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Strategies and Systems Architecture for Emergency Management Decision Support – A Northern Australia Case Study

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Abstract: Emergency managers are increasingly responsible for considering multiple and often disparate information in highly pressurised situations to make evacuation decisions. Under these circumstances there is significant potential for the application of high performance computing technology to provide decision support. An important characteristic of the development of decision support is engagement with end users. In the emergency management setting end users operate in a highly standardised and rule structured environment which has developed based on existing information sources and products. In this context it is very difficult to discuss innovations and new approaches or systems designs with end users.
This paper is a case study of an integrated stakeholder engagement emergency management decision support system architecture used enable emergency managers to overcome the innovation constraints of the emergency management context. The case study is of the *Surge Impact Project* a partnership between Griffith University and the Queensland State Government to apply high performance computing to emergency management. The Surge Impact Project has developed a web based Storm Tide Hazard Assessment Tool for Queensland Local Government Disaster Managers. The tool has been developed to inform the timing and location of areas subject to evacuation notices during Tropical Cyclones for coastal areas of Queensland.

***Keywords**: decision making; stakeholders; storm surge; emergency management; support tool*

1. INTRODUCTION

Determining the storm tide hazard for a given tropical cyclone event currently requires that emergency managers assess multiple and disparate sources of information under significant political and economic pressure to avoid evacuations. The use of high performance computing and modelling tools provide significant opportunities to deal with large amount of data and provides relevant analysis and insights which meet the specific needs of decision makers. The challenge is finding ways for risk adverse decision makers operating in strictly rule governed settings to identify opportunities for innovation provided by technology for the assessment of storm tide hazards.

For the North Queensland Coast the location of the case study analysed in this paper, the threat to life from Storm Tide events during Tropical Cyclones is managed though the evacuation of communities. Decisions to evacuate communities rely on Tropical Cyclone forecasts with many factors influencing peak magnitude and location of the accompanying Storm Tide. Slight changes in TC parameters such as the radius of maximum wind, the forward speed, the angle of approach to the coast, the central pressure or the interaction with the local bathymetry could cause varying flood areas. Similarly the impact of a given Storm Tide will vary based on the location affected. For example a shallow slope will produce a greater storm surge than a deep slope. In addition to the local topographic characteristics the evacuation timing needs to consider characteristics of the community such as, the ability to evacuate, and the ability to shelter.

Given this complexity the current decision process has evolved based on the types of forecast information available and as such changes to forecast information require changes to the decision process. This paper will describe the method to improve support emergency based on stakeholder engagement in the development of decision support systems through the use of a prototyping process and decision support systems architecture which is based on possible hazard vectors which allow users to develop impact scenarios.

2. METHOD

A case study methodology has been used to assess how decision support for emergency management can be developed. Case study provides a methodology for observing process in context which is important for the development of an emergency management decision support as such a system has a range of interdependencies with institutional and social processes. Two interdependent frameworks have been used to structure the case, the first represented in figure 1 sets out the stakeholder consultation process and the second sets out the systems architecture.

The case used is development of the SurgeImpact tool which is a partnership between Griffith University and the Queensland State Government to apply High Performance Computing to Emergency Management decision. The project operated from 2012 to 2014 and developed a product called SurgeImpact which is a web based Storm Surge impact assessment tool for emergency managers in Queensland Australia.

2.1 Stakeholder consultation

The stakeholder engagement was organised in two phase as shown in Figure 1. In the first phase the current system was analysed and key issues were identified to explore the possible improvement from previous experiences and understanding local vulnerabilities and community response to warnings in recent events. This phase was done by both, a literature review and then a survey across 19 of 24 coastal Queensland Local Government Authorities to identify the requirements of emergency management stakeholders currently using the Queensland Storm Tide Warning System.

Subsequently a web-based platform was developed by Griffith University for informing storm tide hazard assessment during the response phases of a TC event. This product has application to emergency managers for evacuation planning purposes as a cyclone approaches the coastline, and enables a view of the possible area of inundation based on an uncertain forecast. QSurge is a pilot tool that means it is not intended to replace the forecast storm tide prediction tool but it serves as operational storm tide hazard prediction tool. In other words it could serve as an implementation of a design idea for further testing and consideration by stakeholder agencies including Queensland Fire and Emergency Services and the Bureau of Meteorology.

The second phase of Stakeholder engagement exercise was organised between May and July 2014 in two stages processes and QSurge product was presented and tested by many stakeholders. The first stage was a series of semi structured interviews with four Emergency Management stakeholders who hold responsibility for emergency management decisions and are familiar with the current Queensland Storm Tide Warning framework including the BOM Storm Tide Warnings. By supplying the stakeholders with an interactive visual medium for examining a new information product, it was possible to elicit more details regarding the requirements for storm tide warnings. The persons interviewed had all experience with application of storm tide warnings to emergency management decision making and were currently employed in an emergency management role. In addition they were all familiar with TC and storm tide impacts in the areas of Cairns and Townsville included in geographic coverage of QSurge product. The second stage was a workshop hosted by Queensland Fire and Emergency Services.

And then a new version of storm tide forecast system tool, “SurgeImpact” addressing disaster management needs was developed.

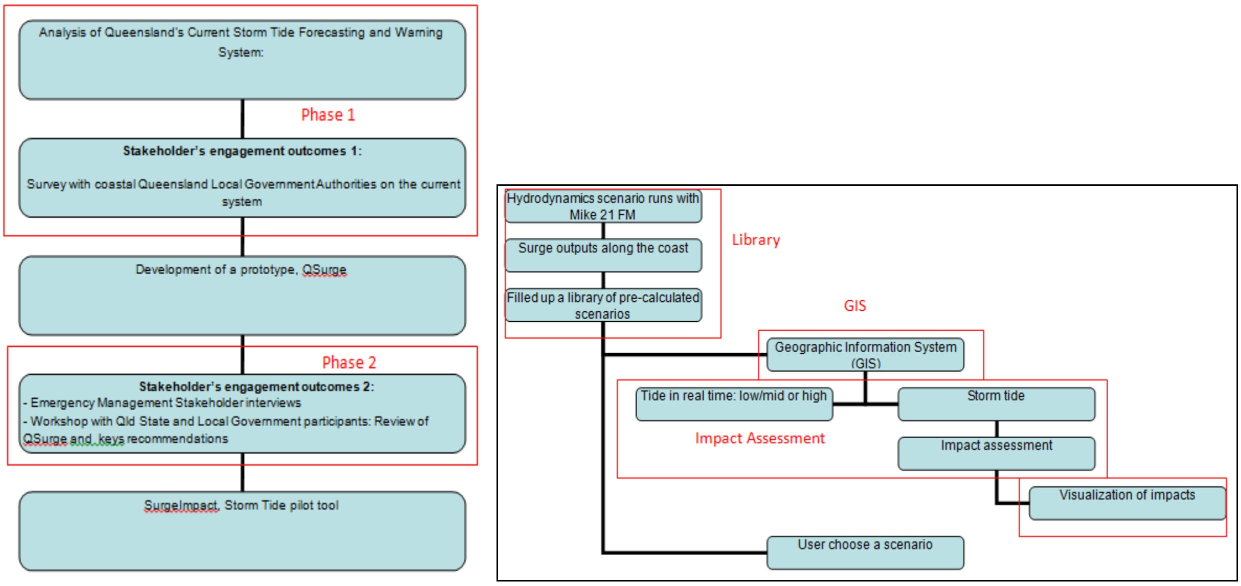

Figure 1. Stakeholder consultation phase to development of a pilot tool (left) and pilot concept architecture (right)

2.2 Building a forecasting system

A concept of an alternative real-time decision support system for storm tide forecasting revolves around a large range of TC scenarios, pre-calculated surge outputs for each scenario stored into a library, Geographic Information System (GIS) and impact assessment to allow visualisation of impacts. Each scenario output has been stored for dynamical time to let the user to visualize result across the time. Storm tide is calculated by adding the surge output to the tide of the selected day.

To publish the storm surge forecast and impacts, GIS has been used and serve the massive amount of data representing scenarios stored into a library as illustrated in Figure 1 (right). This pilot tool provides a composite image of the maximum storm tide inundation expected giving the worst case view or allows the visualization of the impact assessment from a range of cyclones scenarios selected from input by the user. This tool enables a view of the possible area of inundation based on an uncertain forecast (Burston et al., 2014).

This concept could be used to help decision makers in the evacuation during of any other extreme events.

3. RESULTS

3.1 Current system and outcomes from the literature review

Queensland Disaster Management Arrangements (QDMA) is organised in multi-layer levels of committees and coordination centre at state, district and local levels. These arrangements recognise that each level must not only work collaboratively but in unison to ensure the effective coordination of planning, services, information and resources necessary for comprehensive disaster management (Queensland Disaster Management, 2016). The principles are executed through four priority areas as well as the risk management, the Local Government Capability and Capacity, the Community Capability and Capacity and the Effective Disaster Operations.

The Bureau of Meteorology (BOM) used an existing storm tide warning system consisting of matching the deterministic consensus forecast TC track to a library of pre-run TC simulations made using the MMU-SURGE hydrodynamic model forced with single Holland (1980) parametric cyclonic wind fields (Burston et al., 2013a).

The Bureau activates the Storm Tide Warning Response System if it is anticipated that a storm tide could occur which would result in a total water level in excess of the Highest Astronomical Tide (HAT) in the area under threat (DSTIA, 2013). The storm tide warning response system is divided into four phases. During the Tropical Cyclone information phase, if a TC track crossing the coast is issued only

verbal briefings will be held with SDCC and DSTIA Storm Tide Adviser and no additional storm tide products are issued. During the watch phase, if there is a possibility that the Highest Astronomical Tide (HAT) will be exceeded a Storm Tide Standby Bulletin will be provided to SDCC and to the DSTIA and it will be updated only if significant changes are estimated. In the Storm Tide bulletin only the possible surge is given. Preliminary Storm Tide Warnings are updated every 6hours and specify maximum storm tide estimates assuming the peak surge coincides with local high tide. During the warning phase, a storm tide warning is issued if the possibility of exceeding HAT is identified and wind gust affecting the coastal areas are expected to exceed 100 km/h within 24 hours. The Storm Tide Warning indicates the coastal zone that may be affected, the approximate time of occurrence of the Storm Tide and the estimated storm tide height above AHD. Finally a Final Storm Tide Warning is issued after the cyclone has crossed the coast or the chance of exceeding HAT has ceased.
The relatively limited attention to the information needs of disaster managers in response phase has been recognised by a number of authors (Baumgart, et.al, 2006). To improve the current system the quality of forecast information and decision process of public emergency have been identified at the two keys factors which influence the level of preparation of a given community.
While this forecasting system achieves the primary objective of providing emergency warning to residents and communities, it is limited by its deterministic nature and lacks information regarding alongshore spatial variability of the storm tide hazard due to sparsely dispersed warning sites along the Queensland coastline. At the early stage of the project only three discrete locations along the Queensland coast at the shoreline provided storm tide height. Also the current system does not give emergency managers a view of forecast scenarios displayed at different times and then the range of risk at different time for location along the coast.

3.2. Outcomes from first phase of stakeholder engagement

Both greater accuracy and timeless of information delivery under real-time pressure were the two inevitable outcomes from the survey in 2012. In addition to reduce complexity of interpreting storm tide warning information, visualisation of the continuous nature of storm tide hazard at high spatial resolution and in term of inundation over the land was identified as another the key requirements for decision makers during an emergency situation. Representation warning data information needs to be displayed for a varying range of users and understandable by non-specialist users who could have difficulties in interpreting technical language. Communication language between forecasters and those responsible for issuing flood warnings could lead to misunderstanding information. Review of data sharing arrangements between Local Disaster Management Committees and district state committees has been identified as a recommendation to address asymmetries and inconsistencies in information in order to improve the warning system.

3.3 QSurge storm tide tool for decision support

Literature reviews, analysis of the current system and outcome from the first phase of stakeholder engagement lead in 2012 has allowed developing a real-time inundation forecasting system, QSurge, for informing storm tide hazard assessment during the response phases of a TC event. It consists of a web-based storm tide mapping interface drawing from a large database of pre-simulated events based on parametric winds making landfall in the Queensland.
The scope of this product was limited to the Coral Sea coastline and was constructed using MIKE 21 Hydrodynamic (HD) Flexible Mesh (FM) module for high performance computing (HPC) and implemented on Griffith University and QCIF's HPC facilities. The model uses parametric windfield values within Holland et al. (2010) and has been optimized for the real-time forecasting of storm surge due to tropical cyclones (Burston et al., 2013b) It has been calibrated and validated to the astronomical tide for 13 measurement sites from the Gold Coast Seaway (27.95 °S) to Cooktown (15.45 °S)). Further information on the Coral Sea HD model establishment and calibration are documented in Burston et al. (2014). The model bathymetry is the best available as sourced from multiple local, state and federal agencies and industry and then adjusted to AHD in Figure3.
Slight changes in TC parameters such as the radius of maximum wind, the forward speed, the angle of approach to the coast, the central pressure or the interaction with the local bathymetry could cause varying flood areas. For example a shallow slope will produce a greater storm surge than a deep slope. The user had the possibility to change these tropical cyclone parameters. Landfall locations are 5km spacing along the coast from Cooktown to the Whitsunday. The user has two options in terms of

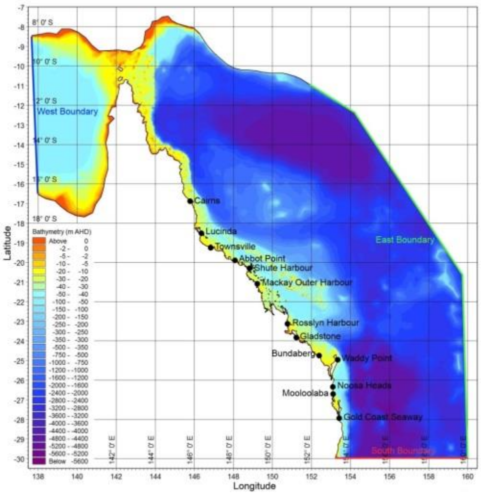

Figure 2. Coral Sea Hydrodynamic model extent, bathymetry and calibration sites.

considering the tidal contribution to the storm tide level of the ocean, either a constant plane such as MSL or HAT, or a dynamic tide information using the maximum tidal water level for a range of time. Further details of QSurge are documented in Burston et al. (2014). For each TC events, to obtain the maximum storm tide water levels, outputs of storm surge model located 1-2km spacing along the coast are added to the tidal water levels and then storm tidewater levels are displayed over the land with a bath-tub method.

This procedure assumes linear interaction between the tide and the surge. However, this approach would be conservative as storm surge development is higher in shallower water (Burston et al., 2014). The consideration of the tidal level information is a considerable advance over the current practise of looking up tidal levels at standard locations on separate interfaces or in tide tables.

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Then it generates visual spatial continuous inundation mapping of storm tide in GIS giving the "worst case" for a varying range of TC scenarios selected by the user. A Google Maps overlay (KML format) is then generated from the inundation depths for the gridded land points. The resultant depth is displayed using a discrete colour scale in 0.5 m increments to easily identify different water levels. QSurge makes considerable advance over the current storm tide risks product.

3.4 Outcomes from Phase 2: interviews and workshop

As an outcome of workshops and interviews with disaster managers and local stakeholder engagement during the second stakeholder engagement phase, some keys requirements for the forecast and display of storm tide hazard in an emergency situation were identified. Both timeless and spatial representations were identified as important. Providing estimates of Storm Tide Hazard at an earlier phase of the cyclone track than is currently the case 48 hours from landfall provides insufficient time for disaster response planning and proceed for a safe evacuation. Others gaps have been found as uncertainties with the phasing of the peak storm surge with the tide and the flooding. In addition improve the spatial resolution and continuity of storm tide height information and overland inundation maps was highly desirable.

The harmonisation across different information products has also been identified as an issue. For example the range of timing of possible landfall can be in either UTC or AEST time zones. Disaster managers tried to match water levels with pre-defined hazard maps with consistent colour coding to identify evacuation zones. Sometimes disaster managers who were not very familiar with tidal data could find issues of aligning vertical data with topographic maps as well as tides tables and were not very familiar with terms such as Lowest Astronomical Tide (LAT) or Highest Astronomical Tide (HAT). Difficulties in tidal phasing were also one of the issues reported. To reduce complexity of interpreting storm tide warning information, the main keys requirements were the visualisation of inundation over the land at high spatial resolution, timeliness of information delivery and a simple representation warning data information by non-specialist users due to difficulties to interpreting language in communications between forecasters and those responsible for issuing flood warnings.

Another issue found was the lack of consistency between each governance and agency and which resulted in different public messages to the community. The accessibility of information was also problematic. While full public access could to lead people to be responsible of their own safety, a poor understanding and misinterpretation could endanger their lives. Controlled access data is viewed as a safer particularly if inundation maps are given at a street level resolution.

And finally accuracy of the tide forecasts within warning had raised some issues as false alarms or overestimating forecasts in the past. These have leaded some communities to not response to a storm tide warning. Premature "false" evacuations have produced road accidents and unnecessary costs. The storm tide real tide forecasting tool has been tested during the workshop and was highly valued. The capacity of visualising special inundation was identified as an optimal disaster response. However the main recommendations were to improve the resolution from 100 m pixels to the street level, around 30 m pixels to provide more details and the addition of impact assessment like asset information, population affection could help decision maker The possibility of choosing a range of scenarios in QSurge would allow managers to plan varying options. This could help disaster managers to better deal with uncertainties. Disaster managers deal with timing of decisions relative to hazard information. Disaster managers should be able to assess when they will need to act and equally due to the need to assess the alignment of the arrival of the surge with the tidal cycle the timing of the event will impact on the height of the surge and the magnitude of the hazard. The inclusion of time series plots would be a way of providing storm tide information in a format that would inform the timing of decisions. The incorporation of the wave set-up and the time relevant information was quite desirable.

3.5 Impact assessment: QSurge to SurgeImpact

Following outcomes from the second phase of stakeholder engagement, the real-time inundation forecasting tool, QSurge has been improved to an updated version called SurgeImpact.
SurgeImpact pilot tool use the same structural architecture as QSurge but has been developed for the district area of Townsville due to the timeframe and computer facilities. However it could be extended to all Queensland depending on data available and time allocated. To develop this tool and reduce the computational time, sensitivity modelling experiments were conducted. This sensitivity analysis consists of identifying the appropriate increments in TC parameters for use in TC ensemble track formation and finds any potential relationship between TC parameter and surge to reduce computational time. Landfall locations for developing this tool test have been selected as 100 km north of Townsville and 30 km south of Townsville respectively.
We established the size of the pre-simulated database required to capture the full range of cyclonic events producing storm surge for the district of Townsville to be 38808 simulations per landfall point, giving a total of 931 392 storm surge scenarios for landfall locations in the district of Townsville. The sensitivity analysis documented in Faivre et al. (2015) has allowed reducing the number of scenarios to 2520 simulations per landfall point giving a total of 60 480storm surge scenarios running on high performance computer. For the optimized Coral Sea tidal model, it was found that one day simulation take 130s with 16 cores and runs in 72s with 32 cores. The model performance in terms of simulation time varies with number of computer cores. To extend the pre-required database to all districts in Queensland high performance computing facilities are highly required.
As QSurge, SurgeImpact website runs a script, written using R, to determine ‘worst case’ predictions of inundation, and consequent impacts, given a range of possible storm scenarios. The script calculates those predictions using a “refined”bath-tub method with connections between catchments. This method consists of gridded points over land, with information attached to each point including elevation, a reference point to use for sea level and statistics on roads, population and dwellings. Gridded points are spaced one arc second apart and are generated from one second DEM from Geoscience Australia which gives elevation relative to Mean Sea Level (Gallant et al., 2011). Each land point was assigned a surge model output point from the database using the Hydrodynamic Coral Sea model to use as its reference point for sea level. If the land point was located within a stream catchment, the surge model point located closest to the point where the stream enters the sea was assigned to the land point. Road lengths were calculated using road network data published in 2010 by Department of Natural Resources and Mines, Queensland. The average numbers of residents and dwellings were calculated using 2011 census data collected by the Australian Bureau of Statistics (ABS). The census gives the numbers of residents and dwelling within ‘mesh blocks. In urban areas, mesh blocks generally equated to street blocks, but were often very much larger in rural areas. In developing the impact model, it was assumed that residents and dwellings are both distributed evenly within each mesh block.

3.6 Spatial representation on a web-based platform

Feedbacks from stakeholder engagement were very useful to improve Qsurge tool and to develop an updated version called SurgeImpact. The version SurgeImpact has improved the spatial resolution from 100m in QSurge to 30 m in SurgeImpact and thus provides water depth mapping at the street as shown in Figure 3 for many TC scenarios for the district of Townsville.

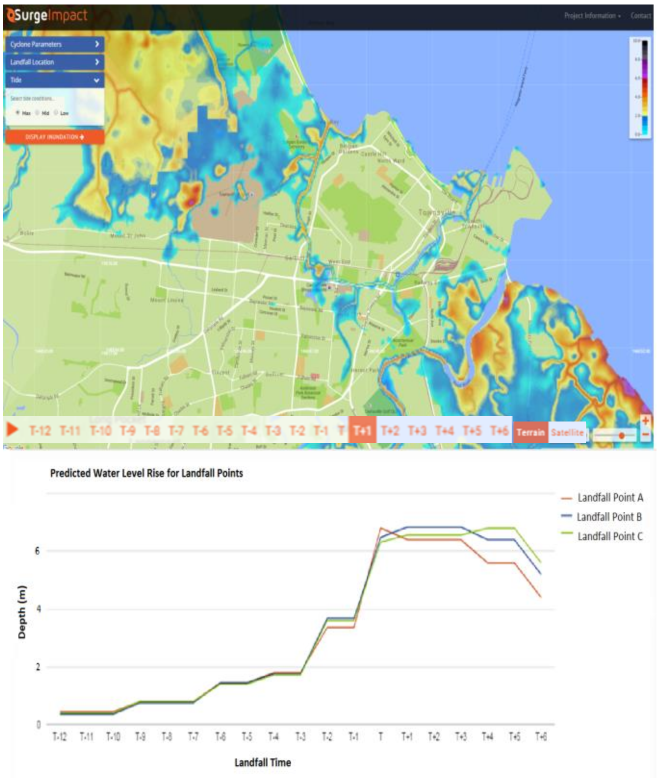

Figure 3. Water depth in Townsville (top) and Delivery report from SurgeImpact for a Tropical cyclone category 5 making landfall 60 km north of Townsville with a RMW =40km, forward Speed =10 m/s and hitting the coast with a 200 °N direction (bottom).

Tidal component in SurgeImpact has been changed to Low/Mid/High tide to simplify the communication language. Low, mid and high tide could be added to the surge to estimate the water depth over the land. This functionality would remove the currently unquantified uncertainty regarding base tide level.

While QSurge has been developed to provide the worst case estimate of storm tide for TC scenarios though the identification of areas that will be impacted upon the peak storm tide, SurgeImpact also has also been developed to identify areas in a dynamic time dimension by including inundation mapping from 12h prior to the land falling time to 6h after the TC made landfall. Moreover time series plots per hours of impacts such as population, main roads, dwelling and area of ecosystem impacted have been added. This format informs the timing of decisions. As the continuous depth maps, impacts are shown from 12h before the tropical cyclone makes landfall to 6h after the tropical cyclone made landfall as shown in Figure 3. In addition, the control of colour opacity over the map allows the user to found name and buildings under the water depth layer.

4. DISCUSSION AND CONCLUSIONS

In this paper, we had developed a great and innovative approach to support decision makers during a severe event. This paper summarises storm tide assessment requirements for evacuation decisions in Queensland. Findings from stakeholder engagement and analysis of the current system have allowed improving support to disaster manager with a storm tide case study established from scenarios using a library and displaying impacts in GIS to the user. While limited attention to the information needs of disaster managers in response phase, it has been found very important to develop the model from stakeholder outcomes. This tool has been improved to SurgeImpact from a series of recommendations for Queensland's current storm tide warning system managed by the Bureau of Meteorology and workshops with local disaster managers.

The concept of using a library of pre-calculated simulations available for a user to determine a scenario and then visualise the impact in a GIS format is quite helpful to understand deal with uncertainties. Knowledge regarding many storm tide scenarios would give a better response to the evacuation system during a severe event. The spatial outputs of SurgeImpact and the ability to input dynamic variables as the cyclone track changes provide an opportunity to improve communication of hazard information for both decision maker and public and would give a better response to the evacuation system during a severe event.

At the early stage of the project only three discrete locations along the Queensland coast at the shoreline. Providing more storm tide heights along the coast would improve the storm tide warning system. SEAtide Real Time Storm Tide Prediction and Warning Model has then been adopted by the Bureau of Meteorology Northern Territory Regional Office in Darwin and Townsville. It is a cyclone storm surge forecasting of Monte Carlo scenario generation, mapping and display. Inundation areas are then calculated by overlapping water levels to pre-calculated flooding maps with resolution at the street level. The advantage of SurgeImpact product is by giving visualisation of the inundation extend at the street level and impact assessment provide to the user a reference to identify areas that may be affected and then evaluate potential risks. As a result plan of actions can be deployed on a potential severy on each location particularly where population is concentrated. Furthermore, the extent of the model time series output allows to show the real-time evolution inundation depth and impacts during an extreme event but some uncertainties are still present.

While some improvements in SurgeImpact pilot tool are conceivable such as waves set-up integration or improvement of the inundation model, this case study has demonstrated the development of an innovative conceptual strategy. It is believable that climate adaptation options, mitigation measures such as levees and seawalls and calculation of assets could be included in this system. To conclude this tool does not intend to replace the current hazard forecasting system but used as a support to help decision makers by his innovative concept.

This concept of decision support could be applied to other natural hazards such as tsunamis, bush fire or earthquake to provide time information about evacuation.

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