Urban flood modeling: beyond the preserve of developed countries

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ABSTRACT
There exist a wide range of commercial desktop urban water and environmental modeling software available to practitioners and researchers. Although these software systems are available, their accessibility and use is limited. Small and medium sized enterprises and many research institutions cannot access and use these software systems due to associated costs and complexity. In this paper we outline the design of a prototype that addresses these two issues by providing a ubiquitous interface that is easily supported with domain expertise. The prototype is designed in client/server architecture accessible through a web browser with GIS support. Its engine is a commercial PC-based urban drainage modeling software. The prototype demonstrates the possibility of a web-based GIS supported urban drainage modeling system as an application.

Keywords: Hydroinformatics, Open Source, prototype, Urban modeling, WaterWebFrame

1.0 INTRODUCTION

Water related engineering and planning is an important component of urban systems. Water is deployed to transport waste either directly through sewer networks or indirectly by rain washing streets and channels of debris, solid waste and other wastes. It however has negative consequences when it contaminates fresh water systems or floods homes and businesses. In urban areas, by altering natural water courses and increasing impervious areas these problems are compounded. City planning, management and development requires understanding of the planning, design and operation of water facilities.

Urban Managers, water engineers and planners use water flow models especially numerical models in their regular decision making processes. They use them to answer questions such as risk and vulnerability of urban buildings and people, planning and design of infrastructure, mitigation of urban flooding and water quality, seeking performance analysis of their drainage systems and in their daily operational decisions. They use numerical models to simulate the transformation of rainfall to runoff and to follow its complex paths across land, into collection and conveyance systems and ultimately to receiving waters in addition to quality transformations. The models simulate the performance of collection systems, roads and natural channels under a variety of rainfall events, antecedent conditions, physical upgrades, and future changes in land use. Whereas this is the case, application of comprehensive numerical models is limited to big companies in developed countries. SME's and individual consultants do not access and use these tools even where there are comparable free (as in freedom and not necessarily gratis) open source tools. These numerical models often have a steep learning curve and are often not supported with manuals and technical expertise.

The world population of the 21st century will largely live in towns or town conurbations (Price 2000) making integration of water resources management a critical issue for decision makers. Competition for physical as well as psychological space will be more intense in these conurbations. Urban utilities will become less and less a preserve for engineering as they serve more social, political as well as economic values. Issues of urban flood and flood mitigation, water quality, city development planning will become central to decision making in this 21st century. With city population pressure, improving standards of living (or the chasing of such a dream) will bring into the engineering preserve more and more stakeholders.

Developers of "greenfields" projects, city planners, insurance businesses, and farmers will demand tools to meet their objectives whatever they may be. Information and communication ubiquity will be more apparent enabling more and more stakeholders' access to decision making tools. Manufacturers of water and environmental tools and engineering practices have to respond to these needs in some way. The challenges and problems identified here relate to complexity and cost ownership and maintenance. To elucidate these challenges and justify my approach to dealing with them by developing a prototype, I will here sketch historical development of urban water models. I will then discuss the concept of open source. From this, I will describe the model prototype developed here and conclude this paper.

2.0 THE CONCEPT OF URBAN WATER MODELING

Rainfall on an urban watershed either falls on either a pervious or an impervious surface. It loosens or dissolves the pollutants and either transports them as buoyant material or takes it to the subsurface. Urban water and environmental modeling is either stochastic, if it depends on probability distribution otherwise deterministic. A deterministic model always gives the same results for the same input parameters unlike stochastic models. These models may also be classified as either conceptual or empirical depending on whether they are based on physics or data respectively. Models are also classified as either distributed or lumped depending on how they treat spatial variability (Refsgaard and Knudsen 1996).

Conceptual numerical models use the laws of conservation of mass, momentum and energy to simulate flows. This means that storage = Inflow- outflow. Urban drainage can be divided into two main modeling parts. The first part of urban hydrology is concerned with translating rainfall into effective runoff (generating surface and sub-surface runoff from precipitation excess) and accumulating runoff at the mouth of a drainage system including the build-up of pollutants. The temporal distribution of rainfall and flow is usually external to the model. The mouth of a drainage system may be a manhole, retention basin or even streets with kerbs. The second part is the routing of flows (both quantity and quality) through a drainage system to the ultimate disposal infrastructure. The routing of flows are governed by the aforementioned conservation laws.

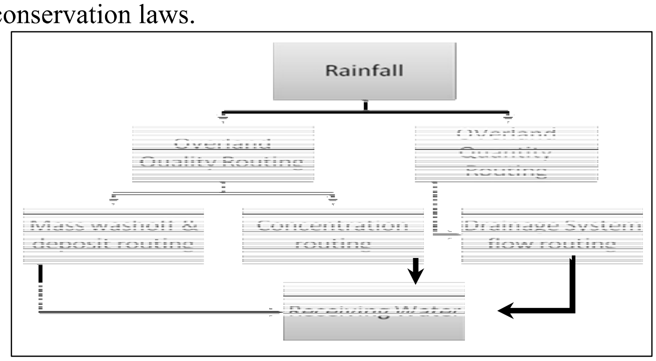

Figure 1: General outline of a numerical storm water model

modeling uses such methods as the unit hydrograph, tank model or the empirical rational method. The rational formula is such that flow Q is a function catchment area (A) and rainfall intensity, i.e.

$$Q = CIA \tag{1}$$

Where C is a runoff coefficient

Pipe flow routing is approximated numerical schemes such as finite differences, finite elements and method of characteristics where analytical solutions are not possible. The Saint

Venant equations of continuity and momentum are normally approximated using equations (2) and (3).

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0 \tag{2}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) + gA\left(\frac{\partial h}{\partial x} - S_o + S_f\right) = 0 \tag{3}$$

The S represent the source vectors where *g* and *A* are the acceleration and surface area and So and Sf are the bed slope and frictional factor respectively. Q is the flow rate, x is longitudinal distance, and t is the time. The frictional slope is determined either by the Chezy or manning's formula. The Manning's formula is given by:

$$S_f = K^{-2}|Q|Q = \mu^2 \frac{|Q|Q}{A^2 R^{4/3}} \tag{4}$$

Where K is the conveyance, μ is the manning's coefficient, R is hydraulic radius.
For very steep channels or where overland flow predominates, it can be assumed that frictional slope is equal to bed slope reducing the above equations to the kinematic wave model. In this model the local, convective and pressure slopes are neglected.

These models will do fine except where conduits are flowing full or completely dry. Where conduits are surcharged, flows will be under pressure and the free surface flow models here will not suffice. The *Preissmann* slot (Cunge and Wegner 1964) is added for pressurised flows and *Abbott* slot is used for dry conduits. There are other modeling concerns such as data uncertainty, optimisation, and economic analysis. These are normally part of an urban water modeling software. Dynamic, linear and non-linear programming methods may be used for system optimisation. Monte-Carlo method of data assimilation is the most common method for uncertainty prediction.

It is apparent here that any software package is combination of many different methods as well as many environmental engineering domains. All this knowledge is and can usually not be possessed by a single expert. This section therefore introduces the question of complexity of model at the level of the methods employed to solve urban water problems. Already, by adumbrating these methods, the necessity of availability and reliability of data is apparent. The ingenuity of the modeller is not as important as reliable data as identified by Orlob (1983).

3.0 RESEARCH JUSTIFICATION

To address the challenges of data capture new tools and interfaces were developed and superimposed on the simulation core. The different tools e.g. simulation engines, SCADA (*Supervisory Control and Data Acquisition)*, DSS (*Decision Support Systems*) and databases are put together to form a single software stack. On top of these are added comprehensive user interfaces. The Software becomes an encapsulation of knowledges from disparate fields therefore complicated for new and upcoming practitioners and often with steep learning curves. The problem here is where does a new user start from and how does she proceed to solve a particular problem. The hydro part of hydroinformatics is largely understood while most of the ongoing work is on the informatics side. Development of these extensive data capture mechanisms, multiple user interfaces has also made these systems very expensive and hidden the hydro part. However Abbott (1998) notes that hydroinformatics aims to enfranchise stakeholders, and that users who are merely objects do not achieve this objective.

The current hydroinformatics software development approach is the closed source, non-free or proprietary where software is written by one company to be sold to other companies. This situation creates one group of producers of knowledge and a different group of consumers of this knowledge. There is however an alternative software development approach advocated by the Free Software Foundation that seeks to make a software development a collaborative project between stakeholders. Raymond (2001) describes this open source approach and contrasts it with the current model in his book “the Cathedral and the Bazaar”. This approach puts more “eye balls” on the job and creates a shared ownership or interest in the software. This is the approach that is demonstrated in this research which has already been proposed in Harvey & Han (2002). It aims to modify the current software business model and proposes a new model in which revenue is extracted from expert, archiving and hosting services.

4.0 RELATED RESEARCH

This paper is itself continuing research that was introduced in Tumwesigye (2005) and was further elaborated in Abbott et al. (2006). The use of Service Oriented Architecture (SOA) and web services technologies to integrate different hydroinformatics applications is adumbrated in Hildebrandt & Holz (2002). Tumwesigye developed are client/server architecture for a proprietary modeling software engine using RMI and Java Technology. This development was of limited application scope. Abbott et al (Abbott et al. 2006) outlines the main possibilities and directions or web-based in general, identifies challenges and opportunities.

In computational hydraulics, Velickov et al. (1998) implemented an open-channel model using different client/server technologies. As a proof of concept, it represents a different way of delivering modeling tools and technology. This process was then taken further in the ELTRAMOS project (Yan, Velickov, and M. B. Abbott 1999), developing a *Decision Support System* (DSS) with a Case database to guide the selection of appropriate proprietary software. Objectives and deliverables in the ELTRAMOS project were discussed in Price et al (2000).

Argent (2004), identifies the major steps of model development and integration, and outlines the main challenges of integration as the entrenched linear processes within the research community. This linear process thinking is what we can see resulted in these generic complex systems that are additions from different fields that are not immediately synchronised. The process of developing integrated systems from reusable components is itself investigated elsewhere by the same author. The application of these integration efforts to a case study brings into focus the expected challenges in these approaches (Argent 2005).

5.0 WATERWEBFRAME DESCRIPTION

WaterWebFrame is web-based GIS-supported urban drainage modeling system in which the client side is almost always thin. The high level architecture is shown in Figure , using Web services technology to deliver services to the client through the SOAP (*Simple Object Access Protocol*) layer. At the server side are GIS aware database, configuration files, routines and engines, GIS servers and engines, and simulation engines. At the client side is the web-browser with embedded JavaScript and WSDL codes. The simulation engines installed at the server contain many different modules and perform a variety of tasks. In a previous research (Tumwesigye 2009), it was established that connecting individual modules to the web interface is quite cumbersome and difficult to implement without access to source code or signed *objects*. In this research, the engines are treated as a black boxes receiving inputs and providing results.

The server database stores individual project data and is linked to the client web-browser through the SOAP layer. Projects elements correspond to tables in the database and the features of each of these elements correspond to columns. Other information in the database includes project location, access rights and similar information.

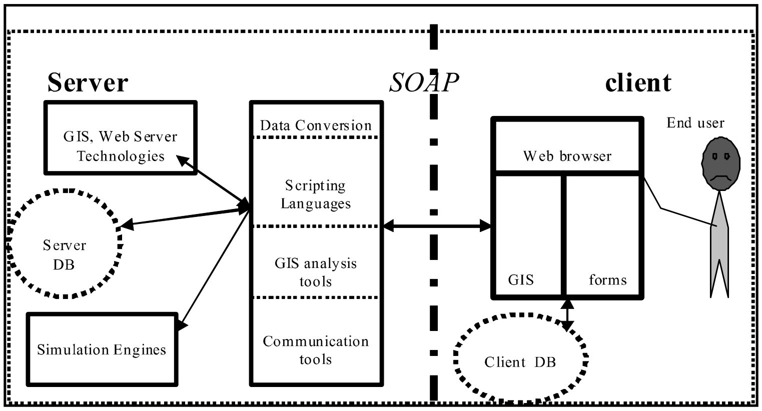

Figure 2: High level architecture of the *WaterWebFrame* framework.

The configuration routines and files are use for building the web GIS interface and maintain an ontological description of the urban drainage modeling terminology. These ontological descriptions help to build the GIS system and specify the different elements and associated urban system features. The web GIS system is built on top of *MapServer* and is extended using OGC schema to define polygons points and lines as catchments, manholes and sewers. The specification of catchments example below explains the configuration setup of the model.

5.1 SPECIFICATION OF CATCHMENTS

A typical catchment representation in a rainfall runoff model is shown in Figure . The figure shows the relation between the catchment (polygon) and the associated drainage objects. The catchment information spatial (coordinates and catchment area) and non-spatial features (land-use and model type) are defined in the OGC schema.

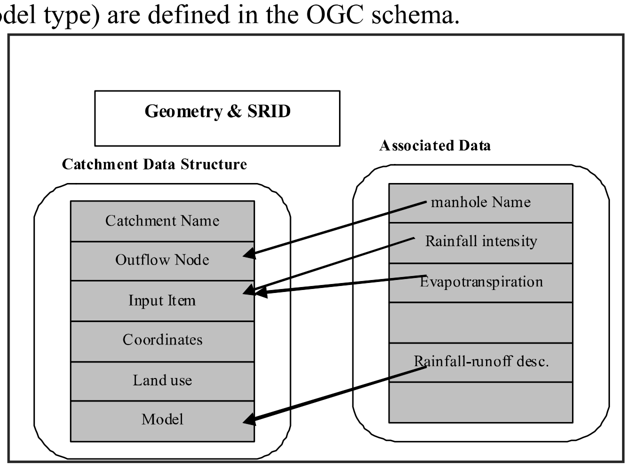

Figure 3: An ontological data structure defining an urban drainage catchment and mapping to other data source objects.

The arrows in Figure show the relations between catchment features and external data elements. For example, an *outflow node* in a catchment corresponds to a *manhole name* in a manhole table. Geometry and SRID are global values that refer to all catchments and define polygons. All other urban drainage elements like manholes and pipes are specified in a similar way to develop configuration files in this demonstrator.

6.0 WATERWEBFRAME USER INTERFACE

The prototype framework *WaterWebFrame* has a web-based GIS system. The interface is built from PHP, *Mapscrip*t, *JavaScript* and XML templates and configuration scripts. Figure

4 shows the GIS user interface with a map in the centre, menu and toolbox to the sides with numbering and key added for clarity.

Figure 4: Web-GIS interface web-page dump for an urban drainage task

In order to allow for importation and analysis of data from these different databases generic import, sorting and pre-processing functions are provided in the web-pages. Web-pages with forms and links guide users in model setup and provide sequential parameter and data input forms.

7.0 CONCLUSIONS AND FUTURE RESEARCH

This paper demonstrates the implementation of a web-based GIS supported urban modeling framework. It describes the prototype architecture and implementation of a web-based model setup and instantiation. The *WaterWebFrame* is a demonstration of a new business concept that has value for specific users identified in this paper and can be used to support education in modeling and simulation. The demonstrator is specific to an urban drainage case but may be extended to include such activities like model archiving.

As a web based modeling system, it does not require investments in IT infrastructure, software maintenance, and upfront procurement. This approach provides an inherent advantage to small and medium enterprises which do not use a single software system for long periods and do not actually wish to be tied down to one. The approach also demonstrates a mechanism by which user such as distributed concerns. Users function as developers, technology-consumers, support-experts, in this way shaping technology and being shaped by it. As concentric rings of user communities develop around the technology, they function as a halo. This of course is the hallmark of this new business context that could form part of the fifth generation of hydroinformatics.

Development of the *WaterWebFrame* was targeted to one class of users, engineering practitioners and researchers. In the present form the framework is not suitable for the other users who are not specialists in the engineering fields. Managers require a different format of a web interfaces and forms suitable for decision making. Challenges of architectures of single instance, single user legacy applications forming the backbone of the *WaterWebFrame* prototype have to be addressed. These legacy systems have to be transformed to multiple instance, multiple user application frameworks. The key to the approach in this paper resides in construction of a software application by way of an orchestration of prefabricated and pre-tested software components and the attendant web services.

It is also to be noted that mindsets rooted in the current business approaches may be resistant to changes. These resistant mindsets and entrenched software protection mechanisms have to be overcome to develop new successful businesses. This research was concerned with demonstrating possibility and did not review the requirements for interoperability and standards. It also was not possible to carry out a detailed analysis of all software components in *Mike Urban* to determine the smallest size units that may be used in a commercial modeling environment.

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