A DECADE
OF
STUDIES AND RESEARCH

December 1988

NATIONAL INSTITUTE OF HYDROLOGY
ROORKEE - 247667 (U.P.)
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FOREWORD

Water as the medium of life, has been a well recognised fact since time immemorial. Increasing demand on its usage due to growth in population, general living standards, industrialisation, urbanisation, use of modern agricultural practices, pollution control, demand on energy and recreation has given rise to its harnessing, control and allocation for the benefit and use of mankind. A large number of projects, therefore, have been undertaken world over to develop the water resources.

National Institute of Hydrology, the premier research institution of India in the field of hydrology has been engaged in undertaking, assisting, promoting and coordinating systematic scientific studies through theoretical and applied researches for bringing about improvements in the present practices in planning, designing, operation and management of water resources projects of the country. From its inception in 1979 till the end of Sixth Five-Year Plan, the emphasis of research has been on selected areas including computer oriented studies. During Seventh Five-Year Plan (1985-90) the scope of research has been broadened through the inclusion of field, laboratory and multidisciplinary studies with the help of fourteen scientific divisions:

- Hydrologic Design
- Surface Water Analysis and Modelling
- Flood Studies
- Mountain Hydrology
- Groundwater Assessment
- Conjunctive Use
- Drainage
- Water Resources System
- Man's Influence
- Drought Studies
- Information Systems and Data Management
- Remote Sensing
- Hydrological Investigation
- Hydrological Applications of Climate Information

Alongwith its research programmes, the Institute provides services in the form of consultancy projects, technology transfer workshops, etc., to various organisations of the country. As such besides others, twenty-three research projects have been undertaken for extensive study under various divisions of this Institute. In order to bring out their broad objectives, status till 1988 as well as further works to be undertaken, a summary of each project has been brought out through this brochure.

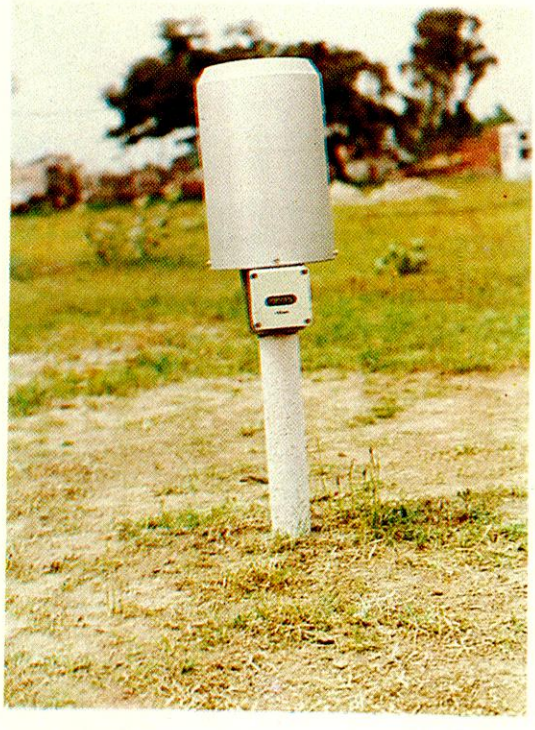
SATISH CHANDRA
DIRECTOR

CONTENTS

ANALYSIS OF HYDRO-METEOROLOGICAL VARIABLES

Hydrometeorological analysis form an important and integral part of hydrological studies and research. The Hydrometeorological analysis have been carried out in the institute by experienced hydrometeorologist and provided the input to several Hydrological analysis relating to surface water and ground water studies. Besides, studies and applied research has also been carried out in this important area.

Computerised procedures for processing and quality control of precipitation data have been evolved and software for analysis were prepared. A user's manual and Manual were prepared for use by field agencies. Course material for transfer of the technology on this topic through short duration workshops has been prepared and workshops were conducted in Roorkee, Madhya Pradesh and Maharashtra.



Hydrometeorological studies of storms over Narmada basin, Rajasthan and Saurashtra were carried out. Analysis of trends and periodicities in rainfall series of Belgaum district in Karnataka and districts in East Rajasthan were carried out. Network design of raingauges for Rajasthan State was carried out as part of the institute's activity of interaction with States.

Hydrometeorological analysis were carried out for the following consultancy projects:

- Ground Water Modelling Studies for Upper Ganga Canal Command area.
- Design Flood Estimation for Narmada Sagar and Sardar Sarovar.
- Water Availability of three sites in Mahanadi basin.
- Design Flood Estimation for Kishau Dam.

FLOOD ROUTING STUDIES

Flood routing techniques are the tools for simulation of flood wave, resulting due to reservoir release or outflow from a watershed in the channel for issue of flood warnings and taking up emergency measures in the downstream reaches. Use of an appropriate flood routing technique enables the engineers to forecast the flood wave characteristics accurately. This project envisages study of various flood routing techniques available in literature, bring out their usefulness, limitations, applicability to complex channel processes, compound channels and theoretical basis for development of simplified techniques for use in the field and design.

Various hydrologic flood routing methods, viz., Muskingum, Kalinin-Milyukov and lag and route, modified pulse, working R & D, Multiple reach Muskingum, Two and Three parameter gamma distribution, linearised St. Venant's equations, Multiple linearization and simple non-linear models have been reviewed. To use and select a model for a particular situation the data requirements and usefulness of the routing methods have been compared with the various hydraulic routing models based on St. Venant's equations, and their advantages and disadvantages compared. In view of their easy applicability and advantages, generalised software have been developed for some of the simple models such as Muskingum, Multiple reach Muskingum, Muskingum-Cunge, Kalinin-Milyukov and two and three parameters Gamma distribution.

Muskingum-Cunge and Kalinin-Milyukov methods have been used for case studies carried out for reach between Mortaka and Garudeswara of river Narmada and the reach between Dharoi and Ellis-bridge of river Sabarmati respectively. Both these methods have yielded good results in reproduction of outflow hydrographs for respective river reaches. User Manuals have also been prepared to provide the user with computer programmes and procedure for easy use of these methods. Further review to study the complexities due to flood plains and channel processes on flood routing have been carried out.

A simplified model, which uses the concept of varying the parameters of achieving linearised solution at each time level has been developed for rectangular and trapezoidal channels to model the non-linearity of routing process. This model has further been found to bring out explanation as well as, justifications for the cause of reduced outflows at the start of the Muskingum method and its negative weighing parameters.

An explicit finite difference model based on full Saint Venant's equation has been satisfactorily used to study the behaviour of kinematic wave in rectangular storm sewers, with different inflows. The study also gives the mathematical expression developed for finding the time lag of kinematic wave at downstream section based on the information about channel parameters and peak flow. Another finite difference model has also been developed which uses the diffusion scheme in finite difference approximation and overcome the problem of using lesser time interval for computation as in case of simple explicit finite difference scheme. This model has also the option to choose the different shape of storm sewers.

The above studies carried out under this project have been documented and brought out in the form of review notes, technical reports, case studies and User Manuals on various hydrologic and hydraulic flood routing techniques including development of a simplified flood routing model.

It is further envisaged to review and study the effect of tributary junctions on routing characteristics of flood using the models available at NIH. It is also proposed to develop and use hydrologic and hydraulic techniques for flood plain zoning for typical river reaches, flash flood studies and paleo flood studies.

WATERSHED MODELLING

The rainfall runoff process in a watershed is a complex and complicated phenomenon governed by large number of known and unknown physiographic and storm characteristics. Precipitation over a watershed undergoes a number of transformations and abstraction through various component processes to merge as runoff at the catchment outlet. Since hydrologists are interested in knowing the amount of runoff and its distribution in time resulting due to precipitation over the watershed for planning and designing of various water resources structures, water yield estimation, simulation of flows for reservoir operation and flood forecasting besides others, it is necessary to establish the precipitaion runoff relationship for the watershed for future use.

The objective of this project is to study the various watershed models developed and compare their structure with respect to various component processes and ascertain therefrom a suitable model structure which can model component processes typical to Indian conditions.

In order to achieve the above objectives, various hydrologic component processes, viz., interception, evapotranspiration, overland flow, infiltration, percolation, interflow and baseflow have been reviewed in eleven watershed models and different simplified techniques to model those components processes have been identified for considering development of rainfall-runoff model suited to Indian conditions.

As a part of case studies, Betson and USGS models have been applied for simulating the runoff from Kasurnala Basin in Punjab. Performance of Betson and USGS model was tested on the basis of their capabilites in simulating the peak flow and direct runoff volume. In another case study, 4×4 Tank model was used to simulate daily runoff for two sub-basin Jamtara and Ginnore, of Narmada basin. Besides using these models in simulation their limitations as well as usefulness were also brought out.

Recently, under a project agreement ALA 86/19, Hydrological computerised modelling system, signed between the Commission of the European Communities (CEC) and the Government of India (GOI), transfer of the Systeme Hydrologique Europeen (SHE) hydrological modelling is being carried out by the consultant a group headed by the Danish Hydraulic Institute (DHI) and composed also of SOGREAH (France) and the U.K. Natural Environment Research Council's Water Resources System Research Unit at the University of New Castel upon Tyne (UON) to National Institute of Hydrology. SHE model is a physically based model in which each of the major hydrological processes of water movement is considered. The model has been applied to simulate the runoff and water table conditions for three sub-basins of Narmada Basin.

The above studies have been brought out in form of review note, case studies and user manuals for selection of a proper model including the simulation studies of three sub-basins in Narmada Basin using SHE model.

It is further envisaged to apply SHE model for some more basins in India. It is also proposed to develop a suitable model through hybrid of various simplified component processes identified from different watershed models that could be useful for Indian conditions. It is also envisaged to bring out users' manuals on other watershed models for easy operation on computer.

UNIT HYDROGRAPH IN FLOOD ESTIMATION FOR SMALL BASINS

Estimation of runoff from a catchment is needed for comprehensive water resources planning, flood flow forecast, adequate design of hydraulic structures etc. Unit hydrograph representing the catchment response function has been well accepted for its use in computing the runoff from rainfall. But many a times designers faced the problem of derivation of proper unit graph out of available inadequate records as well as for ungauged basin, hence misled with unrealistic flood estimates.

In order to overcome such practical difficulties, this project aims at bringing out an appropriate technique for derivation of event based unit graph from the several ones, for the gauged basins and to extend it for regional study such that unit graph parameters can be evaluated for estimation of floods from ungauged basins of a particular region. To broaden the scope of the study further, it is also aimed at derivation of geomorphologic unit hydrographs which not only would attach more physical sense to the unit graph but also be useful for estimation on floods from any ungauged basin.

For accomplishing these objectives, a comparative study of various unit hydrograph methods available in literature had been carried out and assessed for their suitability along-with their limitations. Five methods based on two different approaches viz, parametric system synthesis and non-parametric analysis have been used for derivation of unit hydrographs analysing the rainfall-runoff data of flood events for six small catchments of Godavari basin subzone 3f. Based on the consistency in physically realisable and non-oscillating ordinates, use of the former approach had been recommended. Simulation studies carried out with independent events using the unit hydrograph derived by the parametric synthesis approach have yielded satisfactory results.

For computation of regional unit hydrographs, a detailed review of the regional studies carried out in India as well as abroad have been made and development of regional unit hydrograph relationships for typical Indian regions are in progress. Attempts are also being made to evaluate the parameters representing different aspects of catchment and storm characteristics.

Several documents in the form of review notes, case studies and user manuals on derivation techniques of unit hydrograph for gauged as well as ungauged catchments have been brought out.

It is envisaged to carry out regional studies covering a large number of hydrologically similar regions of the country, for which collection of data is in progress using the most appropriate regionalisation.

Further attempts to derive geomorphologic unit hydrographs for Indian basins for which hydrological and hydrometeorological networks are either inadequate or not at all existing, are also envisaged.

STATISTICAL MODELLING OF ANNUAL PEAK FLOODS

Estimation of flood of different frequencies based on annual peak discharges is one of the primary tasks engaging the attention of the hydrologists all over the world. Such hydrologic event being treated as random, need use of frequency analysis through which it is possible to predict the design flood at specific probability and significance levels. This project, therefore, has been aimed at studying some of the extensively used statistical models which can explain the varying magnitude of events and the varying time that has elapsed between them. It is also aimed at studying the usefulness of transformation techniques in flood frequency analysis for gauged catchments and in carrying out regional flood frequency analysis for design flood estimation for ungauged catchments. Further it is aimed to develop a uniform guidline for carrying out flood frequency analysis in the country.

For accomplishing the objectives mentioned above a general review has been made for two categories of model i.e.,annual flood series model and partial duration series model used in flood frequency analysis. Flood magnitudes for different return periods for Narmada Sagar dam have been estimated using partial duration series model with postulated Poisson and Exponential distributions as a case study. Efficiency of this model against the annual flood series model has been compared and brought out.

Power transformation techniques, used for transformation of annual peak flow series to the normally distributed series, have been used to estimate the floods of different recurrence interval. Usefulness and limitations inherent in power transformation techniques have also been brought out. Attempts have also been made to transform the annual flood series to the EV-I distributed series. Inadequacy of data forms a major limitation in reliable computation of plotting position. In order to study the appropriate plotting position formulae for EV-I distribution, study based on Monte Carlo Experiment has been carried out in which Gringorton plotting position formula has been recommended for use in EV-I distribution as it better fits in uppertail region. A critical review of various regional flood frequency analysis studies conducted in India as well as abroad has been made. Further, regional flood frequency analysis has been carried out in a case study for the subzone 3D region of Mahanadi basin taking into consideration 18 stations with varying records. Three methods viz. the Index Flood Method, the method based on normalisation of peak flood data and method based on Wakeby regional parameters with at site estimates of James corrected means have been used in the study which have shown comparable performance. In order to choose an appropriate method of parameter estimation for EV-I distribution a Monte Carlo experiment study has been carried out.

Studies carried out so far in the Institute have been documented in form of review note, technical note, technical report, user manual and case studies.

It is further envisaged to carry out flood frequency analysis for other regions of the country with inadequate data. It is also proposed to study a suitability of the plotting position formulae for different frequency distributions and to develop a uniform guideline for carrying out flood frequency analysis. Risk analysis for various hydraulic structures would also be carried out.

STOCHASTIC MODELLING OF HYDROLOGIC VARIABLES

Hydrologic variables which exhibit significant serial dependence are stochastic in nature. For forecasting and synthetic data generation, modelling of these variables is essential for proper and optimal planning, designing, management and operation of water resources projects. This project has been aimed at studying various models available in literature explaining the stochastic realisations, and chose from them suitable ones that could be used for forecasting and synthetic data generation based on short length of records of the variables at single or multiple sites.

For accomplishing the above objective, a general review and state of art reports have been prepared about various stochastic models such as Auto Regressive (AR), Moving Average (MA), Auto Regressive Integrated Moving Average (ARIMA), Fast Fractional Gaussian Noise, Filtered Fractional Gaussian Noise and Broken Line Model,etc. In the area of forecasting, a methodology has been developed for forecasting of runoff from monsoon rainfall based on a comprehensive review of various flow forecasting models related to short term as well as long term forecasting. The methodology has been tested for Mahanadi basin as a case study. Monthly stream flow has been generated for Chaliyas river basin using univariate Thomas Fiering Model and for Mahanadi river basin using bivariate Thomas Fiering Models.

The studies carried out so far under this project have been documented and brought out in the form of review notes, technical report, state of the art report and case studies.

In order to cover the project objectives, it is envisaged to take up further case studies in the above two areas and carry out studies for multisite generation of data. Studies on disaggregation and aggregation models would also be taken up alongwith their applications to some of the Indian catchments.

DAM BREAK STUDIES FOR PLANNING OF FLOOD PROTECTION MEASURES

More and more dams have come up or are being constructed with the aim of using the available Water Resources optimally for developmental purposes or for protecting rivers and properties from the fury of floods. With the assured water resources facility and flood protection provided by the dam, the encouragement for improving the overall economy of the country has led to various developmental activities in the downstream of dam resulting in the settlement of large population and agricultural and industrial activities in the flood plains and adjoining areas. Since failure of any such dam can be catastrophic due to inundation of adjoining areas besides the flood plains, it is essential to study and plan, necessary preventive measures so that in such an eventuality, the disaster or damage could be minimum. This project, therefore, has been aimed at studying various hypothetical dam break situations and predetermining the peak flood stages and warning time at specific downstream locations for their use in planning necessary safety measures.

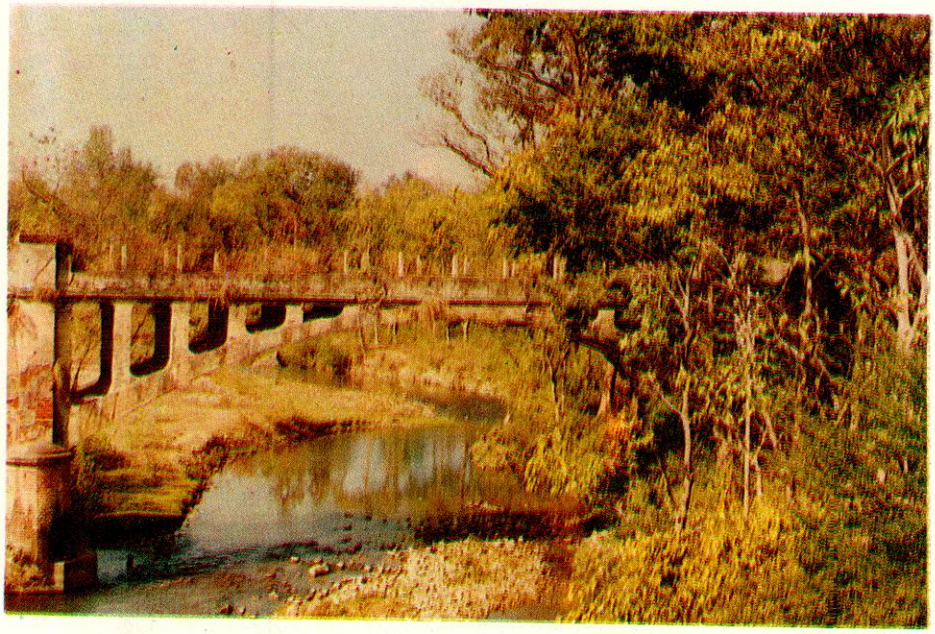
To achieve the objective of this project, study of one of the well known dam break models was taken up. The data requirement and preparation for dam break analysis with this model has been identified and a case study of Machhu-dam-II failure, in Gujarat State, has been carried out. Under this study, the actual dam break has been simulated with equivalent trapezoidal shape. This study includes the routing of inflow hydrograph including dam break flood along the channel by sub-critical dynamic flood routing method. The results obtained by the study, compared well with the observed highest flood elevation inspite of assumptions regarding shape of break and data limitations.

Further study for quick estimation of characteristics of dam break flood wave i.e., peak discharge, peak stage, and time to peak at the dam site and other specified downstream locations have been carried out. Dimensionless flood hydrographs based on computed dam break flood wave characteristics have been developed using the dam break model. These hydrographs show the significance of dimensionless parameters for time and discharge corresponding to different sizes of breach. The relationships between area of breach vs. peak flow, peak flow vs. time to peak have also been developed with respect to various breach sizes, thus providing a methodology for estimating the peak flow and time to peak graphically, when the area of breach at the time of failure is known or could be assumed. The above studies carried out under this project have been documented and brought out in the form of technical note, technical report and a case study on Machhu Dam-II.

It is further envisaged to carry out the studies based on hypothetical dam failure scenarios for some other dams and case studies for dams already failed in our country subject to availability of data. Data collection for such studies have already been taken up.

HYDROLOGICAL STUDIES IN FORESTED CATCHMENTS

Forests, major component of the ecological cycle, have great influence on hydrological variables. Studies have been done in our country and elsewhere to assess the forest influences on various component processes as well as hydrological variables. The results of such studies have been compiled in the form of status reports and needs for further studies have been identified.



Mathematical modelling has been one of the best tools of dealing with various kinds of water resources problems. Application of mathematical model to evaluate forest influences is one of the studies being undertaken. Another study to evaluate forest influences on ground water regime is being attempted using mathematical modelling. However, due to lack of relevant data, initial handicaps have been faced. Under the project, one more study to compile water requirements of eucalyptus, as has been reported in various studies, is also under progress.

SNOW AND GLACIAL HYDROLOGY

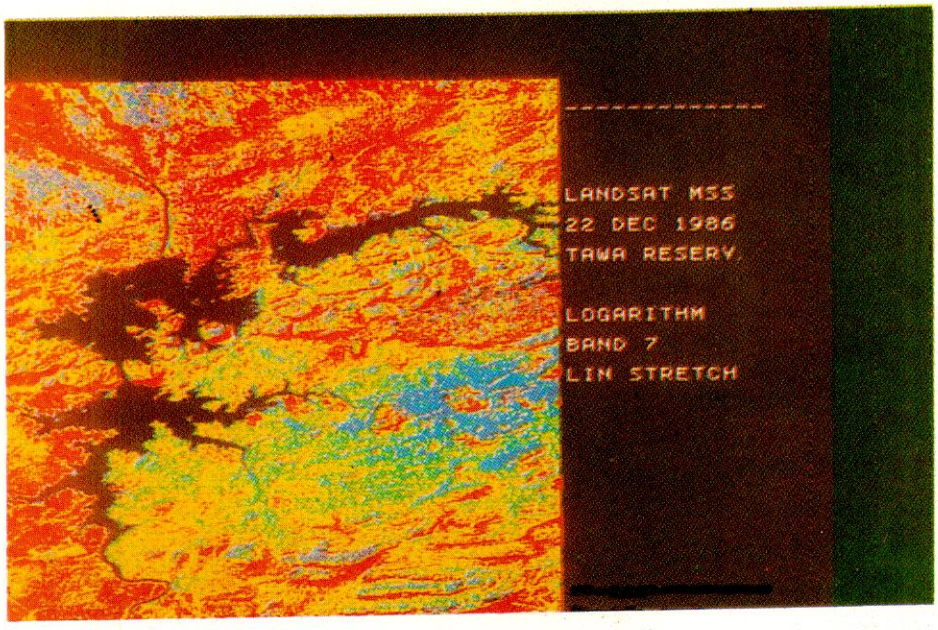
The major rivers draining out from the Himalyas have a large contribution from snow and ice melt. The studies pertaining to snow and ice melt have been initiated in 1986 by establishing a Mountain Hydrology Division in the institute. To initiate the scientists to understand the processes of snowmelt, review of literature in the area has been carried out and some technical notes were prepared. A comprehensive review of the instrumentation and snow measurement techniques and hydrological models for modelling snowmelt has also been carried out.

To estimate the melt contribution from a glacier, hydrological investigations in Chhota Shigri Glacier (H.P.) have been carried out under multidisciplinary expeditions organised by DST. Scientists of the Institute have participated in the expeditions during 1986, 1987 and 1988 and measured glacial melt, suspended sediment, density and water equivalent of snowpack. A technical report on the glacier melt and physics of the glacier was prepared.

The Institute is planning to carryout the snow and glacier melt runoff modelling studies in Jammu & Kashmir. The institute is proposing to organise a short course on snow hydrology at Roorkee in the beginning of 1989.

REMOTE SENSING APPLICATION TO HYDROLOGICAL STUDIES

Success of any hydrologic study/analysis primarily depends upon the available informations and exhaustive data base. Remote sensing technique in conjunction with conventional methods is useful in creating an exhaustive data base of the space and time variant hydrologic phenomena/characteristics by use of imageries taken through repetitive and synoptic coverage of the satellite. This project is envisaged to take up case studies using remote sensing applications for snowline and snow cover mapping, land use/vegetal coverage mapping, flood inundation studies, reservoir sedimentation studies, watershed characterisation and its mapping and monitoring of drought prone areas.



In order to accomplish the aforesaid objectives, review of works already undertaken in the areas of various hydrological applications have been made and the status of the technology brought out. Case study in respect of land use mapping of Upper Yamuna Catchment has been carried out and six land use categories of hydrologic importance viz., thick forest, thin forest, barren and built-up area, cultivated area, snow bound area and rivers demarcated. Land use classification of two test sites using digital image processing and visual interpretation have been carried out and found comparable. A case study is performed in the Mahanadi basin downstream of Hirakud based on 1985 and 1986 Landsat data. This study presents the Land use/Land cover and flood inundated mappings. Detailed maps at

1:250,000 scale is prepared for the study area. In another case study, district Aligarh in west Uttar Pradesh has been taken up to map the salt effected areas. The study presents the change detection also in these areas over two dates in 1984 and 1987.

Technical studies have also been performed in the field of reservoir sedimentation, snow and its metamorphism and the reflectance characteristics of various ground features. Watershed characterisation study is also made for Ong sub basin while the flood plain mapping and its change detection study is carried out for River Ganga between Raoli and Narora in Uttar Pradesh. Other studies in progress are for Chilika lake and its surroundings using IRS data, sedimentation studies in Tungabhadra reservoir.

The instalment of COMTAL Digital Image Processing and Display device has been completed. Software development and Digital studies are also in progress. The studies carried out on this project have been documented in form of review notes on various applications of remote sensing techniques such as snow cover mapping, land use mapping, flood inundation and sedimentation etc. in hydrological studies.

Further works in respect of delineation of river course, river levees, inundated areas and sediment deposits for the river Mahanadi are in progress. It is proposed to carry out digital analysis using image processing software, visual analysis and analysis using maximum likelihood classifier approach in respect of the flood plain mapping.

REAL TIME RESERVOIR OPERATION

The design and development of water resources projects require, inter alia, the formulation of strategies for operation policies for their operation. Generally, these operating policies are developed using long time horizons and the expected benefits the system are assessed over the economic life of the system. The observed historical data are used for this purpose. Nevertheless, it is only after the project has been constructed and is in operation that the benefits are actually realised.

The aim of water resources management is to operate the system in such a way that the benefits are maximised or costs are minimised. Achievement of this requires quantification of appropriate cost, benefit and loss functions of the complete system. Essentially, the optimum control of water resources system means the operation of the system so as to optimise some performance function. The optimization problem can be divided in the following three parts:

(*a*) exact definition of the performance function
(*b*) the description of the complete system
(*c*) determination of optimum policy using a and b.

The operation policy derived in step c specifies, over some specified time horizon, target levels for the system and how to achieve them. Development of a worthwhile control strategy for water resources system also requires that the stochastic nature of the system must be taken into account. The controls or releases are applied so that the targets are met as best as possible.

The aim of a control theory is to determine the operating strategy for a system during its day-to-day operation. Basically, the operation can be performed in two modes: off-line control and on-line control. For the off-line control, the measured data about the state of the system and demands are used for later analysis. The computation and implementation of the control policy are separated in space and time. In a large number of situations encountered, off-line control can provide satisfactory results. If the response of the system to a control is slow, say of the order of few days as is often the case of many water resources problems, the off-line controls are usually adequate.

The other mode of operation is on-line control where processing of data is done as soon as it is observed and then the control is determined and applied in a closedloop. The need for on-line control arises where the response of the system to the application of controls is quick and any delay in taking a decision may result in significant losses. This requirement comes during the operation of a reservoir for flood control where the decisions have to be implemented, evaluated and modified in quick succession.

The gains from on-line operation can be substantially increased if good algorithm giving reliable forecast of the inputs to the system is available. The forecasting can be done in two modes: long-term forecasting and short-term forecasting. The long-term forecasting is usually aimed towards generation of random events which preserve, to a certain extent, the statistical behaviour of historical data. The variables used in this type of forecasting are aggregate parameters like monthly discharge, weekly rainfall and so on. On the other hand, short-term forecasting is done in real-time and the processing is done at some time when the events take place. The forecasting is also continuously updated using observed values of the variables at discrete times. The interest is not only in the statistical behaviour of the variable but in the absolute value of the forecasting variable. It has been revealed by a number of studies that benefits from real-time operation of a reservoir can be substantially increased if good forecasts are available.

The aim of this project is to develop procedures which can be used for real time operation of reservoirs. As a first step the available techniques for reservoir operation have been reviewed and procedures developed for their implementation. Now the attention will be focussed on review of methodologies for real-time operation of reservoir and then to develop and to implement such procedures.

TECHNIQUES FOR CAPACITY COMPUTATION AND OPTIMAL RESERVOIR OPERATION

A reservoir is developed by constructing a dam across a stream thus giving rise to storage space. This storage space is utilized to store water during high flow periods. The water from the storage is released when the natural flow of the stream is less than the demand. Thus the temporal availability of water is changed by means of the reservoir.

The most important decision to be taken while developing a reservoir site is the storage capacity to be provided. Due to high cost of construction, it is imperative that the capacity provided is no more than what is required to satisfy the purposes for which the reservoir is constructed. Further, if the capacity is less than the required value then the reservoir may not be able to fulfil the demands. Hence a careful analysis of the problem is necessary to obtain the best result.

Although a number of techniques are available for determining the required capacity of a reservoir, they are mostly associated with one or more deficiencies.

Among the techniques available for reservoir capacity computation, mass curve method is the oldest and most popular technique. This method was suggested by Ripple in 1983. The mass curve analysis uses historical hydrological record. If the cumulative inflows are plotted against time, the resulting curve is known as mass curve. Critical period hydrology is used to compute the storage size. This size is equal to the range of cumulative departures from the demand. The mass curve technique is essentially a graphical technique though computer programmes have now been developed for this analysis.

With the advent of computer, the techniques, which beneficially use its computational capabilities are increasingly being used. Optimization techniques are being increasingly used to solve the capacity computation problem. Among these techniques, Linear programming and Dynamic programming are the most commonly used techniques. The deficiencies of mass curve method can be quite satisfactorily removed by application of these techniques. The major handicaps in using these techniques are the complexity of the problem formulation, unavailability of computers and reliable generalized codes.

Another popular computer based method is simulation. This method is very simple to use and general purpose programmes can be and have been developed using this algorithm. Using simulation, it is quite easy to study various other aspects of the problem which are otherwise difficult.

Once a reservoir has been constructed, the degree to which the benefits can be reaped depends upon how the reservoir is operated. The ideal solution to the problem will be a reservoir with optimum storage capacity and which is operated using best possible operation policy.

The aims of this project are to develop practical procedures for computations of storage capacity of a multi-purpose reservoir and also to develop techniques for determination of optimal operation policies for a reservoir. Several reports have been prepared under this project covering various aspects of this problem.

SEDIMENT YIELD AND RESERVOIR SEDIMENTATION STUDIES

Generally suspended solid/sediment causes the most serious pollution of water bodies. This not only reduces the reservoir storage and its life but also restricts the use of water for multipurposes. Hence the process of sedimentation is of great concern to water resources engineers as this affect the flow measurement, capacity of rivers, reservoir capacity etc. This process combined with soil erosion in watershed is primarily dependent on the land use pattern or land management practices. This project aims at studying the sedimentation phenomena, estimation of sediment yield and soil loss and attempting of using mathematical models.

To achieve these objectives, a comprehensive review was attempted wherein various mathematical models available in India and abroad were studied, compared and their limitations/usages were brought out. This exercise gave an insight to the modelling efforts in the area. Realising the importance of the phenomena of reservoir sedimentation, a review of sedimentation processes, status of reservoir sedimentation in India has been brought out. Various empirical, analytical/mathematical and experimental methods for forecasting of reservoir sedimentation have been discussed. Knowledge gaps in terms of physical phenomena including physics of sedimentation, quality of sediments, lacuna in measurement techniques, surveying and prediction methods have been brought out.

Keeping in view the requirement of field personnel, an attempt has been made to bring out a summary table for specific ranges of sediment yield from different land uses. In all, seven land uses have been considered. The data is based on studies conducted in India on small watersheds/catchments. In continuation of this effort, it has been attempted to review various techniques of soil loss computations and a specific area has been taken up to compute the soil loss. The results of the model compare fairly well with actual field observations.

The studies carried out so far have been documented in form of review note, status report, technical report on various aspects of sedimentation leading to sediment yield, soil loss estimation and their effect on reservoir management.

At present studies are being carried for assessing the reservoir sedimentation in a typical reservoir of South India. It is also proposed, to compute the sedimentation by using suitable mathematical model and comparing the results. This may lead to review of project hydrology pertaining to reservoir sedimentation with aims of possible improvement and further refinement.

ASSESSMENT OF GROUNDWATER BALANCE COMPONENTS

Uncertainities of rainfall and increasing demand on water have necessitated exploitation and management of groundwater. In order to make optimal utilisation of groundwater resources of a particular basin, it is essential to assess the various components that influence groundwater reserve. This project, therefore, aims at identifying and modelling such components for evaluation of groundwater potential of a basin.

To achieve these objectives, factors responsible for framing groundwater budget viz. recharge into the basin and discharge out of the basin have been identified and processes contributing to these have been brought out. Existing methodologies for evaluation of various components have been reviewed. Studies carried out so far have been documented in form of case studies, technical reports, technical notes and review notes.

A case study for seasonal groundwater balance of Upper Ganga Canal command area for the period 1972-73 to 1983-84 has been carried out. The various recharge and discharge components are quantified and rainfall recharge coefficient for the study has been established. It is further envisaged to take up mathematical modelling of the area for predicting impact of surface water application on groundwater regime and to assess the amount of exploitable groundwater.

Different methods of estimating recharge components are outlined and methodologies have been recommended to estimate the various components leading to groundwater recharge with particular reference to alluvial plains of Northern India. A detailed study has been made on the rainfall recharge process under the three main areas such as: empirical formulae, experimental studies and combined deterministic and analytical studies. Methodologies are elaborated and recommended for finding rainfall recharge. A methodology has been developed to quantify seepage from canals using tracer technique. A mathematical model for seepage studies from two parallel canals has been developed and interference to two parallel canals is studied. The temporal variation of seepage from the canal hydraulically connected with the aquifer has been quantified. The evolution of water table due to recharge from a strip source has been analysed. The analysis has been extended to find the evolution of water table due to seepage from two parallel canals. Efforts have been made to study the return flow from irrigation and to understand the various factors affecting it. Different methods of quantifying return flows from irrigation have been reviewed. A mathematical model has been developed to assess recharge from Suratgarh depression storage.

Guidelines have been laid for sample survey for minor irrigation works and methods for computing draft from groundwater are indicated. A detailed review has been made for the methods for estimation of evapotranspiration for variable water table situations which considers both the soil properties and meteorological factors. Different methods of estimating evaporation losses have been reviewed. The estimation of evaporation rate under quasi steady state conditions has been studied. The amount of evaporation loss in a soil and the soil moisture variation at different time steps due to evaporation losses has been estimated.

Besides, it is envisaged to take up further studies on the following themes to obtain a complete scenario of groundwater balance assessment project: Coastal aquifers and well interaction; Economics of dug wells and bore wells in alluvial areas; Optimum distance between dug wells in alluvial areas; Assessment of groundwater in hard rock areas; Analysis of flow to a dug well in hard rock areas in an unconfined aquifer by cell theory; Evaluation of pollution free zone for drinking water from dug wells; and Interference of large diameter wells in hard rock areas.

GROUND WATER MODELLING

Ground water hydrology is a combination of concepts and perspectives that pertains to the scientific, engineering and management aspects of ground water in the hydrologic cycle. It encompasses the occurrence, origin, movement, quality, recovery and use of ground water. At present utilisation of ground water has become a tenet in every nation's water resources development policy. The rational limit of ground water exploitation is that quantity which may be withdrawn from a ground water reservoir with a prescribed development policy during a definite planned period taking into account the technical economic efficiency and the water quality within the adopted standard. The rational limit of the rate of groundwater exploitation should be such that protection from depletion is provided, protection from pollution is provided, negative ecological effects are reduced to a minimum and economic efficiency of exploitation is attained. Determination of exploitable resources should be based upon hydrological investigations. These investigations logically necessitate use of a mathematical model of ground water system for analysing and solving the problems. The aim of this research project is to develop sound mathematical ground water flow model to assess ground water potential in static and dynamic reserve, the recharge due to rainfall, the stream aquifer interaction during the passage of a flood and to analyse flow in multiaquifer system.

In order to achieve the objectives envisaged in this project, a review focussing the important methods available for determination of hydrogeological parameters in alluvial as well as in hard rock areas has been made, appropriate duration of test pumping has been recommended, charts for determination of aquifer parameters in hard rock area from knowledge of specific capacity have been developed. Type curves for aquifer test conducted in a multiaquifer well which is open to two aquifers have been developed. Using a three/ dimensional finite difference model recharge from large depression storage has been studied. Reach transmissivity constants for various hydrologic boundary conditions have been determined to assess exchange of flow between stream and aquifer. Parameters which affect baseflow have been studied. Ground water recharge during the passage of a flood through the flooded river bed has been estimated. Also recharge to deeper aquifer during the passage of a flood has been analysed. Design and performance of large diameter well in hard rock area has been studied. Storage in confined aquifer with flowing artesian well has been quantified. Unsteady flow towards a well with storage in leaky aquifer have been analysed. Solution technique for unsteady flow to a multiaquifer flowing well have been developed. User manuals for modelling ground water flow by a finite element aquifer flow model which has been developed by Massachusetts Institute of Technology has been prepared. Besides, a user manual on Tyson Weber ground water flow model has been prepared.

The above studies have been documented in form of review notes, technical reports and technical notes on various aspects of ground water assessment and their development. The future research programme envisaged under this project is to undertake detailed studies on:

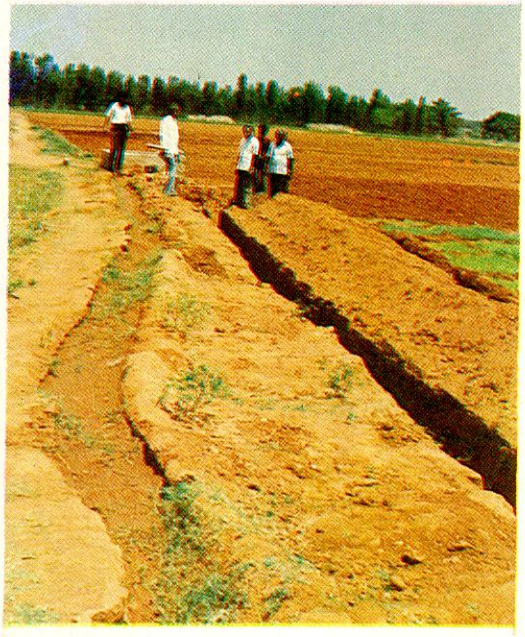
- Augmentation tubewell
- Assessment of ground water from surface water bodies
- Stream aquifer and well interaction
- Spring flow studies
- Recharge from ephemeral streams

After studying different component process it is proposed to develop a model to quantify ground water recharge from various sources and to assess the ground water potential in static and in dynamic reserve.

DESIGN OF DRAINAGE SYSTEM FOR AGRICULTURAL WATERSHEDS

The aim of agricultural drainage is to maintain favourable moisture-oxygen-salt balance in the root zone for plant growth. Improper agricultural drainage has been found to create waterlogging and conditions of salinity in the agricultural watersheds, thereby resulting in loss of crop yield. Experience has shown, often quite forcefully, that it is better to fully equip a restricted area than to put water on a greater surface without sufficient provision for application efficiency and appropriate drainage. Therefore, whenever irrigation is planned, special consideration is given to the peculiarities of the natural soil, the position of the ground water table, salinity of the ground and the soil and unsatisfactory natural drainage. The aim of this project is to come out with necessary guidelines for overcoming problems encountered in agricultural drainage.

To accomplish this objective a detailed review identifying several hydrological parameters used in design of surface and subsurface drainage systems has been done. Runoff coefficients to be used in design of surface drainage system have been highlighted and daily runoff from agricultural watersheds using SCS method with soil moisture accounting quantified. A study has been made to estimate the daily runoff from a natural catchment based on watershed simulation models. Various techniques used in different part of the country to provide drainage in heavy soils have been reviewed.



For subsurface drainage system, irrigation return flow and drainage coefficients adopted in practice for various land uses have also been reviewed. Study on the leaching requirement for salinity removal has been undertaken and such requirements quantified. A model has been formulated using Green and Ampt equation for estimation of infiltration volume from different soil layers.

A drainage manual based on various physical, meteorologic and hydrologic variables is being prepared for design of subsurface drainage system. Guidelines for design in saline soils have also been prepared and other appropriate techniques such as plantation and layout of intercepting drains suggested.

Documents based on the above studies have been brought out through review notes, technical notes, technical reports and case studies, dealing with aspects related with drainage problems and their remedial measures for agricultural watersheds.

Recently the attention has been paid towards the problems of drainage in coastal areas and in Urban areas. Works on salt balance in root zone, control of waterlogging by vertical drainage, design of drainage system in heavy soils are proposed to be taken up in subsequent study.

CONJUNCTIVE USE OF SURFACE AND GROUNDWATER

With the increasing demand placed on groundwater for irrigation, industry, and municipal use, the need for rational management of groundwater has become evident. Groundwater is often connected with surface water and their optimal use in many cases depends on the conjunctive management of both surface and groundwater. The aim of this project is to develop a conjunctive use model for the optimal utilisation of water resources in a river basin.

In order to achieve the objectives envisaged in this project, various aspects of artificial groundwater recharge have been discussed with reference to their design criteria, application, economic feasibility etc. and methodology has been developed to predict the temporal and spatial distribution of the artificially recharged water in a groundwater basin. Various methods of assessment of crop water requirement, a prerequisite for implementation of a conjunctive use model, have been described. A review of several empirical relations giving details of data required for determining evapotranspiration has been presented. A computer program for estimating evapotranspiration using Blaney Criddle, Radiation, Modified Penman and Pan evaporation methods has been implemented at the institute's computer system. A status report reviewing the research works done in the fields of crop water requirement, field efficiency and irrigation planning has been prepared.

A conjunctive use model for optimum agricultural production in the sub-basin of Ghataprabha command area in Karnataka State has been formulated. A linear programming model has been used to allocate the optimal areas to different crops subject to constraint of surface and groundwater availability.

Optimal crop plan, which is economically feasible and socially acceptable exploiting the irrigation potential both from surface and groundwater has been suggested.

The future research programme envisaged under the project is to undertake detailed studies on:

- Conjunctive use planning in Sharada Sahayak canal command
- Assessment of groundwater recharge from percolation tanks
- Control of waterlogging through conjunctive use
- Conjunctive use of surface water, groundwater and rainfall

After studying the different process level models, it is proposed to develop an aquifer management oriented conjunctive use model which will address to the withdrawal from groundwater reserve keeping in view the availability of surface water so as to get maximum benefit from the land resources without causing harmful effects such as waterlogging, excessive drawdown and deterioration of water quality. The crop planning will be the outcome of the optimization model which is also envisaged to take into account the uncertainty of availability of surface water. The study will be undertaken for some of the river basins in hard rock areas and in alluvial plains.

HYDROLOGICAL ASPECTS OF DROUGHTS

Hydrological uncertainties together with extreme manifestation of some of the related phenomena are main reasons for droughts. The occurrence of drought leads to reduction in stream flow and consequent reduction in reservoir and tank levels and depletion of soil moisture and ground water regime. This, on a continued basis, leads to reduced availability of fodder and decline in agricultural production. A study on the hydrological aspects of drought in 1985-86 has been carried out. Two districts from each six selected drought prone states viz., Banswara and Barmer from Rajasthan, Khargone & Jhabua from Madhya Pradesh, Cuddapah and Anantpur from Andhra Pradesh, Bijapur and Belgaum from Karnataka, Ahmednagar and Solapur from Maharashtra, and Jamnagar & Rajkot from Gujarat have been chosen for the study. The study deals with rainfall analysis for drought characteristics including analysis of dry spells, soil moisture index for drought analysis, stream flow analysis including low flow analysis for drought investigation, reservoir inflow forecasting and impact of drought on ground water regime. The analysis of rainfall data of 12 various districts indicated a rainfall deficiency enough to cause the drought conditions as per the established rainfall indices. Also based on analysis of long term rainfall data (1901-1986) scarcity of rainfall was observed in more than 20% of years. The Herbst's analysis done to evaluate drought intensity indicated greater intensity of drought during 1985-86. Based on limited data of soil moisture, attempt has been made to characterise drought based on soil moisture index. The analysis of streamflow data of 20 years for Krishna basin had shown deficiency in streamflow on a result of drought, which was verified by comparing hydrographs and annual

flows. Flow duration curves have also been developed based on which values of low flow index were established. The analysis of deficit volume and duration based on some demand level has also indicated greater drought intensity during 1985-86. The levels of ground water as observed from various ground water wells in the study area were analysed for predictive trend of ground water regime. A general declining trend in ground water level was observed. A technique to forecast the monsoon runoff and its application to Krishna basin has also been discussed.

A similar study on the hydrological aspects of drought in 1986-87 is under progress. In order to increase the zone of study, four districts for each state have been selected for study. The study is expected to end up with more comprehensive results.

A comprehensive review of important drought indices has also been carried out to assess their applicability as well as limitations while selecting a particular criterion for drought quantification. Attempt has also been made to develop a simple approach of soil water budgeting for simulating daily soil moisture in dry lands in order to study the incidence, severity, duration and frequency of drought. A study on performance of percolation tank to determine the recharge, area of influence and evaporation losses etc. is under progress.

Various studies carried out under this project have been documented in the review notes, technical reports, status report and case studies. Further efforts are in progress to collect more field data to study the hydrological aspects of drought in the required details.

WATER AVAILABILITY AND DROUGHT MANAGEMENT

The dependence of India's agriculture on the southwest monsoon and its consequent vulnerability has brought to focus the crucial role of water resources development, conservation and utilisation and land development also. The comprehensive strategy required for the development, conservation and utilisation of water resources is governed by the many interlinked factors like water availability (surface or ground water), its quality, location, distribution and variation in its occurrence, climatic conditions, soil type, competing demands (agricultural & non agricultural), land use system and socio-economic conditions.

An important factor in planning of strategy of drought management is the proper and reliable collection and storage of data. In this context, a status report has been prepared which has highlighted the various types of shortcomings as are observed in storage and retrieval of hydrological data needed for drought studies.

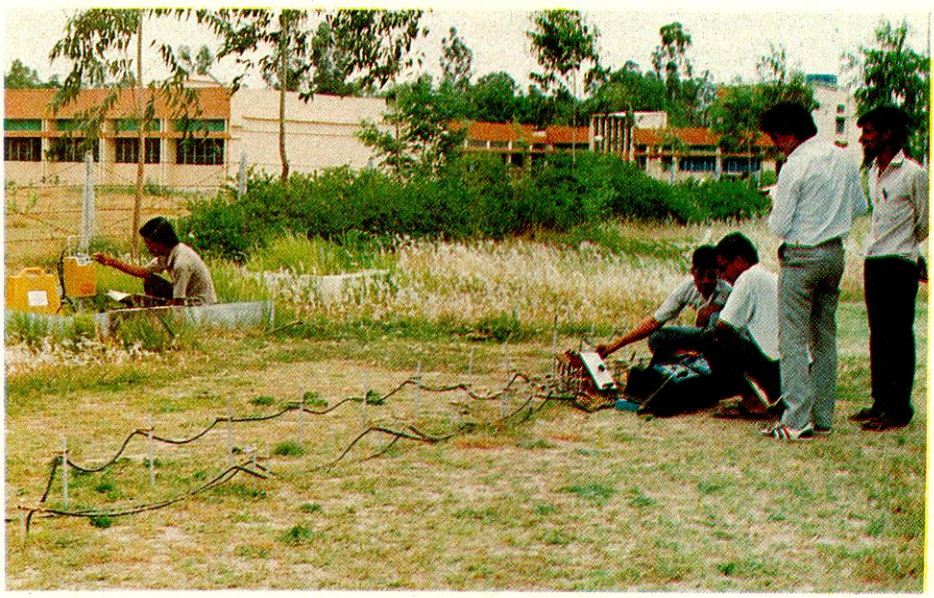
Another important feature of drought management is to know the low flow regime of rivers. In this connection low flow studies have been carried out to review the various deterministic, statistical and stochastic approaches for use in determination of magnitude, frequency and duration of low flows.

Evaporation of water is worst enemy in drought stricken areas. In view of this an effort was made to put together all methods of estimating evaporation from water bodies like lakes and reservoirs. An intercomparison of the methods has been done to indicate the choice of methods under different situations. Evaporation from typical reservoirs of Karnataka in the semi-arid region of the country has been estimated by mass transfer and penman method using the available climatological and water level fluctuation data.

Another study under this project relates to artificial measures for increasing runoff for combating drought conditions. Various measures like surface clearing, vegetation management, mechanical means, chemical treatments, surface binding treatments etc. have been discussed in details for the purpose of their applicability in augmenting runoff yield or conserving moisture. Based on studies conducted in the country and elsewhere estimates of effectiveness of employing various measures have been made.

MATHEMATICAL MODELS FOR WATER QUALITY AND POLLUTION ASSESSMENT

The planning of water as a national resource is not merely a question of ensuring the availability of water in the right quantity at the right time for diverse purposes, but also one of ensuring the right quality for use in view. The biggest threat to such ensuring are pollution problems which need in-depth study. Such studies are very helpful to hydrologists in not only assessment of the water quality but also its monitoring and management. Similarly development of water resources has to be closely linked with environment protection. This project has been undertaken with the objective of carrying out various water quality modelling efforts to arrive at some simple, easily applicable, appropriate models on the one hand and to arrive at certain indices to assess the impact of water resources development on the environment. The project also contributes to our knowledge in the area of thermal pollution and thermal stratification.



With a view to achieve these objectives, different available water quality models have been studied at the Institute. Their capabilities, complexities and usages have been assessed. Some simulation experiments using these models have been carried out for variables like

dissolved oxygen, phosphorousetc. under changing physical and biological conditions such as flows, wasteloads as well as varied climatic conditions. Based on the performance of various models, appropriate models have been identified. The modelling efforts have been directed towards modelling the dissolved oxygen in streams and a typical river reach in U.P. has been modelled with very encouraging results.

Various models available for temperature stratification in deep reservoirs have been studied, compared and data requirement worked out so that these can be used for Indian case studies. This has a link with earlier conducted study on thermal pollution. Realising the importance of groundwater pollution, a typical area has been taken up and the groundwater contamination in the area has been quantified by regular monitoring and analysis. This can serve as a model study for future work.

Realising the need for a strong database for further validation of various mathematical models, a water quality laboratory equipped with some of the latest and sophisticated equipment has been established at the Institute for carrying out regular tests on water samples to obtain the input variable for mathematical models.

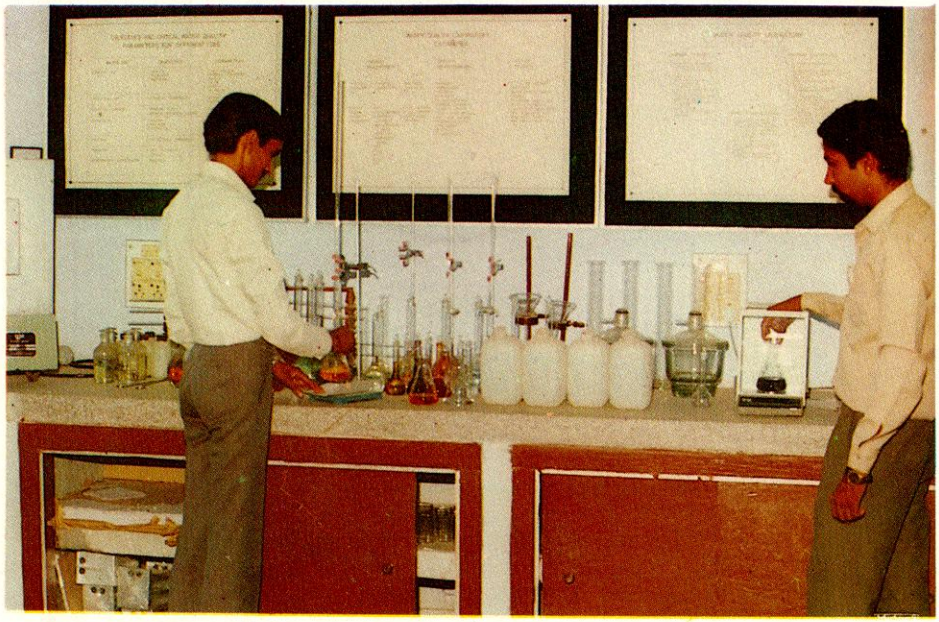
Under the project, the second major aspect which is being studied is the environmental impact assessment of water resources development. An attempt has been made to identify various hydro-environmental indices to evaluate such impacts. Similarly, an attempt has been made, accounting the already commissioned major and medium WR Projects, to highlight the positive benefits of the WRD projects.

For reinforcing the objectives envisaged in the project, further work is in progress. Modelling studies for various constituents in rivers is in advance stage of progress. These variables include nitrogen, algal contents etc. An attempt to use most recent models such as QUAL-IIe etc. is also being made. Efforts are being directed to collect data for few completed water resources projects in India so that the positive benefits of such projects could be highlighted in quantitative terms.

MEASUREMENT OF HYDROLOGICAL VARIABLE USING GEOPHYSICAL AND NUCLEAR TECHNIQUES

Measurement of sub-surface hydrological variables and determination of geologic and hydraulic parameters need the help of exploratory techniques such as geophysical and nuclear techniques. This project has therefore, aimed at carrying out various hydrological studies using the above techniques.

In order to accomplish the objectives, various available geophysical and nuclear methods for carrying out studies like ground water exploration, assessment of water balance components, ground water pollution, geothermal exploration, seepage losses from reservoirs and canals, soil moisture variation and movement, permeability, transmissivity and lithology of soils have been reviewed.



Use of environment isotopes for study of ground water recharge and interconnection between surface and subsurface waters have also been reviewed.

Insitu studies for soil moisture content in top soil layer using nuclear and resistivity techniques have been carried out. Field measurements of soil moisture movement in artificial ponding conditions have also been carried out using Neutron Probe. In order to establish the

effect of variation of degree of saturation, conductivity of electrolyte saturating the soil and porosity, theoretical study has been done. An experimental study on temporal and spatial variation of soil moisture using resistivity and S.P. techniques has also been completed.

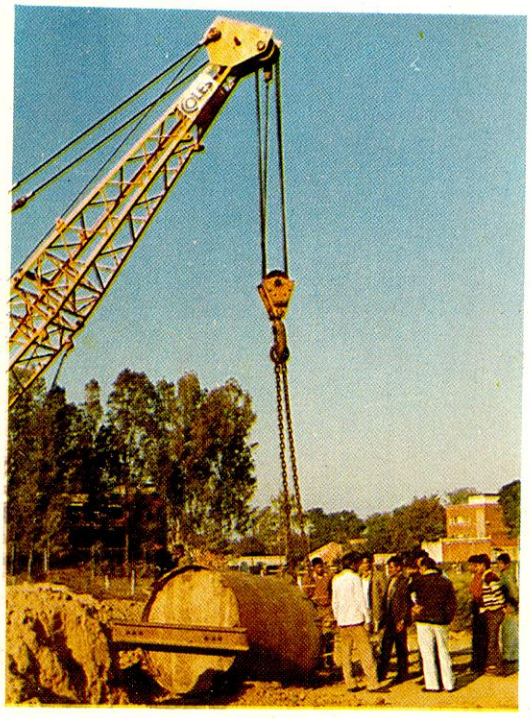
The findings of various studies carried out at the Institute have been documented in form of review notes and technical reports on use of geophysical and nuclear techniques for investigation of soil moisture variations.

Use of electromagnetic method for similar studies is also envisaged with an aim to develop comprehensive nomograms between soil moisture and soil-resistivity. Field investigations utilizing resistivity, S.P. and nuclear technique for studying ground water pollution are also proposed.

AUTOMATED COLLECTION AND TRANSMISSION OF HYDROMETEOROLOGICAL DATA

Most of the hydrological research studies being data based necessitated collection and transmission of relevant data for further analysis and use. Advent of sophisticated sensors, microprocessors and microcomputers have made it possible to accomplish these tasks on-line and with high degree of reliability. It is, therefore, envisaged in this project to study in details the use of computers in collection and transmission of hydrometeorological data based on which develop a suitable data acquisition system for future use.

In order to accomplish these objectives, various schemes of data collection and transmission systems in hydrology and hydrometeorology, use of microprocessors and microcomputers in modern data acquisition system and use of some of hydrometeorological sensors based on microprocessors have been reviewed.



Various pre-processing operations viz., amplification, filtering, trend removal, decimation and calibration needed for the input signal to be compatible with the recording system have also been reviewed. Studies on two types of data acquisition system have been carried out and their configuration brought out. Operational details of automatic hydrologic station, to be installed at the Institute, have been studied and outlined.

In order to evolve a suitable configuration for the type of data acquisition system being developed at the Institute, various telemetry systems for transmitting data from remote data collection sites have been reviewed.

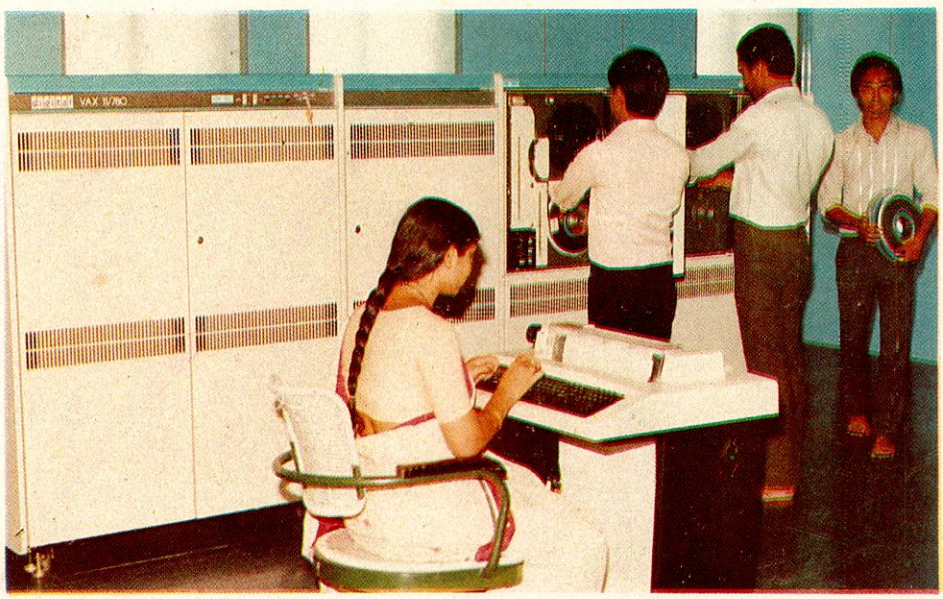
The above studies have been documented and brought out in form of review notes on data collection and transmission system (telemetry system) and use of micro processors in hydrological studies.

It is further envisaged to develop a suitable data acquisition system using the latest technology and connect it to a telemetric device for remote data collection and transmission.

DATA BASE MANAGEMENT AND INFORMATION SYSTEM

A Data Base Management System (DBMS) may be defined as a collection of interrelated data stored together without harmful and unnecessary redundancy to serve multiple applications. Specific data item (s) may be searched/retrieved from this system very quickly and easily.

Hydrology is an applied science and therefore hydrologist has to deal with vast amount of data. In the conventional way, data are mostly kept in registers or files and whenever demanded, they are manually copied and supplied. Usually, no data inventory is available and many times, data are lost with the passage of time due to several reasons like physical damage to the storage media.



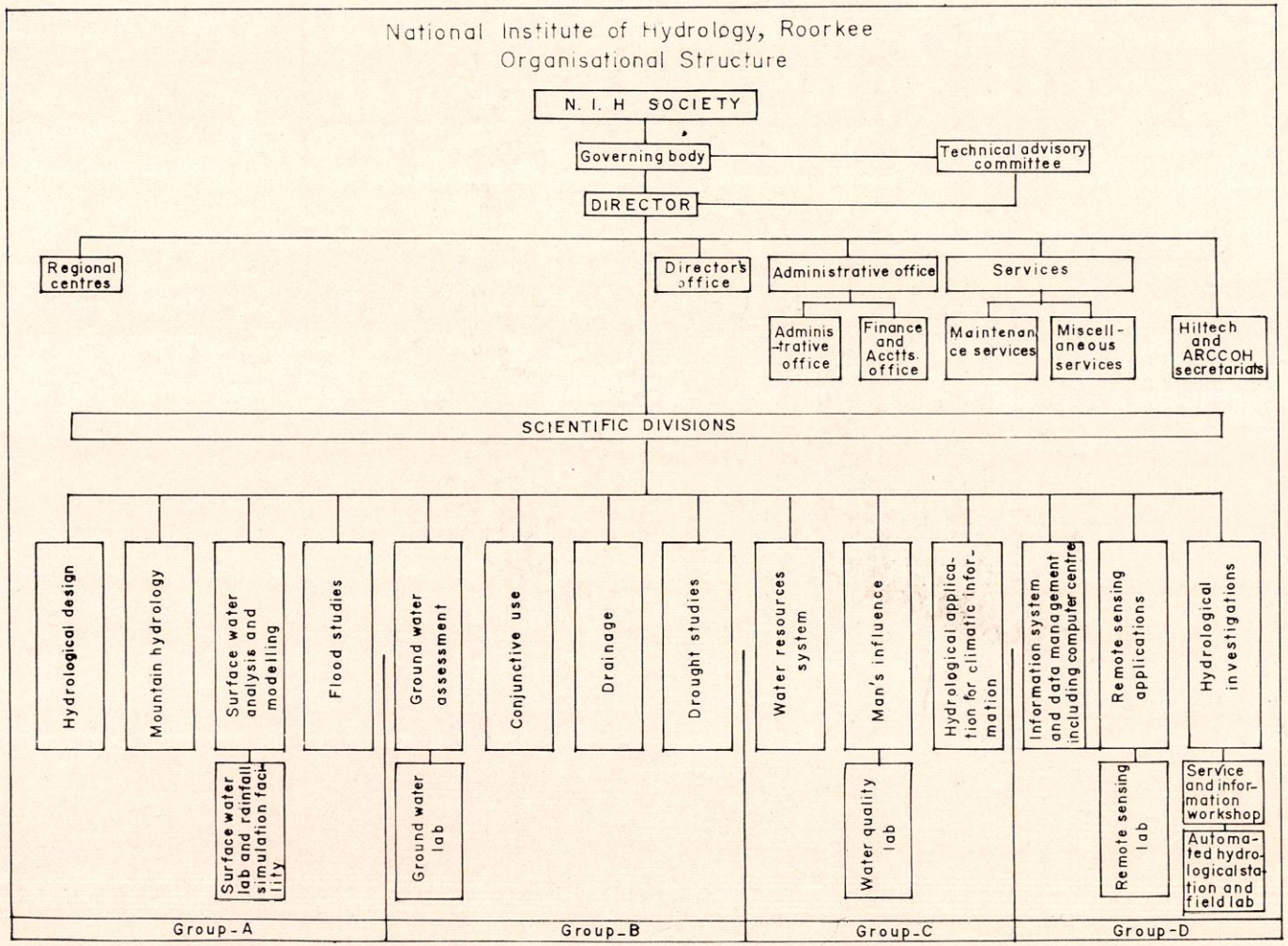
Informations which are outcome of data processing primarily depend upon an exhaustive data base. The accuracy of the results obtained depends upon the quality and extent of data used. Although, techniques are available for synthetic generation of data, the generated data cannot be perfect substitute of the observed data.

Once data are collected, the next important and necessary step is their proper storage. Computer oriented data management techniques assist in rapid, easy and economic handling of these data. The objective of this project is to develop a data storage and retrieval system for hydrological data using personal computers.

In order to accomplish this objective, a Data Storage and Retrieval System has been developed using which data can be stored and retrieved from the data base through a common and controlled approach. This system has been kept flexible in such a way that the data stored are independent of the program which uses them and their structure can conveniently be modified.

Status of data systems has been reviewed. Based on which a Library Retrieval System has been developed using an appropriate input, output and process design. Further studies on data base management techniques have been carried out. Management Information System for computerized accounting has been developed. Documents based on the above studies have been brought out through technical notes and status reports on Management Information System, data system and library.

Further development and improvement of this Data Storage and Retrieval System is in progress. This will make the package more general and be able to account for all types of hydrometeorological data alongwith physical characteristics of any basin.


National Institute of Hydrology, Roorkee
Organisational Structure
N. I. H SOCIETY
Governing body
Technical advisory committee
DIRECTOR
Regional centres
Director's office
Administrative office
Services
Adminis-trative office
Finance and Acctts. office
Maintenance services
Miscell-aneous services
Hiltech and ARCCOH secretariats
SCIENTIFIC DIVISIONS
Hydrological design
Mountain hydrology
Surface water analysis and modelling
Flood studies
Ground water assessment
Conjunctive use
Drainage
Drought studies
Water resources system
Man's influence
Hydrological applica-tion for climatic infor-mation
Information system and data management including computer centre
Remote sensing applications
Hydrological investigations
Surface water lab and rainfall simulation facility
Ground water lab
Water quality lab
Remote sensing lab
Service and infor-mation workshop
Automa-ted hydro-logical sta-tion and field lab
Group-A
Group-B
Group-C
Group-D

INSTITUTE'S CAPABILITIES

With the expertise available and developed over the years at the Institute, the studies and projects in the following areas can readily be undertaken:

1. Water Yield Studies
2. Flood Routing and Forecasting
3. Hydrologic Water Balance Computation
4. Design Storm and Design Flood Estimation
5. Watershed Modelling and Simulation
6. Snow and Glacial Hydrology
7. Reservoir Operation and Integrated Planning
8. Water Quality Modelling
9. Ground Water Balance
10. Ground Water Modelling and Aquifer Response Studies
11. Conjunctive Use of Surface Water and Ground Water
12. Synthetic Data Generation
13. Application of Computer in Hydrology
14. Remote Sensing Applications
15. Digital Image Processing
16. Water Availability and Drought Management

CONSULTANCY PROJECTS COMPLETED AND UNDER PROGRESS

Till 1988 the Institute has undertaken and completed several consultancy projects to advise various state and central organisations as listed below:

1. Groundwater Modelling in Upper Ganga Canal Command Area' sponsored by Water and Power Consultancy Services (WAPCOS), Delhi.
2. 'Design Flood Studies for Narmada Project' sponsored by Narmada P & P Cell, Ministry of Water Resources, Govt. of India, Delhi.
3. 'Water Availability Studies of Mahanadi Basin' sponsored by National Water Development Agency, Delhi.
4. 'Hydrological Studies of Kishau Dam' sponsored by U.P. Irrigation Department.
5. 'Generalised Computer based Groundwater Data Storage and Retrieval System' sponsored by Ground Water Investigation Organisation, U.P.
6. 'Design of Well Point System for Dewatering Solani Aqueduct, Upper Ganga Canal Modernisation' sponsored by U.P. Irrigation Department.
7. 'Software Development for Ground Water Balance' sponsored by Ground Water Investigation Organisation, U.P.

Some of the projects currently under progress as well as under consideration are:

1. 'Study for Developing a Model to Forecast the Availability of Drinking Water in different Areas of the Country Linking it with the Monsoon Performance' sponsored by Department of Rural Development, Ministry of Agriculture, Govt. of India.
2. 'Preparation of a Reservoir Operation Manual for Dharoi Reservoir' sponsored by Gujarat Irrigation Department.
3. 'Preparation of a Reservoir Operation Manual for Machhu Reservoir' sponsored by Gujarat Irrigation Department.
4. 'Hydrological Studies of Lower Indravati Project' sponsored by Orissa Irrigation Department.
5. 'Hydrological Studies of Barak Basin' sponsored by Brahmaputra Board.
6. 'Flash Flood Studies of Punjab' sponsored by Punjab Irrigation Department.

APPENDICES

(DETAILED LIST OF REPORTS BROUGHT OUT UNDER VARIOUS PROJECTS)

ANALYSIS OF HYDROMETEOROLOGICAL VARIABLES

Review Notes:

Atmospheric general circulation models
Rainfall simulator studies

Technical Notes:

Study of depth area duration and depth duration characteristics
Methodology for estimation of design storm

Technical Reports:

Statistical analysis for rainfall in Belgaum district, Karnataka
Mathematical modelling of moving storms

User Manuals:

Rating curve analysis
Processing and analysis of rainfall data

Manual:

Processing of precipitation data

Case Studies:

Study of hydrometeorological aspects of Narmada basin
Rating curve for gauging sites on Narmada river
Network design of raingauges in Rajasthan State

Documentation Program:

Rating curve analysis

FLOOD ROUTING STUDIES

Review Notes:

Hydrologic flood routing including data requirement
Hydraulic routing techniques
Effect of channel processes on flood routing
Flash flood studies
Effect of flood plain on flood routing

UNIT HYDROGRAPH IN FLOOD ESTIMATION FOR SMALL BASINS

Review Notes:

Use of catchment characteristics for unit hydrograph derivation
Regional unit hydrograph

User Manuals:

Unit hydrograph derivation
Model parameter evaluation using catchment characteristics
Init hydrograph analysis

Case Studies:

Comparative study of unit hydrograph methods

STATISTICAL MODELLING OF ANNUAL PEAK FLOODS

Review Notes:

Partial duration series models
Regional flood frequency analysis
Flood forecasting models
Procedure for hydrological network design
Regional approaches for flood estimation in mountainous areas

Technical Reports:

Suitability of power transformation based gumbel EV-1 distribution for flood frequency analysis
Some studies on plotting position formulae for gumbel EV-1 distribution

User Manuals:

Frequency analysis
Multiple linear regression
Polynomial regression
Flood frequency analysis on a microcomputer with basic language
Techniques for flood frequency analysis

Case Studies:

Regional flood frequency analysis
Partial duration series models

Documentation Programs:

Flood frequency analysis using power transformation
Best fit distribution
Ordering the series and interpolation
Multiple linear regression
Polynomial regression

STOCHASTIC MODELLING OF HYDROLOGIC VARIABLES

Review Note:

Time series analysis models

Technical Report:

Forecasting of monsoon rainfall and runoff

Case Studies:

Monthly stream flow generation
Application of Bivariate Thomas-Fiering model for monthly stream flow generation in Mahanadi river basin

State of Art Report:

Time series modelling

DAM BREAK STUDIES FOR PLANNING OF FLOOD PROTECTION MEASURES

Technical Note:

Data requirement and data preparation for dam break programme

Case Studies:

Dam break analysis for Machhu Dam II

HYDROLOGICAL STUDIES IN FORESTED CATCHMENTS

Review Note:

Vegetation management for increased water yield

Technical Report:

Ecosystem simulation sub-models Flora and Fauna

Status Reports:

Forest influence on hydrological parameters
Status of hydrological studies in forested catchments

Technical Reports:

Cause of negative outflow in Muskingum method
Development of a variable parameter simplified hydraulic flood routing model for rectangular channels
Comparison of some variable parameter simplified hydraulic flood routing models

User Manuals:

Muskingum-Cunge routing procedure
Hydrologic flood routing
Kalinin-Milyukov method of flood routing

Case Study:

Application of Muskingum-Cunge method of flood routing

Documentation Program:

Flood routing (Muskingum-Cunge procedure)

WATERSHED MODELLING

Review Notes:

Overland flow
Comparative study of components of watershed models
Rainfall runoff relationship
Overland flow in mountainous area

Technical Note:

Watershed resources development model

Technical Report:

Overland flow modelling

User Manuals:

Application of tank model for daily runoff analysis
Application of tank model for flood analysis

Case Study:

Simulation of daily runoff of two sub basins of river Narmada using tank model

SNOW AND GLACIAL HYDROLOGY

Review Notes:

Measurement of snow and estimation of snow cover
Snow melt processes

Technical Note:

Study of glacier melt and physics of glaciers

REMOTE SENSING APPLICATION TO HYDROLOGICAL STUDIES

Review Notes:

Snow line and snow cover mapping by remote sensing techniques
Land use/vegetal cover mapping using satellite data
Remote sensing application for flood inundation studies
Remote sensing application to sedimentation studies

Technical Report:

Remote sensing application for sedimentation studies in reservoir

Case Study:

Land use mapping of upper yamuna catchment using remotely sensed data

REAL TIME RESERVOIR OPERATION

User Manuals:

Preparation of working table
A flood control operation of a reservoir

Manual:

Multipurpose operation of a reservoir

State of Art Report:

Reservoir operation studies

TECHNIQUES FOR CAPACITY COMPUTATION AND OPTIMAL RESERVOIR OPERATION

Review Notes:

Optimization and programming techniques for reservoir operation
Range analysis for storage

Technical Report:

Water balance of a reservoir

User Manuals:

Optimum reservoir operation using dynamic programming
Mass curve analysis and sequent peak algorithm
Storage yield analysis

Manual:

Reservoir capacity computation

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Review Note:

Sedimentation in reservoirs

Technical Report:

Study of soil erosion for different land use and vegetal covers using universal soil loss equation

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Rainfall recharge
Estimation of evapotranspiration for variable water table situations
Irrigation return flow

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Estimation of seepage from canal using tracer techniques
Seepage from water bodies
Exchange of flow between river and aquifer system
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Seepage from parallel canals
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Technical Notes:

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Parameterisation of hydrogeological factors in ground water study
Duration of test pumping
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Study of parameters affecting baseflow
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Determination of aquifer recharge for varying river stages
Surface fitting of ground water table by means of least square approach
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Hydrological parameters in drainage studies

Technical Notes:

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Leaching requirement of agricultural land and study of movement of salts

Case Studies:

Modelling of daily runoff for Kasurnala basin using Betson and USGS models
Soil water accounting using SCS hydrologic soil classification

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Technical Notes:

Artificial recharge of groundwater
Water requirement of crops

Technical Report:

System approach to optimize conjunctive use of surface and groundwater

State of Art Report:

Crop water requirement field efficiencies and irrigation planning

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Review Notes:

Hydrological aspects of droughts
Comprehensive review of drought indices

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Case Studies:

Hydrological aspects of drought in 1985-86 (an interim report)
Hydrological aspects of drought in 1985-86 (final report)

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Technical Note:

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Technical Report:

Estimating evaporation losses from lakes and reservoirs

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Positive impacts of water resources projects

Technical Reports:

Water quality modelling of rivers
Identification of hydro-environmental indices
Groundwater quality variation in Saharanpur district (U.P.)
Thermal stratification in reservoirs

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Status Reports:

Status of thermal pollution in water bodies
Water quality and sediment modelling in surface water

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Application of resistivity method for moisture estimation in top soil layer

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Field measurement of soil moisture movement in ponding conditions
Estimation of soil moisture variation using resistivity techniques

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Review Notes:

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Comparative study of self recording raingauge
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Technical Notes:

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Management information system

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Generation of hydrological graphs using computer graphics
Graphical representation of information related with floods
Graphical representation of flow duration curve

Status Report:

Data System and library

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