TRAINING COURSE

ON

SOFTWARE FOR GROUNDWATER DATA MANAGEMENT

UNDER

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LECTURE NOTES
ON

GROUNDWATER DATA BASE & GROUNDWATER MAPS

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GROUNDWATER DATA BASE AND GROUNDWATER MAPS

1.0 INTRODUCTION

Extensive groundwater exploitation during past two decades for meeting irrigation, water supply and industrial needs, has drawn the attention of groundwater hydrologists towards maintaining sufficient groundwater supply throughout the year. The assessment and management of groundwater resources are more important in the sense that groundwater is more protected against pollution, has natural system for its storage, does not have the problem of huge evaporation losses. In order to arrive at the management alternatives, the assessment of groundwater potential and the behaviour of groundwater system under various stress conditions are required besides the alternatives for the creation of additional resources. All these require the collection of reliable data and their compilation and processing in an intelligent manner.

This lecture, data required for groundwater assessment and preparation of groundwater maps has been discussed. Interpretation of various groundwater maps has also been discussed.

1.1 GROUNDWATER DATA

Groundwater is an important natural resource. Availability and utilisation of groundwater plays a leading role in social and economic development of the nation. For scientific exploitation of groundwater, all proper and good quality data is required to be collected and well documented. All geological and hydrological data are required to be collected before initiating a groundwater problem. This includes information on surface and subsurface geology, aquifer type, aquifer parameters, water tables, precipitation, evapotranspiration, stream flows, land use, vegetative cover on the surface, extraction from wells, aquifer boundaries, irrigation, aquifer characteristics etc. These data are important not only for exploitation but for planning, design and operation of the groundwater structures. Since groundwater is a dynamic source, the accuracy and reliability of acquired data usually increase with the time available for observation and interpretation.

There is no definite list of basic data required for ground water studies. However, the following data should be collected.

A. Maps, Cross Sections, and Fence Diagrams

- Topographic
- Geologic
- Hydrologic
- Vegetative cover / landuse
- Soils

B. Data on Wells, Observation Holes, and Springs

- Location, depth, diameter, types of well, and logs
- Static and pumping water level, hydrographs, yield, quality of water
- Location, type, geologic setting, and hydrographs of springs
- Observation well networks

C. Aquifer Data

- Type, such as unconfined, artesian, or perched
- Thickness, depths, and formational designation
- Boundaries
- Transmissivity, storativity, and permeability
- Discharge and recharge
- Ground and surface water relationships

D. Geological data

- Soil texture
- Soil structure
- Soil moisture characteristics
- Infiltration characteristics
- Structural geology and stratigraphy

E. Geophysical Data

- Electrical resistivity data
- Seismic data
- Gravity and Magnetic data
- Geophysical logs

F. Climatic Data

- Precipitation
- Evaporation and Evapotranspiration
- Other data such as temperature, wind velocities and directions etc.

G. Surface Water

- Surface water use
- Quality of water
- Runoff distribution, reservoir capacities, inflow and outflow data

H. Other data

The details of the data required to be collected are discussed below.

1.2 MAPS, CROSS SECTIONS AND FENCE DIAGRAMS

Analysis and evaluation of subsurface data for a groundwater study are readily performed using maps, cross sections, and fence diagrams. Some of the important maps are topographic map, geologic maps and sections, hydrological map, vegetation map, soil map etc. General maps which are useful in groundwater studies are discussed in this section Specific groundwater maps have been discussed in section 2.

1.2.1 Topographic Map

A Topographic map presents both horizontal and vertical positions of the physical features of a land area on a flat plane at definite scales. Such maps supply information on surface gradient and drainage pattern and are used as the basis for construction of cross sections and maps showing geology, depth to water, surface and water table gradient, contribution and recharge areas etc.

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: 25,000 to 1:50,000 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.

1.2.2 Geologic map, cross section and fence diagram

Geological maps are those maps which depict the lithology, structure, and stratigraphy on a map. The information about faults, fractures and joints should also be plotted on these maps. These maps are useful in most groundwater investigations and are essential where complex stratigraphy and structures are involved. Analysis of these maps give information on recharge areas, possible aquifers, structural and stratigraphic control on movement of water.

Vertical geologic profiles drawn through the geological map with the help of dips and strike of the lithological boundaries and drill hole data is known as geological section. The geologic sections are important to know the geometry of the aquifer system.

Fence diagram are three dimensional cross section that are helpful in presenting an areal picture of geologic conditions. As for sections, they are based on geological maps, logs of the holes and topography.

1.2.3 Landuse Map

Landuse map depicts the usage of land for various purposes such as, agriculture, forest, builtup area, barren area, pastures, mining, roads, rivers and canals etc. These maps are important to estimate evapotranspiration losses, infiltration rate, runoff etc. These maps are prepared using field survey data or remote sensing data.

1.2.4 Soil Map

A soil maps is a map designed to show the distribution of soil types or other soil mapping units in relation to other prominent physical and cultural features of the earth's surface. Soil type includes sand, silt, clay, sandy clay, sandy silt, silty clay etc. These maps are important in deciding the location of infiltration tests and estimation of recharge due to rainfall or irrigation return flow.

1.3 DATA ON WELLS, OBSERVATION HOLES, AND SPRINGS

1.3.1 Data on wells

Wells are the groundwater structures which are used for discharge/recharge of water from/to groundwater reservoir. Important data to be collected regarding the wells is

- location of well, i.e., its coordinates and reduced level of the ground surface
- depth and diameter of well, and type of penetration fully penetrating/partially penetrating
- type of well, i.e., dug well, bore well dug-cum-bore well etc.
- type of casing, i.e., cased or uncased, and if cased material of casing, casing diameter
- location, perforation size and orientation of screen slots
- logs, if any geophysical logging i.e., electrical resistivity, Spontaneous potential, calliper, radioactive, or geological logging, has been done than its logs should be recorded.
- static and pumping water level
- hydrographs i.e, variation of water level/piezometric surface with time
- yield including discharge, drawdown with time, pumping hours etc.
- quality of water, physical, chemical and biological quality of water

1.3.2 Data on observation holes

Observation holes/well are the groundwater structures constructed to measure the water table/piezometric surface at a particular location.

- location of observation holes, i.e., its coordinates and reduced level of the ground surface and measuring point
- depth and diameter of observation well
- type, i.e, piezometer or dug well or any other well
- aquifer tapped be the observation bole
- Observation well networks, if available for the area

1.3.3 Data on Springs

A spring is a concentrated discharge of groundwater appearing at the ground surface as a current of flowing water. To be distinguished from springs are seepage areas, which indicate a slower movement of groundwater to the ground surface. Water is seepage areas may pond and evaporate or flow, depending on the magnitude of the seepage, the climate, and the topography. Various characters of the springs which are important to be recorded are :

- character of openings through which the water issues i.e., seepage spring, fracture spring and tabular spring
- rock structure and the resulting force that brings the water to the surface i.e. gravity spring, artesian spring.
- lithological character of the aquifer that yields the water i.e. limestone spring, sandstone spring etc.
- geological horizon of the aquifer giving rise to the spring i.e. Vindhyan limestone spring
- quantity of water discharged
- variability in discharge with time
- permanence of discharge i.e. perennial spring and intermittent spring
- quality of water
- temperature of water

1.4 Aquifer Data

Aquifer data includes information about type of aquifer, type of confining layer, aquifer parameters, type of boundaries, areas of recharge and discharge etc.

1.4.1 Type of aquifer

Groundwater occurs in many types of geologic formations; those known as aquifers are of most importance. An aquifer may be defined as a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs. Aquifers can be classified into three types:

- Unconfined aquifer i.e, aquifer in which groundwater is under atmospheric pressure.
- Confined aquifer i.e, aquifer in which groundwater is under pressure greater than atmospheric pressure due to presence of overlying impervious strata (aquiclude).
- Semi-confined aquifer i.e., aquifer is which confining layer is semipervious (aquitard).

1.4.2 Type of confining layer

There are various types of confining beds, i.e,

- Aquiclude i.e., a saturated but relatively impermeable material that does not yield appreciable quantities of water to wells, e.g. clay.
- Aquitard i.e., a saturated but poorly permeable stratum that impedes groundwater movement and does not yield water freely to wells, but that may transmit appreciable

water to or from adjacent aquifers and. where sufficiently thick, may constitute an important groundwater storage zone, e.g., sandy clay.

- Aquifuge i.e., a relatively impermeable formation neither containing nor transmitting water, e.g., solid granite.

1.4.3 Aquifer geometry

Aquifer geometry includes shape of the aquifer. It facilitates the boundary conditions to be applied during modelling. It also gives an idea about the recharge zone and discharge zone. Example is a paleo-channels in alluvial plains. This includes the aerial extent and thickness of the aquifer/aquiclude/aquitard and depth to impervious layer. Aquifer geometry can be obtained from the fence diagram constructed using well logs.

Aquifer geometry is generally well defined in hard rock areas, whereas, in alluvial areas it is difficult to ascertain the exact geometry of the aquifer.

1.4.4 Thickness of unsaturated zone

The zone between ground surface and the water table is known as unsaturated zone. The thickness of unsaturated zone is required for making a number decisions such as, waterlogging, irrigation application artificial recharge etc.

1.4.5 Degree of anisotropy

Most aquifers are anisotropic, i.e., flow conditions vary with direction. In granular media, the shape and orientation, and the process and sequence of deposition usually results in vertical permeability being less than horizontal permeability. In nor granular media, the size shape orientation and spacing of fractures, joints and other voids may result in anisotropy. Therefore, it is important to record the direction and degree of anisotropy in an aquifer.

1.4.6 Aquifer Parameters

Aquifer parameters include, hydraulic conductivity, transmissivity, storage coefficient, and specific yield.

Hydraulic conductivity

Hydraulic conductivity (K) of a porous medium is the volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow. The unit of hydraulic conductivity are

$$K = -\, v/(dh/dl) = -\,(m/day)/(m/m) = m/day$$

The hydraulic conductivity is a parameter reflecting both the intrinsic rock permeability and the physical properties of the water. It represents as a whole, the facility of the water circulation within an aquifer.

The hydraulic conductivity of a soil or rock depends on a variety of physical factors including porosity, particle size and distribution, shape of particles, arrangement of particles and other factors. In general, for unconsolidated porous media, hydraulic conductivity varies with particle size (clayey material exhibits low values of hydraulic conductivity, whereas sands and gravels display high values) and in consolidated media, hydraulic conductivity varies with degree of weathering, density and degree of continuity of joints, fractures and bedding planes.

Transmissivity

Transmissivity (T) is defined as the rate at which water of prevailing kinematic viscosity is transmitted through a unit width of aquifer under a unit hydraulic gradient. It follows that

$$T = K.b = (m/day)(m) = m^2/day$$

where, b is the saturated thickness of the aquifer.

Porosity

Porosity (θ) of rock or soil is defined as ratio of void space (V_v) to the total volume (V) of the rock/soil. i.e.

$$\theta = 100\ V_v/V$$

Storage coefficient and specific yield

A storage coefficient (or storitivity) is defined as the volume of water that an aquifer releases from or takes into storage per unit surface area of aquifer per unit change in the component of head normal to that surface.

For confined aquifer, the storage coefficient (S) equals the volume of water released from the aquifer when the piezometric surface declines a unit distance.

For storage term for unconfined aquifer is known as specific yield (S_y). The specific yield of a rock or soil is the ratio of the volume of water which the rock or soil, after being saturated, will yield by gravity drainage to the total volume of the saturated rock or soil.

Hydraulic diffusivity

The ratio of transmissivity to storativity in transient flow conditions can be expressed in the formula

$$\alpha = T/S$$

where alpha is hydraulic diffusivity and has the dimensions L^2/t. In an ideal aquifer, the time of response at a distant location to an imposed stress, such as a discharging well, is inversely proportional to the diffusivity.

Hydraulic resistance

The hydraulic resistance (c), also called reciprocal leakage coefficient, of a semi-permeable layer is the quotient of the thickness b' and hydraulic conductivity K' of that layer, and is a measure of its resistance to vertical leakage.

$$c = b'/K'$$

leakage factor

The leakage factor of a semi-confined aquifer is the square root of the transmissivity of the aquifer (T) and the hydraulic resistance (c) of the semi-pervious layer.

$$L = \sqrt{Kbc}$$

1.4.7 Aquifer boundaries

The confining beds of an artesian aquifer and the water table and the lower confining bed of a free aquifer represent a type of boundary which limits transmissivity. However, most common boundaries are those limiting the horizontal extent of aquifers. These may be negative (impermeable), or positive (recharge), or both types of boundaries may be present.

An impermeable boundary is one in which there is a significant reduction in transmissivity. Examples where the permeable alluvial fill of a valley abuts the buried valley sides that consist of impermeable granite or where a permeable sandstone is faulted against an impermeable shale.

A recharge boundary is one in which there is significant increase in transmissivity, for example, where a permeable material is in direct connection with a surface body of water or a permeable material is faulted against a more permeable one.

1.4.8 Aquifer response data

Water table

The upper surface of the zone of saturation is called the water table or phreatic surface which separates the zone of saturation from the overlying zone of aeration. The important data to recorded is variation of water table with time.

Water table fluctuation

The water table represents the groundwater reservoir level and changes in the groundwater in storage. The magnitude of water table fluctuation depends on climatic factors (rainfall, evaporation and evapotranspiration), drainage, topography, specific yield and geological conditions. The water table fluctuations also occur due to pumping and artificial recharge.

Surface water irrigation rises the water table in the areas with inadequate drainage facilities and may cause waterlogging.

Base flow

Streamflow originating from groundwater discharge is referred to as groundwater runoff or base flow. During periods of precipitation streamflow is derived primarily from surface runoff, whereas during extended dry periods all streamflow may be contributed by base flow. Therefore, in a groundwater basin the baseflow should be separated from the total streamflow and recorded for different periods.

1.4.9 Discharge and recharge areas

Areas should be delineated into recharge and discharge areas depending on whether water is added or abstracted from the zone of saturation.

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.

Discharge areas are areas where the aquifer loses water from the aquifer through springs, evaporation and pumpage etc.

The location, size and features of the area within which recharge/discharge occurs to an aquifer are important data to collected.

1.4.10 Groundwater and Surface water relationships

Surface water body may have hydrological connection with groundwater aquifer. Where the stream channel is in direct contact with an unconfined aquifer, the stream may recharge the groundwater or receive discharge from the groundwater, depending on the relative levels.

The streams may be classified influent (losing), effluent (gaining), and insulated. Such areas where the stream changes its characteristics should be recorded.

1.5 HYDROGEOLOGICAL DATA

1.5.1 Soil texture

Soil texture refers to the relative proportions of the various size groups of individual soil grains in a mass of soil. Specifically, it refers to the proportions of clay, silt and sand below 2 mm in diameter.

1.5.2 Soil structure

Soil structure refers to the aggregation of primary soil particles into compound particles, or clusters of primary particles, which are separated from adjoining aggregates by surfaces of weakness. Field data about soil structure consists of (i) the shape and arrangement, (ii) the size, and (iii) the distinctness and durability of the visible aggregates.

1.5.3 Infiltration characteristics

Infiltration rate is defined as the volume of water entering into the soil per unit area per unit time. Infiltration characteristics of a soil are required for the determination of recharge rate.

1.5.4 Soil moisture characteristics

Soil moisture is the water available in the unsaturated zone and is defined as the ratio of the volume of water to the total unit volume. The soil moisture in the unsaturated zone is a function of suction head. The relationship between the moisture content and the suction head should be established for the soils of the unsaturated zone.

1.5.5 Structural geology and stratigraphy

Geologic factors such as stratigraphy, structure, and lithology constitute the skeleton or framework which controls the occurrence and movement of groundwater. Therefore, the information about the geological conditions in the area should be collected. Some of the important data is :

- structure of the aquifer system i.e., whether folded or faulted; if faulted the magnitude and direction of displacement; if folded type of fold, i.e., syncline, anticline, isocline etc.
- presence of absence of a dyke (because dyke may act as a barrier)
- thickness and depth of fractures, joints, density of fractures, filling in the fractures i.e., quart veins etc.
- thickness and of weathered zone and degree of weathering
- presence of channels or solution cavities in limestones/dolomites, if present then their dimensions
- Stratigraphic position of the aquifer
- lithological characters of the aquifer
- depositional environment of the aquifer system
- bed rock topography

1.6 GEOPHYSICAL DATA

Geophysical methods detect differences, or anomalies, of the physical properties within the earth's crust. Density, magnetism, elasticity, and electrical resistivity are the most important properties which are measured by these methods.

Geophysical surveys made in conjunction with surface geological investigations, and exploratory drilling permit a rapid and relatively low cost evaluation of the subsurface geology and groundwater conditions of the area. The main geophysical methods which are commonly used to study the subsurface geohydrological conditions are the electrical, seismic, gravity and magnetic methods. Besides these, borehole geophysical methods are also employed which includes, electrical logs, calliper logs and nuclear logs.

1.6.1 Electrical Resistivity data

The electrical resistivity of a rock formation limits the amount of current passing through the formation when an electric current is applied. It may be defined as the resistance in ohms between opposite faces of a unit cube of the material.

Resistivity of rock formations vary over a wide range, depending on the material, density, porosity, pore size and shape, water content and quality, and temperature. There are no fixed limits for resistivity of various rocks; igneous and metamorphic rocks yield values in the range 10^2 to 10^8 ohms-m; sedimentary and unconsolidated rocks, 10^0 to 10^4 ohm-m.

1.6.2 Seismic data

Seismic method is based on the measurement of travel times of artificial elastic waves. There are two type of seismic methods, e.g., seismic reflection and seismic refraction. Seismic refraction is probably the most widely used among the two, for detailed determination of depth and nature of the bedrock, and to locate the water table. This method is also used to locate the buried channels/valleys.

1.6.3 Gravity and Magnetic data

The gravity method measures differences in density on the earth's surface that may indicate geologic structure. This method can be useful to identify the large buried valleys, and configuration of aquifer on regional scale.

The magnetic method enables the mapping of magnetic field of the earth. This method is useful to study the extent of magnetic aquifers i.e., basalts and to determine the configuration of the basement. This method can also be used to identify the dikes which may form the aquifer boundaries.

1.6.4 Geophysical logs

Geophysical logging involves lowering sensing devices in a borehole and recording a physical parameter that may be interpreted in terms of formation characteristics; groundwater quantity, quality, and movement; or physical structure of the bore hole. A wide variety of logging techniques are used to determine various parameters as given below:

Required Information	Possible Logging Technique
Lithology and stratigraphic correlation of aquifers and associated rocks	Resistivity, sonic, or calliper logs made in open holes; radiation logs made in open or cased holes
Total porosity or bulk density	Calibrated sonic logs in open holes; calibrated neutron or gamma - gamma logs in open or closed holes
Effective porosity or true resistivity	Calibrated long-normal resistivity logs
Clay or Shale content	Natural gamma logs
Permeability	Long-normal resistivity logs
Secondary permeability-fractures, solution openings	Calliper, sonic, or television logs
Specific yield of unconfined aquifers	Calibrated neutron logs
Location of water level or saturated zones	Resistivity, temperature, or fluid conductivity logs; neutron or gamma - gamma logs in open or closed holes
Moisture content	Calibrated neutron logs
Infiltration	Time-interval neutron logs
Dispersion, dilution, and movement of waste	Fluid conductivity or temperature logs; natural gamma logs for some radioactive wastes
Source and movement of water in wells	Fluid velocity or temperature logs
Chemical and physical characteristics of water, including salinity, temperature, density and viscosity	Calibrated fluid conductivity or temperature logs; resistivity logs

Though various type of logging techniques are available, only electrical resistivity, Spontaneous potential (SP), calliper, radiation logging is common in groundwater exploration.

Resistivity log

In resistivity logging, current and potential electrode are lowered to measure electrical resistivity of the surrounding media and to measure its variation with depth. The resistivity curves thus obtained indicate the lithology of rock strata penetrated by the well and quality of the water. As the resistivity of the material in controlled by porosity, packing, water resistivity, degree of saturation, and temperature, these parameters can also be estimated by the electrical resistivity logging.

Spontaneous potential (SP) logging

The spontaneous potential method measures natural electrical potentials found within the earth. Measurements, usually in millivolts, are obtained from a recording potentiometer connected to two like electrodes. The potentials are primarily produced by electrochemical cells formed by the electrical conductivity differences of drilling mud and groundwater where boundaries of permeable zones intersect a borehole. Therefore, SP logging may be used to identify the permeable zones.

Radiation logging

Radiation logging, also known as nuclear logging or radioactive logging, involves the measurement of fundamental particles emitted from unstable radioactive isotopes. Logs having application to groundwater are natural gamma, gamma-gamma, and neutron logs.

Natural-gamma Logging - All rocks emit natural-gamma radiations, a log of theses radiations constitutes a natural-gamma log. The radiation originates from unstable isotopes of potassium, uranium, and thorium. In general, the natural-gamma activity of clayey formations is significantly higher than that of quartz sands and carbonate rocks. The most important application to groundwater hydrology is identification of lithology, particularly clayey or shale-bearing sediments, which emit higher gamma intensities.

Gamma-Gamma Logging - Gamma radiation originating from a source probe and recorded after it is backscattered and attenuated within the borehole and surrounding formation constitutes a gamma-gamma log. Primary applications of gamma-gamma logs are for identification of lithology and measurement of bulk density and porosity of rocks.

Neutron logging - Neutron logging is accomplished by a neutron source and detector arranged in a single probe, which produces a record related to the hydrogen content of the borehole environment. In most formations the hydrogen content is directly proportional to the interstitial water; therefore, neutron logs can measure moisture content above the water table and porosity below the water table.

1.7 HYDROMETEORLOGICAL DATA

In major groundwater investigations, records of precipitation, temperature, evaporation and evapotranspiration, and relative humidity may be essential or useful data.

1.7.1 Precipitation

Precipitation is the atmospheric discharge of water in the solid (hail, snow) or liquid (rain) state on the earth's surface. It is usually measured and expressed in mm, cm or inches. Parameters to be recorded in respect of precipitation are

- type of precipitation i.e., rain, hail or snow
- daily precipitation
- location of measurement site
- network of raingauge stations

1.7.2 Evaporation and Evapotranspiration

Evaporation is the process by which water precipitate on the earth's surface is returned to the atmosphere by vaporisation. Water is available for evaporation from three types of surfaces i.e., surface water body, ground surface, and vegetation. A part of the precipitated water which makes the soil moisture (and sometimes directly from groundwater) is absorbed by the plants and evaporated through the leaves by transpiration. The cumulative loss by evaporation and transpiration is termed as evapotranspiration. Both evaporation and evapotranspiration are measured in mm/day or cm/day or inches/day. The data to be collected about evaporation and evapotranspiration are :

- daily evaporation / evapotranspiration rate
- location of measurement site

1.7.3 Other climatological data

Other climatological data includes, temperature, relative humidity, wind speed, wind direction, radiation etc. These data are required to calculate the evaporation and evapotranspiration loses if that data is not available. The data to be collected in respect of these parameters for ground water studies include location of measurement, and monthly minimum and maximum values of the parameters.

1.8 SURFACE WATER DATA

Surface water data includes, streamflow and runoff, surface water bodies, water quality, etc. The important surface data which is required to be collected for ground water studies consists of

1.8.1 Water quantity data

This includes the quantity of surface water available in the study area i.e.,

- Water level in streams, canals lakes and reservoirs
- Discharge rate

1.8.2 Reservoir or lake data

This includes the size and depth of the surface water body and change in volume of water with change in stage i.e.,

- Storage-elevation relationship
- Area-elevation relationship
- Elevation-discharge relationship

1.8.3 Water use data

This includes the abstraction of water for various uses such as irrigation, domestic use etc.

- Effluent to rivers, lakes and reservoirs (quantity as well as quality)
- Abstractions from rivers, lakes and reservoirs

1.8.4 Water quality data

Water quality data is to be collected for streams, lakes and reservoirs, etc. The data in respect of chemical, physical and bacteriological characteristics should be collected.

- Physical parameters i.e, colour, taste, odour, surface water temperature, transparency, salinity and conductivity
- Chemical parameters i.e., electrical conductivity, carbonate alkalinity, bicarbonate alkalinity, dissolved oxygen, nitrate, phosphate, sulphate, ammonia, organic nitrogen, biological oxygen demand, hydrogen sulphide, chemical oxygen demand
- Bacteriological parameters i.e., total coliform, faecal coliform, faecal streptococci and heterotrophs

1.9 OTHER DATA

Other data including :

- Cross section and longitudinal sections of the canals and its distributaries, depth of water in the canal
- Monthly discharge in the main branch canals at the off take points.
- Monthly discharge at various sections of the main branch canals.
- Land Use Data- forests, orchards and tall vegetation, waterlogged area, cultivated area, canal irrigated at well Irrigated area, and unirrigated area
- Irrigation practices over the area.

2.0 GROUND WATER MAPS

Hydrological maps are defined as presentation of terrestrial hydrological information in geographical relationships. Hydrological maps are commonly used to represent large amounts of information about the water regimes of the surface and near surface of the earth because they display the information in its spatial relationships and in relationship to the configuration of the land itself. This is the major and overriding advantage for showing information on maps. Without maps it is impossible to study water balances, geographical interrelationships and relationships of individual elements to each other.

Ground-water mapping is a method of recording the results of investigations of the subsurface part of the hydrosphere. Ground-water maps provide a bank of information on gravitational water in the upper part of the lithosphere and also provide the basis for learning about and understanding the relationship between ground water and its geological and hydrological environment.

Ground water maps are the result of investigation of the subsurface part of the hydrosphere. Ground water maps provides a bank of information for understanding the relationship between ground water and its geological and hydrological environment.

2.1 NEED FOR GROUND-WATER MAPPING

The water that constitutes the ground-water resources is temporarily diverted from the more rapidly recycling elements of the hydrological cycle; nevertheless, it remains an essential part of that cycle. Moreover, once below the surface, it becomes part of the structure of the earth, affecting rock strength and earth movements. In addition, because ground water moves through rocks whose interstitial and solubility characteristics change in space and time, it is subject to changes in temperature, composition and other characteristics. The interactions of ground water with its environment must be considered not only while it moves through the subsurface, but also as it discharges, naturally or artificially, at the surface of the land or into fresh and saline waters.

It follows that ground water must be depicted in several different ways to show its diverse aspects. Where it is related to the geology, ground water is shown as essentially static, presented either in terms of average conditions, or the condition at a particular moment or within an arbitrary period. Regardless of how slowly, it moves continuously, and the characteristics of its movement must be depicted on the same map or on a supplementary map. This aspect of virtually continuous movement on a time scale sensible to man emphasizes the fundamental difference between the mapping of ground water and of geology.

Because of man's increasing demands on available water resources hydrologists must predict the state and properties of ground water as it moves in space and time. Maps showing relationships between ground water and other elements of the water regime, such as atmospheric and surface water, must be drawn, or explained, so that there is no confusion over the significant differences in their respective residence times.

To predict future ground-water conditions, it is sometimes necessary to reconstruct natural ground-water conditions, even though they may no longer exist. This must be done in order to understand the influence of the stresses imposed by man. The palaeohydrology of an area, or the events that shaped the existing or recent natural situation, can only be reconstructed by representing the information available on sedimentation, uplift, deformation, and erosion, and relating this to a logical sequence of hydrological events.

Mathematical approaches, based on theoretical considerations of data density and the spread of numerical values, may be useful in selecting the values to be assigned to various cartographic features, such as isolines, when the volume of data is large. Where the amount of data is more readily manageable, the map compiler may be able to obtain equally useful values by applying common sense, trial and error, and simple arithmetic to the problem. The common-sense process takes only minutes and adjustments may be made equally rapidly. The more cumbersome theoretical methods remain useful or essential where a great deal of data and large areas are involved.

To summarize, ground-water maps should represent the existing conditions of ground-water dynamics and physical- chemical properties, and the forecasting of the effects of existing and future stresses imposed by man.

2.2 DATA REQUIRED FOR GROUND WATER MAPPING

The material required for the compilation of ground-water maps includes all relevant pre-existing information as well as what can be collected during the investigation and any that will provide the basis for regional extrapolation. All available information should be collected and studied before proceeding to collect new field data and make maps based on new data. The quality of preexisting information may vary greatly and its value to the new study have to be weighted on the basis of its reliability. Where maps include areas virtually without data, the map-compiler may be forced to present approximations on the basis of extrapolations from similar near-by areas, regional generalizations and such other information as he may have at his disposal.

The following list tabulates items useful in the preparation of maps, although they are not all needed for every map. Particular attention should be given to sources with long periods of records. The items are not listed in any order of priority.

- References to published and unpublished records and other material regardless of archival sources.

- Geological maps showing the stratigraphy of both bed-rock and superficial deposits, structure, geomorphology and rock characteristics.

- Results of various types of geophysical surveys.

- Local details about special terrains, such as karst, arid zones and areas of permafrost.

- Aerial photographs, supplemented by ground photographs to show surface conditions of earlier times.

- Remote-sensing imagery from aircraft and satellites.

- Location and altitude of point sources of ground-water information.
- Analyses (including isotopic) of chemical content and characteristics of waters and with information about their distribution.

- Well logs, including data on temperature, chemical quality, inflow, natural gamma ray and resistivity measurements.

- Data on discharge from wells, springs, line springs, and seeps; rates of evaporation and water-level fluctuations of lakes in hydraulic continuity with ground-water bodies; and variations in the amounts and chemical characteristics of discharge and lake waters.

- Precipitation and related meteorological data such as evaporation.

- Stream discharge records, hydrographs and related data.

- Permeability, transmissivity and storage coefficients, and calculated estimates of ground water availability and water flow.

In using similar data from different sources, it is important to establish their relative validity and identify the most appropriate information.

2.3 GROUND WATER RELATED MAPS

Ground-water maps are probably the most common and diverse of all hydrological maps because ground-water work is mainly undertaken by geologists who are map-oriented by training and practice. UNESCO (1977) has categorised the groundwater maps into four broad categories, depending on their basic content or principal purpose: (a) General purpose ground water maps - relating ground water to the classical geological frame-work without detailed regard for hydraulic continuity; (b) Special purpose ground water maps - relating ground-water occurrence to the hydraulic properties within the classical geological framework; (c) Groundwater assessment maps - showing ground water as a resource; and (d) Maps showing environmental relationship and special ground water conditions - showing the relationships of ground water to the water-bearing characteristics of the rocks and to the dynamics of the hydrological regime.

Typical maps covered under category (a) to (b) are described below in detail. The maps covered under (c) and (d) are very specific and will not be discussed in this lecture.

2.4 GENERAL PURPOSE GROUND WATER MAPS

General purpose ground water maps represent the state of ground water knowledge of he territory, the current scientific ideas about the occurance of ground water and the solutions of the scientific and applied problems related to ground water. Their scientific significance is to further a better understanding of the natural laws of ground water movement, establish the pattern of distribution and quality of ground water, depict the areas of recharge and discharge of various aquifers, and indicate the direction of groundwater movement. These maps facilitate the efficient use of the ground water for various economic needs and assist in taking the positive measures to safeguard resources.

The information which can be depicted on general purpose ground water maps can be divided into two groups :

(i) Related to water-bearing rocks, i.e., lithological characteristics; information on elevation, depth and thickness; geohydrological characteristics such as coefficient of permeability, transmissivity and storage.

(ii) Related to ground water, i.e., the hydraulic levels and heads; and, physical and chemical characteristics of ground water.

A map showing all this information would make it possible to compare the characteristics and ascertain the inter- relations between them simultaneously. However, such a map is not practicable because in showing so much information it would become overloaded and difficult to read and interpret. Usually each element is mapped separately, or two or three of them combined on one sheet, with appropriate titles. A set of these maps will then give all the information available for interpretation of general ground- water conditions.

2.4.1 Location map

Location maps should have a topographic base or coordinate grid. The topographic base should include standard local, national or international symbols for position, number of routes, wells, springs, boreholes, sampling points, sites for stream gauge and drainage network, sites for meteorological observations etc.

2.4.2 Maps of water-bearing rocks

Ground-water mapping is a record of the distribution and properties of gravitational ground water but a primary problem is to identify the strata which contain ground water. This task is carried out by field and office studies of the facies and lithological characteristics of rocks in terms of their hydrophysical properties of permeability, transmissivity and storage.

Litho-facies maps

The main elements of ground-water mapping are aquifers, aquifer complexes, aquitards, local water-bearing layers, fractured water-bearing zones of both regional weathering and local tectonic origin, and ground-water levels (Fig. 1).

The pore-size distribution of rocks, which determines many characteristics of ground-water occurrence, movement and chemical composition, should be taken as a basis for the delineation of aquifers and aquifer complexes from aquitards.

2.4.3 Maps of parameters of water-bearing and non- water-bearing rocks

Mapping of geometrical parameters related to water-bearing and non-water-bearing strata, for example, thickness of sedimentary cover, thickness of regional aquiclude, depth to unconfined ground-water body or depth to the first aquifer complex with confined water is of considerable practical value. These elements are usually shown by isolines or coloured areas to denote thickness or depth.

Maps of thicknesses of water-bearing bodies

The three basic types of ground-water information obtained from thickness maps refer to potential and effective availability of water, potential and actual transmissivity of the aquifer, and the potential and actual time response or sensitivity of the aquifer system to natural or man-made stresses.

In the basic ground-water flow equations, the thickness of the water-bearing system, b, enters into the determination of the total pore volume, V_p, available for storage or production when the total volume is expressed in terms of the areal extent of the aquifer, A, an average thickness, b_{av}, and the porosity, n, in fractions by:

$$V_p = A.b_{av.}n$$

It further enters in the determination of the storage coefficient, S, for confined elastic aquifers. More directly related to the productivity of an aquifer is its transmissivity, T, at which water is transmitted through a unit width of the aquifer under a hydraulic gradient of unity at prevailing viscosity conditions. Thickness enters into the definition by:

$$T = K.b$$

where K is the hydraulic conductivity.

It is clear that thickness will have some influence on the relative sensitivity of the aquifer to extraneous stresses, either by determining the total volume involved in the reaction or dilution as indicated above or as a mixing length dimension where dispersion occurs after introduction of contaminants from the surface.

FIG. 1

continued

LEGEND

FORMATION	AGE	LITHOLOGY	AQUIFER CHARACTER	GROUND WATER POTENTIAL (YIELD IN LPS)
			POROUS FORMATION	POROUS FORMATION
Unconsolidated	Quaternary Upper Cainozoic	Blown sand, Recent Alluvium, Clay, Silt, Sand, Gravel, Pebbles, Calcareous-concretion etc.	Fairly thick and regionally extensive, confined to semi-confined aquifers down to 300 m.b.g.l. and more	40-100 High
		Older Alluvium, Laterite, Silt, Sand, Ferruginous concretion, Lithomargic clay, Gravel, Pebbles, Cobbles etc.	Moderately thick but discontinuous confined to semi-confined aquifers down to a depth range of 30 to 300 m.b.g.l.	10-40 Medium
Semi-consolidated	Cainozoic Mesozoic Upper Palaeozoic	Siltstone, Claystone, Grit, Sandstone, Shale, Conglomerate, Limestone	Discontinuous aquifers with limited thickness down to 100 m.b.g.l.	<10 Low
			FISSURED FORMATION	FISSURED FORMATION
Consolidated: Effusives	Cainozoic Mesozoic	Basalt with inter-trappean clays	Local / Discontinuous Unconfined to semi-confined aquifers restricted to weathered mantle and fractures	10-25 Normally high
Consolidated: Sedimentaries	Proterozoic	Sandstone, Shale		5-10 Low to medium
		Dolomite, Limestone		1-5 Normally low
Consolidated: Metasedimentaries & Metavolcanics	Lower Proterozoic	Slate, Quartzite, Phyllite Schist, Gneiss, Marble		<1 Very low
Consolidated: Basal crystallines	Archaean	Phyllite, Granite		

GROUND WATER

Boundary of area of Artesian Flow

Spring, Hot Spring (with Temp. °C)

TUBEWELL

- T Transmissivity (m^2/Day)
- Wl Water Level in m.b.g.l.
- Pz Piezometric Head m.a.g.l.
- D Depth of the Well in m.b.g.l.
- S Drawdown in Metres
- Q Discharge in l.p.m.

A' Hydrogeological Cross-Section Line

HYDROCHEMISTRY

Fresh water overlain by saline ground water

Fresh water underlain by saline ground water

Ground water saline at all levels except local patches

SURFACE WATER

Reservoir

River / Stream

Salt Lake

Surface water divide

STRUCTURE

Tectonic zonal boundary

Axis of major Fold

CLIMATOLOGY

Isohyetal Contour (mean annual precipitation in mm)

TOPOGRAPHY

Triangulation Point (Altitude in Metres)

The basic data needed to construct thickness maps are:

1. Elevations above a common datum and a coordinate system for points. Some information is usually contained on topographical maps, from which interpolation can be made for any point with an accuracy dependent on the scale. Only in special cases is it necessary to take length and elevation measurements for each individual point.

2. Direct or indirect information about the horizontal limits of the particular ground-water units.

Geophysical surveys by electrical resistivity, seismic refraction and reflection, and gravity methods are indirect aids to determination of thicknesses of geological units. The applicability of these procedures depends on the material contrasts of the units whose thickness is being measured, and compliance with certain simplified conditions both for number and position of layers as well as for the application of background corrections.

Geophysical measurements in boreholes can be used for the precise location of boundaries of formations or aquifers in an existing well where original geological sampling was either not carried out or lacked precision. The techniques used are resistivity and self potential measurements, sonic logging and various natural and induced radio-activity recordings.

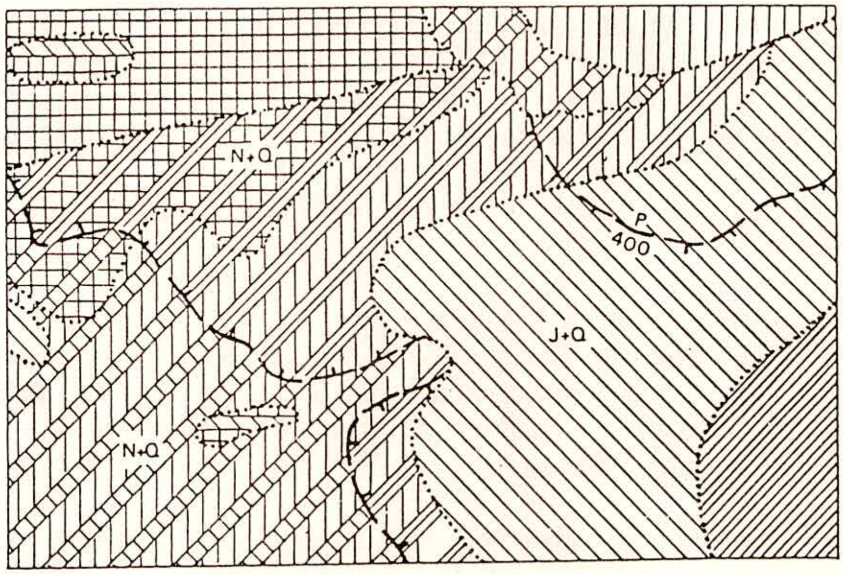
Maps of hydraulic conductivity, transmissivity or storage coefficient

The hydro-physical parameters which characterize the movement of ground water are connected with the distribution and intensity of mass-transport processes. These parameters include the coefficients of permeability, or hydraulic conductivity and transmissivity. They are also design parameters and are used in the solution of many practical problems of ground-water dynamics. Their value is derived from data obtained by test pumping wells. Areal interpolation and extrapolation of the data from test pumping are possible if the strata are known to maintain a constant composition.

Permeability or transmissivity may be shown for any part of an aquifer or for an entire artesian basin (Fig. 2)

2.4.4 Maps of depth-to-water, water-table and piezometric surfaces

A great deal of information, both qualitative and quantitative, can be obtained from maps which show depths to ground water, and related data such as elevation of the water table or piezometric surface. Such information is usually presented on maps showing lines of equal depth to water, contours of equal elevation of water table, or piezometric surface, above a datum plane, or lines of equal change in depth to water over a given period of time. The water table or piezometric surface could also be shown in a block or fence diagram, although these modes of display might be difficult to apply to a quantitative analysis.



1. Transmissivities and permeabilities

	Transmissivity K_m(m^2 day^{-1})	Permeability by K_F(m day^{-1})
Impermeable (with normal gradients of pressure)	< 1	10^{-3}
Poorly permeable	1-10	10^{-3}-10^{-1}
Permeable	10-100	10^{-1}-1
Highly permeable	100-1,000	1-10
Very highly permeable	> 1,000	10

2. Change in filtration properties with depth

Permeability changes from top to bottom.
Gradually: the wide band corresponds to rock permeability of upper part.

Sharply and not uniformly, alternation of rocks in section with different permeability—the wide band corresponds to the greater value, the narrow band to the smaller value.

Sharply and uniformly; the upper band corresponds to the upper formation and the lower band to the lower one.

3. Boundaries

Boundaries of areas with different permeabilities.

Distribution and thickness of regional aquicludes: the sign refers to the age of the formation and the figure to its thickness.

FIG. 2. Map of transmissivity and permeability of rocks.

Depth-to-water maps

In order to prepare maps involving the positions of water levels, two items of information must be obtained at each point from which the depth to the water level is measured: (a) elevation of the measuring point above some datum plane, usually mean sea level but may be some other datum plane such as the elevation of the bottom or top of the aquifer; (b) depth from the measuring point to the water level in the borehole.

Other information needed to make a proper interpretation of water-level data are driller's or geologist's logs for each borehole, or geological sections of the area. These are needed to determine whether to expect artesian or water-table conditions and the possibility of leakage into the aquifer from underlying or overlying formations. The information will indicate whether or not individual wells are open to multiple aquifers, the possibility of natural hydraulic connection between the aquifers, and whether or not the measured water levels are compatible.

Water level and other information can be obtained by well-logging geophysical techniques. These include electric logs (spontaneous potential and resistivity), radiation logs (natural gamma, neutron and gamma-gamma), calliper logs sonic logs, and fluid logs (temperature and fluid resistivity).

The simplest type of water-level map to construct is the contour map, showing lines of equal value. Points on a given contour line can be determined by linear interpolation between pairs of data points (Fig. 3). A curve is then drawn through the contour points, making use of all available hydrological and geological data as well as the experience of the person drawing the map. The lines could also be drawn by digital computer.

Depth-to-water and related data can also be presented in fence and block diagrams. Fence diagrams are useful for displaying water levels in multiple aquifers, and showing the relationships between water level, piezometric, land and aquifer surfaces.

A map of depth to water has a number of applications. In general, such a map defines the dimensions of the unsaturated zone. Knowledge of regions in which the water table is near the surface, as well as information about the height of the capillary fringe (from grain-size distribution or borehole geophysics), can be useful in hydrological studies such as infiltration and run-off rates, soil-moisture distribution, and artificial recharge projects. The information may also be applied in agricultural studies, such as the need for soil drainage, phreatophyte eradication, or cultivation and various engineering projects requiring either drainage or stabilization of saturated soils.

Water-table maps

A contour map of the water table is useful for determining the direction and rate of ground-water movement. If the aquifer is isotropic, sectionally homogeneous, and relatively thin (such that the flow can be assumed to be essentially horizontal), then flow lines can be drawn normal to the water-table contour lines. The rate of flow between two such flow lines

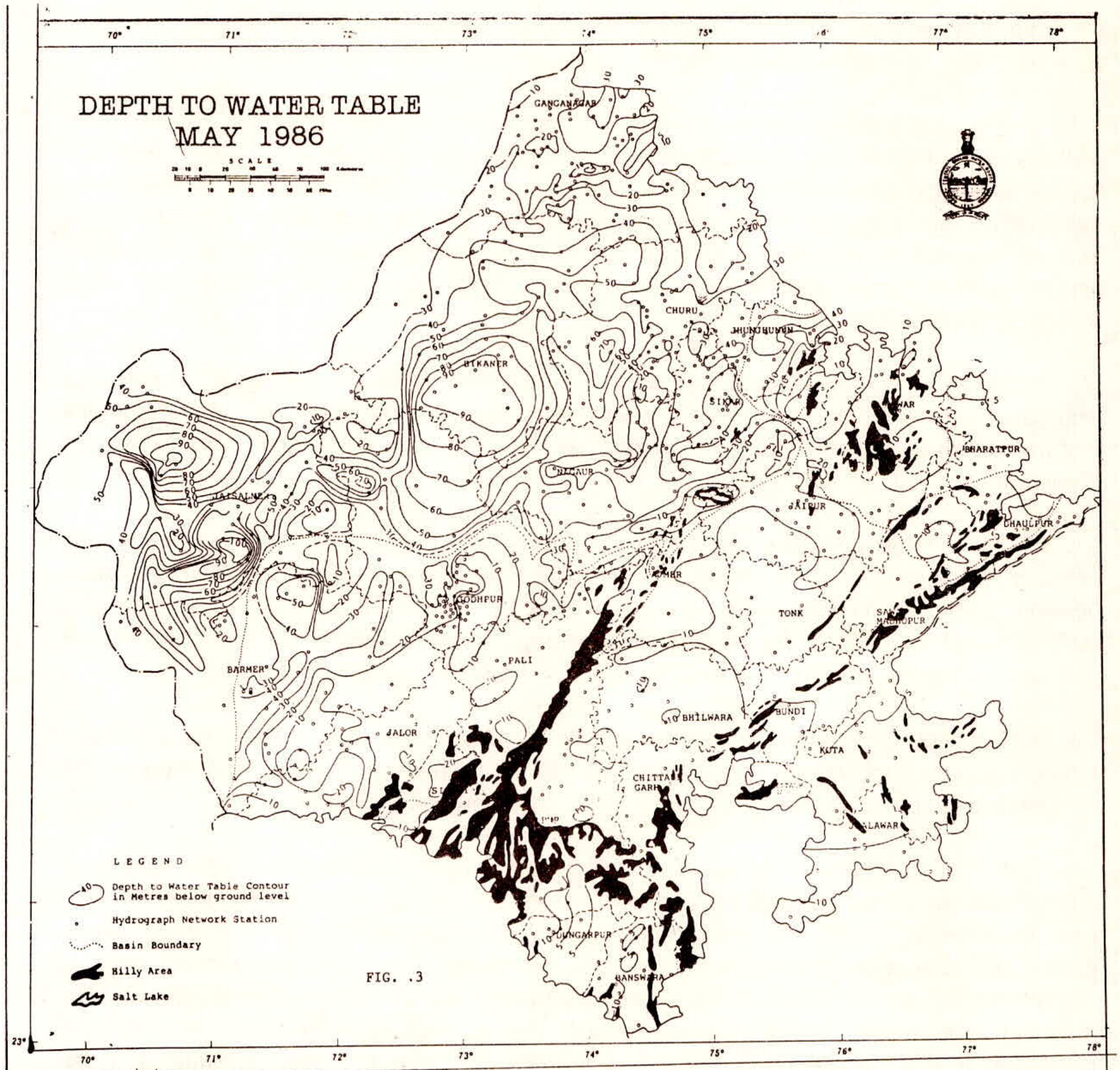

DEPTH TO WATER TABLE
MAY 1986
SCALE
GANGANAGAR
CHURU
JHUNJHUNUN
BIKANER
SIKAR
BHARATPUR
NAGAUR
JAISALMER
JAIPUR
DHAULPUR
AJMER
JODHPUR
TONK
PALI
BARMER
BHILWARA
BUNDI
JALOR
KOTA
CHITTAURGARH
JHALAWAR
DUNGARPUR
BANSWARA
LEGEND
Depth to Water Table Contour in Metres below ground level
Hydrograph Network Station
Basin Boundary
Hilly Area
Salt Lake

FIG. .3

is proportional to the distance between them. Convergence or divergence of flow lines can be interpreted as being due to pumping, recharge or leakage.

Where the aquifer is relatively thick, vertical flow components must also be considered. In such cases, curves drawn normal to the water-table contours indicate only the horizontal components of flow vectors; vertical flow components can be shown in vertical sections of the aquifer (Fig. 4). Even with these diagrams, a contour map of the water table would still be useful to show areas of recharge and discharge, and possible hydraulic connection with surface water bodies. Knowledge of the location of recharge and discharge areas can be applied in general hydro- geological investigations, as well as in studies of various surface hydrogeological features, pollution problems occurrence of saline soils and other geochemical problems.

Maps of water-table fluctuations

Another type of map dealing with the water table is a map of changes in its position which can be used to calculate changes in the quantity of ground water in storage, as well as to determine recharge of the aquifer or leakage from it to underlying aquifers.

Water-table fluctuations are normally shown by contour maps or their derivatives. The simplest way is to show the water-table position at two or more different times on separate maps. This is an effective method, particularly when the maps can be shown on the same page or sheet. A second method is to show contours of the water table at two or more different times by different line patterns, or by lines of different colour, on the same map.

The extent of the fluctuations can be shown by isolines derived from two or more sets of water-table elevations. Such maps are particularly useful in areas where lowering of water tables is excessive or is considered to be potentially so. The extent or amplitude of the fluctuations can be derived either from the elevations themselves or from contour maps showing the water-table configuration at different times (see Fig. 5).

Maps of amplitudes of water-table fluctuations are useful as a basis for computing average values of specific yields and changes in ground-water storage. The same types of maps can be used to show water-table fluctuations, regardless of whether they are seasonal, annual or long-term, as well as fluctuations of the piezometric surface.

Piezometric maps

The configuration of the piezometric surface is usually shown by contours of equal piezometric head above mean sea level, less frequently, it is referred to the base of the aquifer. Occasionally, it may be useful to contour the difference between the piezometric surface and the top of the aquifer. In the case of a multiple-aquifer system, the piezometric water level for each aquifer may be contoured on the same map, using standard cartographical methods (line widths, patterns or colours) to differentiate the water levels from the various aquifers.

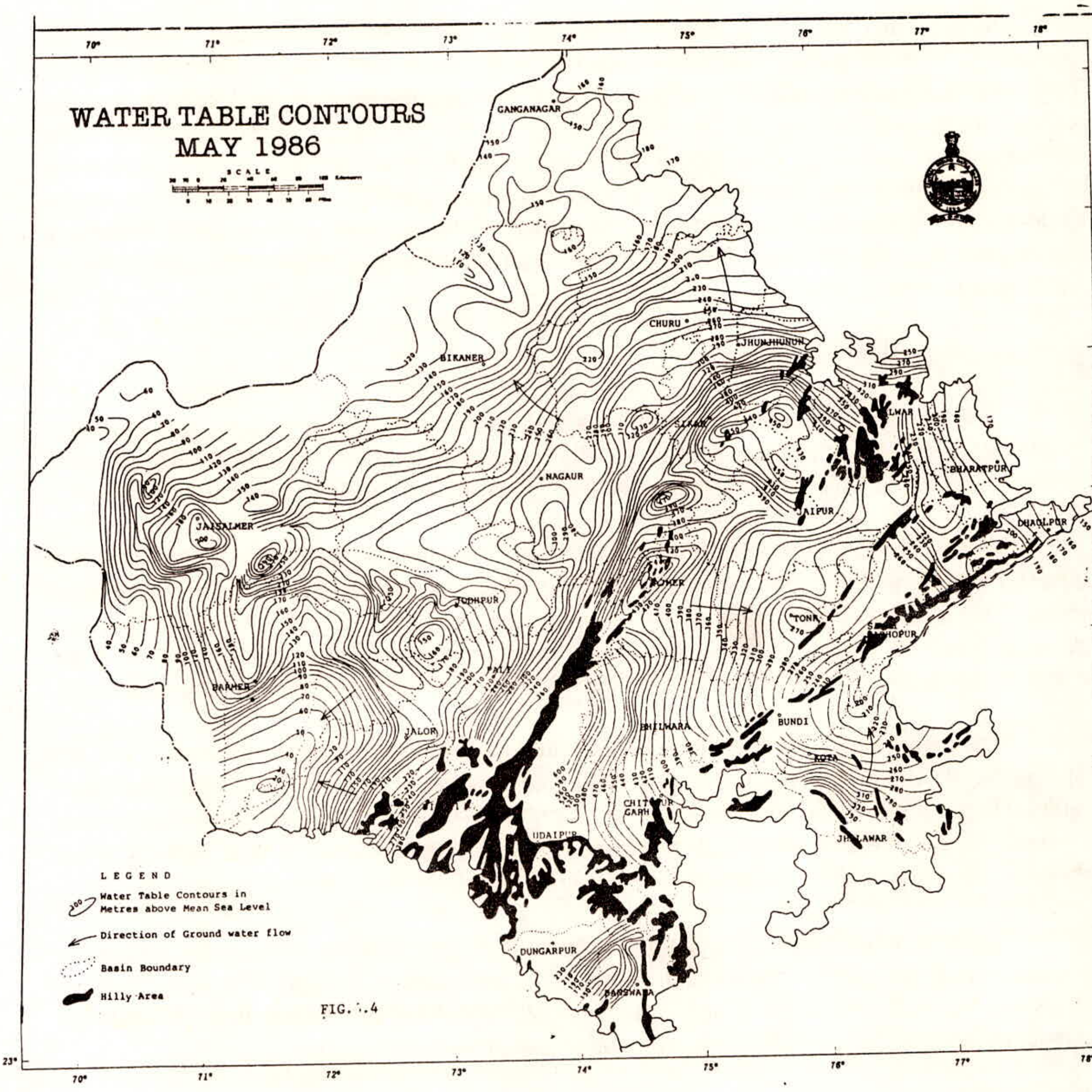
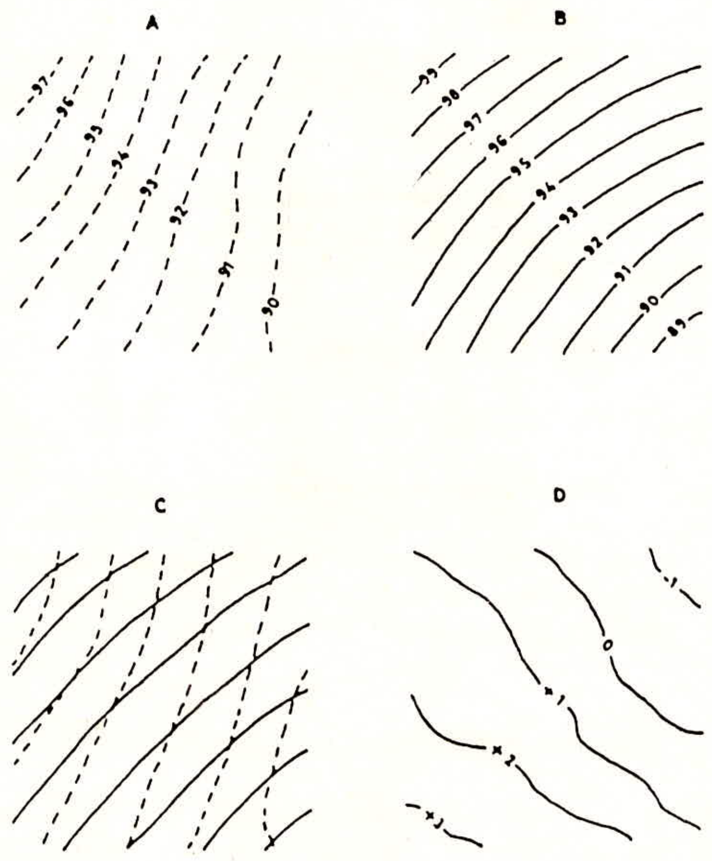

WATER TABLE CONTOURS
MAY 1986
SCALE
GANGANAGAR
BIKANER
CHURU
JHUNJHUNUN
SIKAR
NAGAUR
JAISALMER
JODHPUR
BARMER
JALOR
PALI
AJMER
JAIPUR
ALWAR
BHARATPUR
DHAULPUR
TONK
BUNDI
KOTA
JHALAWAR
BHILWARA
CHITTORGARH
UDAIPUR
DUNGARPUR
BANSWARA
LEGEND
Water Table Contours in Metres above Mean Sea Level
Direction of Ground water flow
Basin Boundary
Hilly Area
70°
71°
72°
73°
74°
75°
76°
77°
78°
23°

FIG. .4



FIG' 5 CONSTRUCTION OF WATER LEVEL FLUCTUATION MAP BY SUPERIMPOSING WATER TABLE CONTOUR MAPS OF TWO HYDROLOGICALLY DIFFERENT YEARS. A : PRESENT WATER LEVELS , B: PAST WATER LEVELS , C: MAPS A & B SUPERIMPOSED, AND D RESULTING WATER LEVEL FLUCTUATION MAP.

Maps of the piezometric surface can be used to determine:

- the direction and rate of ground-water flow
- total amount pumped from a centre
- areas where the water level could fall below the top of the aquifer
- the effects of discharge from, or recharge to, the aquifer and to calculate these quantities

Contours showing the elevations of multiple piezometric surfaces above a common datum plane can be drawn on the same base. The resultant map can be used to determine areas where upward or downward leakage between aquifers is possible.

2.4.5 Maps of ground-water characteristics

Maps showing movement of water

Movement of ground water is shown on maps primarily by two methods, used separately or together: the first by arrows, and the second by water-table or piezometric-surface contours. Arrows show the movement directly and specifically whereas the direction of movement is inferred as being at right angles to the water-table or piezometric-surface contours. A map showing the directions of movement inferred from contours is called a flow net (Fig. 6).

Areas of recharges discharge, and movement of water between them

The elevation of water-table contours on a map will rise towards areas of recharge and fall towards areas of discharge. The distance between contours decreases as the water table steepens towards the area of recharge, giving the water table the configuration of a steepening surface or a mound (Fig. 7). A mound is usually an indication of recharge. The presence of a steepened slope always indicates some change in the hydrological parameters which control ground-water movement. Their significance must be analysed on the basis of local changes in the permeability of the routes through which the ground water is moving.

2.4.6 Physical-chemical characteristics

Physical-chemical characteristics of ground water include its chemical and gas composition and temperature. A number of hydrochemical classifications are in use based generally upon the predominance of particular anions and cations or groups of them. Usually chloride, sulphate and bicarbonate/carbonate are distinguished and their association with calcium, magnesium and sodium/potassium (Fig. 8).

Hydrogeochemical maps are widely used to show in plan or section the pattern of distribution of various values and types of mineralization in ground water. One method for showing the hydrogeochemical characteristics is to divide them into groups which depict: (a) distribution in area of maximum ground-water mineralization; b) distribution in area and in depth of the principal chemical groups of brackish waters, salt waters and brines; (c) depth

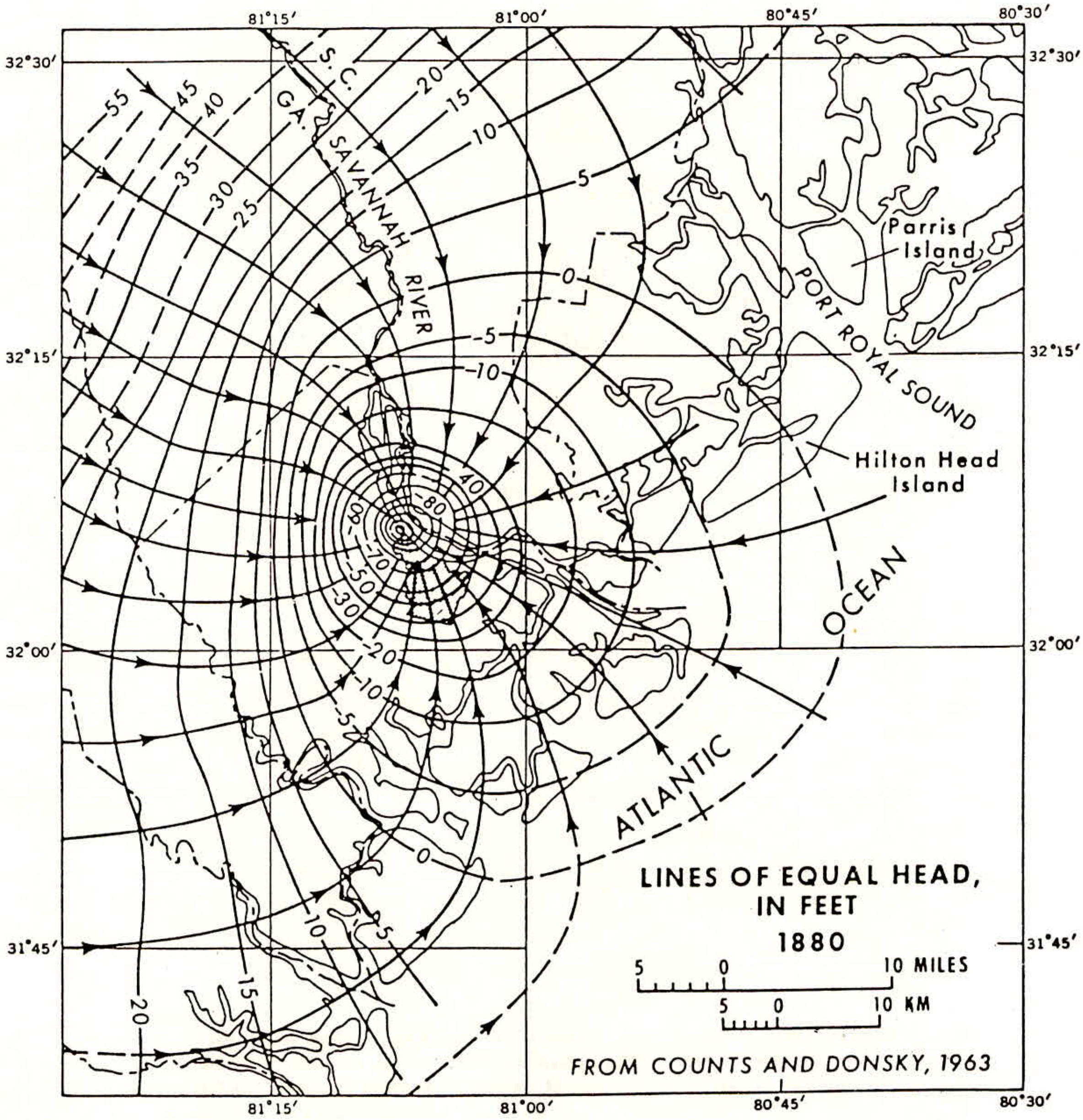
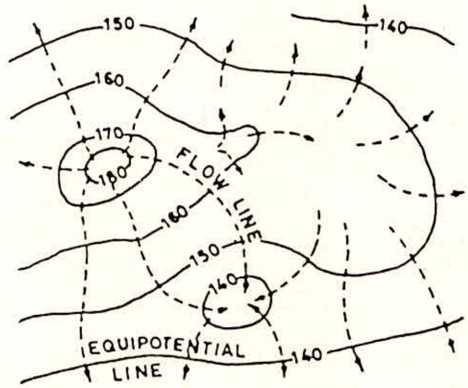


FIG. 6 Map of Savannah area, Georgia, United States, showing approximate altitude of the artesian head in 1880 and the general pattern of ground-water flow-lines (after Counts and Donsky, 1963, as shown in Back, Hanshaw and Rubin, 1970).



PATTERN OF EQUIPOTENTIAL LINES AND FLOW LINES

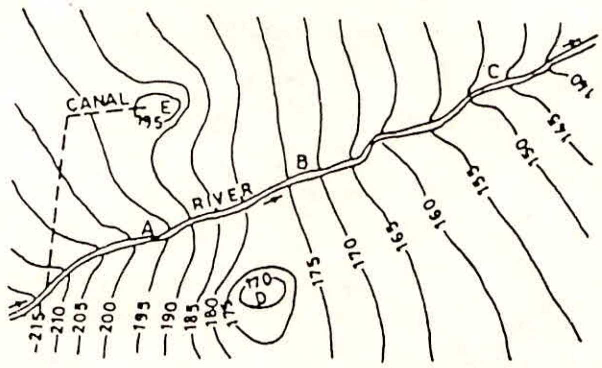


FIG. .7 WATER TABLE CONTOUR MAP. A: AREA OF RECHARGE, RIVER INFLUENT (LOSING); B: WATER TABLE ELEVATION IS THE SAME AS WATER LEVEL IN THE RIVER; C: AREA OF DISCHARGE, RIVER EFFLUENT (GAINING); D: AREA OF DISCHARGE, PUMPED WELLS; E: AREA OF RECHARGE, DEEP PERCOLATION OF IRRIGATION WATER.

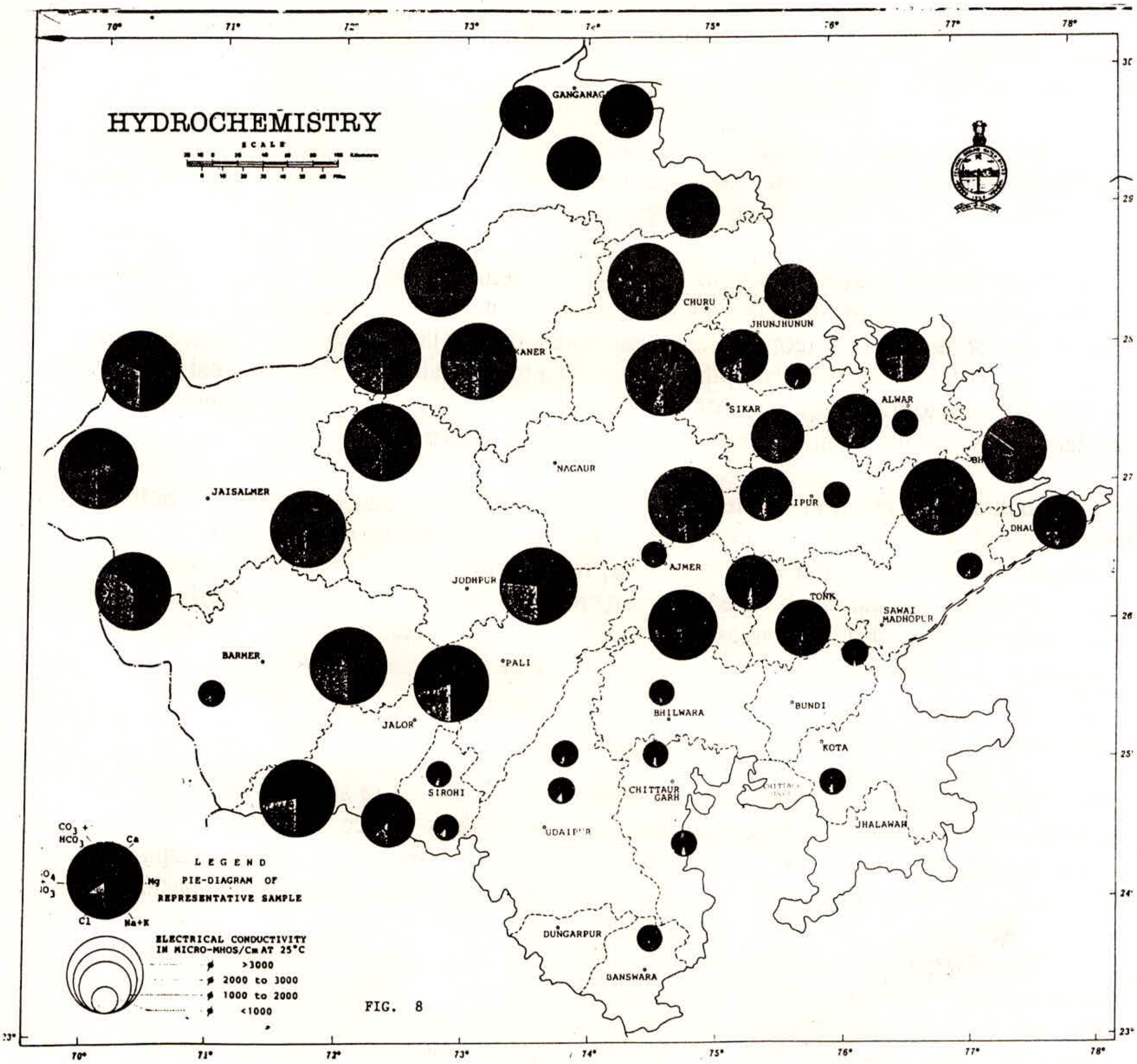

HYDROCHEMISTRY
SCALE
GANGANAGAR
CHURU
JHUNJHUNUN
SIKAR
ALWAR
NAGAUR
JAISALMER
AJMER
JODHPUR
TONK
SAWAI MADHOPUR
BARMER
PALI
BHILWARA
BUNDI
JALOR
KOTA
SIROHI
CHITTAUR GARH
UDAIPUR
JHALAWAR
DUNGARPUR
BANSWARA
LEGEND
PIE-DIAGRAM OF REPRESENTATIVE SAMPLE
Ca
Mg
Na+K
Cl
ELECTRICAL CONDUCTIVITY IN MICRO-MHOS/Cm AT 25°C
>3000
2000 to 3000
1000 to 2000
<1000
70°
71°
72°
73°
74°
75°
76°
77°
78°

FIG. 8

to brackish water, salt water and brines.

In hydrogeological mapping importance is attached to the collection and systematic arrangement of data on ground-water temperature. Ground waters have been divided according to temperature into the following categories : super-cooled water (within permafrost areas), 0° C; very cold, 0-4° C; cold, 4-20° C; warm, 20-37° C; hot, 37-42° C; very hot, 42-100° C; super- heated, >100° C.

A hydrogeothermal map can be drawn to depict those indices which characterize the distribution of thermal flows in the interior part of the earth. The flows originate from different sources, and influence the hydrogeological features.

Such indices may be used to represent the temperature at the roof of the rock basement, distribution of temperatures throughout the depth of the sedimentary cover, or distribution of permafrost (continuous, interrupted or insular perennially frozen strata). Distribution of temperature with depth can be shown by the value of the geothermal gradient isolines of depth to the temperature of 0° and 20° C or isolines of temperatures measured at the depth at which the annual variation of temperature is zero.

Such a representation enables the degree of rock cooling below the freezing point to be determined. Fresh water turns into ice, and forms a continuous or interrupted cryogeneous aquiclude. Where salt ground water is present, rock cooling below 0° C does not lead to the formation of ice. A map can be used to distinguish by coloured contours the distribution of brines cooled below 0° C and areas over which rocks are cooled below 0~ C but whose drainage pores and fissures do not contain either ice or brines.

Maps showing quality of ground water

Maps showing quality of ground water may be required to satisfy three needs: (a) guidance in development, management and protection of the resource; (b) documentation or assessment of the resource at a point in time (actual or estimated); and (c) display of information for research on some facet of the ground water or the ground-water basin.

The types of maps include time-related (historical, present day or future conditions); aquifer quality (for model construction and problem solution) related to the quality of ground water for use or potential development; and general assessment of quality, such as electrical conductivity, total dissolved solids, or specific display of one facet of the quality, such as nitrate content or temperature (Fig. 9).

Agricultural-water quality is usually shown by units of electrical conductivity. The Sodium Adsorption Ratio (SAR) and Total Dissolved Solids (TDS) may provide supplementary information. Specific elements, such as boron, should be mapped if their presence could limit the usefulness of the water.

Domestic-water quality is shown usually by TDS and hardness. In addition, information about specific trace metals (such as arsenic, mercury, iron or manganese) or

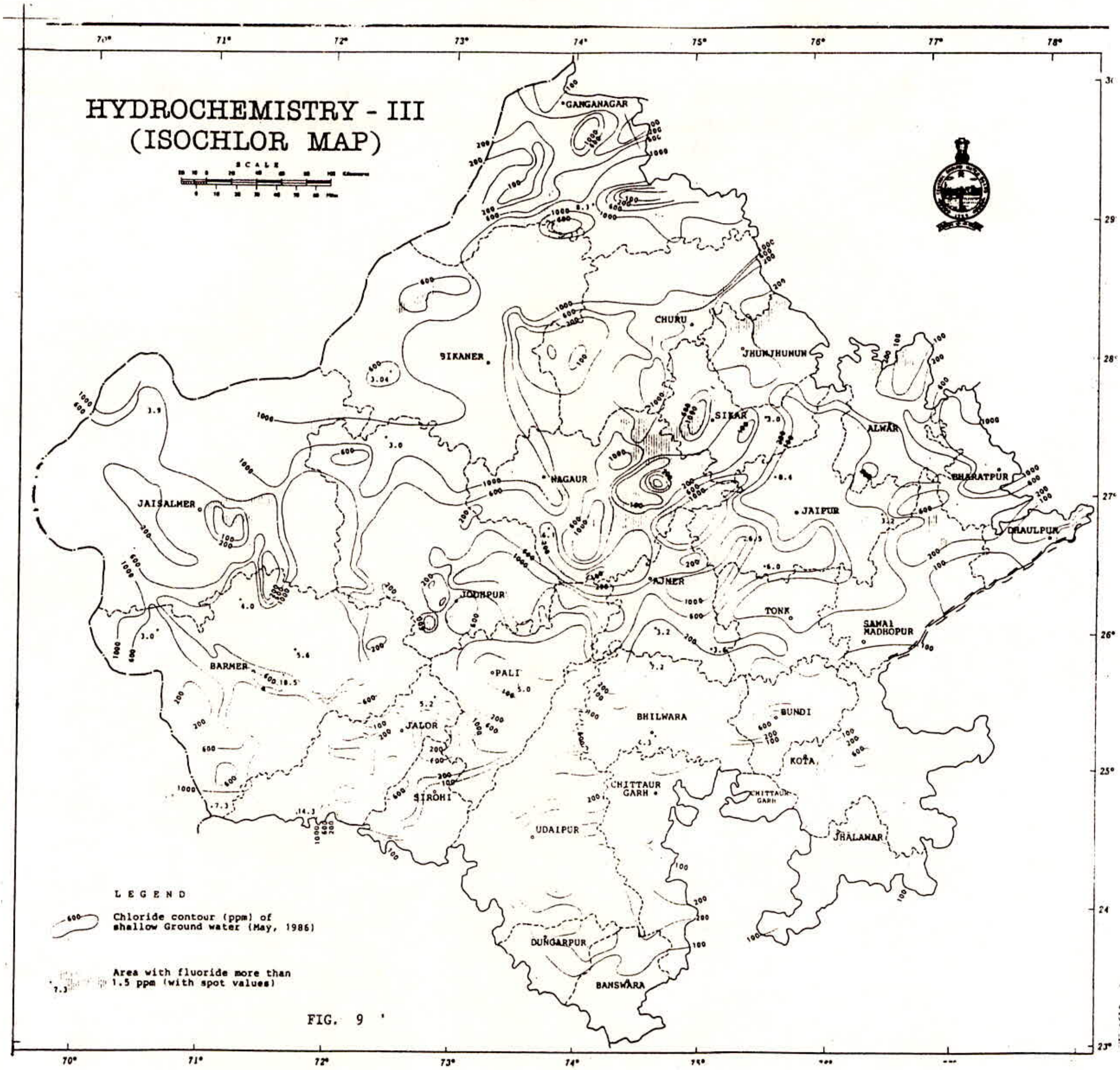

HYDROCHEMISTRY - III
(ISOCHLOR MAP)
SCALE
GANGANAGAR
BIKANER
CHURU
JHUNJHUNUN
SIKAR
ALWAR
BHARATPUR
DHAULPUR
JAISALMER
NAGAUR
JAIPUR
AJMER
JODHPUR
TONK
SAWAI MADHOPUR
BARMER
PALI
BHILWARA
BUNDI
JALOR
KOTA
SIROHI
CHITTAUR GARH
UDAIPUR
JHALAWAR
DUNGARPUR
BANSWARA
LEGEND
Chloride contour (ppm) of shallow Ground water (May, 1986)
Area with fluoride more than 1.5 ppm (with spot values)

FIG. 9

chemical ions (such as fluoride or nitrate) should be plotted in some areas.

Industrial-water quality can also be shown by TDS and hardness. However, some industries have highly specialized requirements and maps should be prepared to show the specific elements significant to those industries.

Water quality maps can be prepared in various ways, i.e., contour or block-area maps, circular or pie diagram, Stiff diagram, and bar diagram.