FloodBank: An Internet-Based Architecture For Distributing Spatial Flood Data

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Abstract: Spatially explicit flood models are becoming a common feature of urban flood hazard risk management in Australia. Local governments, state and federal emergency management agencies and private consultants all play some role in their development. Similarly, numerous stakeholders have a keen interest in accessing these models to support their risk management. However, a significant impediment to improved risk reduction is access to flood model results in a structured and user-friendly framework. The advent of the Internet and its associated technologies creates excellent opportunities for improving access to hazard data. This research describes the development of an Internet architecture called *FloodBank*, which provides a structured depository for flood model results making them rapidly available to multiple stakeholders. In addition to an user authentication manager, a flood model metadata manager and a relational database management system, FloodBank also incorporates an online GIS. Flood model custodians can readily deploy FloodBank as it is constructed using very affordable software components. New FloodBank nodes can be readily deployed to provide faster access for local users. Similarly, the database architecture behind FloodBank is designed to allow for rapid integration with desktop GISs to facilitate more complex spatial analysis. This paper describes the architecture and software components behind FloodBank and describes the development of two associated software technologies that compliment FloodBank. These include the FloodBank pre-processor for preparing data in the FloodBank database structure, and *i*Flood, a standalone GIS-based SDSS for analysing flood model databases. The ultimate aim of FloodBank is to improve access to flood model results to multiple stakeholders, and to provide a structured framework to ensure the long-term utility of flood model results in Australia.

Keywords: *Flood modeling; Internet architectures; RDBMS; GIS; risk management.*

1. INTRODUCTION

The advent of internet-based mapping systems has enabled the widespread dissemination of spatial information to multiple users, using relatively ubiquitous web browser software. Such approaches offer many advantages to organisations wishing to enhance their decision support capabilities. Foremost is the ability to provide a GIS capability through readily available, and inexpensive web browsers, such as Internet Explorer or Netscape. However, barriers still exist preventing the widespread adoption of such technology by smaller organisations. The cost of Internet mapping technologies such as ArcIMS, MapExtreme or Mapguide is prohibitively high, when only rudimentary GIS functionality is required. This paper describes the development and system components of an affordable Internet-based system for distributing flood hazard information to decision makers via the Internet called FloodBank. FloodBank is designed to allow multiple emergency management agencies to rapidly, and affordably, deploy new FloodBank nodes.

2. INTEGRATING GIS AND FLOOD MODELLING

The link between GIS and flood modelling has traditionally adopted a number of integration paradigms. These range from very tight integration (or coupling) where all modelling occurs within the GIS, to less integrated approaches where GIS is used for data pre-processing, model parametrisation and post event display and analysis via the use of common data interchange formats. Goodchild (1993 in Clark 1998 p.825) summarises the three broad approaches for integrating GIS and hydrology as:

- Pre-processing data into a format suitable for analysis (scale, coordinate system, data structure, data model etc).

- Direct support for modelling so that the GIS carry out tasks such as analysis, calibration and prediction itself.
- Post processing data through reformatting, tabulation, mapping and report generation.

The first approach is relatively ubiquitous in flood hazard modelling and can include the development of terrain/bathymetric models, integration of landuse and building databases to represent surface roughness, parameterisation of flood models, automated watershed and stream network delineation or for the preparation of spatial databases in a format suitable for modelling (Bates and Roo 2000, Pickup and Marks 2001). The second approach is relatively rare and most examples are restricted to 1D flow calculations (Jain *et al* 2000). Correia *et al* (1999) attributes this to the fact that for it to be successful, the GIS architecture must be sufficiently open. As most GISs are commercial products utilising proprietary data formats and algorithms, this is rarely possible. However, the advent of open GIS architectures provides significant opportunities (OGC 2002).

And finally, the use of GIS is common during the post-modelling phase for the presentation of maps that delineate flood zones, as a framework to integrate other contextual spatial data such as satellite imagery of hazard events, as a spatial decision support system (SDSS) for flood risk management and for impact assessment or cost-benefit analyses (Biza *et al* 2001). In the case of 2D hydrodynamic modelling, this third approach to integration is most common owing to the complexity of modelling spatially dynamic phenomenon such as flood events within a GIS (Dutta *et al.* 2000). The focus of this paper is this later model of integration, with the addition of an Internet capability.

Given that the role of GIS for flood modelling commonly focuses on post-modelling requirements, limitations exist in how model results are currently integrated with GIS. At the most common level of integration, linking means the simple conversion of a raster flood surface into a format suitable for GIS display and comparison with other databases (i.e. buildings, road networks, utilities). The raster flood surface will typically represent the peak flow, or a recurrence interval that has some risk management significance such as the 1 in 100 year event. A limitation of these approaches is that times-series data so critical to modelling an event is either not used, or proves so cumbersome to manage computationally, that it cannot effectively support decision making.

FloodBank adopts a database-driven approach to managing spatial data, and demonstrates how an affordable Internet mapping system can be developed to couple flood models outputs with GIS. In the long-term, database-driven architectures for spatial data analysis are flexible enough to also support innovative approaches to environmental decision support including data warehousing (Di Mauro et al. 2002), knowledge-based databases and decision support (Seder *et al.* 2000) or intelligent data analysis systems (Sanchez-Marre *et al* 2002). In addition, the Internet can provide the link between these new technologies. Cameron *et al.* (2002) describe the benefits of using the Internet as middleware for the development of decision support systems for natural resource management.

3. INTERNET MAPPING

Map-based Internet applications have recently become available as decision support tools for organisations managing large amounts of spatial data. Data custodians often adopt proprietary software solutions such as MapInfo's MapExtreme, ESRI's ArcIMS or Autodesk's Mapguide. Each have very different capabilities, provide varying level of support for raster data, and significantly, they adopt very different data distribution architectures. Primarily we see a difference between so-called 'thin-clients' such as ArcIMS, and 'thick-client' models such as MapGuide. The fundamental difference is that thick clients perform much of the processing at the client-end, while thin-clients rely on server-side processing. Each offers advantages, and the approach used will depend on the complexity of the spatial processing required, the anticipated number of users, data volumes commonly transferred, and the level of custodian control over analysis that is required.

The most important benefit of Internet mapping systems is the ability to provide GIS functionality to multiple desktops, without the need for specialised GIS software. However, saying that, the development of an Internet mapping system utilising proprietary software can still be prohibitively expensive for smaller agencies, such as those involved in natural hazard risk management. For example, Internet mapping systems from companies such as ESRI and MapInfo can cost in excess of $20,000 to deploy. Such a system may only support less than 50 concurrent users, and costs increase when the user-base expands. This makes scalability and widespread deployment very expensive.

Foremost in the recent adoption of proprietary Internet mapping systems are utility companies and local governments, who have developed on-line asset and facilities management systems for spatial features such as pipelines, roads and telecommunication infrastructure. The rapid adoption by these industries is due to three factors. Developing an Internet mapping capability is very expensive; most proprietary systems to date have only supported vector data models, which are prevalent in the asset management industry; and these early-adopters traditionally service a relatively large user base, with limited need for advanced spatial analysis capabilities. The natural resource and land management communities have seen a less rapid adoption, however it must be remembered that the technology is still in its infancy. For example, amongst the hazard community, CSIRO's Sentinel (http://www.sentinel.csiro.au/ last accessed 23/2/2003) project has shown the benefits of Internet mapping to support real-time hazard risk management.

The FloodBank system described in this paper, albeit simpler in GIS functionality than proprietary systems, shows how an affordable mapping solution can be deployed by hazard risk management agencies. Such a approach may be an excellent first step, before a more ambitious internet mapping initiative is undertaken, or in other cases it may indeed provide the level of GIS functionality that is required for most lay users.

4. THE FLOODBANK SYSTEM

FloodBank is an Internet mapping system used to catalogue study areas and associated flood event databases generated from flood models. The technology enables users to visually interrogate the catalogue of study areas and associated simulations of flood events, to spatially visualise flood risk, and for distributing flood event data to users requiring more sophisticated analysis. There are three major components to the FloodBank system including the FloodBank Internet system, the Pre-processor utility for migrating raw flood data to FloodBank, and the *i*Flood decision support system for performing more detailed risk assessments.

FloodBank is an Internet application comprising a user interface and a data querying and reporting toolbox, a data management catalogue (i.e. metadata database) and a data warehouse. The application has been developed using a range of technologies that includes Microsoft Active Server Pages (ASP) for the construction of the user interface and database querying engine, Microsoft Access databases for the data management catalogue and for the storage of flood event summary statistics and ASPMap, a third party component used for online map rendering of GIS data. The application is divided into two major modules including the Study Manager and User Manager, described in detail below.

The data management framework is based on the assumption that risk models are pre-run and results are stored in a relational database management system (RDBMS). In this case study of FloodBank, a hydrodynamic flood modelling system called Mike21 has been used to create flood events for Cairns, Queensland. This approach is designed to allow risk managers rapid access to model results (via SQL requests), and provides a generic data management framework that allows for rapid data analysis (creation of reports, summary statistics and graphs)

4.1. Study Manager

The 'study manager' contains basic information about different study areas recorded in the system (Figure 1). Study areas can be added, edited and removed. Recorded attributes for each study area include the name of the study area, the software used to generate the flood model data, the agency responsible for the flood model and the location of the study area. Each study area can have any number of associated flood modeling events. For each flood modeling event a standard set of information is recorded. Event attributes include the description of the flood event, the number of surfaces generated in the modeling process, the model parameters used, the model start time and the time increment. Each event has a corresponding database derived from the preprocessing software, containing summaries of the modeling analysis. Databases must be uploaded when new events are recorded in the system.

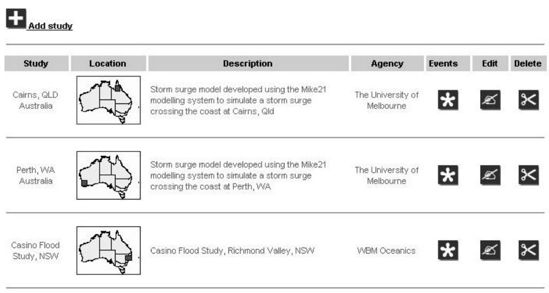

Figure 1. FloodBank Study Manager

Events and event databases can be interrogated with the aid of an Internet mapping utility (Figure 2), which allows users to execute basic queries on the database then visualize the results spatially. Point locations can be queried using a nominated threshold water height and a specified time. Point locations meeting the search criteria are displayed in a map with a series of GIS layers. The GIS layers used in the construction of the map can be formats supported by ASPMap and include ArcView shapefies, MapInfo Tab files and GeoTiff images. The mapping utility provides users with a means to visualise and interrogate database content without the need to download database files locally. This is important, as data custodians can periodically update flood models, hence controlling the information available to decision makers. If required, event databases in Microsoft Access database format can be downloaded for more detailed analysis using *i*Flood, or any other user customised software.

4.2. User Manager

1 The user manager is used to delete, edit, and register users. The module is also used to modify and set user authentication and permissions. Permissions are set for each study area to ensure that any sensitive data can be hidden from unauthorized users. Each user has a username and password that must be used to access any part of the system. Users can be granted system 'Administrator' rights by existing system administrators.

The case study currently available to authenticated FloodBank users shows a Landsat TM satellite image for Cairns provided as a backdrop to road networks stored in the Shapefile format. Figure 1 shows the Study Manager used to manage the flood data multiple study sites, and Figure 2 shows the mapping tool used to analyse the risk for one event.

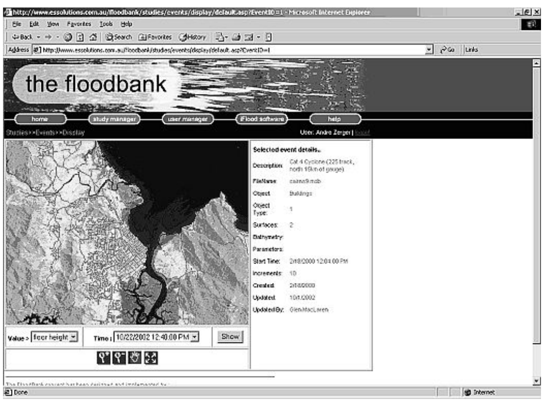

Figure 2. FloodBank Event Viewer

5. *i*FLOOD SPATIAL DECISION SUPPORT SYSTEM(SDSS)

Earlier research has attempted to interface flood model results with the proprietary GIS ArcView (Wealands *et al.* 2001). Developing SDSS software entirely within a proprietary GIS had a number of limitations including the high cost of ArcView, the size of the software installation and limited flexibility to customise its functionality. In addition, the ArcView approach was relatively slow in querying data and its database connectivity capabilities were limited. To overcome these limitations, development of the SDSS has been completed using ESRI's MapObjects 2.1 mapping objects and Microsoft Visual Basic 6.0. A software application, *i*Flood, has been developed with viewing, analysis and hazard event management capabilities (Figure 3 and 4). Advantages of the *i*Flood approach include:

- Custom GIS functionality that removes the complexity of commercial GISs for risk managers
- A very small software footprint making for easy distribution;
- Efficient data management capabilities including fast SQL execution to external Relational Database Management Systems (RDBMS);
- An inexpensive software platform (approximately $300 per installation); and
- Ability to develop custom analysis algorithms using compiled code rather than interpreted macro languages such as Avenue.

*i*Flood is coupled with FloodBank as it adopts the same hazard event relational database design. In other words, a user with sufficient permissions, can download an event database to their local computer, and perform a more detailed *i*Flood analysis. Alternatively, *i*Flood users can connect to the FloodBank depository to perform an analysis using FTP protocols. However, owing to the size of event databases (i.e. 33mb for one event of 24,000 buildings, and 273 flood surfaces), local analysis is more efficient.

The shift towards database driven spatial data management provides opportunities not available in standard GIS data models (i.e. Shapefile and Coverage). This trend has been evidenced by the recent availability of spatial data modelling capabilities in RDBMSs, including such products as Oracle Spatial and IBMs DB2 Spatial Extender. Similarly, GIS vendors are moving towards

RDBMSs as a way to manage spatial data models. For example, ESRIs Geodatabase format, is based on a Microsoft Access relational database model. Both industries are seeing a convergence in how spatial data is managed, with an overall shift towards SQL compliant, relational database models. Advantages of such approaches include:

- Query and data analysis capabilities not available in most GISs;
- Generic query languages such as SQL means data custodians can use other RDBMSs;
- The efficient management of time-series risk information such as flood data;
- Decision makers can develop their own DSS software using SQL protocols, and access existing FloodBank databases; and
- The ability to integrate hazard data with other corporate RDBMs.

Figure 3. *i*Flood interface showing inundation for Cairns

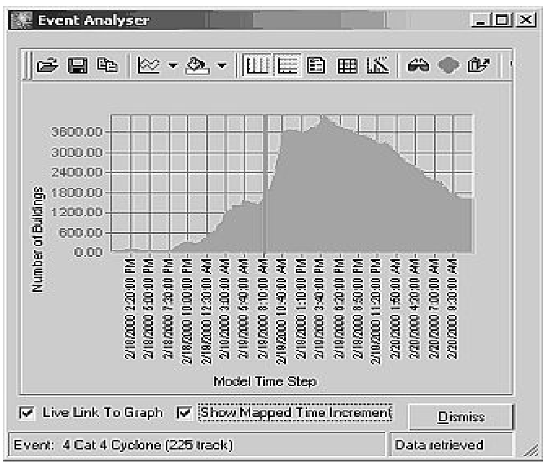

Figure 4. Event time series graphing and data analysis tool

5.1. FloodBank Pre-Processor

A flood modelling exercise results in the output of raster or grid surfaces containing predicted water heights for each simulation time step. The FloodBank 'Preprocessor' is a desktop application that interrogates these flood model surfaces using point location data (Figure 5). These data can represent any geographic feature of interest (e.g. Buildings, Bridges, Cultural Sites). Water height data is extracted for each point location for each time step. The summarised data is then organized and migrated into a new relational database, designed specifically to store this information.

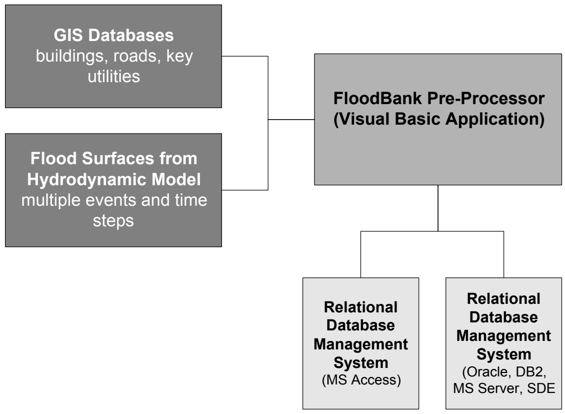

Figure 5. The FloodBank pre-processor design

The software was developed independently of any proprietary GIS software in order to minimize cost and to provide maximum flexibility in its use. The preprocessor accepts input of generic data formats such as ASCII grids for the raster surfaces and comma delimited text files for the point data. Databases generated by the preprocessor can be interrogated by *i*Flood or can be registered with and uploaded to FloodBank - the online catalogue and distribution system described above.

6. CONCLUSIONS

The aim of developing FloodBank is to improve access to flood model results to multiple stakeholders, and to provide a structured framework to ensure the long-term utility of flood model outputs. There is little doubt that to date, accessing flood model results from numerical models to support decision making, is frought with technical challenges. FloodBank attempts to overcome some of these.

In addition to its on-line mapping capability, FloodBank also ensures that model results are stored systematically, with detailed metadata, and in a standard that facilities future software interoperability (SQL compliant RDBMS). The interoperability issue is receiving increasing attention in the geospatial industry as data custodians attempt to interface spatial data holdings with other corporate databases. There are examples in the hazard and risk management where such linkages could lead to improved decision support. For instance, establishing links between multiple hazard risks (fire, flood and landslide) to buildings, with corporate databases containing owner contact information, may assist with disaster planning. The development of Internet architectures such as FloodBank, in combination with *i*Flood, moves some way in this direction. The next phase of FloodBank development will include an operational case study, followed by a formal system evaluation with hazard risk managers.

7. ACKNOWLEDGMENTS

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