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# Integrated Modelling and Decision Making for Urban Water Management

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**Abstract**
Integrated urban water management has emerged as an important concept for several reasons. The growing need to manage the urban water cycle on a global basis, the increasing availability of alternative technologies to process different aspects of the urban water cycle, and advances in urban hydroinformatics enable different phases of the entire cycle to be modeled and to use such models to optimise each phase locally and in the global context. The main objective of Work Package 1.2 of the SWITCH project is the development of an integrated modelling and decision-making methodology which will guide and support an integrated urban water management process. Nowadays, there are attempts to develop a mechanism for linking of different detailed physically-based models which represent a component of the urban water system for integrated modelling but efforts in instantiating such models, their linking and running, which usually takes substantially long computational time, is far too impractical for high level strategic planning purposes. What is then therefore needed is the ability to undertake a holistic analysis of the entire urban water cycle by setting up a relatively simple model with reasonable accuracy. The integrated modelling work within work package 1.2 will address the issue of setting up the conceptual modelling platform to replicate the larger part of an urban water cycle. It will explore the use of integrated surrogate models where parameters of such models are derived either from measurements or from a detailed physically-based model results. With regard to decision making the intention is to fully automate the process of defining urban water-related problems, visioning, scenario and strategy development within a web-based Knowledge Management System and to enable better communication, discussion and negotiation between different stakeholders. The present paper discusses the ongoing work regard to the integrated urban water systems modelling and the development of the decision support system in relation to the objective of the work package 1.2.

**Keywords:** integrated modelling, decision making, web-based knowledge management system

# 1 Introduction

Since the urban environments and services interact both spatially and temporarily with the various components of the urban water cycle (drinking water distribution, sewerage, stormwater, groundwater, waterways, etc.) in different ways (physically, economically, legally), the intention of the Work Package 1.2 of the SWITCH project is to develop the necessary means that will enable analysis at different levels: strategic planning and more refined. The main objective of this Work Package is the development of an integrated modelling and decision-making methodology which will guide and support an integrated urban water management process. Such a methodology will be embedded in a software based tool within the framework of a generic Knowledge Management System (KMS), which will then be implemented as a web-based application and tested on two SWITCH demo cities (Birmingham and Belo Horizonte). The purpose of such a system is to enable safe and reliable evaluation of different urban water strategies during the decision making process.

# 2 Integrated urban water systems modelling

Integrated urban water management has emerged as an important concept for several reasons. First, there is the growing need to manage the urban water cycle on a global basis. Second, a range of alternative technologies to process different aspects of the urban water cycle are becoming available. Third, advances in urban hydroinformatics enable different phases of the entire cycle to be modeled and to use such models to optimise each phase locally and in the global context. In particular, the advances in urban hydroinformatics have made significant impacts on the development of new strategies for urban water management. The use of computer models pervades all aspects of water management, supporting wealth creation through products and services, contributing to many improvements in the quality of life. As a result, there is a growing increase in demands for better use, productivity, flexibility, robustness and quality of such modelling systems.

The need for integrated analysis has been discussed in literature (see for example, Rauch et al. 1998; 2002) and it has also been formulated within the EU Water Framework Directive 60/2000 with a water-quality orientated view on the whole system which calls for new ways of assessing its performance. Nowadays, there are attempts by commercial software companies to develop the links between different detailed (or refined) physically-based models (Moore et. al., 2004) but efforts in instantiating such models, their linking and running (which usually takes substantially long period of time) is far too impractical for high level strategic planning purposes. What is then therefore needed is the ability to undertake a holistic analysis of the entire urban water cycle by setting up a relatively simple model with reasonable accuracy. Implicit in this is a requirement both to understand and to be able to model not only the individual urban water processes but also their interactions irrespective to the strength of their interaction (Fig. 1).

Since there are several limitations which make the use of detailed physically-based models, which are based on the conservation of mass and momentum, inefficient and impractical for strategic planning purposes, such models need to be replaced by fast surrogate (an approximate substitute) models. The weakness of fast surrogate models is the limited content of encapsulated knowledge of physical processes that they posses and such weakness has to be compensated by more extensive calibration (Meirlaen J. et al, 2001). Once fit for purpose, the surrogate models can be then used as a strategic planning tool for different scenario analysis and decision making.

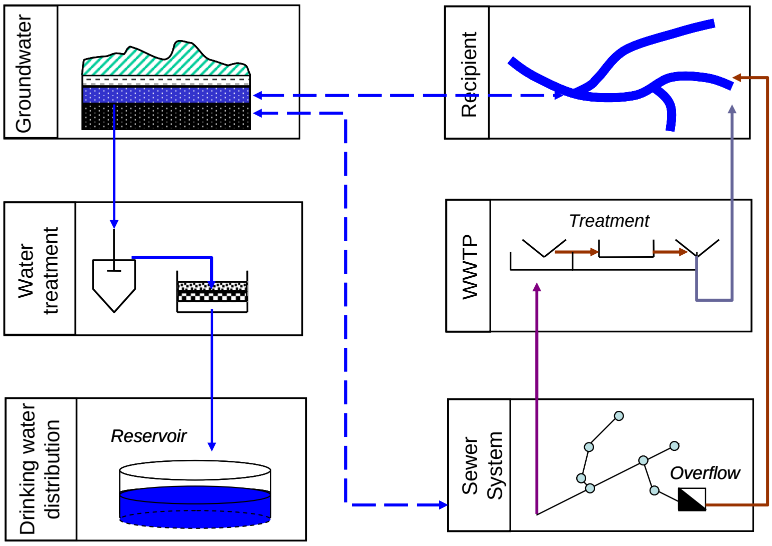


Figure 1: Schematisation of urban water cycle and interactions between different components.

Surrogate models require much more data for calibration than physically-based models. Since the collection of such data can be very expensive and time consuming, one way of approaching this problem could be to calibrate and validate the physically-based models with less data and generate sufficient virtual data using the physically based models for calibration and validation of surrogate models. If this is done for every urban water cycle component, the knowledge of the physically-based models can be transferred to the surrogate models and as such they could be efficiently used for strategic planning and decision making (see for example, Meirlaen J. et. al., 2001).

The integrated modelling work within work package 1.2 will address the issue of setting up the conceptual modelling platform to replicate the larger part of an urban water cycle focusing on the urban drainage componenets. It will explore the use of integrated surrogate models in a procedure where the model parameters of such models are derived either from measurements or from a detailed physically-based model results. The work will attempt to develop a framework for a two layer modelling approach of an integrated urban water system (Fig. 2) where the first layer contains refined deterministic models of the individual subsystems such as sewer model, river model, wastewater treatment plant model, flood model, etc. The second layer is the layer aimed for strategic modelling and contains surrogate models within an integrated model. Since the surrogate models will act as a simplified replica of detailed physically-based models they will be less complex and computationally less expensive when compared to the physically-based models but still be able to produce reasonably accurate outputs for strategic planning purposes. In addition to the development of necessary modelling systems, this research work will also attempt to develop a mechanism for linking the two layer models for a two-way information exchange.

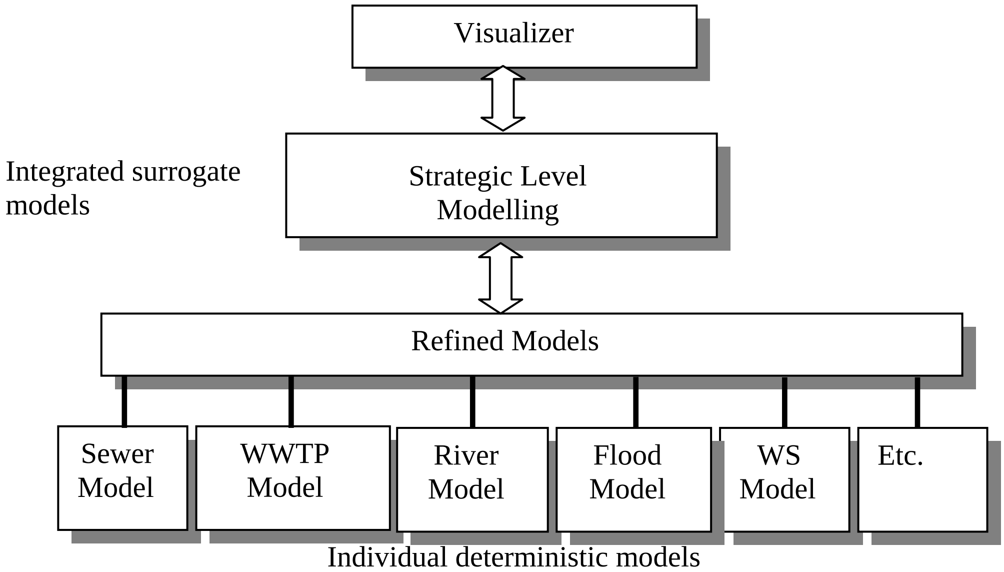


Figure 2: A two-layer modelling approach.

After developing the two-layer modelling approach and the necessary modelling tools, the model results will then need to be transferred to a comprehendible form by the use of a visualizing (communicating) tool which is also planned to be developed as part of this work. Currently the modelling work is on stage of reviewing available tools for integrated urban water systems modelling and the possibilities of utilising and modifying any of the existing commercial or free source code modelling systems (e.g., Aqua Cycle or similar).

## 3 Knowledge management system (KMS)

Same as the work on integrated modelling, the work concerning knowledge management systems will start with the review of relevant literature and current practices. In particular, topics that relate to defining urban water problems, understanding them and analysing them will receive detailed attention. The knowledge and information sourced form literature and industry best practices will then be used to formulate the steps and functionalities of the knowledge management system. This at the first place relates to the *city visioning, scenario development* and *strategies formulation*, being the elements of the first phase of the integrated urban water management process, Fig. 3. The knowledge management system that will be developed as part of work package 1.2 will also support other subsequent phases such as: *detailed analysis, decision making* and *vision refinement*.

Knowledge management is essential in order to make sure all information and knowledge that can be gather from individuals involve in urban water management can be use in efficient way. The primary source of new and important knowledge or urban water is from the experts. Knowledge management is used to make sure the experts are provided with the sort of analysis tools including the tools for knowledge discovery and mining, document content analysis and so on. Knowledge management can also be designed to provide the experts disseminate knowledge to stakeholders, publics and other organization involved in the project. Using knowledge management, an individual involved will be assisted to identify and locate the knowledge they requires whether to store it in knowledge banks, encapsulated in modelling system or residing in databases or decision support system. They will also provide with facilities that can help them to set up virtual teams and can facilitate on problem specification and solution. The recipients of knowledge which in this case can be the public or stake holders need to appreciate the original context of the knowledge given by the experts in order to make sure the knowledge can be assimilated properly. Knowledge management system therefore addresses the individuals to learn on-the-job and just-in-time in order to do this.

In urban water management system, knowledge management can used:

i. To facilitate research (experts)
ii. To disseminate knowledge to all stakeholders
iii. To facilitate collaborative working
iv. To monitor project implementation and documentation
v. To provide individual and organization learning
vi. To support efficient communication between stakeholders.

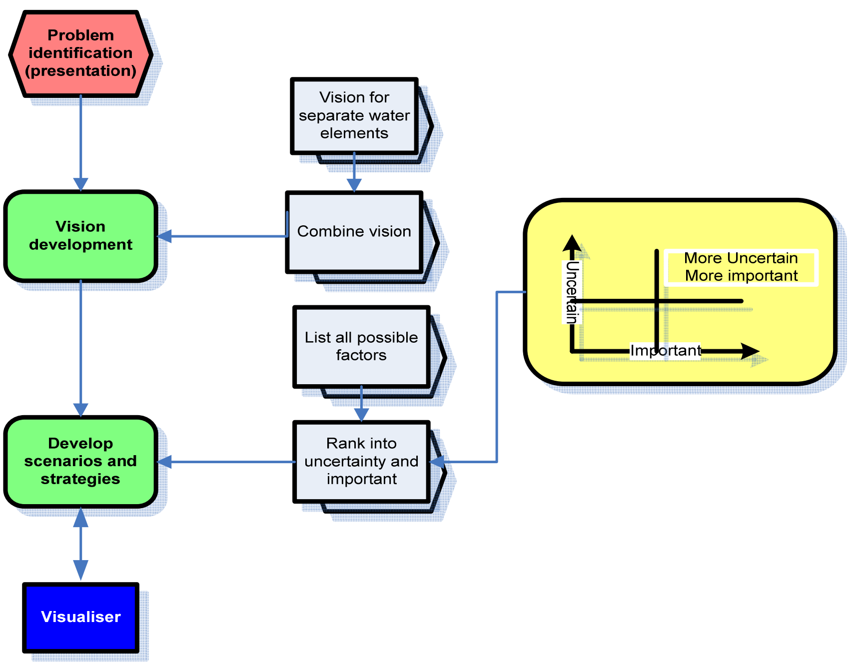


Figure 3: Visioning and scenario development process.

What has been the standard practice so far is that the process of defining urban water-related problems, visioning, scenario and strategy development has been carried out by the conventional power point slides and flip charts at the workshop (an example of such workshop has recently been carried out in Alexandria). On the first day of the workshop, specialists from the water-related institutions were invited to discuss their work and to present critical issues facing their specific area for which they have direct responsibilities. Following the presentation, the participants were then divided into several groups and asked to develop their joint vision. This process has led to the development of an overall vision formulated into a narrative phrase. Once the vision has been defined, different scenarios were formulated (e.g., *worst case*, *business as usual* and *best case*). After this, all necessary activities that contribute to each of the three scenarios were identified and for each scenario individual votes were given by each group member.

The intention of the work package 1.2 would be to fully automate this process within the web-based KMS and to enable better communication, discussion and negotiation between different stakeholders. With such automated system, a set of different questionnaire will be produced and distributed to the participants in advance of the workshop in order to have more thorough input and better preparation for the workshop. Furthermore, the work in this work package will attempt to develop an interactive tool that can visualise causes and effects of different scenarios.

In urban water environment, the automated planning is usually includes the spatial analysis functionality, and also consider the integrated use of different analytical models. In order to deal with this situation, a Spatial Decision Support System (SDSS) seems to be the most suitable system. As compared to conventional approach, Spatial Decision Support Systems provide the integrated environment for solving the decision-making problems in urban water management related to spatial and analytical analysis with wide range of functions.

As part of that, in order to serve multiple users especially for public participation in urban water management, web base KMS can be integrated with SDSS. It is believed that the combination of both systems can assist in better urban water management in the future. DSS and knowledge management are interdependent activities. This is because an effective DSS can be made with the process and facilities that support the use of knowledge management. In the decision-making process, decision makers combine different types of data and knowledge in various ways. This process is made to improve the understanding of the problem and develop new knowledge. This proves that the decision-making process and knowledge creation are interdependent Proper integration of DSS and KMS will support the required interaction that will make new opportunities for enhancing the quality of support to each other system. Therefore, when these two systems are combined, synergy might be created.

KMS is not a single application. It is a collection of relevant components, which are usually including GIS, simulation models, functionalities for data, time series analysis and multi objective evaluation of result. The heart of decision support is decision matrix. It represents a structured illustration of decision space. When problem has been structure, the possible options are defined and criteria aiming at evaluation of their performance are identified. The options performance in terms of the criteria scores is modelled using decision matrix. The rows of this decision matrix contain management objective and represented by the indicator. The scenarios, which are built by GIS and other important info, specify the column. Decision matrix serves as a plot for planning process. It defines which decision that should be considered and what indicator should be calculated. The most important rules that are provided by decision matrix are to identify values for every scenario, so a better environment for comparison can be created (Sieker H. et al, 2006).

In decision process, decision makers need to know the varying of involve criteria. The criteria weights are used to provide the information about the relative importance of the considered criteria. There are many techniques commonly used for assessing the criteria weights such as ranking and rating methods, pair wise comparison and trade-off methods. Sensitivity analysis (SA) is an important task in multicriteria decision-making. This analysis is used to looks how robust (or weak) the final decision. Sometimes the sensitivity analysis is distinguished from a robustness analysis: while the sensitivity analysis is assumed as the analysis of the effects of changing data and model parameters in a constrained vicinity to a base solution, the robustness analysis is considered as a systematic analysis of a large set of variations which are plausible in the decision problem context (Jaroslav M et al, 2004).

There are many approaches for SA such as:

i. Most critical criterion - Identifying the criterion for which the smallest change of current weight may alter the existing ranking of options

ii. Tornado diagram - Graphically comparing the chosen option with any other one and showing ranges within which the parameters may vary. Figure 5.4 shows the tornado diagram.

In summary, the methodology of a KMS being developed is based on the following key aspects: ***p**roblem*, ***o**bjectives*, ***s**olutions*, ***e**ducation* and ***d**ecisions* (**POSED**). The functioning and appropriateness of this system will be demonstrated and validated on two SWITCH demo cities: Belo Horizonte and Birmingham. Figure 4 depicts the KMS research framework.

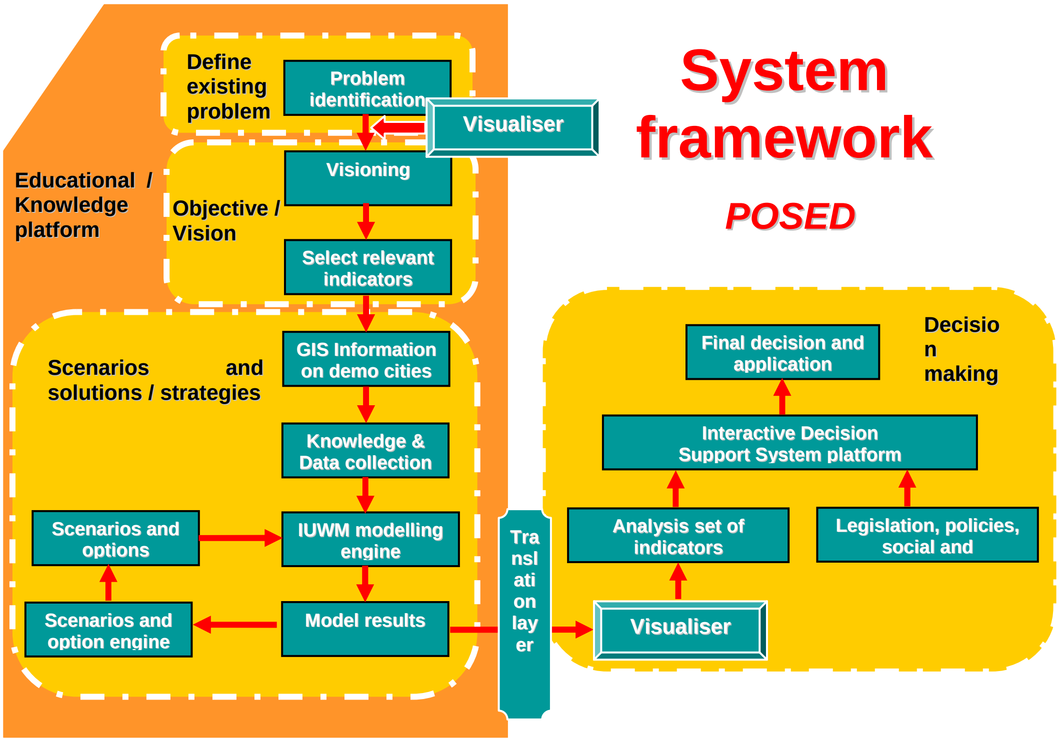


Figure 4: POSED framework.

So far, two modules have already been developed; Web GIS module and visioning module. WebGIS module is able to view GIS data online. It is customised using ArcIMS, ServletExec from New Atlanta, JAVA 2 SDK, JAVAScript and HTML. Fig. 5 shows the architecture of the module. Data stored in data storage tier. In this spatial data comprised of image and shape files. In the presentation tier, clients are using the system by normal webpage (internet explorer) to view GIS data. Data is rendering using jpeg file. Every time users want to view the data, the requests are sending to the data storage tier using business logic tier and vice versa.

The second module is visioning module. This module is aim to help facilitator in the process of visioning. Application was developed using Macromedia MX, Coldfusion, JavaScript and HTML. Using this module, stakeholders are guided to define the problem in the city. Then they need to define the vision for the city and finally to set up scenarios and strategies. All the manual process in visioning are automated in this module. The results will be set of problem in the city, vision of different stakeholders and also strategies to face certain scenarios. So far, all input from stakeholders will be summarised by administrator manually. All the information will be summarised and presented to stakeholders using appropriate ways.

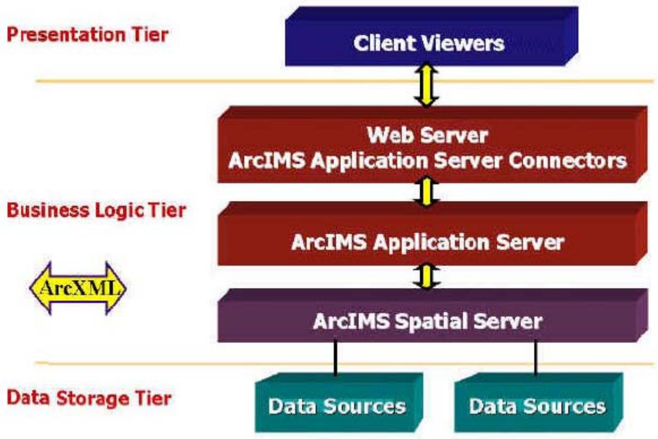


Figure 5 WebGIS software architecture (Sources : ESRI)

# 4 Conclusion

The work within work package 1.2 will address the integrated urban water modeling giving emphasize on the urban drainage component. It will explore the use of integrated surrogate models where parameters of such models are derived either from measurements or from a detailed physically-based model results. With regard to decision making the work will fully automate the process of defining urban water-related problems, visioning, scenario and strategy development within a web-based Knowledge Management System.

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