Annals of Arid Zone 41(3&4): 233-262, 2002

Watershed Management: New Approaches and Paradigms

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Abstract: Integrated watershed management is being increasingly accepted now-a-days for environmental and water resources conservation, protection and management. Watershed management links human activities within the watershed to water quantity and quality of the receiving stream or lake and requires mathematical models that can quantify the impacts of management strategies. They involve conceptual integration of hydraulic and hydrologic models with concurrent models of physical habitat, chemical transport, biological populations and socio-economic, political, administrative, legal, governmental, financial, and other models. For example, in case of water allocation, estimating the value of in-stream water use permits recreational, ecological, and biological concerns to compete with traditional consumptive uses, i.e., agriculture, municipality, and industry, energy generation, waste disposal. Thus, a watershed management approach must be comprehensive, interdisciplinary, and integrated to address today's needs, taking into consideration likely future repercussions.

Key words: Watershed management, integrated, mathematical models, hydrology, data, planning, water rights, sustainable development.

The word watershed has been derived from the German word *wasser-scheide,* which means water parting (Kauffman, 2002). The word entered the English language much later. A watershed is a naturally defined spatial context in which water occurs. It may be as small as a flower bed or a parking lot or as large as hundreds of thousands of square kilometers, as exemplified by the Ganga River basin in India or the Mississippi basin in the United States. Governing water resources are the operative hydrologic processes. These processes and their spatial nonuniformity are defined by climate, topography, geology, soils, vegetation and land use, and are related to the watershed size.

The natural resources of a watershed are land, water, air, and bio-life. The term bio-life includes humans, animals and plants. All these resources are closely interlinked and, therefore, a change in the availability and utilization of one resource influences those of others. For example, if the land use at a place is changed from forest to agriculture, then the following may change: availability and quality of water downstream, depth of groundwater table, water available for wild-life and tribals that might have been using the watershed as their habitat, production of biomass from the watershed, pattern and quality of wind, and so on. In a watershed, these resources are limited and coexist in a natural balance. If this balance is disturbed, many unwanted and harmful consequences may ensue.

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The objective of watershed management (WM) is to exploit the natural resources of a watershed in a planned, coordinated, and systematic way for the overall benefit of the society. Since the resources are limited, this necessarily implies that the development should be optimum, balanced, and sustainable. By sustainable development, it is meant that the management activities cause no adverse impact on the environment and ecology and at the same time, the health of the watershed is maintained. Of course, the precise nature of these objectives will be different for different watersheds and the objectives of a society may also change with time.

Like all management activities, WM operates under a set of constraints which arise because the availability of natural resources is limited, the amount of man-power and financial resources that can be put to use is limited, and the topography and climate of the watershed limit the decision space. Further, the available technology, the political and government set-up, the legal and judicial system, the social system, the religious beliefs and faith, and the outlook of the people are different for different watersheds and are essentially constraints. The constraints have a profound influence on the management approach and the tools to be used. It is important to emphasize that the socio-economic and technological and other constraints are unique for each watershed. As a result, the approach for planning and management of a watershed in the United States will be different from the one for a watershed in India.

Fundamental to WM is the management of water resources of the watershed, for water is central to its natural resources and to understand its behavior. Water is central to environmental and ecological continua. The famous Italian philosopher Leonardo da Vinci correctly stated: *Water is the driver of nature.* Water forms landscape and shapes it. The sustenance of life and economic and social development are not possible without water.

The basis of water resources management is hydrologic modeling which constitutes the focus of this paper. Hydrologic models help to understand the behaviour of the watershed system, evaluate alternate decisions, and determine the consequences of a decision. Integrated watershed management models combine hydrologic, environmental, agricultural, and socio-economic models. The use of these models is facilitated by recent technological developments, including computers for data storage, management and retrieval, and doing computations; space technology for preparation of database and inputs to these models; GIS to manage and display spatial data; artificial intelligence techniques for data analysis, model calibration; and graphical interfaces for effective communication between the user and the computer. Since the interest is in long-term goals, planning must be an integral part of WM. As WM activities have a significant impact on social life, it is important that the decisions are taken by involving stakeholders and soliciting their views. Finally, it is advisable to learn from success stories and use the experience gained when chalking out the future course of action.

A conceptual framework for WM depicting the objectives, the inputs, and the tools is given in Fig. 1.

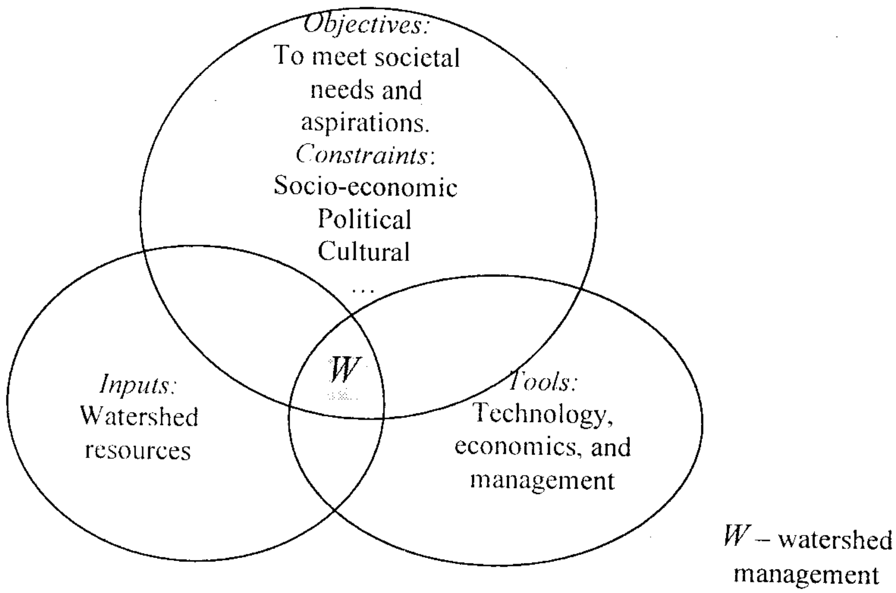

Fig. 1. A conceptual framework of watershed management.

A Perspective of Watersheds

The availability of water at a given place depends on the properties of its upstream watershed. Most of the consumptive water use, such as irrigation, and non-consumptive uses, such as hydropower production, recreation, and navigation, take place in the watershed itself. A watershed also receives most of the return flow from irrigation and wastewater. Due to these reasons, watersheds are considered to be the most important management units. The ecosystem approach to WM aims to integrate social, economic and environmental interests within the wider framework of the watershed. The basic motivation behind this is that people depend on their ecosystem and, therefore, the capacity of the ecosystem to deliver goods and services should be maintained in the long haul.

Black (1997) identified five functions of watersheds: three hydrological and two ecological. The hydrological functions are: (i) collection of water from rainfall, snowmelt, and storage that becomes runoff, (ii) storage of water, and (iii) discharge of water as runoff. Ecologically, a watershed has two additional functions: (a) providing diverse sites and pathways along which vital chemical reactions take place, and (b) habitat for the flora and fauna that constitute the biological elements of ecosystem. Two integrative responses to these five functions are important. The watershed hydrologically attenuates the energy inherent in the irregular and often abrupt delivery of precipitation in a unique manner. Second, through outflow of water from storages, the watershed flushes a water body and this action, in turn, regulates the movement of mobilized chemicals.

Watersheds provide a number of goods and services to global, regional, national, and local economies. These goods and benefits include water, fish, timber, fuel, biota, wildlife, fertile land, and so on. A diverse range of industries, such as agriculture, tourism, fisheries, forestry, and construction, benefit both directly and indirectly from freshwater ecosystems. Clearly, interaction of such a large number of technical and non-technical factors makes WM a highly complex but at the same time highly relevant and necessary endeavour.

The necessity to re-examine and, if necessary, re-orient WM has risen because the freshwater sources have come under tremendous pressure during the 20th century. This has occurred due to a number of somewhat inter-related factors. While the world population increased by a factor of about three during the 20th century, water withdrawals have increased by a factor of about seven. Consequently, currently one-third of the world's population lives in countries that experience medium to high water stress (TAC, 2000). Increased water use has also resulted in more pollution in water bodies. Contamination of water has two adverse impacts. It limits the use of water in various activities as well as renders water use expensive because treatment is required before use. Secondly, the biological life which is dependent on water is infected by various diseases that require expensive treatment (in case of humans) and similar problems for plants and animals, including extinction (in rare cases).

A balanced and coordinated management of water and related resources can be achieved through Integrated Water Resources Management (IWRM). "IWRM is a process which promotes the coordinated development and management of water, land, and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (TAĊ, 2000). IWRM should be viewed as a process of balancing and making trade-offs between different goals in an informed manner. In this process, there are two fundamental categories of integration: the natural system and the human system. Watersheds are the best natural spatial units for this integration.

A model for integrated WM helps develop implementable solutions to problems by combining all the essential component models into an umbrella scheme. The model incorporates or accumulates all of the interactive forces or influences. Hence, it aids the decision-making process and keeps the policy results within the intersection of the social goals of the management policy and the legal constraints. Such a model is shown in Fig. 2.

Management of water resources is central to watershed planning and management. This requires an understanding of the various hydrological processes that take place in a watershed and their interaction with other elements, such as humans, plants, other life, and socio-economic factors. Currently, a large number of watershed models of various complexities are available. A number of models are described in Singh (1995) and Singh and Frevert (2002a, 2002b).

Watershed modeling is an integral part of WM. Therefore, before initiating a

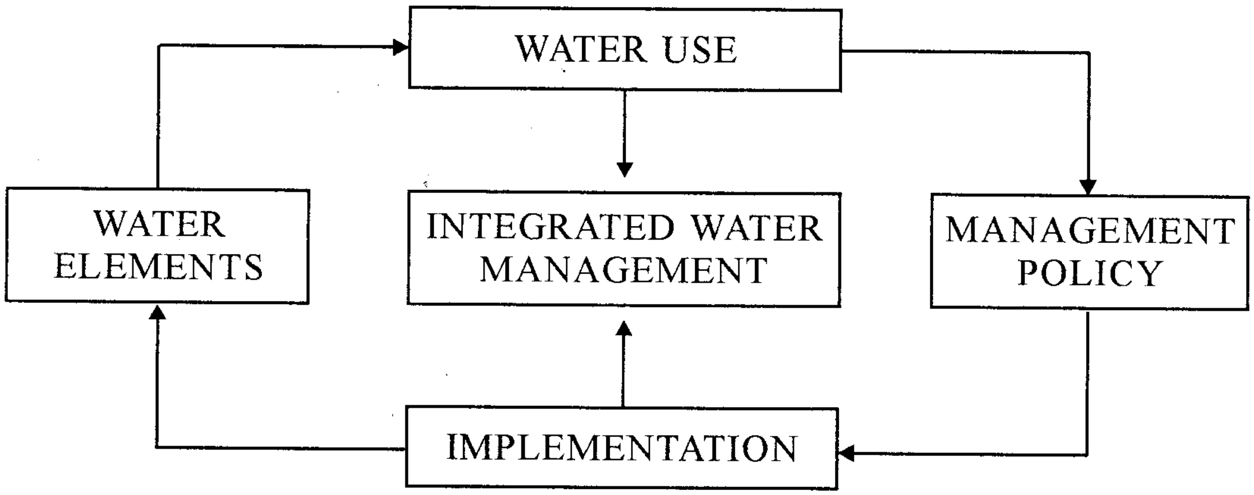

Fig. 2. Integrated water management (after Singh, 1995).

discussion of WM, a brief review of watershed modelling is in order.

Watershed Modeling

The hydrological models constitute the core in planning WM activities, in design of projects, in understanding the impact of various alternative designs, and in operation of facilities. These models also help in understanding the limits of feasible regions for various decisions and in identifying the optimal decision. Watershed hydrology deals with integration of hydrologic processes at the watershed scale to determine the watershed response. Mathematical models of watershed hydrology are employed in a wide spectrum of areas ranging from watershed management to engineering design (Singh, 1995). They are used in planning, design, and operation of projects to conserve water and soil resources and protect their quality. At the field scale, models are used for varied purposes, such as planning and designing soil conservation practices, irrigation water management, wetland restoration, stream restoration, and water table management.

Mathematical models of watershed hydrology

Watershed models are fundamental to watershed management. They are, for example, used to analyze the quantity and quality of stream flow, reservoir system operations, groundwater development and protection, surface water and groundwater conjunctive use management, water distribution systems, water use, and a range of water resources management activities (Wurbs, 1998). The water and heat transfer between the land surface and atmosphere significantly influences hydrologic characteristics and yield, in turn, lower boundary conditions for climate modeling (Kavvas *et al.*, 1998). An assessment of the impact of climate change on national water resources and agricultural productivity is made possible by the use of watershed models.

Watershed management requires integration of watershed models with models of irrigation management, soil conservation, physical habitat, biological populations and economic response.

Estimating the value of in-stream water use allows recreational, ecological, and biological concerns to compete with traditional consumptive uses, i.e., agriculture, hydropower, municipality, and industry (Hickey and Diaz, 1999). Watershed models are utilized to quantify the impacts of watershed management strategies, linking human activities within the watershed to water quantity and quality of the receiving stream or lake (Mankin *et al.*, 1999; Rudra *et al.*, 1999) for environmental and water resources protection. In summary, watershed models have become an essential tool for planning, development and management of water and related resources.

Classification of watershed hydrology models: A watershed hydrology model is an assemblage of mathematical descriptions of components of the hydrologic cycle. The model structure and architecture are determined by the objective for which the model is built. For example, a model for watershed planning is significantly different from the one used for water resources design or ecological management. Likewise, a hydrologic model for flood control is quite different from the one for watershed management. Singh (1995) classified hydrologic models based on (i) process description, (ii) time scale, (iii) space scale, (iv) techniques of solution, (v) land use, and (vi) model use. ASCE (1996) reviewed and categorized flood analysis models into (1) event-based precipitation-runoff models, (2) continuous precipitation-runoff models, (3) steady flow routing models, (4) unsteady-flow flood routing models, (5) reservoir regulation models, and (6) flood frequency analysis models.

Although the mathematical equations embedded in watershed models are continuous in time and often space, analytical solutions cannot be obtained except in very simple circumstances. Numerical methods (finite difference, finite element, boundary element, boundary-fitted coordinate) must be used for practical cases. The most general formulation would involve partial differential equations in three space dimensions and time. If the spatial derivatives are ignored, the model is said to be "lumped"; otherwise it is said to be "distributed" and the solution (output) is a function of space and time. Strictly speaking, if a model is truly distributed, then all aspects of the model must be distributed, including parameters, initial and boundary conditions, and sources and sinks. Practical limitations of data and discrete descriptions of watershed geometry and parameters to conform to the numerical solution grid or mesh do not permit a fully distributed characterization. Most watershed hydrology models are deterministic but some consist of one or more stochastic components.

Several scientific disciplines have developed mathematical descriptions of the components of the hydrological cycle, using basic physical principles in conjunction with experimental data. The physical fidelity of these models depends on the objective of the researcher and the tools available to solve the resulting equations. The watershed modeler has a wide latitude in choosing the level of rigor or detail required of an individual component model, and the choices are affected by the objectives, watershed topography, geology, soils, land use, and the available information.

Although watershed models may be complicated, with many parameters, frequently the information that they are required to provide is very simple, as for example, the mean annual groundwater recharge rate over part of the basin, or the 100-year flood. Statistical tools, including regression and correlation analysis, time series analysis, stochastic processes, and probabilistic analysis are necessary to analyze the output to provide this type of information. Because of uncertainties in model structure, parameter values like precipitation and other climatic inputs, uncertainty analysis, and reliability analysis can be employed to examine their impact.

Wurbs (1998) highlighted the availability and role of generalized computer modeling packages and outlined the institutional setting within which the models are disseminated throughout the water community. Generalized water resources models were classified into: (i) watershed models, (ii) river hydraulics models, (iii) river and reservoir water quality models, (iv) reservoir/river system operation models, (v) ground water models, (vi) water distribution system hydraulic models, and (vii) demand forecasting models.

An exhaustive review of watershed models and various issues related to their application has been recently provided by Singh and Woolhiser (2002).

Water quality and environmental considerations

In view of the concerns for deteriorating quality of raw water resources and impacts of climate change on water resources that began to rise during 1980s and 1990s, this period saw attempts to link hydrologic models with those of geochemistry, environmental biology, meteorology, and climatology. This linking became possible primarily for two reasons. First, there was increased understanding of spatial variability of hydrologic processes and the role of scaling. This was essential because different processes operate at different scales and linking them to develop an integrated model is always challenging. Second, the digital revolution made possible the employment of GIS, remote sensing techniques and data base management systems.

Early water quality models were one-dimensional and could compute only temporal variation of a relatively few water quality variables, such as temperature, dissolved oxygen (DO), and biochemical oxygen demand (BOD). Subsequent models that accounted for spatial variability were one-dimensional and allowed for simulation of more complex variables subject to adsorption or decay processes, such as nutrients and coliforms. Recently, three-dimensional, time-dependent models incorporating more realistic description of processes affecting water quality have been developed. A number of watershed hydrology models, for example, HSPF, SHETRAN, LASCAM, DVSM and DWSM, have water quality components built into their architecture (see Singh and Woolhiser, 2002, for details).

Integrated watershed models

Watershed-scale models that require hydrologic, crop and economic input data, and simulate the behavior of various hydrologic, water quality, economic, or

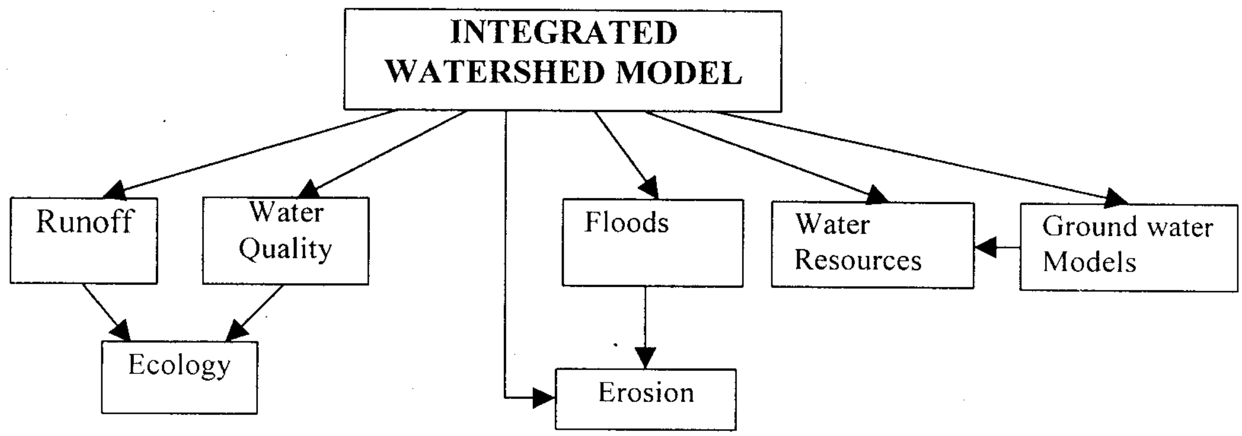

Fig. 3 Elements of Integrated watershed model (after Harmancioglu et al., 1998).

other variables under a fixed set of water allocation and infrastructure management policies, are being increasingly used these days. A useful outcome of simulation of the operation of a water resources system under a range of conditions is identification of the system components that are likely to fail. The models that use detailed hydrometeorological input data can also be employed to assess the system performance under various scenarios of climate change, and changing demands, such as those due to population growth, change in command areas, cropping patterns, etc. Fig. 3 shows the elements of an integrated watershed model.

Many models of current generation are supported by graphical user interface, GIS for input and analysis of spatial data, and screen display of results. These models are gradually becoming common in river basin simulation. The WaterWare model was developed by a consortium of European Union-sponsored research institutes under a collaborative research programme Eureka EU 487 (Jamieson and Fedra, 1996). WaterWare has a powerful GIS component and modules for expert systems, and a two-dimensional, finite-difference groundwater model. The model has modular architecture and components for demand forecasting, water resources planning, and groundwater and surface water pollution.

RIBASIM (River Basin Simulation Model), developed by Delft Hydraulics of the Netherlands, is a tool for river basin simulation and modeling. This software is capable of simulating the behaviour of river basins under various hydrological conditions. The model links hydrological inputs at various locations with specific water uses in the basin. It can be used to evaluate alternatives related to infrastructure, and operational and demand management through a Decision Support System (DSS). RIBASIM has facilities to link various GIS systems. Important modules of RIBASIM are: *WADIS* (a generic water balance model), *AGWAT* (a generic agricultural water demand and impacts model), and HYMOS (hydrological data processing and analysis system).

The MIKE BASIN is a water resources management tool developed in Denmark. It is structured as a network model in which rivers and their main tributaries are represented by a network consisting of branches and nodes. MIKE BASIN uses a graphical user interface with a linkage to a GIS. The model output includes information on the performance of each individual reservoir and irrigation scheme within the simulation period, illustrating the frequency and magnitude of water shortages. The combined effect of selected schemes on river flows can also be handled through simulation of the time series of river flow at all nodes (DHI, 1997, 1998).

Future outlook for mathematical models of watershed hydrology

The following conclusions can be drawn from the foregoing discussion: (i) Many of the current watershed hydrology models are comprehensive, distributed and physically based. They possess the capability to accurately simulate watershed hydrology and can be applied to address a wide range of environmental and water resources problems. (ii) The scope of mathematical models is growing, and the models are capable of simulating not only water quantity but also quality. (iii) The technology of model calibration is much improved, although not all models have taken full advantage of it. (iv) The models are becoming embedded in modeling systems whose mission is much larger, encompassing several disciplinary areas. (v) The technology of data collection, storage, retrieval, processing and management has improved by leaps and bounds. In conjunction with literally limitless computing prowess, this technology has significantly contributed to the development of comprehensive distributed watershed models.

Watershed Planning

Planning is the process by which the society directs its activities to achieve goals it regards as important (Weiss and Beard, 1971). A sound planning is a pre-requisite for optimal use of available resources. It involves estimation of short-term and long-term needs and ways to meet these needs, and then a comparative evaluation of alternative solutions with respect to their technical, economic and social merits.

Watershed management includes a wide range of activities like soil conservation, slope stabilization, river training, storage, treatment and supply of water, collection, treatment, and disposal of waste, flood protection, and forest management. Because of wide variations in distribution of resources and diversity of issues, watershed planning is always broad in scope. Such planning is needed at different levels and for different purposes. It, therefore, requires that many different uses of water, land and other resources are considered and evaluated, leading to the articulation of trade-offs among conflicting and competing objectives. It requires that decisions are made at many different levels, involving experts and decision-makers who have varied backgrounds: politicians, lawyers, and social scientists.

Watershed planning requires a compatible team who can draw a plan that is acceptable to the decision-maker and the public. However, future trends in demography and economy are difficult to predict and hence, elements of uncertainty enter the process. The other noteworthy aspect is that many decisions are more or less irreversible. For instance, once a dam has been built, it exists practically forever, regardless of whether there is a need for it or not. It will never be possible to restore the site to its original condition, even if a dam that is no longer needed is carefully decommissioned.

Integrated planning

A wise exploitation of watershed resources calls for integrated planning, which is the planning for water, land and other associated resources with coordination among geographical, functional and procedural aspects. It is important to note that unplanned use of resources is likely to lead to an imbalance because the availability of one resource in natural ecology is closely related to the use of another. The two basic requirements that must be met in basin-wide integrated planning are: improved coordination of a diverse variety of human activities, and integration and utilization of larger amounts of information.

As the awareness of the inter-relationships among diverse management actions has increased, it is imperative that planning should more explicitly consider and evaluate a large number of variables and functions. Now-a-days, while planning a water resource development project, it is essential to consider and examine its environmental impacts, rehabilitation of displaced people, submergence, afforestation, catchment area treatment, soil conservation, and command area development. These measures orient the project towards a balanced overall development.

Data and hydrological considerations

A sound planning requires a broad database and this should include topographic maps, demographic data, hydrogeological maps, soil properties, data about precipitation, related meteorological variables, water availability and demands, water use, effluents discharged with and without treatment and the quality of sources of water. The agriculture-related data include cropped areas, cropping patterns, water requirements and yields. This information would be most suitable if it is available for each planning unit, say at sub-watershed level. Such a database is not readily available for most watersheds in India, and often planners have to spend considerable time on creation of databases.

The use of water can be divided into two categories: consumptive use, in which water is an end to itself, and non-consumptive use, in which water is a means to an end. The consumptive use includes the use for municipal, agricultural, industrial and mining purposes. The non-consumptive uses are in-stream uses, such as hydropower, transportation, fish production and recreation. Consumptive uses are modeled using consumptive functions and non-consumptive uses are modeled using production functions. Modern water resource projects are mostly multipurpose in nature. A drop of water may be put to a number of uses from source to final disposal as shown in Fig. 4.

Water demand and use exhibit hourly, daily, monthly, seasonal and annual variations. Forecasts of water demand

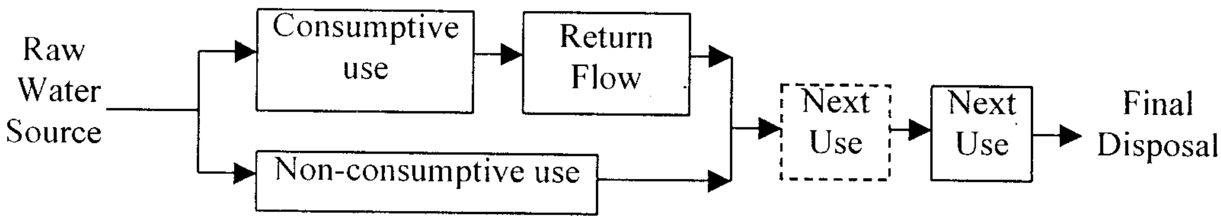

Fig. 4 Steps in use of water resources.

should also reflect technological changes in production processes, product outputs, raw materials, water handling and waste treatment methods, and public policies with respect to water use and development. Besides the magnitude, the variation of demands is equally important to examine how far the various uses are compatible with each other.

Social, political and cultural considerations

Watershed management schemes influence social, political and cultural life of the area, and it is important to consider these in the planning stage. WM activities that affect social life include building means of communication, such as roads, bridges, hospitals, parks, recreation centers, and drainage systems. As a result, trade and commerce grow, interaction with outside world grows, and there are more opportunities for social intermingling. This 'opening up' may also accelerate migration to and from the area.

The interaction with outside world also induces cultural exchange – new ideas seep in and local culture is exposed to larger audience. These may as well accelerate further WM activities as people begin to see the benefits of these actions. Sometimes, the social set-up and life styles change rapidly and society may undergo a complete transformation over a period of 15-20 years.

The political involvement in WM can work for its betterment as well as detriment. If right support is available, it can help in mobilizing funds and facilities. If the political support is not of 'right' kind, it may lead to mutual conflicts, differences, and various other problems.

In the process of WM, there will be beneficiaries as well as adversely affected people. Some people may have to be relocated because WM requires new projects (such as dams) to be built. It is necessary that the relocatees are adequately compensated and are helped to adjust to their new surroundings and professions.

Administrative, legal and other considerations

Since WM activities frequently involve work on land, administrative complications due to ownership of land, lease, rentals etc., arise and many times these issues result in court cases. Unfortunately, court cases take a long time to settle in India; the time horizon may be of the order of years. All this implies cost over-runs, delays, and tension.

The major factors determining the cost of a project are the size and areal extent of the project, e.g., area for soil conservation, slope stabilization, river training, quantity of water that must be stored, treated, supplied, and of waste water to be collected, treated, and disposed. While government continues to be major fund provider, private trusts are known to have funded many public welfare programs. There are numerous examples where projects were completed by funds collected through donation or labor arranged through 'shramdaan'.

Water rights

Water and land resources in a basin are owned by various categories of people and institutions. The concept of water rights is not much in vogue in India but it is discussed here because of its importance and wide acceptance as a management tool. According to the riparian doctrine, water rights are a component of the property interest that arise from the ownership of the land bordering a natural water course and include the right to make a reasonable use of water on the riparian land. There are two types of water rights: ownership rights and the right to use water. Resources in a watershed can be government-owned, privately owned, or these can be the property of a whole community. The ownership status depends on the national legal system and the type of resource. The practice of riparian water rights is followed in many countries and under this, land owners along natural water bodies have certain minimum rights to water use.

If the government is the owner of water, the use rights are generally granted by means of permits, concessions, etc. Once individuals own a confirmed right to a proportion of the resource, they have an economic incentive to exploit that resource efficiently. When a user has the assurance that he can continue to use the resource, he will invest in maintaining and running the system. If the rights are appropriately determined and allocated, the aggregate level of consumption will gradually reach an optimal level. For the rights to be acceptable, it is essential that the historical pattern of appropriation is taken into account. The rights to pollute can also be issued to ensure that the concentration of waste in the water body does not exceed the optimal level. Rights are one of the management tools and rights alone do not ensure an efficient use of water resources.

In developing countries with a high density of population, such as in India, most of the farmers have small landholdings. In some countries large farms are cultivated with extensive use of machines. The concept of *water banks* has been used in the USA as a method to match sellers with excess rights to buyers who can exchange the rights for a limited period of time.

Watershed Management in India

Although India is home to about 18% of the world's human population and 15% of the livestock population, it has only 2% of the world's geographical area and 0.5% of pasture lands. The per capita availability of forests in India is about 1/10th of the world average. In India, out of 3290 lakh hectares of geographical area, nearly 50% land is said to be either waste or degraded. Clearly, the land, water, and botanical resources of the country are under tremendous pressure. The carrying or sustaining capacity, in many cases, is either exceeded or is nearing the limit. This is the reason behind increased interest in WM activities in India. The main objective of WM in such a situation is to exploit resources, such as soil, water, land and vegetation, in a manner that these resources provide the maximum benefit to the society and at the same time are not degraded. The humans are central to WM and have different roles and responsibilities as the facilitators of development and beneficiaries, although in some cases they have also caused the destruction of resources. In these settings, the key to a good WM program in India is to apply the best available technology and organize, motivate, and involve people to attain the long-term objectives of social growth and development.

Depending upon the state of development, watersheds can be classified into three groups: virgin, properly developed, and degraded. In the first case, planning will have an important role in WM, while its role will be limited in the second case. In the third case, it would be desirable to place more emphasis on watershed restoration. The practices that protect, enhance, or rehabilitate the watershed are referred to as the 'best management practices' (Black, 1991).

The natural resources of watersheds have large variations, and it is neither possible nor advisable to exploit all of them simultaneously. The use pattern depends upon the demand and supply as well as preferences and priorities of the society. Many natural resources, such as water and timber, can be put to multiple uses. The multiple use management has two fundamental types: resource-oriented and area-oriented (Brooks *et al.*, 1991). It is helpful to understand the processes and regenerative capacity of a watershed. In fact, the unbalanced exploitation and use beyond the regenerative capacity is the root cause of degradation of a large number of watersheds in India.

A developed society prefers conserving its resources while a developing one is likely to be more interested in meeting the immediate needs. The decisions of private investors are likely to be governed by economic gains. Thus, the objectives will depend upon the nature of problem, and preferences of the local and regional society. The constraints arise due to physical, financial, cultural, technical, political, and social factors. In practice, there is a continuous interplay between objectives and constraints and these need not be considered sacrosanct. The severity of a problem may force managers to relax a constraint. For example, a watershed may be so badly degraded or the political lobbying so strong that the planners may be forced to relax the budgetary constraint.

Current programs and approaches

In India, watershed development or management has conventionally aimed at treating degraded lands with the help of locally available low-cost technologies (sometimes termed as appropriate technology), and through a participatory approach by close involvement of user-communities.

The broad objective of these programs was the promotion of overall economic development, and improvement of the socio-economic conditions of the poor sections of people living in problem areas. A large number of programs were formulated by the Govt. of India as well as the state governments. The Drought Prone Areas Programme (DPAP), the Desert Development Programme (DDP), and the Integrated Wasteland Development Programme (IWDP) were converted into the watershed mode in the late 1980s and 1990s. Several other programs of various ministries are now being implemented with a watershed as the basic unit because the common theme has been the natural resource management for sustainable development and community empowerment.

Based on a number of studies and discussion in various fora, a set of guidelines has been formulated to develop and execute watershed development projects. These have been updated from time to time. According to these guidelines, the broad aim of watershed development is to ensure:

- Program-specific and focused project approach,
- Greater flexibility in implementation,
- Well-defined role for state, district and village-level institutions,
- Seeking a combination of GO/NGO as project implementing agencies,
- Removal of overlaps,
- A "twin track" approach to the implementation of projects,
- A greater role of women,
- An effective role for the Panchayat Raj Institutions,
- Bringing to centre-stage self-help groups, comprising rural poor, especially those belonging to scheduled caste and scheduled tribe categories.
- Establishing a credit facility from financial institutions,
- Transparency in implementation, and
- Effective use of remote sensing data.

It is a matter of satisfaction to note that quite comprehensive guidelines for watershed development have been evolved. Many state governments have placed these guidelines on their web-sites for easy and wider dissemination.

Normally, a watershed of about 500 ha is the unit of development for each project. Most states have developed watershed atlases and have assigned code numbers to various watersheds. These numbers are also used to track development activities in the watersheds. To ensure coordination among various bodies, state level committees have been constituted in most states and constitution of district level committees is also envisaged. The Zilla Parishads and Panchayati Raj Institutions (PRIs) have very important role to play in WM in India. To ensure community participation and help in training at village levels, the Gram Panchayats are being deeply involved in the implementation of the programs.

Management of groundwater

In India, groundwater is the main source for irrigation and drinking purposes. In early days, abstraction from the shallow aquifer was limited, mainly because demand was less and water-lifting devices were animal-powered. The high growth of population a spurt in industrial activities over the last 4 decades and conversion of vast waste lands into cropping land have forced abstraction of more groundwater. The number of wells has increased and the animal-powered lifting devices have progressively been replaced by energized pumps.

Traditionally, groundwater is considered in India to be the personal property of the landholders. Each landholder develops his shallow or deep bore wells without any coordinated plan. The rapid development of groundwater has resulted in fast decline of water table in many parts of the country, particularly in hard rock region, causing shallow wells to dry each year. This has resulted in deterioration of water quality, and widespread drying-up of wells following a 'failure' of the monsoon. Large resources are wasted due to drying up of wells and new wells are drilled without understanding the hydro-geological system of the basin. Many poor farmers are unable to deepen their wells to chase the declining water levels. This has resulted in socio-economic conflicts. In coastal areas, declining water levels are also associated with the ingress of saline water, leading to reduced crop yields, loss of drinking water supplies and ultimately loss of both fertile land and water supply wells. Though sporadic attempts had been made by government to regulate the over-abstraction of groundwater, so far nothing significant could be achieved.

Given the importance of groundwater to the national economy, efficient management of groundwater resources is essential. Addressing the problem of over-exploitation in India is a complex phenomenon. Deepening of wells does not appear to be a viable option as most wells have already fully penetrated the shallow weathered aquifer. Traditional methods of groundwater management are a mix of regulation (controlling the abstraction) and pricing of the water and energy used for pumps. However, this has not worked in any part of the country.

The groundwater problem in India is a sensitive issue and can not be solved by mere legislation. The need is to educate the rural folk to share the available groundwater by themselves. This needs a technical approach, using simple groundwater models which make people understand the problem and ensure community participation for groundwater management. We have to evolve an implementable methodology for rational management of groundwater and thereby find a lasting solution to the problem of water scarcity, quality and debt trap.

Role of NGOs

Non-Governmental Organizations (NGO) have an important role to play in watershed management. In India, the most visible involvement so far has been through the Water Users Associations (WUA) or WM at the local level. In a few cases, the NGOs are involved in planning and design or decision-making. Reputed NGOs, like Tarun Bharat Sangh (TBS), Adarsh Gram Samiti (headed by Sri Anna Saheb Hazare of Rale Gaom Siddhi) have done praiseworthy work in the field of WM and have won international recognition. It is a matter of pride that Mr. Rajendra Singh of TBS was awarded the Magsaysay award for his pioneering and inspiring work. Many NGOs have made significant contributions in the area of rainwater harvesting.

However, there are a number of NGOs, some with large membership, who have been at the forefront for their opposition to big projects.

A watershed council is a local group that collaboratively participates in the management of water and other natural resources at the watershed scale. The main aim of the council is to develop/improve relations and establish communication among the stakeholders and managers. The local context of councils helps avoid conflicting decisions that will hurt local interests, traditions, and customs. Broadly, the membership of a WM council consists of active and inactive members. Active members enthusiastically participate in activities/meetings while the inactive members are happy to just receive regular communication such as a newsletter. A criticism of councils is that these try to involve only the people who have similar or supporting views.

The source of funding has a strong bearing on the working of a council. Normally, a source that puts minimum conditionalities is preferred. Many government departments tend to put so many constraints and strings that the council may itself become another bureaucratic set-up. Many NGOs/councils are unwilling to accept those government supports that put so many constraints that it is difficult to devote enough time for real work. Of course, it is pertinent to ask: why should people approach a council? Mostly, private persons or businesses approach a council only if they require some funding.

There has been a mushrooming of NGOs in India during the last two decades. While there are many good NGOs, there are some others who do not have requisite expertise or commitment. Therefore, evaluation of their working and monitoring is necessary to ensure proper use of financial and other resources. At present, the evaluation of the working of NGOs is highly subjective.

Role of institutions

The role of government institutions covers the entire spectrum of WM, from law-maker to facilitator. Many times, special organizations are established if the existing ones prove to be inadequate due to budget, man-power, financial, or procedural constraints. The government institutions also help in WM activities by providing direct funding, funding through an NGO, or by commissioning of specific studies.

A vast and well-organized institutional structure is necessary to carry out the various tasks of WM. This structure should facilitate the necessary coordination within the water resources sector and linkages with other sectors, such as land-use and environment, to achieve sustainable water use and maintain the ecosystem balance. The institutional structure in India should also be a means of empowerment. All stakeholders, local communities and women should be able to play an active role in WM.

The infrastructure requirements depend on the tasks to be performed in WM. Three major tasks of a watershed management organization are (i) planning, (ii) design and construction, and (iii) operation and maintenance. The infrastructure and expertise needed for these tasks are completely different. Although planning receives much attention in the initial years, it is in fact a continuous activity. Since the requisite expertise may not be available within the organization, it is usually necessary to involve experts from other institutes, sometimes through commissioned studies. Usually, the construction activities are most important during the initial years when infrastructure is being developed and a large share of funds as well as man-power is allocated for the same. This, however, diminishes appreciably after the infrastructure is in place. In addition, the organization may also be responsible for enforcement and implementation of decisions. Legal issues also may arise.

Role of financiers

Many water resources projects require large financial outlays and it is often necessary to seek loans or funding from international financiers. Since the funds available with these financiers are also limited and many of them are under obligation to promote the policies of their promoters, the project proposals are scrutinized by them before funds are allocated. The likely adverse environmental impacts of a project are carefully examined these days, and it is difficult to find a reputed funding organization willing to support a project which does not pass strict environmental conditions. Of course, most governments are themselves keen to maintain or improve environment quality. International funding agencies are sometimes able to significantly influence the management policies by providing funds to the activities that are designed and operated following the principle of sustainable development. Of late, most international agencies treat water as an economic commodity and emphasize active participation of stakeholders. Agencies like World Bank also emphasize decentralized management and active participation by stakeholders.

Water charges

An important and sensitive issue in watershed management relates to water charges. Charges are an effective and efficient means to finance developmental activities, and minimize wastage and pollution. It is easier to attract and involve the private sector if water charges reflect the full cost of providing services and some profit. However, a caution is to be exercised here since water is also a social good and, therefore, it should not be so expensive that the poor are not able to afford it. Moreover, high water charges can substantially reduce margins on agricultural products and can have cascading effect on other commodities. Inputs to agriculture are subsidized to varying degrees in most countries and there is always a political opposition and resistance to high water charges. From a management point of view, high charges are difficult to enforce. The concept "user pays for use and polluter pays for the pollution that he is causing" has been successfully used in France.

Water can be charged based on the actual usage or on a lump-sum basis. The charges that are based on actual water use certainly help reduce the water use and wastage; the extent of the savings depends on the price elasticity or the sensitivity of water use to the cost to the user. It is generally low in the case of drinking water and high for irrigation water.

Ideally, water rates should be based on the opportunity cost of the water use (the value of the next best alternative use). If this is not feasible, the charges should be fixed so as to at least recover the cost of providing water-related services. This will ensure that enough funds are available for operation and maintenance. By assigning prices equal to their marginal cost, the full benefit of those goods to society will be reflected in equilibrium. Users facing such prices will base consumption decisions on the real economic cost of providing the goods. The fixation of water charges is somewhat easier in case of municipal water supply and irrigation while the evaluation of benefits of drainage and flood control is more complicated. Of late, many countries have privatised water services or are in the process of doing so with a view to improve the efficiency.

In many countries including India, consumers pay much lower prices than the cost of providing services. In view of the non-recovery of operational expenses, the quality of services has degraded at many places. Maintenance of the infrastructure usually is the first casualty in case of the shortage of funds. For poor users, lower charges can be fixed, but the economic viability of providing the services should not be undermined. Ironically, if the services are not up to the desired level, the poor people are the first and the worst sufferers. A possible solution is to link the rates with the ability to pay. Evidently, fixing water prices is not a technical or economic issue; it is more a socio-political issue.

Watershed Management: New Approaches and Tools

The preceding discussion brings out the complexities and dimensions of WM and factors involved in it. A satisfactory solution of the problem requires application of the best tools that are available. Some issues and tools, as well as approaches that are widely practiced in the western world, are being described below. These are not yet being used on a large scale in India due to various reasons, though the concepts may be well known.

The most important development paradigm in the developed countries is the concept of sustainable development. This is now considered to be the first guiding principle in many countries for formulating any management policy. The following two recent approaches appear to have made make the best use of technology and human resources.

New Techniques of Data Acquisition and Analysis

There have been several revolutionary changes in techniques of data acquisition and analysis in the last decade. The most notable are the use of global positioning systems (GPS), remote sensing and geographic information system (GIS).

Global Positioning System

GPS is a satellite-based radionavigation system developed and operated by the US Department of Defense (DOD). The GPS concept of operation is based on satellite ranging. The system permits users anywhere in the world to determine their position with a precision and accuracy far better than other available radion-avigation systems. Users figure their position on the earth by measuring their distance from a group of satellites in space. The satellites act as precise reference points. GPS reached full operational capability on July 17, 1995.

Useful information about GPS is available at web-site http://www.gpsy.com/gpsinfo/. GPS consists of three segments: space, control, and user.

The space segment consists of 24 operational satellites in six circular orbits 20,200 km above the earth at an inclination angle of 55 degrees with a 12 hour period. The satellites are spaced in orbit so that at any time a minimum of 6 satellites will be in view to users anywhere in the world. The satellites continuously broadcast position and time data to users throughout the world.

The control segment consists of a master control station in Colorado Springs, with five monitor stations and three ground antennas located throughout the world. The monitor stations track all GPS satellites in view and collect ranging information from the satellite broadcasts. This information is sent back to the master control station, which computes extremely precise satellite orbits.

The user segment consists of the receivers, processors, and antennas that allow land, sea, or airborne operators to receive the GPS satellite broadcasts and compute their precise position, velocity and time.

Each GPS satellite transmits an accurate position and time signal. The user's receiver measures the time delay for the signal to reach the receiver, which is the direct measure of the apparent range to the satellite. Measurements collected simultaneously from four satellites are processed to solve for the three dimensions of position, velocity and time.

GPS provides two levels of service — a Standard Positioning Service (SPS) for general public use and an encoded Precise Positioning Service (PPS), primarily intended for use by the Department of Defense. SPS coverage is continuous and worldwide and the signal accuracy is intentionally degraded to protect US national security interests. This process, called Selective Availability (SA), controls the availability of the system's full capabilities. The SPS available to civilian users should give 20 m horizontal accuracy. However, it is normally degraded to 100 m (95% of the time) due to Selective Availability (SA). The vertical accuracy is about 1.5 times worse than the horizontal, due to satellite geometry (satellites are more likely to be near the horizon, than directly overhead).

Differential GPS (DGPS) is a means of correcting for some system errors by using the errors observed at a known location to correct the readings of a roving receiver. The basic concept is that the reference station "knows" its position, and determines the difference between that known position and the position as determined by a GPS receiver. This error measurement is then passed to the roving receiver which can adjust its indicated position to compensate.

The differential reference station computes the errors in the pseudorange measurements for each satellite in view separately, and broadcasts the error information, and other system status information, by some means. A differential beacon receiver receives and decodes this information, and sends it to the "differential ready" GPS receiver. The GPS receiver combines this information with the individual pseudorange measurements it makes, before calculating the position. DGPS eliminates the error introduced by Selective Availability, and errors caused by variations in the ionosphere, resulting in reported positions within about 10 m of the true position 95% of the time, especially for typical marine DGPS systems using inexpensive navigation receivers. Better receivers can get within 3 m, or so. The DGPS correction data can be used as far as 1500 km from the reference station, depending on the DGPS setup.

GPS has proved to be a very useful tool in a large number of fields. A GPS receiver is handy in locating the position of observer during watershed surveys and mapping, and therefore, it is becoming an indispensable tool in field trips.

The land phase of the hydrologic cycle is influenced and controlled by surface and near-surface features of earth which have inherent spatial variability. In the absence of a reliable technique to measure spatial features, point values are commonly used in the analysis. Remote sensing (RS) is a technique which has the potential to provide measurements of areal properties.

Of late, the term RS is chiefly used to denote the acquisition and analysis of satellite data for exploration, mapping and management of the earth resources. The main advantage of the technology is that it provides a broad perspective over a large area. One can "see" beyond visible electro-magnetic (EM) radiation band, and data of inaccessible areas can be obtained easily. Remote sensing techniques have extended the scope of utilization of the EM spectrum to almost its entire range. Depending on the sensor, it is also possible to infer the characteristics of a top thin layer of the earth's surface.

One of the main advantages of RS techniques in management of natural resources is the synoptic coverage of the earth on a periodic basis with small expenses. The other advantages of RS over the conventional methods are enumerated below.

Data resolution: With the availability of data of sensors with resolution of the order of a few meters, highly accurate maps can be prepared using RS technique. For watershed modeling, the accuracy is well within the desired limits.

Speed of analysis: Time can be saved by the use of the RS, particularly the time spent in field. Although collection of ground truth data is essential, this can be minimized by visiting selected spots in the study area.

Sampling frequency: Currently RS data are available at an interval of 15 days or less. This helps in better evaluation of temporal changes in the land resources.

Digital Image Processing (DIP) involves the manipulation of digital data to improve the image qualities or to enhance the features of interest with the aid of a computer. The process helps in maximising clarity, sharpness, and details of features of interest and leads to better information extraction. DIP may involve procedures that can be simple as well as quite complex. Basically, each pixel of an image is mathematically manipulated and the operation may involve more than one image. The results of computation for each pixel form a new digital image which may be subject to further manipulation, and can stored, as a soft copy of a hard copy.

The main fields of RS application in watershed management are measurement of precipitation, evapotranspiration, irrigation water management, snow cover mapping, landuse/land cover mapping, and hydrological modelling. The use of RS data in hydrology requires efficient storage and retrieval of RS raster data in a data bank coupled to a GIS. The GIS aids the hydrologist to produce a series of derived maps from the original RS data and helps derived data for hydrological modelling.

The term 'sustainable development' came into usage in the 1980s. This term was popularized mainly by the Brundtland Commission report, Our Common Future (WCED, 1987). However, the concept itself is not new. As noted by Biswas (1994), the general philosophy behind the sustainability concept was expounded centuries, if not millennia earlier. Similar thoughts on living in harmony with nature can be found in ancient Indian religious texts, such as *Rig-Veda*.

There are many ways in which the term 'sustainable development' has been defined. It was defined by WCED (1987) as the "development that meets the needs of the present without compromising the ability of the future generations to meet their own needs". With specific reference to water resources, ASCE (1998) defined the concept as: Sustainable water resource systems are those designed and managed to fully contribute to the objectives of society, now and in the future, while maintaining their ecological, environmental, and hydrological integrity. Watershed systems that are able to satisfy the changing demands placed on them over time without serious degradation, can be called "sustainable".

Basically, sustainable development aims at maintaining equilibrium between human needs and economic development, while preserving the environmental conservation through efficient use of natural resources. It emphasizes the need to review environmental protection and economic growth with parallel compatibility. Nowadays, it is considered to be the most reasonable way of combining the current growth with planning of future projects.

The current interest in sustainable WM has stemmed from the realization that some of the past or current activities have or could cause irreversible damage to the ecosystem. This damage may adversely affect not only our own lives but also the lives of our successors. To address these questions, it is helpful to differentiate growth from development. According to Loucks *et al.* (1995), growth involves making the pie bigger, building new capacity in new places, improving the standard of living, etc. Development involves capacity expansion *in situ*, redistribution of existing resources, more efficient use of scarce resources, and the like.

The relevance of sustainable development in Indian context emanates from the fact that the current development trends in India appear to be unsustainable in a variety of ways. For example, many canal command areas in India are facing water-logging and soil salinity problems. These are the results of faulty design and/or bad water management. Given concerns with economic decline, population growth, and heavy resource depletion during the past two decades, many analysts have made pessimistic predictions about the future possibilities for the continued growth of economy and the ability of developing countries to attain the economic levels reached by developed industrial societies.

Decision support systems (DSS)

The management of natural resources requires integration of a large volume of disparate information obtained from diverse sources. A framework is required to couple this information with efficient tools for assessment and evaluation that allow broad, interactive participation in planning and decision making process, and effective methods of communicating results to a broad audience. Relevant and useful information needs to be made available to a multitude of participants in open and participatory decision making set-up, and this information is to be effectively utilized.

A DSS helps in attaining this objective. 'Computer-based models together with their interactive interfaces are typically called decision support systems' (Loucks, 1995). The integration of techniques, such as data base management, GIS, simulation and optimization models, and interactive, symbolic and graphical user interfaces, animated graphics, hypertext, and multi-media systems, often provide the necessary power and flexibility to support environmental planning and management (Fedra, 1994). A typical user of a DSS will be a decision maker who may want to view a problem in various perspectives and solve it, or the one who requires data to make an informed decision. The common objective of all DSSs is to provide timely information that supports decision makers. Decision makers need information when the opportunity to use that information exists, for any information provided thereafter is of little use. This need is the key consideration that motivated the development of DSSs.

The key to useful computer-based decision support is integration. In a real-world application, several sources of information, more than one problem representation, and a multi-faceted user interface ought to be combined in a common framework to provide realistic, timely, and useful information. At the level of data and background information, numerous and often incompatible, non-commensurate data from disparate sources have to be compiled together. Advances in information technology have made it possible to easily access large volumes of information and databases.

The typical components of a DSS are: models for system design and determination of operating policies, optimisation and simulation models to determine values of decision variables or system performance indices, algorithms to calibrate models, geographic information systems for analyses and display of spatial data, knowledge-based expert systems that can process rules and data to draw conclusions, management information systems, and utilities (statistical, graphical, and spreadsheets software for data analyses and display).

A user interface communicates the results in a form that are better appreciated by the user and facilitates interactions between him and the computer. The visual interfaces also make it simpler to interpret model output. Many planning and management concepts, such as risk or reliability, are rather abstract and are better understood through graphical representation.

Many DSSs are being applied to a wide variety of problems. The growth in the DSS development and use has been substantial in the water resources fields (e.g., Labadie, 1989; Loucks and da Costa, 1991; Santos, 1991). Applications of DSSs for watershed studies have been discussed by HEC (1993), Basson *et al.* (1994), Loucks *et al.* (1995), Randall *et al.* (1995), Andreu *et al.* (1996), and Jamieson and Fedra (1996).

People's participation

Evaluation of many past development projects has shown that poor identification of the needs of local communities and inadequate assessment of the social impacts are key reasons for project failures and nonacceptance. Local residents with sound knowledge about the area can sometimes provide better input than 'an outsider planner' or the officers of a government agency. At the same time, local communities may not be able to appreciate new ideas unless they understand the thought process which has generated these ideas. An important remedy is more rigorous pre-project analysis of social and cultural conditions, more interaction with people, consulting local communities during project design, and implementation of 'open' planning.

Public participation (PP), also termed as public or people's involvement, is the process through which the views of all interested parties (persons or groups having an interest in the project or stakeholders) are integrated into project decision-making. PP should not be limited to just ascertaining different views. It should also make the project-affected people conversant about the decisions being made and implications on their life and environment. At the same time, it is important to ensure that expression and consideration of public viewpoints does not improperly impede the decision-making process.

The main aim of PP is to create openness and dialogue so as to improve decision-making. Although PP may appear to be time-consuming and costly at first, the long-term benefits far exceed initial costs. It is an iterative and flexible process which should take place throughout the lifetime of a project. This process should, ideally, start when the project is being conceived.

The concept of PP has evolved over time through learning and experience. The PP includes a number of activities where each step is a prerequisite and leads to the next. Considerable pre-planning is needed and PP has to be carefully handled to gain the most out of it. The four main activities of PP are: (1) information gathering, (2) information dissemination, (3) consultation, and (4) participation.

In several countries, water resources planning and management is the responsibility of specialized agencies which represent the interests of all water users. The public is represented through political representatives. Except this, generally there is no public participation in water resources planning activities in many countries. In some cases this has led to serious problems during execution of projects. It is necessary to acquire land for reservoir and canal projects; there may also be displacement of population due to land inundation. There might be resentment against the project among the adversely affected people if they feel that they have not been adequately compensated.

The key advantages of PP is that it reduces the risk of project failure by improving the quality of planning and decision-making. It helps in development of the feeling of partnership with local communities. PP helps in improving the project performance by using the technical expertise of the public. The government gets increased credibility, legitimacy, and positive image through transparent decision-making, particularly when decisions are controversial. Also there is reduced risk of serious confrontation, thereby minimising project costs and delays. The public gets an improved understanding of the impact on their lives and finally a better project.

In the US, a paradigm shift in public participation is being noticed from the adversarial, top-down, public-meeting approach to a collaborative, bottom-up, citizen-led and citizen-organized approach (Griffin, 1999). A growing number of watershed councils is being established, particularly in the western states of the US. An important indicator of this shift is the emphasis on ecosystem management. Agencies are using a hierarchical system of mapping ecosystems to support management.

Indian Scenario

The first step of WM is to identify the watershed and demarcate its extent. Selection of watershed of an appropriate size to manage is difficult and this depends, inter alia, on the nature of the problem too. The main difficulty arises in identifying a problemshed (geographical area) that is large enough to encompass the issues but small enough to make implementation feasible. Further, a watershed boundary may not always coincide with all the problemsheds. For example, problemsheds based on wild-life, forests, etc., may spill over watershed boundaries. In such cases, it is advisable to establish close coordination with other organizations who have expertise in the relevant disciplines. As per the Watershed Development Guidelines of the Government of India, the watershed area may be about 500 ha. This size is suitable for small-scale development and a typical NGO would be able to manage it. If the interest lies in large-scale development, one will have to adopt a much larger watershed.

Watershed and problemshed boundaries seldom coincide with political and social boundaries. Within a watershed too, many human boundaries exist, such as individual farms, villages, ethnic groups and provincial boundaries. This 'mismatch' between a watershed perspective and socio-political perspective has important implications in WM. Two options are available to identify the study area: one can choose hydrologic boundaries either or the political/administrative boundaries. In the first case, the organizational structure for management is based on top-level watershed, sub-watershed and so on. If the administrative boundaries coincide with the hydrologic boundaries, there is least chance of upstream-downstream conflicts.

When following hydrologic boundaries, the entity that is responsible for overall management at the topmost level, is the 'river basin authority'. In India, there are many river basin authorities, such as the Bhakra Beas Management Board, Damodar

Valley Corporation, Brahmaputra Board, etc., but these cover only a small part of the country. Moreover, within the jurisdiction of their basins, these authorities control only a small domain of WM. In a large part of the country, administrative boundaries are followed for water management. As is well known, WM requires large volume of data. Many data items that are needed for watershed management, e.g., agriculture data, are available at district/tehsil level. If these data are to be used in WM, these are required to be appropriately reorganized and interpolated.

After the area and the problems have been identified, one needs to choose the tools. In many studies, particularly those in which a foreign agency is involved, approaches and models that have been developed in other countries are applied directly. However, there are significant cultural, social, and behavioral differences between India and the western world; the infrastructure (electricity, transportation) support, application of technology, resources, equipment maintenance facilities, etc., are at a different level. These have to be given due attention while planning/executing any WM activity. Besides, differences could be noticed in the viewpoint of the people. For example, computers/Internet are an essential means of communication in western countries while in India most people still prefer face-to-face meeting or hardcopy letters. But a face-to-face meeting means people have to travel and hence meetings are an expensive affair and can not be organized frequently. A significant number of stakeholders/tribals are still illiterate although the literacy rate is gradually increasing. Besides, the local language changes from region to region and sometimes within a district. This involves extra expenditure on education, training, and skilled man-power in different languages.

Despite the odds and handicaps, many people have done praiseworthy work and have achieved success by applying the limited and conventional methods. This was possible due to their hard work, commitment, and dedication. It is worthwhile to recall a few success stories before making suggestions to improve WM in India.

Success stories

A look at the current scenario of WM in India reveals a number of success stories.

Among the studies that have been widely reported is the pioneering work by an NGO named Tarun Bharat Sangh in Rajasthan. This NGO has taken up WM work in a number of watersheds and has been able to improve water availability in them. They have also been involved in construction of hydraulic structures at some places with the active involvement of local community. Another noteworthy achievement is the work at Ralegam Siddhi by Sri Anna Saheb Hazare. Water conservation and catchment treatment was undertaken over a large area in Maharashtra by his group, and they were able to conserve water and provide irrigation to about 1200 acre land that could produce crops worth nearly 50 lakh each year. Increase in agriculture output has cascading effect on many sectors of economy.

The Chipko movement launched by Sri Sundar Lal Bahuguna in the hills of

Uttranchal mainly to check deforestation has also generated considerable interest. The watershed restoration work in many districts of Madhya Pradesh has also won praise.

Neeru-Meeru Program of Andhra Pradesh

The total geographical area of Andhra Pradesh is 275 lakh hectares out of which wasteland and degraded lands constitute 115 lakh hectares (42%). The state receives an average annual rainfall of 896 mm. Out of the total volume of 244.4×10^9 cubic metres rainfall received, 41% is lost as evaporation and evapotranspiration, another 40% is lost as surface run-off, about 10% is retained as soil moisture, and 9% is recharged as ground water. In this scenario, the objective of the water conservation mission is to develop a clear vision and strategy for water conservation and its sustainable utilisation at the state level, prepare time bound action plan and take measures to ensure convergence of the plans and programs of the various departments working directly or indirectly for water conservation and utilization.

A ten-year watershed program for development of all degraded and waste lands was launched during 1997 to treat 100 lakh hectares. So far, about 32.20 lakh hectares of degraded and waste land has been treated by 8574 watershed committees under Rural Development department and 16.82 lakh hectares of degraded forest land has been treated by 6726 Vana Samrakshana Samithis (VSSs) under Forest department. The AP government has brought all water conservation activities into campaign mode to ensure convergence of the efforts of all water-concerned departments in the name of Neeru-Meeru (Water and You) to promote water conservation on a mission basis. The Neeru-Meeru concept envisages creation of awareness amongst people for ensuring their participation in water resource management.

While prioritising areas, the ground water department has identified 494 Mandals. Besides, villages/habitations which experience drinking water scarcity and areas with groundwater within 10 m from surface have been included. The departments involved in executing Neeru-Meeru work include Rural Development, Forest, Minor Irrigation, Rural Water Supply, Municipal Administration and Urban Development, and Endowments. Neeru-Meeru envisages to co-ordinate and guide the water conservation efforts initiated by various departments. The activities taken up by different departments are aimed at creating more filling space for harvesting rain water, which contributes to additional ground water recharge. The work involved in implementation of Neeru-Meeru program includes constructing check dams, percolation tanks, ponds, channels, and restoration of these for higher recharge of ground water.

The state groundwater department has conducted impact analysis studies of works taken up under Neeru-Meeru on ground water levels and found that due to deficit rainfall of 27%, the depth to water level at the end of August 2002 was 10.62 m as against 10.40 m at the end of August 2001. Net fall of 0.22 m was recorded in the state between August 2001 and August 2002, due to long dry spell and over-exploitation of groundwater. Seasonal bore wells (dried up bore wells, hand pumps) were reduced from 9594 to 4079 between September, 2001 and September, 2002. Drinking water transportation to habitations was reduced from 320 to 314 between September, 2001 and September, 2002. Expected additional recharge due to Neeru-Meeru work is 6.1×10^9 cubic metres.

The Government has constituted committees at state, district, constituency, municipal, mandal and gram panchayat levels, involving elected representatives, officials, NGOs and other concerned agencies to facilitate people's participation in water conservation movement. Neeru-Meeru is executed by stakeholder groups or committees, viz Vana Samrakshana Samithis, Water user associations, Yuva Shakthi and village education committees.

Despite many success stories, a perceptible change in the condition of watersheds is not visible and much needs to be attained in the field of WM. Currently (2002), India is under the grips of a severe drought. The rainfall deficit is of the order of 30% and this is said to be the worst drought in past 30 years. Reports indicate that the country is still as vulnerable to natural water related disasters as it was many decades ago, and that many WM initiatives have failed to make any significant dent in combating floods and droughts.

Recommendations

In view of the alarming situation in many watersheds in India and the future projections of demands for various watershed resources vis-à-vis supply, a number of steps need to be taken to restore and maintain the limited natural resources of watersheds. Many of these are long-term measures. Some important ones are listed below.

i) A nationwide integrated WM program may be launched. This program could be an integral part of the 5-year plans and ideally should consolidate the scattered efforts. Although this will be a national effort, the focus in various areas should be based on the problems of that area, and the programs should be tailored accordingly.

ii) The emerging technology, such as remote sensing, GIS, and improved models, have been used in some recent studies in India. It is necessary to multiply these efforts and Indian scientists should develop models that can specifically consider the Indian conditions. The assumptions and parameters of these models should suit the conditions in the watersheds in Indian. This will be a long-term effort and may be carried out as a multi-agency collaborative work.

iii) Currently, a large number of WM projects are implemented in different parts of India. Many of these are supported by international funding organizations. The tools and techniques applied in these projects as well as the valuable experience gained would certainly be of immense use to those who are working in this field. This would require a coordination of efforts and creation of a database of all relevant studies and works. Since codes have been assigned to watersheds, these could be used to organize the database.

iv) The creation of a hydrological and meteorological database is equally important. A modeler has to put in a lot of effort in data collection and assembly. Digital maps are almost non-existent in India. A database of digitized watershed maps and other hydro-met data will give a big boost to application of latest models to Indian conditions. These databases should be easily accessible to bona fide users.

v) There is also a lack of project follow-up action. A large number of pilot projects have been launched and implemented all over the country. Usually, after the project is over, the staff are transferred elsewhere, the equipment are not maintained, and the models and techniques are lost or get buried in files. To avoid these eventualities, one of the associated organizations should be assigned responsibility to follow up the project activities for a reasonable period after the study is over.

vi) In India, rainwater harvesting has received considerably attention during the last few years. This is a step in right direction and rainwater harvesting is to be practiced on a large-scale. However, then this alone will not be enough. Rainwater harvesting can only partially help in extreme situations. The experience of the drought of 2002 shows that so far we do not have a workable strategy and means to fight severe droughts in a meaningful way. Since preparedness is necessary to deal with such disasters, WM needs to be backed up by a long-term weather forecasting set-up.

vii) In India, one frequently comes across instances of conflict between government organizations and public at large. A possible reason could be that during the last 50 years, watershed management has gradually moved from a people-centered program to a government-centered program. The participation of communities through bodies, such as Panchayats, has gradually declined. In the process, the traditional wisdom has been relegated to oblivion. While some traditional practices may not be optimal, it would be unwise to ignore them altogether. The recent guidelines do talk about involvement of Panchayats and communities but still the government set-up is viewed with suspicion and definitely not as a friend or benefactor.

viii) All multi-agency efforts, such as WM, require a clear identification of who own the responsibility and who pays (Grigg, 1999). This first aspect requires a good coordination among various organizations that are associated with WM. Such coordination is currently missing, and it is common to see people having a limited perspective of the problem. Even there are instances of conflicts among government organizations. The situation regarding payment is also not very clear in India. Except in a few states, people simply do not pay for the water they use. A poor recovery of operational expenses has led to deterioration of facilities and dis-interest by private sector in management. To overcome these hurdles, it is necessary that charges for use of watershed resources are fixed and recovered such that the cost of providing the services is recouped and wastage is avoided.

ix) Lastly, integration of all WM efforts and proper documentation is very crucial and necessary.

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