TRAINING COURSE

ON

SOFTWARE FOR GROUNDWATER DATA MANAGEMENT

UNDER

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LECTURE NOTES
ON

BASICS OF GROUNDWATER

(UNIT - 2)

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GROUNDWATER BALANCE - CONCEPT AND APPROACH

1.0 INTRODUCTION

Groundwater is an important source of water supply throughout our country. Though, the groundwater resource of the country is limited, its use in irrigation, industries, municipalities and rural homes continues to increase. A greater emphasis, therefore, needs to be laid on the resource utilization studies and proper planning for the safe development and management of this vital resource. Based on the norms recommended by the "Groundwater Estimation Committee, March 1984", the total replenishable groundwater resources of the country have been estimated as 45.22 m ham, out of which 6.94 m ham have been kept for drinking, industrial and other committed uses and the remaining 38.28 m ham of utilizable groundwater resources are meant for irrigation purpose. The present draft is 10.65 m ham, leaving a balance of 27.63 m ham of groundwater resources available for exploitation.

Thus, when seen for the country as a whole there is considerable groundwater still required to be developed. However, when viewed from micro level angle, there are pockets where intensive development has led to rather critical situations and manifestation of problems like declining groundwater levels, shortage in supply, ingress of sea water in the coastal areas etc. On the other hand, in many major canal command areas, the water table is progressively rising because of excessive seepage from surface irrigation and poor subsurface drainage leading to the creation of water-logging and salinity problems. Therefore, there is need for planned and integrated development of surface and groundwater resources and their scientific management.

While planning for the development and management of groundwater basin, it is to be ensured that a balance exists between the recharge to and discharge from the basin and the groundwater levels fluctuate within a particular range over the monsoon and non-monsoon seasons. Therefore, an appropriate strategy will be to develop water resources with planning based on conjunctive use of surface water and groundwater. For this, the first task would be to make a realistic assessment of the surface water and groundwater resources and then plan their use in such a way that full crop water requirements are met and there is neither water logging nor excessive lowering of groundwater table.

Water balance technique has been extensively used to make quantitative estimates of water resources. Besides, it also serves as a means of solution to various important theoritical and practical hydrological problems. The knowledge of water balance assists prediction of the consequences of the man's activities on the hydrologic cycle. In coastal areas where sea water intrusion is a common problem, the quantity of fresh water storage in the basin aquifers can be assessed by accomplishing the groundwater balance. With water balance approach, it is possible to evaluate quantitatively individual contribution of sources of water in the system, over different time periods, and to establish the degree of variation in water regime due to changes in components of the system. Further, the initial analysis used to compute individual water balance components and the coordination of these components in the hydrologic balance equation make it possible the identify deficiencies in the distribution of observational stations and discover systematic errors of measurements. Finally, water balance study enables evaluation of one unknown component of water balance from all other known components. Thus, for proper assessment of potential, present use and additional exploitability of groundwater resource at optimal level, a groundwater balance study is necessary.

2.0 DEFINITION AND CONCEPT OF GROUNDWATER BALANCE

The study of water balance is defined as the systematic presentation of data on the supply and use of water within a geographic region for a specific period. The principle of conservation of matter when applied to a groundwater basin establishes that all waters entering an area during any given period of time must either go into storage within its boundaries, be consumed or flow out during that period. This basic concept of groundwater balance can be expressed mathematically as below :

$$I = O + \Delta S$$

Where, I = Inflow to the system
O = Outflow from the system
ΔS = Change in groundwater storage

The inflow and outflow terms in the above balance equation of a groundwater system may include a number of components which are discussed in detail in section 6.

3.0 SELECTION OF STUDY AREA

A basinwise approach yields the best results where the groundwater basin can be characterized by prominent drainages. A thorough study of the topography, geology and aquifer conditions should be taken up. The limit of the ground water basin is controlled not only by topography but also by the disposition, structure and permeability of rocks and the configuration of the water table. Generally, in igneous and metamorphic rocks, the surface water basin and ground water basin are coincident for allpractical purposes, but marked differences may be encountered in stratified sedimentary formations. Therefore, the study area for groundwater balance study is preferably taken as a doab which is bounded on two sides by two streams and on the other two sides by other aquifers or extension of the same aquifer.

4.0 SELECTION OF STUDY PERIOD

Precipitation is the main source of supplies. Although its distribution varies greatly from period to period, yet the variance from year to year is not so marked and precipitation over the area under study follows a net annual pattern. The period of study for hydrologic water balance is therefore generally taken as a year.

The level of the groundwater table fluctuates according to the input to the groundwater reservoir. The water input is received during the monsoon, while withdrawal from it takes place during the non-monsoon period. The water table is therefore at its maximum level of the year at the end of or somewhat after the monsoon.

In areas where most of the rainfall occurs in a part of year, it is desirable to conduct water balance study on part year basis, that is, for monsoon period and non-monsoon period. Generally, the periods for study in such situations will be from the time of maximum water table elevation to the time of minimum water table elevation as the non-monsoon period and from the time of minimum water table to time of maximum water table elevation as monsoon period. In India, the monsoon and non-monsoon periods are generally taken as June to October and November to May next year respectively.

It is desirable to use the data of a number of years preferable covering one cycle of a dry and a wet year. This will enabie to determine, the recharge for an average year, so that the groundwater potential of the area is known.

5.0 DATA REQUIREMENT

The data required for carrying out the water balance study can be enumerated as follows.

5.1 Rainfall Data

Monthly rainfall data of sufficient number of stations lying within or around the area should be available. The location of raingauges should be marked on a map.

5.2 Land Use Data and Cropping Pattern

Land use data are required for estimating the evapotranspiration losses from the water table through forests and orchards. Crop data are necessary for estimating the spatial and temporal distributions of the groundwater withdrawals and canal releases, if required. Evapotranspiration data should also be available at few locations for estimation of consumptive use requirements of different crops.

5.3 River Data

River data are required for estimating the interflows between the aquifer and hydraulically connected rivers. The data required for these computations are the river gauge data, monthly flows and the river cross-sections at a few locations.

5.4 Canal Data

Month wise releases into the canal and its distributories alongwith running days in each month will be required. To account for the seepages losses, the seepage loss test data will be required in different canal reaches and distributories.

5.5 Tank Data

Monthly tank gauges and releases should be available. In addition to this, depth vs area and depth vs capacity curves should also be available. These will be required for computing the evaporation and the seepage losses from tanks. Field test data will be required for computing final infiltration capacity to be used to evaluate the recharge from depression storage.

5.6 Water Table Data

Monthly Water table data or atleast premonsoon and post-monsoon data of sufficient number of wells should be available. The well locations should be marked on map. The wells should be adequate in number and well distributed within the area, so as to permit reasonably accurate interpolation for contour plotting. The available data should comprise reduced level (R.L.) of water table and depth to water table.

5.7 Aquifer Parameters

The specific yield and transmissivity data should be available at points sufficient in number to account for the variation of these parameters within the area.

5.8 Details of Draft from Wells

A complete inventory of the wells operating in the area, their running hours each month and discharge are required for estimating groundwater withdrawals. If draft from wells is not known, this can be obtained by carrying out sample surveys. For getting the draft of each month, the consumptive use of crops can be adopted for evaluating the same.

6.0 COMPONENTS OF GROUNDWATER BALANCE EQUATION

As sated in section 2.0, the inflow and outflow terms in the groundwater balance equation can include a number of components which are listed below.

1. Inflow :

A] Natural Recharge :
  i) Recharge due to rainfall
  ii) recharge from rivers (influent seepage)
  iii) Inflow from other basins
  iv) Recharge from tanks and reservoirs

B] Artificial Recharge :
  i) Recharge due to seepage from irrigation channels
  ii) Recharge from deep percolation of irrigation water from fields
  iii) Recharge by injection

2. Outflow :

A] Natural outflow :
- i) Evapotranspiration
- ii) Regeneration in river or effluent seepage to rivers
- iii) Outflow to other basins

B] Artificial Outflow :
- i) Pumpage through open wells, and tube wells

Considering the above components the groundwater balance equation can be rewritten as

$$R_i + R_c + R_r + R_t + I_g + S_i = T_p + E_t + O_g + S_e + S$$

Where,

R_i = recharge from rainfall
R_c = recharge from canal seepage
R_r = Recharge due to deep percolation from field irrigation
= $R_{rs} + R_{rg}$
R_{rs} = Recharge from surface water irrigation
R_{rg} = recharge from groundwater irrigation
R_t = recharge from reservoirs and tanks
I_g = subsurface inflow from other basin
S_i = influent seepage from rivers
T_p = withdrawal from groundwater
E_t = evapotranspiration losses
= $E_{tf} + E_{tw}$
E_{tf} = evapotranspiration losses from forested areas
E_{tw} = evapotranspiration losses from water logged areas

O_g = subsurface outflow from the basin
S_e = effluent seepage to rivers
ΔS = change in groundwater storage (positive for increase and negative for decrease)

The above expression considers only one aquifer system and thus does not account for the interflows between the aquifers in a multi-aquifer system. However, if sufficient data related to water table and piezometric head fluctuations and conductivity of intervening layers are available, the additional terms for these interflows can be included in the equation. Each item of the equation represents a volume of water during any given time interval. For the purpose of study any consistent units of volume and time interval can be adopted. However, the water year extending from 1st June to 31st May is preferable to the calender year and the water balance is computed for monsoon and non-monsoon seasons. Theoretically, the hydrologic equation must balance but it rarely happens in practice as there may be some inaccuracies in the estimation of various parameters. If the amount of unbalance (n) is given as a residual term of the water balance equation and includes the errors in the determination of the comonents and the values of components which are not taken into account, the equation may be rewritten in the following form.

$$R_i + R_c + R_r + R_t + I_g + S_i - E_t -_{TP} - O_g - S_{e\,-}\ S - n = 0$$

In order to avoid huge errors, all the componens of water balance equation must be estimated independently and adjustments, if required, should be made in items subject to large errors.

6.1 Recharge from Rainfall (R_i) :

Recharge from rainfall is the most important parameter among a variety of inputs used in the groundwater balance equation. The increase in groundwater storage takes place mainly due to recharge of aquifers through deep percolation of rain water. the natural phenomena of rainfall recharge is very complex to study and analyse, and any work on the estimation of recharge of aquifers by rainfall needs a clear understanding of the physical processes of the soil, vegetation and atmospheric system. The rainfall after being affected by vegetation interception reaches the land surface where it fills up the surface depressions and also infiltrates into the soil surface. Infiltration is the term applied to the process of water entry into the soil through the soil surface, vertically as well as horizontally. A portion of the infiltration reaches the groundwater storage and is called groundwater recharge. This recharge which is faraction of total rainfall depends upon several factors such as soil characteristics, topography, vegetal cover, land use, soil moisture condition, depth of water table, intensity, duration and seasonal distribution of rainfall and other meteorological factors. The recharge from rainfall, therefore, varies in space and time.

6.2 Recharge from Canal Seepage (R_c) :

The process of water movement from a canal into and through the bed and wall material is referred to as canal seepage. The seepage losses from canal after percolating deep joins the groundwater table. The recharge from seepage depends on the infiltration capacity of the canal bed and sides, subsurface litholgoy, extent of wetted perimeter, length of canal, discharge, sediment load, physical and chemical properties of water and relative position of water level in canal with respect to the groundwater table. Recharge rates may decline over the years due to water logging, clogging of pores of the bed material or cementation by calcareous precipitation.

6.3 Recharge from Field Irrigation (R_r) :

When irrigation water is applied to the field crops, a part of it is lost in meeting the consumptive use of crops and the balance infiltrates into the soil and recharges the groundwater aquifer. The infiltration from applied irrigation water, derived both from groundwater and surface water sources constitutes one of the major components of groundwater recharge especially in areas under wet crops like paddy, in view of continuous submergence of soil for long duration. However, in dry crops,, where water applied is much less and the soil is saturated for a short duration, the recharge may be insignificant as the maximum part of water applied is abstracted by crops for meeting the consumptive use.

6.4 Sub-Surface Inflow and Outflow (I_g & O_g) :

A groundwater basin may also experience flow from or towards the aquifers. If the water table level in the basin aquifers is lower than that of the adjacent basin aquifers, there may be recharge or inflow to the basin. If the water table positions are vice-versa, the flow direction will change forming discharge component. The amount of this flow depends mainly on hydraulic gradient and the transmissivity of the aquifers at the boundary of the basin. Since the hydraulic gradient and the transmissivity may vary from place to place, the net amount of flow should be estimated for different sections seperately by using the transmissivity of the aquifer and the average hydraulic gradient for that section. The length of the section, across which groundwater inflow/outflow occurs, is determined from water table contour maps, the length being measured parallel to the contour.

6.5 Effluent and Influent Seepage (S_e & S_i) :

Rivers, streams in a basin also affects the groundwater regime in the basin aquifers. The interaction between a river and an aquifer may be of two types - 1) the flow from the aquifer to support river flow, and 2) the flow from river to the aquifer. Depending upon whether water is entering the stream or going out of the stream, the stream is called as effluent or influent respectively. The direction of flow is governed by the hydraulic gradient of the water table in respect to the river stage and the amount of flow depends upon the both hydraulic gradient as well as the transmissivity of the aquifer system. For estimation of the total flow, it is desirable to divide the entire river system into a number of small reaches, each reach having atleast one observation well, and then computations be made for each segment. Adding the flow through all segments will give total flow.

6.6 Draft from Groundwater (T_p) :

Draft implies the extraction of ground water through shallow tube wells, deep tube wells and dug wells. In order to meet various demands of water, groundwater is extracted from the aquifers through different types of water lifting devices. Draft from individual well may vary widely depending upon the yield, type of well, source of lifting, depth of water level, type of water use etc. An inventory of wells and a sample survey of groundwater draft from various types of wells are, therefore, pre-requisites for computation of groundwater use.

6.7 Evapotranspiration Losses (E_t) :

Evapotranspiration, in its simplest form is the amount of water loss by evaporation and that transpired through plants for a certain area. The water requirement for evapotranspiration process
is met partly by rain water, partly by applied irrigation water and partly by direct abstraction from groundwater reservoir. In the present context of ground water balance study, only that amount of water which is directly exracted from groundwater storage through evapotranspiration process is relevant and needs to be computed. When this

evapotranspiration is from an area where the water table is close to the ground surface, the evaporation from the soil and transpiration from plants will be at the maximum possible rate, i.e. at potential rate. This potential evapotranspiration will take place in a water logged tract due to the rise in water table or the forested or other tree vegetation area which has the roots extending to the water table or upto the capillary zone.

6.8 Change in Ground Water Storage (ΔS) :

As a result of deep percolation losses of rainfall, irrigation water and seepage from surface water bodies, the groundwater reservoir experiences an increase in its storage volume. Similarly, there may be a decrease in ground water storage due to outflow of ground water in non-monsoon or dry periods resulting from pumping or subsurface drainage of aquifers. The cumulative effect in terms of net increase or decrease in ground water storage over a given period of time thus depends upon the total recharge to or discharge from the ground water storage during the given peridd. The change in ground water storage between the beginning and end of the non monsoon season indicates the total quantity of water withdrawn from groundwater storage, while the change between beginning and end of monsoon season indicates the volume of water gone to the reservoir. The change in ground water storage is exhibited by the change in water table levels in the aquifers. The water levels are highest immediately after monsoon in the month of October or November and lowest just before rainfall in the month of May or June. To monitor the water table levels, a number of observation wells with a suitable grid are installled in the basin.
Water levels in these wells should be measured under conditions as near static as possible, preferably after the season of heavy draft and again after the season of recharge. A few control wells should be equipped with automatic water level recorders or have their water levels measured monthly to facilitate detailed study of ground water fluctuations.

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REGIONAL AQUIFER SIMULATION MODELS - CONCEPT AND NEED

1.0 INTRODUCTION

Groundwater comprises of 98% of the total available fresh water resources in the entire world. The phenomenal rise in the demands for water for different purposes in the recent past, has made it imperative to exploit the ground water resources to the fullest extent possible. Though, it is necessary to exploit the groundwater for sustaining the present growth of civilisation and industrialization, it is also imperative that utmost economy must be exercised while using these resources. The formulation of a project for the optimal management of this resource demands a knowledge of the relationship between the pumpages to the drawdowns in the aquifers in spatial and temporal coordinates. Such relationships are available from the several analytical solutions, the notable among those being by Theis and Hantush. However, these solutions have been derived under highly idealised conditions and at points locations in space. Thus, there exists a need to refine the analytical solution by incorporating actual field conditions to the extent possible.

During the past two decades, it has been fully realised that quantitative assessment of the water resources is needed before using them. Computation for the available resources has brought about an awareness about its management. Before the ground water resources can be managed, they must be quantitatively assessed. Proper planning and management of this important resource requires the testing of all possible segments and apprising of the relative merits of various alternatives. It is concerned with the sustaining yields of aquifers, interrelation between well and well fields, the interrelationship between surface and sub-surface water and the quality of water. Thus, the need of the day is proper and realistic assessment of the water resources especially the groundwater resources.

The hydro-geologic properties, dimension of aquifers and existing aquitards, and the resourcesfulness of aquifers are of utmost importance in relating cause and effect. This relationship cannot be established until proper hydro-geologic maps are available. A water pumping stratum is called an aquifer that may be either confined, semi confined or unconfined.

There have been a series of developments between 1856 and until now which lead to groundwater resource evaluation as a quantitative science. Darcy did experimental works on the flow of water in sand and developed a formula known as Darcy's law which serves as basis for numerous quantitative methods in the field of groundwater flow. In 1935 Theis, first of all analysed and solved the case of unsteady flow in respect of flow towards wells in confined aquifers. The hydraulics of flow, that has been developed until now, could lead to the estimation of the aquifer properties. However, the properties determined by such methods, like pump tests, give point values for the aquifer properties and do not reflect the behaviour of the aquifer system as a whole.

It is commonly known that the groundwater in a basin is not at rest. Rather, it is in a state of continuous movement. Its volume increases by the increase in percolation of surface water, causing the water table to rise. At the same time its volume decreases by the natural phenomena, like evaporation, evapotranspairation or by means of the man-made causes, like extraction through wells, thus causing the water table to fall. When considered for a long period of time, the recharge and the discharge components may counter-balance each other keeping the water table by and large stationary. If man interferes in the hydraulics of the natural phenomenon, he may create undesirable side-effects For example, if the abstraction from well is more than recharge from rainfall and/or from surface water, the discharge component causes the water table to gradually decrease. On the other hand, if the abstraction from the ground water is reduced and in turn surface water irrigation is created abundantly, the recharge components would increase compared to the discharge components and cause the water table to rise. This may create the problem of water logging.

It can thus be seen that in spite of the greater understanding available in the literature over the groundwater movement, the greater details concerning estimation of the water table rise or fall in relation to the recharge and abstraction components over a basin are yet to be studied and analysed. Unfortunately, there are many groundwater flow problems for which the analytical solutions are difficult to obtain, since these problems are complex in nature and possess non-linear features. These features, such as, variations in an aquifer's hydrogeologic conductivity, boundary conditions that change with time, can not be considered by analytical means and hence, can not determine the long-term time depending effects. Though, certain times the analytical solutions are applied to such problems by oversimplifying the complex hydro-geologic situations, the solutions thus obtained are untrue. Thus, it is obvious that such results will be inaccurate or at times may be even totally erroneous.

Owing to the difficulties of obtaining analytical solutions to complex groundwater flow problems, there has been a need to find alternate procedures which may lead to meaningful solutions. With the advent of fast computers, such techniques exist now. They are in the form of numerical modelling which can be used for understanding and simulating the aquifer behaviour under different stress conditions. Though, the technique of solving groundwater flow problems by numerical methods is not new, it has gained momentum over the past two decades.

The formulation of governing differential equation for transient groundwater movement and some of the various types of models that are developed, giving emphasis to numerical models are discussed below.. The data requirement, for conducting a model study is also discussed alongwith estimation of aquifer parameters from the field data and from parameter estimation methods is also discussed.

2.0 THE NATURAL SYSTEM BEHAVIOUR

Although groundwater is traditionally defined as that body of water that exists in the saturated zone below the ground surface, its phase of the hydrologic cycle does not operate in isolation of all other components. The occurrence and movement of groundwater should be considered both on regional scale and local scale. When it is viewed on regional scale, the interest is not concentrated at any one point of the aquifer but overall water balance of a large aquifer with known physical boundaries and is aimed at for large scale planning of the groundwater resource. In the latter case region of interest is limited, say, in the vicinity of a well of well field. The groundwater moves from the place of recharge to the place of discharge. Under the natural conditions and over a long period of time, the groundwater system is in a state of dynamic equilibrium condition wherein recharge is equalling the discharge keeping water table levels stationary. However, with the man made interferences, the ground water levels are no more in a state of equilibrium. At places where there is an abundant irrigation and less of pumping, water tables are on rising trend tending the land to become waterlogged. In regions where there is excessive pumping, the reverse is the trend causing alarming problems like salt water intrusion near the sea coasts, land subsidence etc.

Recharge to the aquifer may result basically from the infiltration of rainfall and by seepage from streams or other surface water bodies. At times, recharge to an aquifer may take place through the lateral and or vertical movement of another groundwater body. The natural mode of discharge of an aquifer is to rivers, springs and lakes, and evaporation to atmosphere. Besides these with the increase on demand for the additional supplies of fresh water for sustaining the developmental needs of the society, heavy pumpages are made from the groundwater system. Depending upon the location of the well, it may draw off water from the storage or intercept some natural discharge.

The movement of water in the soil is governed by two forces, namely, the driving force mainly due to hydraulic gradient and the opposing force due to friction between moving water and soil particles. While determination of the former is rather easy, it is difficult to determine the latter force, since the soil matrix is generally heterogeneous and anisotropic in nature, making its exact structure impossible to define. Model complexity is usually proportional to the extent to which actual conditions are taken into consideration. In planning for most uses of groundwater, not only the amount of water available but also its quality is of great importance. A ground water model, therefore, should after processing certain given information, be able to give to the planner the quantity and quality of water that is available at the required point in space and time. However, the quantity and quality are not always modelled concurrently in most of the present day models. The majority of models are deterministic in nature and only recently have some statistical stochastic models appeared in the literature.

2.1 Groundwater Flow

The Darcy law states that the velocity of groundwater flow is proportional to the hydraulic gradient, subjected to the condition that the flow is laminar. Slchter Showed the validity of Darcy law to flow in any direction. He later applied the continuity equation with the assumption that no external stresses are acting and derived an equation describing the movement of ground water under steady state conditions. The equation resembled the famous Laplace equation which facilitated the solution of many steady state groundwater problems on the direct analogy with the corresponding heatflow problems. The unsteady state problem (transient state problems) in any elastic artesian aquifer was first analysed by Theis when he derived an equation giving the relationship between the lowering of head and discharge of a well using groundwater storage. The concepts of coefficient of storage and transmissivity were introduced by him. Later in the three dimensional unsteady state problems were analysed by Jacob, De Weist, Cooper which lead to the governing differential equation in Cartesian Coordinate system for groundwater flow, as

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} + \frac{\partial^2 h}{\partial z^2} = \frac{S_s}{K} \cdot \frac{\partial h}{\partial t} \qquad ....(1)$$

where S_s = $\rho g(\alpha+\theta\beta)$ ....(2) and is termed as Specific Storage, L^{-1}
K = hydraulic conductivity, LT^{-1}
h = head above datum, L
α = Compressibility of the aquifer medium, $LT^2 M^{-1}$
β = compressibility of water, $LT^2 M^{-1}$
θ = porosity of the medium(d-mensionless)
x,y,z = Space coordinates, L
g = acceleration due to gravity, LT^{-2}
ρ = Sp.wt.of water, ML^{-3}

Multiplying S and K by saturated thickness of aquifer,b the equation (1) and using the Laplacian operator, it can be rewritten as

$$\nabla^2 h = \frac{S}{T} \cdot \frac{\partial h}{\partial t} \qquad ......(3)$$

where S = storage Coefficient (dimensionless)
T = Transmissivity, $L^2 \ T^{-1}$

S,T are defined as the aquifer Parameters. Though, equation(3) is derived for flow through Confined aquifers of homogeneous and isotropic nature, the same can be used for flow through unconfined aquifers also, provided that the vertical component of flow is negligible and that the saturated thickness of the aquifer is large enough compared to the drawdown. In the case of unconfined flow, the storage coefficient, S is to be replaced by the specific yield term, S_y . Considering that there is an external stress on the aquifer system, the equation(3) for the unconfined flow through non-homogeneous and anisotropic medium would be

$$\frac{\partial}{\partial x}\left(T_{xx} \cdot \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(T_{yy} \cdot \frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(T_{zz} \cdot \frac{\partial h}{\partial z}\right) = S_y \cdot \frac{\partial h}{\partial t} + Q$$

............(4)

Where Q. is the external stress on the system.

2.2 Analytical Solution

Complex boundary conditions, non-homogeneous and anisotropic nature of the system and wide variations in space and time of the external recharge/discharge (Q) term(as is the case of a real life system) make the analytical solution of the equation for practically impossible. Even for the cases of steady state flow, analytical solution is possible only if the geometry of the boundaries and conditions imposed along these boundaries are simple. In general, these restrictions are not compatible with the majority of ground water problems that are encountered in real life situations and as such analytical solutions rather become impracticable. However, there are number of analytical Solutions available in the literature for many different and defined boundary Conditions which are of great help in understanding the behaviour, though, they can not be used for the management of large basins.

2.3 Simulation Studies by Models

A model is termed as a system which can- by and large duplicate the response of a groundwater reservoir. The state of art on modelling all techniques for the evaluation of groundwater potential was presented by Prickett(1975). He also gave exhaustive references of almost all the widely used groundwater models. Various aspects of groundwater studies like, groundwater resource evaluation, groundwater quality, groundwater development and its management was published by Journal of Groundwater (1963 to 1976). An overview of the literature reveals that the models can be grouped under the following heads:

a) Physical models
b) Analytical models
c) Analogue models
d) Digital models

2.3.1 Physical models

These models are the first ones used in the field of subsurface flow. The prototype aquifer system is scaled down and physically represented. The boundaries and other features are also truly represented. Usually these models are prepared in circular containers and the sides of containers are made of transparent material. Generally sand, crushed stone, graded river sand or glass spheres are used as porous media. The container is packed with either of the above said materials under to achieve a homogeneous and isotropic medium.

Though the prototype aquifer system is physically represented by these models, there are many limitations due to the following

a) Scale reduction generally poses a problem
b) Capillary action, entrapped air and organic growth create trouble.
c) Overall modelling of large and complex basins is difficult.
d) Changes for different aspects of study cause inconvenience.
e) Good laboratory facilities are needed.

2.4.2 Analytical models

It is possible to evaluate the response of wells with analytical methods by devising approximate methods of analysis based on idealised aquifer situations. The case histories where the analytical models are used suggest that the predicted behaviour of the aquifer system may not deviate substantially from the observed one, provider that the idealisation does not drastically alter the physical system. However, the analytical models can not describe in detail hydrogeologic systems having complex geometry and great variations in the hydraulic properties.In such cases, it is necessary to go in for other types of models.

The well field problems are solved by image well theory, method of superposition and the appropriate theoretical ground water equation. Prickett gives a summary of some selected applications of analytical models. However, with the present day development in the field of numerical modelling, the analytical modelling for solving the problems on a regional basis have become outdated.

2.4.3 Analogue models

Analogue models can be either viscous flow models or electrical analogue models. In the former case, the analogy between flow of groundwater and that of viscous flow between two closely placed parallel plates is used. These parallel plates can either be horizontal or vertical. The comprehensive articles describing these models are presented by Santinga and Collins Generally viscous flow models can simulate two dimensional flow problems. Cecer and Omay indicated the use of single plate viscous flow model to simulate three dimensional flow problems as well.

Electrical analogue models can be divided into two categories: a) continuous models b) discrete models. While in the continuous models, an electric conducting medium, like a resistance paper is used, in the latter case an assemblage of discrete electrical components are used. These are also termed as network models. They consist of regular arrays of resistors and capacitors. In the resistor-capacitor network, resistors are approximately considered as inversely proportional to the hydraulic conductivity of the aquifer, and the capacitors store electrostatic energy in a manner analogous to the storage of water within an aquifer. The electrical network resembles closely to an aquifer and can be considered as scaled down version of it. The network model is connected to an exitation-response apparatus consisting of power supply, wave form generator, pulse generator and oscilloscope. This apparatus forces electrical energy in the proper time phase into the model and measures energy levels within the energy-dissipative resistor- capacity network. Oscilloscope traces are analogous to time drawdown graphs that would result after a stop function type change in discharge or head. A catalogue of time voltage graphs provide data for construction of a series of water-level-change maps.

These models can deal with problems of much greater complexity then is practicable with analytical models. The accuracy, flexibility speed give added advantage to analyse rapidly almost any conceivable aquifer system. Transient and complex conditions can easily be handle. A digital computer working in conjunction with network model is used for instantaneous solution of groundwater flow problems. In spite of the fact that these models can truly represent hydrogeologic nature of an aquifer system, they became outdated with the advent of fast digital computers.

2.3.4 Digital models

The digital models gained momentum for solving groundwater flow problems since early 1970s. These models offer several advantages over the other types of models, because of which they gained popularity. The convenience with which they can be modified for solving varied problems and the accuracy of the solutions are some of the advantages. There are several numerical techniques available in literature, the commonest being finite difference and finite element methods. The models that are widely adopted for solving the groundwater problems, at present times, use either of these techniques. Wide variety of aquifer conditions were considered in formulating the digital models like two and three dimensional flow on non-homogeneous and anisotropic media under confined and unconfined conditions. Besides the above, for other problems like; evapotranspiration coupled saturated-unsaturated flow, combined watershed-aquifer-stream system, mass transport induced infiltration from rivers and channels, coupled flow and heat-transport and combined evapotranspiration, stream-aquifer interaction, these techniques are used .

a) Finite difference method

The governing differential equation (Eq.4) is replaced by difference equation, in the finite difference scheme. The region is discretized into rectangular grids or polygons with each grid/polygon centering about a node with the basic assumption that over the area represented by a grid, the recharge, abstraction, hydrogeologic properties remain unchanged and are represented at its nodal point. This assumption facilitates the discretization of aquifer parameters and other variables which are really continuous. Thus, the governing differential equation involving the head values at the nodal points is solved by applying suitable boundary conditions and solving the set of equations. There are several efficient methods in the literature for solving the system of simultaneous equations. Of those Alternating Direct Implicit Scheme, Strongly Implicit procedure, and Slice Successive Over relaxation scheme have been widely used. The Gauss elimination scheme, though rather simple, requires larger computer memory. Gauss-Seidel iteration technique is also used widely. Generally, a relaxation factor is used for faster convergence.

b) Finite element method

The application of finite element method to subsurface problems followed distinctly two paths, i) Galerkin approach ii) variations approach. The Galerkin finite element approach is generally used petroleum industry, the first of its kind being introduced by Price, et.al. Although, the objective was to overcome problems generally associated with finite different solutions to the convection-dominate transport equation, it has greater potential appeal. Subsequently this method was applied to a two phase flow water flooding problems. Because of their computational inefficiency, this approach is non- competitive with finite difference algorithms, though solutions are highly accurate.

In groundwater hydrology, finite element theory has been employed using triangular and isoparametric elements. Mostly, first degree Lag-range polynomials as basis functions are used in ground water simulations. Finite difference element method is particularly suited to free surface flow problems because of the simplicity of deforming the mesh and updating the element matrix coefficients to accommodate the changing geometry of the solution domain and changing element properties due to nonlinear material behaviour. This is more evident in the case of land subsidence problems.

The finite element approach consists essentially of the following steps:

a) Discretization of the region and defining the nodal points and elements.
b) Defining the flow matrix and flow load vector corresponding to a single element derived on the basis of appropriate choice of element type and basis function
c) Assembly of element matrices and load vector to obtain global matrix.
d) Solution of the system of equation for nodal values.

In spite of the fact that finite element approach is more powerful than finite difference methods, the application models for real life situations still lack momentum.

c) The Boundary element method

The boundary element approach is a relative newcomer. one of the early papers in this area was written by Jaswon and Ponter who applied this method to solid mechanics problem. In groundwater hydrology, this method was introduced by Liggett for solving the problems of free surface flow. Though this method is advantageous for solving elliptic equations, it loses much of its appeal for problems or problems involving variable coefficients. Unlike in the case of finite difference, finite element methods, the matrix generated in the boundary element method is full, because of which it loses the computational efficiency.

d) The Collocation method

Although collocation method has been used since the 1930s, for the solution of engineering problems, it is only during the last decade that the technique has been employed over subspaces in a manner analogous to finite element method. This method has been applied to groundwater flow problems by Pinder et.al. The relative merits of the collocation method as compared to other methods for solving subsurface flow problems are yet to be established. It appears that real life simulation problems are yet to be attempted by using either Boundary element method or collocation method.

3.0 PROBLEM DEFINITION

Whenever a groundwater model study is to be conducted for any basin, it is highly essential to know the purpose for which the study is to be conducted. The scope of the study will define the problem formulation and the extent to which the solution is to be accurate. As already seen from the review, there are number of models which have been developed and used for real life situations. However, each by model has its own limitations and advantages. A particular model can be less accurate but it may be simple in its formulation and faster in convergence. In order to choose a model, it is necessary to understand the limitations, the assumptions made in its formulation. Also,it is essential to know the requirements of data for the use of a specific model. Most of the times, sufficient data with regard to these hydrologic characteristics like aquifer parameters and topographical chacteristics like boundary conditions to be incorporated, may not be available. Even if such data are available, at times, the data may not be accurate enough. Thus, the analysis of data plays an important role. Sometimes, the data may be available at few discrete points only Which may have to be regionalised. Rational procedures for such analysis and refinement of data have to be adopted. These situations make the ground water modeller to have an in-depth knowledge of the available techniques in literature with respect to the types of models, the methods for the estimation of the values for the aquifer parameters and the various techniques of solution procedures.

Background information is necessary for simulating an aquifer on a regional scale. The various methods available in literature for parameter estimation and the different criterion function with their implications and the requirement are discussed.

4.0 DATA REQUIREMENT AND COLLECTION

Data collection forms the initial phase of any model study. All geological and hydrological data are required to be collected before initiating a groundwater problem. This will include information on surface and subsurface geology, water tables, precipitation, evapotranspiration, stream flows, land use, vegetative cover on the surface, extraction from wells, aquifer boundaries, irrigation, aquifer characteristics etc. In case a little or no data are available, the first effort should be directed towards field work for collection of data. This is very much essential to develop a conceptual model on a rational basis with its various inflow and outflow components. A conceptual model is based on a number of assumptions that must be verified in a later phase of the study. Developing and testing a model requires a set of quantitative hydrogeological data which can be broadly grouped into three classifications, namely:

1. Physical characteristics
2. The exitations on the system,
3. Other relevant information.

The various requirement of data under these Classifications are given in table 1.

Table 1 - Data requirements for groundwater model study

Physical Characteristics		Extension of the System		Other information	
a)	Topographical map showing surface water bodies, other features	a)	Water table mpa	a)	Legal and administrative rules
b)	Hydrologeological mpa showing area extent of boundaries, boundary conditions and types of aquifer.	b)	Type and extent of recharge and discharge areas	b)	Environmental factors.
c)	Lithological variations within aquifer.	c)	Rates of recharge and discharge	c)	Planned change in water and land use
d)	Aquifer parameters and their distribution.	d)	Groundwater balance	d)	Economic information of water supply.

It is customary to present the results of hydrogeological investigations in the form of maps, geological sections and tables.

4.1 Physical Characteristics

4.1.1 Topographical map

An accurate topographical map of the groundwater basin to be modelled is a pre-requisite. The scope of the study and size of the basin determines the scale of the topographical map. A scale of 1: 50,000 to 1:75,000 will suffice generally. This map should indicate all surface water bodies, streams, big lakes, and other water transportation systems. It should also indicate the ground level contours with a contour interval of 5 to 10 m.

An inventory of dug wells, deep tube wells and types of pumping structures in the area should be made. Observation wells which are used to define the water table elevations should also be identified on the map. Proper numbering of these wells for identification should be made. The datum level, the ground level after proper levelling for each of the observation wells should be marked on the map. The measured water levels should be converted into water levels above/below a particular datum level, say, mean level by conducting a systematic levelling.

4.1.2 Hydrogeological maps

Intensive geological and geomorphological studies of the ground water basin wilt be required to delineate its geomorphological features or land forms and to evaluate the manner and degree in which they contribute to the basin's hydrology. The type of the material forming the aquifer system and confining material, location and nature of the aquifer's impermeable base, the hydraulic characteristics of the aquifer and location of any structures affecting groundwater movement are of special importance.

Groundwater basins, which are usually defined as hydrological units containing one large aquifer or several connected and interrelated aquifers, may be classified on the basis of their main depositional environment. For a proper understanding of the basin's hydrology, it is necessary to recognize and delineate the morphological features, which are grouped into topographical high lands and topographical low lands. The high lands are generally the recharge areas, characterized by a downward flow of water and the low lands are usually the discharge areas, characterized by an upward flow of water.

The geological history of the basin must be known as the resulting geological structure controls the occurrence and movement of groundwater. The number and type of water-bearing formations, their depth, inter-connections, hydraulic properties and out crop patterns are all the results of the basin's geological history. The study of the subsurface geology is required to find out the type of materials that make up the groundwater basin, their depositional environment and age, and their structural deformation, if any. The geological information has to be related to the occurrence and movement of the groundwater by translating it in terms of water bearing formations, confining layers, leaky aquifers. Also, isopach maps of the aquifers are to be prepared which will indicate the thickness of the aquifers. From logs of the wells, the configuration and elevation of impermeable base of the aquifer can be determined.

The condition at the boundaries of the aquifer must be properly defined. Different types of boundaries exist, which may or may not be a function of time. They are: a) zero flow (noflow) boundaries, b) head-controlled boundaries, c) flow controlled boundaries.

The model of the basin requires that external noflow boundaries be delineated and indicated on a map. It also requires that the configuration and elevation of the impermeable base, which is an internal no flow boundary, be determined. Groundwater divides, which acts as no flow boundaries must be indicated. In mathematical terms, the condition at a no flow boundary is $\partial h/\partial n = 0$, where h is the ground water potential and n is the direction normal to the boundary.

A head controlled boundary is a boundary with a known potential or hydraulic head, which may or may not be a function of time. Examples of this type of boundary are: large water bodies like lakes, oceans whose water levels may not drastically change with the events, water courses and irrigation Canals with fixed known water levels. Mathematically, a head controlled boundary that changes with time is expressed as $h = f(x,y,t)$ if it varies with time or $h=f(x,y)$ if it is independent of time. Similar to the no-flow boundaries, head controlled boundaries can be differentiated as internal boundaries or as external boundaries.

A flow controlled boundary is a boundary through which a certain volume of groundwater enters/leaves the aquifer under study per unit of time from adjacent basin, whose hydraulic head and/or transmissivity are not known. Flow controlled boundaries are simulated by setting the hydraulic conductivity at the boundary equal to zero, and entering the underflow into the model as a recharge/discharge term. Mathematically, the flow is represented, for a steady state, by the normal gradient dh/dn, taking a specified value for it.

While modelling, it is preferable to delineate the basin for study at the no-flow boundaries or head controlled boundaries. If it is not feasible to do so, it is desirable to choose an arbitrary boundary and estimate the flow across it by knowing the heads on either side of the boundary.

4.1.3 Lithological variations in an aquifer

No aquifer is lithologically uniform over the entire basin. Both lateral and vertical variations do occur. Since the grain size of the aquifer material has bearing on the hydraulic conductivity and porosity, and thus on the flow and storage of groundwater, the preparation of sand percentage map forms an important part of modelling.

4.1.4 Aquifer parameters

The magnitude and distribution of the aquifer characteristics must be specified. These characteristics depend on the type of the aquifer. They may be:

a) hydraulic conductivity(for all types of aquifers),
b) storage Coefficients for confined and leaky aquifers),
c) specific yield(for unconfined aquifers)
d) hydraulic conductivity for leaky aquifer, if exists.

There are various field, laboratory and numerical methods to determine or estimate these parameters.

i) Estimation of hydraulic conductivity

Aquifer in-situ tests are the most reliable methods of determination of these parameters,though they are costly. · In view of this, only few tests can be conducted in regional aquifer studies. The data, thus collected may not be adequate to draw the hydraulic conductivity maps or storage coefficient distribution maps. Supplementary data have to be collected by conducting tests, like, well tests, slug tests and point tests. A well test consists of pumping an existing small diameter well at a constant rate and measuring the drawdown in the well. When the steady flow conditions are obtained, the transmissivity of the aquifer can be determined using the following modified Theis equation,

$$KD = 1.22Q/S_w \qquad ....(5)$$

where,

K is the hydraulic conductivity in m/day
D is the thickness of the aquifer in m
S_w is the drawdown in the well in m
Q is the constant well discharge in m /day

This test can be used either for confined or unconfined aquifers. However, if it is applied for unconfined aquifers, the drawdown suitably corrected as $s_w^* = s_w - (s_w^2 /2D)$ where s_w^* is the corrected down and D is the saturated thickness of the unconfined aquifer values of transmissivity thus obtained may not be accurate, especially when well construction information is not available or when the well screen is partly clogged.

A slug test Consists of abruptly removing a certain volume of water from a well and measuring the rate of rise of the water on the well. Sufficient drawdown is to be created for this test be effective. Bouwer gave the formula for estimating the transmissivity and specific yield for partially and fully penetrating in an unconfined aquifer. Using these formulae an estimate can be for the aquifer parameters.

A point test is a permeability test made while drilling exploratory bore hole. This is also termed as a packer test When hole has reached a certain depth, a small screen whose length equals its diameter is lowered into the hole. After the casing has been pulled up over a certain distance and a packer is placed to close the as space the water level in the pipe is lowered by a compressor. When the water level stabilizes, the pressure is released and the rates rise of water level is measured. These are plotted against corresponding time on a semi-log paper. The points fall on a straight the slope of which can be determined. Using the following formula, the hydraulic conductivity of the aquifer material at the depth of the screen can be determined:

$$K=0.575\frac{r_c^2}{r_s}\cdot\frac{1}{\Delta t} \qquad ......(6)$$

where,

r_c = radius of the casing pipe in m
r_s = radius of the screening pipe in m.

However, when applying this formula , the resistance of screen, the well storage are to be properly accounted.

The hydraulic conductivity can also be estimated using the grain size distribution. Aquifer material do not generally consist of uniform particle of one single diameter but of particles of different sizes to be grouped in fractions, each with certain limits of particle based on which classification of sands is made. It was found that hydraulic conductivity is inversely proportional to the square the specific surface of the aquifer material.

Other methods like flow net method can also be used in estimating the hydraulic conductivity. In regional aquifer simulation, it is important to know the order of magnitude of hydraulic conductivity at as many places as possible in the study area rather than very accurate values at few places. Hence, estimation of hydraulic conductivity even by less accurate methods will be of great importance for model studies which will provide quantitative data. Thus the data obtained by any of the methods should be used to compile a transmissivity map from which hydraulic conductivity map can be prepared. For this purpose, isopach map can be used.

ii) Estimation of specific yield

It is a dimension-less parameter. It characterizes the storm capacity of unconfined aquifers. It can be determined from the data of an aquifer test. But these tests may have to last for days together for the value of specific yield to be reliable. This can also be measured by other techniques, like by determining in the laboratory the difference between volumetric water content at saturation and the water content when most of it has drained from the pores (water content at field capacity). The other method consists of measuring the drop in the water table and the amount of water drained from the field. Then the specific yield is determined by dividing the quantity of drained water per unit area by the drop on water table. This method is often used in experimental fields. However, these methods are time consuming and costly because of which they can be performed at few selected locations only. While conducting groundwater model studies, where the distribution of specific yield is of more interest, it may not be possible to have so much data by these methods only for obtaining fair and realistic distribution of this parameter over the entire basin. So generally using the grain size distribution, the estimates will be made. The table 2 gives the orders of magnitude and ranges for specific yield of different materials.

Table 2 - Orders of magnitude and ranges for specific yield of different materials (after Morris and Johnson 1967)

Type of material	Specific yield(percent) Range	 Mean
Coarse gravel	13-25	21
Medium gravel	17-44	24
Fine gravel	13-40	28
Coarse sand	18-43	30
Medium sand	16-46	32
Fine sand	1-46	33
Silt	1-39	20
Clay	1-18	6
Loess	14-22	18
Eololian sand	32-47	38
Duff	2-47	21
Sandstone(fine)	2-40	21
Sandstone (medium)	12-41	27
Siltstone	1-33	12

iii) Estimation of storage coefficient

The aquifer test data has to be for the determination of the storage coefficient for case of confined and leaky aquifers. Van der Gun has presented an empirical expression for finding out the order of magnitude of the storage coefficient knowing the depths upper and lower surface of the aquifer below ground surface. The information obtained from the well logs, thus, can be used in case the wells are fully penetrating.

In spite of the best efforts, the distribution maps of the aquifer parameters can not be completed due to the complexity of the aquifer systems. It is, therefore, necessary to adjust these values at the time of model calibration.

4.2 Exitation on the System

4.2.1 Water table map/Piezometric map

The exitations caused due to the infiltration,stream-bed percolation, evapotranspiration, pumping from wells etc. create hydrological stress on the aquifer system and reflects in the form of a change in the configuration and fluctuations in the water-table. Thus,preparation of water table contour map is essential which requires realistic water table data. Appropriate network of observation wells/piezometers are needed depending upon the size and nature of the basin to study the magnitude and distribution of the hydraulic head. Proper selection of sites for observation wells have to be made depending upon the variation in the aquifer thickness, lateral and vertical variations in the lithology. The data thus obtained is used for the preparation of water table map/piezometric contour map. Many times other maps like depth to water table maps, water table change maps, head difference maps are also prepared to give sufficient insight into the hydrogeological conditions of the basin and its ground water regime. Depending upon the time discretization adopted in the model study, these maps are prepared accordingly, i.e.if the time unit is a month the maps are to be prepared on monthly basis.

4.2.2 Type and extent of recharge and discharge areas

Recharge areas are areas where the aquifer gains water through infiltration,stream-bed percolation, surface runoff from adjacent hilly terrain, percolation from irrigated areas, seepage from canal conveyance systems etc. On the some arelines, there will be discharge areas from where the aquifer losses water through springs, evaporation and pumpage etc. A study of topographical maps and aerial photographs, in addition to field surveys will be able to identify the type and extent of recharge and discharge areas.

4.2.3 Rate of recharge and discharge

Several methods exist for the determination of the recharge and discharge components. After proper identification of the factors that contribute to the recharge and discharge, they are to be quantitatively assessed.

a) Recharge components

The main source of recharge to the aquifer is the recharge from precipitation. It is, thus, necessary to have a detailed knowledge of the account of precipitation and its distribution spatially and temporally. The rate of recharge can then be assessed either by using the water table fluctuation method or by the empirical formulae which have been derived earlier for the region under study. Similarly, the recharge from the irrigation canals, deep percolation from irrigated fields, stream bed percolation have to be properly assessed. Various methods, like lysimeter studies, insertion of tensiometers, isotope studies can be used for this purpose.

b) Discharge Components

The sources of discharge are springs, outflow towards rivers/streams, evapotranspiration and pumpages. Springs are the most common form of groundwater discharge. Their occurrence is governed by local hydrogeological conditions. When the water table is cut by the ground level or due to faults, springs are generally originated. The outflow through springs can be assessed using runoff hydrographs.

The evapotranspiration is a combined effect of evaporation from soil and transpiration by natural vegetation and cultivated crops. Assistance of agronomists may be necessary in realistic assessment of this component. The basic factors which govern this component are: climate, soils, soil water availability, crops, their intensity and pattern, environment and exposure, methods of irrigation etc. The data with regard to land use, irrigation practices, crop survey, climatological information .are, thus, needed for proper estimation of evapo-transpiration.

Due to the fast growing needs of the society, the groundwater pumpage is on an increasing trend. The assessment of this component, thus,requires a realistic approach. The data pertinent to the total number of wells, different types of structures and rate of pumping from each of these structures at different times forms an important source of information. Inquiries about the time of operation of wells can be made and the rate can be assessed. Alternatively, data on fuel or electricity consumption can be used to assess the rate of pumpage.

4.3 Groundwater balance

The groundwater basin must be in dynamic hydraulic balance during a time period of any duration. This condition can be written as:

$$R + E + I + O + \frac{\partial S}{\partial T} = 0 \qquad \ldots\ldots\ldots\ldots(7)$$

where,
R = total recharge
E = total extraction
I = lateral inflows at the boundaries
O = lateral outflows at the boundaries
∂S = change in storage over a time period ∂T

When hydrogeological investigations have been completed and inflow and outflow components of the aquifer have been quantified, an overall groundwater balances of the basin must be assessed, which will serve as a verification of the results of the model study. Also, the water balance technique can be used as a valuable tool for quantifying certain components of the equation (6) which are otherwise difficult to determine. It is very much essential to note that while using this approach, the quantification of the other components should be precise, otherwise, the results may be misleading.

The data requirement for Water Balance Study is summarised below:

1. Precipitation: Daily rainfall data at raingauge stations lying within and around the study area.
2. Stage and discharge of all rivers flowing within the basin and rivers forming external boundaries at various control points.
3. Monthly discharge in the main branch canals at the off take points.
4. Monthly discharge at various sections of the main branch canals.
5. Cross section and longitudinal sections of the canals and its distributaries, depth of water in the canal.
6. The dates or days on which water is supplied to the canals and the running hours.

7. Ground Water Table Data: Monthly water table data observed at the observation wells available in the study area and corresponding ground elevations.
8. water table hydrographs near raingauge stations,if available.
9. Ground Water Withdrawal Data: Number and capacity of Ground Water draft structures area-wise: Sample survey of drafts and running hours.
10. Test pumping data to evaluate specific yield and transmissivity
11. Infiltrometer test data at few places within the study area
12. Seepage from canal estimated either by inflow-outflow met or ponding method.
13. Grain size distribution of the soil Sample obtained from canal bed.
14. Land Use Data- forests, orchards and tall vegetations, waterlogged area, cultivated area, canal irrigated at well Irrigated area, and unirrigated area.
15. Existing Cropping Pattern.
16. Daily pan evaporation values.
17. Daily minimum and maximum temperature, minimum and maximum relative humidity, average wind speed,sunshine hours.
18. Well log data.
19. Irrigation practices over the area.

5.0 USE OF GROUNDWATER MODELS

Among the numerical groundwater models, models with four different major purposes can be distinguished. These are (1) prediction models, which simulate the behaviour of the groundwater system and its response to stress; (2) resource management models, which integrate hydrologic prediction with explicit management decision procedures; (3) identification models, which determine input parameters for both of the above; and (4) data manipulation and storage procedures, which process and manage input data for all of the above.

5.1 Prediction Models:

Most of the models produced to date are prediction models which may be subdivided into four major categories: flow, subsidence, mass transport, and heart transport.

Flow models utilize information on aquifer parameters, boundary conditions, and man-induced development to solve mathematical equations for determining quantitative aspects of groundwater flow such as direction and rate of flow, change in water level, stream-aquifer interactions, and interference effects of wells. While most of these models simulate flow in aquifers, flow models have also been developed for the unsaturated zone and for coupled saturated-unsaturated-surface systems. Flow models are the most commonly used, as well as the best developed of the groundwater models.

Subsidence or deformation models describe the phenomenon of land subsidence which is caused by withdrawals of groundwater. Subsidence models are needed to predict deformation-related impacts of various pumping schemes in affected areas.

Mass transport models deal primarily with question of groundwater quality. They are used to predict the movement and concentration in the aquifer of various pollutants including radionuclides, leached solids from land fills and irrigated areas, and salt water intruding in coastal areas. To accomplish this, the models incorporate mathematical approximations of the transport by means of fluid flow (convection) and/or mixing of one or more chemical constituents in the groundwater. Mass transport models in general tend to be more complicated than flow models. Transport models that describe the movement of pollutants without reactions are called conservative; models that also take into account reactions are termed nonconservative. The oil industry has been active in developing transport models for immiscible fluids, oil and water.

Heat transport models couple the flow of heat with water or steam for problems where thermal effects are important. In practice these models have been applied to problems associated with hot springs, geothermal reservoirs, and heat storage.

5.2 Resource Management Models

Management models have been developed in an attempt to indicate courses of action which will be consistent with stated management objectives and constraints. The objectives may be, for example, to maximize net economic benefits, to minimize costs, or to ensure adequate water supplies. Management models may employ the techniques of both simulation and optimization in deriving their outputs. In contrast to purely physically based prediction models, management models incorporate economic, technological, political and institutional aspects of the problem.

5.3 Identification Models

Parameter identification models have been developed in response to the need to provide improved estimates of parameters. Engineering techniques have long existed for calculating parameters through pump tests. For most regional groundwater systems, regular water level observations are made in wells through the regional system. Parameter identification models are being developed which attempt to derive parameter values for groundwater models through the analysis of water level data.

The task of an identification model can be defined as one of solving a problem which is the inverse of that of prediction, namely, given the historical input to a real system and given a model for predicting its performance, find those parameter values which ensure that the predicted output is as close to the observed output as possible.

5.4 Data Manipulation Codes

The difficulties involved in estimating parameters are closely linked with the more general issue of data collection for groundwater models. While models can be run with any amount of available data, the actual amount and quality of these data directly affected the reliability of the model's results. The task of collecting appropriate amounts of accurate data to ensure model reliability thus implies the need for a fourth class of computer code - data manipulation. These codes can be used in various ways, including specifying data collection procedures, designing data collection networks, identifying critical data, and storing processing data for use in other models.

5.5 Additional Comments

Related to all of the models treated above is the question of the reliability of model outputs. The factors which affect the reliability of prediction are generally uncertainties about equations, parameters, and historical data used to describe the groundwater system. Uncertainties in some data may be caused by unpredictable future events such as demand for water or prices of water. Groundwater modelers are currently divided over the level of effort which should be devoted to incorporating uncertainty into their models. Ways of incorporating parameter uncertainties into prediction models are being investigated actively at the present time.