2nd SWITCH Scientific Meeting
Dan Panorama Hotel, Tel-Aviv, Israel
25 - 29 November 2007

Towards an information system on the water system

Colin Schenk, Marc Soutter, Bastien Roquier and André Mermoud *

Hydrology and Land Improvement Laboratory (HYDRAM)
Ecole Polytechnique Fédérale de Lausanne (EPFL)
Lausanne, Switzerland

Abstract
Integrated water resources management is generally considered a relevant methodology given the pressing necessity to use water in a sustainable manner. However, its application framework still needs refinements. As a first step towards the creation of such an improved framework, a system model for water management has been proposed, including a broad view upon the elements involved directly or indirectly (such as the energy, the public health or the housing conditions) in water management. The model may be applied to large entities such as regions or cities. This could lead to the creation of "information systems about the system", systemic views with access to detailed data regarding the water-related infrastructures, ecosystem, natural and human resources, and legislative context, including relationships between these elements.

Keywords: integrated water management, holistic view, system model, system approach, information system

1 Introduction

Integrated water resources management has been widely recognised by the water management communities (Carter et al., 2005). It indeed proposes an interesting approach to consider holistically water-related issues. However, there is no clear recommendation available for the definition of what should be practically integrated. The often quoted Global Water Partnership's definition to IWRM states (GWP, 2000): "IWRM is a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems".

* Corresponding Author: colin.schenk@epfl.ch

And indeed, this gave raise to many different interpretations (Biswas, 2004). This therefore leaves a first question: what should be integrated within IWRM?

In the literature, albeit water-related issues (such as basic household water needs, industrial, agricultural and energy uses, ecosystem requirements, transportation and recreational purposes, water-related risks, governance issues and relations between water and poverty, health, education, and equity) are extensively documented (Falkenmark et al., 2004; Gleick, 2003; Niemczynowicz, 2000; UNDP, 2006; UNESCO-WWAP, 2006; Zehnder et al., 2003), it remains however difficult to gain understanding of the way these issues interact and therefore, to apprehend the water management system holistically. To facilitate this holistic understanding and to communicate it, Falkenmark (2004) argued that there is a need for a mental map. Then, the second question raised is: how can the holistic apprehension of the water management system be provided?

To adress the two questions mentioned above, the creation of a framework for a holistic approach towards IWRM has been undertaken. An initial step to address the first question was the achievement of a water management system model (Schenk et al., 2008), a graphical map and description of the different water-related components and their interactions. The next step -aiming at addressing the second question raised- is based on the developed model as a reference. It is currently under development and proposes the realisation of an application able to display and navigate the water system-linked information. This application will be based on the concept of “information system on the system” (ISS), a concept defined in this paper as a generic tool able to handle general system information.

The concept of information system on the system and its application under development -the City Water System application-, are this paper’s focus and the topic of section three. Prior to it, the next section provides an introduction to the general framework of this project, as well as a brief description of the water management system model.

2 Context

Within the SWITCH European project (www.switchurbanwater.eu), which aims at catalysing change towards more sustainable water management in cities, a group works more specifically on the strategic aspects. It will develop a decision support system (DSS) for the integrated water management and planning, which will include different components. As shown in Figure 1, this DSS is designed to provide users with information in several different forms, extracted from a common geodatabase (5). The user interface (1) gives access to several tools, such as a knowledge management system (2), a geographical information system (GIS, 3) and an application called City Water System (4). The latter is the topic of this paper and its development is a contribution by the authors to the SWITCH DSS.

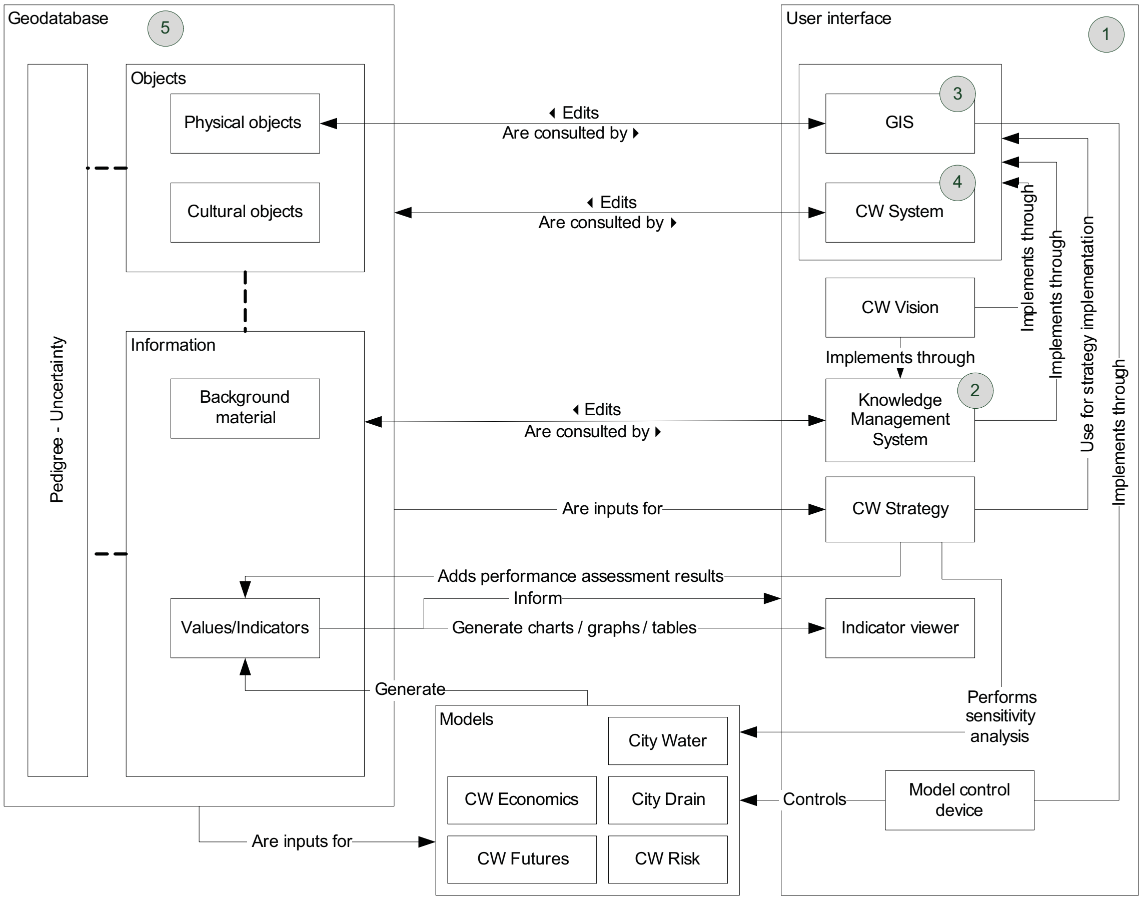

Figure 1: SWITCH DSS components and data flows

As the City Water System is to be the implementation of the water management system model, the latter, described in details by Schenk et al. (2008) is briefly presented here. This model is an effort to provide a holistic reference view upon the water management system in its broader sense, including also elements that don't strictly belong to the field of water, such as energy or housing policies. First, it lists as exhaustively as possible any kind of components involved in this broader view upon water management. Components are classified into two main groups: physical (infrastructures, environment, natural and anthropogenic resources) and cultural objects (policies, laws). Then, it describes the interactions between these components, and finally, it provides a graphical view with a possible way of organising components and interactions. A fragment of this graphical view is shown in Figure 2: rectangles are components and black arrows represent functional interactions; diamond-terminated links represent composition relations (of type "belongs to"). For instance, in this figure, the component "Water" (1) belongs to the general "Resource" component. It has a functional interaction with "Energy" (4), as the latter may require water for its production (directly, for hydropower production by hydropower plants (5), or for cooling). Conversely, water requires energy for its production (treatment processes, pumping, etc.). Water is also required by the ecosystem (2) and may be virtually contained in food and goods (3) (the concept of virtual water covers the water embedded in items, either directly, such as in beer, or indirectly, for production purposes, such as washing or cooling). To conclude this example, point 6, water removal infrastructure such as sewers obviously provides sanitation, but they may also lead to groundwater contamination or health issues whenever they are not appropriate.

In the next section, the way the water management system model is to be applied to real cases will be developed.

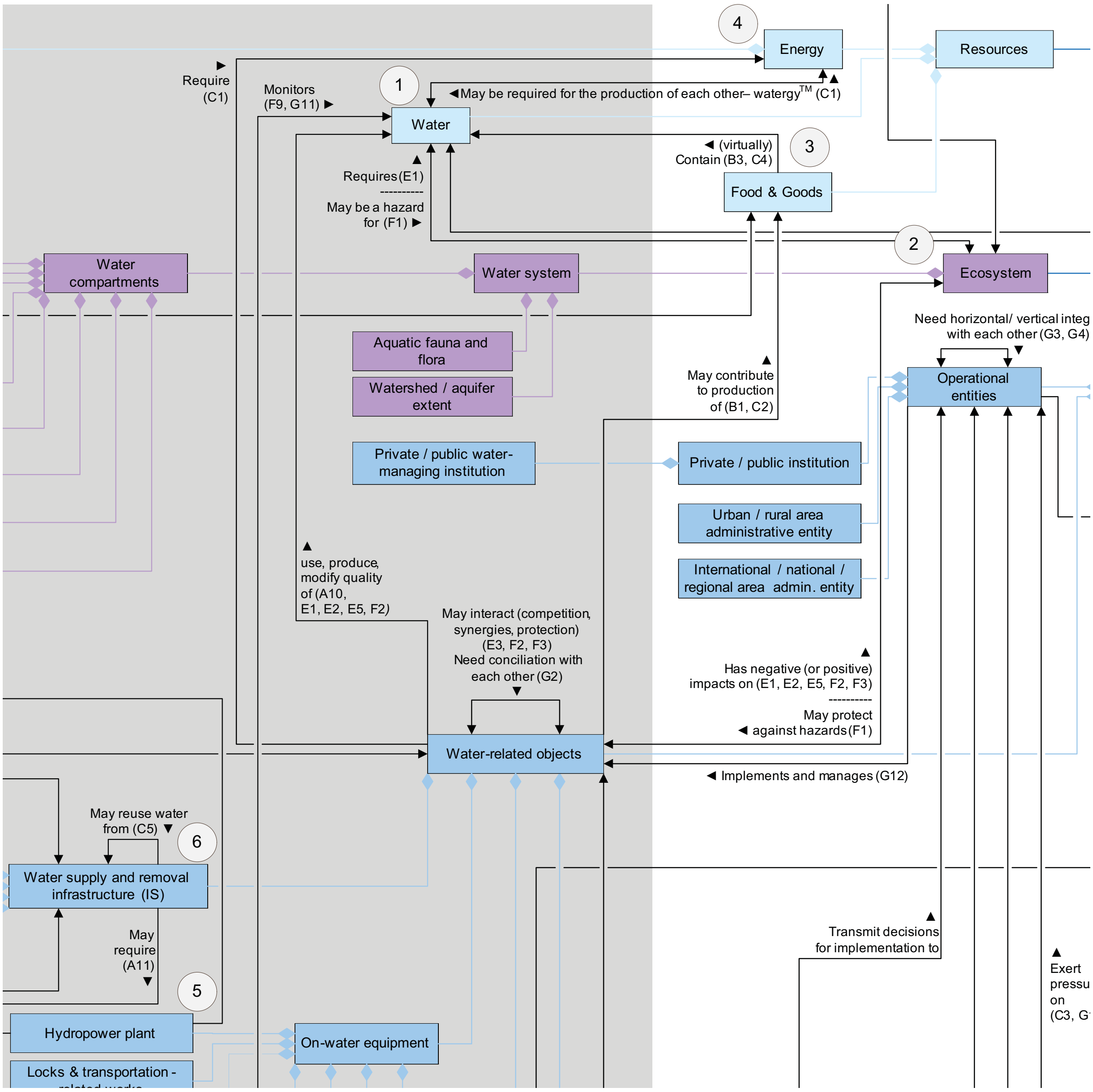

Figure 2: Fragment of the water management system model (source: Schenk et al. (2008))

3 Information system on the water system

A widely spread way of representing information with geographical location is to use geographical information systems (GIS). Only in the field of GIS-based multicriteria decision analysis (MCDA), 319 scientific articles were inventoried between 1990 and 2004 (Malczewski, 2006). In certain cases, the users' needs necessitate the development of new GIS functionalities (not provided by the available applications), as within the SMURF application (Repetti et al., 2006; Soutter and Repetti, 2008), designed to show indicators' values with an easy-to-use interface, or to integrate traffic data (Claramunt et al., 2000), or to manage rescue operations related information (Morin et al., 2000). However, whereas GIS tools provide necessary information to understand the spatial distribution of the information, it fails showing clearly (i) synthetic data and (ii) functional interrelations between displayed elements. It is also obviously (iii) not appropriate to display non-geographical information, such as stakeholders or policies. Regarding integrated water resources management, this translates into the impossibility to easily retrieve information such as for instance: the total pollutant loads into a river aggregated from several different sources, the services (such as sport fishing, protection against floods or self-treatment) that a wetland offer, or the influences water prices policies may exert on the consumption rates.

System-oriented representations organise involved objects according to the role they play in the system. Such views are used for instance in industrial processes, where supervision applications may show real-time data about the state of the equipments and the processes, based on field sensors. In a wastewater treatment plant, such a supervision system may display schematically the process lines in a synthetic view, with on-line water quantity and quality information, water elevation in the basins, temperature in the activated sludge digester, etc. In power system control centres, Handschin and Leder (2001) developed a new visualisation system to provide users with high-level information evaluated on-line on the basis of very numerous individual values. To visualise quality system in production for companies, a system-oreinted application was developed by Blome et al. (2003). A common point of all these applications is that they were developed to monitor very specific aspects of systems and are therefore no generic tools.

To sum up, GIS are not appropriate to handle system data, and the system-oriented available tools are specialised applications. Therefore, a concept definition is hereby proposed for a generic application able to handle general system information, complementing the GIS view, and called "information system on the system" (ISS):
"*An information system on the system (ISS) is defined as an application system able to display a system organisation and its related data. Involved elements are either components (nodes) or interactions (connexions). Components may be of physical (infrastructures, environment, natural and anthropogenic resources, etc.) or cultural nature (policies, laws, etc.); interactions provide a qualitative (textual) or quantitative information about the functional relationship between two components. Groups of components are also components and are appropriate support to the application of synthetic information. Therefore, ISS might be a complementary alternative to GIS, especially to show synthetic information, interactions, and non-geographic data.*"

As an application of this concept to water, an information system about the water system is currently under development and is called City Water System, as a part of the SWITCH DSS. As shown in Figure 1, this application will be composed of a client (4) able to connect to a local or remote geodatabase storing the information to extract and edit it. The functionalities of the City Water System client comprise different system views (influences, physical fluxes, data and monetary flows), the possibility to expand components for gaining access to more details and pop-up boxes to browse and edit the information. These functionalities will be hereafter illustrated using figures 3-5 which present a fictitious example.

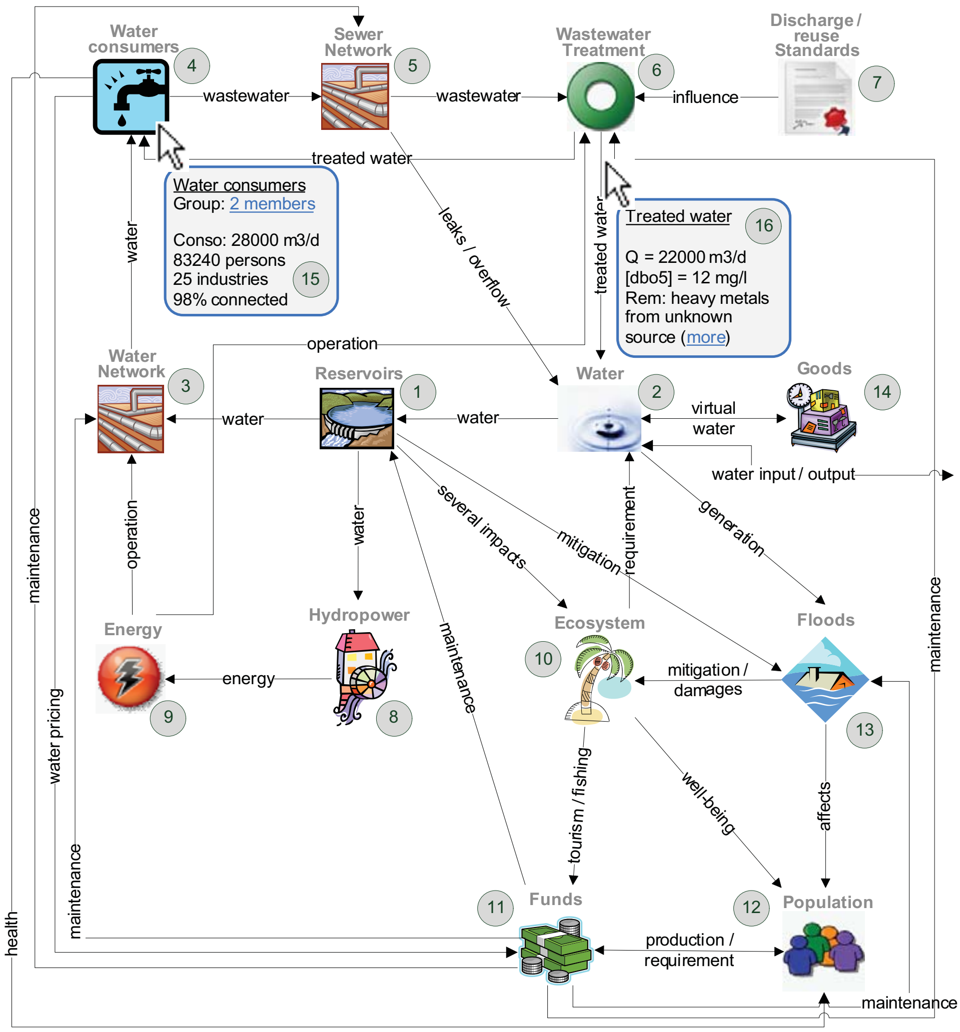

Figure 3: Displaying influences network with the ISS City Water System

First, Figure 3 shows a fictitious partial general view of a water-related system, based on a quite conventional water cycle. Reservoirs (1) extract and store the water resource (2). Water is then processed to consumers (4) through the network (3) and then, wastewater is led to a treatment plant (6) by sewers (5), before release back into the environment or reuse by consumers, according to standards requirements (7). Hydropower plants (8) also take advantage of the reservoirs to produce electricity (9). The ecosystem (10) also needs water to produce services and then funds (11), as well as to provide well-being to the population (12). It finally plays an important role to mitigate the effects of the frequent floods nearby (13), but is also being damaged by extreme events. Finally, there are goods that have important virtual water content (14). Of course, there are many other elements that should be represented to provide a real case exhaustive view, such as the boards in charge of the infrastructures, or the many other policies involved.

To consult and edit information linked to system elements (stored in the geodatabase), the user will be able to pop-up a box showing details extracted from the geodatabase (15, 16). In the case of components (nodes) the information provided is related to the object it represents, such as the number of inhabitants (15). For interactions (connections), the information provided shall not overlap component's data. It may describe textually a functional relationship, provide numeric data -such as water discharge or pollutant concentration (16)- or both. Furthermore, pop-up boxes will contain hyperlinks (underlined blue text) that will enable popping-up other boxes with the related information, and therefore provide an easy way of navigating the information.

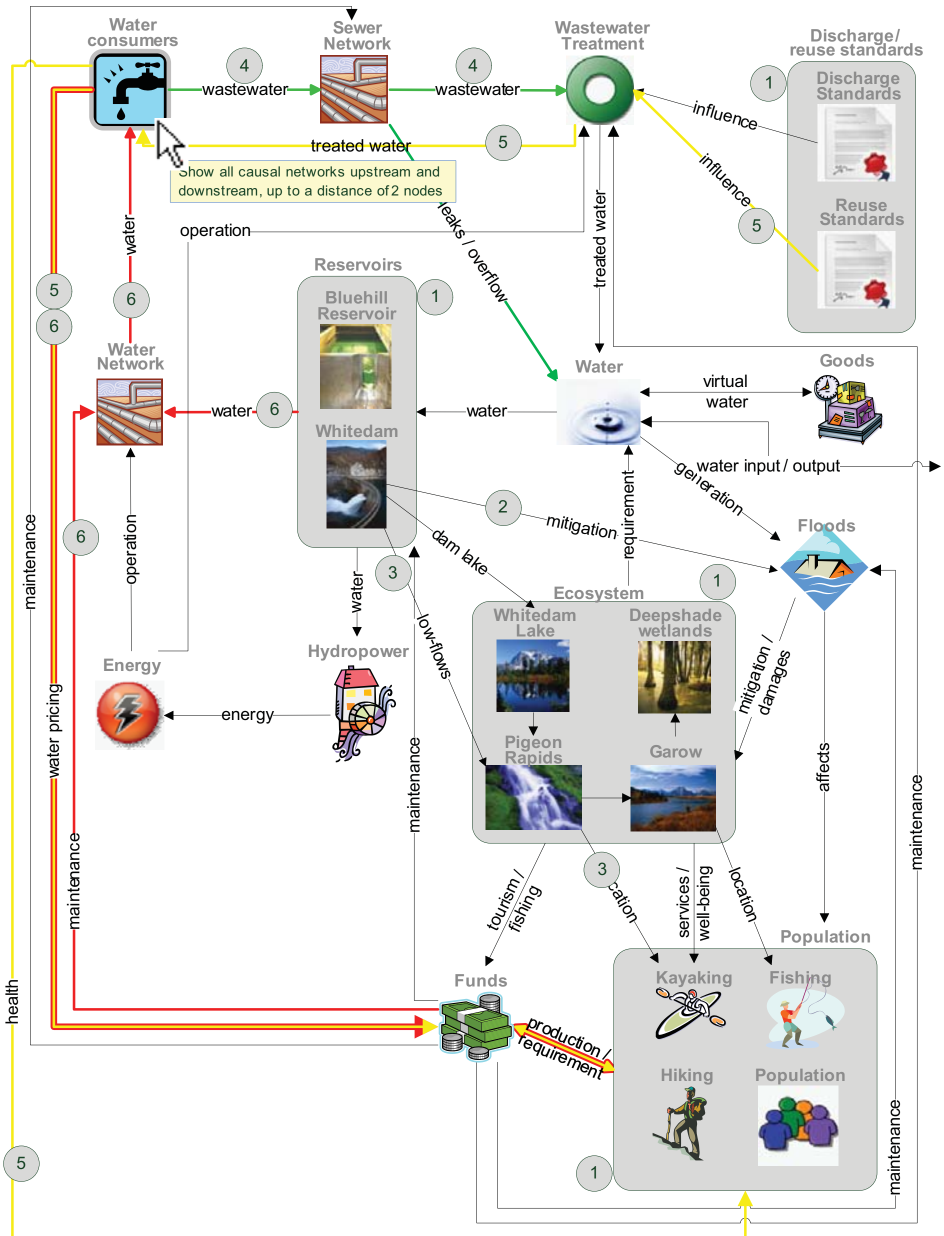

Figure 4: Expanding details in the influences network with the ISS City Water System

The general view shown by Figure 3 is useful to have a simple but holistic view upon the system. To obtain more details about the different components, the user will be able to expand them, as shown in Figure 4 (objects marked with a (1)). Expanding groups will show the members of the group. In turn, these members may contain sub-members, and so on. This approach also offers the possibility to the users to gradually improve the level of details in time, starting from a general view, and then later adding and organising sub-groups. Sub-groups will not only allow adding more details to components: they will also provide the opportunity to refine interactions. In Figure 3 for instance, out of the two existing reservoirs, obviously, only the dam may have a mitigating effect upon floods (2). And kayaking activities, which mainly take place in the rapids, would be threatened by too low flows, which depend upon releases from the dam lake (3).

As more details are shown, complexity may also increase and readability decrease. It may become difficult to follow causality networks, such as in the kayak example, especially if branching is dense. To address this issue, users will have the possibility to store and display causal networks they have once identified. Figure 3 (4-6) illustrate this with an example: three different causal networks could involve the water consumers, and the user could wish to display all of them, but only to a distance of two nodes, upstream (influencers) and downstream (influencees). (Other choices the user would have would be: displaying only one or more selected networks, displaying any influencer and any influencee disregarding whether or not they belong to an existing user-defined network and setting the distance, upstream and downstream.) The first causal network (4) considers wastewater and has its origin at the water consumers' node. The second one (5) emphasises that water reuse standards may have an effect on population's health, if quality requirements are low and therefore if reused water shows potential toxicity. It also highlights that it could have a repercussion on the price of water (if requirements are high, it might cost more to meet them), and therefore a social impact. The last causal network is about the quality of water processed to consumers, and shows branching causes (maintenance funding and water origin) and the same effects as previously, upon water price and subsequently possibly on the population.

Another way to highlight certain interactions is to use the fluxes views. There will be at least three possible fluxes views available in the ISS City Water System: (i) the physical fluxes (water, energy, pollutant loads, etc.), (ii) the monetary flows and (iii) the data flows. The first possibility is illustrated in Figure 4. In this figure, the interactions which do not imply a transfer of water or of energy are discarded. Then, the flows' values are used as a basis to display proportional arrows. With that regard, as several different flow values may coexist (for instance monthly or yearly, daily or nightly mean values, or peak values), the user shall be able to select which one is to be displayed. Furthermore, in the case of water, the possibility will also be offered to display a pollutant load instead of the water discharge, on the basis of the latter and the pollutant concentration.

Figure 4 also shows another functionality, important for information consultation: as shown below, users will be able to access not only the short information visible in the pop-up box, but also to display pictures. They will also have the possibility to open text documents or watch other kind of multimedia files, thanks to one or more external applications.

Regarding monetary flows, they will look very similar to physical fluxes, using only interactions such as those labelled in Figure 2: "maintenance", "tourism / fishing" and "water pricing". Finally, data flows will also look similar, but they will involve other components and interactions, such as "expert", "validation", "model", "assessment" or "indicator".

Finally, with regard to edition functionalities, the user will have the possibility to add and delete components, create or erase new interactions and link them to components; and pop-up boxes will allow edition of their content.

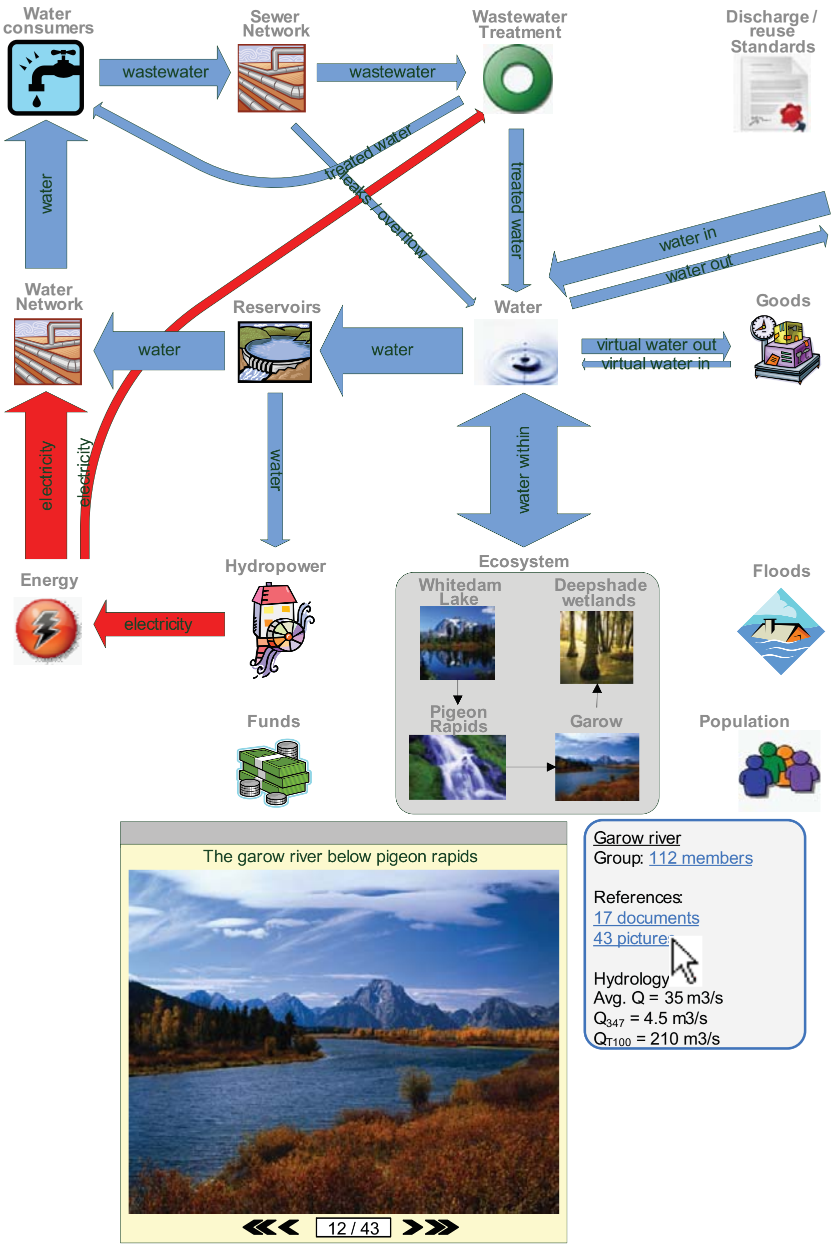

Figure 5: Displaying a fluxes view with the ISS City Water Sytem: physical fluxes

4 Summary and conclusion

To address the issues of (i) the scope of the IWRM system and (ii) the way to provide the holistic understanding of the system, the development of framework has been undertaken. As a first step addressing the first issue, a water management system model has been realised, inventorying the water-related components and their interactions. This paper focuses on the second step, under development, which aims at creating an application allowing displaying and navigating the system information. This application -called City Water System- will be based on the defined concept of “information system on the system” (ISS), whose purpose is to display system organisation and data. Such ISS shall prove particularly relevant to provide synthetic information attached to groups and data about interactions (between components) and about non-geographic objects.

The City Water System application will be a part of a decision support system developed by a group of the European SWITCH project. It will provide the following functionalities:

- The possibility to switch between different interactions views: influences (textual), physical fluxes, data and monetary flows.
- The possibility to expand group components to gain access to detailed information about group members. Then, in turn, group members may be composed of sub-group members, and so on.
- Pop-up boxes to consult short information, textual or numeric. Within these boxes, hyperlinks will provide an easy way to navigate the information, through the popping-up of more boxes. Furthermore, external applications will be called to consult longer information (texts) or multimedia documents.

References

Biswas, A.K., 2004, Integrated water resources management: A reassessment - A water forum contribution. Water International, 29: 248--256.

Blome, M., Johansson, C.R. and Odenrick, P., 2003, Computer supported visualisation of quality systems developed by network teams. Applied Ergonomics, 34: 239-247.

Carter, N., Kreutzwiser, R.D. and de Loe, R.C., 2005, Closing the circle: linking land use planning and water management at the local level. Land Use Policy, 22: 115--127.

Claramunt, C., Jiang, B. and Bargiela, A., 2000, A new framework for the integration, analysis and visualisation of urban traffic data within geographic information systems. Transportation Research Part C-Emerging Technologies, 8: 167-184.

Falkenmark, M., 2004, Towards integrated catchment management: Opening the paradigm locks between hydrology, ecology and policy-making. International Journal of Water Resources Development, 20: 275--281.

Falkenmark, M., Gottschalk, L., Lundqvist, J. and Wouters, P., 2004, Towards integrated catchment management: Increasing the dialogue between scientists, policy-makers and stakeholders. International Journal of Water Resources Development, 20: 297--309.

Gleick, P.H., 2003, Water use. Annual Review of Environment and Resources, 28: 275--314.

GWP, 2000, Integrated Water Resources Management. Global Water Partnership -Technical Advisory Committee, Stockholm, Sweden 67 p.

Handschin, E. and Leder, C., 2001, Innovative visualization of the power system state for predictive process control. Electrical Engineering, 83: 297-301.

Malczewski, J., 2006, GIS-based multicriteria decision analysis: a survey of the literature. International Journal of Geographical Information Science, 20: 703-726.

Morin, M., Jenvald, J. and Thorstensson, M., 2000, Computer-supported visualization of rescue operations. Safety Science, 35: 3-27.

Niemczynowicz, J., 2000, Present challenges in water management: A need to see connections and interactions. Water International, 25: 139--147.

Repetti, A., Soutter, M. and Musy, A., 2006, Introducing SMURF: A software system for monitoring urban functionalities. Computers Environment and Urban Systems, 30: 686-707.

Schenk, C., Soutter, M., Roquier, B. and Mermoud, A., 2008, A system model for water management. Environmental Management, Accepted.

Soutter, M. and Repetti, A., 2008, Land management with the SMURF planning support system. Planning Support Systems in Practice, To be published.

UNDP, 2006, Human Development Report 2006. Palgrave Macmillan, New York, USA 422 p.

UNESCO-WWAP, 2006, Water, a shared responsibility: the United Nations World Water Development Report 2. United Nations Educational, Scientific and Cultural Organization (UNESCO) & Berghahn Books, Paris, France 584 p.

Zehnder, A.J.B., Yang, H. and Schertenleib, R., 2003, Water issues: the need for action at different levels. Aquatic Sciences, 65: 1--20.