MODELLING OUTPUTS FOR EMERGENCY AND EVACUATION PLANNING

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ABSTRACT

During emergencies, time is a critical factor in successful outcomes. When producing emergency action plans mapped results of time to peak velocity and time to peak water depth can greatly assist. Time of inundation maps can be produced identifying the time from the start of an event to the depth at which is no longer safe to walk in water, or no longer safe to drive a car for evacuation purposes. This provides triggers for moving to the next stage in an emergency plan. Combining these outputs with duration of flood maps, for given depths, can also provide input into other time related actions; such as planning how long evacuation centres may be required to be operational before it is practical to return to flooded areas.

Where a greater level of detail is needed, such as for roads that operate as evacuation routes, it is also possible to identify the time at which they become cut off. This may be used to determine when pedestrians, cars and emergency vehicles can no longer safely use a road.

Using these time related outputs from risk based flood models we can better prepare emergency and evacuation plans for disaster coordination during a flood.

KEYWORDS

Flood Evacuation Modelling, Flood Hazard Assessment, XPSWMM

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1 INTRODUCTION

Severe flooding in Australia in 2011 prompted the creation of the Queensland Reconstruction Authority (QRA) who produced documents to drive better preparation for emergency responses to flooding. This included references to the use of computer models and therefore the outputs from computer models, and in particular the time dependent outputs, have become more important.

In a specific case study, this paper explores how modelling outputs were used to identify a single point of weakness in the evacuation routes for a regional town in Queensland. With limited access options to and from the 'local' hospital it was vital to know the water depths, velocities and hazards occurring during a time of flood. Potentially 5000 people would be at risk, with the next nearest hospital 110km away, if the time to inundation was not correctly identified – and understood.

Using the time dependent outputs from XPSWMM for this case study is shown to enable better preparation for emergency and evacuation plans.

2 DISCUSSION

2.1 FLOOD EMERGENCY PLANNING – WHY ALL OF A SUDDEN?

The east coast of Australia has been subject to a number of local and regional storm events during the last 5 years. One of series of events, in 2011, affected a significant proportion of Queensland, with the city of Brisbane, and the Brisbane River, being subject to its largest flood event since 1974. The scale of the flooding, overall, has been recognised as having the greatest impact on record. The economic impact associated with damage to public infrastructure alone has been estimated to cost between $5-$6B AU (QSC, 2013) with the Australian Government implementing a nationwide flood taxation levy for the 2011-12 financial year (ATO, 2012).

In response to these flood events the Queensland Government established the Queensland Reconstruction Authority (QRA) and developed a series of reference documents for local and state authorities to improve planning for future flood events (QRA, 2011). These documents have driven the stormwater industry to improve its understanding of flood events and reporting requirements to afford a higher degree of resilience to such events.

Part 2 of the QRA (2011) document 'Planning for Stronger More Resilient Floodplains' details what type of assessment is required for any given region and the level of detail that should be presented. Urban settlements are defined in the QRA (2011) documentation to be *"discrete settlements greater than 5,000 persons"* and in the event that even low levels of growth are expected that a detailed flood assessment should be carried out. The required outputs from a detailed flood assessment include:

- *Maps showing the extent of various design flood flows (at a range of annual exceedance probabilities (AEP));*
- *Hazard areas are based on depths and velocities; and*
- *Computer models are produced.*

2.2 MODEL OUTPUTS

The improvements in physical computer capacity has led to significant enhancement to engineering calculations with respect to both reductions in calculation times and the number of calculations that can viably be undertaken. The engineering industry, particularly the stormwater sector, has readily taken advantage of this continually improving capacity. The assessment of flood plains in 2 dimensional (2D) models has dramatically changed the way that engineers and planners can present forecast or historic event data to decision makers and the community in general.

Recent enhancements to 2D model input and resultant output can provide significantly improved data for:

- Time to, and duration of, inundation for predefined depth criteria;
- Time to peak velocity and depth;
- Assessment of evacuation routes; and
- Hazard analysis for depth times velocity (d x V).

For emergency service planners this information becomes an invaluable dataset when emergency situation arise. For ambulance services route management is a critical element responding to medical emergencies. Route delays can, at times, result in life threatening situations when flooding occurs.

To demonstrate that the requirements of the QRA (2011) can be met, with respect to model outputs, a simple case study has been undertaken of an urban area in regional Queensland.

3 CASE STUDY

A regional location in Queensland, Australia, was selected as a case study to demonstrate the methods available to assess and identify inundation. It also showed the associated impact on critical infrastructure, which are reliant upon functioning transportation networks for access. The location is adjacent to two State controlled roads and, at the same time, restricted in terms of direct access to a core emergency facility, the Gladstone Regional Hospital.

3.1 LOCATION

The selected location was the town of Calliope, which is part of the Gladstone Regional Council area and is approximately 530km north of Brisbane (refer Figure 1).

In 2011 Calliope had a population of 5,634 persons (ABS, 2011), who reside in an area of 246km^2. Approximately 3,060 persons (54%) reside in the urbanised area located to the west of the junction of the Bruce and Dawson Highways. This satisfies the 'urban settlement' category defined by the QRA (2011).

From a geographic perspective, the urbanised area is bounded by the Calliope River to the west and the Boyne River to the east. The area is also divided by both the Bruce Highway (east to west) and the Dawson Highway (south-west to north). Both of these roads are controlled by the Queensland Department of Transport and Main Roads. These two major roads are intended to have drainage protection for events up to the currently defined flood event, which is the 1% annual exceedance probability (AEP) design storm event (DNRM, 2013).

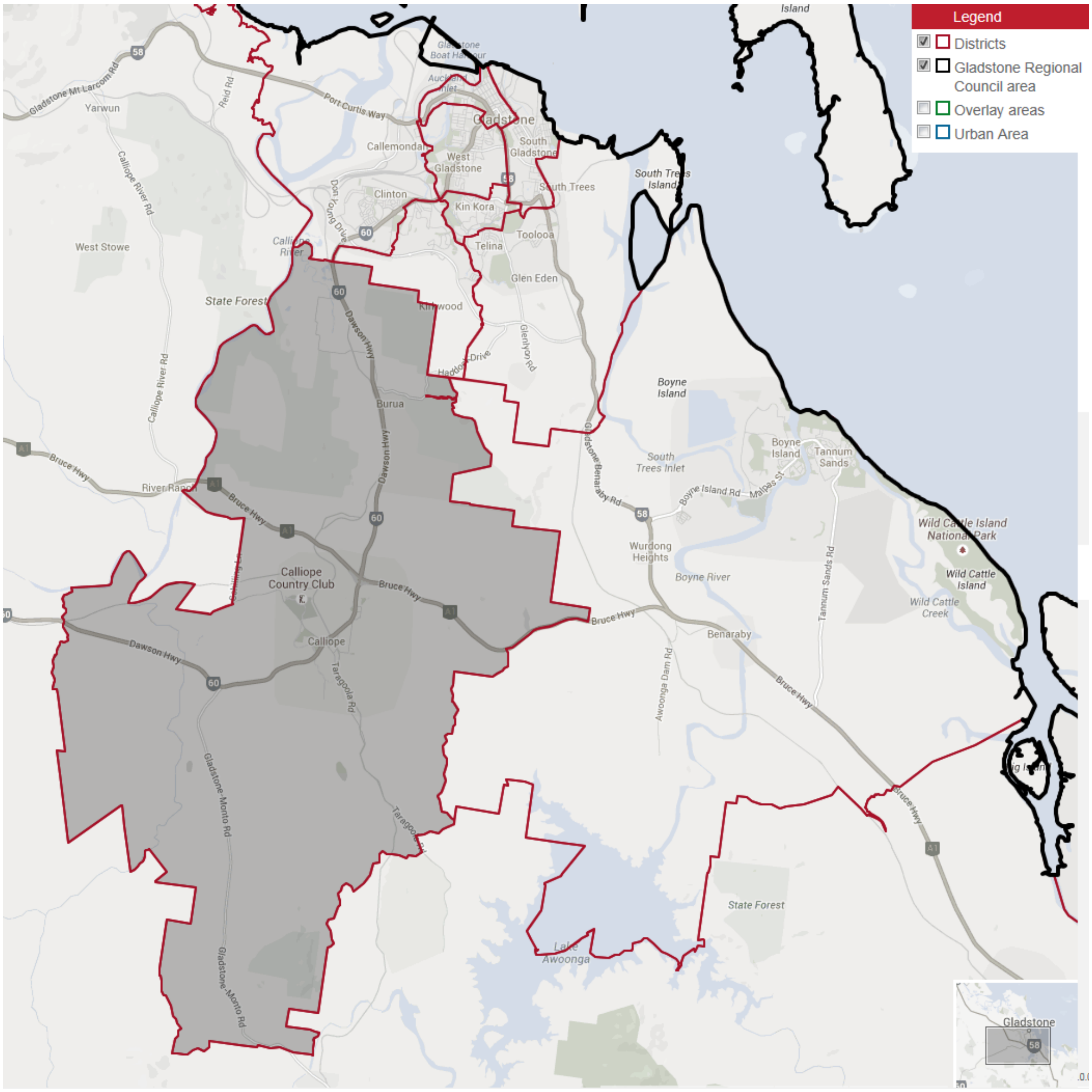

Figure 1: Calliope Locality

Within the Calliope locality a small, discrete, catchment discharges along, and across, the Dawson Highway north of the junction with the Bruce Highway. This area was the specific area investigated, as part of the case study, to demonstrate the flood emergency planning outputs that can be derived through numerical modelling. The catchment area investigated is shown on Figure 2.

The asset of interest for the case study was the local hospital, which is a critical asset for the community during extreme flood events where viable access is paramount. For the residents of the urbanised area of Calliope access to the Gladstone Hospital can be undertaken via three routes. These three routes, and their associated 'normal' travel times are:

1. Across the Bruce Highway and then north along the Dawson Highway (21 minutes);
2. North along the Bruce Highway and then via a Talaba and Weeroona Roads (both rural roads) onto the Dawson Highway (36 minutes); and

3. South along the Bruce Highway and then via Gladstone Benarby Road (major road) (30 minutes).

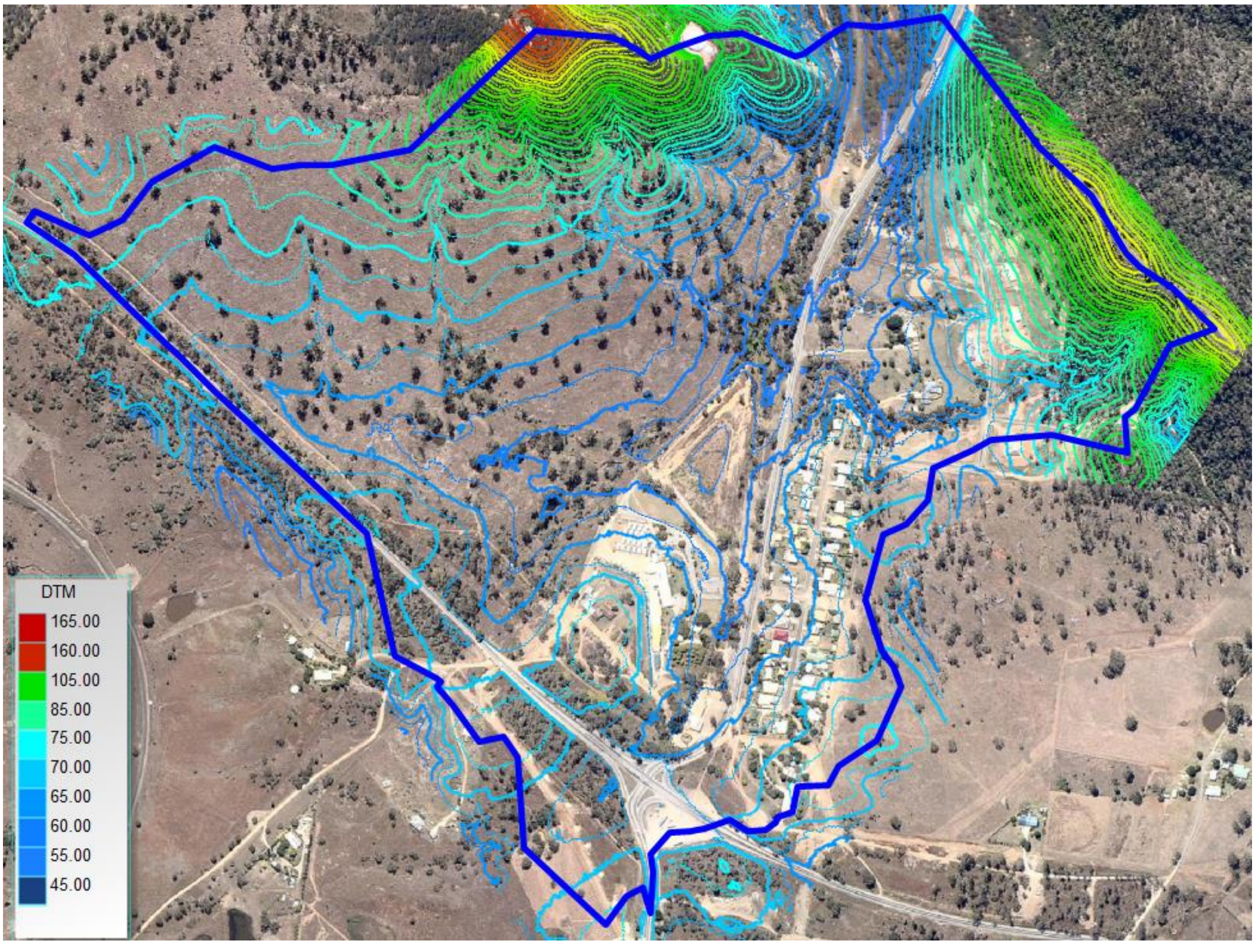

Figure 2: Case Study Catchment Extents

The shortest travel time from Calliope to the Gladstone Hospital is 21 minutes during normal conditions, which is an important issue to consider from a service delivery perspective. The implications of restricted vehicular access along this route can lead to a minimum delay of 9 minutes assuming warning mechanisms can be raised to utilise the next best route. However, it is understood that there is high likelihood that a rainfall event that results in flood impacts along the Dawson Highway will also restrict the alternative routes.

3.2 MODEL DEVELOPMENT

The case study area is small in area and not subject to any river or creek level gauging. As a result, the model was developed on the premise that design storm temporal distributions, in accordance with Australian Rainfall and Runoff (Pilgrim, 1987), would be an acceptable input for the assessment. A coupled 1D/2D model was then developed within the XPSWMM 2013 interface. The model inputs are described in the following sections.

3.2.1 HYDROLOGY

Catchment hydrology has been assessed using direct rainfall in lieu of a typical 1D hydrology method to enable an assessment of the flood characteristics. Catchment boundaries for the case study were determined based on aerial laser survey (ALS) data that is commercially available from the Department of Natural Resources and Mines. The

ALS dataset has a standard grid size of 1m x 1m, which is considered acceptable for the purpose of this investigation. No further detailed survey was incorporated into the modelling.

The catchment characteristics were determined based on a review of aerial photography and planning types defined by Gladstone Regional Council (GRC, 2007). Table 1 summarises the catchment details included in the case study.

Table 1: Catchment Details

Land Use	Fraction Impervious (%)	Impervious Area (m^2)	Pervious Area (m^2)	Total Area (m^2)
Village	20	10,796	43,186	53,982
Village / Highway	40	34,178	136,712	170,890
Rural	20	32,262	129,048	161,310
Total		**77,236**	**308,946**	**386,182**

An initial – continuing infiltration loss model was applied based on the 2D land use, as detailed in Table 2.

Table 2: Initial and Continuing Loss Model Parameters

Surface Type	Initial Loss	Continuing Loss
Impervious	0mm	0mm/hr
Pervious	0mm	2.5mm/hr

We note that the initial losses have been applied at 0mm due to the modelling being based on design storm temporal patterns rather than a continuous simulation of historic rainfall. It was not considered appropriate to apply initial losses to the pervious areas as the Australian Rainfall and Runoff (ARR) (Pilgrim, 1987) temporal patterns represent storm bursts and do not make any provision for the impact of any antecedent rainfall which is typical of natural storm events in Queensland.

Two land use types were applied to the XPSWMM model, which were ‘Road’ and ‘Pasture and Meadow’. Manning’s n roughness values of 0.015 and 0.065 were applied to these land uses, respectively. The above infiltration losses were applied directly to these land uses. This method of applying distributed land use data within the 2D model allows for direct comparison of any modification, which was outside the scope of the current case study.

3.2.2 HYDRAULICS

The hydraulic assessment was proposed to comprise of directly coupled 1D and 2D data set. The 1D elements incorporated into the model were the cross road culverts along the Bruce and Dawson Highway’s.

The 2D model domain was established using a 3m x 3m grid, based on the ALS dataset.

The downstream boundary condition applied to the model was located approximately 300m north of the point of interest on the Dawson Highway. The boundary condition was set as a free outfall controlled by normal flow conditions. The distance from the Dawson Highway is considered appropriate to avoid any influence of any potential backwater effects. We note that the downstream channel is well vegetated, but does have adequate gradient for surface runoff to be considered unrestricted.

3.2.3 EMERGENCY MANAGEMENT PARAMETERS

The purpose of the model is to assess the area with respect to emergency planning requirements and model output. The data in Table 3 was applied within the XPSWMM model to enable pre-defined reporting for flood inundation and duration.

Table 3: Time to Inundation Depths of Interest

Depth (m)	Description
0.15	Kerb
0.3	Road Closure
0.5	Self-Evacuation
2	Cut-Off

The values in the above table were derived from the requirements from TMR (2004) and the QRA (2011).

3.2.4 MODEL RESULTS – DEFINED FLOOD EVENT

The model was assessed to confirm the inundation extents in conjunction with the key reporting points for emergency planning purposes. A number of model runs were completed to identify the critical duration for the catchment relative to the geographic features. It was determined that the 60 minute duration, based on the ARR temporal patterns, was the critical duration for a range of AEPs, as the models generated the highest peak discharge and inundation impacts. Figure 3 shows the discharge graph of the 1% AEP 60 minute design storm event at a reporting point located near the model discharge point downstream of the Dawson Highway.

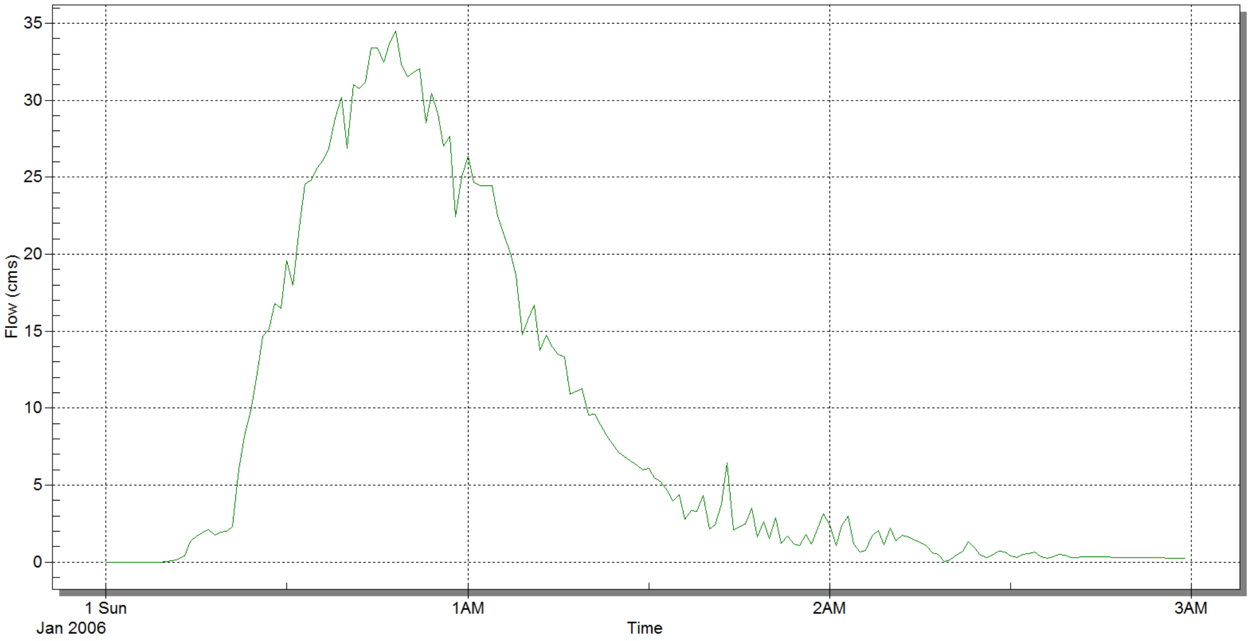

Figure 3: 1% AEP 60 Minute Design Storm Event Model Outlet Discharge

The initial model output that assists engineers and emergency planners is the flood extents. The XPSWMM model produced water depth and elevation results to support this initial output data requirement. Figure 4 presents the peak inundation depths obtained from the 1% AEP 60 minute duration design storm event.

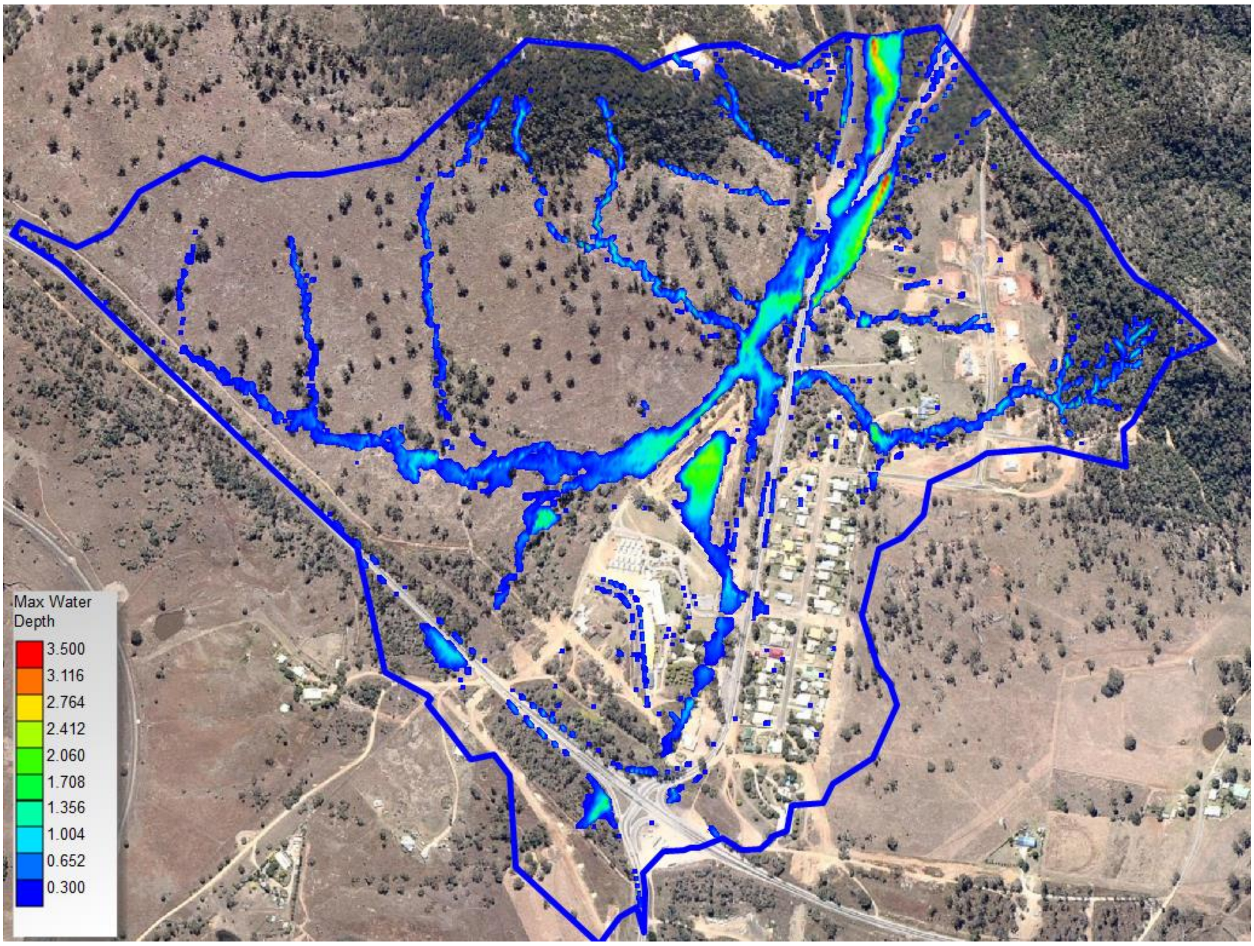

Figure 4: 1% AEP 60 Minute Design Storm Event Peak Inundation Depths

The inundation results confirmed that a low point located along the Dawson Highway was subject to inundation during low exceedance probability design storm events. A section of the road profile was taken in the vicinity of the low point and is shown in Figure 5.

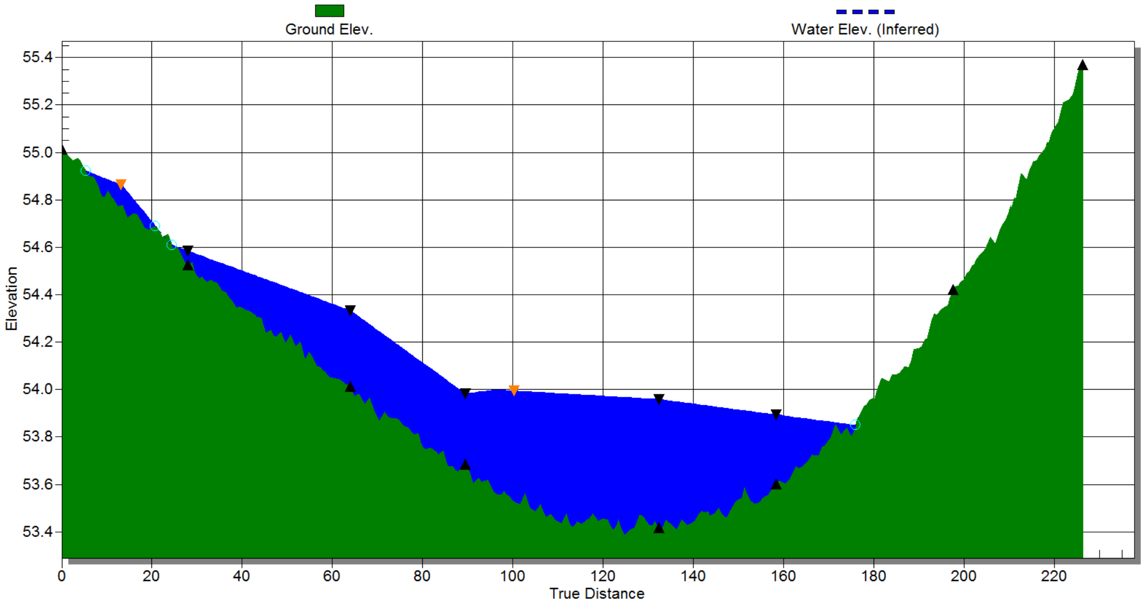

Figure 5: Longitudinal Section of the Dawson Highway and the Inferred Peak Water Elevation during a 1% AEP 60 Minute Design Storm Event

The results indicate that the centreline of the Dawson Highway is subject to a peak depth of inundation of approximately 0.7m. The design standard for this road is intended to be trafficable during a 1% AEP event, which would require a peak depth less than 0.3m in the lanes. To gain an initial understanding of the depth characteristics at this point of weakness a depth reporting point was applied within the model. Figure 6 shows the depth versus time at the reporting point located at the low point on the Dawson Highway.

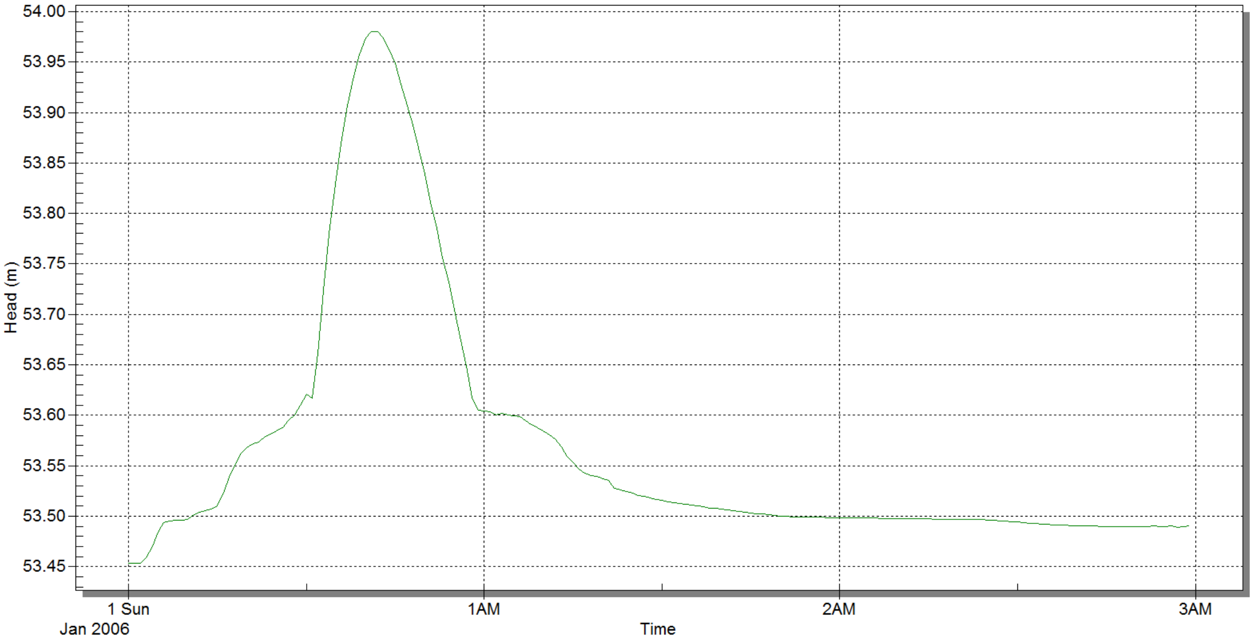

Figure 6: Water Elevation at the Low Point on the Dawson Highway during a 1% AEP 60 Minute Design Storm Event

Historically, the above results would be reviewed manually to determine specific data for emergency planning purposes. Recent enhancements to model result data in XPSWMM, and other similar stormwater packages, allow for specific datasets to be derived automatically. Applying the data from Table 3 above the model was able to report on the locations that the pre-defined depths were exceeded and the duration taken for this to occur. Figure 7 shows the location of the evacuation route assessment and the results for the 1% AEP 60 minute design storm event.

The evacuation route analysis indicates that the Dawson Highway remains trafficable for a period of 33.6mins (0.56hr). When taking emergency response times into account, the effective catchment lag would restrict access via this route when it would likely be required. The time to inundation can also be output as a plan in addition to the simple line based evacuation route assessment. Figure 8 shows the time to inundation output to the depth of 0.3m.

The next point of interest relates to the duration of inundation above a depth of 0.3m. The duration that the depth of 0.3m is exceeded during the 1% AEP is approximately 19 minutes, which is shown on Figure 9.

The model output also includes velocity details, which can be assessed in conjunction with depth to produce hazard maps. A review of the results indicated that the peak velocity at the low point on the Dawson Highway during the modelled 1% AEP design storm event is 2.6m/s over the roadway. Figure 10 shows the hazard values ranging from 0.3 – 2.5 across the site.

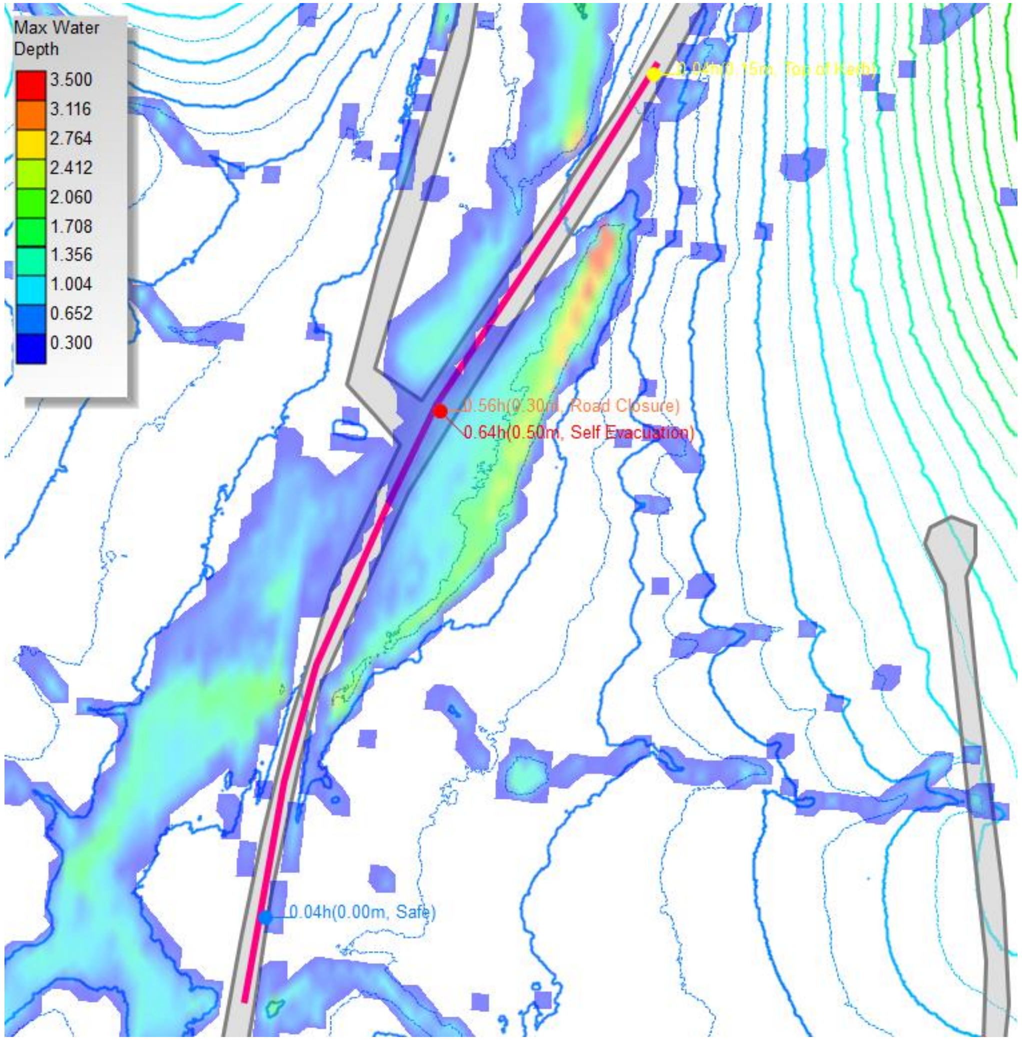

Figure 7: 1% AEP 60 Minute Design Storm Event Time to Inundation of 300mm (Road Closure)

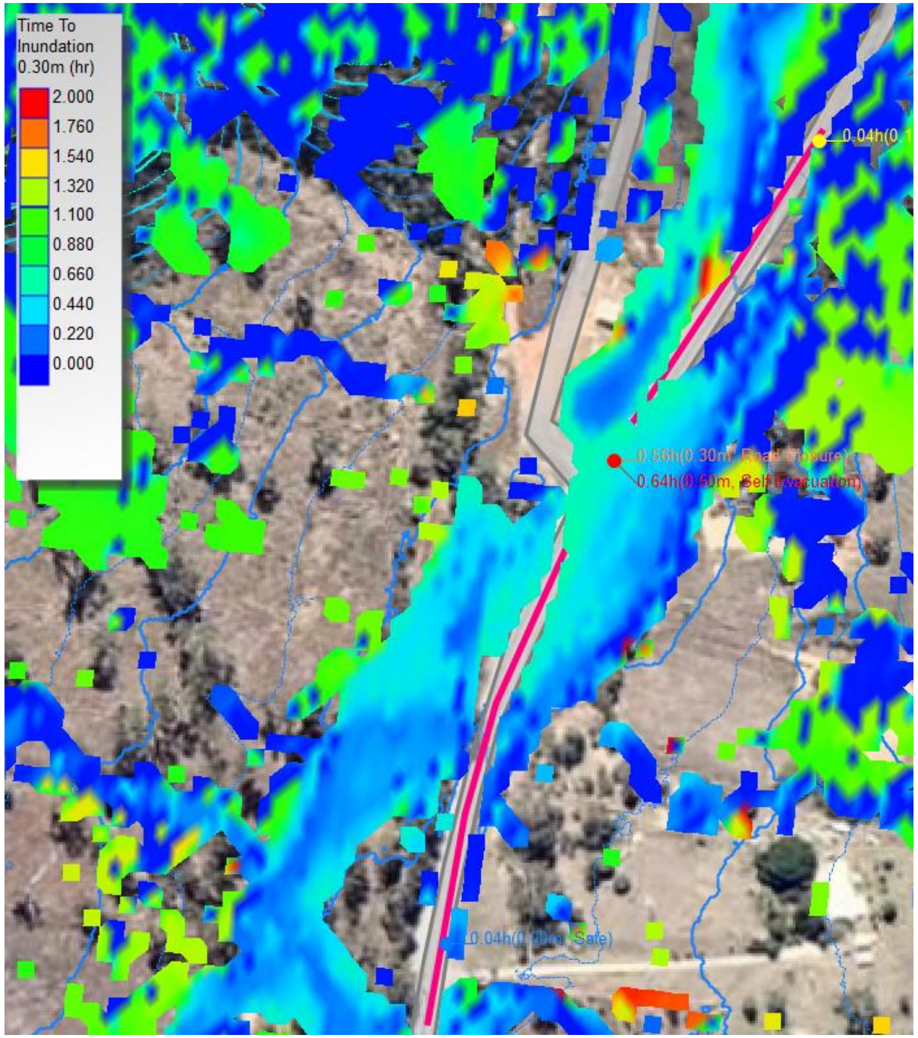

Figure 8: 1% AEP 60 Minute Design Storm Event Time to Inundation to 300mm (Road Closure)

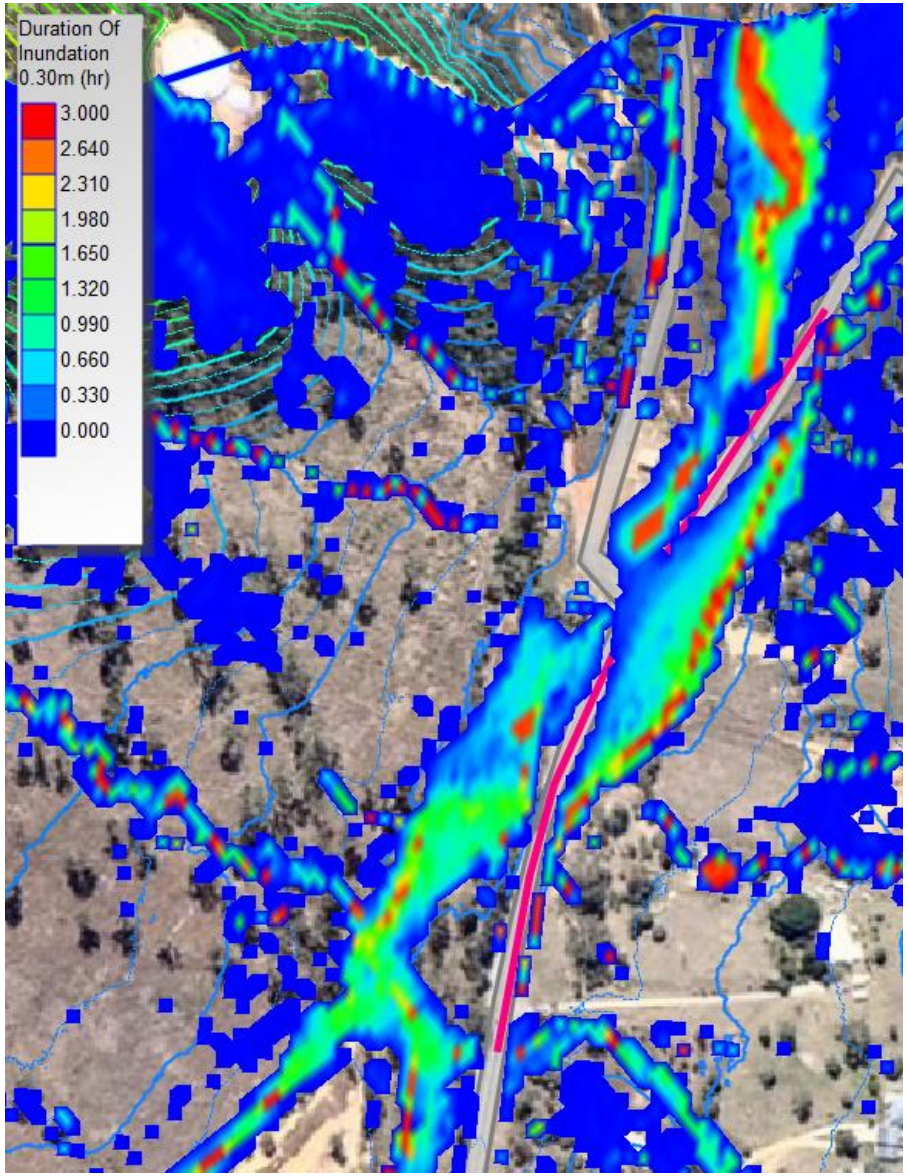

Figure 9: 1% AEP 60 Minute Design Storm Event Duration of Inundation Depths Greater than 300mm (Road Closure)

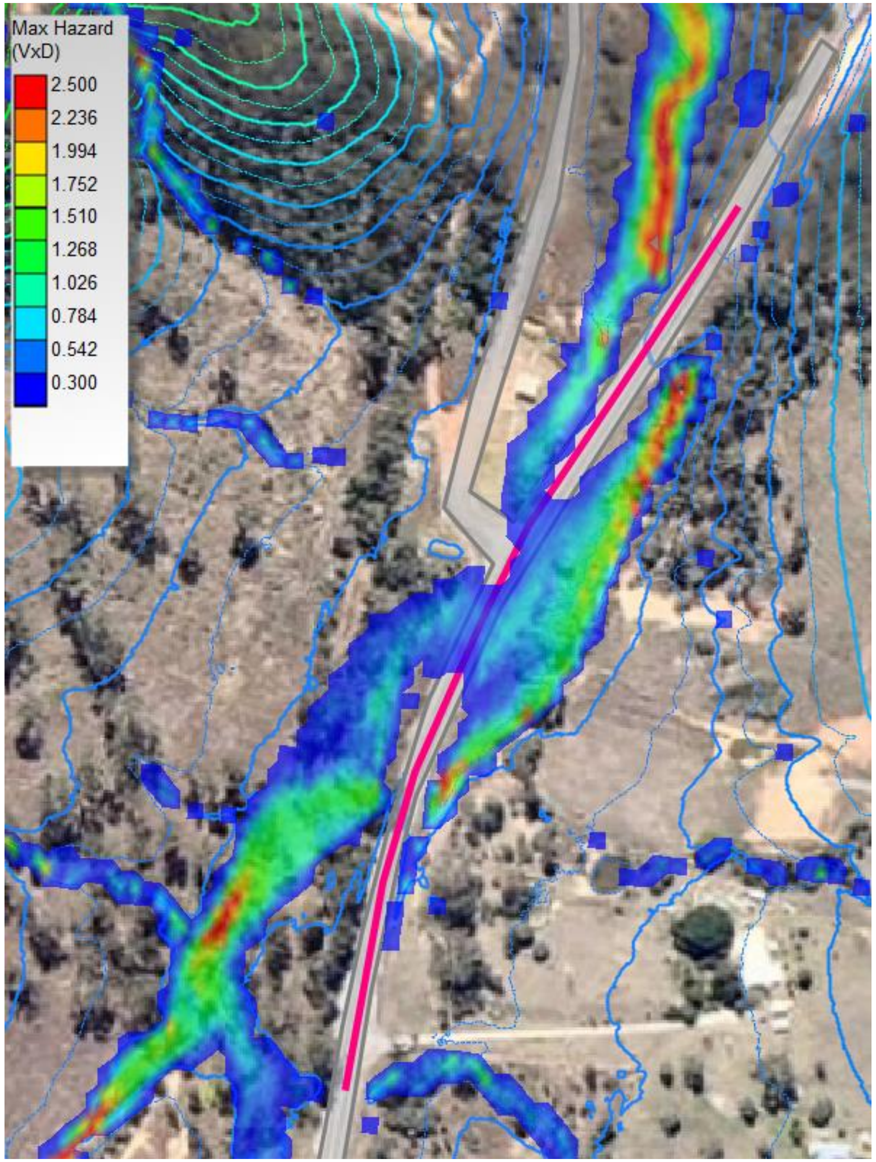

Figure 10: Hazard Map for 1% AEP 60 Minute Design Storm Event

3.2.5 MODEL RESULTS – EXTREME FLOOD EVENT (0.2% AEP)

After assessment of the defined flood event, the model was modified to assess the impacts associated with a 0.2 AEP (1:500) design storm event. Understanding the impacts associated with less frequent events provides guidance for emergency planning purposes. Figure 11 shows the discharge graph of the 0.2% AEP 60 minute design storm event at a reporting point located near the model discharge point downstream of the Dawson Highway.

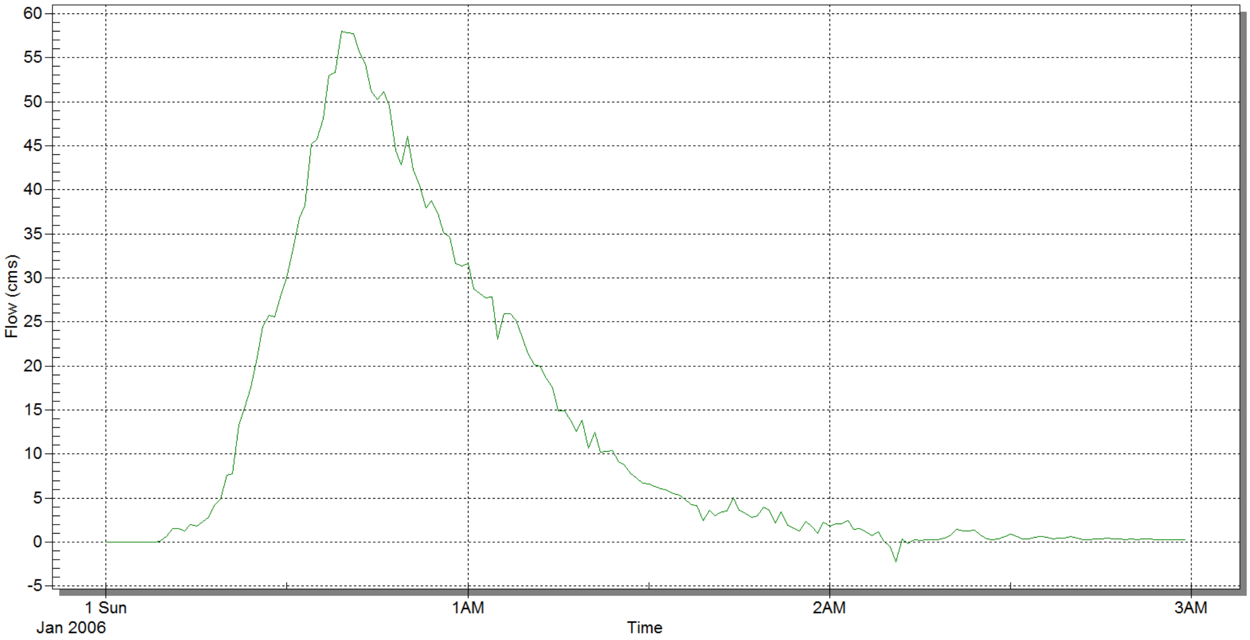

Figure 11: 0.2% AEP 60 Minute Design Storm Event Model Outlet Discharge

Comparing Figure 3 with Figure 11 indicates that the peak discharge from the model increases by approximately 60%. Figure 12 presents the peak inundation depths associated with this increased runoff.

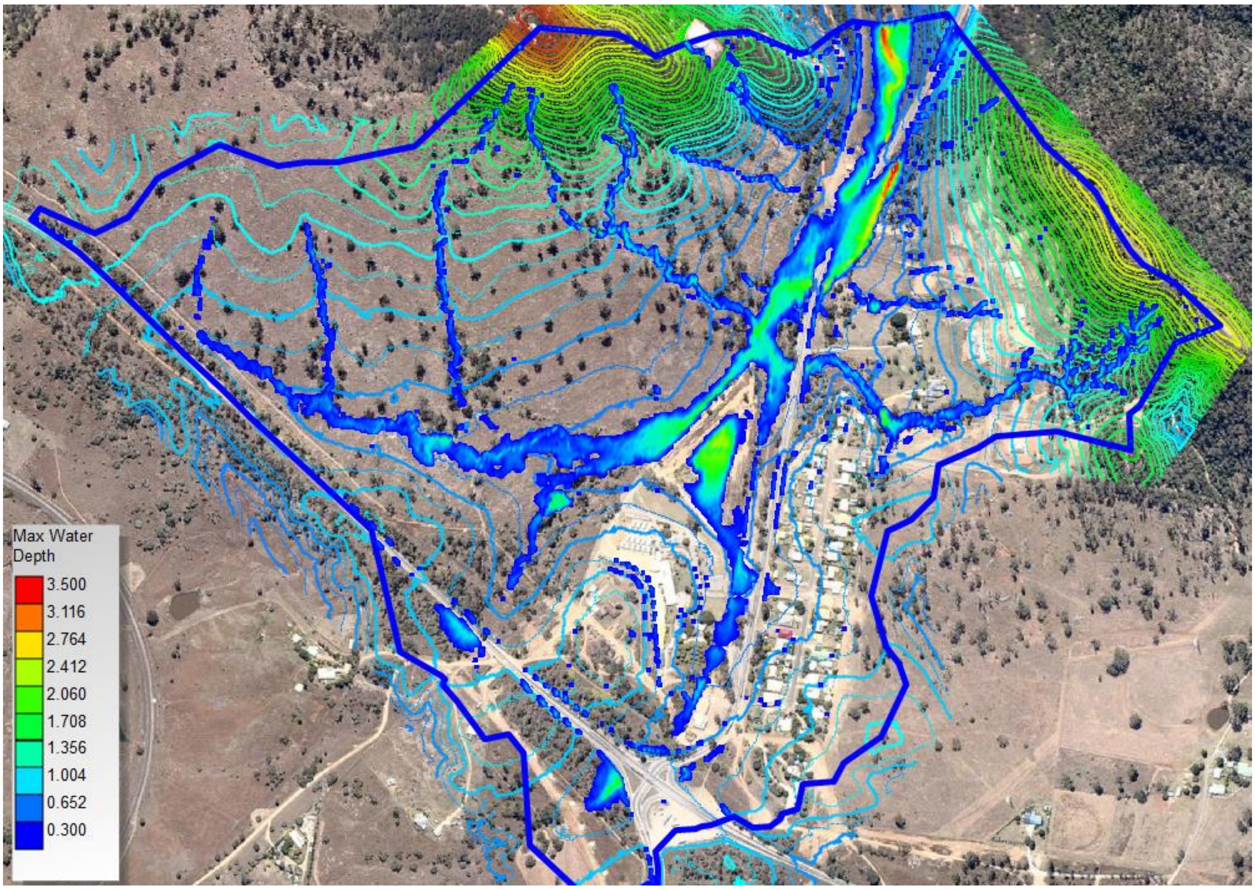

Figure 12: 0.2% AEP 60 Minute Design Storm Event Peak Inundation Depths

The inundation results confirmed that the low point located along the Dawson Highway was subject to further inundation during the 0.2% AEP design storm event. A section of the road profile was taken in the vicinity of the low point and is shown in Figure 13.

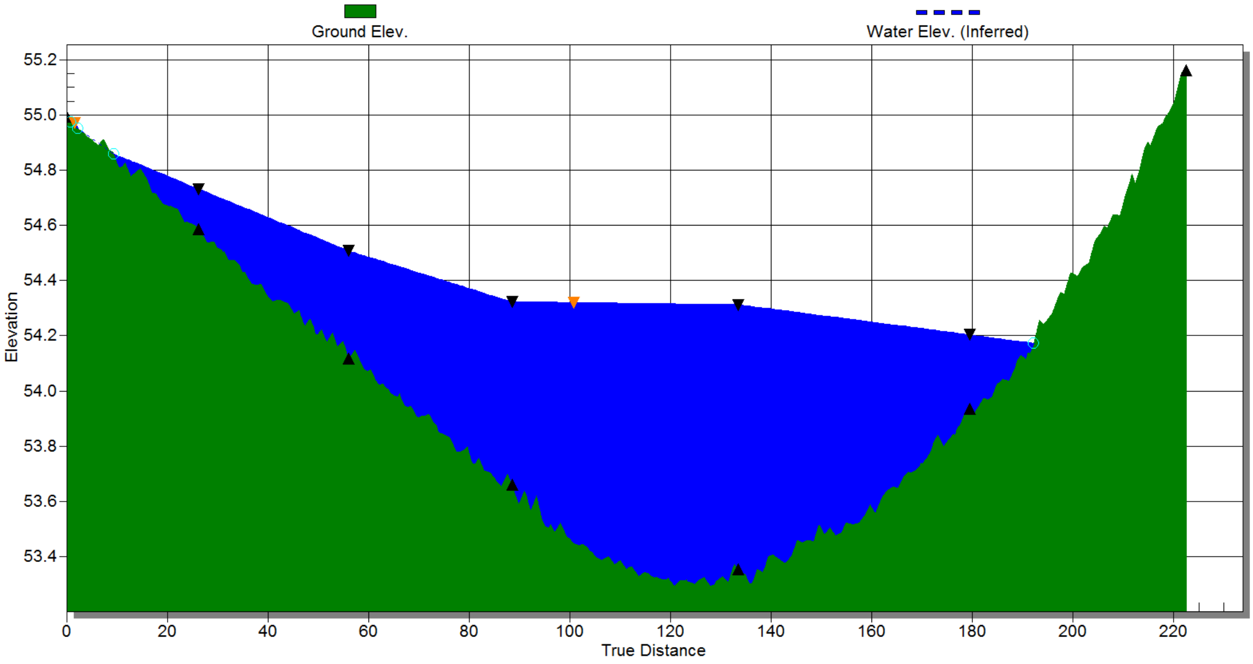

Figure 13: Longitudinal Section of the Dawson Highway and the Inferred Peak Water Elevation during a 0.2% AEP 60 Minute Design Storm Event

Comparing Figure 5 and 13 indicated that the depth of inundation is increased by approximately 0.4m in response to the greater volume of runoff during the 0.2% AEP design storm event. Figure 14 shows the associated depth versus time at the reporting point located at the low point on the Dawson Highway.

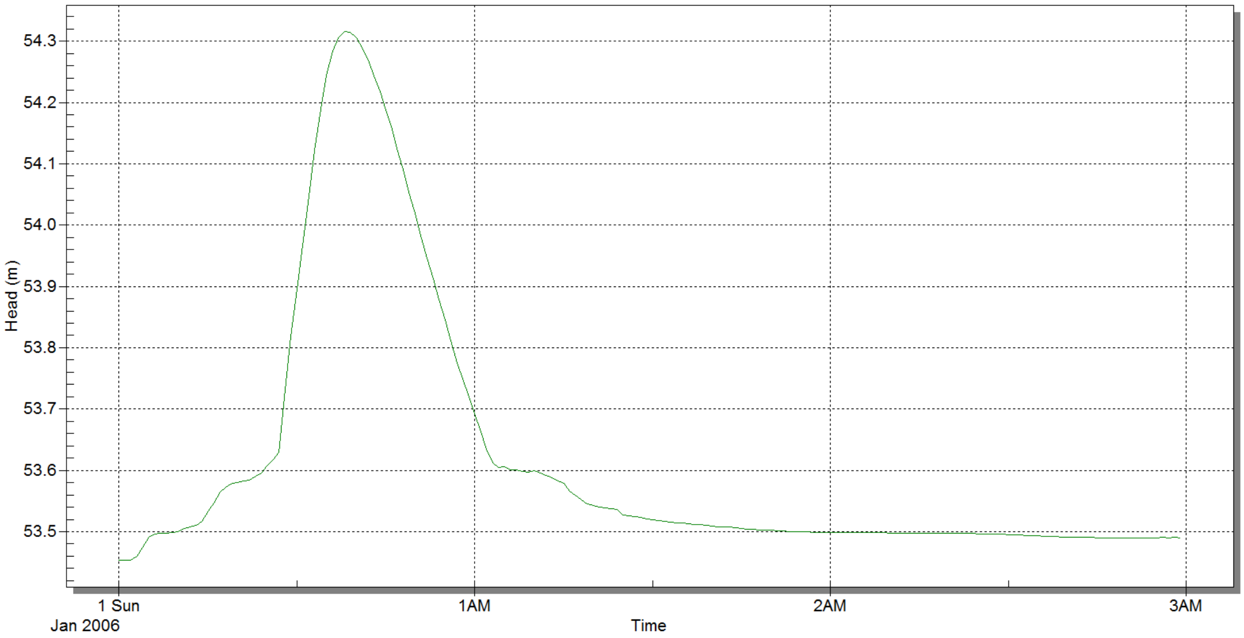

Figure 14: Water Elevation at the Low Point on the Dawson Highway during a 0.2% AEP 60 Minute Design Storm Event

Figure 15 shows the location of the evacuation route assessment and the results for the 0.2% AEP 60 minute design storm event.

The evacuation route analysis indicates that the Dawson Highway remains trafficable for a period of 28.2mins (0.47hr). Compared to the 1% AEP, this equates to a reduction in serviceability of 5mins for the Dawson Highway. Relative to the at risk population of Calliope this is not expected to significantly impact the function of this emergency route. Figure 16 shows the time to inundation output to the depth of 0.3m.

The next point of interest relates to the duration of inundation above a depth of 0.3m. The duration that the depth of 0.3m is exceeded during the 0.2% AEP is approximately 27 minutes, which is shown on Figure 17.

A review of the velocity results across the low point on the Dawson Highway during the modelled 0.2% AEP design storm event identified a peak rate of 2.54m/s over the roadway, which is generally consistent with the 1% AEP event. Figure 18 shows the associated hazard values ranging from 0.3 – 2.5 across the site.

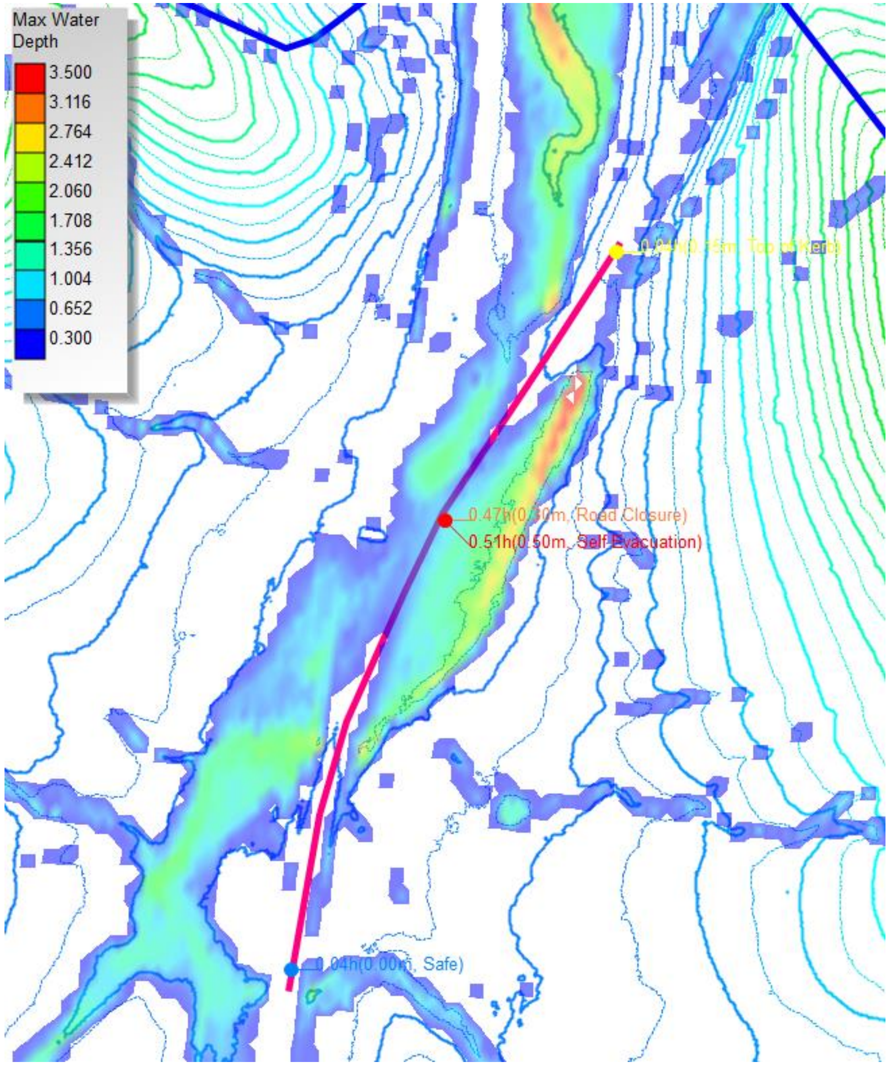

Figure 15: 0.2% AEP 60 Minute Design Storm Event Time to Inundation of 300mm (Road Closure)

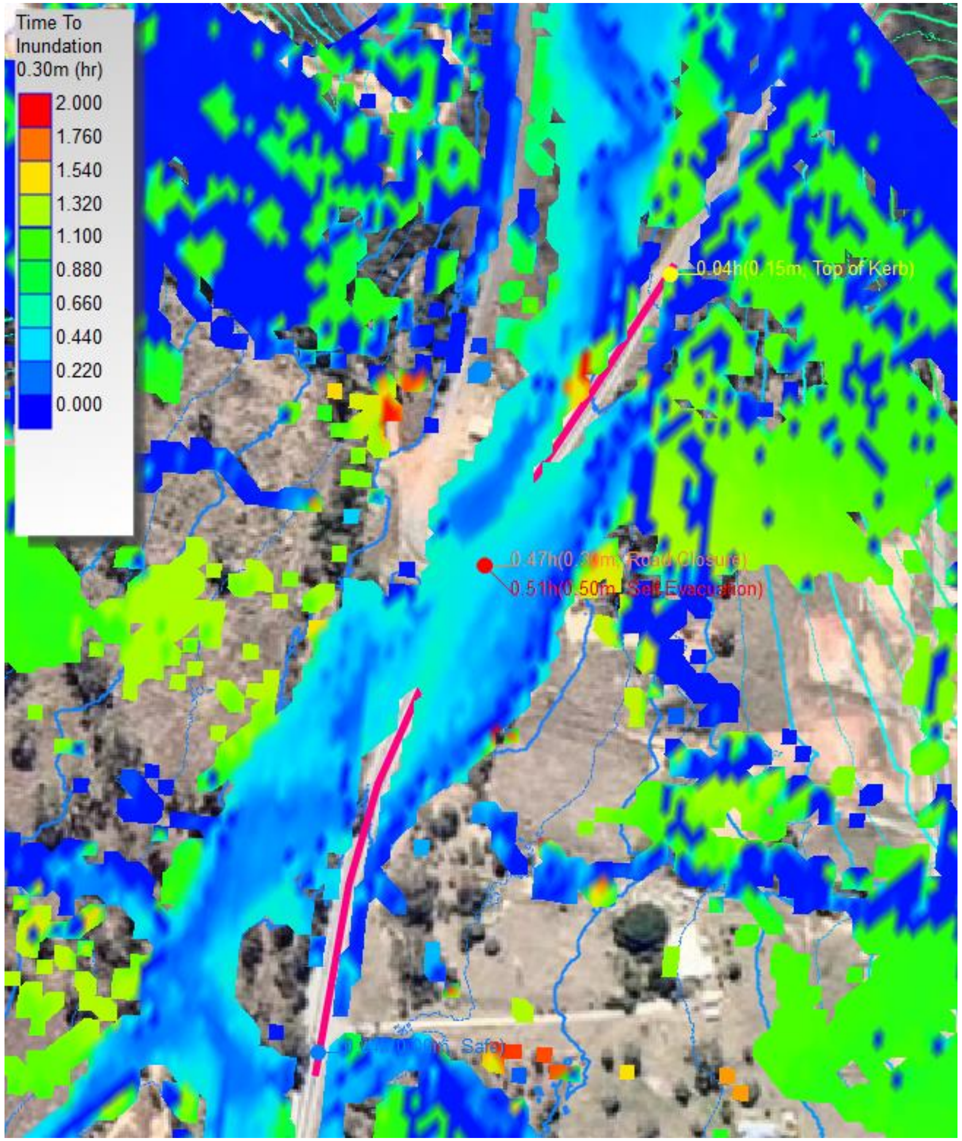

Figure 16: 0.2% AEP 60 Minute Design Storm Event Time to Inundation to 300mm (Road Closure)

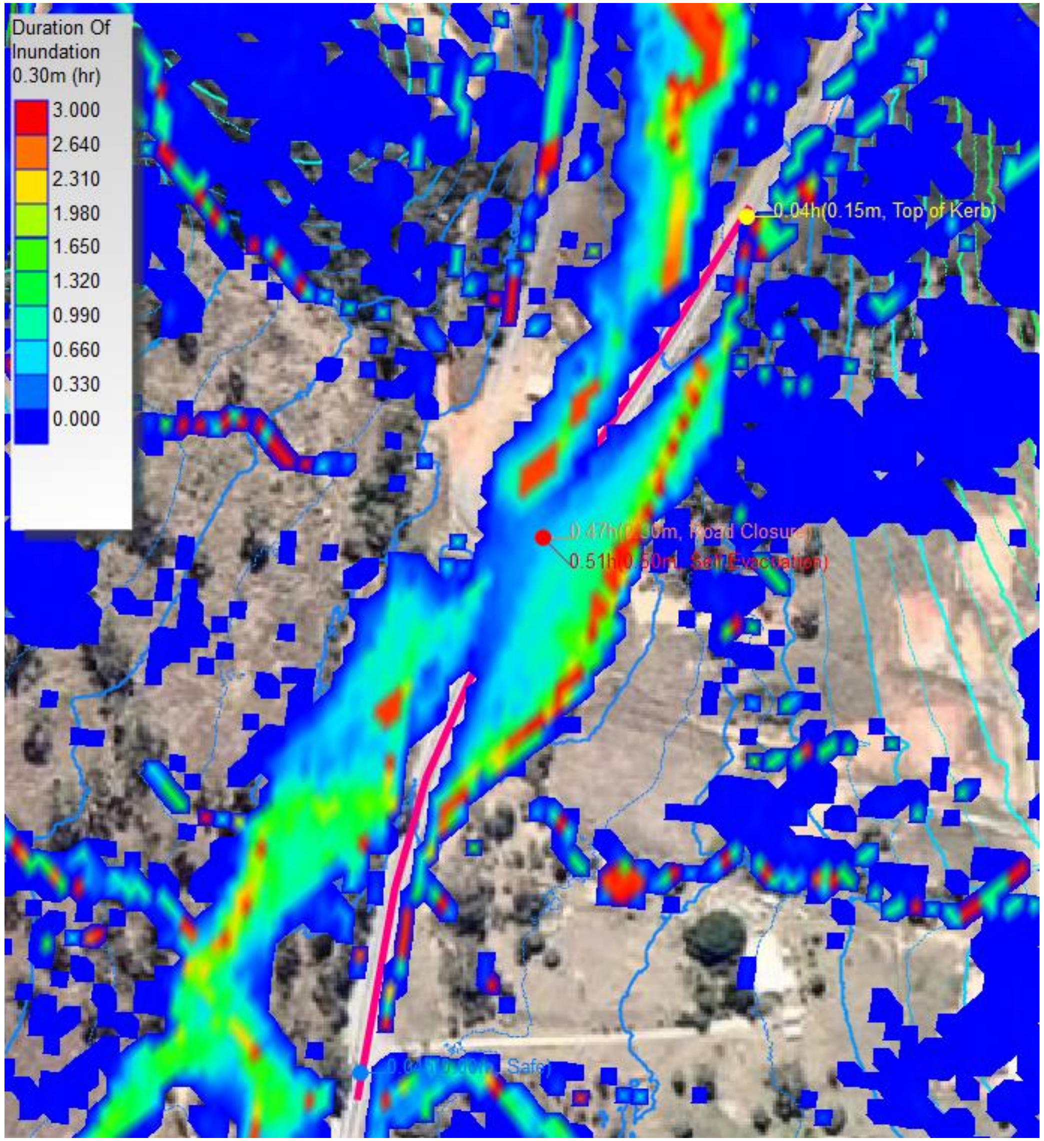

Figure 17: 0.2% AEP 60 Minute Design Storm Event Duration of Inundation Depths Greater than 300mm (Road Closure)

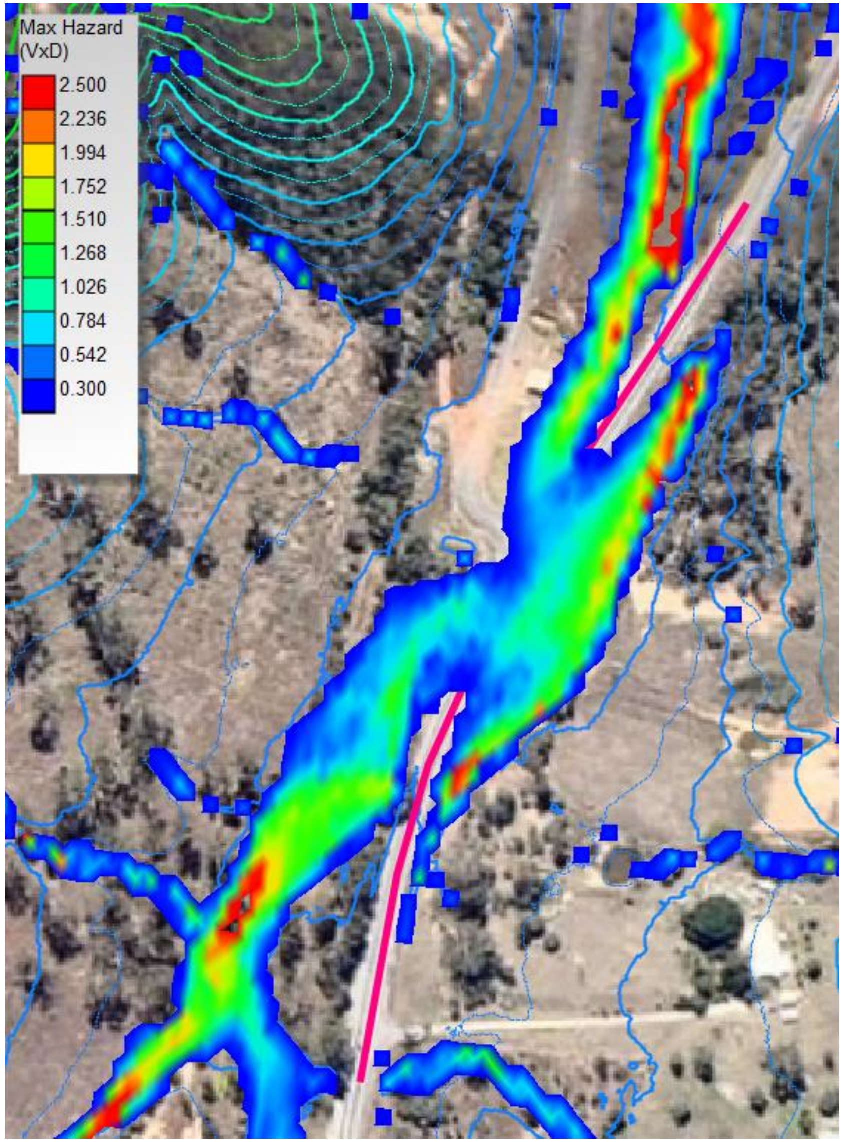

Figure 18: Hazard Map for 0.2% AEP 60 Minute Design Storm Event

3.2.6 CASE STUDY RESULTS DISCUSSION

The results from the case study demonstrate the types of model output that can be obtained efficiently with limited input. Yet the data output provides emergency planners with a clearer understanding of the flood issues that occur in response to extreme rainfall events.

While the case study was limited in its scope and the observed impacts may appear minor, the results highlight the potential for negative impacts from small catchment areas that can restrict our urban communities in terms of egress and access to emergency facilities.

Further options for assessment at this site include improving the data resolution and assessing mitigation options to reduce the severity or eliminate excess inundation across the Dawson Highway.

4 CONCLUSIONS

Recent improvements in the capacity of computers have enabled advanced calculations to be undertaken to provide the stormwater and emergency planning industries with more user friendly information. Modelling tools, such as XPSWMM, are able to produce detailed, and reliable, results that can inform decision makers on the hazards that face our society in response to extreme flood events.

The case study that was assessed demonstrates that for regional locations the impacts of flooding from small catchments can interfere with the ability to gain quick access to core emergency facilities, such as hospitals. The information obtained from the model can also be utilised to assess infrastructure upgrades to reduce the risks faced by the local community.

ACKNOWLEDGEMENTS

Data used in the preparation of the case study is based on or contains data provided by the State of Queensland (Department of Transport and Main Roads [2014] and Department of Natural Resources and Mines [2014]).

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