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Towards Development of Effective Decision Support Systems for Integrated Water Resources Planning and Management

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Synopsis

In order to clarify the requirements for DSSs for IWRM, key functions of DSSs for water resources planning and management are discussed in this paper. Changes in roles and functions of DSSs are reviewed by tracing the past studies on DSS for water resources planning and management. The paper then discusses important points to be considered in the development of effective DSSs for IWRM in the future.

Keywords: DSS, IWRM, collaborative decision making, stakeholder, water efficiency, business process

1. Introduction

Water resource is affected by both of water cycle and human activity. Water circulation is dominated by complex hydrological processes including precipitation and snowmelt as origins as well as interaction between surface water and groundwater. A variety of stakeholders also try to use water for their purposes in different ways while society tries to keep flood waters out of their land where they have installed their capital. Such different interests by stakeholders often cause conflicts, which make water resources management more difficult. The approach of integrated water resources management (IWRM) (Global Water Partnership, 2000) is therefore needed to synthetically consider the complex processes in both the natural and social aspects in the management of water resources.

Water resources management is becoming more and more challenging and complex in recent years. Water cycle is being changed as a result of changing climate, which will change hydrological processes and available water resources in the future. Social condition is also changing because of the economic growth situation, population increase or decrease, or other changes in social and political framework. Water resources management plan has to be revised and updated in order to take those natural and social changes into account for more sophisticated water resources management.

Growing public awareness of conservation of river water environment has also increased complexity in water resources planning and management. River water environment had not been considered in water resources planning in the past, and then it was considered as a constraint. Now it is regarded as one of the important objectives in water resources management. An additional evaluation axis therefore needs to be included in water resources planning and management, which makes it more difficult to balance all management objectives considered.

Growing sense of river water environment has also led to an increase in needs for stakeholders or public involvement in the water resources planning process. This is because various parties along the concerned river can be stakeholders in terms of river water environment, whether they are pollutant sources or beneficiaries of river water environment with good conditions. General public can also be considered as one of those stakeholders, as river water environment is also a matter of public health. The water resources planning process therefore becomes more complicated in order to reflect opinions from those stakeholders to the plan. Transparency of the planning and management processes is very important for consensus building among stakeholders or general public.

Thus, the decision making process for water resources planning and management becomes a complex task which needs to compromise variety of interests from different stakeholders for IWRM. Adequate tools are therefore needed to support these challenging processes to find an alternative measure that maximizes overall satisfaction among stakeholders through rational consensus building based on unbiased information. A decision support system (DSS) is one of these effective tools for helping decision making for water resources management. Although studies on DSSs for water resources management have been carried on, needed roles and functions of DSSs is changing as circumstances of decision making in water resources management changes as described above.

In order to clarify the requirements for DSSs for IWRM, key functions of DSSs for water resources planning and management are discussed in this paper. Changes in roles and functions of DSSs are reviewed by tracing the past studies on DSS for water resources planning and management. The paper then discusses important points to be considered in the development of DSSs for IWRM in the future.

2. Past Studies on DSSs for Water Resources Planning and Management

The history of DSS studies can be traced back up to at least the late 1950s and 1960s for theoretical studies of organizational decision making and for the technical work (Shim et al., 2002). Since then, a conventional DSS concept has gradually been developed considering categories of management activity and description of decision making process (Gorry and Morton, 1971). One definition for typical components of DSS are database, inference engine, and user-interface (de Kok et al., 2009; Guvenc et al., 2015). The database is often replaced by the knowledge base in knowledge-based DSSs (Nohara et al., 2005).

DSSs for water resources management have been studied in parallel with the advancement in the concept of general DSSs for other objectives. For example, a river water management software package reported by Shafer and Labadie (1978) is one of the DSSs developed for water resources management which keeps updated as the MODSIM (Labadie, 2006). Many studies on DSSs for water resources management have reported across the world until 1990s (Davis et al., 1991; Stansbury et al., 1991; Kojiri and Sakakima, 1993; Andreu et al., 1996; Fredericks et al., 1998).

One of the characteristics of DSSs for water resources planning and management in the early years can be considered that they are developed for very specific decision problems which can be well-defined. This can be considered because water resources planning and management was often evaluated by the cost-benefit analysis mainly focusing on the economic aspect which can be quantified by the engineering approach. Most studies in those years also focused on the structure of a DSS. Serrat-Capdevila et al. (2011) pointed out that most studies on DSSs in water resources management until 1990 are focused on software structure (e.g., pre and post-processing, databases, numerical models), user interfaces, and visualization of results. This implies that DSSs are supposed to be provided for uses as a completed software product after they are developed by experts or technicians without any major interaction with the user(s). Another characteristics of DSSs for water resources planning and management is expected users. In most DSS studies in those years, a single user was assumed in design of DSSs (Kojiri and Sakakima, 1993; Ford and Killen, 1995; Arumugam and Mohan, 1997; Ito et al., 2001). The supposed users were usually authorities of water resources planning or management, and DSSs were designed to support decision-making of those authorities.

Various key technologies have been developed in those years. One example of those technologies is soft computing using artificial intelligence. The fuzzy sets and theory (Zadeh, 1965) provided realistic inference engine, while artificial neural network techniques enhanced by the backpropagation algorithm (Rumelhart et al., 1986) provided a fast and non-linear statistical model. Advancement in knowledge engineering also affected DSS development for water resources management. The framework of expert systems were applied to develop knowledge-based DSSs for water resources management (Kojiri and Sakakima, 1993; Arumugam and Mohan, 1997, Mikulecky et al., 2003). These soft computing techniques were often applied to DSSs for real-time water resources management where managers or authorities need to handle various information in a short-time (Kojiri and Sakakima, 1993; Ford and Killen, 1995; Ito et al, 2001).

3. New Paradigm of DSS Studies for Water Resources Planning and Management

In the late 1990s and 2000s, several new paradigms emerged for water resources planning and management. After the Technical Advisory Committee of the Global Water Partnership (GWP) summarized a report on IWRM in 2000, IWRM has been recognized as an important guideline for effective and sustainable water resources management. According to UNESCO, IWRM can be defined as "a step-by-step process of managing water resources in a harmonious and environmentally sustainable way by gradually uniting stakeholders and involving them in planning and decision-making processes, while accounting for evolving social demands due to such changes as population growth, rising demand for environmental conservation, changes in perspectives of the cultural and economic value of water, and climate change" (UNESCO, 2009). Although the concept of IWRM was already discussed in the past decades, it is not yet established how to implement IWRM concepts in water management practice (Rahaman and Varis, 2005).

The needs for a holistic approach for water resources management was also highlighted in the European Union (EU) Water Framework Directive (WFD) which came into force in 2000 (EU, 2000). The key components of the WFD can be summarized as follows (Gourbesville, 2008):

- expanding the scope of water protection to all waters, surface water and groundwater;
- achieving "good status" for all waters by a set deadline;
- water management based on river basins;
- "combined approach" of emission limit values and quality standards;
- getting the prices right;
- getting the citizen involved more closely, and;
- streamlining legislation.

These components were included in the WFD to reflect the increasing awareness of citizens and other interested parties for their water and environmental issues. It also aims at securing coherent planning and management of water in one river basin, where all the riparian countries or states are stakeholders and need to manage their water in a collaborative manner if it is an international or interstate river.

As it is seen in the key components of the WFD, water environmental issues gain more and more attention after 1990s. Water environmental management often falls into an unstructured problem, where there are various stakeholders and multiple criteria to evaluate the condition. The decision process for planning or management of water environment therefore tends to become a very complex process. DSSs have been studied and developed to support this unstructured decision making in environmental planning and management. This type of DSS is often called as an environmental DSS (EDSS) (Denzer, 2005; Matthies et al., 2007). Although studies on EDSSs for operational management are seen, a greater focus is given to decision support for the planning process in the development of EDSSs considering the complexity in the planning process (McIntosh et al., 2011).

With those new paradigms, roles of DSSs have been recognized and understood in a different manner from the original one. Whereas DSSs were been mainly designed for a single user (usually planning or management authority) in the previous years, multiple users are often envisaged considering the importance of involvement of various stakeholders in the planning process. A

DSS with those designs are often called as a collaborative DSS or group support system (Shim et al., 2002) when it is designed to support collaborative decision-making among stakeholders. Some DSSs are even designed for not the decision support, but the discussion support for enhancing mutual understating among stakeholders for better decision making. This type of DSSs is frequently called as a discussion support system (Gourbesville, 2008).

Different goals of decision support are also recognized for water resources planning involving various stakeholders. More importance is recently given to how the decision is made collaboratively rather than what decision is made in the planning process. Involvement of various (or all if possible) stakeholders from the early stage of the planning process started to be a key point for successful development and implementation of the water resources management plan. Some DSSs were therefore developed intending to support consensus building rather than decision making itself among stakeholders (Fassio et al., 2005; Castelletti and Soncini-Sessa, 2007; Castelletti et al., 2007).

One of the key techniques for successful DSSs for multiple stakeholders is collaborative development of the system or its models (Serrat-Capdevila, 2011). The stakeholders can understand and trust the system and models of their DSS by participating the development process so that their interests and perspectives are incorporated in the DSS. The stakeholders can also learn interests of other stakeholders as well as knowledge on response of the target water system from discussions and model behaviors through the collaborative development phase. This kind of collaborative planning process has been studied in both the theoretical approach (Liu et al., 2008) and application to the real river basin (Serrat-Capdevila, et al., 2007).

Effective structure of a DSS has naturally been changed reflecting the changes in requirement in water resources planning and management processes. Gourbesville (2008) defined an engineering approach for collaborative decision-making as collaborative engineering, and provided an effective architecture for a DSS as collaborative engineering environment (CEE). Considering the rapid advancement of technologies related to DSSs, the development of a DSS is recently regarded as an iterative process rather than a single process. This iterative development process with participation of stakeholders is also considered to make the DSS more sustainable, because the DSS can gradually be improved by incorporating feedbacks from the stakeholders (users) in the iterative process, which can maximize overall satisfaction of all stakeholders. This approach is seen in many recent DSS projects for water resources planning and management, especially those for international river basin management (Geogakakos, 2007; Castelletti et al., 2007; Giupponi and Sgobbi, 2013). A DSS therefore tends to include a combination of simple and universal models with different functions for sustainable maintenance rather than a single sophisticated model in recent years.

On the other hand, advent in computer science and information technology have increased the capability of real-time water resources management. More and more data can potentially be used for real-time water resources management. They include real-time observation data of the target water system, real-time water demand data and real-time meteorological and hydrological forecast data. Although these data can be considered to be very useful in real-time water resources management, it is very challenging to handle a huge amount of data in real-time. Therefore, studies on DSSs to support operational decision making with the aid of data management technology have been conducted (Ahmad and Simonovic, 2006; Zeng et al., 2012; Sharma et al., 2015; Gourbesville et al., 2018).

4. Towards the Development of Effective DSSs for IWRM

4.1 Challenges for DSSs for implementation of IWRM

As new paradigms emerges in water resources planning and management, various decision support tools have been developed as described in the previous chapter. Important factors for successful development of a DSS for IWRM can be summarized from the literature review as:

- involvement of stakeholders from the early stage of DSS development;
- iterative development of models and the DSS;
- functions which deepen mutual understanding and knowledge sharing among multiple stakeholders for collaborative decision making;
- functions for scenario analysis which allow stakeholders to understand the response of the target water system evoked by taking each alternative, and;
- effective data management and sharing tool.

Although it is still a challenging goal to consider those key factors in development of DSSs, there are other points that has not been well covered by past studies. One issue is how to decide stakeholders to be included the planning process. Because a wider range of parties may potentially have their interests in participating the planning process for IWRM or integrated river basin management (IRBM), and it is therefore impossible to include all the interested parties in some case, it can be a difficult task to choose who should be involved in the planning process as stakeholders.

Another issue is involvement of general public in the planning process. This issue can be more highlighted in the countries like Japan where there is no international rivers and most major river systems are managed by the central government (river authority) in a coherent manner. In this case, a large information gap tend to be generated between the authority and general public in the water resources planning and management processes, because most data on water resources management is collected and managed by the authority. A support tool is therefore needed to bridge the information gap so that general public can have access to all the data needed for assessing the appropriateness of the planning for their feedback. This will ensure the transparency and accountability of decision making for water resources management, which is considered to be important for consensus building and public participation.

Besides the needs from the social aspect, one of the technical issue is estimation and consideration of uncertainty in the scenarios or effects of alternatives. This technology is especially needed when a DSS is developed for water resources or river basin planning considering projections of climate change simulation models, because projections of climate models have a large degree of uncertainty. A rational method to estimate the degree of uncertainty in the climate change scenarios is needed. A potential effective method to understand the degree of uncertainty in the climate change scenarios is to consider projections of multiple climate models (model ensemble approach). Another way to reduce the effect of uncertainty is to employ an iterative planning approach so that missing knowledge or perspectives before the decision making can be incorporated in an adaptive way in the next stage of decision making (Serrat-Capdevila et al., 2011). Although some studies started tackling to support decision making on water resources planning and management considering climate change (Serrat-Capdevila et al., 2007; Pierleoni, et al., 2014), further studies are needed to establish a holistic approach to design DSSs for integrated water resources planning considering climate change effects.

Handling uncertainty is also important for operational DSSs for water resources management considering real-time forecasts. Although a certain degree of uncertainty is inevitably contained in the hydrological forecasts, water resources management will be improved when the forecasts are adequately considered. One direction to mitigate the adverse effect of uncertainty in the hydrological forecasts is to consider ensemble hydrological predictions that consists of multiple different prediction scenarios, as its potential effectiveness can be seen in some studies (Nohara et al., 2009; Alemu et al., 2010).

4.2 DSS for water efficiency

In order to establish a good implementation of IWRM, not only water resources but also water use needs to be effectively managed. In fact, a wide range of activities in the cities or river basins is associated with water use in quantity or in quality. DSSs can also become an effective tool to support the management of water uses as a result of a variety of activities to increase water efficiency. In this case, it is important to look into activities and business processes of stakeholders (water users) in decision-making to find a room to improve water efficiency.

Although there are various stakeholders who have a wide range of activities for water uses in the river basin, Gourbesville (2011) pointed out that they can be summarized into five invariant activities: investigating/surveying, observing/ monitoring, designing, building and decommissioning, and operating. The business processes of stakeholders for urban uses can also summarized into 29 typical processes. Gourbesville (2011) also pointed out that it is recommended to identify for each business process what kind of decision support techniques can provide added value, and information and communication technology (ICT) is a natural and key solution to bridge the gaps between the potential and reality. A similar concept can also be seen in workflow oriented DSSs (Dietrich, 2007).

An example for the development processes for a DSS for IWRM considering business processes of stakeholders can be summarized as follows:

(1) Decision analysis
- Decision analysis for each water utility (stakeholder) based on their business processes;
- What kind of decisions is made when, by whom, with which time scale?

(2) Identification of required information for decision making in business processes of stakeholders
- Identification of relationship between information and decision making – who, what, when, at which stage, how (and where);
- Identification of what kind of information the stakeholders have and they can provide each other;
- Identification of what kind of information the stakeholders have and they can provide each other;
- Potential ability of information or information and communication technology (ICT) for improvement in water efficiency.

(3) Development of tools and functions
- Hydrological and hydraulic modeling;
- What-if analysis;
- Forecast information;
- Social modeling (if needed).

(4) Development of graphical user interface (GUI)
- Communication with tools and functions.

A good example of DSS architecture for water use management can be seen in Gourbesville et al. (2018). The architecture of DSS was successfully applied to the Var River basin in South France in the Aqua Var Project (Gourbesville et al., 2018; Ma, 2018). The seamless application of the DSS between operational and planning purposes is also envisaged in this project, which is needed for effective and sustainable DSSs for IWRM in the future.

5. Conclusions

In order to clarify the requirements for DSSs for IWRM, key functions of DSSs for water resources planning and management were discussed in this paper. Changes in roles and functions of DSSs were reviewed by tracing the past studies on DSS for water resources planning and management. The paper then discusses important points to be considered in the development of DSSs for IWRM in the future, including stakeholder involvement, collaborative planning, iterative system and model development, uncertainty handling, water efficiency concept and consideration of business processes of stakeholders. Further studies are needed around these directions to establish an effective DSS for Integrated water resources planning and management.

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