



## Towards New Directions in Water Resources Management - Decision Support Systems on the Web

Kazimierz A. Salewicz\*<sup>(1)</sup> and Mikiyasu Nakayama<sup>(2)</sup>

<sup>(1)</sup> Tamariskengasse 102/121; A-1220 Wien, Austria; e-mail:

<sup>(2)</sup> United Graduate School of Agricultural Science, Tokyo University of Agriculture and Technology 3-5-8 Saiwai-cho, Fuchuu-city, Tokyo 183-8509, Japan

**Abstract.** In many countries of the world the Internet and associated technologies became already element of a daily life, offering new possibilities for information access and information sharing.

On the other end, as far as the utilization of natural resources, and especially water resources is concerned, within many nations and societies there is growing conviction and concern that not only technical specialists and politicians should and can be involved in decision making processes associated with utilization of these resources. Many various groups within these societies express the willingness and desire not only to be barely inform about decisions concerning status of natural environment made by technicians and politicians, but they also voice requests to be actively involved in respective decision making processes. This situation creates many challenges not only to political and legal systems, but also creates completely new situation confronting those, who are actively involved in the creation and development of various analytical models and tools applied during various stages of the decision making processes.

Drawing from these developments the authors of the paper are reviewing the status of current trends in the area of decision support systems being created for water resources management. Consequently, the authors are presenting the capabilities and limitations of these tools with respect to their ability to provide understandable and meaningful information for broad range of stakeholders of the decision making process. In this context the capabilities and possibilities offered by Internet technologies are discussed and main methodological and technical challenges are presented. The discussion is enhanced by the presentation of the basic features underlying development of a prototype web-based decision support system that allows users to select among possible development strategies in a case study system and then to display and analyze consequences of chosen strategies.

*Key words:* decision support systems, water resources management, Internet, simulation, optimization.

### 1. Introduction

The decision making processes associated with the utilization of natural resources and water resources management fall into the category of complex situations requiring very thorough consideration and analysis. This complexity manifests itself not only through the sophistication of physical and chemical phenomena taking place in water resources systems, but primarily through very rich and multi-dimensional interactions between various types of human activities; their influence on natural systems and consequently impact resulting from the responses of these natural systems back on a human world. Complexity of phenomena taking place in water resources systems calls for application of adequate tools and methods to analyse and predict consequences of considered development alternatives and/or operational policies.

For last several decades scientists from numerous countries all over the world have been developing and implementing models and tools supporting in various ways decision making processes. The literature dealing with

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\* Corresponding author: kaz\_salewicz@yahoo.com

diverse aspects of decision support in water resources systems is enormous and exceeds by far the scope of this paper, therefore we mention here only these selected references containing representative ideas, concept and approaches applied in practice; followed by many other researchers or which contain ideas underlying reported later study: USACE 1982, 1985, 1986; Loucks and Sigvaldason, 1982; Tsvetkov et al., 1982; Fredericks et al, 1998; Labadie, 1995; Loucks and Salewicz, 1989; Lam et al. 1994; Young et al., 1997; Croke et al., 2000; Nandalal and Simonovic, 2002.

The consequences of policy alternatives considered by decision makers are interesting not only for those specialists, who are involved in design, construction and operation of water resources systems. These consequences are even more important for those, who live in the area influenced by those decisions and who sometimes may even become victims of wrong decisions. Therefore ability to perform a comprehensive and full assessment of the impact of considered decision alternatives is of paramount importance to any party involved in the decision making process. In particular, the access to information about consequences of policy alternatives is of vital importance to these groups and communities, which will be directly exposed to influence of new schemes, constructions and/or developments. The experience shows, however, that despite the importance of such information, a broad public is rarely informed in a sufficient degree about the impact of decisions to be made. There are many reasons for such situation, but the scope of this analysis goes far beyond the subject of this paper. We would like rather to note attempts and positive experiences of public involvement in decision making processes or public participation in a development of tools used then to evaluate consequences of various policy alternatives (Hare et. al., 2002 or Cuddy et. al., 2000).

As long as a model exists (or is available to the broad audience) just on a "paper" (e.g. in an academic journal), the readers are supposed to and can examine (in that paper) the assumptions made by somebody (in most case the modeller himself/herself), but they have no real possibilities to test and use the model in an interactive way.

In a case of model(s) related to important decision problems concerning a broad range of people, the stakeholders have no possibilities to "use" and experiment with such a model according to assumptions they have in mind or according to their interests, ideas and objectives.

From today's perspective such situation when anybody interested in the could make experiments with it in accordance with his interests, ideas and objectives can be described as an ideal one and currently can not and does not take place. However, with the advent and growth of the Internet technology we can envision the situation when anybody interested in a particular issue of water resources development, e.g. construction of a dam in a river system, could use a decision support system implemented on the web platform to simulate the behaviour of considered water scheme and see the outcome of models performing calculations in accordance with the interests of person performing these calculations. On the other end, the existence of a transparent model, which could be accessible to anybody interested and available on the Internet may bring a real progress with respect to improved understanding of the problem at hand, establishing basis for the facts-based dispute between parties involved and help to resolve eventual controversies. Therefore making models accessible by anybody through the Internet can bring a real breakthrough in this connection.

It is still a long way to go to achieve this situation; however the authors would like to report the efforts leading towards this direction by providing insight behind the development of proof-of-concept, "field" experiment concerning a decision support system implemented in the Web environment (DSS-on-WEB hereinafter). This study has been conducted recently within the framework of the International Waters Program of the UNU (United Nations University).

Based on the experienced gained by the authors during their direct involvement in 1980's in the implementation of the research project for the UNEP (United Nations Environment Programme) and concerning the Zambezi River Basin in the Southern Africa (Nakayama, 1997; Salewicz, 2003, and Salewicz, 1991), the authors are confident that decision/policy makers find decision support systems instrumental, if they are given a chance to have an access to such systems with appropriate guidance to make use of them. The recognition of this fact was a motivation for ideas presented in this paper and underlying development of the prototype.

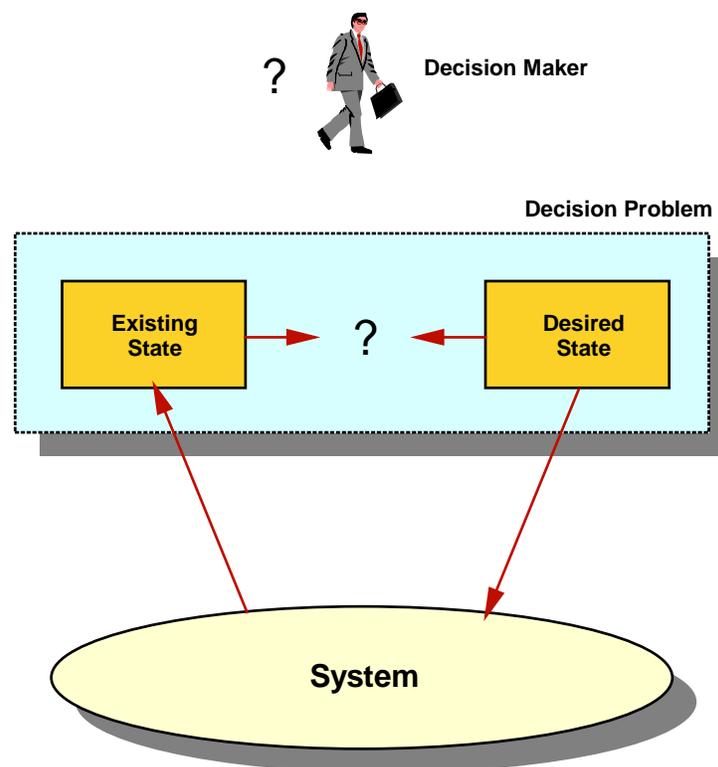
## **2. Decision problems, stakeholders and basic concepts**

The decision making associated with utilization of water resources is understood here as the process of selecting such actions influencing the behaviour of a given water resources system, which at least intentionally (to make provisions for various false or mislead decisions which have been permanently happening all over the world) should result in a better fulfilment of the goals and objectives by the water resources system under consideration. The decision making can be also understood as process of seeking the "best acceptable" solution for a specific system.

The decision making processes are taking place in a structure consisting of the following elements (see Fig. 1):

- the **system** (in our case water management system) under consideration representing material and physical reality;
- the **problem** which requires a decision. The term *problem* refers to the existence of a gap between the desired state and the existing state (Sabherwal and Grover (1989)). Consequently, the decision making process aims to fill, or at least reduce, this gap and thus solve the problem; and
- the **decision maker**, that is the person or personalized organization, who is required to decide upon the action or a set of actions which are to be undertaken in order to achieve certain objectives (fill or reduce the gap between the existing and desired state of the system). These objectives are provided by those to whom the decision maker is responsible. Most methodologies assume an individual decision maker. However, in real world situations, the decisions are usually made by a group or even groups of people representing different views, preferences, expectations, etc..

Political and social developments taking place in various countries in the world cause that the notion of single “decision maker” lost its rationale. Complex economic, social and political structures require the decisions to be made in a framework of sophisticated processes involving many stakeholders, who more or less directly participate in the decision making process. In a case of water management systems the professional and institutional affiliation of decision makers has been changing over time. As Loucks (2003) points out, giving the U.S. as an example, originally civil (mainly structural) engineers dominated river basin development, and this has led to situation where engineers involved in managing river basins must fit into a multi-disciplinary teams including ecologists, economists, environmental specialists, social scientists, water users and lawyers and regulators. The same applies to many countries all over the world.



**Fig. 1** Components of the decision making process.

What connects the above mentioned elements of the decision making structure (system – problem – decision maker) is the information, which is continuously gathered, exchanged, processed, enhanced, evaluated and used during the decision making processes. There is no clear explanation as to how the decisions are made by individuals;

why people make these and not another decisions; what information do they use while making decisions. We can only assume that the decisions can be made faster and better when decision makers are provided with the most up-to-date, possibly complete and correct information relevant to decision problem they are confronted with.

The information used in decision making process may have different forms: starting from collection of various historical data, literature, results of public opinion polls, and actual measurements of physical system's parameters up to forecasts and simulation results of computations showing consequences of considered decision alternatives.

Depending upon concrete decision situation, the information requirements and needs expressed and/or perceived by the stakeholders in the decision making process can be very different. As the experience shows, it is impossible to specify beforehand what information is necessary and sufficient to make good decisions. Usually the process of decision making goes together with a learning process. In a framework of learning process the stakeholders make decisions based on information available; learn about their impacts and consequences and then make further decisions influenced also by the new knowledge and information they have gathered. Consequently, in a repeatable process they enhance their knowledge and understanding of the decision problem and also identify needs for new information and new types of information (at first some numbers characterizing certain properties, then time series of data describing the same properties, then graphical representation of these data, and so on). Information needs and requirements are therefore growing together with the growing understanding of the problem at hand.

Consequently, together with the growing complexity of the decision making problems there are growing demands and challenges concerning tools used to provide information and to support decision making processes.

The methodological framework underlying the process of searching for solutions (decisions) of the decision problem is offered by the scientific discipline called *systems analysis* (see Sage and Armstrong, 2000), which evolved through parallel developments in mathematics, engineering and economics. As the system analysis has been becoming more mature in recent decades, its applicability in water resources planning and management has been also constantly growing and currently it is impossible to imagine water resources management without methods and tools offered by the systems analysis.

As the practice shows, real life decision making problems only very rarely, if at all, boil down to solving clearly-cut optimization problems. The search for solution of the decision problem involves complex patterns of using optimization and simulation models of the system under consideration in order to find feasible and satisfactory values of decision variables (controlled inputs) in a framework of decision making processes. The system model, consisting very often of many sub-models and components, must also encounter for the presence of uncontrolled inputs influencing the system at hand. The information about these uncontrolled inputs is usually available in a form of forecasts or historical and/or generated time series representing the most significant uncontrollable inputs.

Intuitively perceived and already mentioned complexity of the decision making processes associated with utilization and management of water resources calls for use of tools capable to mirror the complexity of problems under consideration. On the other side these tools have to be capable to cope efficiently with the multiplicity and amount of information which has to be processed during decision making. The capability to process relevant information must be accompanied by the capabilities to present this information to the user and consequently, to decision maker. These capabilities are provided by Decision Support Systems.

### **3. Decision Support Systems – basic concepts**

Decision Support Systems can be defined as computer technology solutions that can be used to support complex decision making and problem solving (see Shim et. al, (2002)). Although this definition applies very well to decision making in many purely technical areas, it falls short to reflect one, extremely important aspect of the decision making process in water resources systems: the role of human factor.

Due to very complex nature of water resources management problems; lack of consistent and complete data; uncertainties and ill-structured form of decision problems, the process of finding decisions can not be limited to solving mathematical optimization problems or performing complex simulation. Therefore we will understand the decision support system as a set of computer-based tools that provide decision maker with interactive capabilities to enhance his understanding and information basis about considered decision problem through usage of models and data processing, which in turn allows reaching decisions by combining personal judgement with information provided and processed by these tools.

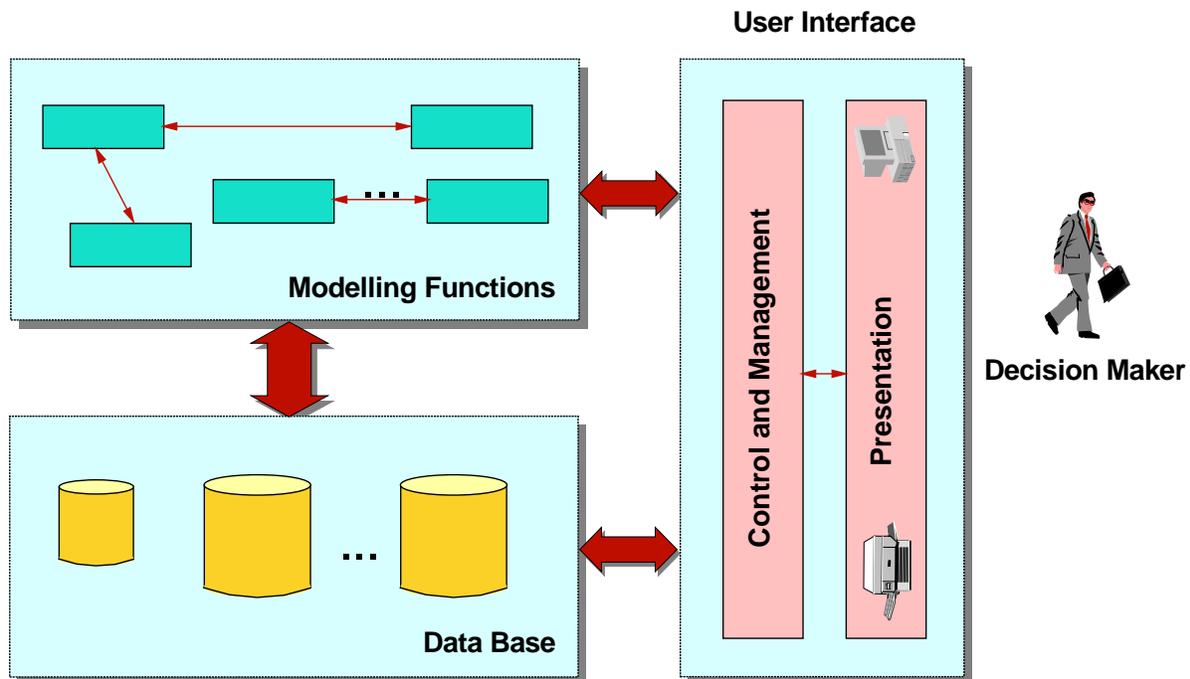
The term DSS was born in the early 1970s. DSS have evolved from two main areas of research: the theoretical studies of organizational decision making conducted at the Carnegie Institute of Technology during the late 1950s

and the technical investigations carried out at Massachusetts Institute of Technology in the 1960s (see Keen and Morton, (1978)).

Classic DSS tool design, as shown on Fig. 2, is comprised of the components for:

- database management capabilities with access to internal and external data, information and knowledge;
- powerful modelling functions accessed by a model management system; and
- user interface designs that enable interactive queries, reporting and graphic functions.

This view on decision support systems concerns their technical architecture and building blocks, which have to be incorporated into design and development of DSS.



**Fig. 2** Main building blocks of the Decision Support System

The classical DSS architecture contains these three basic components. Another, complementary way of looking at the DSS is associated with the role and functions that DSS have to fulfil (Parker and Al-Utaibi, (1986)), as seen from their user's perspective:

- they assist managers in their decision processes in semi-structured tasks;
- they support and enhance rather than replace managerial judgement;
- they improve the effectiveness of decision making rather than its efficiency;
- they attempt to combine the use of models or analytical techniques with traditional data access and retrieval function;
- they specifically focus on features which make them easy to use by non-computer people in an interactive mode;
- they emphasize the flexibility and adaptability to accommodate changes in the environment in which the decision maker acts and the decision making approach of the user.

Very important aspects associated with the development and creation of any meaningful DSS concern the ability of this tool to efficiently communicate with its users.

Traditionally, mathematical models and various forms of decision support tools and systems incorporating these models have been developed by analysts and modellers for the same type of audience. Therefore it was not necessary

to pay any special attention to design and implementation of user-friendly interfaces between the tool and its user. This state has been continued for years and contributed, in fact, to creation and growth of the gap between modellers and analysts on one side and decision makers, not to mention general public, on another side. As long as decisions were taken by a narrow circle of specialists, the awareness of this gap was not so dominating and was not perceived as something meaningful.

The situation became much more complicated, when these tools began to be used not only by a limited range of modellers and analysts, but when other, less technically-minded and less technically experienced groups of users emerged and voiced the request the right and will to use these tools to secure active and informed participation in the decision making process. This caused necessity to spread the development efforts between two areas:

- substantive, concerning the phenomena and processes to be modelled (analysed); and
- communication, securing proper exchange of information between the model(s) and various types of users.

Actually, one of the biggest challenges of the DSS in facilitating access to information by a broad spectrum of stakeholders is associated with the fact, that available information must directly address their concerns and information needs.

#### **4. DSS for water resources management**

The technical and technological developments taking place in the domain of systems analysis and information technology have been causing significant progress and developments taking place in the field of hydrology, water resources management, environmental and decision sciences. The evolutionary process of developing models and tools for water resources management, taking place over a number of decades, has been very closely reflecting the progress in a domain of mathematical modelling, linear and non-linear optimization, stochastic modelling, programming languages and data processing.

This significant progress is extensively documented in a very rich literature dealing with this subject. The multiplicity of works and publications causes that even very superficial review of major publications exceeds the scope and space limitations of this paper. The progress has witnessed development of various approaches and tools, sometimes reflecting even certain “fashions”, nevertheless some of the models and tools created even recently are build upon still valid notions and concepts underlying operation of water resources management and multiple reservoir systems, like storage zones and rule curves (Loucks and Sigvaldason, 1982), which were conceived many decades ago. A lot of fundamental work has been done at the Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers at Davis, California, where a number of models and decision support tools have been developed, such as:

- HEC-1 Flood hydrograph package;
- HEC-2 Water surface profiles model (USACE, 1992);
- HEC-3 Reservoir systems analysis model (USACE, 1985);
- HEC-5 Reservoir operation simulation model containing water quality components (USACE, 1982 and 1986);
- HEC-RAS River analysis system containing graphical information systems extensions (USACE, 1995); or finally
- Decision Support Systems utility programs and components (USACE, 1987).

The programs and decision support tools developed by HEC, like many other tools which have been developed for supporting decision making processes, have been designed for use on powerful computers in a batch mode and did not allow (at least in the first years of the development and operation) for any form of interactive data input and operation. They were specifically designed for use by highly specialized professionals and did not provide any possibilities that would allow for their usage by less technically minded audience and user circles.

With the advent and gradual expansion of Personal Computers and powerful work stations there have been also created possibilities and capabilities for creating flexible and easily transferable tools suitable to work interactively with the user. There exists currently plethora of various models and tools, which have been developed and applied in many countries all over the world.

Very rich information about various models and decision support tools can be accessed using Internet. The following addresses can be recommended as valuable reference sources of information or as a starting point for further investigations concerning availability and access to models and decision support tools:

- The USGS Surface-Water Quality and Flow Modelling Interest Group: [http://smig.usgs.gov/SMIG/archives\\_commercial.html](http://smig.usgs.gov/SMIG/archives_commercial.html);
- Selected World Wide Web Sites For The Water Resources Professional containing numerous links to important water-related web sites: <http://www.wrds.uwyo.edu/wrds/wwwsites.html>;
- Land and Water Management site of the Delft University in Holland: [http://www.ct.tudelft.nl/wmg\\_land\\_water/](http://www.ct.tudelft.nl/wmg_land_water/);
- An Inventory of Decision Support Systems for River Management: [http://www.geocities.com/rajesh\\_rajs/inventory.html](http://www.geocities.com/rajesh_rajs/inventory.html);
- Environmental Organization Web Directory – claiming to be the earth’s biggest environmental search machine: <http://www.webdirectory.com/>;
- Decision Support Systems Resources: <http://www.dssresources.com/>; or
- Inventory of water resources management and environmental models: [http://www.wiz.uni-kassel.de/model\\_db/models.html](http://www.wiz.uni-kassel.de/model_db/models.html).

## 5. Internet technology and conceptual aspects of DSS design

Unlike traditional DSS implemented on single computer or available on the network, where user (decision maker or stakeholder) has an account and direct access to all components of his system, the development and usage of DSS in the Web environment is associated with many conceptual and technical problems.

In a case of the DSS implemented on a single machine or in a network, the user of DSS has access to all resources of the machine and the DSS available either through operating system or through the user interface to the decision support systems. In the latter case the capabilities of the user interface are also very strongly relying on the operating system. The access to resources concerns not only physical resources of the computer, such as disk space, memory, printers, etc.. The user working with the DSS in an interactive mode may also access and manipulate models built into the DSS and their parameters; may “activate” or “deactivate” certain components of the system model, change preferences, select display or printout alternatives. Data used by the DSS can be accessed and modified to allow user to explore various situations and scenarios. Results obtained by the user can be stored for further use; working sessions can be suspended and then started again without losing information and data created during commenced sessions.

In a case of Internet the situation is significantly different: the user is accessing the Web through special program called browser, which does not offer capabilities of the operating system. Also capabilities of the user interface of the standalone DSS are not available to the browser, unless special interfaces have been developed to connect DSS with the Internet functionality. The Web user accessing certain Internet address may use resources and capabilities offered to him only in a range and to the degree defined and controlled by the owner of a particular Web page. It means, in particular, that direct Internet implementation of a DSS created for operation in a traditional environment is impossible without significant programming and development efforts involving usage of sophisticated and expensive components of Internet technology.

Client computer, where the browser is installed and which allows user to communicate with the server hosting particular Web page or site, is connected with the Internet through low-end communication and/or telephone lines with quite often relatively low transmission rates (especially in developing countries). It causes, that the time needed to load one page or to obtain response to action/choice made by the Internet user can be relatively long (taking even minutes), not to mention time necessary to perform computations on the server side. Therefore all operations related to data input and display of results produced by the DSS have to be optimized for high efficiency and speed of the data transfer.

The communication between the client and server has form of exchanging messages between client and server (client’s request to the server and server’s response to the browser). The Hypertext Transfer Protocol (HTTP) used on Internet has no mechanism for keeping information about previous requests or storing information about the current request. Consequently, unless special and advanced Internet technologies are used on the server side, the Internet user has no direct possibilities to store on the server intermediate results of his work for further use during future interactive sessions. Also capabilities to store on a client side intermediate information created during Internet session are limited to possibility of saving data files downloaded from the Internet, which is not sufficient to use this information again on a server side. These factors cause additional conceptual and technical difficulties associated with the Internet implementation of existing (legacy) models and tools. As a result of it either direct implementation

of these legacy solutions in Internet environment is impossible or it requires massive changes, modification and development effort.

The distribution of computing power available in Internet environment can be described by two models (concepts), namely (Salewicz, 2001):

- (i) thin client and thick server concept, or
- (ii) thick client and thin server option.

Thin client and thick server concept means such implementation of the DSS, where user of the model or DSS is connected to Internet and his PC acts as communication terminal only, allowing to enter in an interactive mode certain data (decisions and/or parameters chosen among available alternatives), send them to the server, initiate data processing on the server side and then display results of the computations performed on a remote computer (server) as received from the server. All models and data base are residing on the server and also all computations are performed on the server. Implementation of this concept means that amount of data to be transferred back and forth between the server and the user's computer (client) is relatively low. The data is transmitted in "portions" stepwise from client to the server after each action is initiated on the client side or from server to the client following computations taking place on the server side.

Implementation of such solution requires dynamic usage of the Internet pages and is associated with significant programming effort necessary to secure efficient communication and data exchange between web pages as seen on the browser side and computational models and data processing taking place on a server side. A number of specific technologies can be used here (see Orfali, Harkey, and Edwards 1996), but all of them are make extensive use of Java programming language (Flanagan, 1999) and Java technology, which are not so popular and well known among specialists in water resources management discipline.

There are a number of advantages associated with the concept of thin client and thick server. Relatively low amount of data which has to be transmitted is particularly important for users from countries, where the telecommunication infrastructure (transmission rates) is not very highly advanced and not very reliable. Another advantage of this solution is associated with high security and consistency of data and models: since both critical data and models are residing on the server, they are protected from manipulation and unauthorized changes and modifications, which could be undertaken by users. Such changes in extreme cases may lead to abuse or even fraud.

Very positive feature of this concept is that such DSS can be built using already existing simulation and/or optimization models developed in traditional programming languages like FORTRAN, C, etc., limiting therefore programming effort associated with the implementation.

The disadvantage of this concept is associated with very heavy computation burden and data loads on the server side, which requires installation of very powerful machines acting as servers, especially when access to the DSS by many concurrent users is considered.

Second option, namely thick client and thin server means, that the user's PC is used not only as a data entry and display terminal, but also as a platform to perform all computations using programs and data downloaded from the server. This option represents in fact classical concept of Internet as the means for accessing information stored somewhere in the web. From the implementation point of view it is much simpler solution based making use of simple static web pages.

In this case the role of server is reduced to the repository of executable codes of all components of the decision support system and eventually data sets that can be used with it. This approach is quite popular for dissemination of information and models, and a number of solutions or DSS can be downloaded (at least in a trial version) by anybody interested (see for instance reservoir management tool BayRes described by Palomo et al., 2002; or such decision support system as ModSim, which has been described by Labadie, 1995 or Fredericks, Labadie and Altenhofen, 1998).

The possibility to download and then use models or even particular DSS to address specific issues and decision problems is very attractive, especially to professional and scientific communities in many countries (not only developing ones), since it gives easy and free access to tools already developed or access to alternative solutions that may enhance capabilities of tools already available at hand. However effort necessary to download these tools, install them and then learn how to use them and how to resolve problem at hand seems to exceed interest and devotion of the average representative of so called "public opinion". Therefore this form of providing access to models and decision tools is relevant for professionals and scientists, but not for wide audience.

If the DSS tools can be freely downloaded, there is also a risk that the usage of downloaded models and/or DSS can be subject of abuse. Such development is plausible in a case of controversial problems or decisions (concerning for instance international disputes), when one party, for some unethical or politically motivated reasons, presents results supporting its position and obtained (or even "prepared") without using particular and usually highly

appreciated tool downloaded from the Internet, but claiming at the same time that these results have been obtained with the help of the said tool. In such cases it might be very difficult to prove the wrongdoing and the burden of proving that may fall on the authors of the model. Moreover the reputation of the DSS or its authors unintentionally involved in such abuse may be significantly damaged.

## 6. Internet-based implementation of decision support system

Following the idea of creating “DSS for everybody”; to explore technical possibilities and challenges, and to prove the feasibility of developing decision support system using capabilities of Internet technology, the authors have initiated research aimed at creation and implementation of a prototype (pilot) installation of the DSS on Web. This research was based on technical concept of the “thin client and fat server” and has been built upon following assumptions concerning usage of the DSS and characteristics of the decision problem:

- Target user of the DSS is a non-professional individual representative for a public opinion;
- Prospective user of the DSS is interested in assessing consequences of certain policy expressed in terms of clearly identified alternative actions;
- Actions associated with the policy are preferably formulated in qualitative terms (that is verbally and characterizing properties of the policy, such as low, medium and high level of intensity) and not in quantitative terms (such exact numeric values of policy parameters / decision variables) ;
- The user has no experience in mathematical modelling and has no desire to learn about specifics of any mathematical models and tools;
- The tool should allow for a simple selection among available alternatives and present consequences of selected decisions in a meaningful way allowing for easy interpretation of results;
- Time interval between formulation of the query (question) and obtaining response should be minimal, which means that user queries and model responses should be available in an on-line mode.

Since our study had to combine two components: address problems of water resources management interesting for a broad public, and develop a prototype (pilot) version of the DSS on a Web, the initial efforts were directed towards selection of an appropriate case study system, which:

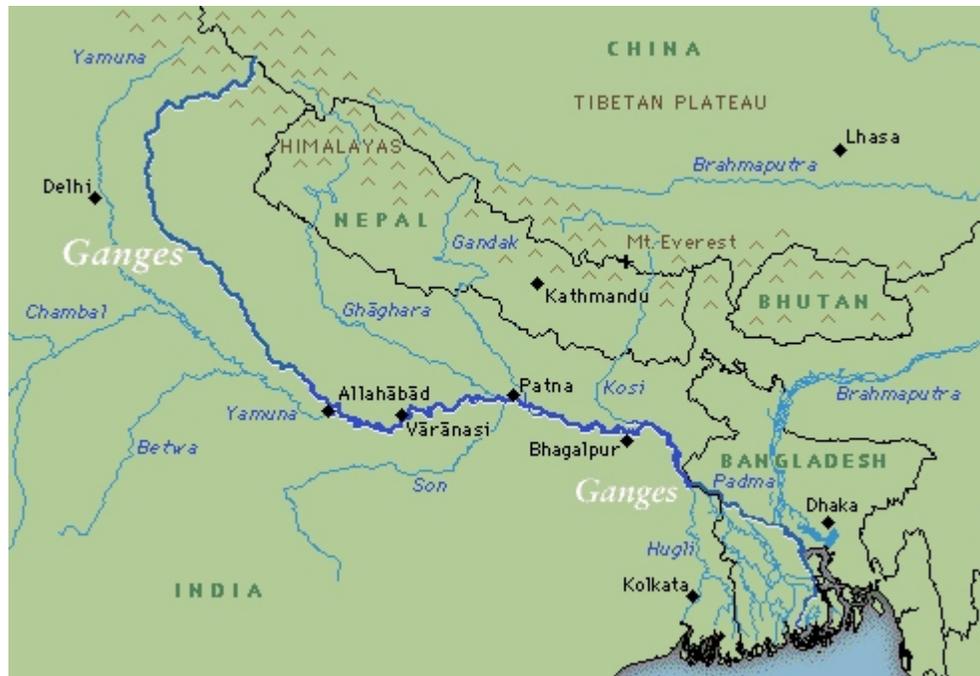
- potentially could attract significant audience;
- concerns controversial issue (possibly international) involving conflicting objectives and interests;
- has been described using sound, verified and viable modelling techniques;
- has been analysed and modelled by objective, unbiased and independent specialists, who are not involved in the controversy.

Extensive search lead to selection of the Ganges River case study (see Fig. 3), which has been subject of extensive research performed at the Center for Spatial Information Science, University of Tokyo (see Ministry of Land, Infrastructure and Transport, (2001)).

The case study deals with analysis of impact of agricultural and urbanization policies applied in India. The agricultural and urban development policies chosen by India have direct impact on the amount of water in Ganges River flowing into Bangladesh. Taking into account a lack of cooperation between these two countries (see Biswas and Uitto, (2001)) and mutual distrust, the availability of un-biased, independently developed model and DSS capable to analyse consequences of selected policy options could help both sides to establish common basis for the discussion and evaluation of plausible alternatives.

In a case of selected system, the relevant strategic policies considered in India concern the following decision variables:

- Length of the Ganges River stretch in India over which the agricultural and urbanization policies will be implemented;
- Intensity of the changes in land use patterns in the area covered by this stretch; and
- Intensity of the urbanization changes over the area considered.



**Fig. 3** Map of the Ganges River Basin.

These policies can be precisely described in quantitative terms using precise values of above mentioned decision variables and then the response of the system can be simulated for each selected combination of these values. However, one run of the simulation to calculate the response of the system to selected policy alternative may require even few hours of computations (Rajan, 2002). This property of the model could be seen as its disqualification at least as far as the usage of the model in Internet-based, interactive decision support system is concerned, since only on-line operation mode of the DSS is acceptable for the user.

Taking also into account fact, that the average user of the model has not enough knowledge and experience to experiment with selection of precise numerical values of decision variables, we had to look for another approach.

This approach is based on the concept of qualitative qualification of decision variables: feasible range of every decision variable has been divided into small number of intervals. With all values of the decision variable belonging to certain sub-interval there have been associated one single, qualitative attribute characterizing this range in descriptive terms (i.e. low, medium, high). Such process of qualitative categorization of decision variables can be performed based only by an expert and is based on a very thorough sensitivity analysis and knowledge of models used to calculate the impact of policy parameters (Rajan, 2002).

Based on this categorization concept, the following set of feasible decision variables (expressed in descriptive that is qualitative terms) has been determined (see Fig. 4):

- Length of the area upstream of the Harding Bridge where changes to the land use policies will be introduced has been divided into three categories:
  - Changes on the stretch shorter than 100 km (representing small scale of changes);
  - Changes on the stretch between 100 and 200 km (equivalent to medium scale of changes) ; and
  - Changes on the stretch longer than 200 km (large scale of changes).
- Intensity of change in land use patterns has been divided into four categories:
  - Shift in the cropping pattern from the current one to more intensive;
  - Shift from current pattern to less intensive;
  - No change in the land use pattern (retain current conditions); and
  - Increase an irrigation command area, which is equivalent to creation of bigger farms.
- Intensity of the urbanization changes over the considered area has been three alternatives:
  - No changes to current density of the population;

- Increase of the population density by up to 50 %; and
- Increase of the density by up to 100 %.

**Fig. 4** Example screen layout used for selecting parameters of the strategic policy alternative.

Consequently, the user who wants to see the consequences of changes in land use policy in India selects respective combination of policy parameters expressed in descriptive terms as defined above. It is worth to note, that if another set of decision variables (policy parameters) would be selected or if the feasible ranges of decision variables would change, then the whole process of performing sensitivity analysis and categorization of decision variables would have to be repeated and another set of simulation results would have to be calculated.

The impact of the policy alternative may be different depending upon natural climatic conditions characterized in this region of the world by monsoon. Also in this case a qualitative description of climatic conditions has been used: the impact of land use policy is analysed using three alternative scenarios of climatic conditions extending over one year long time horizon for: average, better than average (more rainfall) and finally worse than average (less rainfall) meteorological conditions.

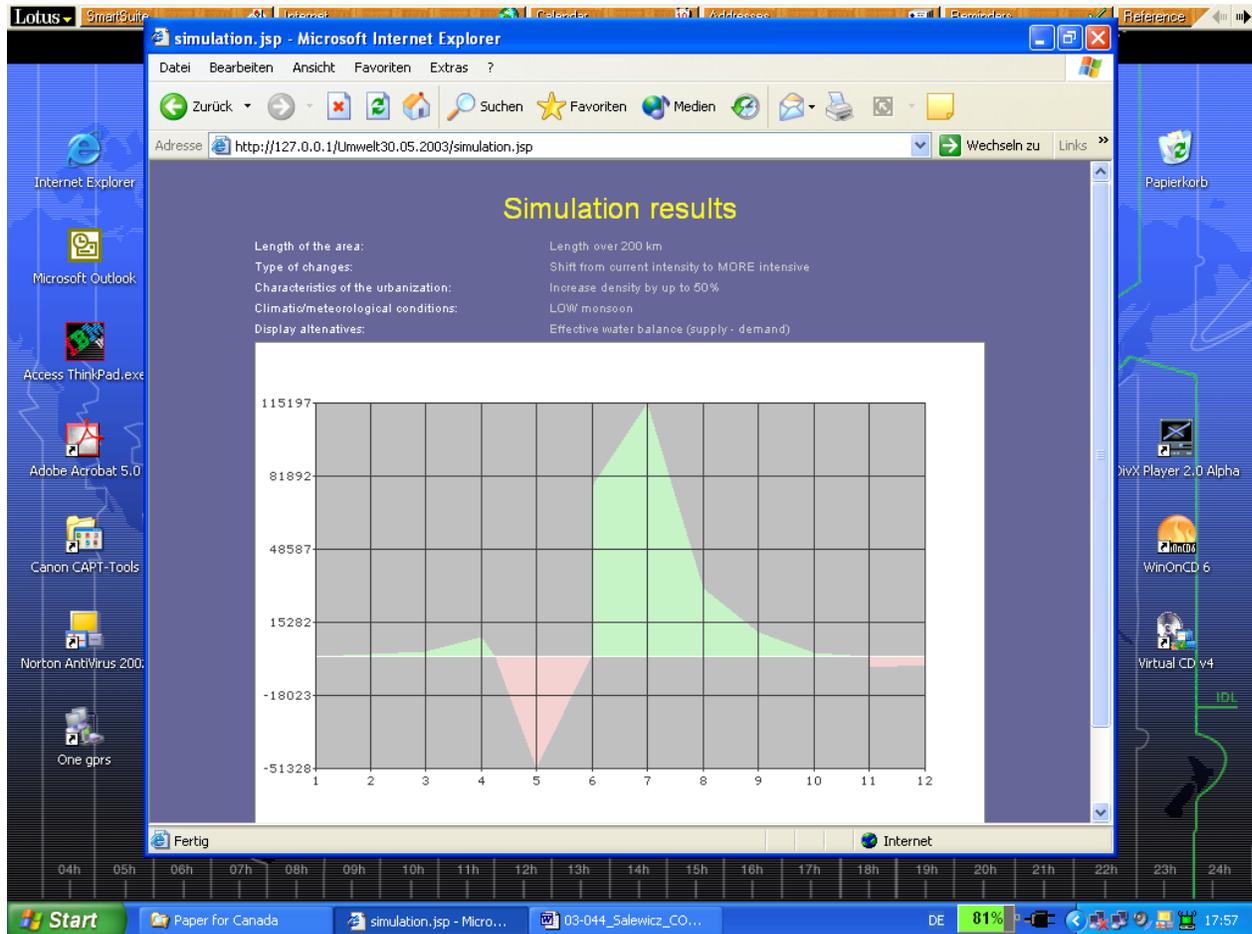
The response of the natural system to all distinguished variations of decision variables and climatic conditions has been calculated off-line and results of these computations are stored in a simulation results data base accessible to the user through consecutive steps of the dialogue between the user and the DSS performed in Internet environment. The impact of selected policy alternative is represented by the monthly time series of the following indicators (see Fig. 5):

- Normal water demand, that is the demand on water associated with currently used and unchanged conditions of the land use in the area of interest (upstream of the Harding Bridge);
- Expected water demand, which is represented by the values of water demand calculated for the selected combination of decision variables;
- Normal water supply equal to flow rate at the Harding Bridge cross-section calculated for current (unchanged) land use conditions; and
- Expected water supply equal to flow rate at the point of interest calculated for user-selected land use policy.

In addition the user may also select two other impact indicators, which are derived from values defined above, namely:

- Difference between water supply and water demand calculated by the simulation model for unchanged land use conditions; and
- Difference between water supply and water demand calculated for selected land use policy options.

Time series showing average monthly values of selected impact indicators over 1 year long time horizon are presented to the user in a form of graph, which can be also printed-out on the printer attached to the PC used to communicate with the DSS. The user may repeatedly change parameters of the policy, climatic conditions and impact indicators and then see resulting values, compare them and analyse.



**Fig. 5** Example screen with display of simulation results.

The system offers also to the user capabilities to communicate with the developers of the DSS. The feedback is provided in a form of free text message, which can be composed and send back. In order to obtain more specific feedback information from the users of DSS, they are also asked to respond to a number of questions concerning:

- Country where they are coming from;
- Their professional background and affiliation;
- Opinion about information which should be presented in visual form; and
- Their general opinion about the usability of the system.

Answers to these and eventually further (modified) questions serve as the basis for improvements of the system and help developers to better understand reactions of the broad public to tools like this one. Consequently, materials and experiences collected in the framework of this study will allow not only improving this particular (prototype)

system, but also will provide basis for improvements of the concepts underlying development of this prototype system and for formulation of future research agenda.

## 7. Summary and conclusions

Through the development and implementation of the pilot Web-based decision support system addressing selected issues of land use policies in the Ganges River Basin we have demonstrated feasibility of the type of research and development efforts. The experiences collected during the development process clearly show challenges, which one has to face while developing real-time, Web-based decision support systems. These challenges concern among others:

- efficient handling of large amounts of data necessary to perform computations (simulation or optimization);
- User-controlled manipulation of the policy and model parameters;
- Availability of computationally efficient and sufficiently exact models calculating consequences of selected policy alternatives;
- Selection and efficient application of available technological solutions.

Apart of technical and technological challenges, which do not seem to be critical (currently available vast technical and technological capabilities do not seem to constitute the main barrier for developing user-friendly and viable decision support tools) further progress in ability of scientific community to support public participation in decision making processes is associated with the “soft” side of development and application. One of the most important difficulties concerning application and acceptance of these tools concerns their ability to “communicate” with a broad circle of users and stakeholders. In order to achieve progress in this area, the tools and models have to provide right, correct and meaningful information to those involved in decision making processes. The information presentation must be improved to allow users grasp and quickly understand important aspects and implication of considered policies and alternatives. As experience demonstrates, very significant aspects in improving form of the presentation and their relevance to problem at hand can be addressed during joint development of decision support tools, when together with analysts and modellers also users work together in building tools understandable and acceptable to all parties involved (see Cuddy et. al, 2000). Cultural and social aspects associated with development and usage of DSS tools have noticed and are currently subject of research efforts (Lai Lai Tung and Quaddus, 2002).

Environmental disputes and conflicts concerning usage and sharing of natural resources can be solved in a framework of long and complex processes, where formal tools and models can contribute to the growths of mutual understanding and objectification of dispute by providing all parties with actual, correct and verifiable information. Particularly important role can be played by all efforts and developments, which are associated with the usage and popularization of Internet technology and Web-based tools and information sources. These efforts should be twofold: low cost initiatives associated with creation and expansion of “traditional” Internet sites providing free and possibly unlimited access to information, data, and literature and models to be downloaded; and - on another side - relatively expensive efforts aimed at creation of Web-based decision support systems. Such systems could be created by international organizations to provide independent, unbiased and objective tools capable to address controversial issues arising between two or more countries in order to establish communication and discussion basis helping in resolving the controversies.

As we see, the realization of the advocated here vision of “DSS for everybody” is still remote, nevertheless through the development of the prototype implementation we have demonstrated the feasibility of this approach and created foundations for further efforts in this direction. The materialization of the vision requires however a lot of commitment and support not only from the scientific community, but also from the side of international organizations and policy makers confronted with specific situations.

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**Kazimierz A. Salewicz** was born in Poland in 1952 and studied at the Warsaw University Of Technology, Department of Electronics, Faculty of Automatic Control, obtaining a Masters Degree in 1976 and PhD in 1983, both in Control Engineering. He has been involved in research concerning water resources management in inland and international river basins, development of decision support systems, risk management, and mathematical modelling of water resources systems. He has managed a number of research and commercial projects, including international studies, and has organized international conferences and symposia. He was a Senior Fulbright Scholar at Cornell University, Ithaca, NY, 1985-1986. He has worked for the Institute of Meteorology and Water Management, Warsaw, Poland; the Institute of Geophysics, Polish Academy of Sciences, Warsaw, Poland; the International Institute for Applied Systems Analysis, Laxenburg, Austria; and the Strobl Gruppe, Voesendorf, Austria. Currently he works for leading world IT provider in Austria. He is an author and co-author of over 40 publications and has received three scientific awards.

**Mikiyasu Nakayama** is the Associate Dean and Professor of the United Graduate School of Agricultural Science, Tokyo University of Agriculture and Technology, Japan. He received his BA (1980), MSc (1982) and PhD (1986) from the University of Tokyo. He served as a programme officer in the United Nations Environment Programme (UNEP) between 1986 and 1989. In UNEP, he participated in projects relating to such international river bodies as the Zambezi River, Lake Chad, and the Mekong River. From 1989 to 1999 he taught water resources management and its international and environmental aspects at the Utsunomiya University. He has also served for several United Nations organizations (UNEP, UNCHS, UNCRD, and UNU), as well as for non-governmental organizations such as IUCN and ILEC. He participated in UNEP's environmental management project for Aral Sea between 1990 and 1992. He is interested in the environmental monitoring and management of river and lake basins. His research

subjects include (a) the application of satellite remote sensing data for environmental monitoring of lake basins, (b) use of Geographical Information Systems (GIS) for environmental management of river and lake basins, (c) environmental impact assessment methodologies applied to involuntary resettlement due to dam construction, and (d) involvement of international organizations in the management of international water bodies.