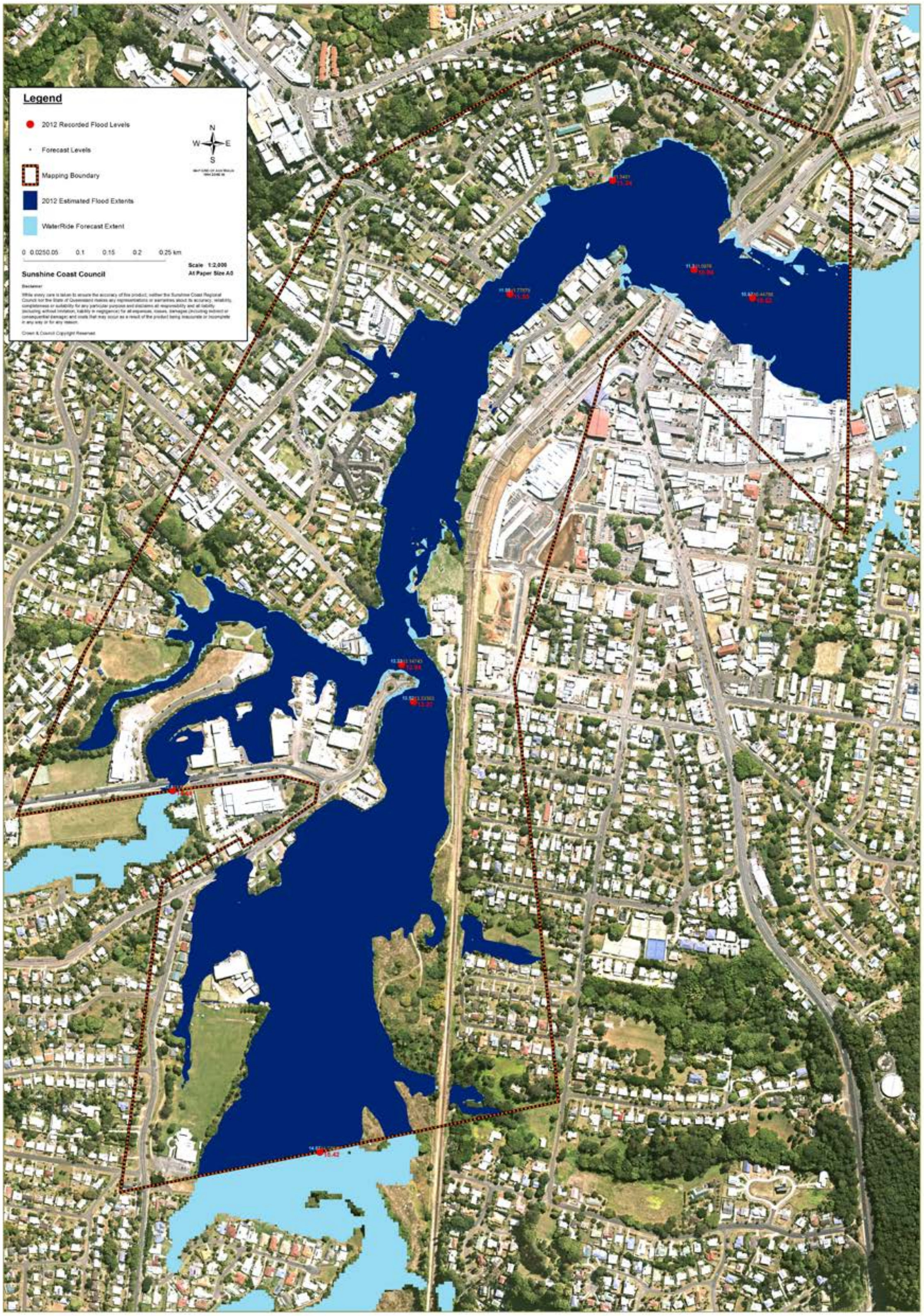

Figure 7 Nambour January 2012 Flood Event Mapping Comparison

Conclusions

It is considered that the methodology presented in this paper and attached case study is appropriate for the determination of peak flood levels and extents. The method relies upon a good spatial coverage of real-time telemetered rainfall gauges and pre-determined flood mapping for a broad range of probabilities that has been calibrated to ensure AEP neutrality.

The reliance upon the assumption of AEP neutrality is critical and for this reason the method in its current form is not recommended for tidally influenced locations, although the authors are currently working on an adjustment method based on tidal prediction.

Similarly large dams can affect the assumption of AEP neutrality and the sensitivity of drawdowns on the value of Tc needs to be understood. The catchment presented in the case study (Appendix A) of this paper does include a large dam, however the area of interest is significantly far enough down-stream for the results to be insensitive to the influence of the dam.

It is considered that this methodology has significant benefits for flash flood determination in small rivers and creeks, when compared to traditional methods of estimation that rely on hydrologic or hydraulic models for intermediate calculations. These benefits include:

- Reduced calculation time
- Reduced process complexity
- Reduced likelihood of process failure or requirement for intervention
- Reduced costs relating to model creation and maintenance
- Not sensitive to compounding volume error associated with flows.
- Not as sensitive to timing error associated with multiple catchment inflows
- Ability to use the results to check the AEP neutrality of design flood results
- Ability to quickly inform the location of post event data collection.

Additional enhancements to the methodology are currently being investigated, these include:

- Estimation of the time to peak based upon the area average rainfall for the Stream Point.
- Conversion of ARI to water level in TARDIS using tabulated information extracted from waterRIDE™. This will allow the immediate determination of a forecast peak water level at Stream Points.
- A method of estimating the value of the exponent ‘m’ utilised in the Tc equation presented in this paper.

The Tc relationship presented in this paper is for natural creeks and rivers only. It is not intended for rational method urban drainage analysis.

Reference:

Bureau of Meteorology, 2015, *MetEye – your eye on the environment*, http://www.bom.gov.au/australia/meteye, Commonwealth of Australia.

Department of Energy and Water Supply 2013, *Queensland Urban Drainage Manual, Third Edition 2013 –provisional,* State of Queensland, Brisbane City Council; Institute of Public Works Engineering Australia Queensland Division

Jordan, P, Weinmann, E, Hill, P, Weisenfeld C 2013, Australian Rainfall and Runoff Revision Project 2: Collection and Review of Areal Reduction Factors, Collation and Review of Areal Reduction Factors from Application of the CRC-FORGE Method in Australia, Engineers Australia, Barton ACT.

Pilgrim, D. H 2001, Australian Rainfall and Runoff Book Four, Estimation of Design Peak Discharges, Volume One, Engineers Australia, Barton ACT.

APPENDIX 1 CASE STUDY EX TC MARCIA 20-21 FEBRUARY 2015

On 18 February 2015 the State Disaster Coordination Centre held a teleconference with their Bureau Meteorologist proving a weather briefing to all Local Disaster Coordination Centres. At that briefing advice was provided in relation to the pending Cyclonic conditions facing the Capriconia Coast and the likelihood of heavy rainfall associated with a leading trough followed by further heavy rainfall associated with a decaying cyclone. The specific advice for the Sunshine Coast was to expect up to 500mm of rain during the period up to Saturday 21 February. This broad long-range forecast proved reasonably accurate as shown in Figure 8.

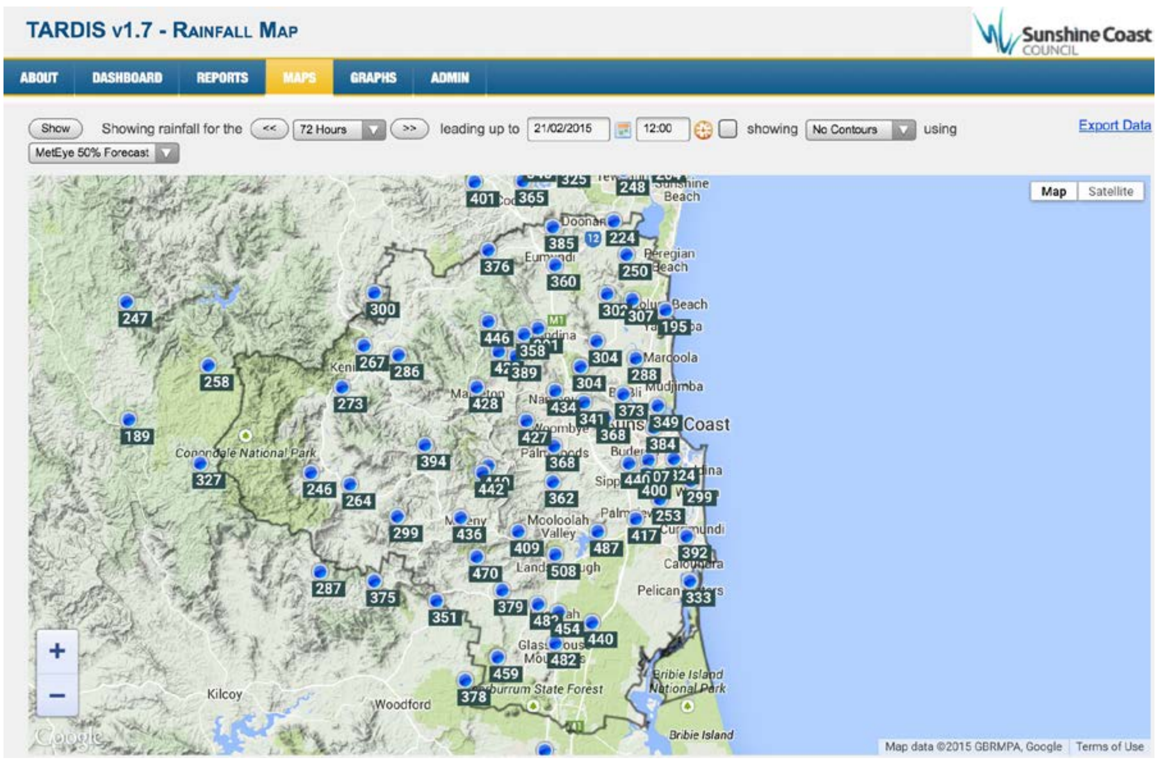

Figure 8 Rainfall associated with Ex TC Marcia

Figure 9 shows the Gympie Radar image at 11:30 hours on Friday 20th February 2015. The rainfall associated with leading trough and the cyclonic shape are clearly visible.

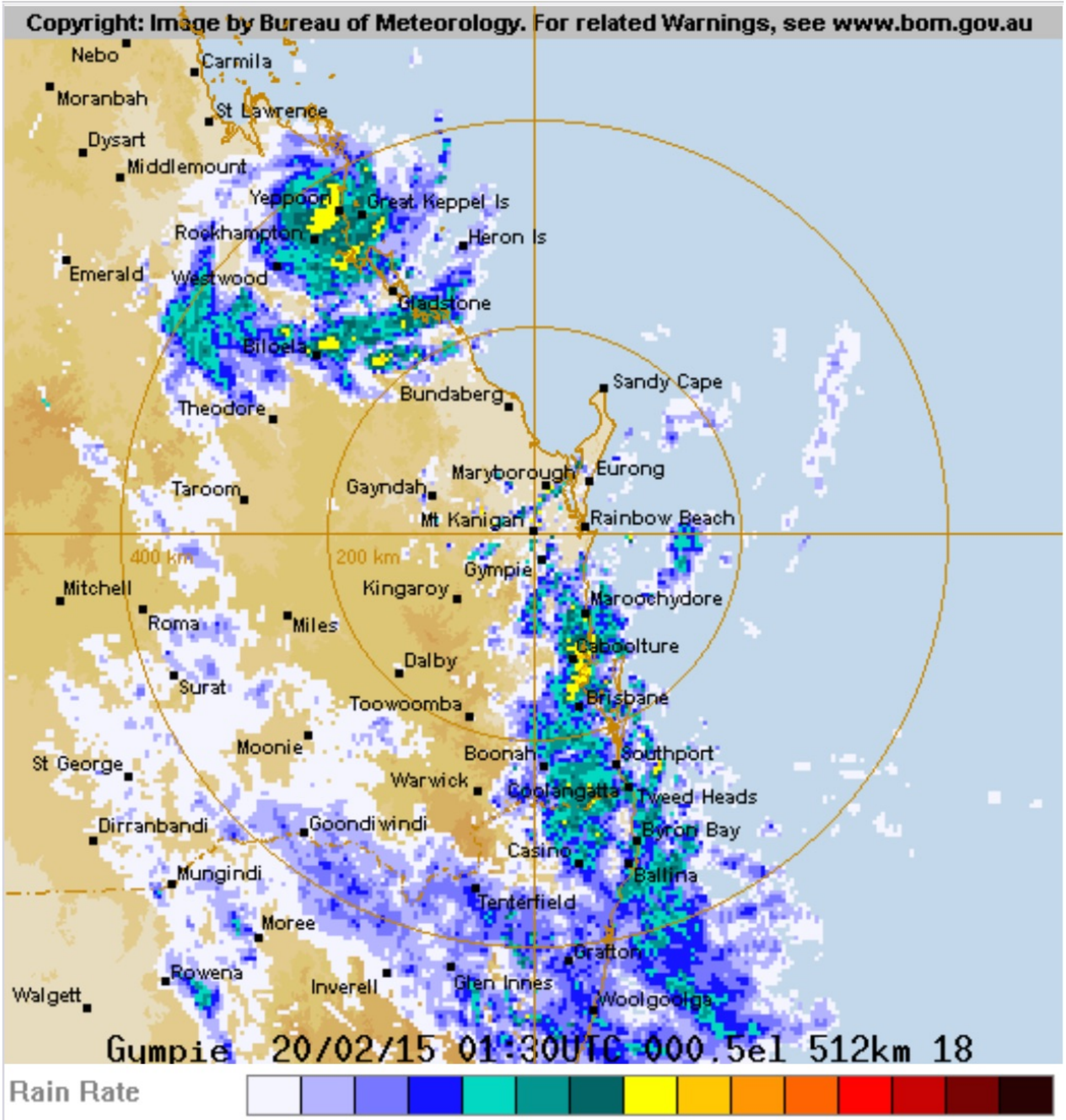

Figure 9 Gympie Radar at 11:30 on Friday 20th February 2015

Figure 10 shows the summary of the TARDIS Dashboard at 11:30 on Friday 20th February 2015 with Stream Point ARIs also accounting for BoM ADFD Forecast estimates to 15:00. Figure 11 shows the Stream Point ARI estimates at that time. Widespread minor flooding east of the dividing range was predicted.

The severity of rainfall or flooding is shown in TARDIS using customised thresholds combined with a colour scheme applied to nodes. Below minor severity is shown without colour (<Q2), above minor (Q2) is shown as yellow, above moderate (Q10) is shown as orange and above major (Q100) is shown as red.

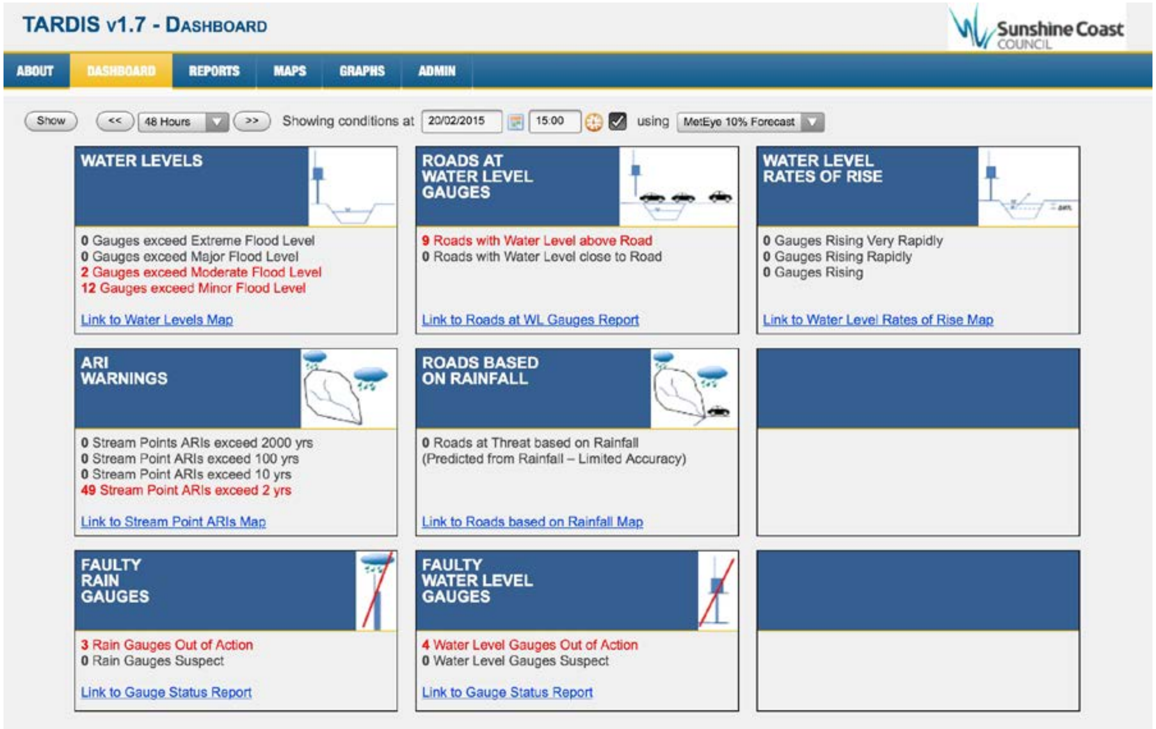

Figure 10 SCC TARDIS Dashboard at 11:30 on 20th February 2015 with forecast rainfall to 15:00

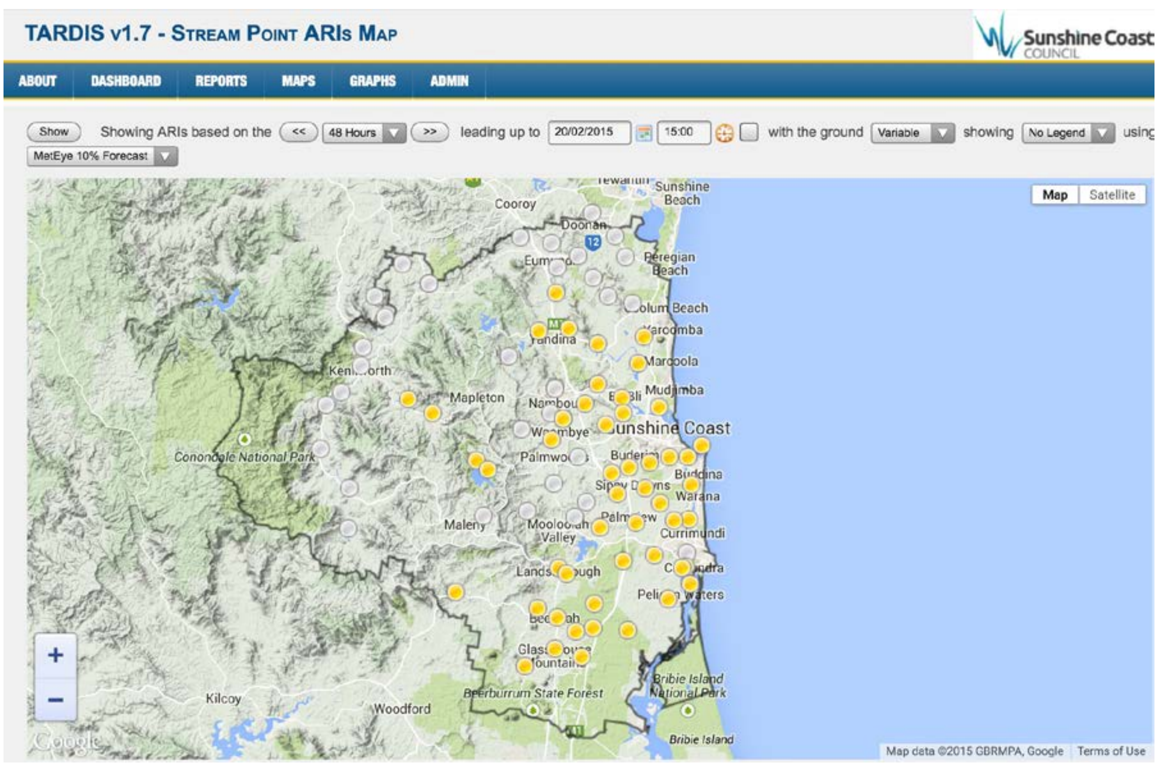

Figure 11 SCC Stream Point ARI Estimates at 11:30 on 20 February 2015 with Forecast to 15:00

At the conclusion of the rainfall for the event on Saturday 21st February 2015, the Stream Point ARI map, Figure 12, shows that widespread minor flooding was again predicted with moderate flooding also predicted in Glasshouse Mountains and the Mary River and Obi Obi Creek downstream of Baroon Pocket Dam.

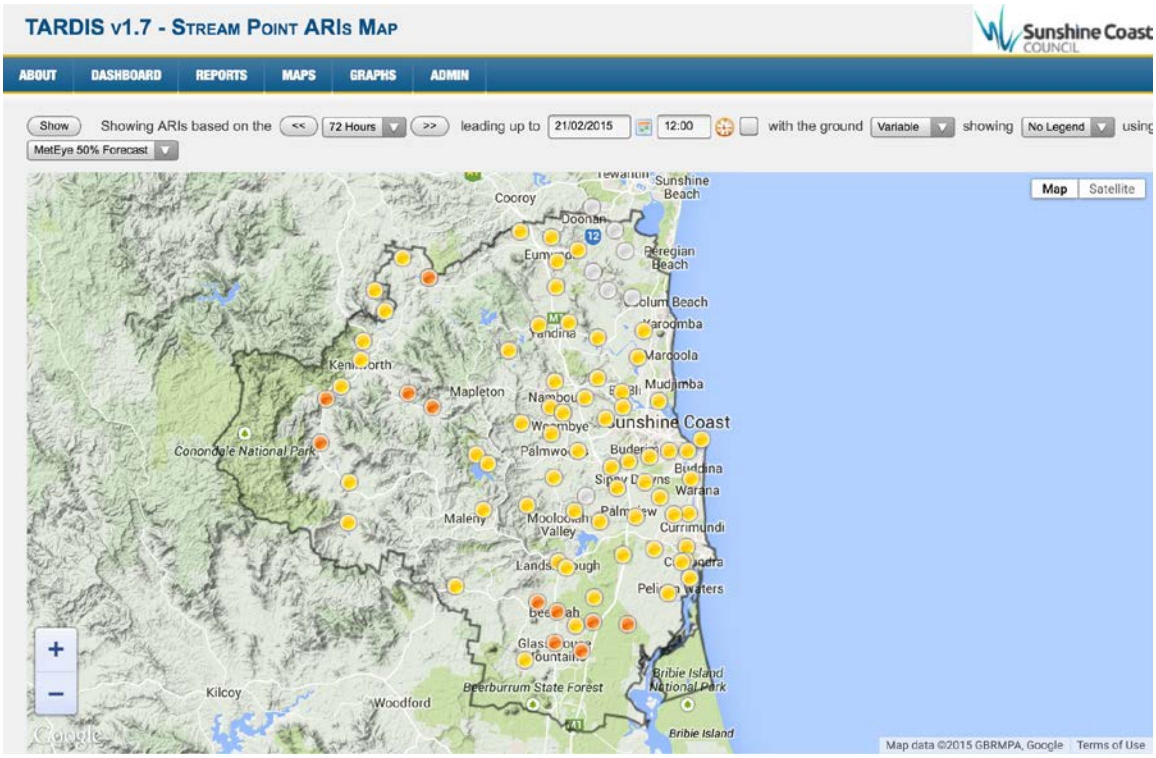

Figure 12 Ex TC Marcia Stream Point ARIs at conclusion of Rainfall

Figure 13 shows a loss sensitivity check of the estimated Stream Point ARIs. As the variable loss condition had determined that the catchment was very wet, a wet catchment saturation was tested. This showed that moderate flooding from rainfall was still likely surrounding Glasshouse Mountains and in Obi Obi Creek downstream of Baroon Pocket Dam.

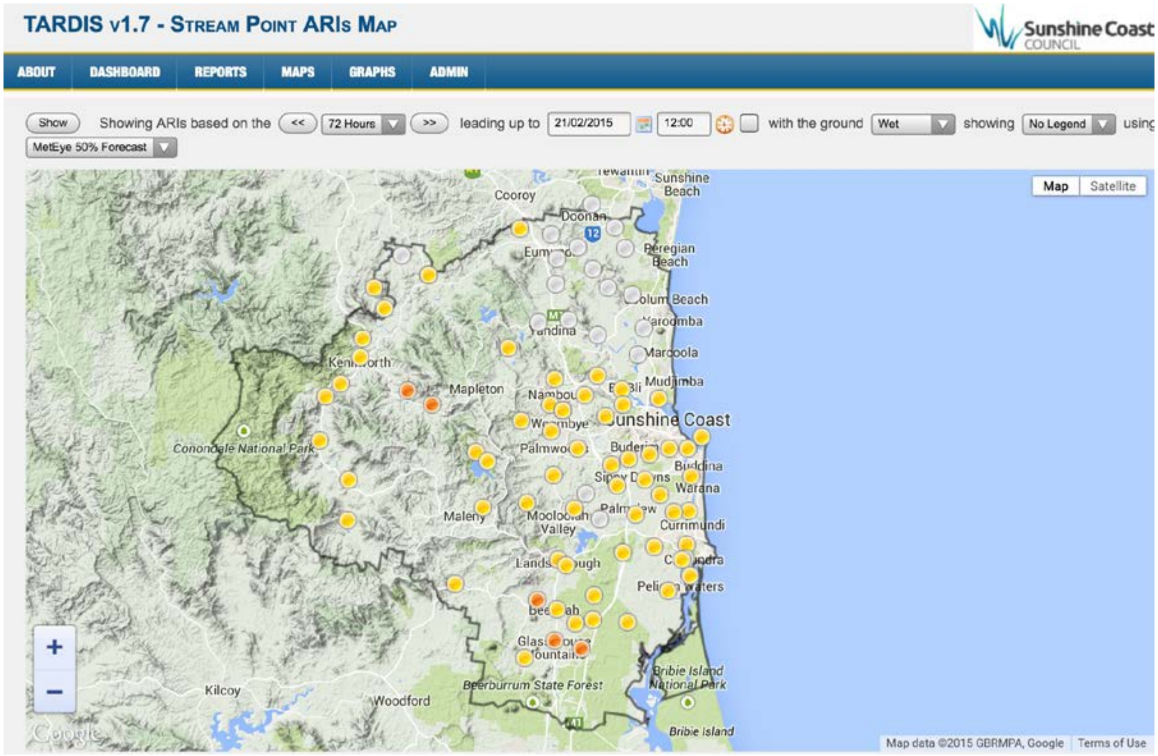

Figure 13 Ex TC Marcia Stream Point ARIs at Conclusion of Rainfall - Loss Sensitivity Check

Flood Levels were collected from maximum height gauges and peaks from flood warning gauges on the Mary River within the LGA. These were then used to prepare an estimate of actual flood extent and levels. The forecast was compared to this estimate and differences determined. This comparison is shown in Figure 14. Table 3 similarly shows the comparative performance of the forecast in predicting peak levels at locations of recorded peaks. The maximum error at these locations approaches 1m, however this is an incised catchment and when this error is presented as a percentage of the variance between modelled Q2 and Q100 levels (17%) it provides a better contextual feel for the significance of the error. The performance of the system to estimate peak flood levels and extents was considered very good.

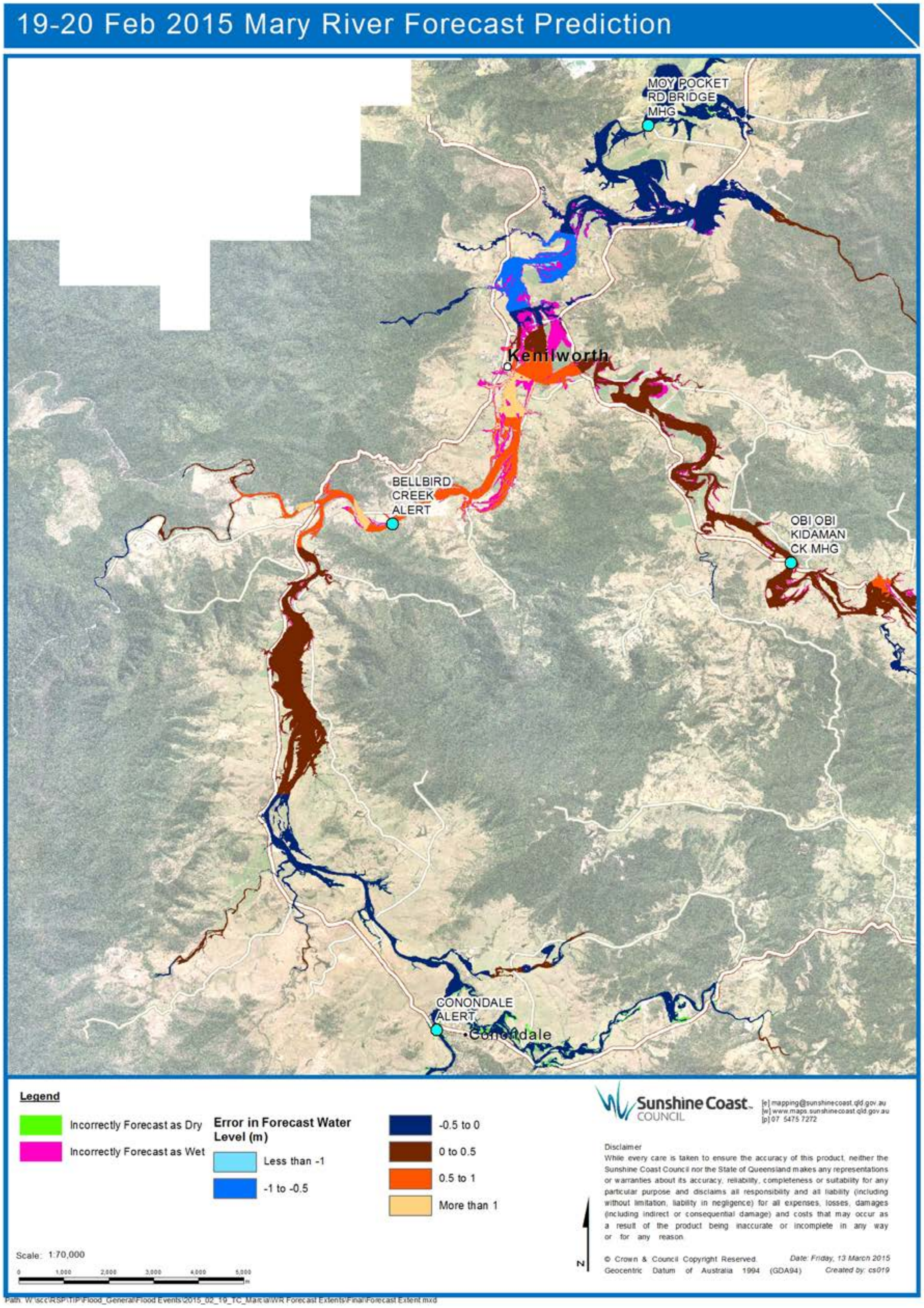

Figure 14 Forecast Performance on the Mary River

Table 3 Comparative Forecast Performance at Locations of Recorded Levels

Location	Flood Level (mAHD)	Forecast Level (mAHD)	Error (m)	Estimated ARI	Forecast ARI	Q100 -Q2 Variance	Error as % Q100-Q2 Variance
Conondale Alert	129.02	128.73	-0.29	10.6	7.6	3.50	8%
Bellbird Creek Alert	101.07	102.02	0.95	4.9	8.9	5.70	17%
Kenilworth Homestead	94.20	93.53	-0.67	7.4	5.2	6.84	10%
Moy Pocket Rd Bridge MHG	87.03	86.89	-0.14	5.3	4.8	6.10	2%
Obi Obi Kidaman Ck MHG	106.59	106.98	0.39	14.0	21	3.70	11%

Table 4 Lead Time in Predicting Peak ARI

			Forecast ARI at			
	Time Peaked on 21/02/2015	**Tc (hrs)**	**07:00**	**08:00**	**09:00**	**10:00**
Conondale	10:25	2	<1	4.1	7.3	7.6
Bellbird	09:50	8.25	<1	4.3	8	8.9
Moy Pocket	15:35	12.75	<1	2.4	4.3	4.8

Table 4 provides detail on the lead time available using this method of forecasting. This lead time is tabulated is without the benefit of any forecast rainfall and quality of the forecast is not consistent and as forecasts are in 3 hourly intervals, they are of little benefit to small catchments with Tc's less than or equal to this interval. The results do show that a reasonable estimate of the peak ARI can be ascertained about 1 hour prior to the peak occurring in reality even on small catchments. On larger catchments, such as at Moy Pocket the peak can be determined about 5.5 hours in advance.

These results indicate that this method of flood forecasting could reasonably be used to estimate flood levels and extent in the significant down-stream community centres of Gympie and Maryborough. As with any forecasting method, good rain gauge coverage of the catchment downstream of the SCC LGA would be required as well as pre-determined flood mapping across a broad range of probabilities, calibrated to ensure AEP neutrality. It is expected that this forecasting method would have a significant accuracy advantage over hydrological modelling, which can be compromised by compounding volume error and the complexity of the timing of the contributions of different catchment inflows.