

An Overview of Hydrological Studies by C. P. Kumar

C. P. Kumar

Scientist 'G', National Institute of Hydrology, Roorkee – 247667, Uttarakhand, India

Abstract— This article presents an overview of hydrological studies undertaken and published by a Senior Scientist working at National Institute of Hydrology (A Government of India Society under Ministry of Jal Shakti), Roorkee - 247667 (Uttarakhand), India. It covers a wide variety of research outcomes related to groundwater assessment; seawater intrusion in coastal aquifers; numerical modelling of unsaturated flow, groundwater flow and contaminant transport; management of aquifer recharge; and impact of climate change on groundwater etc.

Keywords— Groundwater, Groundwater Balance, Groundwater Modelling, Hydrology, Hydrologist, Seawater Intrusion.

I. INTRODUCTION

The National Institute of Hydrology (NIH) was established in December 1978 as an Autonomous Society (presently under Department of Water Resources, River Development & Ganga Rejuvenation, Ministry of Jal Shakti, Government of India). Main objectives of the Institute are to undertake, support, promote and coordinate systematic and scientific research work in all aspects of Hydrology and Water Resources. The Institute has its headquarters at Roorkee (Uttarakhand, India), four Regional Centres at Belagavi, Jammu, Kakinada and Bhopal and two Centres for Flood Management Studies at Guwahati and Patna. The institute is well equipped to carry out computer, laboratory and field oriented studies. The institute acts as a center of excellence for transfer of technology, human resources development and institutional development in specialized areas of hydrology and conducts user defined, demand-driven research through collaboration with relevant national and international organizations.

At the headquarters (Roorkee), the R & D activities and consulting services are carried out through six divisions – Surface Water Hydrology, Ground Water Hydrology, Environmental Hydrology, Water Resources System, Hydrological Investigations, Research Management and Outreach. The comprehensive work program of the Institute covers: (i) In-house R & D studies on emerging areas, (ii) Sponsored R & D studies, (iii) Demand driven and referred problems, (iv) Consultancy and Technical

services, and (v) Capacity building activities through regular training courses and technology transfer.

Ground Water Hydrology division, a key division of the Institute, has collaborated in many national and international projects. The division undertakes in-house R & D studies, sponsored studies and consultancy projects from the Central and State Government departments and other stakeholders of water. As part of the technology transfer program of the Institute, the division organizes various training courses/ workshops/ seminars/ symposia/ conferences from time to time. The division presently has a number of highly acclaimed scientists along with trained scientific and project staff. Two state-of-the-art units, viz., Centre of Excellence for Advanced Groundwater Research and Soil Water Laboratory, possessing advanced computational and analytical facilities are associated with the division. Providing efficient and effective methodologies and technologies for sustainable groundwater resources development and management are the vision of Ground Water Hydrology division of National Institute of Hydrology, Roorkee, Uttarakhand, India.

Presently, Mr. C. P. Kumar is the Head of Ground Water Hydrology division at NIH, Roorkee. He post-graduated in Hydraulic Engineering from University of Roorkee in 1985. From 1985, he has been working for National Institute of Hydrology (NIH), Roorkee - 247667 (Uttarakhand). His major research areas of interest include assessment of groundwater potential; seawater intrusion in coastal aquifers; numerical modelling of unsaturated flow, groundwater flow and contaminant transport; management

of aquifer recharge; and impact of climate change on papers and reports.
groundwater. He has authored more than 100 technical

II. WORK AREAS OF C. P. KUMAR

The specific areas of work by Mr. C. P. Kumar in the field of hydrology and water resources are presented in the following table.

Subject/ Work Area	Specific Studies
Groundwater Assessment	<ul style="list-style-type: none"> • Groundwater Balance of Upper Ganga Canal Command Area • Groundwater Balance of Jamnagar District (Gujarat) • Estimation of Irrigation Return Flow • Impact of Rainwater Harvesting on Groundwater in Savna Watershed
Laboratory and Field Determination of Soil Moisture Characteristics	<ul style="list-style-type: none"> • RD 838 of Indira Gandhi Nahar Pariyojana, Stage-II • Upper Part of Hindon River Catchment • Malaprabha and Ghataprabha Basins • Savna Watershed
Modelling of Soil Moisture Movement	<ul style="list-style-type: none"> • Development of a Numerical Simulation Model for One-Dimensional Infiltration • Prediction of Evaporation Losses from Shallow Water Table • Evaporation from Layered Soils in the Presence of a Water Table • Estimation of Ground Water Recharge due to Rainfall • Effect of Water Table Depth on Recharge due to Rainfall
Modelling of Sea Water Intrusion	<ul style="list-style-type: none"> • Nauru Island (Central Pacific Ocean) • Ernakulam Coast • Goa Coast • Porbandar Coast (Minsar River Basin)
Modelling of Groundwater Flow and Solute Transport	<ul style="list-style-type: none"> • Common Ground Water Modelling Errors • Modeling of Solute Transport in Agricultural Fields • Simulation of Solute Transport in Saline Areas of Ghataprabha Command
Application of Hydrological Models	<ul style="list-style-type: none"> • Application of SHE Model to Narmada (upto Manot) Basin • Application of SHE Model to Hemavati (upto Sakleshpur) Basin • Simulation of Soil Moisture Movement in Barchi Watershed using SWIM Model
Impact of Climate Change	<ul style="list-style-type: none"> • Impact of Climate Change on Groundwater • Impact on Dynamic Groundwater System in Sonar Sub-basin
Books Published	<ul style="list-style-type: none"> • Groundwater Assessment and Modelling • Modelling of Sea Water Intrusion using SUTRA • Assessment of Groundwater Potential (eBook) • Groundwater Data Requirement and Analysis (eBook) • Impact of Climate Change on Groundwater Resources (eBook)

<p>Editorial Board Member</p>	<ul style="list-style-type: none"> • American Journal of Water Resources • Advances in Engineering & Scientific Research • International Journal of Current Trends in Engineering & Research • Earth Science India • Current World Environment • Environmental Science: An Indian Journal • Madridge Journal of Agriculture and Environmental Sciences • International Journal of BioSciences and Technology
<p>Internet Hydrology</p>	<p>Creation and monitoring of the following websites and e-mail discussion groups:</p> <ul style="list-style-type: none"> • Kumar Links to Hydrology Resources http://www.angelfire.com/nh/cpkumar/hydrology.html • Hydrology Forum http://groups.yahoo.com/group/hydforum/ • Hydrological Modelling Discussion Group http://in.groups.yahoo.com/group/hydrologymodel/ • Ground Water Modelling Discussion Group http://groups.yahoo.com/group/gwmodel/

III. HYDROLOGICAL STUDIES BY C. P. KUMAR

Based-upon the hydrological studies undertaken, Mr. C. P. Kumar has published large number of technical reports, papers and articles. Many of his papers, technical notes and PowerPoint presentations are available at <http://www.angelfire.com/nh/cpkumar/publication/> Abstracts of his few publications are presented below.

Triangular Side Weirs (1987)

Discharge characteristics of sharp and broad-crested triangular side weirs have been experimentally investigated. Relations between discharge coefficient and main channel Froude number for different apex angles have been established.

Groundwater Balance in Upper Ganga Canal Command Area (1988)

The water balance study serves as a means of solution to important theoretical and practical hydrological problems. On the basis of the water balance approach, it is possible to make a quantitative evaluation of water resources and its dynamic behavior under the influence of man’s activities. The water balance studies are undertaken in the Upper Ganga Canal command area to evaluate the various hydrological components constituting the recharge and discharge components for the groundwater reservoir and

understand their inter-relationship. This will facilitate for optimal planning and utilization of water resources.

The study deals with an area of around 12,500 sq. km. of Upper Ganga Canal command covering the district of Bulandshahr and parts of the districts of Ghaziabad, Meerut, Muzaffarnagar and Saharanpur. Considerable variations in rainfall, canal supplies, groundwater extraction and cropping pattern etc. exist within the study area.

The scope of the present study is the preparation of seasonal groundwater balance of 12 years (1972-73 to 1983-84) for monsoon (June to October) and non-monsoon (November to May) seasons. The various components which influence the groundwater balance in the study area are identified. These components are evaluated using the data made available by U.P. Irrigation Department and Ground Water Investigation Organization. The methodologies adopted for the estimation of water balance components have been discussed. Using the water balance approach, recharge from rainfall for the study area has been calculated. The values of various components of water balance are also verified with the results of various earlier investigators for their consistency.

Application of SHE Model to Narmada (upto Manot Basin) (1990)

The Systeme Hydrologique Europeen (SHE), a physically-based, distributed, catchment model has been implemented for Narmada (upto Manot) basin in Madhya Pradesh, India. The SHE is physically based in the sense that it is derived directly from equations of flow and mass conservation for the hydrologic processes it aims to represent, and it is distributed by describing the catchment on a rectangular grid system. The capacity of SHE to account for spatial variations in meteorologic and hydrologic inputs represents an important advantage over traditional lumped catchment models.

The computational grid network and channel system was set up for the basin, forming the basis for the spatial distribution of topographic elevation, soil type, land use and rainfall stations in the data files. The basic network was composed of grid squares of 1 km x 1 km, but in view of the heavy computing requirements associated with such densely defined system, this was converted to arrays with grid squares of 2 km x 2 km for the simulation work. Since direct measurements of soil and vegetation properties for the basin were not available, the model parameters were evaluated using information taken from the literature on neighbouring areas. Four land uses were identified (agricultural land, dense mixed forest, thin forest and waste land). Three categories of soil depth were defined for low land, semi-hilly and hilly areas, the distributions obtained from the topographic maps. However, the same soil retention curve, typical of black cotton clays, was used throughout.

The calibration and validation of the model was achieved on the basis of physical reasoning and through consideration of the variation of runoff response from the basin. The calibration was carried out for the period 1982-84 by varying only a few of the parameters and was then validated against 1985 and 1987 hydrographs, on the basis of changes in the initial level of the phreatic surface. Some deficiencies in the simulations were noted but, in general, there were good agreement between observed and simulated responses. Sensitivity analysis was also carried out for the basin to study the sensitivity of model grid spacing and flow resistance coefficients to the simulated hydrological regime.

Application of SHE Model to Hemavati (upto Sakleshpur) Basin (1991)

The Systeme Hydrologique Europeen (SHE) is a deterministic distributed and physically-based hydrological modelling system developed from the partial differential equations describing the processes of subsurface, overland and channel flow solved by finite difference methods. The model is completed by the

processes of interception, evapotranspiration and snowmelt. SHE has been developed in a joint effort by the Institute of Hydrology (UK), SOGREAH (France) and the Danish Hydraulic Institute (Denmark).

The description of the hydrological processes has been simplified by solving the unsaturated flow equation in independent one-dimensional vertical columns of variable depths. The columns link a two-dimensional surface flow component with a two-dimensional groundwater flow component. The catchment is represented in the horizontal plane by grid squares and the river system is superimposed on the boundaries of the grid squares. In the SHE programme, each process is solved in separate model components. The coordination and parallel running of the individual components is controlled by a Frame component. This means that the process components can be applied independently and/or in combination. The processes in the various components can be modelled at different levels of complexity and, in its simplest form, a component can be replaced by a dummy component in which default boundary conditions (flows or levels) are prescribed and transferred to the other components. This allows for great flexibility and the applications with SHE may range from single sub-surface column simulations to runs on large complex catchments. The capacity of the SHE to account for spatial variations in meteorologic and hydrologic inputs represents an important advantage over traditional lumped catchment models.

The computational grid network and channel system was set up for the basin, forming the basis for the spatial distribution of topographic elevation, soil type, land use and rainfall stations in the data files. The basic network was composed of grid squares of 1 km x 1 km, but in view of the heavy computing requirements associated with such densely defined system, this was converted to arrays with grid squares of 2 km x 2 km for the simulation work. Since direct measurements of soil and vegetation properties for the basin were not available, the model parameters were evaluated using information taken from the literature on neighbouring areas. Three land uses (forests, coffee plantations and unirrigated crop land) and two soil types (red loamy soils and red sandy soils) were identified. Three categories of soil depth were defined for low land, semi-hilly and hilly areas, the distributions obtained from the topographic maps. However, only one soil retention curve was used throughout.

The calibration and validation of the model was achieved on the basis of physical reasoning and through consideration of the variation of runoff response from the basin. The calibration was carried out for the period 1975-77 by varying only a few of the parameters and was then

validated against hydrographs for the period 1978-80, on the basis of changes in the initial level of the phreatic surface. In general, there were good agreements between observed and simulated responses. Sensitivity analysis was also carried out for the basin to study the sensitivity to the simulated hydrological regime of model structural parameters, flow resistance, unsaturated flow parameters, saturated flow parameter and spatial distribution of rainfall.

Ground Water Balance of Jamnagar District (1992)

With the ever increasing demand of water and inadequate surface water in drought prone areas, more attention is given on groundwater reserve. The present study forms a part of the development of a model to forecast the availability of drinking water in Jamnagar district. Drinking water availability has to be assessed both from surface water sources and from groundwater reserve. The groundwater balance study has been carried out for Jamnagar district for the period 1981-82 to 1985-86 and the percentage of rainfall that gets recharged to the groundwater storage, has been estimated from the water balance study.

Physically - Based Distributed Modelling of Narmada (upto Manot) Basin using the Systeme Hydrologique Europeen (1995)

The Systeme Hydrologique Europeen (SHE), a physically-based, distributed, catchment model has been implemented for Narmada (upto Manot) basin in Madhya Pradesh. The calibration and validation of the model was achieved on the basis of physical reasoning and through consideration of the variation of runoff response from the basin. The calibration was carried out for the period 1982-84 by varying only a few of the parameters and was then validated against 1985 and 1987 hydrographs, on the basis of changes in the initial level of the phreatic surface. Some deficiencies in the simulations were noted but, in general, there were good agreement between observed and simulated responses.

Developments in Ground Water Hydrology: An Overview (1996)

Groundwater development has shown phenomenal progress in our country during the past three decades. There has been a vast improvement in the perception, outlook and significance of groundwater resource. The objective of this paper is to present the status of developments in hydrological studies related to groundwater hydrology including review of the basic concepts and associated methodologies.

Prediction of Evaporation Losses from Shallow Water Table using a Numerical Model (1996)

A steady state flow problem of interest and importance is the upward movement of water from a water table and subsequent evaporation at the soil surface. This information is desirable when estimating water loss from soils by evaporation and estimating the amount of groundwater available to plants due to the upward movement of water from a water table. Soils may also become saline due to the upward movement of saline groundwater and its subsequent evaporation at the soil surface. To minimize the rate of salt accumulation and thus reduce the salinity hazard, attempts are usually made to lower the water table by pumping or by installation of drains. In order to determine at what depth the water table should be maintained, the relation between depth to water table, soil properties, and evaporation rate must be known.

The purpose of this study is to estimate the steady state evaporation rates from bare soils under conditions of high water table. A finite difference numerical scheme based upon the one-dimensional Richards equation has been employed to attain the steady state moisture profiles and estimate the evaporation rates under conditions of high water table. The procedure takes into account the relevant atmospheric factors and the soil's capability to conduct water. Field data required include soil water retention curves, water table depth, and a record of air temperature and air humidity. Results obtained with the method demonstrate how the soil water evaporation rates depend on water table depth.

Development of a Soil Moisture Prediction Model (1996)

Flow of water through unsaturated porous media is common in nature. The basic equation of flow in the unsaturated zone of a porous medium is Richards' equation. The exact solution to the Richards' equation is not yet known. Therefore finite difference methods are widely used for solving the partial differential equation describing one-dimensional water transfer in unsaturated soil. This paper deals with development of a numerical model for transient, one-dimensional water flow through the unsaturated porous medium. Seven models, employing different ways of discretization of the nonlinear infiltration equation, were compared with Philip's quasi-analytical solution. All models yielded good agreement with water content profiles at various times in a sand column.

Estimation of Natural Ground Water Recharge (1997)

Quantification of the rate of natural groundwater recharge is a pre-requisite for efficient groundwater resource management. It is particularly important in regions with large demands for groundwater supplies, where such resources are the key to economic development. However, the rate of aquifer recharge is one of the most difficult factors to measure in the evaluation of groundwater resources. Estimation of recharge, by whatever method, is normally subject to large uncertainties and errors. In this paper, various methods of estimating natural groundwater recharge are outlined and critically reviewed with regard to their limitations and associated uncertainties.

Effect of Water Table Depth on Recharge due to Rainfall (1997)

Reliable estimates of recharge rates to an aquifer are often a pre-requisite to the development of efficient plans for management of a groundwater resource. Groundwater recharge is a complex function of meteorological conditions, soil, vegetation, physiographic characteristics, antecedent soil moisture regime and properties of the geologic material within the paths of flow. Soil layering in the unsaturated zone plays an important role in facilitating or restricting downward water movement to the water table. Depth to water table is also important in groundwater recharge estimations.

The purpose of this study is to determine the effect of water table depth on recharge due to rainfall by studying one-dimensional vertical flow of water in the unsaturated zone. A model has been formulated for finite difference solution of the non-linear Richards equation applicable to transient, one-dimensional water flow through the unsaturated porous medium. The groundwater recharge has been estimated for various depths of the groundwater table using appropriate initial and boundary conditions to study the influence of water table depth.

A Numerical Simulation Model for One-Dimensional Infiltration (1998)

The theory for transient isothermal flow of water into non-swelling unsaturated soil has been developed to a large extent in terms of solutions of the non-linear Richards equation. In the field, the description of infiltration is highly complicated since the initial and boundary conditions are usually not constant while the soil characteristics may vary with time and space. In this study, a model has been formulated for finite difference solution of the nonlinear Richards equation applicable to transient, one-dimensional water flow through the unsaturated porous medium. The simulated soil moisture profiles for explicit, Crank-Nicolson and implicit schemes

have been compared with the quasi-analytical solution of Philip.

Estimation of Ground Water Recharge due to Rainfall by Modelling of Soil Moisture Movement (1998)

The purpose of this study is to estimate the groundwater recharge due to rainfall by studying one-dimensional vertical flow of water in the unsaturated zone. A model has been formulated for finite difference solution of the non-linear Richards equation applicable for transient one-dimensional water flow through the unsaturated porous medium. Implicit scheme with implicit linearization (prediction-correction) has been used for discretization. The groundwater recharge has been estimated using appropriate initial and boundary conditions for storm and inter-storm periods.

Estimation of Ground Water Recharge from Rainfall through Numerical Modelling (1998)

The amount of water that may be extracted from an aquifer without causing depletion is primarily dependent upon the groundwater recharge. Thus, a quantitative evaluation of spatial and temporal distribution of groundwater recharge is a pre-requisite for operating groundwater resources system in an optimal manner. This paper presents the methodology for estimation of groundwater recharge from rainfall by modelling of soil moisture movement.

Evaporation from Shallow Water Table through Layered Soil Profiles (1999)

Evaporation from shallow water table through a homogeneous soil profile has been studied theoretically and experimentally by many workers. However, uniform soil profiles rarely occur in nature. It is more common to find the soils having well-defined layers differing from each other either in texture or in structure. Therefore, it becomes necessary to determine the effect of layered soils on evaporation from a shallow water table.

The purpose of this study is to estimate the steady state evaporation rates from layered soils in the presence of high water table under isothermal conditions. A finite difference numerical scheme based upon the one-dimensional Richards equation has been employed to estimate the evaporation rates from a two-layered soil profile overlying shallow water for appropriate initial and boundary conditions. The method takes into account the relevant atmospheric factors and soil moisture characteristics of the two layers. The effects of sequence and thickness of the soil layers and water table depth on the evaporation rates have been examined.

Variation of Soil Moisture Characteristics in a Part of Hindon River Catchment (1999)

Mathematical models of hydrologic and agricultural systems require knowledge of the relationships between soil moisture content (θ), soil water pressure (h) and unsaturated hydraulic conductivity (K). Hence, a sustained research effort towards the parameterisation of $K(h)$ and $h(\theta)$ has resulted in the development of several laboratory, field and theoretical methods.

This study aims at field and laboratory determination of soil moisture characteristics in a part of Hindon river catchment and to study their variation along the Hindon river in its upstream reach. A total of 38 soil samples were collected from 14 sites in Aurangabad, Kamalpur, Budhakhera, Gagalheri and Dudhil Bukhara comprising around 24 km reach, upstream of Hindon river. Field determination of saturated hydraulic conductivity was made at 8 locations through Guelph Permeameter. Extensive laboratory measurements were made for each soil sample collected. Soil texture was determined through sieve analysis and laser diffraction technique. Porosity was obtained for each soil sample. Saturated hydraulic conductivity was measured through ICW Permeameter in the laboratory. Retention curve was obtained through pressure plate apparatus. Unsaturated hydraulic conductivity function was indirectly derived through van Genuchten retention parameters. The report presents a thorough soil investigation results for the uppermost part of Hindon river.

Soil Moisture Retention Characteristics in Upper Part of Hindon River Catchment (2000)

Mathematical models of hydrologic and agricultural systems require knowledge of the relationships between soil moisture content (θ), soil water pressure (h) and unsaturated hydraulic conductivity (K). Hence, a sustained research effort towards the parameterisation of $K(h)$ and $h(\theta)$ has resulted in the development of several laboratory, field and theoretical methods.

This paper presents the soil moisture retention characteristics and their variation along the Hindon river in its upstream reach. A total of 38 soil samples were collected from 14 sites in Aurangabad, Kamalpur, Budhakhera, Gagalheri and Dudhil Bukhara comprising around 24 km reach, upstream of Hindon river. Extensive laboratory measurements were made for each soil sample collected. Porosity was measured for each soil sample. Saturated hydraulic conductivity was measured through ICW Permeameter in the laboratory. Retention data was obtained through pressure plate apparatus. Parameters of water retention function of the van Genuchten model

were determined through non-linear regression analysis.

Simulation of Sea Water Intrusion and Tidal Influence (2001)

Coastal zones contain some of the most densely populated areas in the world as they generally present the best conditions for productivity. However, these regions face many hydrological problems like flooding due to cyclones and wave surge and drinking fresh water scarcity due to salt water intrusion. This paper presents the simulation of sea water intrusion in Nauru Island through Saturated-Unsaturated TRANsport (SUTRA) model and examines the effect of tidal forcing on the fresh water resources.

Determination of Saturated Hydraulic Conductivity in Upper Part of Hindon River Catchment (2001)

A proper physical description of water flow in the soil requires that three parameters be specified: flux, hydraulic gradient and hydraulic conductivity. Knowledge of any two of these allows the calculation of the third, according to Darcy's law. Hydraulic conductivity plays an important role in Darcy's law which is applicable for saturated as well as unsaturated soils.

This paper presents the laboratory investigations of soil texture and saturated hydraulic conductivity in upper part of Hindon river catchment. A total of 38 soil samples were collected from 14 sites in Aurangabad, Kamalpur, Budhakhera, Gagalheri and Dudhil Bukhara comprising around 24 km reach, upstream of Hindon river. Extensive laboratory measurements were made for each soil sample collected. Soil texture was determined through sieve analysis and laser diffraction technique. Saturated hydraulic conductivity was measured through ICW Permeameter in the laboratory. An empirical relationship has been derived between soil texture and saturated hydraulic conductivity.

Soil Moisture Retention Characteristics at RD 838 of I.G.N.P. Stage-II (2001)

Mathematical models of hydrologic and agricultural systems require knowledge of the relationships between soil moisture content (θ), soil water pressure (h) and unsaturated hydraulic conductivity (K). Hence, a sustained research effort towards the parameterisation of $K(h)$ and $h(\theta)$ has resulted in the development of several laboratory, field and theoretical methods. This paper presents the soil moisture retention characteristics at RD 838 of Indira Gandhi Nahar Priyojana, Stage - II. A total of 15 soil samples were collected from 4 locations at different depths. Extensive laboratory measurements were made for each soil sample collected. Soil bulk density, particle density and porosity were measured for

each soil sample. Saturated hydraulic conductivity was measured through Permeameter. Retention data was obtained through pressure plate apparatus. Parameters of water retention function of the van Genuchten model were determined through non-linear regression analysis.

Soil Moisture Characteristics in Upper Part of Hindon River Catchment (2001)

Knowledge of the physics of soil water movement is crucial to the solution of problems in watershed hydrology, for example, the prediction of runoff and infiltration following precipitation, the subsequent distribution of infiltrated water by drainage and evaporation, and estimation of the contribution of various parts of a watershed to the groundwater storage. Convenient and reliable techniques for estimating the soil hydraulic properties are required for prediction of soil water flow.

This paper presents the field and laboratory determination of soil moisture characteristics and their variation along the Hindon river in its upstream reach. A total of 38 soil samples were collected from 14 sites in Aurangabad, Kamalpur, Budhakhera, Gagalheri and Dudhil Bukhara comprising around 24 km reach, upstream of Hindon river. Extensive laboratory measurements were made for each soil sample collected. Porosity was obtained for each soil sample. Saturated hydraulic conductivity was measured through ICW Permeameter in the laboratory. Retention curve data was obtained through pressure plate apparatus. Unsaturated hydraulic conductivity function was indirectly derived through van Genuchten retention parameters by non-linear regression analysis.

Simulation of Soil Moisture Movement in a Hard Rock Watershed using SWIM Model (2001)

A very large fraction of the water falling as rain on the land surfaces of the earth or applied irrigation water moves through unsaturated soil during the subsequent processes of infiltration, drainage, evaporation, and the absorption of soil-water by plant roots. The water movements in the unsaturated zone, together with the water holding capacity of this zone, are very important for the water demand of the vegetation, as well as for the recharge of the groundwater storage. A fair description of the flow in the unsaturated zone is also crucial for predictions of the movement of pollutants into groundwater aquifers.

A number of simulation models are available for investigating the soil water balance. SWIM (Soil Water Infiltration and Movement) is a physically based, isothermal, one dimensional model of water flow through the soil coupled with a simple crop water extraction

model in which the growth of the canopy and of the root system is a predetermined input. SWIM is driven by rainfall and potential evaporation, and so appears to be more appropriate than few other similar models if the available meteorological data are limited.

The present study aims at modelling of soil moisture movement in Barchi watershed (Karnataka) using SWIM. Field and laboratory investigations were carried out to determine the saturated hydraulic conductivity at eight locations using Guelph Permeameter and soil moisture retention characteristics using the Pressure Plate Apparatus. The van Genuchten parameters of soil moisture retention function and hydraulic conductivity function were obtained through non-linear regression analysis. Daily rainfall and evaporation data of Barchi for the period 1996-97 to 1999-2000 were used for the simulations. Water balance components like runoff, evapotranspiration and drainage (groundwater recharge from rainfall) were determined through SWIM.

Common Ground Water Modelling Errors and Remediation (2001)

Groundwater models are used to predict the future changes in hydraulic heads or the migration pathway and concentrations of contaminants in groundwater. The accuracy of model predictions depends upon the degree of successful calibration and verification of the model in determining transport flow directions, and the applicability of the groundwater flow and solute transport equations to the problem being simulated. Errors in the predictive model, even though small, can result in gross errors in solutions projected forward in time. This paper presents an overview of the common errors in any groundwater modelling study and ways to remove them.

Derivation of Soil Moisture Retention Characteristics from Saturated Hydraulic Conductivity (2001)

Knowledge of the physics of soil water movement is crucial to the solution of many problems in watershed hydrology, for example, the prediction of runoff and infiltration following precipitation, the subsequent distribution of infiltrated water by drainage and evaporation, and estimation of the contribution of various parts of a watershed to the groundwater storage. Mathematical models of hydrologic and agricultural systems require knowledge of the relationships between soil moisture content (θ), soil water pressure (h) and unsaturated hydraulic conductivity (K). Sustained research effort towards the parameterisation of $K(h)$ and $h(\theta)$ has resulted in the development of several laboratory, field and theoretical methods.

This study involved field and laboratory determination of soil moisture characteristics along the Hindon river in its upstream reach. The soils in this area are mainly sand, loamy sand, sandy loam and silt loam. A total of 37 soil samples were collected from 13 sites in 24 km upstream reach of the Hindon river. Extensive laboratory measurements were made for each soil sample. Saturated hydraulic conductivity was measured through ICW Permeameter in the laboratory. Retention curve data was obtained through pressure plate apparatus. These have been used to develop an empirical relationship to derive the approximate soil moisture retention curve at the places in upper part of Hindon river basin where only saturated hydraulic conductivity data are available.

Numerical Simulation Models for Seawater Intrusion (2002)

The development and management of coastal groundwater aquifers remain a very delicate issue. Under-utilization of the available resource means that valuable fresh water will discharge naturally to the sea and wasted; overdevelopment, on the other hand, will mine the resource and cause a gradual or sometimes sudden degradation of water quality due to the encroachment of seawater. As an aid to effective management, many models have been developed over the years to represent and study this problem. They range from relatively simple analytical solutions to complex state-of-art numerical models using large computing capacity. This paper presents the salient features of available numerical models to enable selection of appropriate code for the specific seawater intrusion problem.

Modelling of Solute Transport in Agricultural Fields using SWIM (2002)

Modern agricultural activities are based on the extensive use of fertilizers and pesticides to obtain high crop yield. Some of the chemicals applied to farm land, however, move down with the deep percolating water from the root zone and can contaminate underlying groundwater. The problem becomes more complicated when dealing with different kinds of soil with varying properties. In the present study, solute transport in three agricultural plots (Jowar, Gram and Safflower located at Belvatgi in Malaprabha subbasin in Dharwad district, Karnataka) has been modelled using a software package, SWIM (Soil Water Infiltration and Movement). Known quantities of fertilizer were applied and field/laboratory investigations were carried out for monitoring the chemical constituent (Nitrogen/Phosphorous/Potassium) at varying depths upto 120 cm. Field observed and simulated (through SWIM)

solute concentration (N, P and K) profiles after application of fertilizer were compared. The model can be used to predict the cumulative solute in the soil profile for different scenarios of fertilizer applications.

Assessment of Natural Ground Water Recharge in Upper Ganga Canal Command Area (2002)

Quantification of the rate of natural groundwater recharge is a pre-requisite for efficient groundwater resource management. It is particularly important in regions with large demands for groundwater supplies, where such resources are the key to economic development. However, the rate of aquifer recharge is one of the most difficult factors to measure in the evaluation of groundwater resources. Estimation of recharge, by whatever method, is normally subject to large uncertainties and errors. In this paper, an attempt has been made to derive an empirical relationship to determine groundwater recharge from rainfall in Upper Ganga Canal command area based upon seasonal groundwater balance study carried out for a number of years.

Conceptualisation in Groundwater Modelling (2003)

Mathematical models are tools, which are frequently used in studying groundwater systems. In general, mathematical models are used to simulate (or to predict) the groundwater flow. Predictive simulations must be viewed as estimates, dependent upon the quality and uncertainty of the input data. Model conceptualization is the process in which data describing field conditions are assembled in a systematic way to describe groundwater flow processes at a site. The model conceptualization aids in determining the modelling approach and which model software to use. This paper presents the conceptualisation process for any groundwater flow modelling study which will help to reduce the level of uncertainty.

Estimation of Ground Water Recharge Using Soil Moisture Balance Approach (2003)

The amount of water that may be extracted from an aquifer without causing depletion is primarily dependent upon the groundwater recharge. Thus, a quantitative evaluation of spatial and temporal distribution of groundwater recharge is a pre-requisite for operating groundwater resources system in an optimal manner. This paper presents a methodology with step-by-step procedure to determine the groundwater recharge by soil moisture balance in the unsaturated zone.

Pitfalls and Sensitivities in Groundwater Modelling (2003)

Groundwater models provide a scientific and predictive tool for determining appropriate solutions to water

allocation, surface water - groundwater interaction, landscape management or impact of new development scenarios. However, if the modelling studies are not well designed from the outset, or the model doesn't adequately represent the natural system being modelled, the modelling effort may be largely wasted, or decisions may be based on flawed model results, and long term adverse consequences may result. This paper presents the common pitfalls and sensitivities which are normally encountered during groundwater modelling studies. It will help in improving the model conceptualisation and understanding the uncertainty in model results.

Basic Guidelines for Groundwater Modelling Studies (2003)

Groundwater flow modelling studies are required to resolve groundwater and catchment issues. A model, no matter how sophisticated, will never describe the groundwater system under investigation without deviation of model simulations from the actual physical processes. As a consequence, in applying a numerical model to a field study, the model user should always understand the implications of simplifying assumptions. This paper addresses groundwater modelling concepts and outlines the approach for commissioning and understanding groundwater modelling studies. It will encourage best practice and help avoid potential problems.

Modelling of Soil Moisture Movement in a Watershed using SWIM (2003)

The present study aims at modelling of soil moisture movement in Barchi watershed (Karnataka) using SWIM (Soil Water Infiltration and Movement). Field and laboratory investigations were carried out to determine the saturated hydraulic conductivity at eight locations using Guelph Permeameter and soil moisture retention characteristics using the Pressure Plate Apparatus. The van Genuchten parameters of soil moisture retention function and hydraulic conductivity function were obtained through non-linear regression analysis. Daily rainfall and evaporation data of Barchi for the period 1996-97 to 1999-2000 were used for the simulations. Water balance components like runoff, evapotranspiration and drainage (groundwater recharge from rainfall) were determined through SWIM. The drainage was found to vary between 38% and 47% of rainfall (1241 mm to 1887 mm) while the runoff coefficient varied between 12% and 32% for the study period.

Constraints in the Numerical Modelling of Salt Water Intrusion (2004)

Mathematical models help us to understand the relevant processes that cause salt water intrusion in coastal

aquifers. In this paper, constraints of three-dimensional (3D) modelling of salt water intrusion in large-scale coastal (homogeneous) aquifers have been discussed. Computer codes, which solve the advection-dispersion equation based on standard finite element or finite difference techniques, can not yet be applied to model large-scale coastal aquifers. The reason is that these codes must satisfy a condition of spatial discretization, characterized by the so-called grid Peclet number. This number imposes that the dimension of the grid block should be not greater than a few times the magnitude of the longitudinal dispersivity, as otherwise numerical dispersion will occur. In addition, stand-alone personal computers are not yet fast enough to execute models with several hundreds of thousands of grid blocks. Finally, reliable and sufficient groundwater data, required for calibration and verification, are not available in most cases. However, effective 3D-modelling of salt water intrusion in large-scale coastal aquifers may be technically possible within next few years, though the availability of data will always restrict practical applications to a certain extent.

Groundwater Flow and Contaminant Transport Models: An Overview (2006)

In the management of a ground-water system in which decisions must be made with respect to both water quality and water quantity, a tool is needed to provide the decision maker with information about the future response of the system to the effects of management decisions. This tool is the model. A model may be defined as a simplified version of a real-world system (here, a ground-water system) that approximately simulates the relevant excitation-response relations of the real-world system. This paper presents an overview of the essential components of ground-water flow and contaminant transport modelling in saturated porous media.

Modelling of a Coastal Aquifer using FEFLOW (2007)

Coastal tracts of Goa are rapidly being transformed into settlement areas. The poor water supply facilities have encouraged people to have their own source of water by digging or boring a well. During the last decade, there have been large-scale withdrawals of groundwater by builders, hotels and other tourist establishments. Though the seawater intrusion has not yet assumed serious magnitude, but in the coming years it may turn to be a major problem if corrective measures are not initiated at this stage. It is necessary to understand how fresh and salt water move under various realistic pumping and recharge scenarios. Objectives of the present study include simulation of seawater intrusion in a part of the coastal

area in Bardez taluk of North Goa, evaluation of the impact on seawater intrusion due to various groundwater pumping scenarios and sensitivity analysis to find the most sensitive parameters affecting the simulation.

Soil Moisture Retention Characteristics and Hydraulic Conductivity for Different Areas in India in Selected States (2008)

Mathematical models of hydrologic and agricultural systems require knowledge of the relationships between soil moisture content (θ), soil water pressure (h) and unsaturated hydraulic conductivity (K). This study involved field and laboratory determination of soil moisture characteristics in different areas of India – Hindon, Kolar, Narsinghpur, Ghataprabha and Lokapavani. Saturated hydraulic conductivity was measured either through Guelph Permeameter in the field or through ICW Permeameter or Jodhpur Permeameter in the laboratory. Retention curve data was obtained through pressure plate apparatus. These have been used to develop empirical relationships to derive the approximate soil moisture retention curve at the places where only saturated hydraulic conductivity data is available.

Determination of Soil Hydraulic Properties in a Part of Hindon River Catchment using SOILPROP Software (2010)

Mathematical models of hydrologic and agricultural systems require knowledge of the relationships between soil moisture content (θ), soil water pressure (h) and unsaturated hydraulic conductivity (K). To model the retention and movement of water and chemicals in the unsaturated zone, it is necessary to know the relationships between soil water pressure, water content and hydraulic conductivity. It is often convenient to represent these functions by means of relatively simple parametric expressions. The problem of characterizing the soil hydraulic properties then reduces to estimating parameters of the appropriate constitutive model. A number of models for water retention function and unsaturated hydraulic conductivity are well reported in literature, the most popular being van Genuchten model and Brooks-Corey model. In general, the van Genuchten model matches experimental data more satisfactorily than Brooks-Corey model. However, the functional form of van Genuchten model is complicated and limits its usefulness for large number of analytical solutions available for infiltration and drainage problems. On the other hand, Brooks-Corey model yields conductivity and water retention functions that are easy to manipulate mathematically.

For this study, 27 soil samples were collected from various locations as well as depths in different villages, namely Aurangabad, Kamalpur, Budhakhera, Gagalheri, Dudhil Bukhara in the upstream part of Hindon river catchment and laboratory investigations were carried out to determine bulk density and grain size distribution. Using these data as input to the SOILPROP software, van Genuchten and Brooks-Corey parameters (α and n & h_d and λ) were determined to derive the retention characteristic and unsaturated hydraulic conductivity. The values of α and n (van Genuchten parameters) were found to vary from 0.00004 to 0.00078 and 1.19 to 1.65 respectively. The values of h_d and λ (Brooks-Corey parameters) were found to vary from 860 to 20200 cm and 0.189 to 0.538 respectively. These results (as necessary input for unsaturated zone modelling) will be helpful for prediction of soil moisture flow and groundwater recharge in the Hindon river catchment.

Assessment of Impact of Climate Change on Groundwater Resources (2012)

Climate change poses uncertainties to the supply and management of water resources. The Intergovernmental Panel on Climate Change (IPCC) estimates that the global mean surface temperature has increased 0.6 ± 0.2 °C since 1861, and predicts an increase of 2 to 4 °C over the next 100 years. Temperature increases also affect the hydrologic cycle by directly increasing evaporation of available surface water and vegetation transpiration. Consequently, these changes can influence precipitation amounts, timings and intensity rates, and indirectly impact the flux and storage of water in surface and subsurface reservoirs (i.e., lakes, soil moisture, groundwater). In addition, there may be other associated impacts, such as sea water intrusion, water quality deterioration, potable water shortage, etc.

While climate change affects surface water resources directly through changes in the major long-term climate variables such as air temperature, precipitation, and evapotranspiration, the relationship between the changing climate variables and groundwater is more complicated and poorly understood. The greater variability in rainfall could mean more frequent and prolonged periods of high or low groundwater levels, and saline intrusion in coastal aquifers due to sea level rise and resource reduction. Groundwater resources are related to climate change through the direct interaction with surface water resources, such as lakes and rivers, and indirectly through the recharge process. The direct effect of climate change on groundwater resources depends upon the change in the volume and distribution of groundwater recharge. Therefore, quantifying the impact of climate change on

groundwater resources requires not only reliable forecasting of changes in the major climatic variables, but also accurate estimation of groundwater recharge.

A number of Global Climate Models (GCM) are available for understanding climate and projecting climate change. There is a need to downscale GCM on a basin scale and couple them with relevant hydrological models considering all components of the hydrological cycle. Output of these coupled models such as quantification of the groundwater recharge will help in taking appropriate adaptation strategies due to the impact of climate change. This paper presents the likely impact of climate change on groundwater resources and methodology to assess the impact of climate change on groundwater resources.

Groundwater Modelling Software – Capabilities and Limitations (2012)

Groundwater modelling has become an important methodology in support of the planning and decision-making processes involved in ground-water management. Ground-water models provide an analytical framework for obtaining an understanding of the mechanisms and controls of ground-water systems and the processes that influence their quality, especially those caused by human intervention in such systems. Increasingly, models are an integral part of water resources assessment, protection and restoration studies; and provide essential and cost-effective support for planning and screening of alternative policies, regulations, and engineering designs affecting groundwater.

There are many different ground-water modelling codes available, each with their own capabilities, operational characteristics, and limitations. If modelling is considered for a project, it is important to determine if a particular code is appropriate for that project, or if a code exists that can perform the simulations required in the project.

In practice, it is often difficult to determine the capabilities, operational characteristics, and limitations of a particular ground-water modelling code from the documentation, or even impossible without actual running the code for situations relevant to the project for which a code is to be selected due to incompleteness, poor organization, or incorrectness of a code documentation. Systematic and comprehensive description of a code features based on an informative classification provides the necessary basis for efficient selection of a groundwater modelling code for a particular project or for the determination that no such code exists.

Assessment of Groundwater Potential (2012)

Water balance techniques have been extensively used to make quantitative estimates of water resources and the impact of man's activities on the hydrologic cycle. On the basis of the water balance approach, it is possible to make a quantitative evaluation of water resources and its dynamic behaviour under the influence of man's activities. In this paper, an attempt has been made to describe the methodologies to understand and evaluate various recharge and discharge components of groundwater balance equation and to establish the recharge coefficient with a view to work out the groundwater potential of an area.

Water Status and Problems in India (2013)

The surface water and groundwater resources of the country play a major role in agriculture, hydropower generation, livestock production, industrial activities, forestry, fisheries, navigation, recreational activities, etc. Traditionally, India has been an agriculture-based economy. Hence, development of irrigation to increase agricultural production for making the country self-sustained and for poverty alleviation has been of crucial importance for the planners. The rainfall in India shows great variations, unequal seasonal distribution, still more unequal geographical distribution and the frequent departures from the normal. In view of the existing status of water resources and increasing demands of water for meeting the requirements of the rapidly growing population of the country as well as the problems that are likely to arise in future, a holistic, well-planned long-term strategy needed for sustainable water resources management in India.

Numerical Modelling of Ground Water Flow using MODFLOW (2013)

Groundwater models provide a scientific and predictive tool for determining appropriate solutions to water allocation, surface water – groundwater interaction, landscape management or impact of new development scenarios. However, if the modelling studies are not well designed from the outset, or the model doesn't adequately represent the natural system being modelled, the modelling effort may be largely wasted, or decisions may be based on flawed model results, and long term adverse consequences may result. This paper presents an overview of the groundwater modelling technique and application of MODFLOW, a modular three-dimensional groundwater flow model.

Recent Studies on Impact of Climate Change on Groundwater Resources (2013)

We are in a period of climate change brought about by increasing atmospheric concentrations of greenhouse

gases. Atmospheric carbon dioxide levels have continually increased since the 1950s. The continuation of this phenomenon may significantly alter global and local climate characteristics, including temperature and precipitation. Changes in regional temperature and precipitation have important implications for all aspects of the hydrologic cycle. Variations in these parameters determine the amount of water that reaches the surface, evaporates or transpires back to the atmosphere, becomes stored as snow or ice, infiltrates into the groundwater system, runs off the land, and ultimately becomes base flow to streams and rivers.

While climate change affects surface water resources directly through changes in the major long-term climate variables such as air temperature, precipitation, and evapotranspiration, the relationship between the changing climate variables and groundwater is more complicated and poorly understood. The greater variability in rainfall could mean more frequent and prolonged periods of high or low groundwater levels, and saline intrusion in coastal aquifers due to sea level rise and resource reduction. This article presents the likely impact of climate change on groundwater resources and recent research studies carried out to assess the impact of climate change on groundwater resources.

Hydrological Studies Using Isotopes (2013)

Isotope hydrology is a field of hydrology that uses isotopic dating to estimate the age and origins of water and its movement within the hydrologic cycle. Water molecules carry unique fingerprints, based in part on differing proportions of the oxygen and hydrogen isotopes that constitute all water. Isotopes are forms of the same element that have variable numbers of neutrons in their nuclei. This article presents the details of hydrological studies using isotope techniques undertaken by National Institute of Hydrology, Roorkee (India) during last few years.

Impact of Climate Change on Agriculture (2014)

Climate change and agriculture are inter-related processes, both of which take place on a global scale. Global warming is projected to have significant impacts on conditions affecting agriculture, including temperature, carbon dioxide, glacial runoff, precipitation and interaction of these elements. The overall effect of climate change on agriculture will depend on the balance of these effects. Assessment of the effects of global climate changes on agriculture might help to properly anticipate and adapt farming to maximize agricultural production. This paper discusses probable impacts of climate change on agriculture.

Modelling of Groundwater Flow and Data Requirements (2015)

Groundwater is used for a variety of purposes, including irrigation, drinking and manufacturing. Groundwater is also the source of a large percentage of surface water. Accurate and reliable groundwater resource information (including quality) is critical to planners and decision-makers. Huge investment in the areas of groundwater exploration, development and management at state and national levels aims to meet the groundwater requirement for drinking and irrigation and generates enormous amount of data. We need to focus on improved data management, precise analysis and effective dissemination of data. Numerical models are capable of solving large and complex groundwater problems varying widely in size, nature and real life situations. With the advent of high speed computers, spatial heterogeneities, anisotropy and uncertainties can be tackled easily. However, the success of any modelling study, to a large measure depends upon the availability and accuracy of measured/recorded data required for that study. Therefore, identifying the data needs of a particular modelling study and collection/monitoring of required data form an integral part of any groundwater modelling exercise. This paper presents groundwater modelling process, basic data requirements for groundwater modelling and commonly used groundwater modelling software.

Concepts and Modelling of Groundwater System (2015)

Groundwater is of fundamental importance in water resources planning, development and management. Groundwater flow has many applications, among which are agricultural developments, domestic use such as supply of drinking water, irrigation, and a variety of water quality applications. As the usage of groundwater expands, our knowledge of groundwater systems must also expand. Numerical groundwater modelling is a tool that can aid in studying groundwater problems and can help increase our understanding of groundwater systems. The purpose of this article is to highlight major groundwater issues, concepts of groundwater modelling, and commonly used groundwater modelling software.

Climate Change Effects on Groundwater Resources (2015)

Climate change is normally defined as any change in climate over time, whether due to natural variability or from human activities. It poses uncertainties to the supply and management of water resources. Although climate change has been widely recognized, research on the effects of climate change on groundwater system is

relatively limited. Groundwater resources are related to climate change through the direct interaction with surface water resources, such as lakes and rivers, and indirectly through the recharge process. This article presents the likely effects of climate change on groundwater resources, and methodology to assess the impact of climate change on groundwater resources.

Contribution of Women in Hydrological Research (2016)

Women play a central part in the provision, management and safeguarding of water. This pivotal role of women as providers and users of water and guardians of the living environment has seldom been reflected in institutional arrangements for the development and management of water resources. Acceptance and implementation of this principle requires positive policies to address women's specific needs and to equip and empower women to participate at all levels in water resources programmes, including decision-making and implementation. The objective of this paper is to highlight some of the recent contribution of women in the field of Hydrology.

Modelling Flow and Transport in Unsaturated Zone (2016)

Unsaturated zone transport models are indispensable tools for analyzing complex environmental pollution problems, and for developing practical management strategies. A quantitative study of water flow and contaminant transport in the unsaturated (vadose) zone is necessary for improvement and protection of the quality of groundwater supplies. This is the region bounded above by the land surface and below by the groundwater table. It is the region through which water derived from precipitation and irrigation infiltrates and transports contaminants to reach the groundwater. This article presents an overview of the modelling process for water flow and contaminant transport in the unsaturated zone, input data requirements and related software packages.

Sea Water Intrusion in Coastal Aquifers (2016)

The coastal regions, particularly deltaic regions, are the most developed and most densely populated regions all over the world. These regions are facing many hydrological problems both due to natural conditions and man's activities. The problems due to natural conditions range from flooding due to cyclones and wave surge to drinking fresh water scarcity due to problem of sea water intrusion. Man's activities compound these problems further. Sea water intrusion is one of the severe problems faced by coastal regions. Natural conditions and man's activities both contribute to this problem. There exists an urgent need to study systematically the causes and

remedial measures for sea water intrusion problem in coastal areas. This article presents the hydrological aspects, control measures and modelling of sea water intrusion in coastal aquifers.

Climate Change and Groundwater (2016)

The Intergovernmental Panel on Climate Change (IPCC) estimates that the global mean surface temperature has increased 0.6 ± 0.2 °C since 1861, and predicts an increase of 2 to 4 °C over the next 100 years. Temperature increases also affect the hydrologic cycle by directly increasing evaporation of available surface water and vegetation transpiration. Consequently, these changes can influence precipitation amounts, timings and intensity rates, and indirectly impact the flux and storage of water in surface and subsurface reservoirs (i.e., lakes, soil moisture, groundwater). In addition, there may be other associated impacts, such as sea water intrusion, water quality deterioration, potable water shortage, etc. While climate change affects surface water resources directly through changes in the major long-term climate variables such as air temperature, precipitation, and evapotranspiration, the relationship between the changing climate variables and groundwater is more complicated and poorly understood. This paper discusses the likely impacts of climate change on groundwater resources and the climate change scenario for groundwater in India.

Groundwater Studies at National Institute of Hydrology, Roorkee, India (2017)

National Institute of Hydrology is a Government of India society under Ministry of Water Resources, River Development & Ganga Rejuvenation. It has been functioning as a research Institute in the area of hydrology and water resources in the country since December 1978 with headquarters at Roorkee (Uttarakhand, India) and six regional centres located in different physiographic regions of the country. This article presents salient details of groundwater studies undertaken by Ground Water Hydrology division of the Institute during last few years.

Subsurface Water Modelling using SWIM and FEFLOW (2017)

Mathematical models provide a scientific and predictive tool for determining appropriate solutions to water allocation, surface water – groundwater interaction, landscape management or impact of new development scenarios. However, if the modelling studies are not well designed from the outset, or the model doesn't adequately represent the natural system being modelled, the modelling effort may be largely wasted, or decisions may be based on flawed model results, and long term adverse consequences may result. This article presents case

studies on modelling of soil moisture movement (unsaturated flow) using SWIM and modelling of seawater intrusion (density-dependent groundwater flow) using FEFLOW.

Hydrological Research at National Institute of Hydrology, India (2017)

The National Institute of Hydrology (NIH) is a premier research Institute in India in the area of hydrology and water resources. The Institute was established in 1978 with the main objective of undertaking, aiding, promoting and coordinating systematic and scientific work in all aspects of hydrology. The Institute has its headquarters at Roorkee (Uttarakhand), four regional centres at Belagavi, Jammu, Kakinada and Bhopal and two centres for flood management studies at Guwahati and Patna. The Institute is well equipped to carry out computer, laboratory and field oriented studies. This article presents an overview of research activities being undertaken by the Institute.

Water Security – Challenges and Needs (2018)

Our fate is intrinsically bound to the fate of our water resources. To build the future we want, we need to harness the contributions of science and innovation for water security. An interdisciplinary and integrated approach is needed for watershed and aquifer management, which incorporates the social dimension of water resources, and promotes and develops international research in hydrological and freshwater sciences. This article presents the challenges and needs pertaining to water security.

Water Resources Issues and Management in India (2018)

Water is one of the most essential natural resources for sustaining life. Its development and management play a vital role in agriculture production. Integrated water management is vital for poverty reduction, environmental sustenance, and sustainable economic development. In view of the rapid increase in population, urbanization, and industrialization, the demand for water for meeting various requirements is continuously increasing. Therefore, we are facing numerous challenges in the water sector, which include reducing per capita water availability, the decline in groundwater table in many areas, and saltwater intrusion in coastal aquifers. The quality of surface water and groundwater is also deteriorating because of increasing pollutant loads from various sources. Climate change may also adversely affect the availability and distribution of water resources. This article presents an overview of relevant issues pertaining to development and management of water resources in India.

Modelling Water Flow in Unsaturated Zone (2018)

The water movements in the unsaturated zone, together with the water holding capacity of this zone, are very important for the water demand of the vegetation, as well as for the recharge of the groundwater storage. A fair description of the flow in the unsaturated zone is crucial for predictions of the movement of pollutants into groundwater aquifers. This article presents an overview of the modelling process for water flow in the unsaturated zone, input data requirements, boundary conditions and related software packages.

Norms for Groundwater Resource Estimation in India (2019)

The occurrence and movement of groundwater are controlled by various hydrogeological, hydrological and climatological factors. Reasonably accurate assessment of groundwater recharge and discharge components is not easy because no direct measurement techniques are presently available. Therefore, indirect methods are generally employed for assessment of groundwater resources. Groundwater is a dynamic and replenishable resource which is normally estimated based upon the annual groundwater recharge. It is subjected to withdrawal for various uses such as irrigation, domestic, industrial etc. This article presents the norms for various groundwater recharge components for estimation of groundwater resources in India.

An Overview of Commonly Used Groundwater Modelling Software (2019)

A groundwater model is any computational method that represents an approximation of an underground water system. While groundwater models are, by definition, a simplification of a more complex reality, they have proven to be useful tools over several decades for addressing a range of groundwater problems and supporting the decision-making process. There are many different ground-water modelling codes available, each with their own capabilities, operational characteristics, and limitations. If modelling is considered for a project, it is important to determine if a particular code is appropriate for that project, or if a code exists that can perform the simulations required in the project. This article presents an overview of most commonly used groundwater modelling codes.

Purpose Driven Studies under National Hydrology Project, India (2019)

Considering the peculiarities and large variation in the nature of problems associated with water resources planning, development and management, the issues

involved in research related to particular region and specific project, there is a provision under National Hydrology Project (NHP) of India is to take up applied and action-oriented R&D studies by the implementing agencies. This article presents the details of purpose driven studies taken up by various implementing agencies under the National Hydrology Project of India.

IV. CONCLUDING REMARKS

This article has been written by Mr. C. P. Kumar to showcase his technical contribution as a Scientist at National Institute of Hydrology, Roorkee, India. He is due to retire from current government service at NIH in September 2020. He is likely to seek suitable post-retirement job opportunity to continue his services from October 2020. Any comments or suggestions are welcome at his e-mail address cpkumar@yahoo.com

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