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Decision Support System for Integrated Reservoir Management in India—Need, Concept and Framework

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ABSTRACT: Typical goals of water resources managers include maximizing the benefit due to use of water for municipal and industrial uses, crop and energy production, recreation, environmental and ecological improvement; and minimizing the negative impacts such as flood, water logging, water quality degradation, land submergence and population displacement. Sometimes, the decision making becomes difficult while achieving multiple objectives. A Decision Support Systems (DSS) is a tool intended to provide timely, valid, and sufficient information to the decision makers for solving relatively large and unstructured management problems. Integrated reservoir management can be best achieved by having a system to support the process of decision making. Such a DSS may consist of the modules for database handling, simulation, optimization, and statistical analysis, and capabilities for analyzing and displaying the results in a unique and user-friendly framework. This paper presents a framework for the development of a DSS for integrated reservoir management. The paper advocates that the design, development, and implementation of effective DSS brings together disciplines, people, and institutions necessary to address today's complex water resources challenges.

INTRODUCTION

A Decision Support System (DSS) is an integrated, interactive computer system, consisting of analytical tools and information management capabilities, designed to aid decision makers in solving relatively large, unstructured water resource management problems. It is a set of tools that helps in effective decision making such as data, models and software interfaces. A typical DSS has following characteristics:

- Assist managers in their decision making process,
- Support and enhance managerial judgment,
- Improve the effectiveness of decision making rather than the efficiency,
- Combine the use of models or analytical technique with data access functions,
- Focus on features, which make them easy to be used interactively by inexperienced users.

A comprehensive DSS would provide a better means for organizing, accessing, and evaluating a wide range of information and alternative strategies. Benefits from such a DSS include better access to information, improved evaluation tools, enhanced communication, and better project management.

Decision Making in Water Management

In real life situations, multiple objectives can complicate the task of decision-making, especially when the objectives are conflicting. A DSS helps the decision makers by considering all the objectives and then evaluating options to identify a solution that best solves an explicit problem while satisfying as many objectives as possible. A DSS helps to collect, organize and process information, and then translating the results into management plans that are comprehensive and justifiable.

A DSS is much more comprehensive than traditional methods of decision-support. Further, DSS recommendations are based on scientific data and models and can account for multiple objectives, cause/effect relationships, risks and reliability, and economical aspects whereas traditional decision processes have difficulty aggregating all these considerations. A comparison of the conventional techniques of decision making and the DSS approach is given in Table 1.

DSS has many useful applications in water resources planning and management as water resources managers have diverse goals, including environmental, economic, and ecological interests. The decision making becomes difficult in achieving numerous and often conflicting objectives, such as achieving peak sustainable yield, minimizing adverse environmental impact, managing costs, maintaining adequate water quality, controlling floods, minimizing energy use, and providing recreational opportunities. A DSS can be used to develop water resources management plans, adaptable operating rules for water and wastewater systems, and regional policies. Many municipalities and water authorities often derive their water supplies from several sources, which may include surface reservoirs, rivers, groundwater wells or combinations of these sources. To identify the best combination of supply sources in the long term or to determine the most effective way of managing existing systems, decision-makers need a lot of information to account for all the hydrologic, hydraulic, water quality, and economic relationships within the system and DSS applications here can be very helpful.

Table 1: Water Management Decision Making

Conventional Way	*DSS Way*
• Uses less data • Decisions may be based on poor quality data • Data are used with time delay • Point-oriented approach • Analysis is manual • Less/no transparency • Model application is tedious • Less participatory	• Can use large quantity of data • Data of better quality is used • Real time data can be used • Spatial approach can be easily adopted with remotely sensed data • Analysis is computer assisted • Transparent system • Model application is easy • More participatory

DEVELOPMENTS IN DSS APPLICATIONS IN WATER RESOURCES

Andriole (1989) defined a DSS as a system consisting of any and all data, information, expertise or activities that contribute to option selection. An alternate definition was offered by Adelman (1992) who defined a DSS as an interactive computer program that utilizes analytical methods, such as decision analysis, optimization algorithms, program scheduling routines, and so on, for developing models to help decision makers formulate alternatives, analyze their impacts, and interpret and select appropriate options for implementation. The key idea common to these definitions is that a DSS integrates various technologies and aids in option selection for solving relatively large, unstructured problems.

Interactive computer technologies and DSS for studying water resources problems began to appear in the mid-1970's and have been discussed in the water resources literature since the mid-1980's. An excellent overview of the work up until the beginning of the past quadrennial was given by Loucks and da Costa (1991). In the early 1990's, a major technology shift occurred from mainframe-based DSS to client/server-based DSS. Some desktop tools were introduced, and during this period the existing network infrastructures were upgraded.

Simonovic (1992) reviewed systems analysis techniques for reservoir management and stated that a significant gap still exists between theory and practice. He proposed the integration of new technologies, e.g., expert systems, with existing simulation and optimization models as a means of closing that gap. With a clue from this work, Djokic (1993) made a strong case for the use of commercially available software within a spatial DSS shell. He argued that the one-time effort of developing interfaces between the software components would require much less effort than customizing existing or writing new software. Similarly, Chang *et al.* (1993) introduced a DSS for the Management of the Irrigation Schedule (DMIS) at field level of medium to large scale irrigation schemes. It was reported the DMIS is an effective tool suitable for the management of the parcel-based irrigation schedule of medium to large-scale irrigation schemes. The Geographical Information System (GIS) was used with DSS for supporting model based scenario analysis in DSS, since it can be used not only for information management but also for spatial analysis and the visualization of model output.

From 1995 onwards the different tools namely fuzzy, ANN, and fuzzy-Nero, respectively and web-based techniques were applied in DSS (Power, 2000; Bhargava and Power, 2001). An integrated DSS was developed by Arumugam and Mohan (1997) to assess the decision making using five years data. It was reported that shortages in irrigation water supplies simulated from the DSSs were less than those occurring in actual operation practiced by water authorities. Later, Hasan *et al.* (2000) reported the application of a DSS in Jordan, specifically to manage and operate the irrigation water demand and supply of the main water carrier the King Abdallah canal in the Jordan valley. A DSS for multi-reservoir system operation of Upper Yellow river basin in China was developed by Yangbo Chen (2004). Similarly, Huang and Yang (1999) developed a DSS for reservoir operation in Taiwan. More recently Koutsoyiannis *et al.* (2001) and Westphal *et al.* (2003) have developed user tools for use in reservoir operations management problems for specific cases.

RESERVOIR OPERATION PRACTICES IN INDIA

Because of the high temporal and geographical variability of rainfall, reservoir operation occupies an important place in the utilization of water resources. In India, the reservoirs are normally operated based on rule curves. It is assumed that a reservoir can best satisfy its purpose if the storage levels specified by the rule curve are maintained in the reservoir at different times. A rule curve, as such does not give the amount of water to be released from the reservoir. The rule curves are generally derived by operation studies using historic or generated flows and implicitly reflect the established trade-off among various project objectives in the long run. The operation of a reservoir by strictly following the rule curves becomes quite rigid. Many times, in order to provide the flexibility in operation, different rule curves are followed in different circumstances. These rule curves can be fine-tuned using different techniques to achieve the targets to the maximum possible extent.

Several methods offering a wide range of choices and solutions are available. The system analysis techniques can be grouped in to optimization methods and simulation models. Simulation techniques are used to ascertain the performance of a reservoir under changing conditions. However, a simulation model is not able to generate an optimal solution to a reservoir problem directly. After making numerous runs of the model with alternative decision policies, it may be possible to detect an optimal or near-optimal solution based on trial-and-error. Inspite of the large number of optimization method available, simulation techniques remain the primary tool for reservoir planning and management studies in practice. Simulation allows a more detailed and faithful representations of a real-world system's performance than optimization models do. Moreover, they can be easily combined with synthetically generated inflow sequences. The main drawback of simulation is that it requires prior specification of the system operating policy. In consequence, the only way to locate an optimal policy is through subsequent trials.

MANAGEMENT PROBLEMS IN INDIAN RESERVOIRS

In India, most of the rainfall is received during monsoon season from June to September. To store this surplus water for the lean season, various conservation measures are practiced. However, this is also the flooding period and the reservoirs are frequently operated for flood management. The conservation demands are best served when the reservoir is as much full as possible at the end of the filling period. The flood control purpose, on the other end, requires empty storage space so that the incoming floods can be absorbed and moderated to permissible limits. Thus, if a multipurpose reservoir is operated for both types of demands, conflicts arise. The conflict between the two purposes in terms of storage space requirements is resolved through proper operation of a reservoir. Many major Indian river basins have limited storage dams. For example, there is only one major dam on the main Ganga river and none on the Brahmaputra. Consequently, most rivers remain highly unregulated and this aspect needs to be considered while operating the reservoirs on their tributaries.

Simulation and optimization methods are increasingly being applied to make decisions in the operational control of actual reservoirs. However, the adaptation of techniques and tools is slow and a gap still exists between research studies and their application in practice. This is largely due to the following reasons:

- Reservoir operators are not directly involved in the development of the computer models and therefore lack confidence in them,
- Many times, requisite data are not timely available,
- Application of models is tedious and many reservoir managers do not have the requisite expertise,
- Interpretation of abstract output is difficult,
- Institutional constraints and lack of incentives to try new things.

Other issues are inadequate data (limited variables, missing spatial variables), increasing loss of storage due to sedimentation, non-availability of data of current demands, operations based on thumb rules, rare use of models for development of operation policy, non-transparent/ non-participatory management, operational constraints, socio-economic constraints, lack of integrated management etc.

Many field organizations in India do not have adequate trained manpower who are familiar with latest tools in the field of water resources management. They do not have the background required to maintain, modify and develop new database and use modeling software. The staff may also not be interested in learning new technique as many of them do not have any incentive for it.

NEED OF DSS FOR INTEGRATED RESERVOIR MANAGEMENT

The aim of reservoir management is to make the best use of the storage capacity of the reservoir for meeting the contractual water-supply obligations, as consistently as possible, having regard to the possible risk of downstream flooding. In determining the releases, the decision maker should take into account the current storage level and current and predicted inflow for all the nodes in the system. Moreover, for each time period, the operator should have a proposed release schedule as well as the opportunity to explore the consequences of alternatives in terms of the reservoir performance criteria. Thus, the design and operation of the reservoir systems are complex tasks in which the experience of the designer or operator is critical. It is important to have a system that can capture and use this experience.

Integrated reservoir management can be best achieved by employing a DSS. Such a DSS should have modules for database handling, data analysis, simulation and/or optimization models and capabilities for analyzing and displaying the results in a format that the user can easily understand. In spite of the proliferation of software for decision support, very few DSSs are available that can help to solve problems covering more than one or two areas of water management. There are systems that are good for flood prediction and management and others that are good for water allocation among competing uses. But there are not many that can cover the broad spectrum of water management from flood protection to drought management. Flooding problems often need models that can handle time steps of the order of tens of minutes whereas water allocation models generally use time steps of the order of weeks or one month.

One of the difficulties encountered in modeling water management systems is the incorporation of operation policies in the model. Some reservoir simulation models (e.g. HEC-RESSIM and WEAP) are difficult to apply to situations which do not follow the standard decision rules programmed in the model. Most of the models have some ability to incorporate user designed policies and several recent softwater (e.g., ModSim, RiverWare, and Oasis) have incorporated rule-processing languages. Many of the models for water allocation have some ability to optimize allocation given management priorities. However, only a couple of them are truly optimization models (e.g., ModSim, RiverWare, and EPIC). A few public domain softwares are available but they have limited features and poor documentation.

Some important considerations for the development of an appropriate DSS for Indian conditions should be:

- Operating rules incorporated in the existing DSS don't conform to Indian conditions.
- Rainfall- runoff simulation or inflow estimation is an important input for reservoir analysis but it is not available in most of these softwares.
- For a commercial software, the developer company should have a long history to ensure that it will be in business and will support the developed software in the future.
- The source code of the software or at least detailed algorithm should be available so that changes or improvements in the package can be made.
- A team of competent and interested officers should be closely associated with software development from the beginning. This will ensure higher chances for user's acceptance of developed DSS.

EXPECTATIONS FROM A DSS FOR RESERVOIR MANAGEMENT

The DSS for reservoir management should have optimization, simulation and other analytic tools, as well as data management and interactive interface to aid model selection and display of results. The DSS should also include the provision of scenario management, i.e. scenario planning, development, organization, analysis and evaluation. Scenario management provides the user with capabilities to create or edit a previously stored scenario and to define a set of policy measures to be examined. Scenario planning includes the activities of identification of the structure and components of scenario, sequence of scenario development and execution. The decision maker can develop scenarios relevant to the problem at hand. Scenario analysis corresponds to the analysis and presentation of computational results through appropriate maps, diagrams and reports. The user can estimate the impacts of the set of policy measures included in the current scenario either by examining a summary report (on-screen or in hard copy) or via an interactive report which utilizes the capabilities of the GIS to produce diagrams, tables and thematic maps. Scenario comparison permits the evaluation and comparison of alternative scenarios. For scenario evaluation, each analysis shall provide similar type of outputs irrespective of the input and those outputs can be presented and compared using tables or comparison graphs.

An efficient DSS for reservoir management must have the following features:

- GIS based basin description,
- Inventory of data and hydraulic structures,
- Capabilities for data consistency, quality check, and filling in missing data,
- Data management services, supporting data input, storage and retrieval,
- Data interpolation—spatial and temporal, including kriging, Akima etc.,
- Input of spatial and temporal data including topographic details and sub-surface features,
- Spatial representation of land use, soil properties, cropping pattern, water quality, water availability,
- Statistical analysis including time series analysis and frequency analysis,
- Synthetic data generation and Monte Carlo analysis,
- Uncertainty and risk analysis,
- User-friendly interface with on-line help.

It is envisaged that the DSS for integrated reservoir management should have tools to support decision making for integrated reservoir operation planning and it should be capable of answering the following:

- Optimum configuration of a system of reservoirs,
- Optimum location, size and spillway capacity of a new reservoir,
- Firm yield for various purposes and capacity-yield-reliability relationship,
- Determination of firm and secondary hydropower generation,
- Consequences of new human interventions,
- Estimation of reservoir inflow,
- Optimum integrated operation policies for a system of multi-purpose reservoirs,
- Detailed reservoir working table at desired temporal frequency,
- Optimum sequencing of reservoirs,
- Impact of sedimentation on the operation of a reservoir,
- Analysis of various scenarios such as inter-basin transfer, climate change, management policies etc.
- Flood control regulation policy for a system of multi-purpose reservoirs,
- Dam break analysis,
- Determination of reservoir backwater profile,
- Economic aspects – benefit-cost ratio and internal rate of return for alternative plans,
- Impacts of different reservoir management policies.

The aim should be to create a system in which the mechanics of linking one component with another are largely transparent to the user. In this way, the person responsible for the actual project should be able to make rational use of the system without an in-depth knowledge of modeling techniques.

STRATEGIES TO DEVELOP A DSS

Components of DSS

A DSS has four major components. They are:

User: User interacts with the system through a computer, directly or indirectly, wherever it is located.

Database: In a DSS, the database plays a very important role. It contains data attribute as well as geographical information in a well organize manner.

Models: It is the set of analysis tools. These tools operate on a particular set of data under the supervision of user and generate corresponding decisions for desired queries.

User Interface: The user interacts with data and models through graphical user interlace. This interface links the user, the data and the models together.

The relationships among these components are shown in Figure 1.

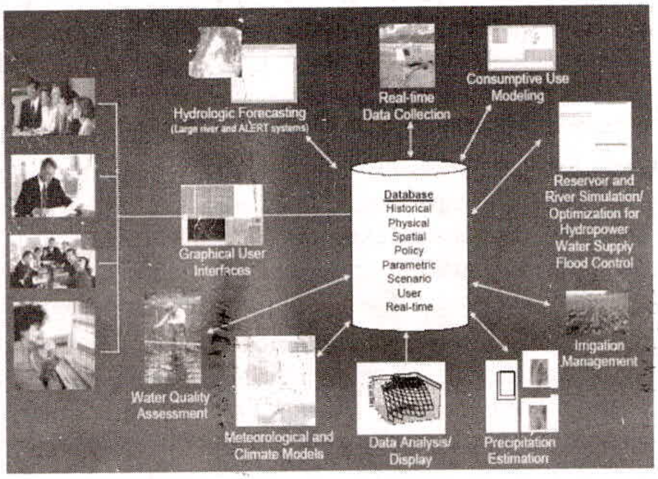

Fig. 1: Relationships among DSS Components

DSS tools can be used to create a specific DSS. They are programming languages, statistical analysis packages, optimization packages, data base management systems, and graphical user interface packages.

Programming Languages: A variety of programming languages have been used in creating DSS modules. One class of languages is procedure-oriented languages, such as BASIC, FORTRAN, PASCAL etc., widely accepted and available on most computers. New languages such as C++, Java, C# etc. are also being used now. These languages may still require programmers to describe a procedure for the computer to follow, but features have been included in the languages that make them especially attractive in dealing with real life problems. Problem-oriented languages can also be used to develop a DSS. A Problem-oriented language allows the programmer to describe the characteristics of a problem to get solved rather than a procedure to be followed.

Statistical Analysis Packages: A DSS frequently requires statistical analysis capabilities. For example, regression analysis may be needed to determine the relationship between a dependent and an independent variable. A number of statistical analysis packages have been developed and are available on many computer systems. DSS developers are also likely to have software for this purpose and if necessary, the same can be easily developed afresh.

Optimization Packages: A function of a DSS may be to suggest the best solution to certain problems, and this procedure may require support from optimization package. This particular problem can often be analyzed through linear programming. The analyst develops an objective function and constraint equations; the mathematical formulation of the problem is then entered into an optimization package. The package performs the calculations and generates the optimal solution. Software for linear and non-linear programming and genetic algorithms are widely available. However, for dynamic programming, these may have to be written.

Data Base Management System: A DSS requires efficient data handling capabilities. The user must be able to enter new data, update existing data extract data, analysis data, display data and present data in reports. If using RDBMS, above user-friendly queries are supported.

Graphical User Interface: The user interacts with the DSS though the software interface, which provides communication among various DSS tools. Microsoft Visual Basic software is simple and conventional one for using as Graphical User Interface (GUI).

Approaches for DSS Development

There are two basic approaches in developing a DSS:

- Model centric approach
- Data centric approach.

In a model centric approach, a DSS is build around a model or a set of models. In such system, the model is first selected and then other components are designed with model requirement. Data centric DSS are those which basically stores all type of available data related to a particular problem. Other components are designed for a general use. At a later stage, the models are selected which may use the entire data or a part of it.

Two ways of development of DSS are:

- *Stand-alone Approach:* Where a DSS is created from scratch as a stand-alone system with a unified input data set and a core of modeling tools that tightly couple to each other, e.g., Aquatool, Mike-Basin, and ModSim; and
- *Framework Approach:* Where a DSS is created by taking a series of existing models and creating an interface that allows a user to execute the modeling procedures in a sequence, passing outputs of one model to another as input in a user-transparent manner, e.g., CWMS, and Waterware.

An important point that needs to be considered for the development of a DSS is whether the DSS should be web-based DSS or stand-alone. The adoption of World Wide Web (*WWW*) technology is an important paradigm shift in hydroinformatics that offers a distributed environment in which data, programs and user interfaces can be exchanged and distributed dynamically over the internet to an independent machine. A web-enabled DSS can be directly used by a user using WWW techniques, without actually installing them on his machine. Since access to the DSS is through a web browser, updating individual user's systems can be avoided. A web-based DSS allows the users to gain quick and timely access, anytime, and from anywhere in the world. However, the limitation of such DSS is that their use is based on the various factors like availability of internet connectivity, the web server hosting the application should be up and running all the time, data security aspects, protection from virus and unauthorised access etc.

PROPOSED FRAMEWORK OF DSS FOR RESERVOIR MANAGEMENT

The flowchart and structure of the DSS for integrated reservoir regulation is shown in Figures 2 and 3 respectively. Here DSS has been structured as a series of components, each of which deals with a separate facet of the system. Data will be passed between modules and can be called upon when simulating reservoir operation.

The over arching aim of DSS should be to meet the contractual obligations for water supply, without exceeding a prescribed risk of downstream flooding. A list of desired features has been provided in section 6.0. To that end, the DSS should take account of the current storage level and predicted inflows when determining the amount of water that can be made available in a particular month for water-supply purposes. However, besides providing a proposed release schedule, the DSS should allow the operator to explore other options by determining their consequences. An important feature of the system may be the ability to quickly evaluate the impacts of different release decisions over an extended period of time for a variety of possible inflow scenarios, including extreme drought and flood periods, helping the operator to establish the robustness of a particular operating policy.

CONCLUSIONS

The growing acceptance of graphical, user-friendly operating systems and software has opened the door for more decision makers and planners to take an active role in the use of DSS in water resources. The keys to success in implementation of a DSS for integrated management of reservoirs are improved level of communications including involvement of decision makers in system development and improved linkage with simulation models which operators more readily accept. Thus, a well developed DSS for water resources management in its entirety, at the national/state level, is a prime requisite for resource planning.

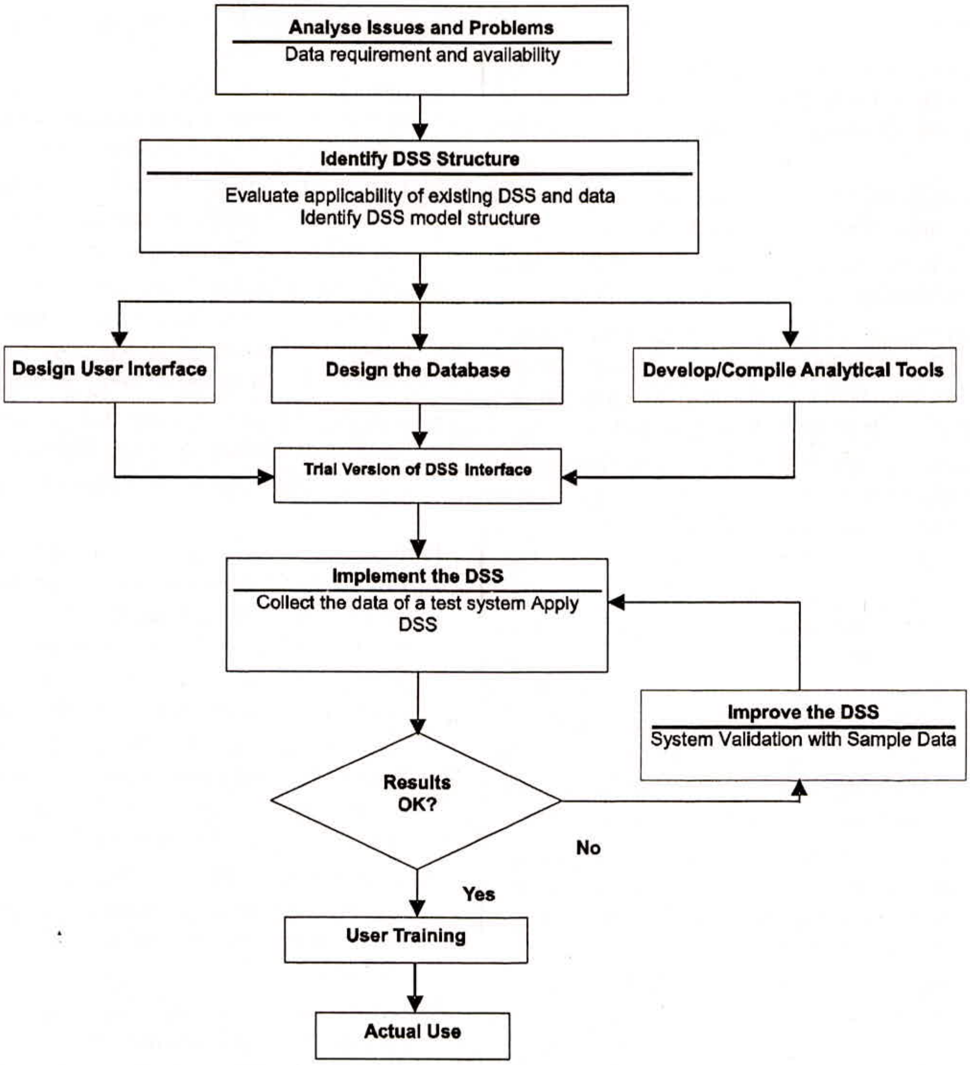

Fig. 2: Flow Chart of DSS Development

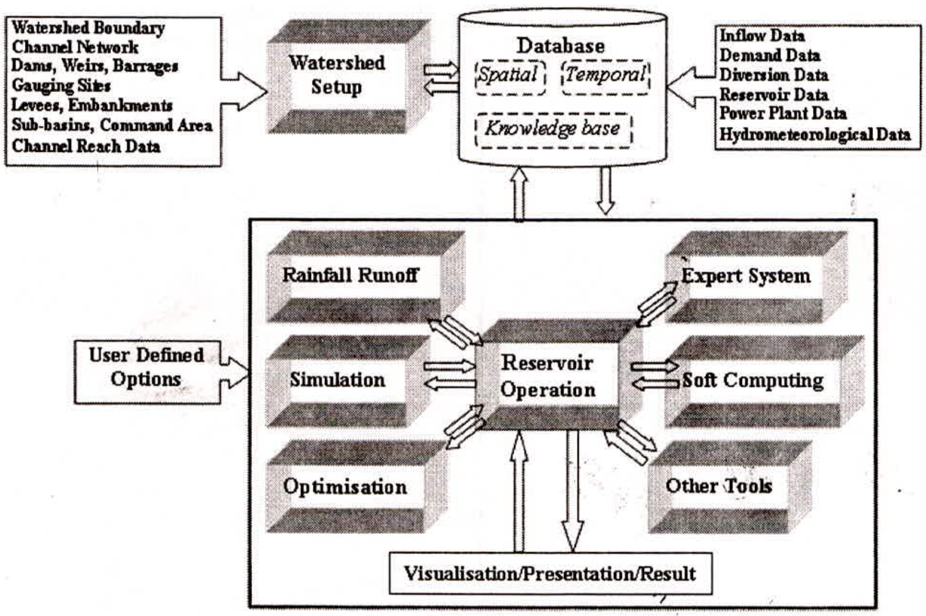

Fig. 3: Proposed Structure of DSS for Reservoir Management

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