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Decision support: Informing flood management

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Abstract

This paper describes the development of a new flood management decision support system which significantly improves the ability of flood practitioners to: 1) Identify adaptation and mitigation solutions to flood inundation; 2) Facilitate objective community flood risk management consultation and 3) Justify floodplain management decisions in a transparent and structured manner to all stakeholders. The nature of a Decision Support System (DSS) and its place in floodplain management is described and it is shown how a DSS can be used as a practical tool to identify options available to flood management practitioners. The new flood management system presented in this paper is shown to have the ability to assist rigorous, transparent and auditable decision making while also facilitating community consultation.

This paper describes research undertaken as part of PhD studies and does not necessarily represent the views of the Office of Environment and Heritage.

Introduction

The ability for flood managers, whether they be individuals, groups, organisations or governments, to make informed decisions about flood management options is critical in order to reduce the social and economic consequences of flood inundation. To make informed decisions a flood manager must have a robust understanding of the best flood management options available. However, turnover of flood staff within councils and the associated loss of background knowledge and expertise means that such an understanding and readily available heuristic knowledge may be limited. Even if this understanding and heuristic knowledge is present within an organisation, transparency and justification of the selected option/s throughout the decision making process is required to satisfy internal and external stakeholders. Hence, a tool as presented in this paper that can objectively facilitate the decision making process of selecting flood management options bridging heuristic knowledge and understanding gaps while engaging the community and providing a transparent means to justify a decision made can only improve a flood manager's ability to make good decisions.

Decision Support Systems (DSSs)

A Decision Support System (DSS) is simply *"…an interactive computer based system that utilises a model to identify and draw upon relevant data in order to aid decision making"* (Lemass, 2004). A DSSs primary role is to assist a decision-maker through a series of procedures, while supplying and delineating quantitative and/or qualitative data to enable the decision-maker to make an informed choice between competing options to solve a problem or meet an objective. It is this ability to aid decision-makers in solving problems and meeting objectives that has seen the emergence of multiple DSSs in the water resources field. These include DSS applications for: flood hazard mapping (FLOOD DSS, HAZUS etc.); flood response routing and emergency management (Gold Coast City Council, River Thames etc.) or a combination of both (REDES); water quality prediction (WATERCAST etc.); aquatic ecological models (CAEDYM etc.); urban stormwater improvement models (MUSIC etc.); and soil and water models (SWIM etc.) (CWCD, 2010; FEMA, 2011; Mirfenderesk, 2009; Sanders & Tabuchi, 2000; Simonovic,1998; Cook et al, 2009; CWR, 2006; Wong et al, 2001; CSIRO, 1992). As raised throughout literature (Simonovic, 1996; Srinivasan et al, 2000; Lemass, 2004) it must be noted that DSSs are not designed to make decisions but are rather tools to support and aid the decision making process.

DSSs and Floodplain Management

Floodplain management option selection is an area that DSSs could be of assistance to floodplain managers both nationally and internationally. DSSs could be utilised in this area as they have the ability to:
1) Store data in an interactive, updatable and accessible format. A DSS has the ability to store an encyclopaedia of knowledge (organisational, heuristic and researched) on the 100s of flood management measures available to flood practitioners in a single organisationally specific program. This data could include information on each flood management measure's specific advantages and disadvantages inclusive of social, safety, environmental/ecological, economic, political and flood behaviour constraints, as well as case studies documenting past successes and lessons learned.
2) Equitably compare any number of flood management measures based on organisationally defined scores and user defined weightings allowing relevant constraints and the associated consequences of each option to be explicitly explored.
3) Provide a structured methodology that is repeatable, transparent and justifiable. The resulting decision should be able to withstand challenges as the approach is coherent, structured and internally consistent with a well documented audit trail.
4) Quickly run sensitivity analysis to compare advantages and disadvantages of selected options and rankings. This sensitivity analysis can further aid in communicating proposed solutions or options to the community in a robust manner.
5) Be used by all stakeholders, stimulating and broadening the scope and range of decision making to achieve better and more inclusive solutions.

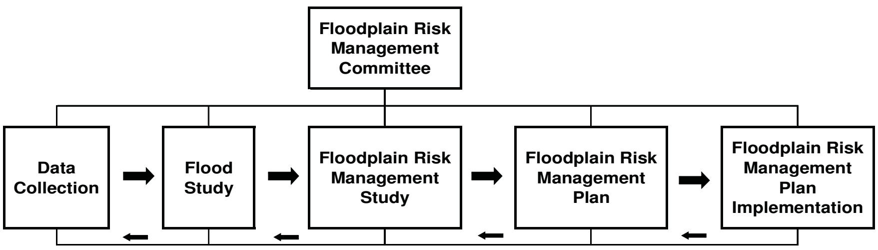

Figure.1: The NSW Floodplain Management Process (DIPNR, 2005)

An informative and well structured DSS used in floodplain management option selection would improve two key processes involved in undertaking a Floodplain Management Study (refer Figure 1, DIPNR, 2005). These processes are: 1) Identifying the options available for managing the risk in consideration of social, safety, environmental/ ecological, economic, political and flood behaviour constraints, and 2) Assessing, comparing and deciding on options using a matrix approach as documented in the NSW Floodplain Development Manual (DIPNR, 2005). A DSS would improve these key aspects as it would contain a knowledge base of all options available and their relative advantages, limitations and constraints, and provide a platform that undertakes a similar methodology to the DIPNR matrix approach; systematically and equitably balancing a range of constraints with identified flood mitigation options which allows the decision maker to better determine which option/s are the most appropriate.

Options Available To Flood Practitioners

There are numerous flood management measures available to flood risk practitioners in recent times. These flood management measures generally fall within four categories: 1) Flood management measures; 2) Building management measures; 3) Land use planning management measures and 4) Response management measures. Flood management measures and building management measures can then be further categorised for comparative purposes. Flood management measures can be sub-categorised as 1) Exclusion of flood water; 2) Conveyance of flood water; and 3) Containment of floodwater. Building management measures can be sub-categorised as 1) Existing buildings and 2) Future buildings. Examples of management measures associated with each category in conjunction with land use planning and response management measures are represented in Table 1.

Flood Management Measures		
Exclusion of Floodwater eg:	Containment of Floodwater eg:	Conveyance of Floodwater eg:
Earthen Levee	New Flood Mitigation Dam	Widen Existing Channel
Concrete Levee	Raising Existing Dam Wall	Deepen Existing Channel
Pop-Up Levee	Detention/ Retardation Basins	Realign Existing Channel
Drop In Boards	Enhanced Floodplain Storage	New High Flow And/Or Low Flow By-Pass Channels
Flood Gates	Increased Permeable Surface	Culvert Upgrades
One-Way Flow Valves		Realign Culverts
Sand Bags		Redesign/ Realign Bridge
Automatic Barriers		Underground Tunnels
Manual Barriers		River/Stream Rehabilitation
		Blockage barriers
Building Management Measures		**Land Use Planning Management Measures**
Existing Buildings eg:	Future Buildings eg:	Land Use Planning Management Measures eg:
Wet Flood Proofing	Flood Smart Housing	State Environmental Planning Policies
Dry Flood Proofing	Flood Smart Sub-divisions	Local Environment Plans
House Raising	Flood Design Standards	Development Control Plans
Upper Story Flood Free Refuge	Flood Free Access	Local Flood Policies
Raise Electrical & Fixed Assets	Upper Story Flood Free Refuge	Incentives For Residential Zone Changes
Flood Resilient Materials And Design	Property Fill	Incentives For Residential Relocation
Strengthen Foundations	Relocatable Construction	
Improved Drainage	Modifiable Construction	
Housing Relocation		
House Removal		

Response Management Measures		
Flood Education Packages	Community Awareness	Drills and Exercises
Flood Intelligence	Response/ Evacuation Plans	Recovery Plans
Flood Prediction	Flood Warning	

Table.1: Management measures adapted from BMT WBM, 2009.

With so many options available, a product that would be of benefit to flood managers both nationally and internationally is a single detailed database, namely a DSS help page containing up-to-date information on the numerous flood management options available and their relative constraint advantages/ disadvantages in order for them to make informed decisions. Moreover, in real world applications as identified in the Floodplain Development Manual, each *"risk management measure should not be considered either individually or in isolation. They must be considered collectively from within the all-embracing framework"* (DIPNR, 2005). This requirement could be provided by a flood management DSS framework.

DSS Methodology

The methodology behind a DSS for flood management option selection primarily revolves around scoring and weighting options against constraints to achieve a ranking that aids decision making for semi-structured problems. This process generally involves eight steps (adapted from DCLG, 2009):

<u>Step 1:</u> Establishing the decision context. This entails developing aims and objectives for the DSS outputs, ensuring the complexity and goals of the system are achievable and quantifiable.
<u>Step 2:</u> Identifying the options to be appraised (refer Table.1).
<u>Step 3:</u> Identifying constraints to assess the options. This involves identifying the various social, safety, environmental/ ecological, economic, political and flood behaviour constraints applicable to the option to be appraised.
<u>Step 4:</u> Scoring the expected performance of each option against the constraints. This involves expert judgement, organisational knowledge, case studies and research queries to derive justifiable and consistent scoring scales.
<u>Step 5:</u> Assigning weights to the various constraints to reflect their relative importance to the decision. This should incorporate stakeholder involvement including the broader community.
<u>Step 6:</u> Combining the weights and scores for each option in a matrix to derive ranked preferences.
<u>Step 7:</u> Conducting a sensitivity analysis as a means of checking the robustness of the rankings and comparing relative advantages and disadvantages of different options. <u>Step 8:</u> Examining the results.

When developing a floodplain management DSS, exceptional care is required when deriving scores in the matrix approach (Step 4). Exceptional care is required as flood management constraints are a combination of both tangible and intangible variables across different scales. In order to achieve relative option comparisons, numerous scales of measurement must be examined for best fit. These scales of measurement include: Nominal scale, assigning a number to an object; Ordinal scale, ranking an object and assigning a number; Interval scale, assigning a number to quantifiable objects at consistent intervals; Ratio scale, assigning a number based on a ratio unit; Absolute scale, assigning a probability based on a relative ratio scale without units or an absolute zero (Saaty, 2009). One particularly straight forward scale is the preference scale. This is simply a *"scale anchored at their ends by the most and least preferred options on a criterion. The most preferred option is assigned a preference score of 100, and the least preferred a score of 0…Scores are assigned to the remaining options so that differences in the numbers represent differences in strength of preference"* (DCLG, 2009).

Another essential consideration in floodplain management DSS development is accounting for the possibility of bias (intentional or sub-conscious) in deriving relative scales of importance for non qualitative data. Bias can occur as inputs such as expert judgment are required to derive appropriate ratings for intangible option constraints such as social constraints. These expert judgments in some cases may be influenced by drivers or factors (perhaps even unconsciously) resulting in option biased preferences. To ensure this is not the case, sensitivity analysis of the scores should be undertaken post system development to assess the robustness and stability of the analysis outcome. Sensitivity analysis can be completed through Automatic Sensitivity Analysis, utilising software packages to analyse variable ranges and their influence on results; and/or Trial and Error Sensitivity Analysis, such as the "What-If" technique, namely **What** will happen to the output **if** an input (variable; assumption; or decision rule parameter) is changed? (Lemass and Carmichael, 2008).

Validation is another essential means of assessing confidence in a floodplain management system. Validation is concerned with assuring the external correctness of the system and can be achieved through asking experts and potential end-users to confirm whether or not the generated results through their experiences are similar to what actually occurs in real world practice. Other methodologies to obtain validation data can involve undertaking test scenarios based on previous case studies and field observations.

Community Consultation

The development of a decision support system for floodplain management option selection could provide unique opportunities for facilitating objective community flood risk management consultation. These unique opportunities include:

1) Providing information in a quick to run, easy to use, digestible, interactive format that community stakeholders can relate to. This can potentially result in community members gaining an increased awareness about the complexities of floodplain management option selection, the problems at hand, the governing processes, floodplain management option specific advantages/ disadvantages, alternative viewpoints and the constraints present. Ultimately, interested residents may become more involved in the floodplain risk management process through committees and/or public exhibition as a result of this increased educational enlightenment.

2) Facilitating community input. A DSS can allow community members, through either face to face or via online consultation, an opportunity to provide input into the decision making process through a structured framework. A well designed floodplain management option selection DSS can operate as a front–end allowing stakeholders to rank constraints that are of importance. This aggregated data can then be used as a mechanism to objectively weight constraints in a matrix approach contained within the DSS allowing options to be identified. As a DSS provides a transparent and auditable framework, community members could then explicitly see how the decision has been made, the process that has been followed, the viewpoints of different stakeholders and the higher level issues that were of consideration. Community members can then realise the trade-offs that occur in

floodplain management option selection leading to a sense of acceptance and potential ownership of the decision/s made.

The Constraints and Limitations of Decision Support Systems

Although decision support systems have numerous relative advantages, there are evident constraints and limitations. One particular limitation revolves around the fact that DSSs are not designed to make decisions, nor are they designed to replace decision makers. A DSS is designed to provide a knowledge-base of information and a structured methodology to equitably determine suitable options, but ultimately it is the role of a decision maker to weigh up the pros and cons of options and make an informed final decision. If the decision maker does not have the required knowledge to make a decision or does not fully understand the problem at hand, poor decisions can result. This can lead to the decision maker blaming the DSS for the decision rather than taking ownership for the poor decision made (North, 2012). Furthermore, if the information provided in the DSS is inaccurate, biased or very limited in content, negative outcomes can result if the decision maker places too much trust in the program.

A DSS designed to analyse a problem at a specific scale is another limitation. This occurs as DSS software is predominantly produced with design and resource limitations. Thus it is unreasonable to expect a DSS to identify detailed option placement or design unless it is explicitly programmed to serve that purpose. Moreover, a DSS with copious levels of information can have a limitation of causing the user to suffer from information overload. This information overload can effectively reduce the efficiency of using a DSS by inhibiting the decision maker's ability to make a decision. However, an interactive and well designed DSS with digestible information can overcome this limitation and prove to be an important mechanism in aiding decision makers to make informed decisions (North, 2012).

Development of A New Flood Management DSS (FLODSS)

A new trial DSS for floodplain management option section has been developed utilising Microsoft Excel and Visual Basic called FLODSS. The primary aims of this system are to: 1) Identify adaptation and mitigation solutions to flood inundation; 2) Provide a structured confirmation of the flood inundation management measure/s selected; 3) Facilitate objective flood management community consultation; 4) Provide an auditable framework that transparently and objectively justifies to all stakeholders the decision making process that was utilised to deduce the selected option/s; and 5) Provide a flood inundation management handover training tool for engineers, developers, planners and councillors, and an effective flood related educational tool for the broader community.

In order to achieve these aims, FLODSS has been developed to date through an aggregation of data using detailed literature reviews, expert judgment, case studies, and research queries. These data collection methodologies have allowed for the identification of available options, a substantiation of their relative advantages and limitations relative to selection constraints, and have allowed for the construction of a theoretically sound system that equitably balances a range of constraints with identified flood mitigation options permitting the decision maker to determine which option/s are the most appropriate.

The back-end of the system has been developed by:

- Establishing the decision context for floodplain management option selection and addressing the aims above.

- Identifying the options to be appraised (Table 1).
- Identifying constraints to assess the options, including social, safety, environmental/ ecological, economic, political and flood behaviour constraints applicable to the option to be appraised.
- Scoring the expected performance of each option against the constraints. This involved utilising the "preference scale" pairwise analysis approach utilising expert judgement, case studies, literature reviews and research queries to derive justifiable and consistent scoring scales.
- Combining the weights and scores for each option in a matrix to derive equitably ranked preferences.
- Conducting an initial What-If sensitivity analysis as a means of checking the robustness of the rankings

The front-end of the system has been designed to allow the user to input data at two critical stages to facilitate the backend calculations. The first stage that requires user input relates to location and the problem specifics at hand (Figure 2). The second stage requires the user to define weightings of social, safety, environmental/ ecological, economic, political and flood behaviour constraints from which the constraints are weighted. An example of one of the constraint user input pages developed so far to achieve this is given in Figure 3. From these inputs in conjunction with the predetermined scores for each option, FLODSS is able to numerically derive objectively ranked preferences as outputs for consideration.

A tool available to users to assist in the front-end process is the Help menu. This tool is useful if the user is unsure of what the question is asking or is unsure of the alternative outcomes at any point. The help menu has been designed with a layperson in mind, providing detailed information in an easy-to-understand interactive format about the specific areas of interest. In providing the user with detailed information, it is anticipated that accelerated learning will prevail allowing developers, planners, councillors and community members to gain a basic level of understanding about the complexities of floodplain management option selection, thus improving the decision making outcome.

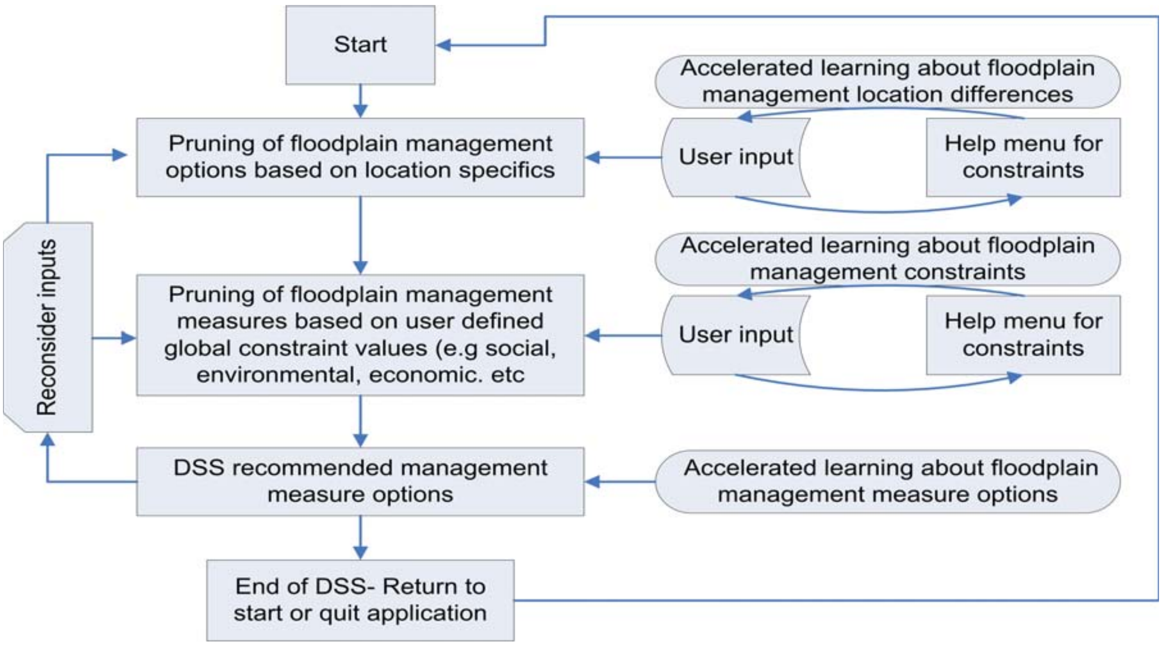

Figure.2: FLODSS Flow Chart

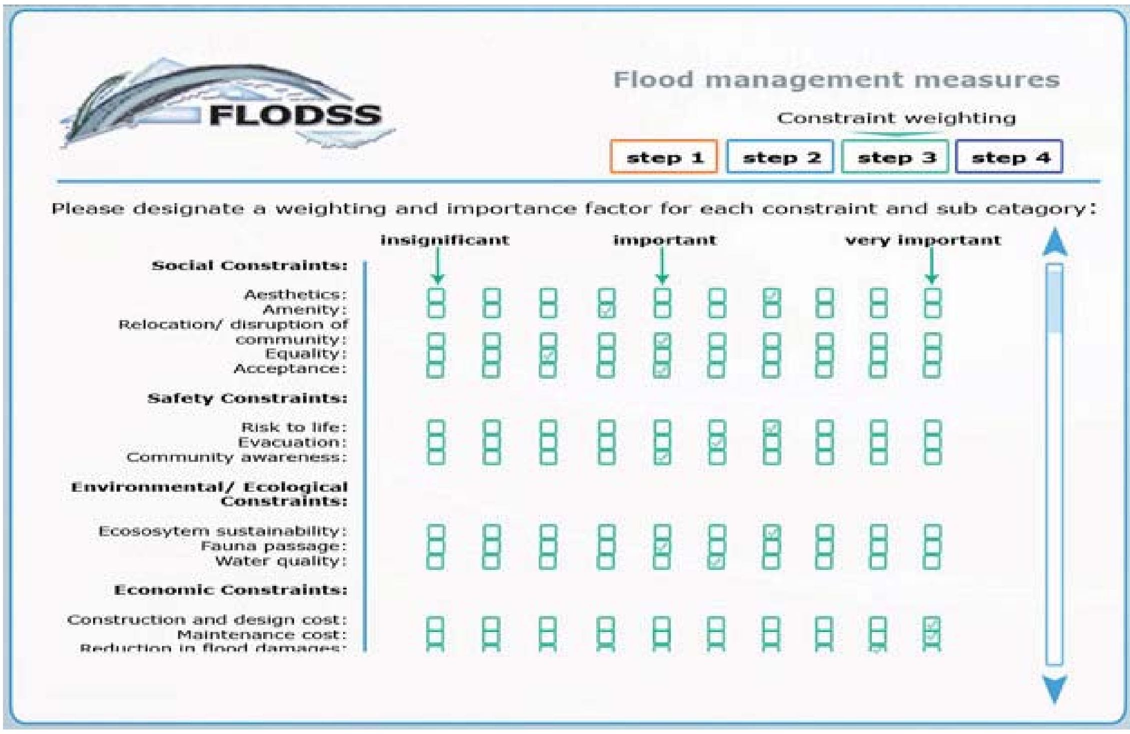

Figure.3: An example of the FLODSS Floodplain management constraint user input screen

It is intended that further system testing, verification, and sensitivity analysis is conducted on FLODSS through expert targeted trials, community surveys, automatic sensitivity analysis and trial and error sensitivity analysis techniques. It is envisaged that through such validation methodologies FLODSS will be used by practitioners to objectively facilitate the decision making process of selecting flood management options by bridging heuristic knowledge and understanding gaps while engaging the community and providing a transparent means to justify decisions made through a structured auditable framework. However, as FLODSS is only designed as a tool to assist the decision maker, it is the decision maker and, in NSW, ultimately the local council that must take responsibility for selecting the appropriate floodplain management option/s to be implemented.

Conclusion

This paper has identified that a decision support system for informing floodplain management option selection is of benefit to floodplain managers both nationally and internationally. This is of benefit as DSSs such as FLODSS have the ability to: 1) Identify adaptation and mitigation solutions to flood inundation, 2) Facilitate objective community flood risk management consultation, and 3) Justify to all stakeholders floodplain management that decisions are made in a transparent and structured manner. A practical system has been developed and briefly described.

Like all tools, limitations and considerations must be addressed such as scaling, ranking, scoring weighting, and validation; however it can be seen that systems like FLODSS could provide unique opportunities to address flood management option selection in the near future. With further refinement and validation, these types of systems could prove to be valuable assets as they can only improve the abilities of engineers, developers, planners, councillors, and the community to contribute to the floodplain management decision making process.

Your feedback on any aspects raised in this paper, particularly in regard to decision support systems for floodplain management option selection, would be greatly appreciated and can be directed to rtl103@uow.edu.au.

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