GROUNDWATER AND CONJUNCTIVE USE

G.C. Mishra* & S.K. Singh**

Although the total amount of water on earth is generally assumed to have remained virtually constant, the rapid growth of population, together with the extension of irrigated agriculture and industrial development, is stressing the quantity and quality aspects of the natural system. Because of the increasing problems, man has begun to realize that he can no longer follow a "use and discard" philosophy-either with water resources or any other natural resource- As a result, the need for a consistent policy of rational management of water resources has become evident.

Groundwater is often referred to as the "hidden" component of the hydrological cycle. It is not directly observable, and its existence and characteristics can only be inferred with some degree of uncertainty. But in many areas the groundwater resources is huge, and its occurrence and hydrological significance cannot be neglected in water management and planning.

However, in response to the increased demands for water, the surface water resources have now become more fully developed particularly in arid areas where the surface water in general is less abundant. This has stimulated the interest in exploiting the groundwater resources and the conjunctive use of the two water bodies. Apart from the constraints which the uncertain knowledge of the groundwater system may impose on exploitation schemes, groundwater has some obvious advantages over surface water: better protection against pollution; little treatment reuired before diversion to user; constant temperature small distances between source and user; and a fairly steady supply due to large storage capacities. These advantages have stimulated the interest in exploiting the groundwater resources and its conjunctive use with surface water.

Development of groundwater systems implies pumping, and in order to design an appropriate pumping scheme the hydrological conditions must the basis for evaluating the pumping strategy under considerations to the recharge capability of the system and the possible adverse effects. The hydrogeological information is primarily obtained from measurements in pumping and observation wells. Since the number of observation points always is limited, the available fragmental information has to be interpolated in time and space in a consistent and reliable way. A mathematical model of the system is equipped to do this by compiling the available information and interpretations in a consistent way The model enables quantitative predictions of the effects of alternative pumping schems and can hereby help to improve the basis for management decisions.

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*Scientist 'F', National Institute of Hydrology, Roorkee-247 667 (UP)
**Scientist 'B', National Institute of Hydrology, Roorkee-247 667 (UP)

Groundwater hydrology has in the last decade emerged from a geological and hydraulic related discipline to an interdisciplinary environmentl science as a result of the widespread deterioration of the groundwater quality by toxic chemicals. Such problems also involve chemistry and microbiology.

Losses from irrigation schemes to groundwater are often significant. In a typical scheme, as much as 50% of the water released from the reservoir is lost to the groundwater. These losses occur in the canals and distributories as well as in the fields. Conjunctive use appears to be a realistic approach to the efficient use of the water. If the water lost from the conveyance system and agricultural field is pumped from the aquifer and supplement the canal water for irrigation, high overall efficiencies could be obtained.

The problem of selecting the best strategy for conjunctive use of surface and ground water in a complex system where confliciting interests compete for limited natural and financial resources can be solved by System Approach. Therefore, the System Approach should increasingly be used to solve various problems associated with conjunctive use planning. Basically the problems are solved in two framework: optimization and simulations.

Indian contribution to the research in the area of groundwater and conjunctive use is given below.

Verma, A.P. (1970) have analytically discussed a theoretical model of groundwater replenishment in a cracked porous medium, with simultaneous occrrence of the phenomena of fingering and imbibition under certain conditions. It is assumed that the injection of water bodies is initiated by imibition, and the 'injected' and 'native' water form two immiscible liquid phases of different salinities with small viscosity difference (Bear and Martin, 1965). If only the average behaviour of fingering is considered, the nonlinear differential equation can be solved by a perturbation technique. An expression for the average cross-sectional area occupied by fingers has been obtained.

Verma, R.D. and W.Brutsaart (1970) have developed a numerical scheme to analyze a two-dimensional unconfined aquifer of rectangular cross section to determine the fall of the water table and the rate of outflow into an adjoining stream, which fully penetrates the aquifer. The main feature of this study is that the capillary flow above the water table is considered through the use of Richard's equation in the analysis. The mathematical formulation of the problem has been presented together with the results of the numerical analysis. Furthermore, because attempts were made to use the numerical schemes by Rubin and Taylor and Lutin and also some other commonly known finite difference methods for the solution of nonlinear parabolic partial differential equations, a brief analysis has been given on the difficulties and limitations inherent in these numerical methods.

Pal, Raj and M.P. Gupta (1970) have evaluated the second order phenomenological coefficients in soil-water-heat system as suggested by Srivastava and Abrol and have reported the discrepancies.

Verma, R.D. and W. Brutsaart (1971) have studied the unsteady free surface groundwater seepage. The results of their study show that: In the numerical soltuions of two dimensional saturated flow in a porous material, the position a moving free surface can be accurately predicted by means of Kirkham and Gaskell's foraward finite difference equation. However, the finite difference approximations of hydraulic gradients at the true surface must be determined very accurately to obtain adequate results. A Hele-Show model can be used to investigate a two dimensional saturated flow problems for predicting the position of the moving free surface line. It is especially useful when mathematical formaulation may be difficult due to irregular geometry of the aquifer.

Rajpal and M.P. Gupta (1971) have studied the nonlinear thermodynamic theory as applied to soil-water-heat system. The discrepancies of the theory proposed by Taylor and Carry have been examined and reported.

Adyalkar, P.G. and V.V.S. Mani (1972) have made an attempt based on Thiem's equilibrium formula to arrive at an empirical factor for the determination of transmissibility. Multiplying such factor by the specific capacity values of the wells tested gives an average value for transmissibility for unconfined water-table aquifer conditions in trappean terrains. Suitability of this method with particular reference to poorly permeable water-table aquifer in trappean tracts of Maharastra has also been discussed.

Adyalkar, P.G. and V.V.S. Mani (1974) have presented the analysis of pumptest data of openwells in a basaltic water table aquifer using methods based on both equilibrium and non-equilibrium formulae. It has been observed that the Thiem's equilibrium formula and the ratio method of Narasimhan appear to be more suitable as compared with Jacob's and Chow's methods. The Narsimhan's ratio method, which does not require the graphical procedure, is more reliable than the Thiem's method, since the latter involves an assumption of the value for the radius of influence. Once the value of transmissivity is obtained using Narsimhan's method, the radius of influence can be determined using Thiem's formula, which is useful in designing the distance between two wells so as to obviate mutual interference.

Sharma, S.N.P. (1974) has derived the expressions for discharge and drawdown in case of a partially penetrating multiple-well system in a confined aquifer under steady state conditions, using theory of images and principle of superposition. Equations have been derived for the discharge in the well and the drawdown at an intermediate point for several well groups with same drawdown in each individual well for the following cases, viz., a) the well being fed from a line source; b) the well away placed in a semi-infinite strip with both longitudinal sides forming potential boundaries; and c) a semi-infinite strip with potential boundary along one longitudinal side, and an impermeable boudary along the other. Equations have also been deduced for drawdown factors for a few cases of well groups in special aray with circular or straight live recharge boundary under conditions of equal discharge in each individual well. General expressions for the penetration factor, applicable for a well in the presence of an infinite line source have been suggested. The analytical results derived are in agreement with experimental results obtained by electric analog and those obtained by equivalent ditch approach.

Saksena, R.S., S. Chandara and B.P. Singh (1974) have presented a gamma transmission method for the determination of moisture content in soils. Soil samples up to 164 m depth have been studied with respect to the linear attenuation coefficient and the mass absorption coefficient for gamma rays and their variation with moisture content.

The variation of gamma counting rate with moisture for different thicknesses of strata and reaction of clay samples have also been dicussed. It has been suggested that the statification can also be determined by this method along with the density of the soils in the various strata.

Sagar, B. et al. (1975) have developed a model to solve the inverse problem. The method does not require the iterative solution of the aquifer equation, which is an essential characteristic of many identification schemes. The shape of the surface representing the observed dependent variables (which may be hydraulic head, chemical concentration, or temperature) is approximated from measured samples by means of various interpolation algorithms. Once the various derivatives of the dependent variable are approximated, the identification problem reduces locally to algebraic equations of small dimension. It has been shown that aquifer conditions of general heterogeneity and amisotropy are amenable to this method. Input may be treated as an unknown to be evaluated. The method is appraised by application to scattered solution points of a simulated solution to a non-homogeneous aquifer equation.

Bardhan, M. (1975) has integrated nuclear approach involving conjunctive application of gamma-gamma and neutran - neutran depth gauges and a strong neutran - absorbent tracer, namely boron, to locate the source and the sink zones supporting vertical groundwater flow as well as to quantify the flow volume in uncased sub-artesian bore-wells sunk in trappean terrain. The results have been utilized in calculating the seepage loss from the saturated zone into unsaturated zone through the well bore, which in turn aided in decision making relating to the design of production wells in the study area.

Abdulkhader, M.H. and M.K. Veerankutty (1975) have derived the equations for transient flow to a well penetrating two aquifers, i.e., a water table aquifer overlaying a confined aquifer. Two cases have been considered for the analysis. In the first case flow towards a well of zero discharge with different initial heads, and in the second case a well penetrating two aquifer with a constant discharge and identical initial heads, have been considered. Schapery's method of inversion for Laplace transform have been used and the solutions for the two cases have been combined to obtain general solutions for different field conditions. From the equations derived, it is also possible to calculate the contributions from indivial aquifers to the total discharge.

Srivastava, R.C., A.K. Jain and S.K. Upadhyay (1975) have conducted experiments for water flow measurements through mixtures of various compositions of keolinite and bentonite clays. The data have revealed an interrelationship among the hydroulic conductivity of clay mixtures, hydraulic conductivities of the constituent clays and the composition of the mixtures.

Sukhija, B.S. and C.R. Shah (1976) have evaluated groundwater recharge to unconfined and confined aquifers using environmental tritium profiles observed over an interval of two years in a semi-arid region of western India. The recharge rate determined for confined aquifers (11% of local rainfall) for a part of selected area using a diffusion type unsteady groundwater flow model has been found to compare well with that determined using tritium method. The tritium method wherever applicable has the advantage of being direct, fast, economical and does not require much hydrological data.

Singh, S.R. and C.M. Jacob (1976) have obtained finite difference solutions of the Boussinesq equation using an extrapolated Crank-Nicolson difference scheme. Arbitrary patterns of recharge and withdrawal and initial and boudnary conditions have been incorporated in the scheme. The scheme requires the solution of only one system of linear algebraic equations to mach the solution by a dimensionless time step and therefore, is more efficient than the predictor-corrector analog. As an example, a problem of groundwater flow through phreatic aquifers lying between two perennial canals have been simulated using the extrapolated Crank-Nicolson scheme. Generalized travelling wave solution of the Bousinesq equation with source and sink terms have been developed. The finite difference solution is compared with a travelling wave solution. The difference between these two solutions is found to be negligible; therefore the accuracy of the extrapolated Crank-Nicolson scheme for the Boussinesq equation is confirmed.

Vappicha, V.N. and S.H. Nagraja (1976) have employed quasi-steady state analysis for predicting the interface movement in a coastal aquifer under various boundary conditions. The basic equation which is a nonlinear partial differential equation has been simplified as an ordinary differential equation of first order using quasi-steady state analysis. The equation has been solved analytically and numerically for three different boundary conditions. The solution has been compared with experimental results from a viscous flow analog model. This method is approximate but simple for rough estimate of the rate of movement of the interface and the length of intusion.

Basak, P. and V.V.N. Murty (1977) have presented an analytical solution to the problem of concentration dependent diffusion with increasing concentration at the source. This solution is of travelling wave type and is applied to predict the contamination in an aquifer from a source wherein the concentration is increasing with time.

Singh, S.R. and C.M. Jacob (1977) have studied the transient analysis of phreatic aquifers laying between two open channels using a transformation for the linearization of Boussinesq equation and have obtained the analytical solution of this linearized equation which is in the form of Fokker Plank equation. They have studied the dynamic behaviour of two dimensional groundwater basins (laying between two open channels, i.e., a) constant water level boundaries and b) variable water level boundaries) subjected to constant and variable rate of recharge and withdrawals. The variable rates of recharge and withdrawals have been approximated by periodic step functions, which represents two different rates of recharge and withdrawals, one each for rainy and dry seasons. The analytical solutions of the linearized Boussinesq equation, thus obtained, compares well with the finite difference solutions of the Boussinesq equation.

Singh, S.R. and B.Sagar (1977) have evolved a method for computing aquifer diffusivity in stream aquifer system. The Boussinesq equation has been chosen as a mathematical model to describe the response of a rising stream on the water level in the aquifer. The rising water level has been chosen because Dupuit's assumptions are more likely to hold during this stage. The explicit solutions for the aquifer diffusivity in stream-aquifer system have been developed by overspecifying the boundary data and using the Green's function of the differential equation. Four types of stream stage hydrographs, i.e., linearly rising water level, exponentially rising water level, water level represented by a sinusoid, and hydrograph approximated by cubic splines, have been analyzed. Stream-aquifer data observed in a sand tank model have been analyzed to determine aquifer diffusivity.

Singh, B.P. and S. Chandra (1977) have given the procedure for the analysis of experimental data for evaluation of the optimal thickness of soil between source and detector, in gamma-ray transmission method. A factor has been introduced and evaluated in the soil-water system which gives the optimum value of thickness of soil, of a better accuracy, in the gamma-ray transmission method.

Basak, P. (1977) has presented a steady state analytical solution for the case of non penetrating wells in a semi-infinite medium incorporating Forchheimers's non-linear velocity gradient response ($i = av + bv^2$). The solution has been compared with the available solution for Darcian linear flow. The effect of nonlinearity in the flow response, on the discharge characteristics and piecometric pressure distribution, in relation to the corresponding linear case has also been given.

Choudhury, P.K. and B. Anjaneyulu (1978) have experimently investigated the recharge from partially penetrating wells in a leaky aquifer. They conducted experiments on a sand model simulating a leaky artesian aquifer underlying an confined aquifer. The unconfined aquifer in the model was overlain by top soil which was kept ponded to simulate the waterlogged condition. The recharge characteristics of a well partially penetrating the leaky artesian aquifer have been studied under different conditions and empirical equations have been proposed for predicting the recharge rates.

Basak P. and M.R. Madhav (1978) have analyzed the effect of inertial forces on the one-dimensional fluid flow in deformable prorous media caused by a sudden increase in external stress, using analytical approach. The solution shows that the presence of an iniertial force leads to higher excess piezometric pressure and a slower subsidence rate in the early stages. However, in terms of magnitude, the effect seems to be insignificant.

Abdulkhader, M.H. and D. Ramadurgaiah (1978) have obtained a theoretical solution for transient and steady state flow to the problem of artesian well flow taking into consideration the partial penetration of well and the finitenes of its radius. The aquifer has been assumed to be homogeneous, anisotropic, confined between horizontal, impervious boundaries and bounded laterally by a recharge boundary of uniform radius.

Chowdhury, P.K., S.K. Shakya and B. Anjaneyulu (1978) have developed analytical solutions for predicting the rate of recharge through a well in a leaky artesian aquifer overlain by an unconfined aquifer of limited areal extent. The ground surface has been considered to be waterlogged. Solution to the basic steady-state differential equation has been presented. The solution can be used to compute the recharge rate on the basis of aquifer characteristics and the steady infiltration rate of the soil.

Basak, P. (1978) has derived the steady state analytical solutions to the problems of fully penetrating and non penetrating wells, incorporating the concepts of the existence of non-Darcy flow regime around the well and a Darcian flow regime away from the well. The exact distances to which the non-Darcy flow extends, have been given. The consequences of neglecting non-Darcy flow regime around the well, in the estimation of piezometric heads and discharges (or flux) have been discussed.

Ramarao, B.S. and R.N. Das (1978) have studied non-Darcy seepage to a fully penetrating well in an unconfined aquifer based on Forchheimer's non-linear seepage law using finite element method. They have considered two type of problems; a) entire seepage domain around the well is assumed to experience non-Darcy flow b) the seepage domain close to the well is assumed to have non-Darcy flow, with the rest of the domain having Darcy flow. A quantitative appraisal is made of the difference between Darcy and non-Darcy flow conditions in relation to the discharge into the well, the form of the free surface, the potential and potential gradient in the flow domain.

Sondhi, S.K. and S.R. Singh (1978) have obtained an analytical solution to determine unconfined aquifer parameters by conducting pump-tests on partially penetrating wells. The aquifer has been assumed to be homogeneous, isotropic and infinite in areal extent. A concept of 'effective penetration' has been developed to find the effective penetration of the well. The applicability of the relationships developed has been verified using a circular sand tank model.

Soni, J.P., N. Islam and P. Basak (1978) have carried out experimental investigation to study the factor influencing the coefficients M and n of the commonly used non-Darcy flow relation $v=Mi^n$. The average value of n has been observed to be 1.8, 1.0 and 0.5 in the prelinear, linear and postlinear ranges respectively, when the gradients are varied from 0.13 to 61.2, and it has been found to be almost independent of the grain diameter. For the same size of material n decreases with increase in diameter, the rate of decrease being greater in the prelinear regime compared to the post linear regime. The coefficient M has been found to increase with increase in diameter and porosity of the aquifer matrix.

Bose, R.N. and T.S. Ramakrishna (1978) have presented the results of electrical-resistivity surveys carried out to guide the shallow tube-well drilling programme aimed at alleviating the drinking water scarcity in the drought-stricken villages in parts of Sangli district, Maharashtra. The results show that a combination of resistivity sounding and profiling is more effective in tackling problems for the location of wells in Deccan trap country. The indispensibility of resestivity profiling for detecting a shallow source of groundwater in fractured/ fissered zones in basaltic trap has been highlighted.

Basak, P. and V.V.N. Murty (1978) have given an analytical solution for the prediction of spread of contaminant caused by nonlinear diffusion in an aquifer adjoining a polluted source. The solution is based on the assumption of the existence of a sharp diffusion front and is similar to the solution of a two dimensional unsaturated flow problem. The effect of concentration dependency of the diffusion coefficient, on the contamination spread have been discussed.

Lakshminarayana, V. and S.P. Rajagopalan (1978) have obtanied a digital model solution for the unsteady state radial flow to a partially penetrating well pumping at a constant rate from an unconfined anisotropic aquifer using iterative alternating-direction implicit scheme. They have analyzed the field aquifer test data in unconfined aquifers to evaluate the lateral permeability, vertical permeability, specific storage and specific yield of the aquifer using their digital model. The advantages of a digital simulation approach in the analysis of aquifer test data have been highlighted as often fewer observation wells are needed, thereby economising on the aquifer-test expenditure. and that the more complex geology can be handled.

Lakshminarayana, V. and S.P. Rajagopalan (1978) have obtained a numerical solution for the unsteady-state radial flow to partially penetrating wells at a constant rate from an unconfined anisotropic aquifer, using an interative alternating-direction implicit scheme. These solutions have been used to generate a series of type curves valid for individual aquifer-test situations.

Jaiswal, C.S. and H.S. Chauhan (1978) have analyzed the flow to a flowing nonpenetrating well in a leaky artesian aquifer and have suggested a method to determine the aquifer parameters using the pump-test data on such wells with constant drawdown in the well. A technique has also been suggested to determine the aquifer parameters using the well itself as the observation well.

Jaiswal, C.S. and H.S. Chauhan (1978) have presented a general solution for nonsteady state, axisymmetric radial flow to a nonpenetrating well in leaky artesian aquifer with a general time variable discharge function, as well as for the specific case of exponential decay discharge function.

Basak. P and V.V.N. Murty (1978) have given an analytical solution to the problem of concentration-dependant diffusion with decreasing concentration at the source. The solution has been nondimensionalised and can be used to predict the contamination in a aquifer from a source in which the contamination concentration decreases with time.

Sagar B. and S.R. Singh (1979) have described the flow in a semi-infinite aquifer with a fully penetrating stream at its boudary using the linearized Boussinesq equation. The recorded stream hydrograph and the computed hydraulic gradient at the boundary have been assumed to be corrupted with Gaussian noise. The aquifer diffusivity has then been found to be given by the ratio of squares of two Normal random variables. The mean and the standard deviation of the diffusivity have been computed for various levels of errors in the boundary data. It has been observed that the mean value of the diffusivity is a function of the errors in data and increases with increasing errors. The increas in the mean diffusivity, however, is not of as much significance as the increase in the standard deviation, which increases at a much faster rate with increasing errors. Any significant increase in the standard deviation would reduce the confidence in the computed diffusivity value. Based on the acceptable value of standard deviation in the diffusivity, one can, therefore, stipulate bounds on permissible errors in data.

Murali, V., G.S.R. Krishnamurti and A.K. Sinha (1979) have developed statistical relationships of water flow parameters with two sets of soil characteristics, viz., hydraulic conductivity and soil water diffusivity. The matrix properties of soils, i.e., sand, silt, clay, organic matter and free iron oxides, were found to have a great influence on the soil water diffusivity and the hydraulic conductivity over a wide range of moisture levels. Among the aggregating agents, the free iron oxides which induce formation of smaller aggregates had inverse relations with the water flow parameters, while organic matter which supports larger aggregates had the opposite effect. Pore-size distribution also had strong influence on water flow phenomena in the soils studied.

Basak, P. (1979), have investigated analytically the problem of transient water table between two parallel ditches subjected to a uniform recharge. A closed farm solution of the Boussinesq equation with recharge term, which is a nonlinear partial differential equation, has been obtained.

Jagannadh Sarma, V.V. et al. (1979) have made a regular monthly inventory of water-level height and water quality of about 100 wells along the coast from Visakhapatnam to Bhimilipatnam for a 13 month period during 1974-1975. The electrical conductivity of water has been found to vary with seasonal water-level fluctuations, but the variation has two different pattern; first pattern is that when water level lowers, the electrical conductivity decreases and the second pattern is that when water level lower the electrical conductivity increases, while the geological environment being the same for both the cases.

Madhav, M.R. and P. Basak (1979) have presented an analytical solution for the problem of time rate of subsidence and piezometric pressure distribution caused by a sudden increase in the effective stress due to an instantaneous lowering of the groundwater table in an aquifer aquitard- aquiclude system of finite thickness, obeying a nonlinear flow low of the type $v = Mi^n$. Unlike for Darcian flow the degree of subsidence and the non-dimensional pore pressure distribution have been found to be independent of both the amount of ground water fall and the thickness of the deforming porous medium.

Panikar, J.T. and G. Nanjappa (1979) have found that the suction head at the wet front, is the important information that is needed in the use of Green-Ampt equation. Mein and Larson have defined S_{av} for this purpose. The vaidity of this equation has been discussed and the suction head at the wet front has been redefined. The conditions favourable for the application of the Mein-Larson model have also been identified.

Basak, P. and V.V.N. Murty (1979) have obtained explicit analytical expressions for the determination of the value of hydrodynamic dispension coefficient in one-dimensional transport problems using 'inverfc' function. These expressions provide a method for quick and exact determination of hydrodynamic dispersion coefficients with data obtained at any arbitrary experimental point. This method thus avoids the need of obtaining the entire breakthrough curve.

Basak, P. and M.R. Madhav (1979) have presented three analytical solutions to the problems of transient non-Darcy drainage through trapezoidal embankments with a central impermeable core under certain simplified assumptions. The solutions show the effect of non-Darcian parameter, n, on the rate of drainage for various geometries of the embankments. The results have been compared with the known expressions for Darcian flow. For Darcian flow, a solution for the problem with inclined central core and partial drawdown has also been reported.

Singh, R.N. and S.N. Rai (1980) have obtained an approximate closed form solution of the Boussinesq, non-linear parabolic equation for a time-varying recharge. The salient aspects of the solution have been illustrated with the help of a typical numerical example. It has been shown that for unit vlaue of a non-dimensional recharge parameter, the water table profile is a function of time, whereas, in the uniform recharge case it is independent of time.

Rao N.H. & P.B.S. Sarma (1980) have suggested a method to identify the extent of the ground-water mound using solutions of the equation of flow for finite aquifers. These solutions have been obtained using two different procedures of linearization, viz., after Baumann and Hantush, and laplace transforms. The resulting expressions are of general nature and the equations of Hantush for infinite aquifers were shown to follow as a special case. The range of validity of the two procedures of linearization has been tested using experimental results from sand tank models of finite aquifers, available in literature. The Hantush procedure has been shown to have wider applicability. However, both procedure have been found to yield results which have satisfactory agreement with experimental results. The effect of variation of the horizontal extent of the recharge mound on the water table profile has been studied by treating the limit of the horizontal mound itself as a parameter.

Athavale, R.N., C.S. Murti and R. Chand (1980) have measured the recharge to the phreatic aquifers in seven different geological formations of Lower Mahanadi Basin, A.P., using tritium tagging method. Variation in the tritium activity and moisture content with depth, in soil profiles have been measured for estimation of tracer movement and calculation of recharge. The total annual recharge to the phreatic aquifers for the basin have been reported as $152 \times 10^6 \pm 15 \times 10^6$ m^3 which is approximately 8% of the average annual rainfall over the basin. The reproducibility of recharge using tritium injection techqnique has been found to be within ± 10% The recharge values have been corrected with local water table fluctuations and with the sand content of the soil and finally compared with those obtained through hydrogeological studies.

Verma R.K., M.K. Rao and C.V. Rao (1980) have used electrical resistivity method for ground-water investigations in a number of areas underlain by metamorphic rocks around Dhanbad. The Schlumberger configuration has been mainly used for resistivity soroundrings, with maximum distance between current, electrodes, of the order of 300 m.. Mostly A or H type of sounding curves have been obtained. The results of geoelectric soundings have been compared with the geological sections wherever available. It has been found that the thickness of the weathered layer as deduced from Schlumberger soundings, include partly the unweathered/fractured layer as well. An attempt has been made to find an empirical relationship between the daily yield of water in gallon/day and the longitudinal conductance of the weathered layer. Two empirical relationships have been obtained, one for the winter months, December-January and the other for the summer months, June-July. A suitable explanation for the two curves has been given.

Deolanker, S.B. (1980) has studied the potential of Deccan basalts of Maharastra as aquifers. The specific yield of Deccan basalts has been found to vary from 1 to 7 % with the maximum value being obtained in weathered basalt. The effective porosity of Deccan basalts has been reported to be less then 10%. Therefore, it has been concluded that the Deccan traps are hydrogeologically anisotropic and heterogeneous in nature and the aquifers are of limited extent, suggesting the localized accumulations of groundwater.

Radhakrishna, I. and T. Venkateswarlu (1980) have demonstrated that non-equilibrium formulae can be applied to hard-rock regions depending upon the stage of hydrological regime and the vertical leakage in the system. A comparative examination of results obtained by different methods, has helped in dilineating the boundary conditions, long term withdrawal effects and well spacing problems in the Sukhinda valley of Orissa.

Gupta, S.K. and S.R. Singh (1980) have developed analytical solutions to the dispersion-convection equation for leaching of saline soils under exponentially decreasing, and arbitrary initial salt profile. The soil profiles have been considered semi-infinite and homogeneous. An other solution incorporating an exponentially decreasing time-varying boundary condition at this surface have been developed. It has been found that the effect of time-varying boundary condition is neglibible for most prectical purposes at or below 15 cm depth of the soil profile.

Sharma, P.V.S, N.H. Rao and K.V.P. Rao (1980) have developed a computer programme to compute the daily evapotranspiration as a residue from the water balance equation. Moisture profiles from field observations of soil moisture tensions are used as an input into the model. The programme evaluates the effect of rainfall or irrigation during the periods of observation and also calculates the water loss from deep drainage. The additional features includes the procedures for the computation of infiltration and the moisture flow. The model has been applied to actual field data and the results are presented.

Elango, K. and K. Swaminathan (1980) have carried out the numerical simulation of the situation of concurrent confined and unconfined zones in a groundwater aquifer system using the finite-element method with four sided mixed-curved isoparametric elements. The model is limited to steady state and is based on Dupuit's assumptions. The results of the model for a test situation indicate that the model can be used for prediction of occurrence of unconfined regions around over-pumped wells in an originally confined aquifer, of which the interfaces between the confined and unconfined regions may be estimated.

Rao, N.H. and P.B.S. Sharma (1981) have obtained a generalized solution for the growth of groundwater mound in finite aquifers bounded by open water bodies, in response to recharge from rectangular areas. Finite Fourier transforms have been used to solve the linearized differential equation of groundwater flow. Unlike earlier solutions, this method requires the use of tables for evaluation of complicated functions. The solution is evaluated by comparison with existing numerical and analytical results. In stream-aquifer systems application of the proposed solution is more realistic than using solutions available for infinite aquifers.

Rao, N.H. and P.B.S. Sarma (1981) have derived an analytical expression for the formation of ground-water mounds on recharge from a rectangular area to a finite aquifer. The validity of the equation has been compared with the field data. The solution presented, describe the actual field response of water table to recharge, better than the equation derived for infinite aquifers.

Arora, C.L. and R.N. Bose (1981) have conducted the electrical method traverses in selected parts of the Abohar area in the Ferozepur district of Punjab, which have indicated prominent anomalies in the out of phase component, and resistivity traverses over these zones yielded lower resistivity values compared to those obtained in the zones where the EM profile is relatively flat. Thus the EM anomalies are attributable to the saline zones, and it has been suggested that the EM method can be effectively used for delineation of fresh and saline-water zones and resistivity-depth probing can then be resorted to, for quantitative estimation of thickness of fresh water bearing material in the areas of promise, thereby considerably reducing the duration and cost of an exploration programme.

Chander, S., P.N. Kapoor and S.K. Goyal (1981) have presented a method for estimating aquifer parameters from pump test data in nonleaky and leaky aquifers, using Marquardt algorithm. It has been found that inspite of the poor initial estimates, the convergence is quick.

Briz Kishore, B.H. and R.V.S.S. Avadhanulu (1981) have developed a generalized aquifer simulation program to handle problems connected with different kinds of complex groundwater systems on microprocessors. It has been found that using this program, the effect of pumping on an aquifer can be stuided for multiple pumping periods and predictions or observations can be scrutinized at various time-steps within each pumping period. This program can also handle conversion problems between confined and water table aquifers under leaky or nonleaky state along with the effects of evapotranspiration, constant recharge or discharge boundaries. The utility and the precision of the program have been tested using a sample problem quoted by Trescott et.al., (1976).

Briz-Kishore, B.H. and V.L.S. Bhimasankaram (1981) have analyzed the water level of wells in a typical weathered and fractured granitic environment of Shadnagar basin, Andhra Pradesh. The study has indicated that the hydraulic continuity and unity of groundwater flow systems in weathered and fractured granites, contrary to the conclusions of earlier workers. The long-term behaviour of hydrographs revealed that the basin is not over-developed and precipitation is only source of recharge to the ground-water system.

Rai, S.N. and R.N. Singh (1981) have presented a matheamtical model for water table fluctuation in an unconfined aquifer subjected to a typical localized transient recharge. The aquifer has been taken to be homogenous, isotropic, underlain by a horizontal impermeable base, and linked with a surface reservoir on one side. Sensivity characteristics of water table due to variation in the rate of recharge, hydraulic conductivity, and specific yield have been illustrated with the help of a numerical example.

The solution can be used in conjunction with the method of successive approximations for the prediction of future water levels. The solutions are applicable when the growth of water table is less than half of the initial depth of saturation.

Briz Kishore, B.H. and V.L.S. Bhimasankaram (1982) have utilized a battery of multilevel observation wells with a central pumping well located in a weathered and fractured medium understand the aquifer characteristics, the flow and the yields of ground water in a crystalline basement. The water levels in all the wells observed during drilling show a rise after drilling is completed. Fair continuity of the flow in the weathered and the underlying fractured system has been observed during periods of pumping and precipitation. A change in the configuration of the flow nets has also been noticed after a prolonged period of pumping due to the effect of surface drainage on the ground-water system.

Kashyap, D. and chandra S. (1982) have developed a numerical scheme to estimate quantitatively the parameters related to geohydrological and hydrological characteristics of groundwater aquifers, employing historic data of hydraulic head, rainfall, pumpage etc. The scheme is based upon the constrained minimization of the sum of the squares of the residues in the Boussinesq equation. Derivatives of hydraulic head are estimated by the least squares polynomial approximation.

Basak, P. (1982) has derived a closed form analytical solution for recovery in fully penetrating large diameter wells taping a confined aquifer. The analysis predicts exponential decreases of inflow rate, a transient logarithmic recovery response and an asymptotic increase of cumulative recovery with time. The solutions are also applicable for unconfined flow, under conditions of small drawdown. The results obtained indicate the validity of the theory in a wide range of geological aquifer formations.

Rao, N.H. and P.B.S. Sarma (1983) have solved the problem of groundwater recharge from strip basins to finite aquifers analytically by the method of finite Fourier transforms. Both impermeable and recharge boundaries have been considered. The analytical solutions have been compared with experimental results of sand tank models reported in the literature.

Rajgopalan, S.P.(1983) has developed a mathematical model for the analysis of recovery data in a large diameter well. It was assumed that the drawdonw in large diameter well is linearly related to the partial derivative of hydraulic head with respect to the radius along the well face, and approximate equations for the drawdown during recovery phase have been derived. Unlike Slitcher's (1906) formula the expressions derived by Rajgopalan takes care of the effect of variable discharges on the rate of recovery and hence, provides useful means of estimation of aquifer parameters from recovery data of large diameter wells.

Patel, S.C. and G.C. Mishra (1983) suggested that a discrete kernel approach is suitable for analysis of large diameter well tests, in this method, a varying withdrawal rate from the aquifer can be represented as a series of step values for uniform time increments. The aquifer withidrawal rate for each time increment is adjusted so, that, when it is combined with the release from the well storage, the total equals the pumping rate from the well . The temporal variation of drawdown has been obtained at the well and at a point in the aquifer. These variations of drawdown compare well with the drawdown given papadopulos and Cooper (1967). The kernel function method proposed by Patel and Mishra is simple and involves inversion of only a 2x2 matrix, while Papadoplos and cooper method requires numerical integration of a improper integral involving Bessel's function, which involves lengthy computations. The only draw back of this method is that the drawdown in the well has been assumed equal to the drawdown in the aquifer at the well face, i.e., no seepage face has been considered. This method can be used for both pumping and recovery phase.

Ruston K.R. and V.S. Singh (1983) have presented type curves using numerical approach for both, constant and variable abstraction rates from large diameter wells. The variation of well discharge was assumed to vary linearly with drawdown which may result in errors because discharge variations in the field may not be according to this assumption. However, it has been stated that the estimation of storage coefficient by this approach is not reliable.

Athavale, R.N., V.S. Singh and K. Subrahmanyam (1983) have designed constant discharge device for aquifer tests on large diameter wells.

Vardhan, K.M. and B. Raghunath (1983) have studied the soil moisture flux in humid tropical latosols under coconut. Soil moisture storage depends on the soil water diffusivity, the cumulative infiltration and the distance that water penetrates the soil. Field observations have been compared with those computed from meteorological variables. The field observations of soil moisture flux agree closely with computed values for wet periods of the year, while they differ significantly for dry periods. Modification have been attempted for the climatic computation by taking into account a lower moisture depletion rate for the dry period. Soil moisture indices have been calculated for the study period as a basis for irrigation management. The observed soil moisture varies from 17.0 to 25.0 cm and 6.8 to 12.8 cm per 75 cm depth of soil profile for wet and dry periods respectively.

Ballukraya, P.N., R. Sakthivadevel, and R. Baratan (1983) have analyzed, over eight hundred vertical electrical sounding (VES) curves from areas underlain by granitic gneisses (Peninsular gneiss of archaean age) of southern India and correlated with the lithological logs of borewells drilled at these sounding sites. Both Schlumberger and Wenner electrode configurations have been used to carry out vertical soundings and a direct current resistivity meter with a constant current source has been used. The depth of investigation for the purpose of estimating depth to aquifers from breaks in VES curves is taken as half the current electrode separation as practised in many empirical evaluation and this curve-break concept has been verified by examining 188 Schlumberger VES curves. The method can be applied with confidence for shallow investigations, generally up to about 50 m from ground surface. In highly heterogeneous hard rock areas, lateral inhonogeneities may cause or mask breaks and differentiating from these breaks becomes extremely difficult beyond a certain electrode separation.

Siyag, R.S., R. Pal, S.R. Poonia and T.C. Baruah (1983) have observed the effect of mixed cation solutions on hydraulic soil properties. The hydraulic conductivity (K) and soil water diffusivity (D) characterizing flow under saturated and unsaturated conditions, respectively have been determined for a sandy loam and a clay loam soil, using water with different combinations of total electrolyte concentrations, C (i.e. 20, 40, 80, 125 and 250 meg/l) and sodium adsorption ratio (SAR). It has been found that both K and D increases with C and decreases with SAR. For SAR < 20, requirement of electrolyte consentration to maintain relative hydraulic conductivity $= 0.5$ has been found relatively more for sandy loam than for clay loam soil. However, for SAR>20, the trend for electrolyte concentration requirement for the two soils has been found to be reversed. The reduction in K of these soils in relation to SAR is attributed to swelling, dispersion and migration of clay particles and consequently affect the pore size distribution. Both swelling and movement of clay particles cause blocking of water conducting pores and hence a decrease in K.

Kumar, N. (1983) have developed analytical solutions for the dispersion problem in non-adsorbing and adsorbing, semi-infinite porous media in which the flow is one dimensional and the average flow velocity is unsteady. The direct relationship of the dispersion coefficient with seepage velocity has been used to solve the unsteady dispersion flow problem by introducing a new time variable. The source concentration of the pollutant has been taken to vary exponentially with time. Owing to resistance in the flow, variation in seepage velocity with times has been considered. The analytical expressions obtained are useful to the study of saline intrusion problems and quantitative prediction of the possible contamination of groundwater.

Sukhija, B.S. and A.A. Rao (1983) have made environmental tritium and radio carbon studies in the Vadavati river basin situated partly in Karnataka and parthy in Andhra Pradesh. The determination of general recharge conditions of the water bearing zones in the gnessic complex, granite and Dharwar Group of metamorphic rocks where groundwater occurs under semi-unconfined to semi-confined conditions and at places under water table condition have been undertaken. Groundwater recharge was relatively high at the western, southern, and eastern boundaries of the Vadavati river basin. An excellent correlation has been found between the hydro-isochrones and groundwater recharge contours, and between groundwater ages and intensity and density of fractures.

Batta, R.K. and V.V.N. Murty (1983) have conducted experiments on undisturbed and disturbed samples to find the effect of medium disturbance on the hydrodynamic dispersion coefficient under laboratory and field conditions. A method to determine the dispersion coefficient uses finite differences; the values obtained with this method compare favourably with other existing methods. Disturbance of a sandy loam caused a reduction of the dispersion coefficient to approximately 0.6-0.8 of its insitu value. The dispersion coefficients for undisturbed samples for different sites vary significantly (range 0.0640 - 0.0799 sq.cm/min) while for the disturbed samples the variation is small (0.0470 - 0.0511 sq.cm/min); this may be attributed to better control of variables in the laboratory than in field experiments.

Rao, N.H. and P.B.S. Sarma (1984) have solved the problem of localized groundwater recharge from a strip basin to an aquifer bounded by a stream and impermeable boundaries using the extended finite Fourier transforms. The solution has been evaluated by comparison with the method of images and with numerical and experimental results. The existing expression for the inverse of the extended finite Fourier cosine transform have been corrected.

Singh, R., S.K. Sondhi, J.Singh and R.Kumar (1984) have used a groundwater simulation model to predict the dynamic behaviour of water table in response to groundwater pumpage and net recharge in a part of the Lower Ghaggar basin. During the last two decades, land use of the major portion of Ghaggar River basin in the Haryana State has been transformed from dry land agriculture to irrigated forming. The pumped water is proposed to be used together with canal water for irrigation of crops and for drinking water demands considering the quality constraints. The study has been conducted at the Farm of Haryana Agricultural University, an area of 1300 ha, to find management practices for controlled the rising water table.

Mishra, G.C. and A.G. Chachadi (1985) have extended the applicability of discrete kernal appraoch proposed by Patel and Mishra (1983) to the analysis of recovery phase of a large diameter well in a confined aquifer of infinite areal extent pumped, at a uniform rate up to a certain time. The drawdown in the well casing was assumed equal to the drawdown in the aquifer at the well face, i.e., seepage face has not been considered. Based on this approach a set of type curves have been provided using which a reliable estimate of aquifer parameters can be made.

Gupta, C.P., S. Ahmed and V.V.S. Gurunadha Rao (1985) have made a quantitative study of the conjunctive utilization of surface water and groundwater to arrest the water-level decline in the Daha region, northern India, using an interactive finite difference aquifer model. The system has been assumed to be a monostratum aquifer. The finite-difference form of the groundwater flow equation has been solved using a backward difference approximation and successive over-relaxation technique. The model was validated for steady and dynamic conditions by progressive modification of the model parameters.

Sridharan K., R. Ramaswamy and N.S. Lakshmanrao (1985) presented a method for the identification of parameters in unconfined aquifers from pumping tests, based on the optimization of the objective function using the least square approach. Four parameters have been evaluated, namely; the hydraulic conductivity in the radial and vertical directions, the storage coefficient and the specific yield. The sensitivity analysis have been used for solving optimization problem. Besides eleminating the subjectivity involved in the graphical procedure, the method takes into account the field data at all time intervals without classifying them into small and large time intervals and does not use the approximation that the ratio of the storage coefficient to specific yield tends to zero. The parameter estimates from the computational and graphical procedures differ significantly.

Gupta, C.P. and V.S. Singh (1985) have discussed the reliable estimate of aquifer parameters from pump-test data, considering the effect of incomplete recovery prior to the pump-test. They have observed that an appreciable aquifer response is observed only during recovery, thus, the data on the recovery phase of pump-test are necessary for the data analysis using the numerical method. Particularly, the later portion of the recovery phase is more important, as the effect of prepumping incomplete recovery is pronounced in this portion only.

Mishra, G.C., M.D. Nautiyal and S. Chandra (1985) have evolved a methodlogy to analyze unsteady flow to a multi-aquifer well tapping two aquifers separated by an aquiclude, using discrete-kernel approach. The contribution of indivial aquifer to well discharge has been estimated when the well is pumped at a constant rate. The contribution of an aquifer has been found to be governed by its hydraulic diffusivity value. In case both the aquifers have equal diffusivity, the aquifer contributions are independent of time but proportional to the respective transmissivity values.

Das Gupta, S.P. and A.B. Biswas (1985) have transferred the theoretical formulation of the steady state fluid potential of a basin to an algorithm with the help of Fourier transform and a sequence of recurring filter functions, for the computations of a three dimensional mathematical model of unconfined multi-aquifer groundwater basins having relatively simple geometry. This method may be a useful substitute to finite element technique in a number of cases with respect to economy, time and technicalities.

Gupta, S.K. and P. Sharma (1985) have shown that in case of semi confined aquifers the ratio of the steady-state drawdown to its gradient with respect to the logarithm of radial distance from the pumping well determines the transmissivity of the aquifer. Utilizing this principle they have proposed a method for evaluation of aquifer parameters. This method does not involve curve matching. The method has been illustrated with an example.

Gupta, C.P., M. Thangarajan and V.V.S. Gurunadha Rao (1985) have made an attempt to evolve the regional pattern of hydrogeologic parameters in a granitic basin using R-C analog model. The calibrated model satisfactorily reproduced the historical response of the aquifer and could be used for prognosis.

Shakya, S.K. and S.R. Singh (1986) have analyzed the hydraulics of fully penetrating injection welis in two semi-confined aquifers overlain by a thick soil slab. Equations for steady piezometric head distribution in the two semi-confined aquifers arising due to constant rate of injection into (a) the lower aquifer, (b) the upper aquifer, and (c) both aquifers have been derived. These solutions have been developed under conditions of accretion from the land surface. In absence of accretion, the well is fully penetrating the both aquifers. It has been analytically shown that the ratio of fluxes through the aquifers is equal to their transmissivity ratio.

Singh, V.S. and C.P. Gupta (1986) have presented a method using numerical modelling for the estimation of aquifer parameters from pump tests on large diameter wells. The method takes care of the variable pumping rate and the recovery of well drawdown. The variation in the pumping rate has been taken care of by splitting the total time of pumping into a number of small time steps which have uniform pumping rate but the pumping rate vary from time step to time step. In order to find the solution, principle of superposition has been utilized. It has been assumed that there is no loss due to entry resistance around the well, the seepage face is negligible and the aquifer response is instantaneous.

Rajgopalan, S.P. and U.V. Josh (1986) have developed a digital simulation model for the solution of the transient radial flow to a large diameter dug well perforating the full saturated thickness of an uncounfined aquifer. The numerical solution is based on the finite difference approach. The time variant discharge from the aquifer and the reduction in aquifer thickness due to water withdrawal during both the abstraction and recovery period have been suitably incorporated in the simulation model. It has been observed that even during recovery period (after the pump has been stopped), the hydraulic head in the aquifer continues to decline for a while before it starts rising. It has also been noticed that beyond a certain radial distance from the well the hydraulic head continues to decline even during the recovery phase. This is because during the recovery period the aquifer continues to discharge appreciable amount of water which accumulate in the well diameter. The results indicate that the model response of hydraulic heads in the aquifer is mainly sensitives to variations in lateral permeability and specify yield alone. Hence. while matching the model response with field response in a parameter adjustment procedure, attention may be focused on these two parameters.

Mohan Kumar, M.S., K. Sridharan and N.S. Lakshmana Rao (1986) have developed a Modified Strongly Implicit Procedure (MSIP) to solve two dimensional groundwater flow problems in non rectangular region. This procedure is a modification over SIP in which problems are solved over a superscribed rectangular computational region with zero transmissivities for nodes outside the regions of interest, resulting in wastage of computer storage and time. This developed MSIP can handle non-rectangular regions directly without such dummy nodes. The method is tested on two test problems and compared with other finite difference methods and MSIP is found to be the best. This MSIP is advantageous in regions with non-rectangular boundaries and where a number of parameters have to be stored for each node.

Vincent, W.U.J. and V.G.Joshi (1986) have conducted step-drawdown pumping tests to determing the components of drawdown due to aquifer loss and well loss. step-test data were analyzed by Rorabaugh (1953) method and by a graphical method. The results indicate that the well losses comprise a significant component of drawdown in most of the wells and these losses are probably, a result of non-Dencion flow in the aquifer adjacent to a pumped well. Constant-rate pumping tests on tube wells have been conducted to determine aquifer transmissivity and specific capacity. Time-drawdown data have been analyzed using cooper-Jacob(1946) approximation to the Theis equation and recovery data have been analyzed by residual-drawdown method. Aquifer transmissivity ranged over two to three order of magnitude, from less than 10 m^2/d to more than 300 m^2/d for the Satpura Hills region of central India. The pumping test results, often enabled the prediction of aquifer conditions such as limited aquifers, recharge boundaries and aquifer dewatering.

Ruston K.R. and V.S. Singh (1987) have pointed out if the seepage face is ignored, both the transmissivity and storage coefficient are under estimated. Ruston and Singh have extended the kernel function technique proposed by Patel and Mishra to include the effect of seepage face which occurs when large diameter wells in unconfined aquifers are pumped.

Rao, N.H. (1987) have proposed a simple conceptual model of the soil water balance which has been tested with field data obtained from an irrigation project area. The model estimates the actual evapotranspiration and the soil moisture content at the end of each week using available information on soil water availability and plant water uptake.

Sharma, H.C., H.S. Chauhan and K.K. Singh (1987) have propcsed a simpler and more realistic technique to solve the inverse problem related to a cavity well. In this method the element of human judgement (used in curve matchingh technique) has been practically eleminated.

Ram, S. and H.S. Chauhan (1987) have solved the Boussinesq nonlinear partial differential equation for unsteady state flow of water through a phreatic aquifer resting on a sloping impervious barrier and receiving time-varying recharge. Two patterns of recharge rates, i.e., linearly increasing and exponentially declining with time, have been considred. The initial conditions of water table have been taken at drain level and transformations have been devised to transform the resulting approximate linearized Boussinesq equation to the form of a one dimensional heat flow equation for each case of recharge pattern, and analytical solution for the height of water table between parallel drains have been obtained in the form of a convergent series. The analytical solutions have been expreimently varified with a Hele-Shaw model. The analytical solution presented can be used with reasonable accuracy for designing subsurface drainage in slopping phreatic aquifers.

Ahmed, S. and G.D. Marsily (1987) have used geostatistical technique for estimation of transmissivity. For regional aquifer modelling it is often necessary to produce maps of the distribution of the transmissivity in the aquifer, e.g., as initial input for the calibration phase of the model, either by automatic or by trial and error procedures. Such estimates must be based on all possible information available in the field; in many instances, direct transmissivity measurements from pumping tests are scarse, where as indirect estimation based on specific capacity data are more numerous. It is, however, possible to use jointly both type of data when a geostatistical technique is used. They have compared four such method a) Kriging combined with linear regression, b) Cokriging, c) Kriging with an external drift, and d) Krigning with a guess field. This comparison has been made both on a set of real field data and on a theoretical case, where the 'true' solution is known.

Singhal, D.C., Sriniwas and B.B.S Singhal (1988) have carried out integrated approach of photogeological, hydrogeological and geoelectrical studies in the south eastern parts of Banda district of U.P.. The integrated studies have indicated the existence of three quifers in the subsurface: (a) a porous, sandy aquifer within the alluvium; (b) fractured (and weathered) aquifers in the sandstone bedrock in the eastern and southern parts, and the granite brdrock in the north-western parts of the area; and (c) a deeper aquifer in the cavernous dolomite, occuring below the compact sandstones, which is expected to be highly productive at a number of lacalities. However, its southward extension beyond a lineament, designated as Manikpur Shear Zone, could not be established.

Ruston K.R. and N.K. Srivastava (1988) have analyszed using a mathematical model, the field information which was obtainied from an injection test in an alluvial aquifer; the test continued for 250 days. Aquifer parameters have been estimated both for the more permeable sound layers and the less permeable clay layers. The mathematical model has also been used to quantify the reduction in hydraulic conductivity due to clogging in the vicinity of the well, during the test.

Sukhija. B.S. et al. (1988) have carried out recharge estimation with the objective of ascertaining the validity of environmental chloride method for the coastal aquifers situated in semi-arid tropical areas under the influence of monsoonic type of hydrological regime. A comparative study, using environmental chloride in conjunction with injected tritium method have been taken in the coastal aquifers of Pondicherry situated about 160 km south of Madras, along the coast of Bay of Bengal. The study demonstrates conformity of recharge rates determined by the environmental chloride method and injected tritium technique and proves the validity of the chloride method for recharge measurement for tropical coastal aquifers.

Prasad, Rama (1988) have proposed a model of root water extraction in which a linear variation of extraction rate with depth has been assumed . Five crops have been chosen for simulation and soil moisture depletion under optimal conditions, from different layers for each crop has been calculated. Rooting depth has been assumed to vary linearly with potential evapotranspiration for each crop during the vegetation phase. It has been shown that the constant extraction rate model results in large error in the prediction of soil moisture deplection, while the linear extraction rate model gives satisfactory results.

Das, B.K. et al. (1988) have compared the isotopic data of groundwater with that of rainfall (during the period 1961-78) of Delhi area and have found that groundwater in all the subbasins and at different depths, is of meteoric origin having undergone direct evaporation and is genetically similar. Their study has shown that the major sources of high salanity are high rate of evaporation, recycling of irrigation water, and re-solution of precipitated minerals by monsoon recharge alongwith non-flushing of deeper waters.

Gupta, C.P. and V.S. Singh (1988) have presented a finite difference model of ground water flow regime associated with a partially penetrating well in a hard rock terrain. The estimation of hydrogeological parameters using the model in such situation has been illustrated by a field example. The model can also be used to study the effect of an in-borewell on the recuperation of the well.

Singh, V.S. and Gupta, C.P. (1988) have presented a numerical method for the interpretation of pump test data for a large diameter well situated near such a boundary as a river, a lake or a dyke which commonly occur in hard rock terrain. The technique considers the time-drawdown data for the pumping as well as for the recovery phase. A field example is presented to illustrate the use of the technique.

Mishra, G.C. and S.M. Seth (1988) have analyzed the unconfined seepage from a river of large width for a steady state condition using Zhukovsky's function and Schwarz-Chritottel conformal mapping technique. Seepage quantities occuring through the bank and the bed of river has been estimated separately. The reach transmissivity constant for river with large width has been determined. It is found that if the distance between the river bank and the observation well is more than 0.5 D_i, where D_i is the saturated thickness of the aquifer below the river bed, the reach transmissivity constant is indipendant of drawdown at the observation well. The reach transmissivity constant depends on the depth of water in the river and the distance of the observation well from the river bank.

Ahmed, S., G. de Marsily and A.Talbat (1988) have made attempts to establish an impirical relation between the electrical and hydraulic properties of aquifers. Cokriging method has been used to estimate the transmissivity based not only on measurements of transmissivity, but also on measurements of specific capacity and electrical transverse resistance, for the aquifer situated in the Madjendra Valley in Tunisia, where very few data can transmissivity and specific capacity are available, but resistivity data are relatively abundant. It has been shown that with the geostatistical technique; one can: a) use several electrical or elastic properties, which are easily measured, in the estimation of desired parameter without establishing any empirical relation; and b) make the estimation at any point where none of these properties has been sampled and at the same time obtain a variance of the estimation error. The method has been compared with the usual regression method.

Kashyap, D., P. Dachadesh and L.S.J. Sinha (1988) have developed an optimization model for computer assisted estimation of aquifer parameters which is based upon the minization of sum of the squares of residues from observed and computed drawdowns. It has been stated that apart from the parameter estimaion, the model can assist in identifying certain hydrogeological features like leakage, discountinuities, vertical amisotropy, etc. and it can also provide a check on the consistency among different data sets monitored during a test-pumping (e.g., drawdown and recovery data). The application of the model has been illustrated by analysis of field data.

Bhar, A.K. and G.C. Mishra (1988) have developed a linear mathematical model using Kernel generator to study the interaction between depression storage and the aquifer. As the recharge from dispression storage continues after filling up the depression in monsoon, the water level of the depression storage goes on declining with time. The variation of the recharge rate under such time varient depression water level has been modelled. The model can predict the groundwater evolution and the water level in the depression with time. The model has been applied for Surathgarh depressions which are being used as flood cushion.

Sakthivadivel, R. and K.R. Ruston (1989) have presented a methodology based on numerical analysis of large diameter wells with a dynamic seepage face for estimating the aquifer parameters from pumping tests in large diameter wells fully penetrating an unconfined aquifer of infinite areal extent. From the analysis of the field data they have proposed an empirical equation for the seepage face.

Sondhi, S.K., N.H. Rao and P.B.S. Sharma (1989) have evolved a methodology for determining the available additional groundwater potential and its distribution in the Mahi Right Bank Canal Project in Gujarat. Their procedure is based on the use of specific empirical constants for estimating groundwater recharge from the water conveyances and distribution system and the annual water balance of the project. The spatial distribtuion of groundwater potential is determined by 'recharge distribution coefficients' derived from a digital simulation model of the groundwater basin of the project area. The results show that the available ground water potential in the basin is about 265 x 10^6 m^3, which is about 1.6 times the existing level of ground water abstraction.. The groundwater potential is relatively high in the central and southern portions of the project area and is low at the northern and western boundaries.

Singh R.N. and S.N. Rai (1989) have analytically derived the solution to the nonlinear Boussinesq equation using integral balance method by averaging the governing equation along the length of aquifer to predict spatio-temporal distribution of phreatic surface in a ditch drainage system (aquifer bounded by two parallel ditches). This solution is the same as that obtained by Basak (1979), where it was assumed that the rate of rise or decline of the surface is constant throughout the aquifer and is a function of time only.

Singh, S.R. and S.K. Shalya (1989) have proposed a nonlinear equation for the entry of water through the perforations in well screen and a new parameter, screen hydraulic conductivity K_s has been described. A problem of steady groundwater flow through a confined aquifer has been formulated using the usual differential equation and a nonlinear (gradient and head) boundary condition incorporatry the proposed flux law at the aquifer-screen interface. the semi-analytical solution yields the drawdown distribution in the aquifer and is useful in computing yields from a screened well for different water levels in the well.

Parasad, R. (1989) has examined the possiblity of advance indication of moisture stress in a crop by in a small prepared plots with compacted or partially sand-substituted soils by an analytical simulation. A series of soils and three crops have been considered for simulation. Using average potential evapotranspiration values and a smiple actual evapotranspiration model, the onset of moisture stress in the natural and indicator plot has been calculated for different degree of sand-substitution and compaction. The effect of intervening rainfall and limited root depth, on the begning of moisture stress has been investigated.

Sridharan, K., D. Satyanarayana and A. Siva Reddy (1990) have proposed a numerical analysis of flow to a dug well in an unconfined aquifer taking into account well storage, elastic storage release, gravity drainage, anisotropy, partial penetration and seepage surface at the well face. The pumping rate was assumed to be constant. The degree of anisotropy is found to be most significant factor influencing the development of seepage face with a pronounced seepage face for relatively low vertical hydraulic conductivity. The degree of anisotropy and well penetration have found to affect flow characteristic significantly. The effect of change in specific yield and elastic storage coefficeint are less significant than those of anisotropy or well penetration.

Radhakrishna, I. and T. Gangadhara Rao (1990) have discussed the quantification of the hydrogeochemical parameters using Self Potential Logs for different aquifers in a major coastal sedimentary basin. They established a relationship between R_w and R_{we} for the system and then used analytical scattar diagrams between dissolved solids and various individual cations and anions for a multi-layered coastal system. This approach would reduce drill-stem tests which are costly and risky and would also minimize the uncertanities in the assessment of quantity variations for individual zones in a multi-aquifer systems.

Sridharan, K., M. Sekhar and M.S. Mohan (1990) have considered the problem of pumping an aquifer in a aquifer-water table aquitard system, accounting for elastic properties of both the aquifer and the aquitard the gravity drainage in the aquitard, and treating the water table as an unknown boundary. The coupled partial differential equations have been non-dimensionalized, yielding three principal parameter governing the problem. The numerical solution of these equations have been obtained for a wide range of parameter values. Type curves have been generated and their use is illustrated through a field application.

Choube, V.D. and I. Shankaranarayana (1990) have carried out hydrological investigations to determine the aquifer characteristics, recharge boundary location, and the amount of groundwater which can be withdrawn safely in order to minimize potential groundwater contamination from open pit coal mining in the Singauli coal field, central India. This study provides the framework for three - dimensional analysis of such problems as the hydrogeology, risk of potential contamination, mine flooding, highway stability, and reclaimed land surface.

Chachadi, A. G., G.C. Mishra and B.B.S Singhal (1991) have suggested a generalized discrete kernel approach to analyse the effect of storages in both production well and observation well on the drawdown at any point in a confined aquifer during pumping and recovery for unsteady flow to the wells. A numerical approximation has been derived to determine the contribution from the production well storage and observation well storage, and to determine the drawdown at any point in the aquifer. Non-dimensional time-drawdown curves comprising the response of the aquifer during the recovery phase have been presented for specific cases. It has been found that the effect of storage in the observation well is more pronounced during recovery than that during abstraction phase. The effect of observation well storage increases with increase in the diameter of observation well. It was confirmed that the drawdown in an observation well of negligible diameter due to pumping in a large-diameter well is the same if the roles of the wells are reversed. The contribution from the observation well storage to the aquifer during abstraction is a function of the diameters of production well and observation well and of the time since pumping commenced. The contribution from the observation well increases from an initial zero value to a maximum value during pumping and then decreases as pumping is continued. Similar trends have been observed during the recovery phase.

Singh, R.N., S.N. Rai and D.V. Ramana (1991) have presented a general analytical solution of the linearized Boussinesq equation with a complex recharge function to describe water table fluctuation in a sloping aquifer of finite width. They have used an eigenvalue-eigenfunction expansion method for obtainning the solution. Some previous known solutions for different recharge functions have been shown to be the special cases of the present general solution. Applications of the solutions in prediction of the spatio-temporal distribution of water table in a ditch drainage system have been illustrated with the help of synthetic examples.

Rastogi, A.K. (1991) has presented a simplified approach to reduce a time varient problem into a steady-state problem by averaging the groundwater head over a seasonal period. This scheme has been applied to solve a two-dimensional problem using a standard finite difference technique of solution. The phreatic aquifer system considered is bounded by two reservoirs and an impermeable base. It also contains a partially penetrating river near the centre of the aquifer. Periodic contribution to the phreatic aquifer from the higher head reservoir, ground water recharge from river seepage, net free surface flux and the total groundwater flow towards lower head reservoir have been worked out.

Vinda, R.R., R.R. Yadav and N. Kumar (1992) have obtained analytical solutions converging rapidly at large and small values of times for two mathematical models which describe the concentration distribution of a nonreactive pollutant from a point source against the flow in a horizontal cross-section of a finite saturated shallow aquifer possessing uniform horizontal groundwater flow, zero concentration or the conditions in which the flux across the extreme boundaries are proportional to the respective flow components, have been applied. The effect of flow and dispersion on concentration distribution have also been discussed.

Chachadi, A.G. and G.C. Mishra (1992) have analyzed the unsteady flow to a large-diameter well in a confined aquifer experiencing well loss, using discrete kernel approach. The well storage reduces the well loss component and the well storage is effective in the beginning of pumping. The inefficiency of a well is overcome by increasing the well radius. The variation of specific drawdonw in a large diameter well experiencing well loss, with pumping rate is non linear. The non-dimensional time drawdown graph at a large diameter well, in which the well loss component follows the Jacob's equation, is not unique but dependent on pumping rate. The conclusions drawn from the analysis are given below.

a) Tractable analytical expressions have been derived for determination of aquifer drawdown at the well face and at any point in a confined aquifer considering well loss effect in a large diameter well.

b) The relation between specific drawdown and pumping rate is non-linear for a large diameter well experiencing well loss.

c) The non-dimensional time drawdown graph at a large diameter well experiencing well loss, that is nonlinearly dependent on pumping rate, is not unique but changes with change in pumping rate.

d) The energy loss due to well inefficiency is reduced with increase in the radius of well casing.

In fine, the following area of ground water hydrology and conjunctive use should be given preferance in research:

a. Analytical/numerical modelling of the movement of fresh-water and saline-water interface under various conditions of recharge and withdrawals from groundwater in coastal aquifers.

b. Analytical/numerical modelling of stream aquifer interaction in a multi-aquifer system along with the groundwater flow modelling in multi-aquifer system.

c. Remote-sensing applications to ground water hydrology and conjunctive use management.

d. Quantification of static storage in different river basins and impact of withdrawal from static storage on hydrologic components and ecosystem should be investigated.

e. Guidelines for conjunctive use practice should be defined for different agro climate zone giving congnigence to geohydrological conditions. For India conjunctive use practice should be planned for (1) coastal belt (2) semi arid zone (3) hard rock region (4) alluvial basins (5) mountaineous terrain. The conjunctive use schemes should be planned keeping in view the following:

. Huge manpower availability which can harnessed for food and fibre production,

. Suitable method of irrigation for different zone so that application losses are minimum.

. Proper design of well field to control saline intrusion, water logging and ground water mining,

. The environmental impact and the socio-economic conditions of region.

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