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By

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GROUND WATER HYDROLOGY

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1.0 INTRODUCTION

Ground water is a distinguished component of the hydrologic cycle. Surface water storage and ground water withdrawal are traditional engineering approaches which will be continued to be followed in future. The uncertainty about the occurrence, distribution and quality aspect of the ground water and the energy requirement for its withdrawal impose restriction on exploitation of ground water. The uncertainty can be reduced by application of ground water hydraulics. In spite of its uncertainty ground water has some obvious advantages. These advantages are: ground water is much protected from pollution; it requires little treatment before its use; it is available almost everywhere; it can be developed with little gestation period and can be supplied at a fairly steady rate. It does not require any distribution system and its interference with land resources is minimum. In hilly region ground water emerging as springs can serve as a viable source for supply of drinking water. In a canal command area use of ground water controls water logging problems. The role of ground water is conspicuous during period of droughts.

Ground water hydraulics is a branch of general hydraulics which by gradual development has become an independent scientific discipline with its own methodology and range of application. Its significance stems from the fact that it forms a foundation for framework of other scientific fields and nearly all of the specialized area of water conservation (Halek, and Svec, 1979). Ground water hydrology is a branch of ground water hydraulics. The fundamentals and basic principles of ground water hydrology, and the methodologies for solving ground water flow problems are well established and various ground water management problems have been solved using the methodologies. However as the human interference with the hydrological cycle is increasing day by day there is a need for developments of methodologies either to solve or control the various flow problems arising due to human interference. Following are some of the research areas for which hydrological studies are needed for development protection and management of ground water resources.

2.0 PRESENT STATUS AND NEED FOR R&D ACTIVITIES

2.1 Evaluation of Components of Ground Water Balance for Assessment of Ground Water Resources

Ground water regime is a dynamic system in which water is absorbed at the land surface and eventually recycled back to the surface. The ground water movement occurs through the porous unconsolidated sediments and through interconnected openings in the rocks that mantle the earth. The occurrence and movement of ground water depend on the geohydrological characteristics of the sub surface formations. These natural deposits vary greatly in their lithology, texture and structure and differ in respect of their hydrological characteristics. The frame work in which ground water occurs is as varied as those rocks and as intricate as their deformation, which has progressed through geologic time. The possible combinations of variety and intricacy are virtually infinite. It has been, therefore, experienced that ground water investigations at a given site almost always exhibit a certain uniqueness (Brown et al.,1972). The movement of ground water in hard rock basin is an example of the uniqueness of sub surface flow.

For estimating regional ground water potential it has been recommended that the general manner in which the regime functions must be identified. The potential for recharge to the ground water regime in an area depends on the amount and pattern of annual precipitation in relation to the potential evaporation in the area and to the occurrence of any surface or sub surface inflow from adjacent areas. Most of this potential recharge is commonly intercepted by the soil veneer and eventually returned to the atmosphere through processes of evapotranspiration or dissipated through surface run-off. The amount that actually contributes to ground water recharge varies seasonally and from year to year.

It is generally difficult to quantify the recharge to ground water from various sources. Similarly, it may be difficult to quantify ground water discharge because of temporal variations, especially if it occurs at a number of scattered locations, either at the land surface in the form of springs, gaining streams, lakes, ponds, marshes or growths of phreatophytes, or at depth through permeable formations (Brown et al.,1972).

There is a need for studying unsaturated and saturated flow through weathered and fractured rocks for finding the recharge components from rainfall and from percolation tanks in hard rock ground water basin. The irrigation return flow under different irrigation practices for different soils and different crops needs to be quantified. Also user friendly software should be developed for quick assessment of regional ground water resources.

2.2 Ground Water Flow Modelling for Multi-aquifer System and Stream Aquifer Interaction Studies

The replenishable ground water resource of India is about 452 cubic km. Nearly 38% of the country's ground water resource is in Ganga basin, 6.2% in Brahmputra basin, 5.2% in Indus basin and the remaining nearly 50% is in the Peninsular India. There is scope for use of ground water in these basins specially for Rabi irrigation. The balance ground water potential available till date in the country is 276.3 cubic km. Endeavour is being continued to use this potential. It should be realised that when the balance ground water potential will be exploited this would lead to induced recharge. Hydrologists have stressed that ground water development should not be planned in isolation. Both surface water and ground water are components of hydrologic cycle and they interact with each other. Use of ground water will deplete surface water sources in some region. Therefore one has to assess the depletion in utilisable surface water resources and the gain from non-utilisable surface water resources while planning for ground-water development. This can be achieved through the study of stream aquifer and well interaction.

The interaction between surface water and ground water has been examined in some detail in recent years. There are two main aspects of this process: 1) the flow of ground water to support river flow and 2) the flow from river to the ground water storage. Recharge may occur whenever the stage in a river is above that of the adjacent ground water table, provided that the bed comprises permeable or semipermeable material. This type of ground water recharge may be temporary, seasonal or continuous. Also it may be a natural phenomenon or induced by man. Man can induce ground water recharge from rivers by lowering the water table adjacent to rivers through ground water abstraction.

In a ground water basin it is common to identify several aquifers separated either by less permeable or impermeable layers. A stream in general penetrates partially the upper aquifer. When the stream stage rises during the passage of a flood, the upper aquifer is recharged through the bed and banks of the stream. The lower aquifer is recharged through the intervening aquitard. A single aquifer stream interaction problem has been studied analytically by several investigators (Morel-Seytoux, 1975, Todd, 1955, Cooper and Rorabaugh, 1963). A digital model of multi aquifer system has been developed by Bredehoeft and Pinder (1970) assuming horizontal flow in the aquifers and vertical flow through the confining layers which separate the aquifers. These assumptions have reduced the mathematical problem to one of solving coupled two dimensional equation for each aquifer in the system. An interactive, alternating-direction-implicit scheme has been used to solve the system of simultaneous, finite difference equations which describe the response of the aquifer system to applied stresses. The quasi three-dimensional model has been developed to simulate a ground water system having any number of aquifers.

Mathematical modelling of ground water flow has been applied for solving lake aquifer interaction problems (Winter,1984). In a lake aquifer interaction problem the geometry of the lake and its hydraulic connection with the aquifer control the flow regime.

There is a need for the study of interaction among a stream and several aquifers which are separated by an aquitard considering the changing river width and stage that may occur during passage of flood. A ground water flow model for a multi aquifer system to cater the need of ground water management should be developed. The assessment of induced recharge due to ground water abstraction in the river basin should be made for planning optimal operation of ground water reservoir. Lake aquifer interaction study needs to be conducted to carry out lake water balance.

2.3 Unsaturated Flow Modelling

Soil-moisture content of a basin controls the rainfall

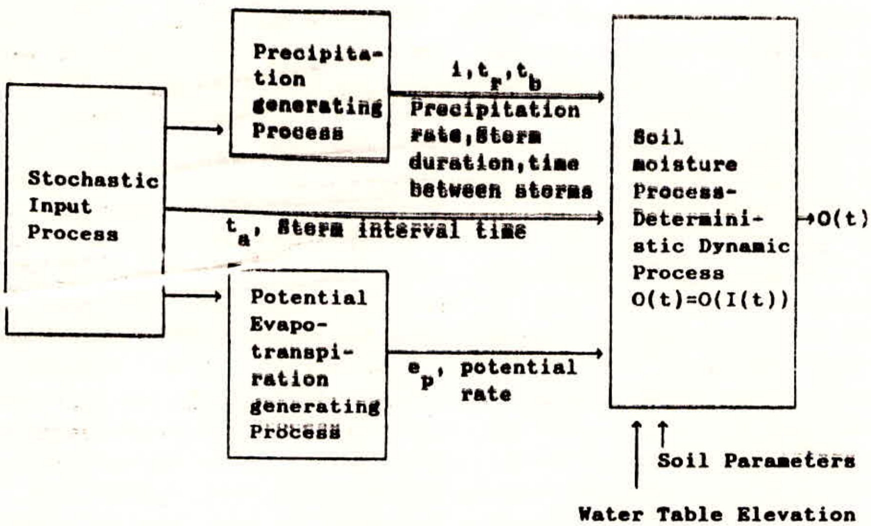
-runoff phenomena. It has been shown that performance of rainfall -runoff models is sensitive to the methods used to specify the effective precipitation and the antecedent moisture conditions (Brutsaret,1991). Study of soil moisture movement on a continuous basis considering both the storm and interstorm periods will not only determine antecedent moisture content but also would enable determination of recharge due to several rainfall events controlled by evaporation losses from soil moisture storage. There is a need for studying soil moisture movement on a continuous basis considering both the storm and inter storm periods.

Flow of water in the unsaturated zone is a complex phenomenon involving transfers of water, air, and vapor through dynamic flow pathways under the influence of hydraulic, temperature, density, and osmotic gradients in a compressible porous medium. In hydrological modelling the physical representation of water flow in unsaturated zone has been made using Richards'equation which combines an equation of continuity with Darcy's law. Richards's equation is based on the assumptions that the fluid is incompressible and the flow takes place under isothermal condition. Both laboratory and simulation experiments have shown that under certain conditions the effects of air, vapor, and thermal fluxes may be important in the unsaturated zone. Theoretical reasoning would therefore suggest that the use of Richards'equation as a simulator of the unsaturated zone should be expected to be inaccurate in some circumstances (Beven,1991). Limiting conditions for the use of Richards'equation for simulating processes in unsaturated zone in the field have not, however, been established (Beven,1991) and it is usually assumed, with some justification, that the error resulting from ignoring the multi-phase nature of the flow process may be negligible, relative to the problems of estimating the single-phase flow parameters for field situations. The complexity in physical representation of unsaturated fluid flow would further manifest in greater requirements for parameter and input data. These would include characteristic curves for the transport of air and vapor, thermal capacity and diffusivity, densities of water and air, and upper boundary conditions for air pressures, humidity, and temperature in addition to water fluxes. There is need to check the applicability of Richards' equation in representing the unsaturated flow.

Another important aspect of soil moisture study which needs to be undertaken is soil moisture forecast. The soil moisture forecast will be useful for water management. A forecast of soil moisture is the prior estimate of the future state of soil water in the zone of aeration. The forecast variables include soil moisture status in the root zone depth, time of occurrence of permanent wilting condition, continuing period of permanent wilting condition, period for which the root zone depth remains in saturated state, time at which root zone attains field capacity, depth fraction of root zone depth that remains at less than field capacity. Roles of a short term forecast i.e. a forecast of future value of an element of the regime for a period ending up to two days from the issue of the forecast, and a medium-term or extended forecast for a period ending between two and ten days, in water management need to be investigated.

The controlling factors of soil moisture may be classified under two main groups viz. climatic factors and soil factors. Climatic factors include precipitation data containing rainfall intensity, storm duration, interstorm period, temperature of soil surface, relative humidity, radiation, evaporation, and evapotranspiration. The soil factors include soil matric potential and water content relationship, hydraulic conductivity and water content relationship of the soil, saturated hydraulic conductivity, effective medium porosity. Besides these factors, the information about depth to water table is also required.

The following general procedure has been suggested by Eagleson (1978) for soil moisture forecast:



The continuous variation of soil moisture with time and depth in soil can be known by solving the Richard's equation. The presentation of the forecast, $\theta(t)$, may be in the form of a single value or in the form of probability distribution and its dissemination may be achieved by regular news bulletin.

Forecasting soil moisture would help in deciding irrigation application, enable prediction of the annual evaporation loss from shallow water table, and recharge to ground water storage due to rainfall. The forecast model needs to be made operational on interactive mode.

2.4 Spring Flow Modelling

Spring is a ready source of water, a place of natural beauty, and a recreational spot. Springs generally provide clean water. They are found in the Himalayas, in the Western Ghats and in other places in India where it is logistically difficult to create storage for water. As such, study of springflow has relevance to the water supply to rural areas, specially in the hilly region. However, there is no systematic hydrologic study of the springs so far and there is enough scope and need to study spring, particularly in respect of mathematical modelling of springflow. Exploitation of forested area for food, fibre and minerals and urbanisation lead to deforestation and changes in the watershed characteristics. This human interference leads to destruction of the internal hydrological system. As a consequence the spring flow diminishes which may lead to drying of the spring (Dewan,1990). A hydrologic study is required to rejuvenate drying springs. Delineation of recharge area of the spring by remote sensing and nuclear methods needs special efforts for controlling human interference.

Springs are basically natural outlets of concentrated discharge from an aquifer. A large spring indicates existence of thick transmissive aquifers whereas a small spring indicates an aquifer of low transmissivity. Discharge rate from a spring depends on the extent of the recharge area, the precipitation on the catchment of the spring, aquifer geometry, area of opening of the spring, geology and geomorphology of the area and diffusivity of the aquifer. The discharge of a spring depends on the difference between the elevations of the water table (or piezometric head) in the aquifer in the vicinity of the spring, and the elevation of spring outlet (called as threshold). During dry season, the spring discharge is derived from water stored in the aquifer. Consequently, the water level in the aquifer gradually falls and the spring discharge declines. The recession part of a spring hydrogram, in a semi-log plot (with time on the linear scale), may follow a straight line. Based on such observation some conceptual linear hydrologic models have been developed to assess the dynamic storage which subsequently appears as spring discharge (Mero, 1963; Bear, 1979; Mandel and Shiftan, 1981). These models assume that the springflow is linearly proportional to the dynamic storage in the spring flow domain. Based on this assumption the following exponential form of spring flow has been derived:

$$Q(t+\Delta t)= Q(t) \quad \exp(-\Delta t/t_0)$$

where, $Q(t)$= springflow at time t during recession, Δt is time increment, t_0=a parameter of the spring known as depletion time.

The dynamic storage of ground water at any time during recession is equal to the product of depletion time and discharge of the spring. It is not yet verified that spring discharge from an aquifer conforming to a linear system would follow strictly an exponential decay curve Thus there is a need for finding the true relationship between dynamic storage and the spring discharge.

2.5 Salt Water Intrusion in Coastal Aquifer

In the coastal margins of ground water basin, the lowering of water level or potentiometric head can result in the intrusion of sea water, with a resulting degradation of water quality in the basin or a portion of the basin owing to the intruded sea water. For saline intrusion to occur, permeable formation must be in hydraulic connection with sea water, either directly on the ocean floor or along a river estuary or bay which contains sea water. Another necessary condition of saline intrusion is that there be an inland gradient, that is, there must be a tendency for water to move from the sea water sources to the pumping area. Such an inland gradient normally would result from pumping at rate higher than the recharge to the ground water basin. If these conditions exist, there will be a sea water wedge moving inland. The wedge-shaped intrusion results from the fact that sea water is approximately 1.025 times heavier than fresh water. The greater the depth below sea level, the greater is the pressure differential between sea water and fresh water , and hence there is faster movement of the sea water. In most coastal aquifers the bodies of sea water and fresh water will maintain, for all practical purposes, separate identities because of the difference in density of the water. An exception to this condition occurs where there is a considerable variation in water levels from pumping and tidal fluctuations and where the formation is very permeable. There ,a transition or mixed zone of fresh water and sea water is known to occur underground.

Several methods to control saline intrusion have been suggested by hydrologists (ASCE Manual, 1987). These are (a) reduction of ground water extraction; (b) Artificial recharge by spreading; (c) physical barrier; (d)pumping trough; (e) hydraulic ridge; and (f) combination of pumping trough and hydraulic ridge. The relationship between quantity of water flowing to the sea and the length of the wedge is available in literature. Also mathematical modelling of unsteady flow of saline and fresh water in aquifer is documented. The method of controlling saline intrusion must be chosen considering the special condition of the area.

2.6 Artificial Recharge

It has been recognized that aquifers are not only sources of water but also storage reservoirs that require proper management for efficient use. With respect to management, an aquifer may be considered as a reservoir for long term storage artificially produced and as a water quality control tool because of its filtering characteristic that reclaims artificially recharged waste water. Artificial recharge may be viewed as an augmentation of the natural movement of surface water into underground formation by some method of construction, by surface spreading of water or by artificially changing natural conditions. The purpose of artificial recharge of ground water is to reduce or reverse declining levels of ground water in a basin, to prevent saltwater intrusion from sea to coastal aquifer and to store surplus surface water and reclaimed water for future use. The base flow of a stream can be augmented by recharging ground water at locations far away from the stream so that the recharged water will reach the stream during periods of lowest flow (ASCE Manual, 1987). The underground fresh water in coastal aquifer can be protected by a hydraulic barrier which can be created by artificial recharge through a line of wells.

The saturated and unsaturated ground water flow equations provide a means of analysing the impact of artificial recharge on ground water system. The complex hydrological conditions that develop during certain type of artificial recharge are:(i) large change in saturated thickness and (ii) transport of contaminants in an aquifer. In recent years numerical models have been exclusively used for solving the complex ground water flow problem.

In a hard rock ground water basin it is common to find a weathered zone underlain by massive and fractured zones. The weathered zone and the fractured zone provide opportunity for storing surplus water in them. Both the layers can be recharged economically through a single injection well provided the well intercepts both the layers. Assessment of the quantity of water which is recharged to individual layer and determination of the part of the recharged water that is available in the zone of interest at any time are important tasks. Thus there is a need for development of methodology to predict quantity of water recharged by different methods and their temporal and spatial availability in the area of interest. Appropriate method of artificial recharge in hard rock basin and method for retaining the recharged water in the sub surface reservoir need to be established.

Construction of percolation tank is a common practice in several parts of India objective of which is artificial replenishment of ground water for lift irrigation in small agricultural tracts. A percolation tank is created by constructing a small earthen dam across a natural stream at a suitable location. It is located upstream of an existing cluster of dug wells. The surface run-off during the short monsoon period is collected in the tanks. Under favourable soil and rock conditions, the water percolates and recharge the ground water. Effectiveness of percolation tanks in recharging ground water has been studied using the isotope method (Nair et al., 1978). It remains to be investigated how effectiveness of percolation tanks decreases with time because of siltation, what fraction of the water stored joins the ground water because of evaporation from tank, how much increment in recharge rate could be achieved through construction of recharge shafts.

In choosing among the several sources of available water for ground water recharge, increasing importance has been placed in recent years on the use of reclaimed municipal waste water. Pretreatment process of the waste water and renovation of waste water with rapid infiltration land treatment system are presently important area of research.

2.7 Modelling of Ground Water Quality

In terms of biologic or organic quality, ground water is generally better than surface water and in terms of chemical quality (dissolved solids) surface water is generally better than ground water. Although it seems that ground water is more protected than surface water against pollution, it is still subject to pollution, and once pollution of ground water occurs, the restoration to the original, non polluted state, is more difficult. Flushing processes in ground water reservoir are inefficient and expensive. It is easier to prevent the cumulative and complex process of deterioration than to prevent once pollutant concentration have reached problem proportion. With the increased demand for water and with the intensification of water utilization, the water quality problem becomes the limiting factor in the development of water resources in many parts of the world. Most essential to developing an appropriate contaminant containment/control program is that a thorough understanding of the sub surface system be developed. A detailed appraisal of the geologic and hydrogeologic setting must be made and the magnitude of the pollution hazard for a specific incident must be evaluated. As the movement of contaminants, and therefore, the methods of containment/control of the contaminants are largely dependent on the hydrogeologic environment, the effectiveness of the various methods will vary with different geologic settings. Designing a program for containment or control of ground water contamination is further complicated by the fact that not all contaminants behave in the same manner in the sub surface. Many contaminants move at different rates in the ground water system, and may occupy different levels in aquifers according to their solubility in water, their density, and other physical properties peculiar to the contaminants. Heavy metals may migrate in ground water at one rate, and water-soluble organics at another rate. Some contaminants, including most petroleum products, are immiscible and float on top, or otherwise move independently of the ground water. Earth materials may attenuate certain contaminants to a sufficient degree as to reduce their mobility and concentration. Various materials, most notably certain types of clays, act as very efficient adsorbents, and may aid in retarding the migration of selected contaminants. In addition, natural microbial action may help to break down toxic organic contaminants to simpler, nontoxic forms. Thus, some chemical constituent of waste products deposited at the surface are absorbed, attenuated, or transformed in the sub surface, while others pass through with little or no attenuation or change. All of the processes of migration and alterations present in ground water are also present in the unsaturated zone. However the flow of water through the unsaturated zone is considerably more complex due to the presence of the air water vapour phases. Nevertheless it is important to note that the attenuation mechanisms in the unsaturated zone can provide a powerful barrier to the passage of contaminants to the saturated zone.

The containment and/or control of contaminated ground water can generally be accomplished using one or a combination of several available techniques. The alternatives available for remedial action can be classified into three broad categories:(i)physical containment measures, including slurry trench cutoff walls, grout curtains, sheet piling, and hydro-dynamic control (ii) aquifer rehabilitation, including withdrawal, treatment, reinjection (or recharge), and in-situ treatment, such as chemical neutralization, and biological neutralization (iii) withdrawal, treatment and use.

The objective of ground water pollution study in a basin is to answer the questions:(i) what contaminations are present in the ground water? (ii)what are harmful levels for specific contaminants? (iii)how will the contamination levels in the ground water system change with time? (v)can the source of contamination be controlled effectively ? These questions could be answered by a hydrodynamic transport model.

A programme of study of the quality of ground water envisages field observations regarding the source and environment of ground water occurrences, source of pollution and other related aspects having a bearing on the quality of ground water. In fact, determination of safe yield for a ground water resource must consider both its quantity and quality.

Analytical solutions for solute transport in homogeneous and isotropic saturated porous media in which the flow velocity is uniform are available for simple one and two dimensional cases.

Contaminant transport problems have been solved by numerical methods which are well documented (Huyakorn and Pinder, 1983). The numerical methods exhibit numerical spatial oscillations while solving the advection dominated transport problems. There is a need to develop numerical scheme to eliminate numerical oscillation.

While exploiting ground water it is appropriate to ascertain whether a ground water abstraction zone is liable to contamination and whether a potential source of pollution is contaminating the aquifer. In either case the present and /or future conditions applicable to the migration of contaminants are determined. For analysis of pollution potential at a particular site, data describing contaminants, their migration characteristics and the characteristics of ground water regime are collected. Whilst inspection of the available data can provide a strong insight in to a potential pollution hazard, the use of models may provide more appropriate and rigorous method for integrating all the available data together and for evaluation of the response of the aquifer system to a contamination event. The models are generally derived from the expression of the flow and transport processes to terms of mathematical equations which are then be solved by incorporating appropriate parameter values and boundary condition derived form the collected field data.

Assessment of ground water quality in many ground water basins remains as a task yet to be performed.

2.8 Water logging Salinisation and Drainage in Canal Command Areas

Water and air, which compete for the same position in soil in the root zone, are both needed for plant growth. The soil moisture deficiency is abated through irrigation and the oxygen deficiency is done away with by providing drainage facilities in the agricultural field. A water table at a depth more than 1m below soil surface during irrigation season should be sufficient to permit adequate aeration in most soils and normal root development of most annual crop plants. For perennial crops a somewhat deeper water table position about 1.5 to 1.8m below ground surface may be required (Framji, 1976). For a short period immediately after irrigation, a rise in the water table to .3 m below soil surface should not be detrimental. An area can be considered to be waterlogged if the water table which is not saline lies within

1.5m below soil surface during the crop growth.

The most widespread and direct factor in the formation of contemporary saline soils in different parts of the world is ground water evaporation and transpiration where runoff is either reduced or non-existent. Both the intensity of ground water evaporation and the salt accumulation processes attain their maximum in arid climate conditions when the ground water levels reaches a depth of 2-3m or less.

Large concentration of salts in ground waters (10-150 g/l) play a determining part in the soil salinization of arid regions. With very intensive evaporation and transpiration, capillary solutions of salty ground water continuously replace evaporating soil moisture, thereby introducing more and more toxic salts into the root zone and leading to plant death. From 4-5 m depth, the ground waters cannot provoke and maintain soil salinization under irrigated conditions. Horizontal drainage does not allow to lower the ground waters to such a depth, but this can be managed with the help of pumping through vertical drainage wells.

Efficient use of land and water resources to a greater extent dependent upon the control of salinisation problem. The long history of irrigation has recorded severe deterioration of land resources due to salinisation and water logging. It is a well known phenomenon that, when an area is irrigated excessively over an extended period of time, the ground water level rises. When the water table reaches a height, which is within the capillary lift of the soil, the soil moisture is brought to the surface where it evaporates. Salts, which were originally present in the irrigation water or which were dissolved in the rising ground water, get concentrated on the land surface by the so called 'tea kettle effect'. This causes soil salinity and some times alkalinity which are harmful to plant growth. When a saline water table rises and remains in the root zone longer than about 48 hours, resulting in an abnormally high saline moisture condition, agricultural production is usually seriously affected. Vast areas, which once upon a time were productive under irrigation, have become sterile and saline waste land in Mesopotamia, North Africa and in the Far East. In modern times, the rate of salinisation and land destruction has been greatly accelerated, especially in areas irrigated with plentiful, low cost water, which contains dissolved salts. Areas affected by salinity and alkalinity in India are about 7 million hectares. Although the growth of salinity of irrigated soils is practically universal, there are a few encouraging example of successful prevention of deterioration and the improvement of originally saline lands. In many irrigation systems in USSR, salinization processes were completely stopped and saline soils were desalinized and returned to cultivation with good results. This was achieved by deep horizontal drainage, leaching of salts in accordance with the salt balance concept, selective application of vertical pumping drainage, introduction of effective hydroisolation in the canals, and overall sound management of the water resources (Dukhovny, 1975,vide Worthington,1978)

Experience has shown, often quite forcefully, that it is better to fully equip a restricted area than to put water on a greater surface without sufficient provision for application efficiency and appropriate drainage. Drainage is required in different methods according to local conditions and according to the quality of ground water. If the ground water is not saline and consequently usable by crops, the aim of drainage network is to get rid of excess water in the root zone quickly, keeping the water table at a rather high level in order to benefit from capillary movement. By avoiding over drainage, the water table can be drawn to an optimum level. If the ground water is brackish, water movement towards the root zone and soil surface must be eliminated. In such cases the drawdown speed is not the first target, and instead of an optimum level, it is a critical level which must be kept in mind. A shallow drainage system would be inappropriate under such situation.

Whenever irrigation is planned it will be dangerous to ignore the peculiarities of the natural soil situation, the mineralization and chemical composition of ground water, salinity of soil and unsatisfactory natural drainage. In order to project irrigation system construction cheaper, deep drainage system if necessary should not be ignored. Construction of irrigation system without drainage installation in arid countries leads to a gradual decrease of their efficiency and is a waste of labour and investment. Most scientists and irrigation specialists of the world agree that, excessive use of water for irrigation should be curbed and that drainage should be provided. The only point of disagreement is on ways of so doing.

The design procedures for surface and sub surface drainage are well established. In order to design surface drainage economically it is necessary to find the design discharge. There are several method such as rational method, unit hydrograph technique and watershed models which are used for design flood estimation. Methods for computation of design discharge for agricultural surface drainage system need to be established considering the small area of the agricultural catchment and the land use characteristics.

2.9 Conjunctive Use of Surface Water and Ground Water

In a canal command, because of continuous and intensive application of surface water for irrigation, the water-table comes up which may lead to water-logging and salinity hazards. These problems can be prevented by withdrawing water from aquifer. If the ground water is not saline it may be used to irrigate part of the canal command or it may be transported to other areas through the canal conveying surface water to the region. Losses from irrigation schemes to ground water are often significant. In a typical scheme, as much as 40% of the water released from the reservoir is lost to the ground water. 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 conjunctive use can also enhance use of manpower availability for food and fibre production.

The main principles of environmentally sound management of water resources with special reference to conjunctive water use have been outlined (David,1986). It has been advocated that all water management activities should be able to serve two basic groups of objectives, namely socioeconomic and ecological ones. The principles and practice of systems planning have been summarised by Loucks et al.(1981). The following basic goals have been suggested to implement environmentally sound management of water resources including conjunctive use: (a) to meet the requested water demand (drinking water supply, irrigation, hydropower, industrial water supply, etc);(b) to provide water damage prevention (flood control, drainage, waste water collection, treatment); (c) to conserve or to improve the productive capacity of the environment affected by the project; (d) to provide the rational use of natural and socioeconomic resources needed for the project (water, land, capital, manpower, energy, etc; (e) to provide harmony between the project and the river basin.

2.10 Water Conservation Measures in Drought prone Areas

Drought is a recurring climatic condition which affects large areas on earth. It is defined as a period of abnormally dry weather that is sufficiently prolonged to cause serious hydrologic imbalance in the affected area (Huschke, 1959). The most powerful effect of drought is to reduce agricultural production over a wide area. Other adverse impacts are: reduction in hydropower generation, shortage of drinking water, deterioration in water quality, loss of aquatic lives, and reduction in recreational facilities. Other adverse economic impacts follow these losses. Agencies at various levels of engineering organisations have to take action to reduce the effect of droughts. Adjustments to drought, relevant for agriculture and for urban areas, include the following: i) Conservation of water; ii) Diversification of crop and live stock and selection of drought-resistant crops; iii) Development of ground water resources to supplement surface water or existing ground water supplies; iv) Integration of waste-water reuse into community management; v) Formulation of priorities among competing demands so that less vital uses can be minimized during drought.

Conservation of water includes protection of water supply by eliminating leakage and evaporation; alteration of cultivation practice to include strip cropping, minimum tillage, application of sprinkler, drip or trickle irrigation methods and development of wind breaks.

Rainwater harvesting methods have been recommended for different agroclimatic zones which include roof water harvesting, diversion of perennial springs to storage structures, collection of water from hill slope, storage of water in tanks and village ponds and in sand fill reservoirs. Constructions of check dams, gully plugging, and contour bunding have also been recommended as rain water harvesting structures in hilly regions. Sprinkler and drip irrigation practices have been found to be more effective in water saving than conventional irrigation methods. It has been reported that water loss in conventional method is 32 to 45% where as it is hardly 6 to 9 % in sprinkler and 1 to 2% in drip irrigation. Soil moisture conservation by mulching not only restrict evaporation losses from the soil moisture zone but also increases opportunity time of infiltration during rainfall. A limited study on performance of different mulches has been made.

Study on the performance of wind breaks is yet to be conducted.

2.11 Drought Indices

The identification and quantification of hydrological drought phenomenon are still complex. There are no universally accepted definitions and indices determining hydrological drought and its characteristics. For a hydrologist, drought is marked depletion of surface and ground water.

The hydrological drought has been defined by many scientists in terms of average low flow, deficiency in water supply, deficiency in runoff accumulation of water in various storage capacities giving arbitrary weightage to supply and demand. Therefore, the development of hydrological drought indices is a major task. In developing a hydrological drought indices on the basis of reduction in stream flow, reduction in ground water and reduction in surface water bodies, the data which will be required are: rainfall data; stream flow data; surface water bodies; ground water table and increased water demand. The dynamic ground water storage can be considered as index of drought. The dynamic ground water storage at any time can be evaluated analysing the stream flow data during depletion period. The depletion time can be regarded as one of the indices. The flow rate at any time multiplied by the depletion time gives the temporal dynamic storage.

3.0 THRUST AREAS

(1) Evaluation of Components of Ground Water Balance for Assessment of Ground Water Resources:

(a) Estimation of recharge due to rainfall in hard rock region;
(b) Quantification of recharge from percolation tanks;
(c) Irrigation return flow in different hydrogeological and agroclimatic conditions;
(d) Assessment of static and dynamic ground water potential in a basin;
(e) Mining volume of ground water extraction during drought;
(f) Development of software for quick assessment of regional ground water potential.

(2) Ground Water Flow Modelling for Multi-aquifer System and Stream Aquifer Interaction Studies:

(a) Stream and multi aquifer interaction;
(b) Induced recharge;
(c) Determination of aquifer parameters in a stream aquifer system without resorting to pump test;
(d) Development of a ground water water flow model for a multi-aquifer system using technological coefficients;
(e) Seepage from lake.

(3) Unsaturated Flow Modelling:

(a) Soil moisture movement considering storm and inter storm period;
(b) Assessment of evaporation losses from shallow water table;
(c) Recharge from rainfall;
(d) Soil moisture forecast;
(e) Software development.

(4) Spring Flow Modelling:

(a) Inventory of springs in India;
(b) Time series analysis of spring discharge;
(c) Mathematical modelling of flow from a spring ;
(d) Identification of recharge zone by isotope study;
(e) Rejuvenation of drying spring.

(5) Salt Water Intrusion in Coastal Aquifer:

(a) Artificial recharge and control of saline intrusion in islands;
(b) Verification of Ghyben -Herzberg relation under dynamic flow condition;
(c) Mathematical modelling of flow and salinity transport in coastal aquifer;
(d) Application of low frequency electromagnetic aerial methods for identifying salt water intrusion front.

(6) Artificial Recharge:

(a) Artificial method of recharge in hard rock region;
(b) Study of recharge through percolation tanks;
(c) Artificial recharge from reclaimed municipal waste water source;
(d) Artificial recharge for control of saline intrusion.

(7) Modelling of Ground water Quality:

(a) Thermal pollution;
(b) Solid waste disposal and ground water pollution;
(c) Contaminant transport in a stream aquifer system;
(d) Contaminant transport in a lake aquifer system;
(e) Waste water disposal and ground water pollution;

(f) Protection zone of drinking water wells;
(g) Ground water monitoring network design.

(8) Waterlogging Salinisation and Drainage in Canal Command Areas:

(a) Sub surface drainage for heavy soil;
(b) Solution to salanisation problems in internal draining basin;
(c) Optimal design of drainage system;
(d) Design discharge for surface drainage system.

(9) Conjunctive Use of Surface Water and Ground Water:

(a) Augmentation well field;
(b) Conjunctive use and crop planning in different agroclimatic zones;
(c) Conjunctive use and flood cushioning;
(d) Conjunctive use and saltwater intrusion control;
(e) Conjunctive use and waterlogging and salanisation control.

(10) Water Conservation Measures in Drought prone Areas:

(a) Economic analysis of closed water conveyance system in semi arid region ;
(b) Experimental study on reduction of evaporation losses by using agricultural mulches; (c) Quantification of evaporation reduction by wind breaks.

(11) Drought Indices:

(a) lowflow analysis;
(b) Soil moisture depletion in root zone;
(c) Dynamic ground water storage.

4.0 RECOMMENDATIONS

The rational limit of the rate of ground water exploitation should be such that protection from depletion is provided, protection from pollution is provided, negative ecological effects are reduced to a minimum and economic efficiency of exploitation is attained. Determination of exploitable resources should be based upon hydrological investigations. These investigations logically necessitate use of a mathematical model of ground water system for analyzing and solving the problems. The study of water balance is a prerequisite for ground water modelling. With water balance approach, it is possible to evaluate quantitatively individual contribution of sources of water in the system over different time periods. Besides it provides a check on consistency of the data used for modelling. A hydrological data base for ground water assessment should be established.

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