THEME - II

GROUNDWATER HYDROLOGY

INFILTRATION SUBJECT TO TIME-DEPENDENT SURFACE PONDING: EXACT RESULTS AND CORRESPONDENCE TO SOLUTE TRANSPORT WITH NONLINEAR REACTION

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Richard's equation, the governing equation for single phase unsaturated flow in soil, is highly nonlinear and, consequently, is difficult to solve either analytically or numerically. The non linearity enters through the soil hydraulic functions, viz., the soil moisture characteristic curve and the unsaturated hydraulic conductivity. Exact solutions satisfying Richards' equation are of interest both in theory (to check analytical approximations and numerical solutions) and in practice (as part of catchment hydrological models). For example, exact solutions can be used to calculate infiltration under ponded conditions, and so check the many analytical approximations existing in the literature.

In this paper an exact quasi-analytical solution for the one-dimensional Richards' equation subject to an arbitrary, time-dependent ponding depth has been presented. The solution depends on solving a first-order ordinary differential equation. For certain special cases, such as when the surface ponding depth is constant, fully analytical results can be derived. The exact results are then used in a number of applications. First, an existing analytical approximation for infiltration subject to a time-dependent head is checked. Second, the moisture profile for a periodic saturated-unsaturated surface condition is analysed. Third, an exact solution for drainage of an saturated soil profile is determined. Next, we present an explicit result for the depth of the saturated zone that develops as an unsaturated soil profile drains, where the soil profile has an impermeable base. Finally, new results for solute transport coupled with a nonlinear adsorption isotherm are derived by making use of an exact mapping between Richards' equation and the governing solute transport equation.

SOME NUMERICAL EXPERIMENTS ON THE VARIABLY-SATURATED FLOW EQUATION

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Infiltration or drainage problems in partially saturated soils have enormous importance in the study of water and chemical movement towards the ground-water system. The variably-saturated flow equation (VSFE) is a special form of the well known Richards' equation for unsaturated flow in which the elastic storage arguments are used to define the specific storativity (which is useful for saturated flow simulation). The Richards' equation under transient conditions is highly nonlinear. Traditionally, numerical techniques have been used in solving this equation. The moisture-content form of Richards' equation requires less computer time and is subject to low mass balance errors while simulating transient infiltration into very dry soils. However, this form of Richards' equation is limited to complete unsaturated conditions and cannot handle positive pressure upper boundary or layered soil profiles. For this reason, while simulating water movement in variably saturated soils, the pressure-based form of Richards' equation is used. The pressure-based form is prone to mass balance errors and requires large amounts of computer time due to the iterative nature of solution. A recently reported mixed form Richards' equation is used in this investigation for its mass conservative property. The computer time requirement for the mixed form Richards' equation similar to the pressure-based form.

A series of numerical experiments were conducted using the VSFE which contained the mass-conservative form of the Richard's equation. The Galerkin finite element technique was used to solve the equation numerically. The effects of the type of mass lumping (matrix diagonalization), initial and boundary conditions on the accuracy, stability and the rate of convergence of this equation are presented. The influences of time varying top boundary conditions and layered heterogeneity on water movement are also presented. In addition, "tricks" for efficient time step control and steady-state simulation using this mass conservative formulation are shown. Finally, simulation results indicate that this mixed-form equation is superior to the pressure-based form.

VISUALISATION OF STATIC AND DYNAMIC WATER PHENOMENA IN SOIL USING MAGNETIC RESONANCE IMAGING

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Nuclear Magnetic Resonance Imaging (MRI) was used to study dynamic soil water phenomena. Two-dimensional and three-dimensional images were obtained to visualise wetting, drainage and redistribution in three soil materials: packed aggregates of Hanslope clay soil, medium quartz sand and coarse quartz sand. The wetting front in a column of the medium sand was the typical piston type, remaining stable during the period of water redistribution. However, a zone with low signal intensity, coinciding with the region of the wetting front from the first step-feed of water, was left after a second addition of water. The wetting front of the coarse sand after the first step-feed of water was curved and the infiltrated water tended to redistribute through a preferential pathway due to wetting front instability. Subsequent wetting of the column by a second addition of water was unstable and water infiltrated down the column through an expanded "finger". In the clay soil column, water appeared to by-pass the top of the soil through inter-aggregate pores during initial infiltration, and then to redistribute into intra-aggregate pores. The images of water draining vertically through the medium sand column showed a uniform drainage profile. Drainage from the coarse sand column initially showed a drying front, and approached a uniform profile after free drainage. In contrast, drainage from the clay soil column showed drying front and a non-uniform drainage profile. Under the experimental conditions, all the results were reproducible. Thus, MRI can provide important information on soil structure and water movement in soil, with potential attendant benefits for modelling preferential flow in such soils.

HYDROLOGIC MODELLING ACKNOWLEDGING SPATIAL AND TEMPORAL VARIATIONS OF HYDRAULIC CONDUCTIVITY

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Physically-based deterministic models are now used extensively to simulate hydrologic and erosion processes at field and watershed scales. In general, these models predict outputs for short period (such as an event) rather poorly with average or total output for longer periods (such as a month or a year) estimated fairly well. A prime difficulty with the prediction of specific runoff and erosion rates is likely to be the lack of accountability for spatial and temporal variations in a number of hydrologic parameters involved. This paper presents an approach to include the spatial variability of hydraulic conductivity in field-scale hydrologic modelling. A spatial hydraulic conductivity function has been developed to generate spatial hydraulic conductivity data which have been incorporated into a Green and Ampt infiltration model. This model has ben applied to a plot-scale situation under simulated rainfall conditions. A preliminary comparison of the simulated and observed infiltration and runoff results indicates that the use of spatial hydraulic conductivity function results in a significant improvement in prediction capabilities. Now the spatial hydraulic conductivity function is being incorporated into a field-scale non-point source pollution model, CREAMS, and a subsurface drainage model, DRAINMOD, to evaluate the performance of the spatial hydraulic conductivity function on field-scale hydrologic modelling.

TYPE STRAIGHT LINES FOR WATER FLOW THROUGH ROUGH FRACTURES

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Analytical solutions of groundwater flow toward a well are incomplete especially for fractured and karstic media as well as non-linear flows for any type of media. These solutions of groundwater problems are achieved overwhelmingly for porous media. As long as the groundwater flow abides with the Darcy law within a porous media the Laplace transformation is sufficient for the solution. However, even for the pores media the classical solutions such as of Theis cannot be attacked by the laplace transformation if the flow is nonlinear. Therefore the researchers sought the solutions in numerical techniques the results of which are boundary and initial value dependent and must be run on a digital computer for even small changes in these conditions.

Another problem in the classical type curve matching to field data for identifying the hydraulic parameters of aquifer concerned is that they invariably yield single storage coefficient and transmissivity values. Of course this is as a consequence of homogeneity and istpropy assumptions. In fact, real aquifers never exhibit such behaviors and therefore their parameters are spatially variable which is overlooked in conventional analytical solutions. This point is alleviated by considering sample functions of aquifer parameters through a technique developed by the author. Sample functions show variation of aquifer parameters with distance from the well center. Arithmetic averages of these sample functions yield the classical approach results.

The main purpose of this major presentation is to review critically existing solution techniques of groundwater flow toward wells and then to propose completely new or modified methodologies for better solutions. Among these methodologies are the volumetric approach method, dimensionless straight type lines, storage coefficient and transmissivity sample functions, etc. Last but not the least, future research trends needed in the groundwater hydrology are suggested.

ANALYSIS OF PUMP TEST DATA ON KASAI RIVER BED (WEST BENGAL): A CASE STUDY

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Pump tests were carried out on Kasai river bed in connection with augmentation of existing water supply of Kharagpur Municipality in the district of Midnapore, West Bengal to cater the need of a population of more than two lacs of the municipal township and for the growing demand of the industries. The draw down data collected during pump tests were analysed to determine the aquifer characteristics, namely, the storage co-efficient (S), Stransmissibility co-efficient (T). Methods adopted were Jacob's and modified Theis for un-confined condition and Hantush inflection point method for semi-confined condition. The values of S and T as obtained from the analysis of data are to be used subsequently for the design of radial collector wells in the area.

COMPUTER APPLICATION FOR GROUND WATER HYDROLOGICAL STUDY

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Presently computers are used in variety of fields of scientific studies. Computers have endless applications in many water management studies. In this paper, an attempt is made to study, whether the application of computer is really useful for the analysis of ground water hydrological data. To know this, the ground water level data of control wells located in Thiruverumbur village, Thiruchirapalli district, Tamilnadu State have been analysed with the help of a personal computer. By applying different methods of permutation and combination technique through this computer, the water level data have been processed in such a way to get the data in different types of desired format both as data and graphs.

AMPLIFYING THE DARCY EQUATION USING THE ENERGY BALANCE OF GROUNDWATER FLOW

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As energy balance of groundwater flow is introduced. It is based on equating the total incoming hydraulic energy flux to the total outgoing hydraulic energy flux plus the storage rate of hydraulic energy and the conversion rate of hydraulic energy to friction of flow. The energy flux is calculated on the basis of a multiplication of the hydraulic potential with the flow velocity. The conversion rate is calculated in analogy to the heat loss equation of an electric current. It is shown that the balance of hydraulic energy leads to amplifications of the Darcy equation when the flow is not uniform, i.e. The flow velocity varies spatially in magnitude and/or direction. The amplifications take into account the energy required for spatial acceleration of the flow velocity as well as the energy added to or removed with the entrance or escape of water into or from the flow system. This is illustrated with a case of confined radial flow, a case of unconfined unvaried flow and cases of semi-confined respectively unconfined

varied flow with a recharge to the watertable. For the latter case, a numerical example is given of the application of the amplified Darcy equation, and its results are compared with those obtained from the original Darcy equation. In the example, gradient and elevation of the watertable calculated with the amplified equation are smaller due to the energy input associated with the percolation water.

RECENT ADVANCES IN MODELLING VADOSE ZONE TRANSPORT

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Modelling solute transport through the vadose zone is difficult due to the complicated networks of interconnected pathways in the soil which can transmit water and its solutes at varying velocities. Preferred pathways resulting from biological and geological activity may transmit water (and it's solutes) at very much higher rates than those predicted by Darcy's theory. Therefore, current transport models for water and solutes based on the assumption of Darcian flux, eg. Richards' equation and the Convective-Dispersive equation may significantly under-estimate the risk to groundwater supplies because they do not consider explicity preferential flow paths but model the bulk flow in an "average" path. A preferential solute transport model developed by us simulates the effects of natural heterrogeneities in the soil layer by identifying paths responsible for the transport of water and solutes. The soil-water hydraulic conductivity function is used to identify these paths and the interaction between these paths are described by mixing functions. This paper discusses the nature of preferential flow and illustrates application of the model to several field experiments.

GROUND WATER RESOURCE EVALUATION — A REALISTIC APPROACH

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Evaluation of ground water resource is a pre-requisite for its judicious development/management. In-depth basin-wise studies are required for evaluation of realistic ground water resource potential. For quick evaluation of the resource, various 'Short-cut' methods have been adopted during the past decades — the most commonly being the one proposed by the Ground Water Estimation Committee (1984) Govt. of India. This methodology often creates anomalous situation; wherein, over an assessment period while the computed change in groundwater storage (using non-normalised annual recharge) is positive, the corresponding water levels exhibit a decline or vice-versa. Estimation of inflow/outflow components on the basis of adopted norms leads to erroneous computations. Particularly, the ground water draft, its monsoon and non-monsoon period break-ups which are rainfall intensity/distribution dependent can't be estimated on the basis of normalised structure wise norms.

This paper presents a 'Short-cut' method for realistic evaluation of ground water estimates and is based on the observed values of rainfall and water levels alongwith the known value of specific yield. The proposed methodology facilitates categorisation of an area for its ground water development stage and computation of ground water balance. For instance, in an area, if over a water balance year (Say June over June) there is a significant fall in water levels inspite of above normal rainfall (consequently below normal draft), the area gets categorised as 'Over-developed'. For ground water balance computation, from the past 5 years data, a near normal rainfall period of 1 to 3 years duration is chosen for which average annual change in ground water storage is computed. Potential ground water resource (static resource down to 5m depth) is added to it to obtain ground water balance for the assessment period which, if required, is updated considering the normal incremental draft during the elapsed period.

REGIONAL GROUND WATER MODELLING USING FINITE ELEMENT METHOD

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Judicious management of the water resources of a ground water basin needs a comprehensive understanding of the total system and its response to recharge and various pumpages contemplated. The ground water

basin of the command area of the D-53 major distributary, Sri Ram Sagar project, Andhra Pradesh was simulated using the Finite Element numerical method. Two dimensional simplex elements with linear trial functions were considered in arriving at the solution of a two dimensional-transient state problem. Net recharge to the aquifer was assessed using a semi-empirical approach. Various components of the water balance of the area were estimated by adopting the norms of Central Ground Water Board estimates committee with suitable modifications based on the soils, crops and climate of the area under consideration. The approach using the ground water level fluctuation as an indicator of spatial distribution of net recharge was adopted. Spatial distribution of net recharge to the aquifer was assessed using recharge distribution coefficients which were estimated by running the model with pumpage alone and by setting net annual recharge at each node to zero. Sensitivity analysis was performed to investigate the model's sensitivity to its parameters viz. Hydraulic conductivity and storage coefficient by varying the parameters in turns in separate simulations.

The model was validated against the historical observed data of ground water levels in the study area for three years from 1983-84 to 1985-86. The computed water levels and the corresponding observed values were used to draw the water table contour maps for the period 1983-84 to 1985-86 and a close agreement between observed and model computed Ground Water levels was found. Since the ground water levels were rising in the command area of D-53 major distributary, Sri Ramsagar project, Andhra Pradesh, the model was used to determine the pumping and recharge rates needed to stabilise water levels under a proposed crop-water management scheme.

GROUNDWATER HYDROLOGY OF SIWANA, WESTERN RAJASTHAN, INDIA — A MULTIDISCIPLINARY APPROACH

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Studies in groundwater hydrology require a multidisciplinary approach. Although there are a number of reported techniques dealing with different aspects of groundwater hydrology; it is often observed that an integrated approach is lacking in most of them. In this paper, we discuss the groundwater hydrology of Siwana, an intermontane basin, western Rajasthan, wherein use of hydrogeological, geophysical, geo-chemical and isotopic investigations have been incorporated and discussed.

Studies reveal that the aquifers in the southern part of Siwana are associated with clay and silt. Clay lenses are also found at shallow depth causing negligible vertical recharge to the groundwater as shown by the injected tritium profiles. Stable isotope contents of deep dug wells in the area indicate that the groundwater is of meteoric origin but has not undergone evaporation. Geo-chemical investigations coupled with the results of other geohydrological investigations indicate the presence of saline water zones north of siwana and potable water at other locations. A general picture of groundwater conditions has been presented on the basis of results of different geohydrological investigations.

FEM MODELLING OF ARTIFICIAL RECHARGE BASINS OF DIFFERENT SHAPES AND THE UNDERLYING AQUIFER SYSTEM

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Details of steady state solutions were considered to compute the influence of artificial recharge by a rectangular basin. An algorithm was developed based on Galerkin's finite element method to compute groundwater head and flux in the underlying aquifer system. Later, head distribution was also computed for a circular, square, hexagonal and triangular recharge basin with equal area and for same recharge rate. A lower groundwater mound build up was found for higher perimeter basin shapes and vice versa. Influence of variation in hydraulic conductivity near to recharge basin periphery was investigated and a mass balanced was checked. Time variant analysis computed a time of 82.3 days to stabilize the mound. The build up was higher initially followed by a much slower ground towards near stability of the mound.

A GENERALISED SOLUTION OF UNSTEADY FLOW TO A MULTI AQUIFER WELL

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A generalised discrete kernel approach has been described for analyzing unsteady flow to a multiaquifer well, which is open to a number of aquifers that are separated by acquicludes. The contributions of each aquifer and well storage have been quantified for a specific case in which the multi-aquifer well taps three aquifers and is pumped at a constant rate. In the very beginning of pumping, the water is withdrawn from the well storage and the contribution of each aquifer starts from zero. It is found that, for some duration in the beginning, the aquifer having the lowest hydraulic diffusivity contributes more water than any of the other aquifers. If the transmissivities of the aquifers are of same order, the contribution of the aquifer having lowest diffusivity is significant in the early period of pumping. When the pumping is continued for a long time, the contributions of the aquifers are in proportion to their respective transmissivity values. If all the aquifers have equal hydraulic diffusivity, their contributions are always proportional to their respective transmissivity values and the piezometric surfaces in all the aquifers do not differ from each other.

GROUNDWATER RESOURCES EVOLUTION

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The development and management of groundwater requires an estimate of the sustained yield of the aquifer. Although it is usually limited by local aquifer transmissivity and storativity, the current rate of recharge can become a practical as well as a theoretical limit to the sustainable yield. Estimating the rate of aquifer replenishment is probably the most difficult of all measures in the evaluation of groundwater resources. Groundwater recharge is an intermittent and irregular process in the hydrological cycle. Direct assessment of the component of recharge from rainfall on a regional scale is difficult. Several indirect approaches, however, can be used to estimate the groundwater recharge. These include the hydrologic budget method, conventional method, hydrograph separation method, tracer technique and conventional rainfall-runoff model.

The most widely used approach is the conventional method based on the soil-moisture balance. The hydrologic budget method has the advantage of relating groundwater recharge to other parameters of the hydrologic cycle and thus providing a fuller understanding of the hydrology in the broader context. Most of these models need data that are not readily available in developing countries. However, for planning purpose, a preliminary estimate is sufficient. Depending on the physical system, a particular method or a combination of approaches is to be adopted seeking an appropriate balance between complexity and accuracy considering the quality of available data and the needs for practical design and analysis. It is to be noted that no single comprehensive estimation technique can yet be identified from the spectrum of those available, which does not give suspicious results. This paper deals with the evaluation of groundwater recharge for selected basins from Nepal and Sri Lanka using conventional water balance technique, groundwater basin simulation model and saltwater upcoming model.

EVALUATION OF RECHARGE TO GROUNDWATER DUE TO APPLIED IRRIGATION UNDER DIFFERENT CROPS IN UTTAR PRADESH USING ISOTOPE TRACER TECHNIQUE — A FIELD STUDY

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A quantitative evaluation of recharge to groundwater due to return flow of irrigation is vital for rational development of groundwater resources. Its estimation in various parts of the country was for long based on adhoc norms and thumb rule. Thus its estimation in the field under different crops has over-riding importance. Development of nuclear techniques and their application to groundwater hydrology show promise of filling the widening gap between understanding the basic characteristics and exploitation of groundwater resources. Conventional methods require long term periodic field

data which are not easily available. Even the use of groundwater balance equation is often restricted on account of non-availability of precise hydrological data.

Keeping the above aspects in view, the Isotope Group of U.P. Irrigation Research Institute, Roorkee, has carried out the studies of recharge to groundwater due to return flow of irrigation using isotope tracer technique in different parts of Uttar Pradesh under different hydrological conditions and different crops viz. wheat, paddy, sugarcane and pasture land.

Based on the studies carried out in different areas of Uttar Pradesh by isotope tracer technique, the recharge due to applied irrigation varies from 23 to 34%, 52 to 62%, 34 to 38% and 22 to 26% for wheat, paddy, sugarcane and pasture land respectively. These findings have also been compared with the studies carried out in other States by various investigators. The technique used compares fairly well.

The use of isotope tracer technique provides a better understanding of the hydrological phenomenon and consequently results in better planning of the optimum use of water resources.

The details of study carried out, methodology adopted, experimental details and results obtained are presented in the paper.

EVALUATION OF RAINFALL RECHARGE TO GROUND WATER IN VARIOUS TYPES OF SOIL COVER & BASE FLOW BY USING RADIO-ISOTOPE IN PARTS OF DISTRICT UNNAO, U.P.

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With a view to estimate ground water recharge due to rainfall & base flow, a Nuclear study has been carried out in different parts of U.P. by U.P. Ground Water Department, Lucknow. The study has been carried out in reference to alluvial area of block Bichia in district Unnao U.P. by Tritium Tagging method.

The downward movement of rain water into the soil during the period from June, 1989 to December, 1989 has been traced out at four injection sites, well scattered over the block Bichhia. The average value of recharge to ground water due to rainfall for the area has been found between 24% to 33% of total rainfall. This figure is enclosed with the results obtained by some other investigation or as per NABARD value also.

Tritium was injected at four sites having different type of soils in pre-monsoon (June 1989) and in post monsoon (December 1989) periods in the study area. The soil samples were also collected from the tritium injecting points upto the depth of water level for analysing the initial moisture content & grain size. Position of water level were also noted down at the time of injections. The position of tritium peak can be demarcated by counting of tritium counts in the tritiated water samples obtained from the soil samples of different depths. The moisture content of layer, in which tritium has been displaced during the period intervening between the time of injection and time of soil sampling, represent the recharge to ground water during the study period.

By this study, it is found, that the recharge percentage from tritium tagging technique in the study area varies at different place having a different type of soils in parts of block Bichhia, district-Unnao, U.P. The rate of base flow is also assessed in the present paper.

IS IT CORRECT TO ASSUME THAT MOVEMENT OF WATER IN UNSATURATED SOIL STRATA IS PISTON FLOW?

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Movement (flow) of water (moisture) in unsaturated soil strata will depend on replacement of 'air-water' held in unsaturated zone. If the soil strata is homogeneous-from surface to water table then it is simple to work with, but in nature this may not be possible. The soil strata may be build up of different layers of different composition, compaction and of different grain size which may complicate the situation. Recharge to ground water from surface is assumed to be piston flow. This piston flow movement of water had been used to find the recharge using tritium tagging method. In order to

study this piston flow, two experimental studies were conducted (1) using Ra-Be neutron probe and (2) gamma-ray transmission method using two bore holes under ponding conditions at the same site. The results by two methods are practically the same for the water held and water drained with time. The authors (1,2) considered and proposed 'column approach', for rate of discharge of moisture above field capacity by introducing two parameters, the residence time (ψ) and movement of water front (T).

The data in these two experiments were re-examined to understand the piston flow model used in tritium tagging method. In this analysis, the movement is like stretching of water pulse applied at the surface throughout the length of the column. This will depend on the residence time (ψ) which is due to capillary forces, holding this water (moisture) at field capacity. ψ & T had been worked out for different ponded height and at different depth of soil strata. For smaller ponded height ψ decreases linearly (below 2 m) with depth. The flux of water (moisture) moving at the slow rate, also decrease with time giving the movement layer by layer. The quantitative estimates are made and discussed on the basis of this model.

(1) Kiran Shankar, Bhishm Kumar and B.P. Singh, Ind. Nat. Science academy Vol.45 Part A (1979) 476-484.

(2) Bhishm Kumar, B.P. Singh and Satish Chandra Joul of Inst. of Engg. (India) Vol.73 (1993) 173-179.

HYDROGEOLOGICAL CONDITIONS IN THE TERAI PLAIN OF RUPANDEHI DISTRICT, LUMBINI ZONE, NEPAL WITH SPECIAL EMPHASIS ON RECHARGE

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Terai plain which forms northern fringe of the Gangetic plain occupies a width of about 25 km in Rupandehi district, Lumbini zone, Nepal. This part of the Terai has been extensively developed for groundwater by the GWRDB under Bhairawa-Lumbini Ground Water Irrigation Project with the assistance of USAID and UNDTCD. In this project 129 tube wells were constructed covering an area of about 875 km^2. The wells range in depth from 45 to 461 m with an average of 150 m. The aquifer zones constitute predominantly gravel with occasional admixtures of fine to medium sand forming multi-aquifer system. But the aquifers are discontinous, pinching and bulging in different parts and dovetail into fine sediments. This reflects the sedimentation pattern of frequently shifting river systems in the Terai plain. Thickness of the aquifer zones tapped in the area varies from 5 to 80 m. Hydraulic conductivity ranges from 3.5 to 595 m/day. The deep tube wells are found to have the yielding capacity of 360 m^3/hr to irrigate 120 ha under each well. They have specific capacities in the range of 60 to 3942 lpm/m of draw down with an average of 1230 lpm/m of drawdown.

Piezometric surface in the area is a replica of its topographic surface. The are a below 120 m MSL contour line is a flowing zone with a few exceptions and with the piezometric head rising to a maximum height of 16.6 m above ground level. The area can be divided into three zones on the basis of piezo-metric surface configuration. Interestingly, the southern most part shows a high. This cannot subscribe to the general belief that the bhabar zone, on the northern part along the foot hills, forms the recharge area for the entire Terai since such a pre-sumption entails a gradual decline in head due to friction of flow. Intensity of piezometric head is found to increase with depth down to 20 m bgl beyond which it remains nearly constant within narrow limits and flowing conditions result. Laterally, the intensity is found to gradually increase towards south with a few exceptions in the south.

The Terai plain has very high groundwater potential. Monitoring of water levels from 1983 to 88 revealed scope for further development. In fact, the plain may be subjected to over exploitation for some period to lower the piezometric heads and thereby to allow more recharge and also to create induced recharge from the present and palaeo-stream beds.

The conventional rainfall methods of recharge estimation is not appropriate for the Terai plain. The study area

is found to be connected to three different regions of recharge. The stream beds of present and palaeo-channels are found to be acting as recharge zones in addition to the stratigraphic horizons such as Bhabar zone.

WASTEWATER RENOVATION THROUGH SOIL AQUIFER TREATMENT IN THE RIVER SABARMATI BED AT AHMEDABAD — PILOT STUDY

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Abundant and assurred supply of ground water in and round Ahmedabad has been a significant input responsible for the rapid pace of development of this important city. In response to increased ground water exploitation in recent years, water levels in the tube wells have been falling at an alarming rate of 2-3m/yr. This is resulting in increased pumping costs and anxiety for the future availability of water supply both to meet the basic needs as well as consumption pattern commensurate with the urban life style. Artificial recharging of aquifers has often been suggested as a solution and some pilot experiments through injection recharge models have already been done. The main constraint to large scale artificial recharging of aquifers in Ahmedabad has, however, been the availability of surplus water of a reasonable quality.

Study of ground water systematics in this region by PRL scientists has established that Sabaramati river at Ahmedabad loses large amount of water to the shallow unconfined aquifer by infiltration through its banks and the bed. The unconfined aquifer has, in turn, been shown to recharge the deep confined aquifer by leakage through the semi-permeable acquittard layer that separates the two aquifers.

It is the confined aquifer that is presently being pumped within the city and around. It is, therefore, suggested that if water of reasonable quality could be made available in the Sabarmati river on an year round basis, its infiltration would indirectly recharge the deep confined aquifers via the unconfined aquifer. The ....? route of recharging the aquifers would, in addition, ensure safety of the confined aquifer against bacterial contamination. However, the problem of availability of water of acceptable quality for flooding the Sabarmati river bed for effecting recharge in the manner suggested above still presents a major constraint.

With a view to obviate this difficulty, a scheme has been formulated wherein the river channel downstream of Vasna barrage which in .....? to be utilised as a factory for production of water of acceptable quality by renovation of partially treated sewage effluent through the concept of Soil-Aquifer-Treatment (SAT). SAT systems essentially replicate the natural process of water purification by infiltration through the unsaturated soil zone and further purification by movement within the saturated ground water zone in the aquifer. However, infiltration rates of SAT systems have to be maintained at orders of magnitude higher than natural infiltration rates. This is accomplished by (i) constructing infiltration beds over highly permacubic sundry strata, (ii) prevention of clogging, and (iii) pumping out of the infiltrated renovated effluent. Use of Sabarmati river as channel for SAT renovation of sewage effluent is possible as its bed () remains dry for almost round th year, (ii) hs adequate thickness (15m), and width (0.5km) with appropriate grade of sand for construction and operation of infiltration beds. SAT systems employ low level technology and under suitable conditions, as prevailing at Ahmedabad, should provide a cheap source of acceptable quality water for unrestricted irrigation and ground water recharge.

Preliminary calculations indicate that a 4km long stretch of the Sabarmati channel downstream of Vasna barrage will be adequate to renovate up to 200 MCM/yr of sewage effluent. Part of this renovated water should be usable for irrigation/horticulture as well as industrial applications like cooling, textile processing etc. The surplus renovated water can be pumped to flood the river channel upstream of Vasna barrage where it would not only provide a scenic water front for the city, but also recharge the ground water aquifers through infiltration and leakage as explained above. It would also help in bringing down the ambient temperature of the city.

A pilot research project for studying the validity of the concept described above regarding quality and quantity

resulting from SAT system using the Sabarmati river downstream of Vasna barrage has been initiated. The project, in addition, aims to quantity the various parameters/processes governing the SAT system at Ahmedabad, namely. (i) hydrologic parameters affecting percolation/loading rates, (ii) rejuvenation capacity of the river filter beds and (iii) evaluation of biological, chemical and hydrological processes in the unsaturated and saturated zones in the river bed under stressed conditions of operation.

Successful completion of the pilot project is expected to lead to a dual role for Sabarmati river (i) in the renovation of sewage effluent and (ii) augmentation of ground water recharge at Ahmedabad. The river may thus provide key to the future availability of water for the city. Additionally, the presence of year round water in the river will open up possibility of river front development which will necessitate shifting of all effluent discharges into the river – from upstream to downstream of Vasna barrage.

SPATIAL EVALUATION OF GROUNDWATER LEVEL OF ATTUR VALLEY, SOUTH INDIA — A MULTIVARIATE APPROACH

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The purpose of observation of groundwater lies primarily in learning its regime i.e. the spatio-temporal variation of the water levels. In the evaluation of the results of the observations, the basic characteristics of the regime of groundwaters are established. Most frequently this processing is restricted only to time series analysis and trend analysis. But in the present study a factorial approach is made to find out the interrelationship between the groundwater level and various parameters like lineament density, drainage density, slope percentage, thickness of soil, thickness of weathered zone, thickness of jointed zone and average annual rainfall. Once this type of functional models are developed it is possible to prepare the management models.

The said analysis is carried out for a typical crystalline aquifer system of Attur valley, Tamil Nadu which covers an area of about 3000 sq. km. The mean groundwater level is obtained for 35 observation wells which are regularly monitored for the past fifteen years. This data is interpolated for another fifteen locations and the sampling points are fixed as fifty. The lineament map is prepared and from it the density is worked out for all the fifty sampling points. Drainage network map is prepared and from it the density is worked out for the same locations. The slope is determined by using Went Worth formula and the contours were developed from the slope percentage an then values are assigned for all the sampling locations. Thickness of soil, thickness of weathered zone and thickness of jointed zone are measured in field for the all sampling points. The 35 years rainfall data is collected for the nine locations located in the study area and the mean annual rainfall distribution is worked out from it for the all sampling points.

The R-mode factor analysis is carried out by using the above eight variables and the interrelationships of groundwater levels with all other parameters are derived. By following Kaiser's recommendations three factors were derived, since three of them have the eigenvalues of > 1. In the next stage, the background noise imposed by unnecessary axes are removed by duly adopting varimax (variance maximisation) criterion.

Among the three derived rotated factors, the first two have appreciable loading of groundwater level. In rotated factor 1 the ground water level (0.6730), drainage density (0.6291), slope percentage (0.8630) and thickness of weathered zone (0.5211) are interrelated with each other. In rotated factor II the interrelationships are found between ground water level (0.4517), lineament density (0.7151), Thickness of soil (-0.7922) and thickness of jointed zone (0.4548). The derived scores for these rotated factors are plotted in their respective geographic locations and spatial distribution of interrelated parameters are delimited.

To further validate this results the multiple linear regression analysis is carried out between the varimax factor scores and the loaded parameters. In the first analysis the rotated factor score of 1 is kept as a dependent variable and ground water level, drainage density, slope percentage and thickness of weathered zone as independent variables. The derived coefficient of multiple determination (R^2) is 0.924. And in the R^2, the percentage of contribution of groundwater level is 33.0% drainage density 14.9%, slope percentage 37.9% and thickness of weathered zone 14.2%. And it is inferred that the slope has higher contribution to ground-

water level and the relationship between the slope and groundwater level is highly positive. The rotated factor 2 scores is correlated with groundwater level, lineament density, thickness of soil and thickness of jointed zone the R^2 derived is 0.926. In this R^2, The groundwater level explains 12.4%, thickness of soil 49.6 and thickness of jointed zone 5.3%. And it is followed from it that the groundwater level has positive relationship with lineament density and negative relationship with the thickness of soil.

GROUND WATER EXPLORATION AND DEVELOPMENT IN BUNDELKHAND GRANITE TERRAIN IN DISTT. JHANSI

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The study area falls in the semi arid region of U.P. which is basically a drought prone area. Normal yearly rainfall and normal monsoon rainfall are 895.88 mm and 808.65 mm respectively. Similarly the average yearly and average monsoon rainfall are 903.22 mm and 754.7 mm respectively. The temperature rises as high as 48°C in summer and falls as low as 4°C in winter.

The search of Ground Water in the granitic country can be carried out in the weathered granitic residuum, fractured zones and in the abandoned channel of the rivers Betwa and Pahuj. The abandoned channel of Betwa and Pahuj Rivers are the most promising horizons of ground water in the area. The weathered and fractured granitic country form the moderately potential ground water zones. The topographic lows, between the hills, have been found more promising for groundwater than the highland areas.

The shallow tube wells of 4" to 8" dia constructed in large numbers in the area are found to have limited success. The reason was that the small diameter of these shallow tubewells could not intercept the productive fractures to ensure good discharges in comparison to the large diameter blast wells, which have more scope of encountering these fractures & which at times can be dilated through horizontal boring to further increase the discharge. The chance of failure of a blast well is very less than the small diameter shallow tube wells. Fracture trace analysis of the granitic terrain through satellite imaginary will serve as an effective tool in groundwater targeting.

PLANNING AND DEVELOPMENT OF GROUND WATER FOR IRRIGATION IN INDIA

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According to VIIIth Five Year Plan (1992-97) issued by Planning Commission, Govt. of India, Irrigation Potential Created through Minor Irrigation Schemes by the end of 1989-90 is 46.60 million hectare in which Ground Water Component is about 35 million ha. The total irrigation potential is 78.12 m. ha. Thus Ground Water accounts for 45% of total irrigation potential in the country. During the VIIIth Five Year Plan (1992-97) also, the target is to create a minor irrigation potential of 10.7 m. ha out of which more than 9 m ha is expected from ground water. The total irrigation potential target is 15.8 m. ha. Thus Ground Water accounts for 57% of target in VIIIth Five Year Plan. This would indicate that a great importance has been given to develop ground water for irrigation. This is because of the fact that irrigation through ground water is assured (except for some insignificant part through Public Tubewells) and within the farmers' own hands. The small ground water structures like dug wells, shallow tubewells and borewells are quick to construct and within the reach of individual farmers, who have access to loan from banks on easy terms and subsidy from Government (for weaker section of farmers only). The reported number of Ground Water Structures at the end of 1989-90 were 9.49 million dug wells, 4.75 million shallow tubewells and 0.064 million of deep public tubewells, through out the country. As Ground Water development is limited to the extent of annual replenishable recharge, very careful planning for its development on scientific lines is needed failing which there may be serious adverse effects on environment and ecology. This paper describes in detail the planning and development process in the country and discusses various issues and connected problems, alongwith important case studies on the subject including that of conjunctive use of surface and ground water.

CONJUNCTIVE WATER USE PLANNING AND MANAGEMENT MODELS: A STATE-OF-THE-ART REVIEW

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Conjunctive use refers to the coordinated and planned utilization of surface and ground water resources in an integrated manner. Conjunctive or integrated water use has long been recognized as an effective strategy for the optimum development and management of water resources, both at regional and project levels. The role of condjunctive water use is particularly significant today, more than ever before, when there is a growing need to satisfy the ever-increasing water demand of human kind within the limited resources available while considering various environmental impacts of water utilization and protecting the resources for sustainability.

The state-of-the-art of water resources management has changed considerably over the last three decades. Systems analysis and its framework consisting of mathematical models, has now been recognized as an important approach for addressing the problems related to water resources systems, especially the complex and large-scale ones. The objective of this paper is to present the state-of-the-art review of mathematical models for the planning and management of conjunctive water use systems for various purposes. Different approaches and techniques reviewed include simulation, optimization (linear programming, dynamic programming and non-linear programming) and decomposition and hierarchical or multilevel approaches. Also included are the approaches for considering key issues such as risk and uncertainties and multiple objectives/criteria. The paper concludes by highlighting some of the limitations and gaps in existing models and some thoughts on the future research needs.

SIGNIFICANCE OF PALAEO CHANNELS FOR HYDROGEOLOGICAL STUDIES — A CASE STUDY FROM ALLUVIAL PLAINS OF PUNJAB & HARYANA STATES, INDIA

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The alluvial plains of Punjab and Haryana States, India have been characterised by the presence of Palaeochannels of Rivers Ghaggar, Sutlej and Beas. Such palaeochannels have been identified with the help of LADSAT and LISS, I,II data. These palaeochannels can be broadly grouped into two different types depending upon their climatic and sedimentary environment. As such two different models are proposed. In the first model, palaeochannels, when surrounded by comparatively finer sediments form water-logged and saline areas as free flow from palaeochannels is restricting. This results into development of saline water in the palaeochannels. In the second model, the surrounding material is either of same nature in terms of grain size, permeability etc or is having more permeability resulting in free flow of water from palaaeochannels to the adjoining areas. In such cases paleochannels are the source of fresh water specially in arid/semi-arid environments. In view of the above it is felt by the author that the significance of palaeochannels should be viewed/studied in relation to climatic and adjoining sedimentary environments as varied results are obtained. The models are supported by the field data.

CONTROL OF SEA WATER INSTRUSION THROUGH BATTERY OF INJECTION WELLS

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The problem of salt water intrusion into coastal aquifers was recognised as early as 1855 by Braithwaite and later was analysed theoretically by Ghyben (1888) and Herzberg (1901). The salt water intrusion into fresh groundwater resources occurs when permeable formations outcrop into a saline water body. As salt water is denser than fresh water, there exists the tendency of fresh water floating above underlying salt water. This phenomenon can be expressed in a simple mathematical form by Ghyben and Herzbergs' principle. Although considerable developments have been made in understanding the behaviour of salt water-fresh water relationships in groundwater systems since the time of Ghyben and Herzberg, salt water intrusion control methods are yet to be explored to the full extent. This paper presents an overview of major theoretical and field investigations regarding techniques for controlling the intrusion and their effectiveness.

The increasing demand for fresh water is being met by groundwater resources on a larger scale during the current century. Unplanned exploitation of fresh water in coastal aquifers has seriously aggravated the already existing problem of intrusion in several parts of the world. Further deterioration of the situation has to be prevented at this stage by adopting a suitable management scheme dealing with control of saline water intrusion. This paper discusses the progress in this regard through theoretical and field studies of control measures, their advantages and disadvantages, implementation and efficiency in preventing intrusion.

GEOELECTRICAL STUDIES FOR THE GROUND WATER INVESTIGATION NEAR KURUKSHETRA, HARYANA

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The surface geoelectrical measurements are very useful to the exploration of ground water as well as in estimating geoelectrical and Geohydrological parameters of the aquifers. Direct current resistivity measurements are carried out aiming the investigations of geoelectrical parameters of aquifers and their possible correlation with ground water quality in terms of salinity variation. Schlumberger configuration has been used for the field measurements and the apparent resistivity data so obtained are interpretted using the matrix method recently developed by the author. The method uses exponential representation of kernel functions and retaining upto finite number of terms. Resistivity of top layer is fixed and taken as the apparent resistivity at a small electrode separation. This reduces the size of the matrix involved in the inversion and thus iteration process become faster. The data may be interpreted either in kernel domain (λ–domain) or in apparent resistivity domain (r-domain). For good quality data results obtained using the two methods are same within the observational error. Other computer methods such as Zodhy (1989) and approximate asymptotic iterative inversion (AAII) published as AAIIM and REDLAY user friendly computer programme for the inversion of resistivity sounding data in kernel domain (Sri Niwas et. al. 1991) also have been used for the comparison purpose. This also help in reducing the geologically irrelevant and insignificant layer(s) from inverted model. Geoelectrical sections of the area is prepared and correlated with the available borehole data.

GEO-ELECTRICAL INVESTIGATIONS FOR SUBSURFACE CONFIGURATION IN THE INDIRA GANDHI NAHAR COMMAND, RAJASTHAN

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The utility of Vertical Electrical Soundings (VES) carried out at short intervals along four traverses for understanding the subsurface configuration vis-a-vis gypsiferous layers responsible for water logging and salinity in the Indira Gandhi Nahar Command, Rajasthan are presented. Field data obtained have been interpreted qualitatively and quantitatively and discussed in the light of secondary data.

Results indicate that the shallow gypsiferous layer, located at the Lunkaransar State Agricultural Farm, has varying thicknesses along the VES profile and govern the salinity and subsoil water movement. Traverses along Suratgargh-Manakteri, Suratgargh-Lakuwali and inside the Central State Farm, Suratgargh, reveal saline water zones at varying depths. Resistivity data obtained at some places have been compared with the available borehole lithology. It is suggested that characteristics of such gypsfierous/impervious layer(s) responsible for altering the hydrological conditions of the canal command at Stage II need to be studied in detail to have minimum effect of water logging and salinty.

THE NUBIAN SANDSTONE BASIN IN NORTH AFRICA, A SOURCE OF IRRIGATION WATER FOR DESERT OASES

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The Nubian sandstone basin in northern Africa is presented in this paper. This basin has total a surface of about 1.8 million km^2, encompassing the northwestern part of the Sudan, Egypt west of the Nile, the extreme north-east of Chad and southern and eastern Libya. This surface is characterized by its extreme aridity. Groundwater is present in the Nubian basin in a range of geological strata, and has been used since

time immemorial for small scale potable supplies and for limited irrigation purposes. The only inhabited areas are located in a series of depressions called the oases, the most important of which are the Kharga, Dakla, Farafra, Bahariya and Siwa in Egypt, and Kufra in Libya. The last few decades have witnessed accumulating evidence of the huge quantities of fresh groundwater the Nubain sandstone contain in storage and can transmit. Safely exploited aquifers can secure the success of carefully planned agricultural development projects. Thirty-five years ago the Egyptian administration supported desert reclamation and development by initiating the New Valley (principally Kharga and Dakhla oases) project. A few years later the Libyan authorities began the work in the Great man-made river project, to which the Nubian basin underlying the Kufra Oasis is a source of supply. Both projects aim at expanding the irrigated surface in the relevant oases. The present paper describes the hydrogeology of the Nubian basin. It also critically reviews the exploitation of its water for land irrigation and reclamation purposes.

ECONOMIC ANALYSIS OF GROUND WATER COST

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The economic feasibility of using ground water has led to rapid growth in its use. Tubewells are increasingly used for both public and private exploitation of ground water. Ground water may be particularly valuable in augmenting surface water supplied during relatively short period of peak demand, such system based on wells can be brought into operation much more rapidly and efficiently than systems based on reservoir construction which may take a number of years to complete. Moreover, ground water development can be phased with demand avoiding costly excess capacity in the early stages of development. With the widespread expansion in ground water resources development, the economic factor related to its production has become increasingly important.

Large scale development of ground water calls for optimum design of wells which would deliver water at the least unit cost. Ground water from subsurface reservoir could be lifted by constructing shallow and deep tubewells. Deep tubewells could be direct irrigation or augmentation wells (wells constructed for augmenting supplies of existing canals).

Designs of deep wells with different capacities ranging between 30 lps and 200n lps and with various values of diameter, depth and entrance velocity are prepared. Cost analysis of these designs has been carried out to compute capital cost and operational cost and determine unit cost of the pumped water. Out of the various designs, optimum design for minimum unit cost of pumped water can be selected.

Effect of the aquifer parameters on the unit cost of pumped water has been determined. The above computations have been carried out considering the cost of wells and pipes alongwith cost of the distribution system and without cost of the distribution system.

For the shallow tubewells the designs have been prepared and economic analysis carried out for well capacities ranging from 5 lps to 20 lps. The detailed design has been carried both for electric motor and diesel engine operated pumps. Optimum capacity of the deep wells have been found to be in the range of 80 lps to 100 lps and that for the shallow wells lies between 10-15 lps. Optimum diameter and well depth has been determined for various well capacities.

The optimum entrance velocity for deep wells is found to be less than 0.02 m/s and for shallow wells it is in the range of 0.0175 to 0.0225 m/s. The unit cost of pumped water decreases with the increase in the values of transmissibility and storativity of the aquifer. The unit cost of pumped water decreases with the increase in the annual operational hours.

For augmentation wells, cost calculations have been carried for different values of aquifer coefficient of transmissibility. Storativity, annual running hours, and for well capacities, 40 lps, 70 lps and 100 lps. From the study, it is found that the optimum distance of well from the canal increases with decrease in storativity, Increase in the value of transmissibility and increase in the duration of continuous pumping. Unit cost of water is less for higher discharge wells under the same conditions.

TECHNO ECONOMIC ASPECTS OF STREAM BED BLASTING, FRACTURE SEAL CEMENTATION AND BORE BLAST TECHNIQUES OF GROUNDWATER CONSERVATION

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Nearly 92% area of the state is occupied by hard rock and of which 82% area is occupied by volcanic layered dark greenish basalt. The inherent characteristics of this rock have put various limitations on the availability of groundwater for long durations upto summer months. The situation has become more critical due to excessive development of groundwater during the last two decades.

More than 70% of rural water supply in the state is from groundwater. In order to protect and augment the groundwater supply sources created, various cost effective techniques of stream bed blasting, fracture seal cementation and bore blast are being adopted in the state. The present paper deals with the techno economic aspects of various techniques mentioned above.

A case study of villages Kurangwadi and Ambode located in Bhor taluka of Pune district is presented in the paper. These villages though fall in moderately high rainfall zone face accute drinking water shortage during summer months. Remote Sensing and Aerial Photograph investigations have laid to the identfication of the above mentioned unconventional techniques to be executed for augmentation of water supply. Post project techno economic evaluation of these projects have been found to be cost effective.

The authors advocate the implementation of such projects to solve the drinking water problem of the villages falling in simlar hydrogeological conditions.

EVOLUTION OF THE PHREATIC SURFACE IN A FINITE AQUIFER DUE TO TRANSIENT RECHARGE

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Understanding of the dynamic response of pheratic aquifers due to transient recharge is most important for the proper management of ground water systems. An analytic solution is developed to describe fluctuation of pheratic surface in a finite aquifer due to localised time varying recharge from a strip basin. The aquifer is lying between an impermeable boundary and a stream. Sensitivity of the solution of varying recharge parameters is demonstrated with the help of a numerical example.

ESTIMATION OF UNSATURATED HYDRAULIC PROPERTIES OF AN IRISH SOIL

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Essential hydraulic and hydrologic behaviour of soils can be described in terms of their hydraulic conductivity and water retention characteristics.

Unsaturated hydraulic properties of a gray-brown podzolic loamy soil on glacial limestone till at Athenry, Co. Galway, were estimated from a field experiment consisting in the measurements of soil water redistribution after infiltration with the soil surface covered against evaporation and protected against rain. The soil moisture content was measured by the neutron probe and the soil water suction head with tensiometers. The unit-gradient (gravity-drainage) theory of Sisson et. al. (1980) was applied to evaluate the results of measurements. The computer code UNGRA was used to optimize parameters of the Van Genuchten-Mualem equations for retention curves and hydraulic conductivity — suction head relationships, with the measured data as input. Two limiting estimates of these parameters and relationships were obtained which provide a semiquantiative insight into the properties of the investigated soils. The latter seem to be dominated, in the wet unsaturated range, by the water conduction in fine macropores.

The neutron soil moisture probe is of insufficient accuracy for measurements of this kind, while tensiometers with mercury or similar manometers are precise enough. Another, more precise type of moisture meter, in addition to the tensiometers, would be desirable but,

if large scale repeated mesurements are to be carried out in a region with relatively homogeneous soils, most of them can be done with tensiometers alone, with the moisture meter used only in several sites.

The need for reliable and representative soil hydraulic characteristics has become increasingly important with the application of simulation models to phenomena involving soil water flow.

ANALYSIS OF LARGE-DIAMETER WELL PUMPING TEST DATA IN FRACTURED ROCKS WITH LINEAR FLOW PATTERN

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Analysis of punping test data from a large-diameter well in fractured rocks with linear flow pattern under unsteady state condition is carried out. The suggested method is a modification of Sen (1986). The proposed method, unlike Sen (1986) method is applicable, to large diameter wells and does not require curve-matching technique involving caution and personal judgement for accurate estimates of aquifer parameters. The analysis leads to computation of the ratio T/S, which is then utilised for estimation of radius of influence by new equation r = T/s.t. With an assumption of length of fracture extending upto twice the radius of influence, aquifer parameters (transmissivity and storage coefficient) are estimated. The analysis deals with extension of fracture in one and two directions. Verification of the formula for radius of influence was confirmed from observed interference in one of the study wells in phyllite rock formation of Udaipur.

ESTIMATION OF HYDRAULIC CHARACTERISTICS OF ANISOTROPIC ALLUVIAL AQUIFERS FROM ELECTRICAL RESISTIVITY DATA

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As groundwater becomes more important as a source of uncontaminated water, methods of locating and evaluating the parameters of aquifer must become more efficient. In past several attempts have been made to establish relations between hydraulic and electrical properties of aquifers. In the present work, the applicability of recently developed geophysical techniques has been examined for evaluation of aquifer properties like transmissivity and hydraulic conductivity of alluvial anisortropic aquifers of Roorkee area, Distt. Haridwar, India.

In this study, the available pumping test data for eight tubewell sites around Roorkee was reinterpreted by using different methods for obtaining the aquifer characteristics. The transmissivity obtained from the analysis of pumping test data range from 96 to 2389 m^2/day. Further, the available data of 18 vertical electrical soundings (VES) in the vicinity of the sites of pumping tests has been analysed by a Direct method given by Zohdy (1989) and the layer parameters (true resistivities and thicknesses) were determined for each site.

In accordance with the approach suggested by Sri Niwas and Singhal the resistivity and transverse resistance of the unconfined aquifer for each well were modified by using a modification factor, which is the ratio of the average aquifer water resistivity (δ_w) and the aquifer water resistivity (δ_w) at a particular location.

In the present study, three types of relations were established from the available results.

(i) Relation between hydraulic conductivity and formation factor.

(ii) Relation between hydraulic conductivity and a modified aquifer resistivity.

(iii) Relation between transmissivity and transverse resistance.

It is also found that though the aquifers in the study area have a wide range of hydraulic anisotropy, the direct relation between the modified transverse resistance of the aquifer and the aquifer transmissivity is still valid, thus confirming the findings.

It can be concluded from the above study that in an alluvial area where exploration for groundwater is

carried out using surface geoelectrical measurements, we can also estimate transmissivity of aquifers without much additional efforts and inputs, by using the above approaches.

GROUNDWATER-SURFACE WATER INTERMIXING MODEL AND RECHARGE CONDITIONS IN DELHI AREA AS DERIVED FROM $\delta^{18}O$ AND δD

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The data on oxygen-18 and deuterium content in Delhi groundwater show a wide range and indicate that a selection effect in favour of water depleted in stable isotope plays an important role in recharging groundwater adjacent to canal and river. Wide range of stable isotope composition of rainfall in the area and inhomogeneity of the rainfall recharge to the groundwater, as well as mixing of water through different flow paths result in spatial variation in stable isotope content of groundwater. By adopting a very simplified model of equal flow through the screens to the well with depth the isotopic gradient with depth has been determind. This simple model on depth variation of stable isotopic content in groundwater indicates contribution of canal water and river water to the groundwater to a considerable depth of the aquifer system. There is a large variation in salinity of groundwater. There is an isotope and chloride content gradient in the upper shallow groundwater because of evaporation. Salinity of deep groundwater seem to be caused due to diffusion of water from shallow aquifers.

SOIL GAS AND GROUNDWATER RADON ANOMALIES ASSOCIATED WITH EARTHQUAKE

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A significant increases in radon concentrain of soil gas and ground water were observed at station Amritsar before the earthquake occurred. Between November, 1990 and March, 1991, the three earthquakes were recorded with magnitude > 4.0 and with epicenter about 400-500 km of the monitoring site. The radon levels increased by 80-120% and then started to decrease before the earthquake. In soil, these features were recorded by continuous radon monitor (silicon diffused junction detector) and discrete measurements [ZnS (Ag) detector] and in groundwater were observed with ZnS(Ag) scintillation detector. The anomalous radon increases were independent of meteorological conditions and appeared to be caused by strain changes, which precede the earthquake.

DEVELOPMENT OF DRINKING WATER SOURCE FOR VILLAGE JANJALA TALUKA SILLOD BY UNCONVENTIONAL METHOD

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In many areas of Deccan Province the adverse hydrogeological conditions are not conducive to support the conventional measures of drinking water. Moreover the problem of drinking water is aggravated as bulk of precipitation goes in the form of run-off and as base flow in the form of spring in hilly and dissected terrain.

Village Janjala from Sillod Taluka of Aurangabad District, is one such hard core village located on isolated plateau and can be described as "Inland Island" on Ajanta hill range. Here, during post monsoon period, year after year the villagers fetch drinking water from some springs located in the valleys.

To alleviate the problem two borewells were drilled during the year 1984-85, however the problem could not be eased out duc to poor yield and deep water levels. A pipe water supply scheme was proposed, to tackle the drinking water problem but due to high per capita cost, it was not viable.

The problem of village Janjala was again entrusted to G.S.D.A. to consider the possibility of unconventional measures for augmenting the Groundwater.

After carrying out the detailed hydrogeological study, the unconventional measures have been suggested to conserve the subsurface run-off by spring and to develop the aquifer system suitably, to provide adequate drinking water to the village. The methodology was successfully executed during February and March 1992.

WATER RESOURCE EVALUATION OF KOVIL AR SUB-BASIN, HARUR TALUK, DHARMAPURI DISTRICT, TAMIL NADU

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Geological, geomorphological and geophysical investigations have been carried out in the Kovil Ar sub-basin, Dharmpuri District of Tamil Nadu for the purpose of water resource evaluation.

The area has temperate climate with a moderate rainfall from NE and SW monsoon. The formations of the area belong to the Archeans with granite gneisses, amphibolite gneisses, hornblend gneisses, charnockites and schists. The formations have been deformed leading to the development of intense local jointing. The basin exhibits geomorphic features such as bazadas, inselburgs, pediments, plateaus and ridges and escarpments. Detailed drainage analysis has been carried out.

Geophysical studies using Wenner array has led to the recognition of different zones of varying thickness and varying degrees of water saturation. Hydrogeochemical studies have shown that the groundwater to be of suitable quality and fit for agricultural and domestic use.

Water balance computations have shown that during seven months there is a soil moisture deficit and at five wet months the rainfall exceeds evaporation.

The collective consideration of the results were used to delineate potential sites for water exploitation. The sites are characterized by the presence of schistose and gneissic formations with frequent exhibition of landforms such as bazadas and pediments.

The study has shown the specific rock types and geomorphic expressions can be advantageously used in this area for groundwater prospecting. It is suggested that check dams may be constructed at suitable sites which will enhance groundwater potential by serving as the artificial recharge points.

STREAM-AQUIFER INTERACTION WITH RECHARGE

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Discharge in a river may come from four sources: (1) Surface flow; (2) inter flow; (3) bank flow, and (4) base flow, or the contribution from ground water storage. Base flow is the net flow to the river from the free-aquifer ground water storage which may be affected by recharge from precipitation, canal and field seepage, upward leakage from underlying aquifers and depletion from pumping, evapotranspiration and downward leakage. A better understanding of base flow can help in controlling irrigation withdrawals during low flow periods, making water supply estimates and forecast, and determining storage requirements for maintenance of adequate flow for waste dilution. The hydrograph of ground water depletion is important in a region that receives nearly all of its precipitation in a rainy season, after which ground water provides nearly all of the river flow.

A variety of analytical solutions are available for saturated and unsaturated flow. Unfortunately, many of the governing equations are non-linear and the auxiliary conditions of most natural systems are extremely complicated. For such situation exact analytical solutions are not available and resource is made to the use of numerical methods of approximation for the solution of differential equation. In this study solution of the problem of stream-aquifer interaction with recharge/abstraction has been obtained. Numerical solution of Business equation has been obtained by using predictor-corrector approach. The model has been calibrated for the observed discharges of river for a year. The observed piezometric levels and water levels of observation wells on either side of discharge/gauge observation site of the river have been used for calibration of the model. The model calibration is done by adjusting monthwide and reachwise net recharge/abstraction, hydraulic conductivity and the value of ratio of aquifer length and thickness. Dimensionless discharge and piezometric heads on either side of the river have been calculated and plotted for various values of aquifer length, thickness and permeability and recharge/abstraction. The effect of various parameters on the discharge and rate of change of water table position have been studied.

ESTIMATION OF SEEPAGE LOSS FROM GANDAK CANAL IN UTTAR PRADESH BY USING TACER TECHNIQUE

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Seepage is a natural process of flow of water from higher potential to lower potential. Among the various factors which influences seepage from canal, the most important are the boundary conditions of the flow domain and permeability of the material comprising the flow domain. But it is very difficult to determine the co-efficient of permeability insitu, accurately. Therefore, in order to avoid the estimation of permeability, nuclear technique has been used in recent years to estimate seepage loss from water bodies.

The seepage factor from canal plays an important role in ground water budgetting in any area. Heavy seepage may also cause water logging in near by areas. By keeping this in view, a series of experiments were conducted along Gandak canal and its branches in the unlined portion.

The result obtained are very surprising i.e. the value of seepage ranges from 0.876 to 3.645 cusec per million sq. feet of wetted perimeter, which is quite lower than the seepage value adopted at present in water balance study i.e. 6 to 8 cusec per million sq. feet of wetted perimeter.

ESTIMATION OF CANAL SEEPAGE IN A LAYERED POROUS MEDIA USING BOUNDARY ELEMENT METHOD

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The major problems with any canal system are the water loss and water logging due to the seepage effect. So estimation of seepage from canals into the adjoining porous media is very important in the canal design and efficient utilization of the available water. Here, boundary element method is used to estimate the steady state seepage losses from a canal in to the adjacent porous media.

Seepage losses from canals can be estimated either directly as in inflow-outflow techniques, ponding method, tracer techniques etc. or be predicted as in analytical solutions, flow nets, electrical analogs and numerical methods like finite difference, finite elements and boundary elements methods. In boundary element method (BEM), the differential equation which governs the seepage flow is transformed into a form of boundary integral equations so that the dimensionality of the problem reduces by one.

The case studies conducted have been described in this paper which showed that the boundary element method can be effectively used to solve seepage losses from canals by using the definite advantages of BEM. The model was compared with finite element method and found to be satisfactory.
