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Integrated water resources management – role of research and development in hydrology

S. M. SETH
Former Director, National Institute of Hydrology, Roorkee, U.P.-247667, India

Abstract
The high rates of population growth and the expectation of improved living standards is leading to increasing pressures on water resources. There is need for continuous monitoring and quantifying changes in the natural environment and dynamic hydrological regimes due to human activities and climate change. Uncertainty in future demands and availability of water has to be properly understood and accounted for. Some of the critical areas would need study over extended periods in a well coordinated manner to provide effective hydrological R&D inputs. Various issues of integrated and sustainable development of water resources require greater use of hydrological knowledge and expertise, improved observations and analysis, and above all effective communication between hydrologists and policy makers. The modern scientific developments in electronics, mathematics and computer as well as remote sensing and GIS techniques offer vast potential for effective R&D in hydrology.

The new ethic of sustainable development reinforces and extends the main principles of water resources management. It has been agreed that there is more of water management crisis than water crisis. It is bad management, bad institution, bad governance, bad incentives and bad allocation of resources, which are threatening our water resources.

INTRODUCTION

Land and Water Resources are the greatest assets and only by their proper utilization poverty can be banished and the standards of living for millions of people particularly in rural areas could be raised. In the past 200 years our population has grown exponentially. We need more food and more water to meet the increasing demands. In the past 100 years the world population has tripled, but water use for human purposes has multiplied six times. In recent years, there have been somewhat indiscriminate developments of urban settlements and industries and encroachment of the flood plains. The high intensity rainfall during the monsoon season leads to the problem of floods causing heavy devastation almost every year. Also, there are serious problems of large scale deforestation and soil erosion on hill slopes causing irreparable damage to the ecology and frequent occurrence of floods. There are many areas that suffer from droughts every year. The increasing pressure of growing population is putting limited land and water resources under stress, particularly in arid and semi-arid regions of the country.

There is water crisis today. But the crisis is not about having too little water to satisfy our needs. It is a crisis of mis-management of water whish has resulted in the suffering of people and the environment. Real solutions require an integrated approach to water resource management. Water resources planning and management for maximum net economic benefits is not sufficient anymore. Introduction of the principles of sustainability is further expanding the range of issues that must be incorporated in the objectives of water resources planning. (Simonovic, 1996). The other aspect of the sustainable water resources planning and management context is the challenge of time (long-term consequences). Sustainable development requires forms of progress that meet the needs of the present without compromising the needs of future generations.

Some of the crucial issue which may require attention in near future may include: limiting the expansion of irrigated agriculture, increasing the productivity of water, increasing storage, recharging groundwater, harvesting rainwater, reforming water resource management practices by pricing water services, by making managers responsive to users, by empowering communities to participate in the water management, increasing cooperation in inter-state basin, valuing ecosystem functions and supporting innovation. Water is essential to life, development, and the environment and the three must be managed together, not sequentially.

RIVER BASIN AS A NATURAL PLANNING UNIT

Optimal development and management of water resources calls for an integrated approach at the river basin or sub-basin level which is the natural hydrological unit in respect of water resources. The prevailing legal and administrative framework is not very conducive to basin level planning and management of water resources. India is a Union of States. Most of India's river basins are inter-State in nature. India's Constitution provides power to the States to develop the water resources within their boundaries. Unlike initial status of water resources development in which large projects in a number of river valleys were taken up by the States to boost up agricultural production to achieve self sufficiency in food and many easier sites for putting up storage structure have already been exploited, the future major water resources projects have to be taken up at rather difficult locations. The new projects are more likely to be inter-state in nature. Also as the demand on available water resources increases with developmental activities, interactions between projects come into play and multi-state interests may have to be taken care of. For flood management activities too, river basin is the most suitable and proper unit for planning and implementation of various programs. All these factors point to the necessity of moving progressively beyond the limited vision of satisfying the interests of a basin State in the waters of the basin to meeting the legitimate needs of water deficit basins by harnessing water surplus basins by inter-linking and onto meeting the Nation's water needs through integrated harnessing of the Nation's water resources.

MAN’S INFLUENCE ON HYDROLOGIC CYCLE

Water, besides being essential to life, is also the most manageable of the natural resources; it is capable of diversion, transport, storage and recycling. And these properties give to water its great utility for man. Its quantity and distribution in time and space are highly variable, but the total amount of usable water remains constant. Thus, man is faced with a wide range of choices in managing his water resources. An approach based on considerations of the hydrological component permits of a relatively systematic treatment of water problems with reproducible predictions that can not at present be obtained otherwise. The hydrological cycle implies that water, unlike solid minerals such as iron or lead, is in constant movement from place to place and from one state to another under the controlling influence of radiation energy received from the Sun. However, since it is neither lost nor gained in the earth as a whole, this movement must be cyclic. In this cycle the water changes state from gas to liquid and back again, but it can never be "lost".

Water has the vital ability of dissolving other substances and carrying them in solution, as well as of transporting solid particles as long as it is in movement. Therefore, we must at all times think not only of the quantity but also of the quality of water.

With large scale water development and increased utilization of water for various uses, many major areas and concerns needing attention have emerged. These include: (i) excessive loss of irrigation water to seepage, (ii) inequitable distribution of water between head and tail reaches, (iii) poor maintenance of the canal systems, (iv) inadequate drainage and water-logging, (v) lack of field channels and poor maintenance, (vi) improper water management, (vii) improper cropping calendar and cropping pattern, (viii) poor extension services, (ix) poor farmer involvement. All development activities involve environmental change. There are some positive impacts and some negative impacts.

Urbanisation and industrialisation represent one of the major human interference with the hydrological cycle. Urbanisation represents a particular form of land use and surface cover. The micro-climate in an urban neighbourhood is modified by the form of urban structures, by changes in the heat balance, there is increased drawl from surface and groundwater sources, reduced infiltration, increased peak flow, increased waste water with corresponding effect on water quality etc. The impact of highway development, and rail lines on soil erosion and water quality is significant. Channel straightening and narrowing, culvert sizing, drainage etc. affect the runoff timing significantly. Historically, the process of population expansion and industrial development in urban areas has proved disastrous to the quality of both ground and surface waters. Receiving waters have often become waste receptacles, subject to increasing flow volumes and effluents harmful to both quality and ecology. The effects of industrial plants power houses etc. is similar to urbanisation. Similarly, large scale mining has effects on topography and also on water quality comparable to those produced by industrial wastes.

Human activities affecting the hydrological regime can be classified in four groups: (i) activities which affect river runoff by diverting water from rivers, lakes and reservoirs or by groundwater extraction (water for irrigation, industrial and municipal water supply, inter-basin water transfers), (ii) activities modifying the river channels (e.g. the construction of reservoirs and ponds, levees and river training, channel dredging, etc.), (iii) activities due to which runoff and other water balance components are modified due to impacts on the basin surface (e.g. agricultural practices, drainage of swamps, cutting or planting of forests, urbanisation, etc.), and (iv) activities which may induce climate changes at the regional or global scale (e.g. modifying the composition of the atmosphere by increasing "greenhouse" gases or by increased evaporation caused by large-scale water project). For proper understanding of these effects appropriate hydrological modelling approaches have to be adopted.

AUGMENTATION OF HYDROLOGICAL NETWORK

Inspite of vital role of water for survival of life on the planet earth, the information on volume, quality and distribution of water resources is rather poor and data on use of water for various purposes is even worse. Furthermore, due to impact of natural and human activities on hydrological regimes and emerging threat of climate change, the stability of hydrological data is no longer valid. There is need for continuous monitoring and to ensure that data collection networks possess the desired reliability, accuracy and representativeness. The data from hydrological networks and from the systems which collect data on water use and quality are acquired, processed, archived and made available through various agencies and systems at different scales from the point to watershed to basin to region to national to global.

In our country, the situation is quite mixed. There are good networks and data systems in some parts while in many other parts the networks are poor and suffer from lack of proper instruments, skilled manpower and proper measurement techniques. There is need for introduction of standardised procedures for data collection and storage. Suitable computerised basin/sub-basin wise data systems and data banks have to be developed of national, regional, state, district levels for proper compilation and processing of water related data for its use for sustainable development and management of water resources. There is also need to provide mechanisms for unrestricted/availability of water data to all users and its exchange/transfer within all parts of the country. Hydrological and water resources data networks and services have to be appropriately linked to services such as water supply, irrigation, hydropower, environmental monitoring etc. There is also need to develop procedures in a user oriented format and these could then be appropriately priced. There is also possibility of involvement of private agencies in such activities including preparation of maps and integrating water related information with remotely sensed data in a GIS mode.

EXPANSION OF TECHNOLOGY TRANSFER ACTIVITIES

The rational development of water resources requires multi-disciplinary approach. It involves fields as diverse as hydrology, ecology, demography, economy and operations research, as well as contributions from social scientists and political analysts. Efficacy and efficiency improvement and corresponding capacity building programmes are required for manpower development at all levels for public as well as private agencies and consultants. In our country, it is necessary to improve the capabilities of operational organisations in the centre as well as states in regard to observations, primary and secondary processing of data, analysis and design for planning and operation of water resources projects. There is also need for creation of suitable cadre, and proper monitoring and utilisation of manpower trained in various specialised areas for sustainable development and management of water resources. While at junior levels the emphasis of technology transfer should focus on skill development, at senior levels it has to lay stress on knowledge development.

One of the peculiarities of water resources is that it requires multidisciplinary teams made up of among other professionals, hydrologists, hydrogeologists, civil and chemical engineers, agronomists, biologists, ecologists, public health experts, geographers, economists, sociologists and political scientists. The coordination of these teams requires properly trained professionals with a solid basis in management and administration and also having adequate background in science, engineering and social needs. The technology transfer programmes, therefore, have to include basic (science oriented) specific (use oriented) and integrated (management oriented) approaches. It is a development of water resources and has to be based on optimal mix of formal and non-formal approaches. The water resources professionals of tomorrow have to be equally well versed with environmental issues and problems, and able to understand the interactions between moving water and the surroundings through which it passes.

BASIN WATER PLANS AND DECISION SUPPORT SYSTEMS

Water resources systems have to be planned by considering uncertain input such as water quality and quantity and future water demand situations, because long construction periods are needed which can include changeable development strategies. Traditional prediction methodologies for water availability and demands analyse averaged values with statistical analysis of past known data. However, the runoff hydrograph and water demand will fluctuate, depending on basin development, population increase, water usage, human activities and other technological developments. To balance sustainable development between human society and the natural environment, unnecessary development should be curtailed. To avoid an over estimation of planning, prediction factors are shifted to lower or upper values according to the preference and perspective levels of the decision makers.

A typical river basin is often under the jurisdiction of several authorities that in many cases prefer to use different models and sometimes even use different standards. Further more, the data stored in the data bases of these water authorities often have different formats. There is need for development of decision support systems which allow each water manager to use the same system and each of the systems in the river basin is a part of all the other systems. In water resources planning decisions often have to be made that can be identified as politically driven. This means that not just objective information and data determine the decision or even the course of the decision process. The aim of a decision support system should be to ensure that all the information (based on large quantities of data) is accessible to both experts and water authorities.

There is need for development of regional water planning decision support system based on expert system and geographic information system to store and analyse spatially distributed water supply and demand data. This will enable anticipatory planning to ensure the long term conservation and sustainable development. It would also be possible to consider the effect of uncertain and imprecise information as well as changes in boundary conditions on the long term planning scenarios. Furthermore, these basin/sub basin plans should also include suitable disaster management plans for dealing with natural calamities like floods, droughts, cyclones etc.

PARTICIPATION OF PUBLIC AND STAKEHOLDERS

For sustainable development and management of water resources, and particularly for putting into practice various findings of research, it is essential to involve public in general and all main stake holders. The stake holders in water resources sector include farmers, urban dwellers, industries and also women, educationalists, mass media, government agencies etc. The activities like observance of Water Resources Day have created necessary seeds in this direction. However, it is necessary to spread the awareness that water resources are becoming increasingly scarce and it is necessary to use these resources in a rational and economical manner. In this connection, particular emphasis is required for farmers, urban dwellers, industries and women. Since the major share of water is used by farmers in irrigated agriculture, they have to be made aware of value of water and need for proper management.

INFORMATION TECHNOLOGY

As a result of continuing reductions in the cost of information and communication technology, information technology offers tremendous opportunities for the distribution and use of water resource knowledge. Now large amounts of water related data is available on Internet, which can be used for scientific research and other purposes. Also updated information on projects, contacts, laws, methods, tools and best management practices are available on various sites. Using satellite connections and remote sensing data farmers could manage water and other inputs better for precision water management and farming.

DEVELOPMENT OF SOFTWARES, MANUALS, GUIDELINES AND STANDARDS

All activities of water resources development and management are to be handled in a multidisciplinary approach with a view to ensure sustainability and at the same time protect the environment. There is need for not only management of supply but also demand of water. Though there have been developments in R&D activities, there is no corresponding progress in our country regarding development of software, manuals, guidelines and standards for use by all concerned. It is necessary to create suitable awareness and also human resources well versed in use of different technologies and procedures. There is need for manuals and guidelines to cater for typical conditions of data availability, accuracy and other requirements. There is also need to introduce practice of detailed investigations and data collection during the project preparation period and use the same as a base data for considering the effect of project on hydrological and environmental regimes.

The availability of standards and software is very much needed not only for those directly involved but also for academic community and all stake holders. These have to focus more on solution of problem, i.e. so called demand driven mode. The expertise and information already available from elsewhere has to be suitably adapted to the local situations without losing quality or scientific vigour.

HYDROLOGICAL RESEARCH AND DEVELOPMENT

Hydrology deals principally with movement, distribution and storage of moisture. Most hydrologic problems are related to either quantity or quality of both. Determination of water yield, duration and inter arrival time of flood peaks, dam breach, etc. are some typical water quantity problems. Singh (1988) highlights the domains under which these problems can be addressed:

Time domain: involving reconstruction of the past (prediction) and construction of the future (forecasting) on different scales, viz. Continuous time or discrete time such as hour or less, daily, weekly, ten daily, monthly, seasonally, annual and longer.
Space domain: involving spatial variability and its sampling, regionalisation, effect of land use change, etc. on different scales such as channel, field or plot, watershed, river basin consisting of number of watersheds, continental or global.
Frequency domain: involving determining frequency of extremes (high as well as low), volumes, means, hydrologic space time characteristics, etc.

In the next few decades, advances in the field of Hydrology might transform the course of water Resources planning and management. There is a need for preparation of suitable action plan to deal with various hydrological problems that confront the water sector. It is important to emphasize the need for having a proper vision and prepare a long term perspective plan for tackling the various hydrological problems related with water resources development and management.

Basic research is necessary in some important areas. Traditional prediction methodologies for water availability and demands are generally based on averages derived by statistical analysis of past data. However, since future demands and availability of water are uncertain, other factors such as basin development, population pressures, human activity and technological developments have to be accounted for. These would need use of modern methods like expert systems and development of decision support systems. This would be a truly research and development effort. Considering the present status of water resources development in the country and the role of hydrology in the water sector, the priority of research should be in the area of applied research and development in order to improve the existing hydrological practices and for testing the various methodologies developed for tackling diverse hydrological problems in the country.

Some of the problem areas in hydrology would need study over extended periods and in a well co-ordinated manner. These include: Management of Floods and Droughts, Urbanization, Inter-basin Transfer, Ground Water Recharge and Re-cycling, Water Logging and Salinity, Conjunctive Use of surface water and groundwater, integrated watershed development. Arid and semi-arid areas, rain water harvesting and Snow and glacier melt contribution, Environmental aspects of water resources development and global warming. In all activities of water resources development and management top priority has to be given for R&D related with provision of water for human and livestock consumption. The advent of high speed computers, and the development in numerical methods and remote sensing and GIS applications as well as communication facilities have opened many interesting possibilities for effective R&D work in hydrology for optimal development and management of water resources in sustainable and environmentally sound manner.

Federal water agencies and other entities in the United States have invested extensive effort during the past three decades to develop generalized computer models for simulating water resources systems. A great deal of expertise, time, and expense was required to develop these models but they are now available to the professional water management community world wide at nominal cost. With recent advances in computer technology, most people working in the water resources field have access to desktop computers providing all the hardware capabilities needed to execute the powerful array of available software. Many of these software packages are widely used by public agencies and private firms throughout the United States and in other countries (Wurbs, 1998).

HYDROLOGICAL SERVICES

Under the increasing pressure of growing population alongwith rapid urbanisation and industrialisation water shortages are likely to become a serious problem. This will require an ever-more accurate determination of the existing water resource base (means, variability in time and space) and forecasts of low flows and groundwater depletion. For optimal development and management of water resources considering river basin as the basic unit, in a sustainable and environmentally sound manner, it would be necessary to set up River Basin Authority. This River Basin Authority would be responsible for preparation of basin plans, collection, analysis and interpretation of hydrological data for both surface water and ground water, including water quality, studies and analysis and interpretation of all data and information, coordination of various activities of water and land resource development in the river basin in a holistic manner etc. Such Authority in case of trans-boundary basin will also have to interact with the concerned Authorities in other basin states for the purpose of hydrological studies and water resources development in the river basin. It would be desirable to create a well defined cadre of hydrologists and set up Hydrological Services for continuance collection and analysis of hydrological data and information for its use in planning, development and management activities of water resources.

Hydrological studies will have to focus not only on traditional issues, but also on unconventional sources of water supply (re-use, recycling, artificial groundwater recharge, use of marginal quality water etc.). For the large river basins having catchment areas shared between different states or between different countries, there is likelihood of problems and conflicts. Accurate and authoritative hydrological data are necessary for dealing with such situations besides legal and institutional mechanisms. Pollution trends due to various point and non point sources and prospects of climate change also pose serious challenges. Hydrological services, infrastructure, capabilities, knowledge and expertise will have to be geared to cater to the growing demands including the following:

(a) Better techniques for estimating the water balance elements without long term on-the-spot measurements.
(b) Arial estimates from point measurements, with increasing use of remote sensing and GIS techniques.
(c) Regionalisation of hydrological data for water quantity and quality.
(d) Data for assessment of possible climate change effects and monitoring of such effects
(e) Flood risk and drought risk analysis; and disaster management strategies.
(f) Real time hydrological forecasting including snow and glacier melts.
(g) Integrated monitoring and modelling techniques for water quality erosion and sediment control linked to land use.
(h) Operation of complex multi-use water management systems integrating water quantity and quality.
(i) Developments of alternative sources of water supply (artificial groundwater recharge, rainwater harvesting, use of marginal quality water etc.)
(j) Technological development and use of highly automated, inexpensive and reliable instruments and field stations capable of measuring and transmitting data on water quantity and quality in real time, and use of data base, processing and modelling techniques.

In order to reduce the uncertainties and risks in river basin planning and management, it is necessary to include the following multidisciplinary interactions (Ayibotele 1993) as essential activities for (i) providing forecasts for operation of existing system and (ii) providing predictions for planning, design and operation of systems for new projects:

(a) Simulation studies to generate system outputs (river levels and discharges, lake/reservoir levels and yields, groundwater levels and yields, water quality parameters) based on following climate inputs and landuse scenarios: existing climate and land use, assumed climate variability and change, and existing land use, existing climate and changes in land use, and assumed climate variability and change, and land use changes.

(b) These outputs should be evaluated against desired multiobjective criteria to select most acceptable alternative project.

(c) In view of non-stationarity in system parameters the outputs should be used to revise: present water allocation and abstraction norms, present waste discharge and pollution control laws, and present land use planning, land allocation and soil conservation laws

(d) The outputs should be used to review present incentives in favour of : demand management, waste discharge management, and land improvement measures

(e) In case worsening water shortage is revealed, it may become necessary to develop policies to mobilise unconventional sources of water such as: inter basin water transfer, recycling of water, treatment and use of waste water, desalination of saline groundwater, desalination of sea water, development of treatment processes for toxic and hazardous wastes, and development of better land use practices

For this purpose the multidisciplinary group of experts in the Hydrological Services should comprise of: (i) climatologists, (ii)hydrologists (including hydrogeologists, hydrogeochemists, hydrochemists, hydrobiologists) (iii) water resources managers, (iv) land planning and land use experts (v) lawyers (vi) public health, sanitary, chemical etc. engineers, (vii) ecologists/ environmentalists, (viii) economists etc. Besides various Govt. Departments and academic institutions dealing with the concerned areas, Hydrological Services of the river basin can draw from the expertise available in various R&D institutes in the country for this purpose.

CHALLENGES OF R&D TRANSFER FROM RESEARCH TO FIELD

The main challenge of transfer from research to field in water sector is to organise, implement, and manage the whole effort in well coordinated manner and to use it in preparation of basin or sub-basin level plans and decision support systems for water resources development and management in an environmentally sound manner. To face the challenges of R&D transfer from research to field in Water Resources Sector there is need for (a) Augmentation of data collection network for both quantity and quality and creation of national, regional, state, district water data and information systems (b) Development of process oriented and problem oriented software, users manuals, manuals, guidelines and standards for wide scale use (c) Expansion of technology transfer activities (d) Increase emphasis on demand driven applied research, (e) Creation of suitable interdisciplinary water resources professional cadres, (f) Participation of public and stake holders, (g) Increasing the role of professional societies and non-governmental organisations.

Some of the critical areas and issues, which should be focussed upon for effective transfer of R&D from research to field, are as follows:

1) Comparative study of different water management systems, planning policies and their implementation and achievements under different agroclimatic zones of the country.
2) Scientific delimitation of water zones taking into account availability of water resources (both in quantity and quality) from various sources as surface and groundwater and also seawater, sewage water and industrial effluent water, their current status and future scenarios.
3) Utilization patterns and demands of water resources for different uses in rural and urban areas, current status and future scenarios.
4) Scientific study of occurrence of natural disasters – floods, droughts, cyclones and evolving disaster management strategies and plans.

5) Planning for optimal development of watersheds involving sustainable management of all resources including land and water, based on systematic and scientific studies.
6) Preparation of strategic action plans and programmes at various levels village/city, watershed/basin, block/district/state, region/country taking into account trends of supply and demands, need for recycling and pollution control, with emphasis on rainwater harvesting and artificial recharge of groundwater, priority actions and costs, and also establishing a well defined organisational/ institutional framework for reliable monitoring and evaluation.

GENERAL REMARKS

In the Indian context in general we need river basin organizations to face the challenge of competition between the users and uses. We need to set up a good database to ensure realistic down to earth planning. Ground water will prove it's supposed worth as resources of the decade only if its availability could be accurately assessed. Developed resources have to be turned over to users and a professional management to improve efficiency and to ensure its sustainable productivity. New development options will be governed by availability of funds, cost effectiveness, quick returns and above all environmental concerns. New storage schemes can not be neglected. Inter-basin transfer is the last option.

Science has to go beyond research to influence governments and society to do the right things and learn to communicate with policy makers, the media and the general public. So for, the emphasis has mostly been on technical aspects of combating the physical problems of development, insufficient attention being given to the related social, institutional and political factors. Although more research is needed in some neglected technical areas, priority in research should now be given to the integration of the technical results with the related non-technical factors, or in other words to merge hard science with soft science. Without this integration, the existing technical achievements can not be applied in a sustainable manner. The integrated approach to water resources management requires that not only technical professionals but also planners, policy makers and the general public should appreciate the possibilities and limitations of man's activities with respect to water resources.

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