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Development of a DSS for Integrated Water Resources Management in Bangladesh

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Abstract: The Institute of Water Modelling (IWM), in Bangladesh, hosts a suite of hydrodynamic models that can estimate river stages and discharge, flood and groundwater levels and water quality variables for most rivers and regions of the country. In the past 10 years, there has been a growing capacity and capability of numerical modelling in IWM. However, there is pressing need to translate the outputs of these models into meaningful information for decision makers. "What is the effect on Aman rice production from an increase in upstream water levels due to a new embankment on the Jamuna River?" "What is the cost of infrastructure damage due to climate change induced sea level rise in Chittagong port area?" To address this knowledge gap, researchers at IWM have developed a water resources Decision Support System (DSS) that can use outputs from their mathematical models to simulate and predict likely impacts on key sectors, such as agriculture, infrastructure, environment, fisheries, navigation, etc. It is envisaged that this DSS will assist policy makers and planners by providing information about likely impacts of climate variability and water-related projects in Bangladesh. The DSS has also been designed to be a communication and educational tool for non-technical users and key project stakeholders.

In this paper, the experiences and findings of the DSS conceptualization, development, testing and consultations with stakeholders are presented. The DSS is GIS-based and primarily data driven. However, it also has features of a model-driven DSS. At the heart of the DSS impact estimates are sector response functions, which consist of quantitative and qualitative relationships that describe how changes in the state of water resources will affect key sectors. For example, for the agriculture sector, response functions include empirical equations that estimate losses in rice yield depending on rice type, growth stage, water level, and duration of inundation. The impacts are presented in terms of yield loss in tonnes and also in monetary units, where relevant price data is available. The DSS users can thus gain insights of the risks associated with climate change and also the efficacy of different adaptation options.

The development of DSSs is a key feature in IWM's long-term plan. This involves meeting the growing demand to advance from integrated modelling software to hydroinformatic objects, such as DSSs. This evolution should assist resource managers and decision makers to adapt better to climate change and chronic water-related challenges, such as arsenic contamination in groundwater. Further development of the DSS involve incorporating optimization routines that can generate adaptation options subject to constraints in the human and environmental systems.

Keywords: *Decision Support System (DSS), water resources, Bangladesh, impact assessment*

1. INTRODUCTION

The Institute of Water Modelling (IWM), based in Dhaka in Bangladesh, has been developing into a major centre for hydraulic and hydrologic numerical modeling expertise in the past 10-15 years (see Figure 1). It plays a key role in modelling impacts of climate change on natural systems (CCC 2009a). IWM began in

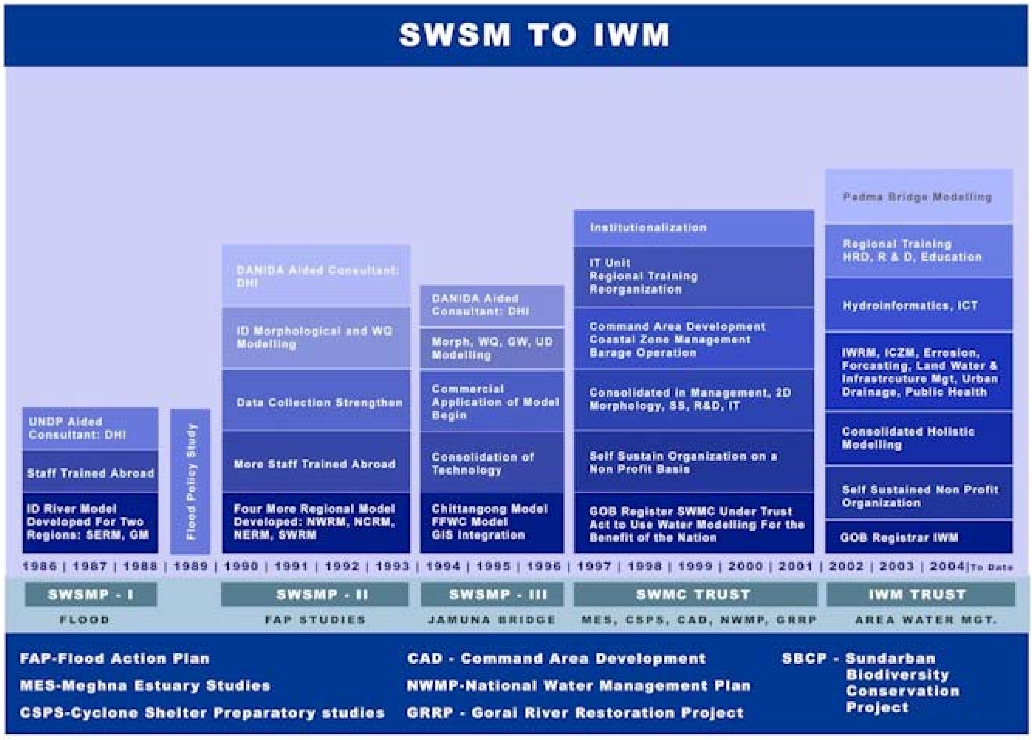

Figure 1. History of the Institute of Water Modelling from inception in 1986 to date, showing main focus areas and major projects (from **www.iwmbd.org**)

1986 as the Surface Water Simulation Modelling Programme (SWSMP) with assistance from the UNDP and Danish Hydraulic Institute (DHI). Up to the mid 1990s, with continued support from DHI and DANIDA, the focus of SWSMP was on developing 1D river models for specific hydrologic regions of Bangladesh, data collection, and staff training. From 1997, the organization has been run on a self-sustained, non-profit basis, as the Surface Water Modelling Centre (SWMC). The focus was on developing 2D models with GIS integration and regional training. Furthermore, "SWMC developed capabilities in areas of hydrodynamic modelling of rivers, estuaries and Bay, hydrological modelling including surface water-ground water interaction modelling based on three-dimensional GW modelling, fully dynamic morphological modelling based on quasi-three Dimensional flow and sediment transport modelling, complete set of water quality modelling (salinity, BoD, CoD, temperature, arsenic etc) of surface water and ground water flows. It also grew as the leading hydrographic and topographic survey institute based on the state of the art technology in order to support its analytical work by strong database through real time measurement campaigns" (www.iwmbd.org). From 2002, the organization was renamed as IWM. Since then, the focus has been on consolidating holistic modelling, regional training and education, research and development.

IWM's suite of mathematical models is useful tools to identify and estimate impacts of climate change and adaptation measures. However, the outputs of these models need to be translated into values that are meaningful to decision makers. To address this problem, one of the R&D activities is to develop Decision Support Systems (DSS) that can translate outputs from the various IWM hydrodynamic models into useful information for water resources planners and policy makers. This is considered a key step to help resource managers and planners of the natural and built environments to adapt to climate change.

This paper describes key development activities for an integrated water resources management (IWRM) DSS for Bangladesh. In this paper, we discuss the limited use of existing DSS in relation to climate change in Bangladesh (section 2) and then we describe the DSS conceptualization and development approach (section 3). In sections 4 and 5 we provide details about the DSS test case study area and stakeholder consultations respectively. We conclude the paper with some discussion about future challenges in the DSS development. Details about the impact functions used in the DSS are provided in Zaman et al (2009).

2. CLIMATE CHANGE AND BANGLADESH

Although "CC impacts" and "adapting to CC" have become "buzz words", the impacts of climate change are already a reality in Bangladesh with literally millions of lives affected (McCarthy et al 2001, Agrawala et al 2003; Ahmed 2006). As a result adaptation policies and projects are being developed (Khan and Islam 2008, CCC 2009b and 2009c).

Often the donor agencies fund "safe" adaptation projects, although their impacts (and benefits) are not well quantified. In Bangladesh, there have been DSSs developed for particular sectors or specific projects, e.g. in agriculture (Ruane et al 2008), reservoir management (Ahmed, Hye and Rahman 2001), fisheries (Hossain et al 2009, CEGISBD 2008, Halls et al 2007), etc. Indeed, the suite of modeling tools used in IWM can be considered as water resources DSSs. However, these tools are for specific applications and geared towards users with a high degree of technical knowledge, typically engineers. The current challenge is to translate the outputs from these models into a form that can be easily understood by other decision makers dealing with climate change adaptation. These professionals come from a broader range of disciplines, e.g. economists, sociologists, ecologists, etc. These decision makers face pressing questions such as: "What is the effect on farm, employment due to Aman rice production loss arising from increased salinity levels?"; and "What is the cost of infrastructure damage due to climate change induced sea level rise in Chittagong port area?". To address this knowledge gap, researchers at IWM are developing a water resources Decision Support System (DSS) that can use outputs from the numerical models to predict likely impacts on key sectors, such as agriculture, infrastructure, environment, fisheries, navigation, etc. This DSS is being developed to assist policy makers and planners by providing information about likely impacts of water-related projects in Bangladesh. The DSS has also been designed to be a communication and educational tool for non-technical users and key project stakeholders. Our contention is that a DSS that can quantify the costs and benefits of adaptation projects and policies can help make the decision making process more effective and transparent. Furthermore, as water is the "lifeblood" of this deltaic country, it makes sense to develop an IWRM DSS.

3. DSS DEVELOPMENT APPROACH

We consider the term Decision Support System (DSS) to describe a wide variety of tools: from spreadsheets to complex GIS-based simulation models. When DSSs are well-designed and built, they help achieve more informed and effective decision-making (Rizzoli and Young, 1997). More advanced and complex DSS integrate environmental, economic, social aspects related to the decisions being made. This is achieved by using different models and datasets to create flexible linkages between the different bio-physical and socioeconomic aspects of a resource system. Thus, a DSS enables its user to quickly analyse and compare alternative courses of actions or strategies under different uncertain developments or scenarios to demonstrate the impacts of different options or alternatives.

There are several DSS development approaches and the selection of a particular approach is determined by the DSS type, purpose and resources (time, money, expertise) available (Huang 2005, Turban and Aronson 2001). Given the constraints of the current research project, a combination of parallel, phased and prototype development has been followed (see Figure 2).

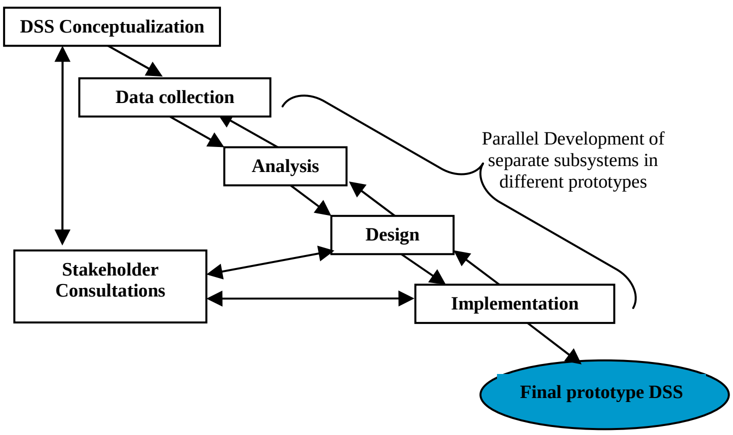

Figure 2. Prototype DSS Development Method

3.1. DSS Conceptualization

At the start of the development process, in the conceptualization stage, the potential uses of the DSS by stakeholders were assessed based on experiences of past IWM projects. From the consultation process, several concepts were developed. In Figure 3, the general usage steps of the DSS are shown. The user will define the scenarios to be analyzed and provide the DSS with relevant outputs from hydrodynamic models and thematic, land-use maps of impact sectors (in the form of GIS layers). The user then selects the necessary impact functions for each sector and the DSS generates impact reports for the scenarios being analyzed. Users do not have to run the IWM models themselves but need to work closely with IWM modelers so that new runs can be specified when adjustments are made to the scenarios analyzed.

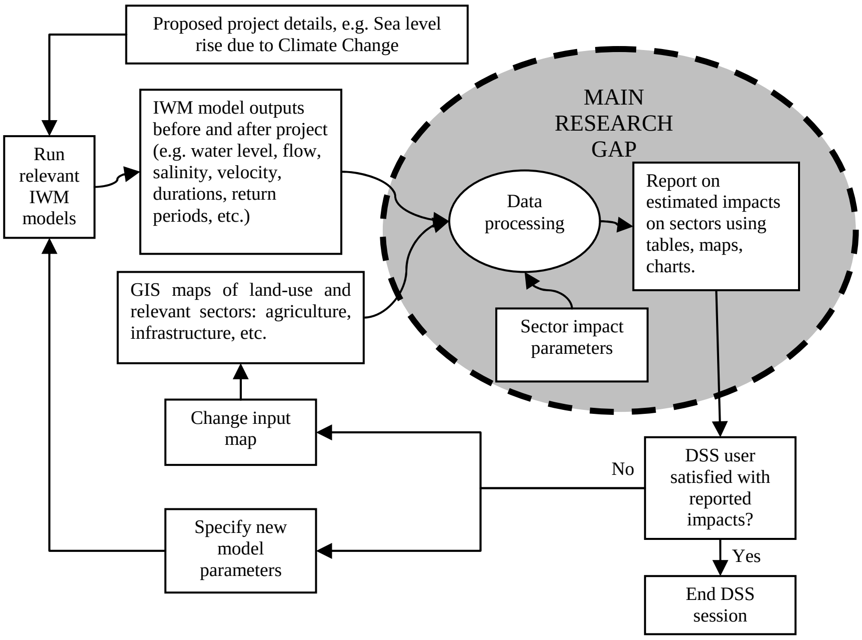

Figure 3. General Concept of how the DSS will be used

From the consultations held in the DSS conceptualization stage, information about the type of DSS required was obtained and the basic architecture was also developed. The development team decided to build a prototype DSS over 6 months, which can then be used to get more feedback from different stakeholders. This prototype DSS is mainly a data-driven DSS with impact functions for some key sectors and default values for the impact parameters. A long-term DSS concept was also developed during this consultation process. This concept involves evolving the DSS into a model-based DSS, where the IWM hydrodynamic models will be incorporated into the DSS framework. Therefore, the prototype DSS has been developed with this long-term concept in mind.

3.2. Data Collection and Analysis

Then relevant data for impact estimates were collected from previous IWM project reports and literature review of research papers and publicly available documents. When required, further data was collected or verified through consultation with multidisciplinary experts. Also, a field trip to a case study site was conducted to collect detailed data.

3.3. DSS Design and Implementation

In the implementation step, the designs were coded by software programmers in relevant platforms for each prototype. The first prototype was a MS Excel file that included separate sheets for: user interface, crop details, crop damage

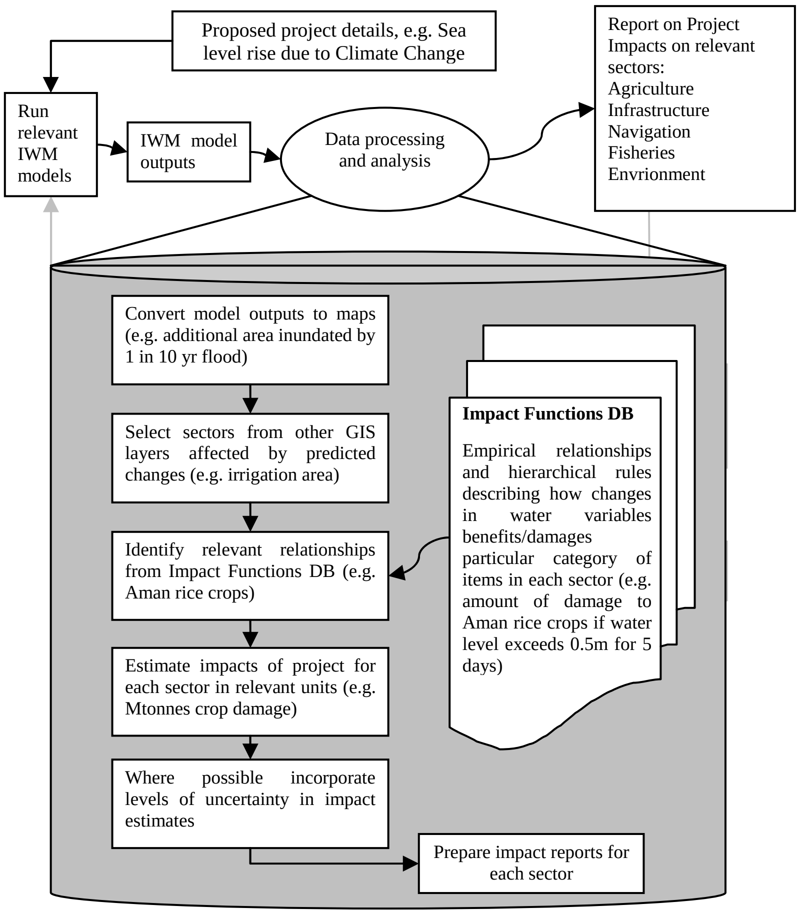

Figure 4. Basic processes in prototype DSS

calculation, fisheries details, river-beel connectivity model, sample hydrodynamic outputs, sample land-use grid (representing a raster map). Several versions of this spreadsheet were developed as more details were added to the sector response modules. These prototypes were used during consultations with different stakeholder groups. When a particular sector response module reached a stable version in Excel, it was passed on to software programmers. The programmers coded the module into a GIS program linked to a geospatial database. During these consultations with stakeholders, it was quickly realized that the interface should be bilingual (English and Bengali) and this was incorporated into the DSS design. Eventually, through testing of several prototypes the final prototype IWRM DSS was obtained.

4. STUDY AREA

The study area for testing the prototype DSS was the Halti Beel[1], which is part of the Chalan Beel wetlands region in the lower Atrai river basin in the Rajshahi-Natore region, northwest Bangladesh (see Figure 3). The Halti Beel area is a semi-closed (empoldered) area of 10,000 ha, located in southeast corner of Polder C of the Chalan Beel region. The problems associated with the study area are interlinked with various hydrological, hydraulic, environmental, social and economic aspects - both inside and outside the project area. Sib Barnai and Atrai River is flowing along the periphery of the area. Major drainage of the area occurs towards east into the Atrai River; no drainage occurs towards Barnai River because of high water levels in this river. The regulator, Jor Mollika, along with some other drainage structures, is the main drainage outlet into the Atrai River (IWM 2007). The flood water enters the area from the northwest direction through the opening of existing railway and also from the Atrai River.

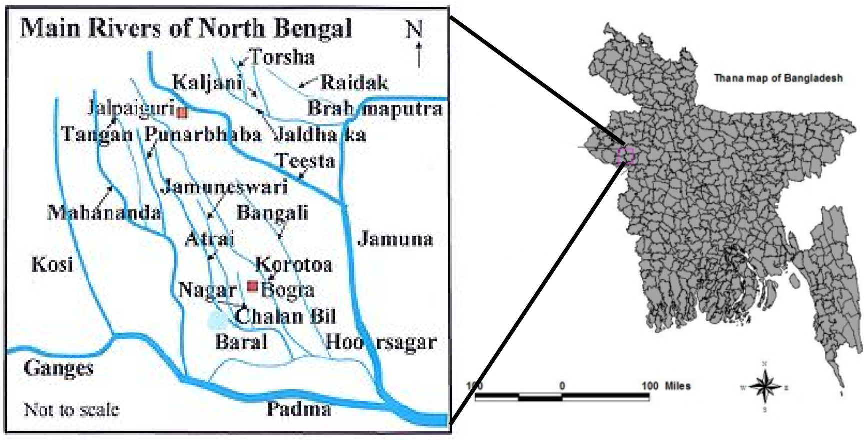

Figure 5. Location of DSS test area – Halti Beel, which is in the Chalan Beel region (from http://en.wikipedia.org/wiki/Chalan_Beel)

In the Beel Halti area, crop damage due to flooding and impacts on fisheries due to flood control are common issues. Also, build up of silt is also affecting the beel storage volume and connectivity between the beel and adjacent river. Furthermore, land reclamation from the beel for agricultural purposes is having negative impacts on fisheries, with subsequent social implications.

In 1992-3, several fish stocking trials were conducted at Halti Beel (Ali and Fisher 1997). The results from these trials provided valuable technical information for improved stocking of the floodplains. Also, as part of the Government's Third Fisheries Project, NGOs organized the fishermen and motivated them to conserve the stocked fish in Halti beel (Ali and Fisher 1997).

In 2006-7, IWM was involved in mathematical modelling and topographic survey of the Chalan Beel region, including Beel Halti area, on behalf of the Bangladesh Water Development Board (IWM 2007). Flood propagation and inundation patterns were modeled for the study area. Also options to completely empolder the study area were modeled.

5. STAKEHOLDER CONSULTATIONS

In this project, several DSS stakeholders were identified:

- technical DSS users,
- non-technical DSS users,

[1] 'Beel' is a local term referring to freshwater lakes formed in natural, floodplain depressions formed by erosion or other geophysical processes. These lakes can be seasonal or perennial and support capture and culture fisheries, irrigation, domestic water supply, etc. Beels are different to 'boars' (ox-bow lakes) and 'haors' (large depressions forming freshwater wetlands).

- community advocacy groups/educators, and
- multidisciplinary experts contributing their knowledge in DSS development.

The first group of stakeholders involve the usual clientele of IWM: Water Resources Planning Organization (WARPO), Bangladesh Water Development Board (BWDB), Planning Commission, Dhaka Water Supply and Sanitation (DWASA) Company, etc. The potential DSS needs and usage of these stakeholders were identified indirectly in consultation with project managers and other senior staff at IWM.

The non-technical DSS user stakeholder group includes people who are likely to be affected by decisions made with the assistance of the DSS, e.g. farmers, fishers, etc. Although these people are considered non-technical, they still provide valuable expert knowledge about the natural systems in which they live and depend on for their livelihoods. Two consultation meetings with this stakeholder group form the test study site were held on 18th March 2009. The general feelings of the local stakeholders were:

Figure 6. From left - Businessmen Abdul Mannan and Nazmul Haque and Farmer Ibrahim Khalil at Singra Meeting, held in an Agribusiness shop

• Increased irrigation, through water resources development, has helped socioeconomic development in the region.

• Local climate has been changing and in general water resources in the dry season (river level and groundwater table) have decreased over the past several years.

• Embankment on Atrai River is regularly cut by local people during floods and this causes damage to crops due to high velocities and inundation

• Siltation from floods is increasing ground levels, such that houses are now affected by smaller flood events.

• Some fish species have been lost after embankment was built.

• Strengthening of embankment or compartmentalization of beel area may reduce impacts.

Also, during these consultations, it was identified that an important design issue is to have a Bangali interface to the DSS and also to present the outputs in a manner suitable for people with poor literacy skills.

The third stakeholder group involves organizations that can use the DSS to educate members of the public about specific water-related issues. For example, NGOs can use the DSS to help explain to fishers how over-fishing in a beel can adversely affect fishing yield in subsequent years. The DSS can also be used by this stakeholder group to assist with conflict resolution and as a supportive tool in a participatory process in general. Also the DSS can be used at secondary and tertiary educational institutions. This stakeholder group has not been actively consulted to date. However, their potential needs have been preliminarily determined through literature review, e.g. Welp (2001), Newham et al (2006).

The fourth stakeholder group includes resource economists, agronomists, fisheries experts, etc. Members of this group have been consulted to confirm the scientific approach in the impact modules of the DSS and also to verify some of the assumptions, where adequate data was not available.

6. DISCUSSION AND CONCLUSIONS

Advanced mathematical models have been used in the water resources management area of Bangladesh for several decades. However, existing DSSs cater for highly technical users and focus on particular projects or study sites. With climate change already impacting large areas and affecting multiple sectors of the economy, there is a clear need for a more robust DSS that can assist in IWRM. IWM is attempting to address this gap through an R&D project. There is a long way to go but some key lessons have been learnt to date. Potential DSS users and stakeholders in Bangladesh have a wide range of skill sets, including language requirements. Detailed data for sector impacts are not readily available but this situation is improving. The DSS has to take this account and designed so that users can input new data easily. Also, the DSS has to be flexible so that new sectors and impact functions can be easily incorporated by advanced DSS user. Also, the DSS should incorporate economic and climate change adaptation modules. When developed, the full DSS can help assess the benefits and costs of various climate change impacts, adaptation policies and projects.

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