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Research and Development in Hydrology -surface water hydrology

By

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SURFACE WATER HYDROLOGY

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1.0 INTRODUCTION

For achieving a reasonable standard of living for our people, we have to make the best possible use of not only water resources but also our land resources for sustaining all forms of agricultural, animal and forestry production. Denuded hill sides, ravines, water logged and saline lands, drought stricken villages, silted tanks, and drying wells, flood ravaged areas, expanding desert, expansion of urban areas with consequent decrease in good agricultural lands, coastal erosion and salt water intrusion, increasing water pollution, etc. all point to the important problems to be faced.

Hydrological problems (Singh, 1989) are related to either quantity of water, quality of water or both. These problems are generally addressed in:

(a) Time Domain - involving reconstruction of the past (prediction) and construction of the future (forecasting) on different scales, viz. continuous time or desecrate time such as hour or less, daily, weekly, ten daily, monthly, seasonally, annual and longer.

(b) Space Domain - involving spatial variability and its sampling, regionalization, 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.

(c) Frequency Domain - involving determining frequency of extremes (high as well as low), volumes, means, hydrologic space time characteristics, etc.

In 1987, the deficiencies/lacuna in the preparation of hydrology of projects were examined by the then High Level Technical Committee on Hydrology. In general, it was felt that data observation networks are inadequate and there is lack of standardised systematic procedures and software (National Hydrology Project, 1987).

The International Hydrological Decade (IHP) was launched by UNESCO in 1965 for improvement of scientific and technological basis of hydrology. In 1974, the General Conference of UNESCO decided to launch the long term International Hydrological Programme, with the main purpose to develop scientific and technological bases for the rational management of water resources, both as regards quantity and quality. The fourth phase of the IHP (1990-95) IHP IV has three main objectives, viz. (i) hydrological research in a changing environment, (ii) management of water resources for sustainable development, and (iii) education, training, the transfer of knowledge and public information. The hydrological research is envisaged to have the main objective to improve knowledge of processes involved in the the hydrological cycle and to determine the manner in which these processes might be most appropriately described to meet the demands for planning, design, construction, maintenance, and operation of water management schemes within changing environmental situations including the possibility of climatic change (UNESCO, 1986). The themes to be covered included:

- (i) Interface processes between atmospheric land and water systems
- (ii) Relationship between climate variability (and expected change) and hydrological systems
- (iii) Changes in water quality through the hydrologic cycle
- (iv) The role of snow and ice in the global water cycle
- (v) Hydrological problems of specific regions (humid tropics, arid and semi arid zones, large flat lands, mountainous regions)

2.0 NEED FOR R & D ACTIVITIES AND PRESENT STATUS

2.1 Project Hydrology

For meeting the increasing requirements of water for our growing population, it is necessary that intensive and extensive investigations and studies are carried out in a systematic manner on various aspects of hydrology of water resources projects. In India, water related projects are investigated, formulated and implemented by concerned State governments. Besides the guidelines issued by Central Water Commission for investigations and preparation of project estimates, Bureau of Indian Standards has also prepared a number of standards and codes of practices for this purpose. For a water resources development project, generally, the hydrologic studies are required for (i) water availability; (ii) Design flood; (iii) Evaporation losses; (iv) Sedimentation studies; (v) Reservoir Simulation studies; (vi) Impact on hydrologic regime.

Recent developments in computers and analysis techniques have led to significant developments in their application in hydrology. Personal/Microcomputers and microprocessors have an important role not only in analysis of hydrologic data, but also for collection of data through automatic recording devices and compilation of data in computer compatible form after proper processing. There has been considerable progress in the introduction of different sizes and types of computers in the country, however, there is no corresponding pace of development in software for use with different computers for the purpose of hydrological analysis and simulation for preparation of projects (Singh, 1989). The development of generalized computer packages by Hydrologic Engineering Centre of U.S. Army Corps of Engineers for use with personal/microcomputers for different types of hydrological studies, indicates a desired course of action. For most of the situations in India, the amount of hydrologic data is rather limited or sometimes quite inadequate. Moreover, the data quality is also not of desired level. This along with different conditions of climate and physiography in the country require rapid development of modern versatile instrumentation, appropriate data base, analysis techniques and software. Such developments could be indigenous wherever needed and could also be through adoption of technologies developed elsewhere (Seth, 1989).

There is an urgent need for developments and standardisation of investigation and analysis techniques covering various areas of project hydrology, and their wide circulation. The use of personal/micro-computers and interactive computer programs for this purpose would provide widespread use of these techniques leading to proper scientific management of hydrological activities for water resources development projects starting right from data collection.

2.2 Regionalization in Hydrology

The transfer of hydrological data, parameters or relationships obtained from one basin to others or their estimation for ungauged basins is of considerable practical importance. Usually, the small projects and even some large hydroprojects are located at ungauged sites or their location does not permit pre-project data acquisition at the site. For such cases, the transfer of hydrological information, especially runoff characteristics, by using conventional methods, e.g. regression analysis, rainfall runoff analysis, etc. is not appropriate. The method of regionalization has been found to be appropriate for such apatial transfer of information. This involves use of basin's physiographic, landcover, and climatic characteristics. The regionalization in hydrology also involves quantification of the components of the hydrologic cycle at a regional scale as opposed to a plot or catchment scale. It enables construction of models at the basin scale from knowledge and data which have been accumulated from smaller scale units (Beran, et al 1990). One of the important inputs available for this purpose is use of remote sensing techniques for the analysis of factors characterizing spatial variability that influence the hydrologic processes in a drainage basin.

2.3 Snow Hydrology

For rivers receiving flow from the Great Himalayan watersheds, the majority of the flow is generated from snow melt and glacier runoff. This spring and summer runoff, comprising mostly snow melt and glacier melt, is the source of water for irrigation, hydroelectric power and drinking water supply. The monsoon rains only penetrate to the lower valleys, so that summer rain is a small contributor to total runoff. The majority of the precipitation input to these watersheds occurs as snow and falls during the mid to late winter period, caused by weather systems approaching from the west. Investigations to understand the snow melt processes and snow melt forecasting techniques are required for proper utilization of abundant water resources available in the Himalayan region (Quick and Singh, 1992).

For runoff forecasting, irrigation planning, supply of drinking water and industrial use, etc. reliable and adequate information on snowfall and snow cover as well as their water equivalent is required. Knowledge of the physical characteristics of the snow cover such as its density, depth and temperature, and their variability in time and space is necessary for hydrologists. A careful survey of snow covered area with its water equivalent in conjunction with observations of atmospheric factors can also lead to flood forecasts and general hazard warning.

Snow cover is a residual project of snowfall and has characteristics different from those of freshly fallen snow. The snow surveys made by traditional methods involve much time and labour. The advent of remote sensing has opened up new avenue for snow cover monitoring and assessment. Once a correlation between areal extent and ground truth has been established, the prediction models can be extended with suitable modifications to other areas where ground truth is not available. With adequate knowledge of gauge characteristics and limitations, gauge catch deficiencies may be minimized and reasonable data adjustments could be made. Further studies to find out the effect of weather and exposure on snowfall measurements are required to achieve improvement in catch efficiency of the snow gauges.

There is need for basic research on snow cover accretion and depletion, and their relation to meteorological and terrain factors. The development of appropriate techniques would require investigations through entirely new approaches free from the deficiency caused by poor exposure and redistribution problem. The point measurements made in representative location is critical for interpretation and applying point measurements as areal indices. Moreover, studies correlating snow covered area and subsequent melt water runoff would set the pace for further application of satellite data in this important area of hydrology (Singh, 1986-87).

There is also need for understanding the snow melt and glacier melt runoff processes, orographic effect on rainfall and snowfall, temperature lapse rate and to develop suitable modelling techniques for snow melt runoff process incorporating use of remotely sensed data besides observed information regarding rain, snow, temperature and other hydrometeorological parameters.

2.4 Urban Hydrology

Urban hydrology deals with water and its interrelationship with urban man. The supply of clean, pure drinking water and the provision of adequate flows for the disposal of waterborne wastes are essential requirements for urban areas. As urban areas continue to expand, new sources of water become increasingly remote from the population that they serve. Moreover, as the predominant land use of a catchment changes from rural to urban, the alterations to the form of the landscape and the surface cover are often so radical that the provision of storm water sewerage becomes essential to protect both property and lives. Besides the problem of flood control and urban drainage the pollution control is also important due to growing amount of waste water problem of urban areas. The replacement of natural ground surfaces with impervious coverings reduces the infiltration of rainwater and hence ground water recharge. On the other hand extensive use of ground water lowers the water table, adversely affects agriculture and forestry, diminishes the base flow of streams and aggravates the pollution problem (Hall, 1984). Urbanisation also leads to changes in the local micro-climates of cities. Since, the process of urbanisation is dynamic and is in a continuous state of expansion, the problems of urban hydrology require continuous monitoring of hydrologic processes. The areas of research needs in urban hydrology include: (i) changes in surface runoff caused by urbanization, amount and quality (including sediment) for storm sewerage and urban streams, (ii) quantity and quality of runoff in terms of precipitation occurrences in experimental catchment areas, (iii) soil moisture and ground water, quantity and quality relationships and effects(McPherson, 1978).

In view of considerable expansion of urban areas and growth of large cities in our country and relative lack of scientific studies in urban hydrology, there is need for increased emphasis. Remote sensing techniques have also a significant role in urban planning in connection with hydrology.

2.5 Flood Studies

A flood is any relatively high stream flow that overtops the natural or artificial banks in any reach of a stream. The optimal development of water resources depends to a considerable extent on flood flow control, design and construction of structural measures and taking proper measures for flood mitigation including non-structural measures like flood plain zoning, flood forecasting and warning, etc. All such hydrologic analysis and design problems require accurate and reliable data for flood estimation using statistical and/or deterministic methods. The estimation of design flood for safety of structures under flood conditions has also to take into account risk as well as economy. The problem of floods varies from basin to basin so also the magnitude of damages caused by floods. The most flood prone areas are in the Brahmaputra basin and the northern sub-basins in the Ganga basin.

There are several situations in which an estimate of future flood conditions is required by many different categories of individual investigation, industry, government agency or other group. Essentially, however, this information is needed for either design or forecasting purposes. In the design situation engineers and planners involved in the design of dams, spillway, river channel improvements, storm sewers bridges and culverts need information on flood magnitude and frequency. In the forecasting situation, local government agencies industrialists, farmers, etc. require more immediate information on flood magnitude and timing so that the appropriate action may be taken. In view of these, a thorough understanding through mathematical modeling of flood formation beginning from sub-basin routing, combining sub-basin floods in the main channel, routing along channel and establishing the flood at the required point is necessary. Therefore, taking up the detailed flood hydrology studies is a must for understanding the runoff process involved in the catchment and stream channel in order to develop general and better methods, for accurate flood forecasts and design flood predictions. Flood studies dealing with flood plain zoning and economic analysis for assessing the actual flood damages are useful for the planners and government agencies involved in flood relief and flood protection activities.

Dam failures are often caused by over topping of the dam due to inadequate spillway capacity during large inflow to the reservoir from heavy precipitation runoff. Dam failures may also be caused by seepage or piping through the dam or along internal conduits, slope embankment slides, earthquake damage and liquefaction of earthen dams from earthquakes and land slide generated waves in the reservoir. Usually the response time available for warning is much shorter than for precipitation-runoff-floods. The protection of the public from the consequences of dam failures has taken an increasing importance as population have concentrated in areas vulnerable to dam break disasters (Perumal, 1992).

One of the preventive measure in avoiding dam disaster is by issuing flood warning to the public of downstream where there is a dam failure. However, it is quite difficult to conduct analysis and determine the warning time regarding dam break flood at the time of disaster.The method used for such analysis gains more credibility and one can simulate the past dam break failure scenario using that method with reference to failure mode and flood wave movement downstream of the dam.

It is generally seen in our country like in many countries that the flood affected area and flood damages are on increase despite massive investments made on flood control measures. Further, human activities in the catchments such as urbanisation, construction of dams for utilization of water resources, flood control levees, etc. have increased the nature of flood hazard. In view of this fact there have been major attempts to improve knowledge of the flood hazard and of the possible responses to it. As a result it is being realised that total elimination of flood hazard is not possible and alternative approacnes to reduce the flood hazard are necessary. The viability and appropriateness of alternate measures must be worked out in relation to the nature of hazards.

Flood plain management includes all planning and actions needed to determine, implement and revise plans for the best use of flood plains and their water resources for the welfare of the country. Its goal is to strike a balance between the values obtainable from the use of flood plains and the potential losses to individuals and society arising from such use. Flood plain zoning means restricting any human activity in the flood plains of a river where the plains are created by overflow of water from the channels of rivers and streams. Generally the term 'flood plain' includes water channel, flood channel and area of nearby low land susceptible to flooding by inundation. The activity of flood plain zoning has the short term objective of preventing more damage from flooding and in the long term to reduce and even eliminate such damage. The application of remote sensing and hydrological analysis is mainly involved in delineation of flood plain area and deciding about limits of flood plains. There is need to develop appropriate methodologies for hydrologic analysis required for flood plain zoning and mapping including flood damage assessment for Indian situation (Kumar and Singh, 1992;Seth, 1992).

Flood forecasting is a process of estimating future stages of flows and their time sequence at selected places along a river during floods. The estimates or predictions required generally are:

(i) Maximum discharge and its time of occurrence (the crest of a flood hydrograph)

(ii) The levels expected at various points of time during rising and falling stages of flood in a river above a specified water level or the warning level (shape of discharge hydrograph above a discharge level)

Utility of forecast is very much dependent on its timeliness and accuracy. If the forecast is not available sufficiently before the event occurs, its value is nil. The entire forecasting service has to be planned around a time factor. This time factor should be large enough so that efficient dissemination of the forecast is possible and adequate time to organise alleviation measures is available.

While the most of the riverine flood forecast models may need hourly precipitation observations/estimates, antecedent moisture conditions or aerial snow coverage, the flash flood forecasting would need weather radar information. Forecasts related with coastal flooding would need critical information on spatial antecedent wetness conditions of the land area, path of incoming typhoon as well as data that permit estimation of storm runoff in space and time e.g. telemetered rainfall, infrared satellite imageries, etc. There is need for development of flood forecasting models for specific regions/basins in the country subject to constraints of data availability and requirements. Parida (1989) suggested use of personal computers for various issues associated with analysis and forecasting of floods.

2.6 Physically Based Hydrologic Modelling

The hydrologic behavior of watershed is a very complicated phenomenon which is controlled by an unknown large number of climatic and physiographic factors that vary with both time and space. A hydrologic model is a simplified description of (parts of) the hydrological cycle. The development and application of mathematical and conceptual models in hydrology have increased tremendously during the last three decades particularly with the rapid developments within computer technology. The mathematical functions or conceptual elements employed to simulate the natural hydrological processes are subject to limitations of the present state of knowledge of physical behavior, mathematical constraints, data availability and ;user requirements. For some hydrological problems the selection of model type is more or less obvious, e.g. probabilistic models for frequency analysis or stochastic time series models for generation of long ;synthetic stream flow series. Empirical (black box) models are mainly of interest as single event models or as sub components of more complicated models. Lumped conceptual models are especially well suited to simulation of rainfall runoff process when hydrological time series sufficiently long for a model calibration exist. For complicated problems, particularly those involving natural and man made changes in land use such as the effects of urbanization, forest clearance for agricultural purposes, forest fires, etc. physically based distributed modelling approach becomes necessary. Such models are also useful for ungauged catchments, studies of spatial variability of catchment inputs and outputs, movement of pollutants and sediments, and general problems arising out of conjunctive uses of surface and ground water (Seth, 1990).

Hydrological models are required not only for deciding about water yields or design parameters, but also for understanding and evaluating effects of developmental and other activities on hydrological regime of river basins. Chander (1986) while reviewing progress in development of real time forecast models indicated future direction of work in this area keeping in view the improvements in data collection systems leading to availability of areal data on precipitation and catchment characteristics. He also suggested linkages of forecast models with decision models. As such prior knowledge of the meteorological conditions increases the scope of hydrological forecasting, lengthens the validity of such forecasts and increases their accuracy and reliability. There have been significant developments in numerical weather prediction and possibility of its application for the smaller scale meteorological phenomena, however much remains to be done for operationally reliable method of weather forecasting for use in hydrological forecasting, particularly for Indian monsoon (Seth, 1986).

The challenging task of preparing developmental plans for managing the limited water resources of river basins in the country for their optimal use necessitates application of multi disciplinary approach of system engineering. For comprehensive planning of water resources projects besides data in respect of various uses, adequate hydrological data base is necessary. The use of physically based distributed modelling approach can provide such information and could also incorporate scenarios of proposed/likely land use changes in the river basin for use in planning/operation of water resources projects.

2.7 Climate Variability

Currently, there is considerable agreement that mankind is facing global warning due to increasing levels of atmospheric carbon dioxide, methane, CFCs and other greenhouse gases. It has been stated by some researchers that the average global temperature has increased by between 0.5 C and 0.7 C. Since the turn of the century or according to some since the 1860s. Current estimates from models ;indicate that it may increase by 1 to 3 C during the next 40-60 years. However, there are considerable gaps in our knowledge and data availability and as such reliability of these predictions can at best be considered as possible scenarios at present. It is also not feasible at present juncture to translate global warming scenarios into specific changes in temperature and precipitation over a watershed with any degree of reliability for the planning, management and operation of specific individual water projects.

There is urgent need to create a long term data base not only for efficient planning, management and operation of water resources systems but also to determine in the future the extent of climatic changes. It is also necessary to critically reexamine the existing methodologies used for hydrologic modelling, synthetic data generation, and hydrologic forecasting to include effects of climatic variability on hydrologic processes at various time and space scales. Particular emphasis is to be given for studies involving hypothetical scenarios of temperature increases coupled with precipitation and potential evapotranspiration changes to study the effect on runoff, soil moisture, snow melt, actual evaporation, etc.

3.0 THRUST AREAS

Based on the above discussion on status in some of the important areas of surface water hydrology and water resources, the following thrust areas for R & D activities in the country are being suggested:

3.1 Priority 1

(i) Preparation of software, user manuals, guidelines, manuals and standards for hydrologic analysis, design and operation of water resources projects

(ii) Methodology for hydrologic design for water resources projects for ungauged/limited data situations and gauged catchments (including design storm estimation and design flood estimation and risk based design)

(iii) Water balance and water availability studies for river basins and water bodies (lakes and reservoirs)

(iv) Regionalization of hydrological parameters for water yield and floods, and preparation of hydrological maps including geomorphological characteristics of river basins

(v) Snow hydrology - (a) Effect of elevation on temperature and precipitation in Himalayan region, (b) Relationship between snow covered area and snow melt runoff

(vi) Urban hydrology - (a) Effect of urbanization on surface runoff and water balance for major urban centers in the country

(vii) Flood studies - (a) Dam break flood studies for major dams, (b) Flood risk mapping and zoning for flood prone areas, (c) real time flood forecasting models for catchments of major dams

(viii) Physically based hydrologic modelling for important river basins undergoing or likely to have significant land use changes for use in integrated planning, flow forecasting, and operation of projects

(ix) Climate variability - Case studies for selected river basins for studying effect of climate variability on hydrologic processes at various time and space scales

(x) Policies for optimal operation of water resources projects (Hydrological aspects)

3.2 Priority 2

(i) Development of integrated models for atmospheric and land surface processes interlinked with general circulation model for atmosphere for studying expected changes in runoff and other water balance components of large regions and water bodies due to climatic changes (greenhouse effect), or man's activities (inter basin transfer of water on a large scale, irrigation, fertilizer use, industrialisation, etc.)

(ii) Development of regionalization methods considering non-stationarity in hydrologic time series.

(iii) Development of snow melt runoff models for Himalayan catchments.

(iv) Development of hydrological models for river basins incorporating use of remotely sensed information on a real time basis.

4.0 RECOMMENDATIONS

Most of our problems in water sector are due to pressures of increasing population and rapidly growing living standards. Development of water resources in different parts of the country is closely related to the position of water with respect to other natural resources particularly the land resources. The drought prone area of about one third the geographical area of the country and the flood prone area of about one eighth the geographical area need special attention. Keeping in view the future scenario in the water use indicating that by the year 2025, the entire quantity of the presently estimated water would have to be put to beneficial use, it is necessary, that R & D sector particularly related with hydrology also launches suitable country plans for short term (say five years) and long term (say fifteen to twenty five years) involving pooling together of available expertise and resources, and with increased emphasis on specific thrust areas in consonance with policies for agricultural and other related sectors. There is also need for consolidation of work already carried out so far.

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