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Decision Support Tools for Water Resources Planning and Management

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ABSTRACT: Water Resources Planning and Management focuses on an integration and consideration of key water management issues that are important on watershed and sub-basin scale. The methodology is facilitated by active use of advanced and state of the art Decision Support Systems (DSS). The DSS adds tremendous value and can greatly improve efficiency and accuracy of decision making for public and private water managers. The DSS provides the ideal platform to consider a baseline (e.g. the "natural system") and evaluate impacts from various projects and alternate operations strategies. Equally important for water resources management projects is the integration of the human system involving a comprehensive institutional approach considering the economy of water, integration with national and riparian policy development, national security and active stakeholder involvement.

Integrated management of land and water use, water storage including hydropower, water quality, environment and flood protection constitutes major challenges around the world. Increasing populations with increasing demands for water necessitates active and comprehensive management leading to development of water action plans that deal with short term needs as well as long term planning (considering eg impacts of climate change).

DSS supports business processes and provides tools for communicating often complex issues to decision makers and stakeholders. A DSS is typically developed around a Water Information Management System that integrates comprehensive databases with GIS and WEB technologies for data management, analysis and presentation of data and decisions. DSS functionality in form of analysis tools, alternatives analysis, business process modeling, decision logic, dissemination can subsequently be incorporated with the information system to form the complete DSS.

Keywords: Water Resources Management, Decision Support Systems, Modelling.

INTRODUCTION

Sound water management constitutes a major challenge and calls for integrated and holistic planning. Decisions made now may impact many and may have impacts on generations to come. Planners and water managers must therefore focus on obtaining a thorough understanding of the available water resource and potential impacts in order to meet current and future demands.

Many aspects have to be considered in order to respond to changes in natural phenomena, increase in demands, and provision of adequate and good quality water at a reasonable cost to the public. The increased competition for a finite resource requires that water managers also consider conservation and wise (re)use of water. New and improved water management tools and technologies provide water managers the means to consider and assess all these complex issues as they plan for the future.

Water Resources Management deals with the management of water under normal conditions as well as under flood and drought conditions. It is increasingly accepted that it is not possible under all circumstances to prevent floods from occurring and a shift has been noticed from flood prevention to flood preparedness and flood management. One important aspect to account for in such management is the trade-off between different interests. Flood prevention initiatives may run counter to irrigation or other agricultural or ecological water use priorities in a river basin and as such the process may not favour a maximum possible prevention of floods.

DECISION SUPPORT TOOLS

Decision Support Systems (DSS) are often fully integrated within water resources planning and management projects. The DSS provide a custom, flexible and dedicated management system, to assist managers, decision makers and policy makers in:

- Provide timely, transparent, well informed and reproducible answers to important questions

- Quickly and effectively streamline workflow, reduce time and cost requirements
- Transform data and information into knowledge and produce understandable results and decisions.

Development and implementation of a DSS is typically structured around a number of phases with well-defined functionality and scope. The DSS focuses on specific needs supporting and enabling development and production of timely, well informed and reproducible answers to essential questions. Initial phases focus on data and information management. WEB and GIS technologies are used to link and integrate databases. The water information management system empowers users to transform data and information into knowledge and provide the basis for analysis and decision support. Subsequent phases may involve adding new data, incorporating and linking to other databases, applying more advanced analysis and modelling tools and expanding the decision support functionality. This evolving and dynamic business process mirrors the ever changing requirements of our society and environment.

Typical (see Figure 1) DSS interactive and integrated components are:

- *Data and Information Management:* The data and information component is key and central in developing a DSS. The focus is integrating database and connecting data islands into a dynamic framework with advanced display, mapping, query and presentation capabilities.
- *Analysis and Modelling:* The data framework provides the basis for further analysis and interpretation of data and information. Depending on stage and scope of the DSS the analysis can range from simple to complex including statistical and numerical models, economic and cost/benefit as well as User Defined and Custom tools.

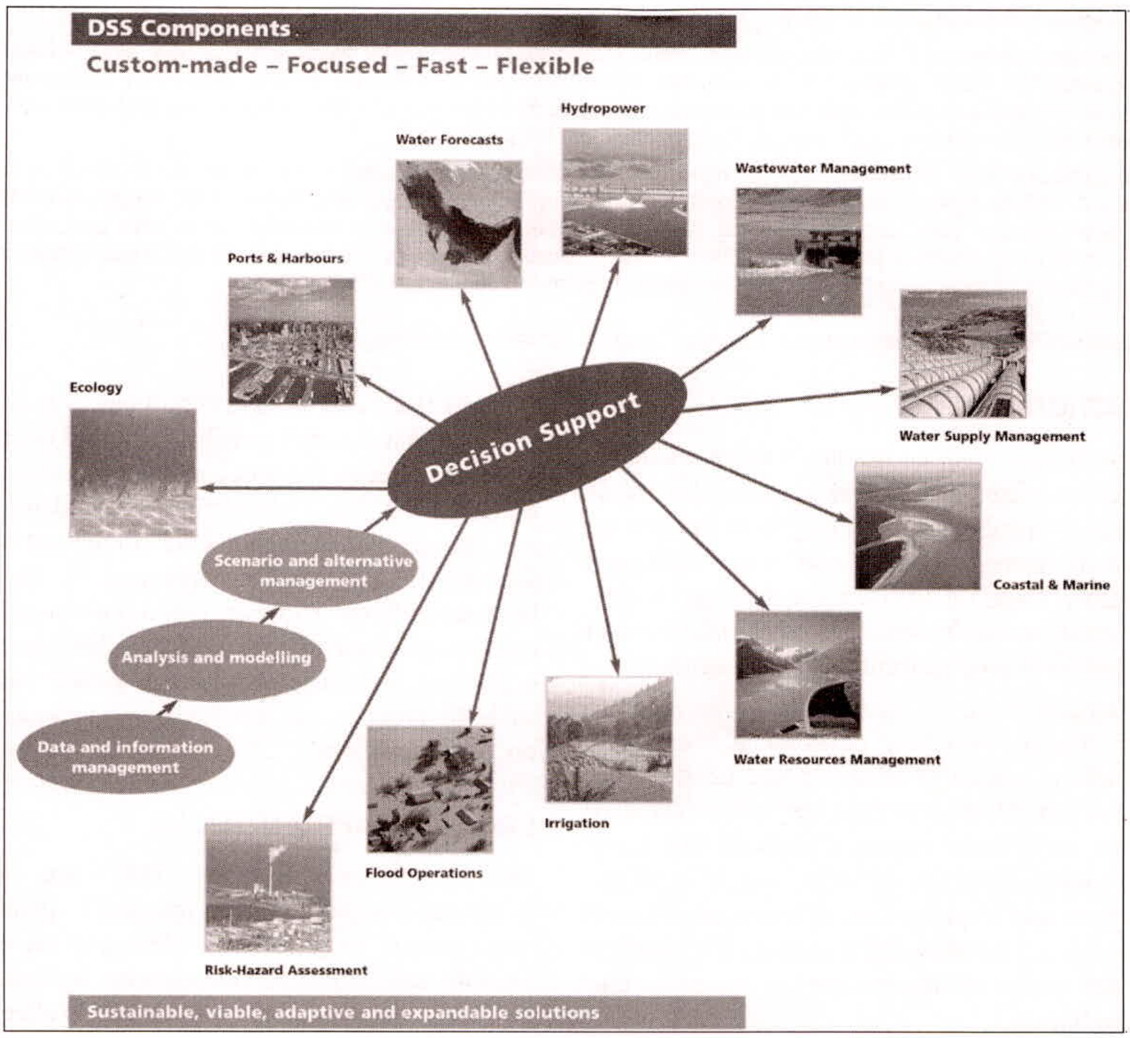

Fig. 1: DSS Components

- *Scenario Management and Alternative Formulation:* The DSS is capable of supporting and providing information (costing and prioritization) for project feasibility and planning projects as well as design and implementation. Upon implementation the project may have an operations component that requires real time and online decision making.
- *Decision Making:* Customizable GIS and Web based interfaces are tailored to meet specific needs and requirements. Advanced graphics, on-line access, custom rules and interpretations can be embedded into the DSS to support and provide the basis for decision makers to make timely, reproducible and well informed decisions.

The DSS can, depending on specific needs, remain specific in scope to support a very focused and dedicated decision process. The DSS may, on the other hand, also evolve into an enterprise DSS to support a wide range of users and a broad management scope.

A DSS provides for cost-effective information management, which enables professional communication between colleagues, other technical staff, managers, decision makers, major stake holders and the public.

The integrated components provide information to formulate the decision logic of the DSS. Rules and interpretations are embedded into the DSS to support and provide the basis for definition of problems and objectives.

Mathematical models are indispensable in providing a stringent and integrated description of the interaction between water-related sector aspects, such as agriculture/forestry, municipal and industrial water supply, hydropower, fisheries, tourism and wildlife could thereby be brought together in a framework allowing an integrated analysis. The models provide a sound scientific framework for coordinated management and planning. Advanced scenario and gaming tools support application of modelling software for planning and operational use. Technology transfer and capacity building is of paramount importance to ensure sustainability and viability of the DSS, this is provided through provision of hands-on training supported by comprehensive documentation and continued support and maintenance.

The following sections describe example projects using DSS for water resources planning and management. The project examples are:

- DSS for water resources planning in the Sichuan Province, China
- DSS for Development of Accession Strategies, Czech Republic
- Hydrology II, DSS for Water Resources Planning and Management, India.

The projects demonstrate the advantages of integrating data base management systems, analysis, modeling and decision support tools in deriving holistic management approaches that are sustainable and viable.

DSS FOR WATER RESOUCE PLANNING IN THE SICHUAN PROVINCE, CHINA

The Sichuan Province, located in the south of China, is the most populous province with more then 110 million people, corresponding to around 10 percent of the population in China. The province comprises the upper reaches of the Yangtze River upstream of the Three Gorges Dam and has a total catchment area of around 570,000 km^2.

The discharge of untreated industrial and domestic wastewater into the rivers has created severe environmental problems. Allthough the Yangtze River still has a large absorption capacity the major tributaries such as Tuojiang, Minjiang and Jialing rivers suffer from severe pollution. The problems are particularly pronounced around the major cities such as Chengdu, Zigong and Chongqing.

In order to assist in the formulation of the strategy for fourteen major cities (ranking of priority investments projects) in the Sichuan province a DSS for water resources management has been established. The project area and 14 selected project cities are shown in Figure 2. Furthermore, the forecast of the effect of different strategies with respect to surface water quality required the establishment of mathematical models for description of relevant physical and biological processes.

The provincial government's general strategy for urban development has been to develop mechanisms for planning and management with respect to waste reduction. The provincial government has therefore launched the Sichuan Urban Environment Project, whose objective is to target a combination of large and moderate population sized cities for selected interventions and to come up with an urban and wastewater strategy for each selected city.

The strategy will comprise such interventions as:

- Construction of domestic wastewater treatment plants
- Construction of interceptors for collection of industrial and domestic waste water

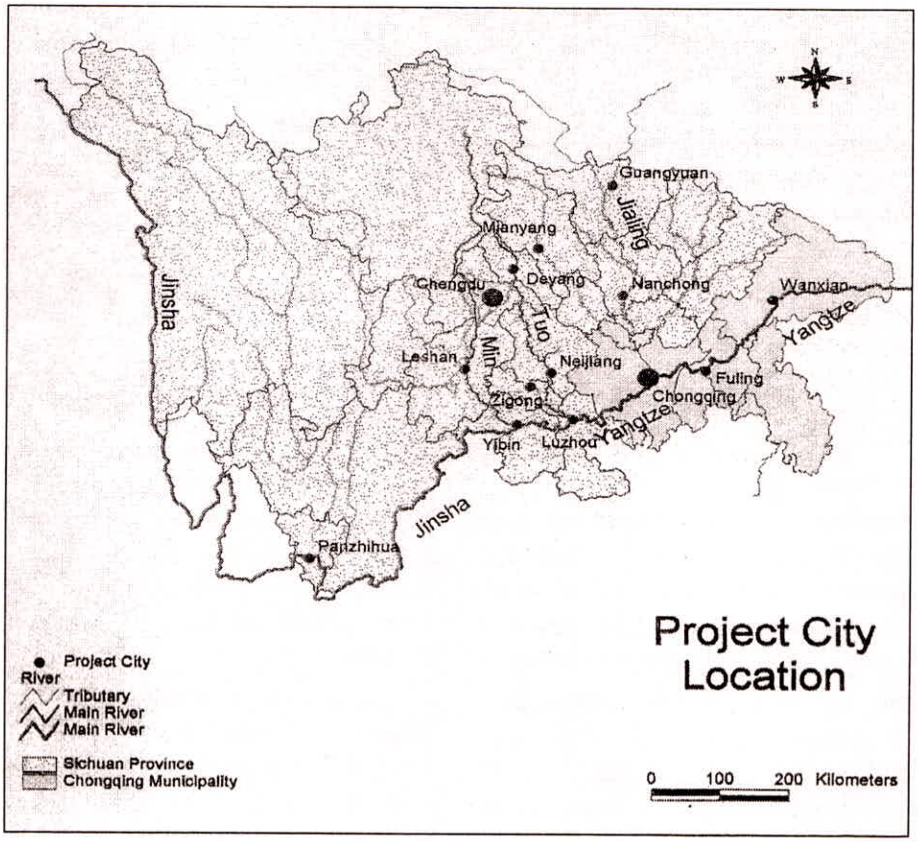

Fig. 2: Study area and location of project cities

- Control of industrial discharge of heavy metals, organic and chemical pollutants
- Reduction in agricultural load
- Improvement of surface water quality by means of water resource conservation and enhanced management of the water sector.

It is the goal that the present pollution situation shall be alleviated in all major cities and that the river water quality shall comply by 2010 with the specified classifications and standards. By 2010 a majority of China's population will live in urban areas and the strategy for pollution interventions shall take into account the projected growth and development with respect to pollutant load.

METHODS

The forecast of the effect of different strategies with respect to river water quality can be carried out using mathematical models describing the relevant physical and biological processes in the river. There are a number of models tailored to model the individual processes in the river basin i.e. water sheds models with GIS interfaces, river models, groundwater models, etc. However, the integration of models and model results often proves to be costly and time consuming making the models inefficient and unpractical as a management tool and during the prioritisation process and design phase.

Combining models with a flexible structure sharing a common platform for data pre- and post processing can on the other hand provide an efficient tool in relation to the strategy formulation. Such a system has been applied in the present project as shown in Figure 3.

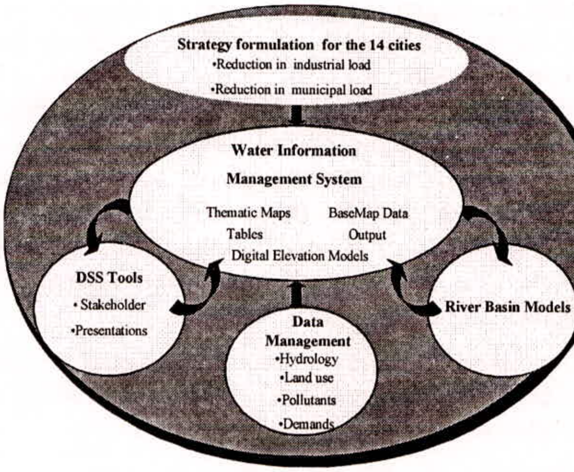

Fig. 3: DSS for Sichuan Province

As illustrated, the holistic approach includes a data base management system for the exchange of data and information with mathematical models for the description of physical and biological processes. In the applied system the database is the focal point for data storage and retrieval comprising input as well as output from the mathematical models.

WATER RESOURCES STRATEGIES

Sichuan has traditionally been a province with ample resources of water for all sectors, but with the rapidly increasing urbanisation, industrialisation and increasing demand for efficiency in agriculture, water shortages are beginning to be felt.

Geographically and temporal, the distribution of the water availability and demand is uneven in both space and time. This narrows the generally broad margin of surplus and creates critical water shortages and environmental conditions for some of the project cities, e.g. Deyang, Neijiang and Zigong in the min and Tuo River Basins. Thus locally water is inadequate to sustain the aquatic ecosystems and maintain the recreational value of the rivers, especially in the urban areas. An integrated water availability and water quality model has been developed, see Figure 4.

In order to assess the potential for redistribution or reallocation of the available water resources several options to alleviate the present and future water shortages have been analysed taking into account present as well as projected sector demands up to year 2010.

The pollutant load to the water quality model included common pollutants of organic matter, total ammonia and nutrients from the following pollutant sources:

- Cities (domestic waste water) comprising sewage collected by the sewage network in the 14 project cities
- Towns (domestic waste water from other major towns with population of more than 25,000) other than the 14 project cities)
- Industrial waste water comprising the 10–25 largest enterprises within each prefecture
- Diffuse rural run-off from cultivated as well as uncultivated areas.

Based on the model scenarios with respect to the 2010 projections the following was concluded:

- Treatment of municipal wastewater from the 14 project cities will bring about substantial improvements in river water quality but will not be sufficient to fulfil the Class III objectives of surface waters.
- Treatment of industrial wastewater alone will not lead to significantly improved water quality, except in the Tuo River where industrial sources constitute a large proportion of the pollution load.

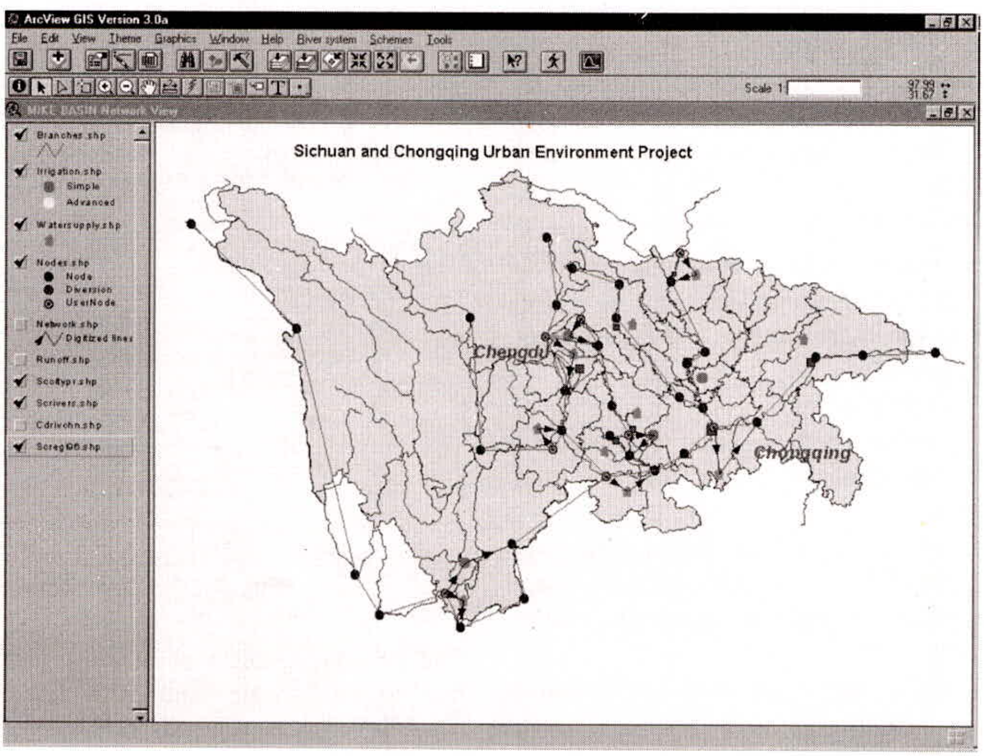

Fig. 4: Regional River Basin Model

- Combined interventions targeted at both municipal wastewater from the 14 project cities and all industrial wastewater will lead to significant improvements in river water quality and may for many river reaches turn the present deteriorated conditions into compliance with the Class III water quality objectives.
- Targeting major towns in addition to municipal and industrial wastewater will have modest extra effect, except in the Min River.

Based on the above findings a three-phased strategy for targeted interventions toward a reduction of the pollution loading on the surface waters in Sichuan province was designed and the impact was assessed in additional simulations.

DSS FOR DEVELOPMENT OF ACCESSION STRATEGIES, CZECH REPUBLIC

This project (Carl Bro, 1999) was completed with the general objective of assessing the legal, institutional and technical implications of accession of the Czech Republic to EU as background for evaluating the economic and financial implications for meeting the requirements of the EU legislation in the water sector.

An essential part of the project was to establish a Decision Support System (DSS). The purpose of the DSS was to support the development and assessment of policies and cost efficient strategies for meeting the legal requirements of directives. Moreover, the DSS are going to be used for development of national water management plans being maintained and applied by Water research Institute under the umbrella of Ministry of Environment. The DSS includes relevant data and information and adequate modeling tools to:

- Provide a national overview of pollution sources, river systems, water quality conditions, existing water supply and waste water treatment facilities, technical options for improvements and facilities for calculation of associated costs;
- Assess water quality conditions as a consequence of implementing various scenarios and estimate the corresponding investment and Operation and Maintenance (O&M) costs;
- Identify least cost strategies for meeting requirements of directives for water supply and wastewater treatment specified as effluent standards and/or water quality standards,
- Estimate economic and financial implications of accession, including effects on investment programmes, recurrent costs and financing options.

Within a particular basin the definition of a scenario includes a specification of the most important parameters involved. This e.g. includes the timeframe involved (i.e. an intermediate and final year of compliance), assignment of certain areas as "EU sensitive areas" (requiring nutrient removal) or "Czech protected areas" (requiring other standards), allocation of selected effluent standards to some groups of point sources (by category, size and/or location), assignment of water quality objectives to selected river segments, assumed developments within the industrial and agricultural sectors, and others.

DSS Components

The DSS comprises databases and models and function as an integrated and user-friendly tool, which is capable to evaluate alternative options for compliance considering legislative requirements, technical options, environmental impacts and economic/financial implications.

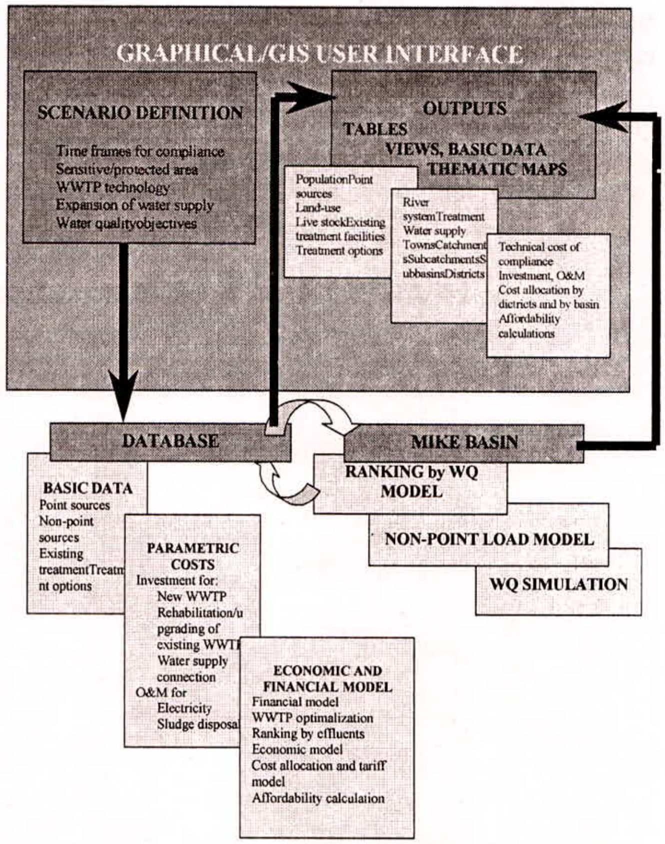

Fig. 5: DSS Components

The DSS facilitates access to relevant information on the national scale and provide a computational capability for the analysis and evaluation of different options to assist in the identification of viable

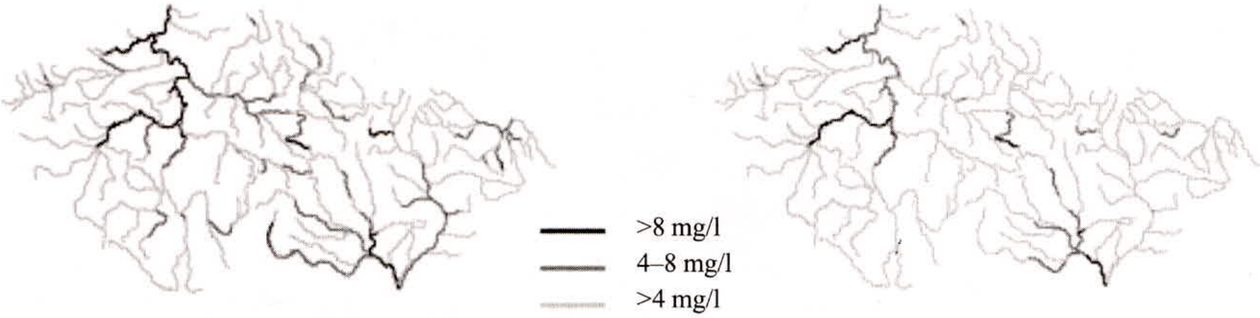

Fig. 6: Simulated in-stream water quality (BOD) from Scenario 3. The baseline status is shown on the left while on the right water quality reached by implementation of all investments within Scenario 3 is presented

strategies. This is accomplished by means of the following components:

- Data base, providing an overall overview of pollution sources (municipal, industry and non-point), recipient waters, existing water quality and hydrological conditions, water supply and waste water treatment facilities, technical options for improvements; basic statistical data from MOE and hydrological and topographical data.
- Parametric cost functions for the different technical options showing the required investments and annual O&M costs as a function of the number of person equivalents and required effluent standard; in case of treatment or water supply facilities and connectivity of inhabitants.
- Water quality models for determining the load from non-point sources and simulation of the resulting water quality conditions as a consequence of assigning different treatment levels to the individual point sources. The model also accounts for the corresponding investments and O&M costs. If appropriate, the simulation models may be used within optimization procedure.
- Optimization model to identify least cost strategies for meeting specified ambient water quality objectives, which are accessible in the combination with certain effluent standards for upgraded treatment. There are available two optimization-ranking algorithms, one based on ranking of effluents from point sources related to executed investment through cost matrix, and the second based on emission principle taking into account pollution reduction in rivers due to the target investment based on ranking. The letter is fully dependent on simulation of WQ by the models.
- Economic and financial models for determining the net present value of compliance costs covering capital investment plans and associated O&M costs in both economic and financial terms. Further, cost allocation between the public sector and water users is assessed based on the various institutional scenarios. The user will have access to the data bases and modeling tools through a graphical/GIS interface allowing a user friendly specification of the scenario, which is to be investigated as well as an easy retrieval of the results generated by the models.

The DSS has been designed to model pre-defined scenarios for accession process and its economical and technical incidence. Relevant data needed for the application of the different models and for the evaluation of defined scenarios have been included in a database, comprising a combined GIS and database.

The scenario definition is one of the essential parts of using DSS. The user has to decide among many different options and technical parameters in order to define just one selected scenario.

In order to present environmental benefits of all scenarios within Czech Republic the maps of WQ for the entire river network were generated directly from DSS.

HYDROLOGY II, DSS FOR WATER RESOURCES MANAGEMENT, INDIA

The Hydrology Project II will assist water resources agencies at both Central and State levels to address the intra sectoral demands and overall water resource planning and management through easy access to Hydrological Information Systems and provision of DSS and related tools for water sector planning and management.

Management of India's water resources is a major challenge. Since independence sixty years ago massive investments in water and agricultural related infrastructure has virtually eliminated threats of famine and created the basis for development. Although the majority of India's population remains rural and agrarian, substantial urbanisation and industrialized

Fig. 7: India State Map

growth is occurring. The availability of fresh water, both spatially and temporally, has become a major factor constraining the ability of water supply, industrial and agricultural sub-sectors to meet the diversified needs of the growing population. In large areas of the country, the available fresh water resources are falling on a per capita basis, groundwater levels are falling and water quality is deteriorating. These stresses on water availability and quality have led to competing demands and disputes among users, including State governments.

Issues of water quality and scarcity and the need for control and protection against natural disasters such as floods and droughts are increasing in importance. One of the key requirements for comprehensive water resources planning is a sound hydrological data base. The Hydrological Information System (HIS) created under HP-I covering 9 states (Andhra Pradesh, Chattisgarh, Gujarat, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Tamil Nadu) has provided a sound basis for moving towards improved and modern planning and design of water resources development and long-term water resource management using tools such as hydrological modelling, Decision Support Systems (DSS) and hydrologic design aids.

Five Central organisations including the Central Water Commission, Central Ground Water Board, National Institute of Hydrology, Central Water and Power Research Station and the India Meteorological Department participated in HP-I.

These central agencies (added are the Central Pollution Control Board) and states (added are Goa, Himachal Pradesh, Pondicherry and Punjab) will all participate in the HP II DSS Water Resources Planning Project.

The DSS will be customised to the unique requirements of each agency. The DSS, consisting of information systems linked to appropriate models, will build on and integrate with the existing HIS used by the nine HP-I states. Based on the water resources issues faced throughout India the DSS Planning will

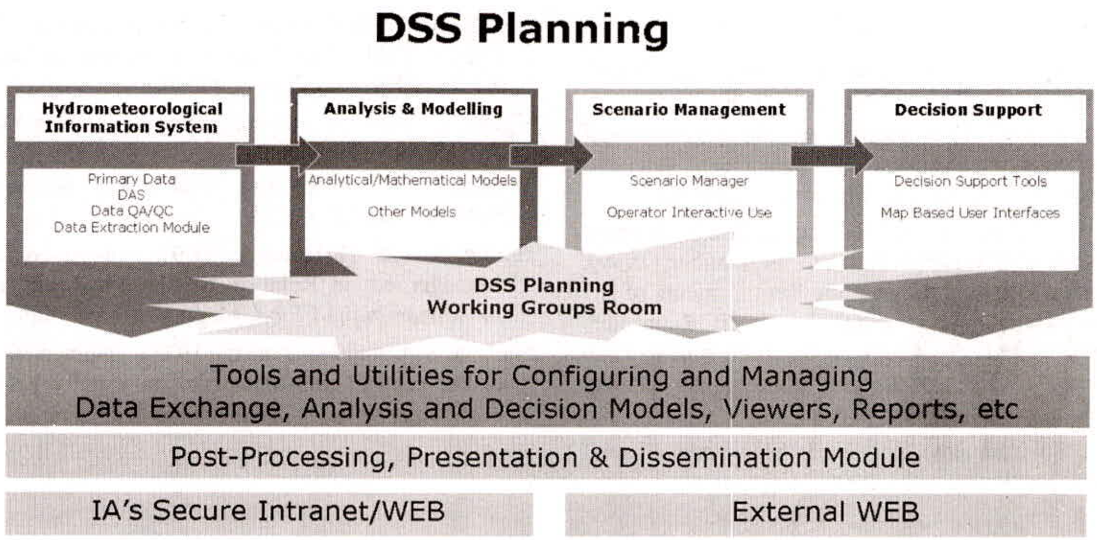

Fig. 8: Structure of DSS Planning

include data, tools and technologies to address the following components:

- Surface water planning
- Integrated operation of reservoirs
- Conjunctive surface and groundwater planning
- Drought monitoring, assessment and management

Management of both surface and groundwater quality. While the overarching theme of the DSS Planning is to have a tool for integrated water resources planning at the level of a river basin, emphasis is placed on these five components keeping in view the problems currently being faced or likely to arise. The DSS will be developed in partnership with National Institute of Hydrology (as the lead agency) and other agencies and states.

It is envisaged that DSS Planning (as show in Figure 8) will comprise a number of modular and component based toolboxes, each of which will include functionality and look and feel designed for a number of user profiles for e.g. drought management, surface water and groundwater modelling, and water quality modelling etc.

- *The Hydro Meteorological Information System (HIS) toolbox* will be based on the existing HIS established under HP-I project. The HIS for DSS Planning will be expanded as needed and include a comprehensive set of tools for accessing, editing, analysing, and visualizing a wide range of data types.
- *The Analysis and Modelling Toolbox* will encompass existing and new tools e.g. statistical analyses, surface water modelling, reservoir operations, conjunctive use simula-tions, drought management, surface water and groundwater modelling, water quality modelling, damage assessments, economic calculations and planning.
- *The Scenario Management Toolbox* will provide robust tools for editing model scenarios, e.g. different reservoir operation scenarios, running scenario simulations, examining the results graphically and disseminating data in predefined formats.
- *The Decision Support Toolbox* will include a series of tools for defining and scheduling works flows, defining and examining events and alarms, examining forecast results, establishing and applying decision trees to aid reservoir operations, and disseminate internally and externally information as needed. Security of information is a key issue and the DS toolbox will adequately address this.

CONCLUSIONS

The ever increasing focus on watershed management and sound use of water requires that scientists, planners, managers and decision makers are able to quickly produce reliable estimates, assess impacts and efficiency of potential strategies.

Successful development and application of DSS's demonstrates the benefits of integrated use of web based and GIS enabled graphical user interfaces with relational databases, visualization techniques, analysis tools and decision logic. Such powerful DSS enables managers and decision makers to quickly obtain answers to critical questions and to focus on transparency and accessibility of results.

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