An enhanced Flood Forecasting and Decision Support System for the Gold Coast

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The evolution of Decision Support Systems (DSS) has generally been in pace with the advancement of computing and communication technologies. More recently, there has been a proliferation in web based technologies and this has opened up new opportunities in terms of facilitating communication of complex modelling projections. However, a literature review has shown that many of the contemporary DSS in the field of flood emergency management deploy surrogate or simplified flood modelling systems. The reason is that undertaking complex flood simulation models has been considered to be unfeasible in the short time available during a flood emergency. This paper challenges that paradigm. The desire for this paradigm shift is underpinned by the recent advent of GPU based flood modelling systems and sophisticated web based GIS systems that can better present and communicate the results of these models. Furthermore, the paper argues that there should be a move away from model based systems to open systems that can house modelling engines and communicate their outputs to decision makers. This approach promotes user focused communities that can cross agency and proprietary lines thereby reducing costs and promoting maintainability of developed systems. Finally, emergency management decision making is usually threshold based and accordingly we should produce outputs that facilitate this type of decision making.

This paper addresses the above-mentioned challenges by introducing a framework for a flood emergency decision support system that is based on model-driven projections whose outputs can be readily presented using freely available web-based applications. This system utilises the most recent advances in computing and communication technologies which integrates (i) hydrological modelling; (ii) two dimensional rain-on-grid hydrodynamic modelling; and (iii) uses custom-made control centres together with a number of freely available web-based applications. This can be used to predict and display real time flood level time series across the Gold Coast City.

The integrated system automatically and routinely:

- Interrogates rainfall gauging stations across the city and the BoM ftp forecast rain site and downloads measured and predicted rainfalls,
- Analyses measured and predicted rainfall to determine their return period and issues warnings accordingly,
- Generates animated rainfall maps from the downloaded rainfall data for input to hydrological and hydrodynamic models and display on the web,
- Predicts flood extents and time series through hydrological and hydrodynamic simulations and displaying the animated outputs on the web, and
- Uses these forecasts to assist emergency management personnel in identifying:

    - At risk people and assets,
    - Available timeframe to respond, and
    - Method of aid deliver/dispatch (i.e. which road network is available and for how long).

The system can be scheduled to produce:

- Round the clock automatic flood forecasts.

- Publication of the flood forecasts onto the Internet.
- Ability for remote-controlled operation and modification of the system operation.

This system enhances Council's existing Decision Support System in the following three areas:

- It provides point forecast flood level time histories for key locations across the city, complementing the BoM forecasts that are issued for major river locations.
- It can provide necessary information to emergency managers through mobile devices, facilitating earlier decision making and extending warning times for flash and regional flooding when there is little time for mobilisation of a Disaster Coordination Centre.
- It provides surface forecasting flood level time histories with increased accuracy through use of real-time two dimensional fine resolution hydrodynamic modelling.

This system is primarily designed for use during flood emergency response management. The system can also be used for emergency planning and as a decision support tool for post disaster recovery.

1) Introduction

Flood emergency management requires regular forecasts of the flood situation and consequently regular detection of at risk people/assets; assessment of available response time and identification of method of aid delivery. This requires processing of a huge amount of data in a short period of time necessitating the use of an effective and robust Decision Support System. Flood emergency Decision Support Systems (DSS) have been used by emergency managers for a long time. In the 1980's and 1990's these systems were usually data-driven and in the form of hard copy flood maps, graphs, tables and other hard copy documents. With recent advances in computer and communication technologies, these systems have morphed into more sophisticated forms; providing real time flood information in more detail, in significantly less time-frame and with higher quantity using sophisticated models and web-based applications.

The Gold Coast City Council developed its first computerised flood emergency decision support system in early 2000. Since then this system has been improved in pace with technological advancements in computing and communication technologies (Mirfenderesk, 2009 & 2010). Council's DSS integrated existing flood modelling, GIS and communication capacities with the city's properties, infrastructure and population data into a single easy-to-use package. Using this system, emergency managers have been able to access flood forecast information.

Over the last year Gold Coast City Council embarked on developing a new generation DSS that is substantially superior to the Council's earlier versions. This paper demonstrates the enhanced capacity of this system and shows that the construction, operation and maintenance of such system is well within the reach of the majority of local authorities in Australia. The paper is structured as follows. First a description of an ideal DSS is presented. This is followed by a description of the new proposed DSS and introduces a framework how such a system can be developed by any local authority. Section four discusses how the proposed DSS meets these criteria. The last section concludes the paper and outlines future work.

2) Features of an ideal Flood Emergency Decision Support System

A review of literature shows that there is no consensus on a definition for Decision Support System (Sauter 1997, Parker and Al-Utabi 1986, Simonovic and Savic 1989, Thierauf 1988). In the context of this paper a DSS is defined as "an interactive computer-based system that helps emergency managers in tactical and strategic decision making during a flood emergency. It helps decision-makers use data and predictive models to identify problems, identify steps in decision making to solve a wide range of emerging problems (unstructured, semi-structured, ill-structured and structured) that they may confront during flood emergency".

Development of a Decision Support System starts from understanding the needs of the people who are going to be supported by the system. This includes emergency management decision makers, SES volunteers on the ground and community. Elements that provide the needs of the abovementioned groups constitute the main ingredients of an ideal DSS. They are as follows:

- Ability to generate timely warning
- Comprehensiveness
- Accuracy
- Speed
- Flexibility
- Ease of construction, operation and maintenance
- Accessibility and effectiveness of system communication with a wide range of audience

Each of these elements is discussed in turn in the following.

<u>Ability to generate a timely warning</u>
A warning should be timely and issued only when an action is required. The scope of warning should be limited to the area of interest. Regular status report of the weather or river condition over a large area, which requires no action, can cause fatigue in emergency managers and should not replace a proper warning system. The language of warning should be easy to understand for emergency managers.

<u>Comprehensiveness</u>
The information should be complete. A complete set of information can answer three fundamental questions, ie who needs help; how much time we have and how the help can be provided. This requires

- Identifying any elements that will be inundated
- Level of inundation
- Time line of inundation
- Identifying all the connecting roads to the vulnerable element and
- The timing of road cut off
- Identifying the location of high velocity flows

In summary we should be able to forecast water level hydrograph at the location of any vulnerable element and all the roads connecting to the vulnerable elements.

<u>Accuracy</u>
It goes without saying how important is to convey accurate information to emergency managers and consequently to the community. An underestimation of a threat can result in damage and possibly loss of life. Overestimation of a threat gradually erodes community confidence and cause public complaint on the adverse impact of dissemination of inaccurate information on the value of their properties.

<u>Speed</u>
Emergency management is a time critical exercise and the speed of information flow can make or break an operation. A DSS needs to be flexible and respond quickly to any type of question. There is always a trade-off between speed, accuracy and comprehensiveness of information. This trade-off varies, depending on the situation. A DSS should have enough inherent flexibility to accommodate every specific condition.

Flexibility
Flexibility allows decision makers to map alternative scenarios to answer “what if” queries. Decision makers are guided through most optimistic, most pessimistic and in-between scenarios through a “what if queries” exercise.

Ease of construction, operation and maintenance
Local authorities are responsible for assessing the impact of a natural hazard on their communities; as such they are the main users of Flood Emergency Decision Support Systems. Local governments generally have limited resources and are not equipped adequately to deal with complex systems. Such systems will generate high overheads for their maintenance and operation and usually become too costly for a local authority.

Effectiveness of user interface
A DSS should provide a user-machine interface enabling the user to interact with the machine and allow a merger between the computer outputs with the subjective judgement of the system operator. Such an environment allows the user to obtain answers to “what if scenarios”.

An effective decision support system should be able to generate outputs that can be easily understood by both experts and non-expert audience. The outputs should be as much as practically possible in graphic forms and adequately small in size to allow its transmission through the Internet and to the mobile devices. Quantity and quality of dissemination of information should be at a level that allows for collective decision making by a decentralised group of decision makers, hence enabling a coordinated response to a disaster.

3) Gold Coast City Flood Emergency Decision Support System

This system comprises of four tiers (Figure 1):

1. **Tier one – rainfall analysis (Warning module)** – This is a data-driven module that has the capacity for data warehousing, data processing and information analysis. The information generated at this tier answers the question “should the Disaster Coordination Centre be mobilised”. This information is generated automatically in a fraction of second. This module automatically interrogates more than 80 gauging stations across the city and downloads measured rainfall from the Gold Coast Alert gauging stations. It then undertakes frequency analysis of the measured data and generates Intensity-Frequency-Duration (IFD) curves for each gauging station. In parallel the system downloads rainfall forecasts from the Bureau of Meteorology webpage and generates catchment based IFD curves for each catchment of the city. The system analyses both sets of IFD curves. Once the predicted and measured rainfalls cross a certain thresholds (in terms of catchment averaged rainfall return period), the system sends warning messages to emergency managers automatically. The frequency of this exercise can be set at any rate, depending on the situation. The information processing and generation of warnings is undertaken in a matter of seconds in this module.

2. **Tier two – point forecasting module** –This module is model-driven and has an emphasis on access to and operation of hydrological models and analysis of their outputs. This module is triggered once tier one issues a flood warning. The information generated in this tier answers the question “are the consequence of impending flood is high enough, requiring actions such as evacuation”. Information at

the second level is generated in less than a minute. This module comprises of two main elements:

a. A fully automated process administrator (control centre), comprising of a suite of computer programs. This sub-module is data-driven and has two roles
    i. To provide an effective user interface for “what if scenario” operations.
    ii. To control the flow of data into, out and through the system (between modules). For instance, it imports the real time rainfall and water level gauge data and prepares them for use as input to hydrological and then hydro-dynamic modelling.
b. An integrated hydrological model. This element is model-driven and generates two main outputs:
    i. Point forecasts of water levels at critical control points at upper reaches of the catchments such as dam walls. This output provides decision makers with a quick assessment of the response of the flood storage capacity of the city and potential impact of impending flood.
    ii. Point forecasts of flood flow at the input points of the hydrodynamic models of the city’s catchments.

3. **Tier three - Surface forecasting module** – This is a model-driven module responsible for the generation of a comprehensive set of information about the consequence of the impending flood. This module will provide emergency managers with all the information that they need for informed decision making and actions, such as rescue and evacuation operations. This module is comprised of two main elements:
    a. A suite of detailed two-dimensional hydrodynamic models for all the city’s catchments. The models are informed both by the inflow from hydrological models and direct rain on the urbanised section of the catchment. The models are two dimensional and have very short run times, depending on the location and flooding condition.
    b. A suite of computer programs operating within organisation ARCGIS system for the analysis of the output of the two dimensional models.

    This module provides the following information:

    c. Flood extent and flood depth information across the city – This output provides decision makers with a global view of maximum flood level and depth across the city.
    d. Evolution of flood surface in time across the city – This output shows that how flood level and extent changes as rainfall continuous. This output provides decision makers with a sense of timeline of forecasted flood. This helps them to understand at what time which part of the city will experience flooding.
    e. Time series of water level variations at critical locations – This output is the hydrograph of water level variation at critical locations across the city. Using this output, decision makers can determine for instance when a road is inundated and how long the inundation will take.
    f. Status report of city’s vulnerable elements –This output of system is both in the form of maps and reports. The output includes the assessment of the status of every vulnerable element in the city, i.e. every home, school, age care centre, child care centre and hospital. Every elements that is inundated

will be identified on a map an in a report. The required time for the completion of operation of this module is in the order of a minute.

This module enables the system to be used in post disaster recovery, as it generates the time line of raising and falling flood levels accurately and based on two dimensional model results. This knowledge enables decision makers to prioritise recovery and cleaning programs.

4. **Tier four - Communication module** – This module is communication driven and is designed to enable group decision making by a decentralised decision making group. Decision making will be based on a set of comprehensive and easy to understand flooding and flood consequence information that is provided via the Internet. The system allows for the exchange of information through a number of freely available web-based applications such as Google Map, via a number of KML files. These files can be easily transferred by email. Once the email is received by the decision makers, a graphic display of information (KML file) can be displayed using Google Earth. The display includes the following graphic materials:
   a. An animation of the both measured and forecasted rainfall map across the city,
   b. An animation of flood evolution map across the city,
   c. A map identifying all the affected properties and vulnerable elements such as child care centres, age care centres, schools and health care centres. Clicking on the identified affected assets, more detailed information such as depth of inundation and contact details will be displayed on the screen.
   d. A colour coded map showing all the inundated roads and the level of inundation.
   e. A map displaying the flood level hydrograph at all the critical locations. By clicking at the desired location on the computer screen the hydrograph appears on the screen. This map shows when an access road to a specific vulnerable site is cut off and for how long.

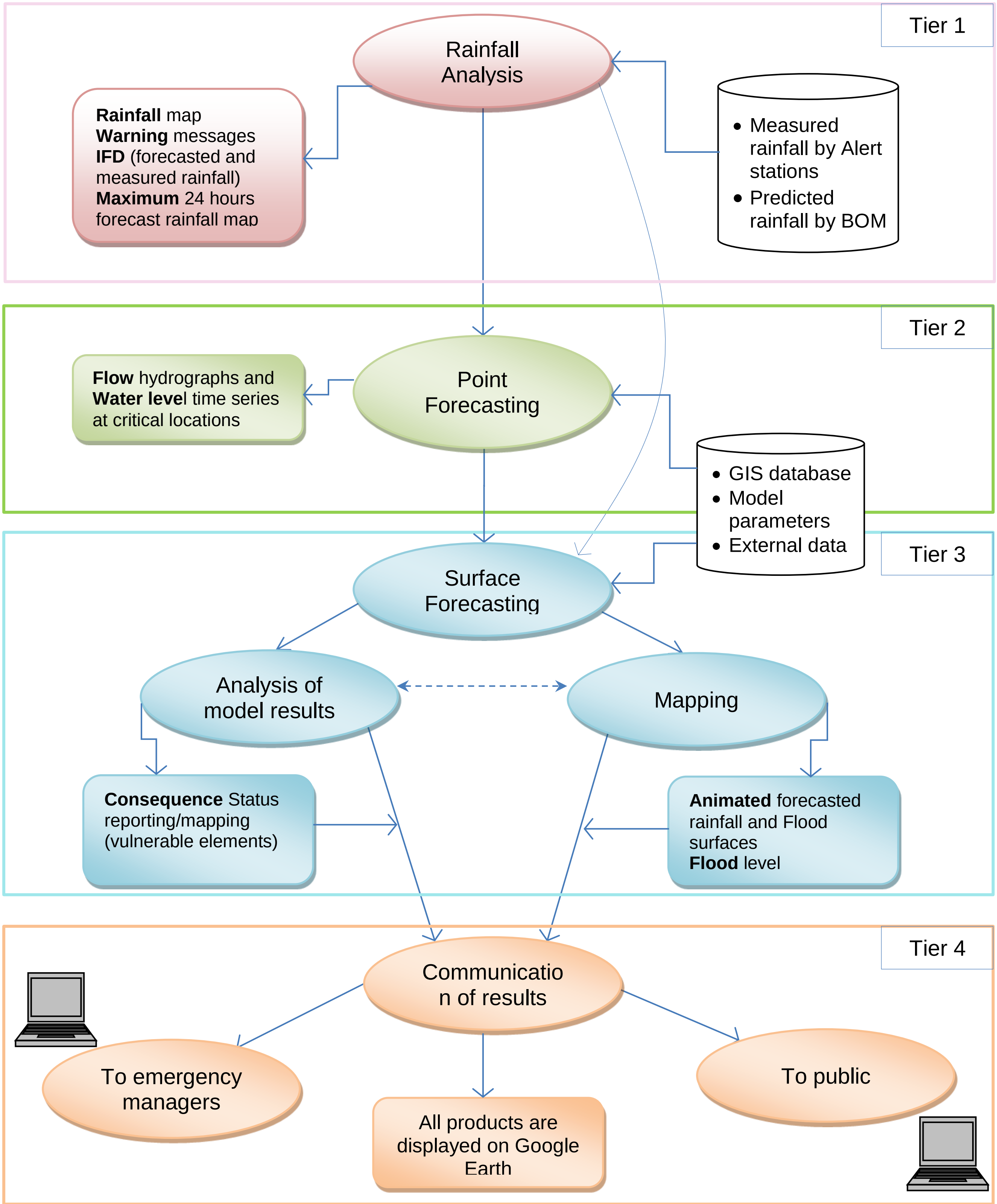

Figure 1 – Decision Support System Structure

4) Discussion

This study demonstrates that computing technology and the Internet bandwidth has reached to a level that generating comprehensive model-based surface forecasts and communication of large size of outputs via the Internet are now possible. The paper describes the criteria for an ideal DSS for real time flood emergency management and demonstrates that the proposed DSS meets these criteria.

The proposed warning module of the system undertakes a full analysis of rainfall across the city and provides a global view of the rainfall return period for each catchment. This analysis is then used to generate the scientifically most accurate estimate of the threat level and consequently timely and realistic warning to decision makers. This is an improvement to the available warning system by the State agencies to the City's Disaster Management Unit (DMU) that is based on point measurements and forecasts at selected locations within the main river system. The proposed warning system is fully automated and continuously monitors the weather condition and the warning is issued only once certain thresholds are crossed. This is also an improvement to the existing warning system that provides regular status report of forecasted flood level at limited locations. High frequency of the existing status reporting increases the risk of fatigue of the emergency management personnel who must actively monitor the numerous warnings of which many require no action.

The proposed system achieves comprehensiveness and accuracy by undertaking surface forecasting using two dimensional modelling. Two dimensional modelling is the only viable option for achieving spatially accurate forecasts particularly in tidally influenced floodplains. The outputs of a real time two dimensional model contain all the information that an emergency manager may require, in particular the time line of events, such as when access to a particular vulnerable element will be cut off and for how long. The accuracy is further enhanced, as the system allows real time calibration of hydrological model of the system, based on the observed rainfall,

The proposed system achieves the required speed by using the latest technology in modelling and analysis of information. The system can produce point forecasts in the matter of minutes and surface forecasts between 10 and 60 minutes, depending on the location and type of required information. These run times can be reduced to half in near future, once the existing research level technology is made available in the market.

Ease of construction, operation, maintenance and communication of the proposed system is achieved by building the system using the existing tools that normally can be found in an average local authority.

Flexibility of the system is achieved through an effective user interface. The users can interact with the system and undertake “what if scenarios”. System output is available to users via the Internet in graphic form and easy to understand style. The capacity for undertaking “what if scenarios” makes the system suitable for emergency planning exercises.

5) Conclusion and recommended future work

This paper describes the framework and working prototype of a Flood Emergency Decision Support System that is capable of supporting both tactical and strategic decision making during a flood emergency. The system is fully automated and operates in data-driven, model driven and communication-driven tiers. Each tier of operation is triggered by the previous one and the comprehensiveness of the output information increases progressively in each tier.

The proposed framework improves two aspects of contemporary DSSs in the field of flood emergency management. The system includes a model-driven module for real time two-dimensional simulation of events. This module greatly improves the comprehensiveness and accuracy of the system. The building blocks of the proposed DSS are generally freely available or are software that almost every organisation already uses. This makes the construction of such a system within the reach of most organisations and reduces the efforts for operation and maintenance and greatly improves cross-organisational collaborations.

Although the system is designed for during flood emergency management, it can be used for emergency planning or post-disaster recovery.

Lessons learnt

- Start from emergency management decision makers and work backward.
- Ensure that there is an emergency management operation mode for the whole organisation and the switching to this mode is automatic and seamless. All the security, resourcing and technological issues must have been addressed prior the emergency and not during an emergency.
- A DSS should have a focus on finding an optimum solution.
- Corporatize your DSS as much as practical.

Next step

- Socialising the DSS with the community and industry, in order to maximise the tangible benefits of the system to the day to day business of the community.

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