UPPER JAMMUNA PROJECT
&
GHAGGAR RIVER BASIN PROJECT

THE PROJECT
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**Preface**

The Upper Yamuna project has been established to solve the water disputes between the concerned states, and the Ghaggar River Basins has been newly established by the aid of United Nations Development project due to the effective needs of water in the area.

And so these two projects have a great importance for the geohydrological student.

The author personally observed the borehole geophysical exploration, zone testing, river gauging, water table measurements etc. The author's observations of various techniques in exploration and exploitation of groundwater are most important gains during the project.

Lastly the result of U.J.P is not disclosed yet as it completed its four year duration and while as G.R.B. Project is just recently established, which has great purpose behind it that to make the concerned states economically rich as they have no natural mineral reserves.
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India has more than a fifth of world's irrigated area. Nevertheless, the country suffers from chronic food shortage when India attained independence in 1947, besides various socio-economic problems, one of the greatest challenges that had to be faced was food. The Indian subcontinent has diverse physiographic and climatological regions. The bulk of precipitation is during monsoon months which are capricious. The agricultural production can rest on a firm basis only by assumed supplies of irrigation waters.

At the beginning of the plan period in 1951 the area under irrigation from all sources was 22.66 million hectares. As a result of works carried out during the three five year plans and annual plans upto March 1969 the irrigated area increased upto 27.98 M.H. The total irrigation potential is, however, estimated as 82 M.H. A lot of ground still remains undiscovered.

The total surface water resources in the country are put as 1675 million cubic meters out of which 550 milliard cubic meters are considered utilizable. Only 93 milliard cubic meters, which represent 17% of the irrigated utilizable resources have been utilized till 1957. Upto the end of March 1969, 205 M.C.M. which represent 37% of the utilizable quantity of water has been utilized. Therefore substantial quality of water remain still to be exploited for irrigation and other uses.

The water resources in the country are considerable about 41 million k.w. of the electricity can be generated from the
hydropower potential of the country. Till 1951 the total installed capacity was 2.3 million K.W. Till the 1968-69 the installed capacity was raised to 41.29 million K.W. out of which 40 % is hydropower.

FUNCTIONAL USES OF WATER

Water has two different economic functions. Firstly it forms a part of the infrastructure of the economy and secondary it constitutes a means of production. The infrastructure use of water constitutes its utilization for domestic or normal industrial requirements when used as a means of production it forms what is known as its consumptive use such as its use for irrigated agriculture or its use in substantial quantities in some industries.

The general purpose infrastructure use of water is the right of all areas falling in the particular river basin. The general development of the region and the use of waters consequent there upon are interlinked. However, the consumptive use of water as a means of production is dictated by the economic objections such as increase in production and though these economic objections of reaching still wider social and political objections.

Optimisation of the socio-economic objections govern from the outset engineering and planning considerations for water development and should rightly have a decisive influence on the ultimate engineering proposals. India has regions which are arid
and others which are visited by famine or are subjected to vagaries of monsoon. Different lines of approach one, therefore, followed in the various agro-climate zones.

The policy in arid and semiarid regions is to give priority by providing water for human beings and animals for drinking purposes and only the balance of water used for meeting the irrigation needs. Agriculture in areas should be such as to minimise the wastage of water. Sprinkler or trickler type irrigation could be used with profit.

In draught affected areas the main policy approach is the conjunctive use of available waters from R.F., surface irrigation, exploitation of underground water resources. The Agricultural crop pattern best suited for such areas is the one which provides maximum protection from draught and at the same time ensures as good and stable, an income permit of land is possible. The main policy approach has to be protective irrigation.

For all such areas which can be called occasionally draught affected the main policy approach is to maximise income (yield) per unit of land and per unit of time. It has to be realised that there is an over all shortage of cultivable land in the country relative to population and other factors. The crop pattern and supply of water has thus to be so arranged that the total annual or season production of crops are maximised both in terms of quantity and profitability at any time. Irrigation in such cases has to be productive instead of merely protective.
EVALUATION OF HYDROLOGY

The first and foremost engineering investigations to be made in any water resources development project is its hydrology. Broadly these investigations are made to determine the rain fall in the project catchment and run-off up to the proposed diversion or storage site. The data to be collected for the purpose comprises of (i) a water shed map with rain-gauges, discharge sites and isohyets; (ii) available monsoon R.F. data for the catchment gauge for as long a period as possible; (iii) available gauge and discharge data for the main river and its tributaries; (iv) hydrographs of the river; (v) gauges at short intervals during flood occurrence and observed maximum flood; (vi) observed sediment data; (vii) evaporation data. It is rare that all these data is available. However, in such cases there are known statistical and other methods by which the known R.F. and catchment characteristics the run-off can be estimated. Also with known floods in the region on the particular stream or adjoining streams the max. flood at the particular site can be estimated. In large projects investigations are spread out over a number of years, say between two to five depending on the magnitude of the project are checked and authenticated by actual observation at the detailed investigation and design stages.

The standard practice for assessment of dependable yield in irrigation projects is that the project should be successful for at least 75% of the time i.e. to say 3 out of four years; while in power projects the basis is 90% availability i.e. the
required power draft should be available in 9 out of 10 years. In case of water supply projects the supply is to be ensured at all times i.e. 100% availability. For purposes ensuring the water at the desired dependability at the required time three types of works can be considered viz. run-off the river schemes for recharging groundwater or underground storage schemes have been undertaken in many parts of the world.

**TYPES OF THE PROJECT**

The run-off the river types of works comprises of weir or barrage or pumping schemes either fixed or on floating barages with the necessary conductor system. The conditions for which the types of works and availability of water all-round the year equal to or in excess of the demand. The necessary head for driving the water in the water conductor system is created by the construction of a weir (with or without gates) or barrage or by direct pumping from the river or from natural or artificial recharge groundwater.

When the availability of water is short of the demand, the same has to be stored and made available at a requisite head during periods of demand. The requisite storage has to be created either near the demand areas or higher up or in some cases even on another stream depending on engineering suitability. To tide over bad years of water shortage, some times depending on suitability of the site, carry over storage is to be provided the extent of which again depends on an economic analysis of increment.
benefits and optimisation thereof. Alternatively irrigation requirements in parts or full can be met by exploitation of groundwater. The surface and groundwaters together can also be made to meet the demands.

The other controlling factors which have a direct bearing on the type of control structure and the topography of the valley and type of lands or properties submerged versus storage volume created, physical properties and potentialities of the site for location of surplusing works, availability of construction materials and machinery and existing communication facilities for transporting the same to site of works. Geological investigations are carried out by competent hydrologists.

The various problems which had given birth in U.J.P. and Ghaggar both respectively were and are studied extensively on micro and macro levels, so that it can be able to take more and equal benefits by the concerned states, and which shall at last lead them to stabilize themselves in the agro-industrial road.

One of the main aspects of U.J.P. is to settle the dispute between the concerned states for the unequal distribution of water, is being applied. The C.C.W.B. is determining the extent of groundwater available in the region and irrigation requirement for surface water can be modified in the demand schedule for irrigation. Or in the Ghaggar the flood water can be utilized for recharging the subsurface storages or for desalinisation of salt water storages.
GENERAL INTRODUCTION OF THE U.J.P.

The Upper Jamuna project aims at an extensive appraisal of groundwater resources of the Upper Jamuna Basin spanning over parts of the states of H.P., Haryana, U.P., and Delhi. In the multidiscipline approach planned for undertaking this appraisal, the geological control of the groundwater regions assumes prime importance. The objection of the hydrogeological studies and the approach proposed for achieving it, has been summarised here.

The following broad objections are set up for hydrological studies.

To arrive at a better understanding of the sub-surface geology of the basin lying south of Siwalik foot hill zone up to the depth of interest. This includes the determination of the geological boundaries, aquifer mapping and the study and the nature of sub-surface strata to evolve the sedimentological history of the basin as far as possible.

To study the groundwater flow pattern within the sedimentary strata up to the depth of interest. The flow has to be studied in dimensions and its relation to the geological and hydrological control has to be established. The effects of the man made feature have to be studied in detail in order to arrive at the safe yield and the basin for the artificial drawals.

To study the continuously changing stress and strain relation in groundwater basin caused due to the various natural man made
factors for prognosis of the behavior of the groundwater basin in time space.

As a subclass the above objection to study and evolve the aquifer parameters for the aquifer system of interest in order to understand the behavior of the groundwater storage and flow.

The spatial limit of the study area has been defined in the E.F.C. memo. However, the depth of interest for the surface of hydrological studies and observations has not been defined. This is proposed to be kept 450 m. below ground level on the following consideration. The existing private wells over most of the basin has been constructed at shallower depth of 70 to 60 m. b.g.l. The existing strata tubewells over the basin are generally restricted in depth down to 100-150 m. The recently constructed deep augmentation and direct irrigation wells go down to the 200 to 300 m. depth b.g.l. However, there are relatively few in number. The major works are thus existing down to the shallower depth of 200 m. b.g.l. and the development in the future is likely to be restricted down to 300 m. b.g.l. since the maximum thickness of the alluvium into the basin is likely to be of the order of 300 mts. (except in certain areas where it is shallow) carrying out the present studies down to the entire depth of alluvium is out of consideration. The depth limit of 450 mts. approximately are both necessary and sufficient and shall also keep the investigation work to continue the development for extensive future.
Within the above defined depth, it is advisable to have variable emphasis on the different depth sections. It will be natural and logical to pay maximum attention to the aquifers which have been developed most for groundwater viz. those occurring from 20-150 mts. b.g.l. Incidentally maximum hydrological information is available for this section. The aquifer system lying at a general depth of 150 to 300 mts. b.g.l. though not extensively developed at present have started appearing on the same and may hold storage into the near future good development progress. Substantial observations on the strata in the above depth rate will have to be made, though some what a reduced level as compared to the overlying strata.

The aquifer system occurring at the deeper level below 300-450 m b.g.l. may or may not be developed for groundwater in the somewhat near future. However, some observations will have to be made mainly for studying sedimentological history to study the hydrometric continuing with the overlying strata. Below the depth only stratigraphic beds down to 800 mts. are proposed to drilled at a few situated points.

THE SUBSURFACE GEOLOGY:

The catchment area of Yamuna rain falling to Siwalik foothill zone is not of interest at the main alluvial basin commences from Siwalik zone S-wards. The contact of Siwalik and the alluvial alluvium of recent to sub-recent age has an unconformable contact and is overlain by the Bhabhar piedmont formations which intur
are interfingred with *Terai* and axial deposits. Siwalik formations are suspected to have been remembered at a relatively shallow depth at Ganeshpur. Exploratory well of E.T.O. of Roorkee, Dehradun Road. Some structural disturbances within the lower Siwalik strata were also suspected from shallower depth at which these are located. It is not unlikely that structural disturbances within the Siwalik even overlying alluvial beds of Delhi (the Delhi's and Aravalis). The seismic survey indicates that the bed rock occurs relatively at a shallower depth (-200 to -500 m) in an area extending from Panipat to Delhi and infact there is an underground ridge extending towards NNE along Aravalli axis. A major Boundary Fault cuts across this ridge extension, the north eastern side being the Down throw side. Thus the basin is deepest (-1000 to -3000 m) in an elongated area lying between this boundary fault and the foothill zone. Though the peninsular shield area (the Aravalli Delhi systems) also have been a source area presently no significant drainage (transporting agency) is visible. May be in the past, some drainage emanating from peninsular side existed but has become extinct and obliterated. Presently the Jamuna flows over this area close to the Delhi-ridge. The extension of Jamuna drainage over area underlain at shallow depth by bed rock may be representing the latest phase in its shifting courses.

It is, thus, likely that sediments coming from two distinct provences may have got mixed up the these areas, the dominant contribution being from the Himalayas.
A huge amount of permanently land locked river alluvium (down to -3000 to -4000 m. depth) has naturally suggested that the bottom of the basin was sinking as the deposit was being layed. This sinking has also has to be of such order that at the time of river flow towards the sea was maintained (otherwise, if the sinking of the river level goes below the graded profile, the river instead of flowing into in the sea, would flow into a land locked depression, in The environment of deposition was the peculiar and the changing land forms witnessed by history will not have characteristics of the land forms of an erosion basin. It is conceivable that the river build up flat and broad embankments of its deposits along any particular course and often cut across these deposits to shift towards an adjacent lowlying area all the while maintaining some residual gradient towards the sea. Thus it will be logical to expect many changes in the river courses, which could have wandered all over the basin, keeping the emerging point from Himalayas more or less stable. In this connection it may be recalled that the river Jamuna was once supposed to be tributary of the mighty Sarawati which was following west-wards and joins the Arabian sea (Krishnan).

If that was not, the major change in the drainage from westwards into Sarawati to south easternwards into the Ganga basin would be relatively a recent phenomenon. No possible reason for such a major change (river piracy) is in evidence at present. May be, the area, underlying the triangle formed by Karnal, Thanesan and Jagadhari bears some evidence of the change.
Another complicating factor is the proximity of the Mighty Ganga, whose basin limits might have changed and hence overlapped at places on Jamuna basin.

The above background will throw some light on the complicated nature of the sub-surface lithology. For any particular relict river course, the sediment will have two gradients: one along the channel and other across the same. Lensing out or pinching off of particular beds may be expected in these directions overlapping of the sediments of the adjacent relict drainages of the problem of reworking (cut-outs so called) will complicate the picture. Therefore, any attempt to exactly mark out extensions of individual stratum over such a large basin may not be meaningful. What may be attempted is to evolve a broad similarity of strata from one point to the other and study the regionality of the prevalence of particular lithotypes. In the present case the sands and clays which form the aquifers and confining beds, respectively, so that it can be easy for surface hydrologists and sedimentologists to delineate easily the aquifers. Many devices and methods have been evolved to overcome such difficulties which are met within the basin. The major method is to study the respective drill coring from various site stations.
for evolving such sub-surface lithology the existing
data collected from state tubewells will be used since these
data represent only a limited depth, are drillers log, and have
no logging electrical log counterparts their use may be limited
to make up this short coming and to extend the observations down
to the depth of interest defined earlier, stum holes will be
drilled down to 450 m. depth at about 100 sites (distributed
evenly over the project area) on both the banks about 8 key holes
down to 1000 m or bed rock which ever is earlier would be drilled
to study the sedimentological history of the basin.

The method of extension of individual stratum will be
based on lithology and a bore hole geophysical logs. The S.P.
log, natural gamma and normal resistivity curves may be used
for these purposes. Surface resistivity surveys connecting
different bore holes are also proposed along a number of L & T
sections across the present river course to establish/verifying
continuity of the individual stratum.

The direct rotatory method drilling with attendant
difficulties normally does not yield accurate representative
strata samples. It is therefore, doubtful if the litho samples
collected through the bore holes collected would qualify for
a rigorous sedimentological lab. techniques like mechanical
analysis, study of heavy minerals or other such studies for
correlatin purposes, however, attempts for analysis would be
made.

For the reason mentioned above in the matter of sub-
surface lithology more reliance may have to placed on the bore-
bore hole geophysical data.

GROUNDWATER FLOW:

The Groundwater flow is governed to a large extent by the sub-surface geology. The medium through which the flow takes place may be uniform, homogenous, isotopic. Infinite in areal extent or may be non uniformly layered, and anisotropic and limited in areal extent. Further within the individual layer a gradual change in texture, composition may take place. The sediment under consideration may fall in the latter category. The sediment up to 450 m depth is expected to be a multilayered mass, the individual layers having local extension and depth hydraulic characteristics like the transmissibility, vertical permeability and storativity. The extension of individual layer is due to be controlled by good geological and hydrodynamical factors which governed transportation and deposition of the river alluvium.

The upper surface of the saturated strata represents the W.T. All the strata occurring below this irrespective of its transmissibility etc. is saturated with water. Since the water-table is a free surface expressed to atmospheric pressure.

The movement of water in the W.T. aquifer which may extend to various depths at various places takes place from higher elevation to the lower. The W.T. may be under laying at a poorly permeable or almost impermeable layer which
in turn may be underlain by another aquifer. This second aquifer may be leaky confined or unconfined and in turn will be underlain by another poorly permeable or impermeable layer. This sequence goes on repeating with depth. The peculiarity to note is that these permeable and non-permeable layer not have a regional extension and hence the confined or unconfined behaviour will hold good over smaller area. Secondly substantive water exchange between permeable and less permeable layers seem to be occurring. It is truly that when viewed on a regional scale the deeper confined layer will have hydraulic continuity with the shallower water-table zone through lateral extension and indirectly through innumerable leaky confining layers. However, this is not to concede as some as some may argue that even the deeper aquifer could be taken to be under W.T. conditions rather the flow characteristics and aquifer parameters of these layers even while being connected with shallower aquifer is likely to be closer to the / confined leaky confined aquifers.

To study the Groundwater flow pattern through such a complex deposit is going to prove a complex job. The flow of water in the shallower W.T. aquifer may be observed from behaviour of water level in the open well shallow piezometric and streams. For this purpose a network of observation station of requisite intensity will be (and has been) established covering the or entire basin observation of water level of these stations will be carried out five time during an year viz, pre-monsoon (15-25 Aug.), post-monsoon 25th September to 10th Oct), Mid-winter (1st to 15th Jan) and spring (15th - 30th April).
Water samples will be collected at the time of pre-monsoon and post-monsoon measurement. Supplementary shallow piezometric tapping W.T. aquifer will be set up in limited section across the river at five or six places its closely study influent/effluent nature of the river flow.

Piezometric heads of deeper aquifer have also to be measured in each type of piezometer will represent the maximum cumulative head for that group of aquifers at the time of observation. Since the areas of recharge of individual aquifers are likely to be lying within similar mixed alluvial strata occurring at higher elevations (Northwards) and since significant exchange of water even through the less permeable zone is likely to occur no significant difference in head of one bed and its immediate neighbour is expected (No recharge across the Siwalik contact is assumed). An individual aquifer's piezometric head towering over the piezometric heads of the overlying and underlying beds will be possible only if very good confining layers overlying and underlying and substantially different areas of recharge are presumed. This is highly unlikely to obtain as a general condition, the deeper aquifers of Tarai area being an exception of local extent.

It will not be essential to give equal weightage to the above four gps, for purpose of establishing observation stations. Maximum observations will be made for dug well zone, and progressively reduced number of piezometers may be installed as the depth increases. Thus, it is proposed that the following number of observation station may be established over the entire basin.
1. Open well/v.s. piezometer  |  200 to 250  
2. 30 m. to 150 m.       |  40 to 60    
3. 150 m. to 300 m.     |  30 to 40    
4. 300 m. to 450 m.     |  20 to 30    

At fifteen sites, piezometers of all the three categories will be installed in order to observe change in piezometric heads with reference to depth, at a particular spot. On a few of these sites automatic water level recorders will be installed. The piezometric heads will be observed every month. Thus, four different piezometric contour maps overlying each other will be obtained every month and flow nets prepared. While in the recharge areas the heads of shallower piezometers will be at a higher elevation as compared to those of the deeper ones, in the discharge areas, heads of the lower aquifers will be at a higher elevation as compared to the shallower zones. In any case, detailed analysis of the flow pattern studied in this way, will, in a gross way, afford study of the groundwater flow in four dimensions viz. length, breadth, depth and time dimensions.

Installation of piezometers in this fashion will also afford a great operational and economical advantage as the piezometers could be installed (and are being installed) in the slim holes drilled for sub-surface lithologic studies. Otherwise, the piezometers could have come only in a second phase, which would involve repetition of drilling activity over the same area all over again after completion of slim holes in the first phase.
AQUIFER PARAMETERS:

The flow of water through the aquifers are governed by their characteristic parameters like the storativity, transmissivity and vertical permeability. The characteristics of the leaky confining layers like the lakance (b/m') and storage of such layers also govern the flow. Added to these parameters, the flow is also governed by the various hydraulic boundaries which represent different physical boundary conditions.

For field determination of the various aquifer parameters and for the study of various boundary condition various mathematical models having simple and graphical solutions have been evolved. These models generally apply only to data of single aquifer wells, and are based on various idealized conditions for the aquifer. No doubt, the conditions obtained in nature seldom fit, the various idealizations for a single aquifer and the well may, in the most normal situation, tap more than one aquifer horizons. Hence in most cases the complexity of geologic conditions and well constructions dictates that the quantitative appraisals derived from any method of analyses can at best be considered on approximation. However, with sound professional judgement, these methods could still be applied to get reasonable approximations of practical value.

The programme of construction of test wells, with suit number of observation wells will be taken up in the second ph after envolving sub-surface lithology based on slim holes dr programme. The idea is to tap only a particular well defined
of aquifer which appears interconnected within itself but has well defined confining layers. From the point of view of pump tests, whether the confining layers are of local or regional significance may not be of immediate consequence, as each test may run for a limited period, not extending beyond 10,000 minutes (about seven days). It cannot however, be ruled out that even within such limited period of pumping, boundaries may occur, as the nature of the sediment is non-homogenous, and the confining layers are expected to be leaky in nature. A large number of pumping test results for the existing exploratory and production wells in the area are available. Thus, on left bank, whereas water-table conditions are inferred for Ganeshpur Exploratory well the exploratory well at Ismailpur indicates deeper aquifers of Tarai region to be underflowing artesian pressures. Around moree a number of tests were run on state tubewells using abandoned tubewells and open wells, from upper to lower or (vice versa) layers will have to take place through innumerable layers of different permeability of strata and the aquifer geometry of various layers will be the deciding factor. However, if the pumping periods are long enough to reach beyond the long periods a steady state of recharge of water may be attained between various layer were tested designed, observe and such \$ effect yield tangible results remains to be verified. Maybe the time log involved in the slow exchange of water is so long as not to be verified through a constant discharge test and may be apparent
on a large time scale (say a month) or a year such effects will be studied by correlating G.W. draft over the basin with the levels of piezometers described earlier.

While investigating the G.W. condition down to -600 in the DOAB areas of west Punjab and Pakistan which more or less similar hydrologic conditions. The U.S.G.S. had evolved a special techniques observation wells in pairs one shallow (tapping on W.T. aquifer) and second one regular to the same site. It was observed that the rate of Draw Down in both wells after a long period of pumping become equal the data fitted (leaky confined conditions) analysis methods, as well pairs method based on the direct mensuration was evolved to calculate the storage coefficient for aquifers. The transmissibility and vertical permeability of the layers were also computed since this procedure has a special relevance to the problem in hand it is proposed to conduct as following the methods for multi aquifer (Boulton) wells (Papada pulos).

The method at 3 and 4 may have special reference to the problem in hand. Since it is likely that G.W. reservoir of the basin as a whole may be all interconnected and resemble an unconfined aquifer in that, since the behaviour of individual water bearing layers under short duration of pumping may be like confined/leaky confined layers. The method's Boulton which takes into account layers, it is also likely that since almost a continuous sequence of permeable and leaky confining layers could be expected, the actual field conditions may be complex
and may not fit the solution based on the sample boundary conditions and the other core idealisation underlying any of the above methods. To obviate this difficulty, methods of direct observation may be resorted to.

If the Reservoir conditions are as they expected to be (complex unconfined/confined relation), it will be of interest to observe the effects of long duration pumping of wells and pumping deeper strata on those lapping the shallow strata vice versa. If the reservoir as a whole is to behave as unconfined groundwater body, the resulting of dewatering at deeper levels will get communicate to the upper levels and finally the resultant dpression caused will be reflected in the lowering water-table caused obviously this will involve a great time log effect as the transfer of water.

As observation wells Rao, K.V.R.C. Doctral (Thesis) has inferred the aquifers in Roorkee area occurring at a depth relatively shallower (zone) -100 m. b.g.l to be underlain conditions and possibly during recharge from the area lying Northwest of Roorkee along Hindon traced. Roorkee aquifers parameters were obtained only from one pump test (Gupta B.I.C.D. Th.) conducted a number of pump tests on state Govt. production wells in Muzaffarnagar and Meerut districts using again abandoned tubewells as observation wells. He has inferred that deeper aquifers in the area occur under leaky conditions aquifer parameters are obtained from 15 pump tests Chaturvadi R.S. and Pathak, P.N. has concluded the aquifer in Meerut area to be
under water-table conditions. For the right bank the C.G.W.B. have constructed a number of exploratory wells in Haryana and Delhi. The final test results for some of these indicate deeper aquifers to be under confined conditions and some wells have yet to be tested and data issued. The Haryana M.I.I.C. have constructed a number of exploratory wells in the augmentation canal project area and test results for most of these wells indicate confined or leaky confined condition. However, while calculating the groundwater balance the H.S.M.I.T.C. assume the aquifer down to 2500 depth to be under water table condition.

The major drawbacks of the present data are as under:

(1) The most of the wells are likely to be tapping a large thickness of strata and hence may be multi-aquifer wells. The results have cumulated validity and hence of doubtful analytical volume.

(2) The number and type of observation wells are generally inadequate in most cases only a single observation wells available.

(3) The duration of tests is normally limited to a day or two or even less. In only one or two cases more than 3 days of continuous pumping has been done.

(4) The analysis of data has been carried out by all the available those without much quantitative judgment and the results arrange as a particular method with reference to the existing situation in the site has not been given adequate thought.
(5) Complicated probable of hydrolic boundaries have not been touched.

In the tests to be conducted the above short coming will be obtained through (1) constructing wells in limited well developed aquifer thickness. (2) Adequate number of required observation wells in different desired wells be made. (3) The duration of the tests will be adequately long up to 10,000 minutes (7 days), (4) The methods of analysis will be selectively used based on the situation obtaining at the site.

Normally the following group of methods may be used for the analysis of pump test data with multiple observation wells.

1. Equilibrium formulation (MINIES (THIES) and
2. Non equilibrium formulation (THIES) and etc. modification.
   (a) Non study state, (b) No storage released from confining beds,
   (c) Study state.

As per E.F.C. memo total and 50 test wells with number of observation wells have been planned out and these about 15 tests may be conducted tapping very shallow zones of the water-table constraints. (say up to 30 m.) for determining the aquifer/maximum. The parameter and of the very shallow zone are present and not available and these permanently figure calculations of the chart and account of influent/afluent seepage. The zone between the -30 to -150 m deep is adequately reprinted in straight tubewells which could be tested by number of observations tapping the same
strata about 15-20 tubewells, may be constructed in deeper strata between 152-300 m. in deeper strata. Only 3 or 4 tests may be made on aquifers between 300-450 mts. Aquifers parameters will be evolved on the basis of all the above pump tests. In addition to the pump tests barometric efficiency of deeper horizon will be utilized for computing storage coefficient volume. lab. test may also be conducted on sand sample of shallow horizons to get the volumes of specific yields.

SAFE YIELD AND WATER BALANCE STUDY:

Through evolution of safe yield of groundwater basin lied within the p p s re view of hydrological studies. The larger problem of water balance studies basin including scopefull for conjuctive use involves consideration of hydrometrological surface hydrological and other factors. An attempts for such an evolution which is the principal aim of this project should came out the collection at the end of collection and analysis of the elaborated at this stage.

The problems of recharge to the groundwater basin and draft from it being attempted separately.
INTRODUCTION TO GHAGGAR PROJECT

The area covers about 34000 square kilometers and it has recently been modified more. The project covers three states: (1) Punjab, (2) Haryana, (3) Rajasthan, (13500 km$^2$, 10000 km$^2$, 10000 km$^2$) respectively. North-east part Siwalik hills of and the area is lying below these hills southwest and southwards, the width of the whole project varies from 3 to 20 km. The land slopes towards south and southwest. Makanda is main tributary, Dangi and Saraswati are other two important rivers.

PHYSIOGRAPHY OF THE AREA:

Rainfall in the area occurs about 80 cms average and in the western part it is about 20 cms. The area is arid and semi-arid in climatologically. Soils are mostly alluvial, produce crops like wheat, gram, mustard, and other vegetables.

TOWNS: Chandigarh, Ambala, Patiala, Malarkotla, Singeor, Sesa Batenda etc.

Communications are developed, population is dense. The western part of the project is desert.

There is no mineral wealth in the region so they are developing their agro-industries. As the region is progressing in these sphere, the foremost need is water, canal water as well as groundwater for which the C.G.W.D. is working. We have the water which is of varying chemical compositions at various places
The consumption and the age of water is studied by the C.G.W.B. for how long time we can tape it for various purposes whether for irrigation, industrial use or for domestical purposes. Or the other problem is that some parts of the basin have shallow water-table which causes water logging. In the eastern part of the project some drill holes were put by C.G.W.B. at 300 to 500 meters were good water was found but in the eastern region we have salt waters, so the eastern part is put to water floods so that recharge can take place to decrease the salinity of saline waters.

The other purpose of the project is that the systematic utilization of water is to be carried so that we can check the water scarcity.

The integrated use of surface and groundwater, agricultural development can also be increased.

The methodology evolved under the project in assessing the groundwater resources and tapping its safe utilization in conjunction with surface water in the type alluvial tract in semiarid to arid regions can advantageously be applied to similar areas to other parts in the country.

The mathematical model studies of the project for out managing of the water resources of the basin may be carried out co-ordinately with any university and institute or of the country.
OBJECTS OF THE PROJECT:

The project is included in the UNDP country programme for India.

A. A long range object of the project is to develop a basis for planning the use of water resources in the Ghaggar River Basin in support of agriculture.

B. Immediate objects are:
   a) to quantify the groundwater reservoirs in the basin.
   b) to identify areas of over exploitation which demand legislative measures or other limitations for control.
   c) to investigate the scope for feasibility of artificial recharge of aquifers with flood waters in general emphasis on Kandi area.
   d) to investigate areas with water logging problems and device control and reclamation measures.
   e) to perform hydrochemical studies of the basin.
   f) to conduct digital model studies for management of groundwater in conjunction with surface water and,
   g) to train counterpart personal to do such work independently in the future. The proposed investigation will help to check over exploration of groundwater resources in part of the basin.

The detailed scientific investigations planned under the project would also enable to impart training to professional men already in the field of groundwater investigations and
development other from state as well central organisations.

The proposed mathematical modelling studies in the project will help to plan the management of the groundwater reservoirs in conjunction with surface water resources in the entire Ghaggar river basin.

The project will also help in showing more economic problems related to the development of agriculture in the basin.

The present phase of the project in Rajasthan and Gujarat was completed in September, 1974. The entire equipment of this project would be transferred to the new project. This would enable the new project to start in full swing immediately.

INSTITUTIONAL FRAMEWORK:

The Central Groundwater Board has been engaged in groundwater exploration for developing groundwater reservoirs of the country since 1954. The Board has seven regions for groundwater exploration in different parts of the country.

Installation of tubewells both shallow is already in progress in the basin as availability of groundwater is assumed, based on the first approximation studies. The result obtained during the project will greatly help in formulating the new groundwater developed schemes and expanding the present scheme in a planned manner.
HISTORY OF DRILLING & TESTING OPERATIONS OF EXPLORATORY BOREHOLES

The exploratory drilling was carried out by the hydraulic direct rotary method first an uncased borehole of 6\textfrac{1}{2}\ inches diameter was drilled by circulating sufficiently viscous and heavy drilling fluid under pressure which flushed out the drill-cuttings and facilitated in preventing collapse of borehole wall. The key hole were drilled down to a maximum depth of 250 m. or about. The drill cuttings coming out of the mud flush were collected at regular intervals of 3 or 3.5 m. or whenever any change in formation was noted. In addition to collection of samples recorded were made of drilling time taken for fixed depth ranges, drilling action and the condition of drilling fluids. At necessary depths core samples were collected to ascertain the nature of the bed rock. On completion of this process, electrical logs were on in the drilled holes. These logs recorded graphically the two most important parameters e.g. the electrical resistance of the formation, and the S.P. spontaneous potential by the formations and the fluid fluid contained in them. These two graphs indicated variation in physico chemical properties of the formations with depth.

On the basis of the result of the step-draw down test, aquifer performance test on the wells conducted at fixed R.P.M. During the period of the test, discharge from the well was kept constant and the test was continued till the water level in the wells attained a more or less state of equilibrium. Both yield and draw down data were collected at regular intervals of time
and water samples were collected for complete chemical analysis.

The data thus collected were then projected on the non-equilibrium equation (Theis and Jacob methods) for computation of coefficient of transmissibility ($T$) and coefficient of storage ($S$).

The equations used are:

$$T = \frac{114.6}{s} \text{QW}(u), \quad S = \frac{u}{1.87} \frac{t_d}{r^2} \quad \text{--------} (1)$$

and

$$T = \frac{264}{s} \quad \text{------------------------} (2)$$

were $T =$ coefficient of transmissibility in gallons (U.S.) per day per foot.

$W(u) =$ well function of $v$, constant situation,

$$u = \frac{1.87 r^2}{T} \frac{s}{t_d}$$

$S =$ Coefficient of Storage

$Q =$ rate of discharge in gallons (U.S.) minute.

$s =$ draw down in feet

$r =$ Radial distance (in ft) from the discharging well to the point of observation.

$td =$ time in days

$s' =$ change in residual d.d($s'$) in feet per log cycle of time ($t/t'$).

**Non Equilibrium Formula of Theis:**

The value of $S$ and $r^2/td$, were possible were calculated from the observation well data and $S$ (dd or recovery) was
plotted against $r^2/td$ on a log log co-ordinate graph paper. The curve of observed data was superposed on the "type curve" of $W(u)$ and $u$. The co-ordinates of the match point on the both sheets were recorded and values, thus obtained were used to solve the equations (1) mentioned above and the values of $T$ and $S$ were computed.

**THEIS RECOVERY FORMULA:**

Where the observation well data were not available, the water level data collected from the test wells only were computed to determine the $T$ of the aquifers by using the equation (2).

The values of $s'$ and $t/t'$ obtained from the pump well data were plotted on a semi-logarithmic co-ordinate paper, $s'$ being plotted on the arithmetic scale and $t/t'$ on the logarithmic scale. From the slope of the straight line thus obtained the values of $s'$ over one log cycle of $t/t'$ were determined and substituted in the above equation.

This semi-log plot is an approximation method and gives only an approximate idea of the transmissibility of the aquifers and it is not possible to determine the storage coefficient, $S$, from observations within the pumping well, by this method because the effective radius of the well is not known. (Wisler and Braler, 1959).

**FIELD OF COEFFICIENT OF PERMIABILITY**:

The degree of influence of heterogeneity of saturated granular material encountered in different sections of a well
is not known. However, in order to have a better visualization of the rate of percolation of water through the granular material, it is considered that computation of field co-efficient of permeability will be of comparatively added advantage, since it represent the average of aquifer characteristics inner sections of the aquifers.

The field co-efficient of permeability which is a function of transmissibility and thickness of the saturated granular material has been determined by using the non-equilibrium formula,

\[ pf = \frac{114.6 \times W(u)}{m \times \text{S.M.}} \]

i.e. \( pf = \frac{T}{m} \)

where,

\( m \) is average total thickness ft. of the saturated granular material screened

and \( pf \) is the field co-efficient of permeability in U.S. gallons per day per sq. ft.

**CONSTRUCTION OF PUMP WELLS:**

**Screens:** The type of screen to be used in the construction of the pump-wells in the circular pattern was decided to be bridge-slotted. During the course of construction of wells, centralizing guides were provided with screens to ensure proper emplacement and to prevent the screens from coming in contact with the formation. The bottoms of screens were either provided with a dummy or bultnose. Blank pipes were provided between the screen for pump section. The need to provide a blank pipe against zone s or
against clay horizons, has to some extent mitigated the need for having blanks for suction at the lowest level.

Gravel packing: In view of the need to have materials of proper size for gravel-shrouding, the corporation authorities in sufficient quantities. Recommendations based on partial sieve analysis of samples collected during drilling were given for materials to be used for gravels required it has not been possible to use the same type of materials from ground level to the bottom of the borehole.

The materials used for gravel-shrouding consisted chiefly of quartz and angular sand. In all other cases, the materials do not conform to the recommendations. In effect, in the case of other wells, it would appear as if we have used a graded pack.

In giving recommendations for the material to be used for gravel-shrouding, great consideration had to be given to the size of the openings of the screens rather than to materials of the formations themselves.

Developments of wells: The wells are developed by air lift pumping using compressors with maximum working pressure of 504 kg/m. (100 psi) and a displacement of 14.16 m³ (500 c ft). In most cases air lift pumping was done with the raising main of the eductor pipes kept at one point and as soon as the water appeared to be clear, the eductor pipes kept at one point and as soon as the water appeared to be clear, the assembly was pulled out and pump installed. This method of development could effect a proper rearrangement of materials only against small portions.
of screens. The geologists, however, preferred to complete development by airlift pumping as they felt that, since drilling had been done only by reverse rotatory method, the formations would not have been contaminated by mud fluid and airlift pumping could effectively remove the finer materials from the formations.

**ANALYSIS AND INTERPRETATION OF DATA:**

It is common to come across the differences in the values of observed drawdowns and drawdown computed theoretically using values of aquifers constants. The theoretical computations assume, interalia, that logarithmic head distribution should prevail right down to the well face and that the physical radius of the well can be taken to be same as the effective radius. It is frequently noted that the theoretical drawdowns are less than the observed drawdowns such differences between them cannot be attributed to screen losses only. Many factors enter the picture and seven losses is only one amount them. A proper understanding of these factors is essential for study of well hydraulics.

Recent studies by various investigators have widened our knowledge of well hydraulics in respect of heat distribution one of the important publication in this subject are by C.E. Jacob (1946) and M.I. Rorabaugh (1953) considerable one has been made of the results of these studies and of the method of approach, as they relate to the problem of well hydraulics.
The draw down in a well tapping a confined aquifer is the sum of the head loss resulting from the laminar flow in the formation and head loss resulting from the turbulent flow in the zone outside the well, through the well screen and in the well casing itself. This brings out prominently that the entire head loss cannot be accounted for by the head loss resulting from the laminar flow in the formation.

Studies by various investigators have clearly demonstrated that the flow near the well face, above a particular limit, is turbulent flow, commonly referred to as "well loss" proportional to some power of discharge exceeding the first power. The head loss in a well can be represented by the equation (Jacob, 1946):

\[ S_w = BQ + CQ^2 \]

where \( S_w \) is the total draw down in the well, \( B \) is head loss per unit of discharge due to laminar flow in the formation, and \( C \) "well loss" coefficient for turbulent flow for a given well is based on the theoretical assumption that the loss due to the interesting results, the applicability of this equation has been extended by a modification suggested by M.I. Rorabaugh (1953), who has analyzed the relative merits of Jacob's equation and the one proposed by him. The modified equation of Rorabaugh, which is an exponential one, has a wide range of applicability and it can be solved by a graphical method with the attendant advantages of ease and a lower sensitivity. The
empirical equation which uses the same rotation as of Jacob's is

\[ S_w = BQ + CQ^n \]

It can be seen that the empirical equation becomes identical with Jacob's equation, when the value of exponent 'n' becomes. (2) This equation thus conforms to the theoretical basis of Jacob's equation. The merits Rorabaugh points out, among other things, that, for the range of discharges upto 0.512 m³ (4 cubic ft) per sec. Draw down computed by each equations are closed to the observed data. Comparing the head loss due to the differences in flow conditions, he points out that the empirical equation assigns a smaller value due to "well loss" than does the theoretical equation.

It may not be out of place to mention here a few words about the devices used in measuring water levels during the tests. The electrical devices used had always given different results from those given by wetted tape methods. It is clear that the data of water levels especially from pump wells shall not come up to the degree of accuracy for proper analysis and interpretation. This, couples with the fact that the discharges shall not be precisely metered has made it necessary to apply caution in comparing the data collected and in making use of them. The graphical method of analysis of test data adopted
here, is on the same lines as followed by Rorabhaugh. It involves the plotting of values of \( \frac{S_w}{Q} \) against values of \( Q \) (\( Q \) expressed in cubic feet per second) on log log paper assuming various values for \( B \). The value for \( B \) for which a straight line passing through all the points is obtained is taken as final one. The value of \( e \) is taken as to be equal to the value when \( \frac{S_w}{Q} - B = 1 \). \( n \) is determined from the slope of straight line which is taken to be equal to \( n-1 \). The value of \( S_w \) for any step is taken to be equal to the sum of the incremental draw down. These being determined by plotting the data from test well and extrapolation to get the probable pumping level, had the pump discharged at the same rate during the period of neat step.

In the pal. 1 is shown the method of determining graphically the value of \( B \), by plotting \( \frac{S_w}{Q} - B \) against \( Q \) for various trains of \( B \).

The values of \( B, Q \) and \( n \) are determined from the graph and substituted in the equation \( S_w = BQ^n + CQ^n \) to complete the value of \( S_w \) for each step.

Analysis of data of step tests in terms of equation \( S_w = BQ + CQ^n \) leads to an analysis of the factors responsible for head loss in the wells and in particular, to the factors contributing to the well losses. The lack of uniformity does not permit a ready comparison of the data. It would therefore be necessary to bring in a measure of uniformity before
attempting any comparison. This could be achieved by the application of the empirical equation for processing the list data before doing so it would be necessary to know the relationship between the observed and computed data, by the application of empirical equation.

Per pertaining to the discussion on the materials used for gravel shrouding of the wells, is an understanding of the rule of thickness of the gravel envelop. Gravel shrouding is often resorted to, to provide a zone of material of higher permeability around a screen and there by minimize the Draw Down in the well, or in other words, increase the specific capacity of the well. Another equally important purpose of shrouding is to prevent sand coming into the well. It is possible by a proper selection of filter materials, to control the size and amount of sand entering a well. This is a very essential to ensure a long life to the pump operation in a well. While the size of the sand entering a well depends on size gradation of the gravel materials, amount of sand entering the well, depending both on size gradation and thickness of gravel envelop. Transportation of sand from the formation through the envelop into the well depend upon the grain diameter and the velocity of the transporting medium, namely water. Velocity of water plays a greater part as it controls both the sizes and amount of sand that can be carried with a well.
velocity of water in movement, changes with the medium through which the water flows. The permeability and porosity factors of the medium directly influence the rate of movement of water. These two factors viz., permeability and porosity are different for the formation and the gravel pack. It would be reasonable to assume that the permeability and porosity values of gravel should always be greater than those of the adjacent formation. In view of this the velocity of water flowing through the gravel envelope is sound to be less and therefore, the transporting capacity of the water through the gravel envelope is also bound to be less. It therefore, follows that the materials, which could be carried by the water, owing to higher velocities prevailing in the formation are to some extent likely to be deposited in the interstices of the gravel envelope as the water flows through the envelope at a lower velocity. The longer the duration of water travels through the gravel envelope, the more perfectly will be water in respect of transporting capacity, get itself adjusted to the medium viz, gravel envelope through which it travels. In other words a thicker gravel envelope will become a receptacle for all the fine materials which are deposited during reduced velocity and which would not enter the well owing to limitations of screen opening.

The above situation can happen only when the size of the materials selected for the gravel envelope is more than four times the grain diameter of the formation materials and more than four the size of screen openings. But if the screen opening all very
little than gravel pack then there will be no entry and thereby water will accumulate in the gravel shroud, and reducing the permeability of gravel shroud in course of time as the interstices will be filled.

The maximum permissible thickness of the gravel envelop is dependent on the maximum size of the hole, which a rig can safely drill and minimum degree of tolerances required for inserting pipes and screens in holes which may go out of plumb. All these discussion means the max rearrangement of materials of the formation, so that there is a gradual variation in the sizes of the materials with the coarsest gravel packing which "automatically grades the sand or gravel in such a way that every portion is in exactly right relation to the next portion so that each acts to stabilize the one next to it" (Bulletin No. 234, published by Edward E. Johnson, St Paul 4, Minnesota).

The above subject brings in the question of technique of development. The presently adopted method of an lift pumping by compressed air can not give satisfactory results, as the pumping rate remains constant and consequently the velocity developed in the zone out side the wells remain constant with a constant velocity, an effective removal of fine materials of the formation and proper gradation of sizes can not be achieved. It would be necessary to try other techniques of well development such as back washing, raw-hiding etc. in order that velocities much higher than can normally prevail may be achieved and a satisfactory rearrangement of formation materials.
JACOB LIST FOR PUMP TEST WELL DATA

Date: 2.4.1975    Site: Nahar House (Chur Majri)

8¼" - 10" head -186 USGPM
704 LPM

HP is top of housing which is 0.6 Majh
C.W.L. -25.4.29

Static water level 20.71 m 5 P.M.

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Hold cut = W.L.  Static W.L. = DD 25.38  20.71  4.67
\[ Q = \frac{704}{1000} = 0.704 \text{ m}^3/\text{day} \]

\[ T = \frac{230 \times 10.14}{12.56 \times 0.38} = 116.6 \text{ m}^3/\text{day} \]

\[ \frac{12.304}{1.256} \]

\[ \frac{11.66}{0.99504} (468) \]

\[ \frac{170960}{109184} \]

\[ \frac{207760}{198172} \]

\[ 08748 \]

Approximately \[ T = 468 \text{ m}^2/\text{day} \]

\[ 470 \text{ m}^2/\text{day} \]

\[ T = \frac{264 \times 0.704}{6.38} = \frac{264 \times 704}{3.8} \]

\[ = 1.35 \times 264 = 268 \]
HYDROLOGICAL TEST DATA

"Modle Town Ambala City"

Test A.P.T. pre-pumping water level 22.85 m gc M.P. 0.60 m Agl.
Discharge: 871 LPM.

<table>
<thead>
<tr>
<th>Time</th>
<th>Time minutes since pump test</th>
<th>Time since pump test started t</th>
<th>RDD</th>
<th>t/f</th>
</tr>
</thead>
<tbody>
<tr>
<td>1201</td>
<td>1</td>
<td>241</td>
<td>0.56</td>
<td>241.0</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>242</td>
<td>0.45</td>
<td>121.0</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>243</td>
<td>0.42</td>
<td>81.0</td>
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<tr>
<td>4</td>
<td>4</td>
<td>244</td>
<td>0.40</td>
<td>61.0</td>
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<tr>
<td>5</td>
<td>5</td>
<td>245</td>
<td>0.38</td>
<td>49.0</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>246</td>
<td>0.37</td>
<td>41.0</td>
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<tr>
<td>8</td>
<td>8</td>
<td>248</td>
<td>0.33</td>
<td>31.0</td>
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<tr>
<td>10</td>
<td>10</td>
<td>250</td>
<td>0.32</td>
<td>25.0</td>
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<tr>
<td>15</td>
<td>15</td>
<td>255</td>
<td>0.32</td>
<td>17.0</td>
</tr>
<tr>
<td>20</td>
<td>20</td>
<td>260</td>
<td>0.31</td>
<td>13.0</td>
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<tr>
<td>25</td>
<td>25</td>
<td>265</td>
<td>0.29</td>
<td>10.60</td>
</tr>
<tr>
<td>30</td>
<td>30</td>
<td>270</td>
<td>0.29</td>
<td>9.0</td>
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<tr>
<td>40</td>
<td>40</td>
<td>280</td>
<td>0.22</td>
<td>7.00</td>
</tr>
<tr>
<td>1300</td>
<td>50</td>
<td>290</td>
<td>0.22</td>
<td>5.50</td>
</tr>
<tr>
<td>1310</td>
<td>70</td>
<td>310</td>
<td>0.19</td>
<td>4.43</td>
</tr>
<tr>
<td>1320</td>
<td>80</td>
<td>320</td>
<td>0.16</td>
<td>4.00</td>
</tr>
<tr>
<td>1330</td>
<td>90</td>
<td>330</td>
<td>0.15</td>
<td>3.66</td>
</tr>
<tr>
<td>1340</td>
<td>100</td>
<td>340</td>
<td>0.14</td>
<td>3.40</td>
</tr>
<tr>
<td>1350</td>
<td>110</td>
<td>350</td>
<td>0.13</td>
<td>3.18</td>
</tr>
<tr>
<td>1400</td>
<td>130</td>
<td>360</td>
<td>0.13</td>
<td>3.00</td>
</tr>
<tr>
<td>1420</td>
<td>140</td>
<td>380</td>
<td>0.13</td>
<td>2.70</td>
</tr>
<tr>
<td>1440</td>
<td>160</td>
<td>400</td>
<td>0.12</td>
<td>2.50</td>
</tr>
<tr>
<td>1500</td>
<td>180</td>
<td>420</td>
<td>0.12</td>
<td>2.30</td>
</tr>
<tr>
<td>1520</td>
<td>200</td>
<td>440</td>
<td>0.11</td>
<td>2.09</td>
</tr>
<tr>
<td>1540</td>
<td>220</td>
<td>460</td>
<td>0.11</td>
<td>2.04</td>
</tr>
<tr>
<td>1550</td>
<td>230</td>
<td>476</td>
<td>0.10</td>
<td>2.00</td>
</tr>
<tr>
<td>1600</td>
<td>240</td>
<td>484</td>
<td>0.10</td>
<td>2.00</td>
</tr>
</tbody>
</table>
P.W.L. = 22,85 Mbgl  Measuring point 0.60 m
pumping = 240 mts.

\[ Q = 871 \text{ LPM} \quad \text{Max. DD} = 1.10 \]

(1) Specific capacity \( Q/s \) \( 871/1.10 = 781.8 \text{ m}^3/\text{day} \)

(2) \[ T = \frac{264}{s} \quad 264 \times 871/0.2 = 114972 \text{ m}^2/\text{day} \]

\[ T = \frac{269}{Q} \quad Q = 3\text{ m}^3/\text{m} \times \frac{264 \times 0.871}{0.20} \]

\[ T = \frac{2.30Q}{4s} \quad Q = \text{m}^3/\text{day} \quad T = \text{m}^2/\text{day} \quad S = \text{meters} \]

\[ T = \frac{264Q}{s} \quad Q = \text{m}^3/\text{day} \quad T = \text{m}^2/\text{day} \quad Q = \text{meters} \]

(1) THEIS method

\[ \theta = \frac{Q}{4\pi T} W(u) \quad \ldots \ldots \ldots \ldots (1) \]

\[ U = \frac{r^2s}{4\pi t} \quad \ldots \ldots \ldots \ldots (2) \]

\( \theta \) = drawdown in mts in observation well at a distance \( r \) from the test well in
\( Q \) = Discharge \( \text{m}^3/\text{Day} \)
\( S \) = Storativity
\( t \) = time in days some pumping station.

\( W(u) \) = Theis well function
Match from e - analyz

\[ w(u) \]

\[ \frac{1}{n} = 10 \quad n = 10 \]

\[ \ell = \min \quad \ell = \text{min} \text{ days} \]

\[ T = \frac{\theta}{n} \quad \theta = \omega(u) \]

\[ \dot{\lambda} = \lambda^2 / \text{day} \quad \dot{\lambda} = \lambda^2 / \text{day} \]

Equation \( \dot{\lambda} \) can be written as:

\[ s = \frac{u_T \ell u}{2} \]

\[ s = \frac{10^4 \ell \cdot 10^{-3}}{2} \]

\[ s = 10^8 \times 10^4 \]

\[ \omega = 0.5 \times 10^{-5} \]

\[ T = \frac{2 \times 10^3 \theta}{2 \times 10^3} \]

\[ s = 2 \times 5 T \ell \]

\[ r_0^2 \]
\[ JHES. RECOVERY \]

\[ \frac{10,000 + 1}{1} = \frac{10,000 + 1}{1} \]

\[ \frac{2}{10,000 - 1} + 1\frac{1}{2} \]

\[ \frac{10,000 - 1}{1} \]

\[ + 1\frac{1}{2} \text{ vs Residual algae} \]

\[ \Delta \theta = 0.3 \text{ m/yr} \]

\[ \frac{T}{2.30} = 0.01 \text{ m/yr} \]

\[ \Delta \theta = \text{ mm/yr} \]

\[ 16 = \frac{x}{1440} \text{ days} \]

\[ S = 2.85 T + 0 \]

\[ \gamma^2 \]
\( A = 700 \ \text{rpm} \)

\[ 1 \ \text{USN RPM} = 3.705 \ \text{USN RPM} \]

Observably well data are more important.

Diagrams report the logarithmic methods of DD curves.
<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Depth Range (in Meters)</th>
<th>Lithology</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>76</td>
<td>161.02 to 164.59</td>
<td>Clay grayish yellow, with slightly silty, with kankar also having grains of ultrabasic rock such as rhyolite. A few of the white Quartz grains are also present which are generally subangular. The kankar is of bigger size as compared to the rock pieces and the Quartz etc.</td>
<td>Clay = 60% kankar = 30% Rock pieces (R.P.) = 8% Quartz = 2%</td>
</tr>
<tr>
<td>77</td>
<td>163.02 to 165.70</td>
<td>Lithology same except that the Qtz. grains are not present here</td>
<td>Clay = 65% kankar = 30% R.P. = 5%</td>
</tr>
<tr>
<td>78</td>
<td>165.70 to 168.70</td>
<td>Qtz grains are not present</td>
<td>Clay = 60% Kankar = 35% R.P. = ± 5%</td>
</tr>
<tr>
<td>79</td>
<td>168.70 to 171.67</td>
<td>Grenish yellow sandy/silty clay with kankar and rock pieces</td>
<td>Sand/ Shaley clay Kankar = 50% R.P. = 5%</td>
</tr>
<tr>
<td>80</td>
<td>171.67 to 176.67</td>
<td>Silty clay with kankar and rock pieces</td>
<td>Silty clay = 50% kankar = 48% R.P. = 2%</td>
</tr>
<tr>
<td>81</td>
<td>176.72 to 178.72</td>
<td>Sandy clay with kankar &amp; R.P.</td>
<td>Sandy clay = 55% kankar = 43% R.P. = 2%</td>
</tr>
<tr>
<td>82</td>
<td>178.72 to 180.72</td>
<td>Yellowish clay with kankar and R.P.</td>
<td>Yellow clay = 60% Kankar = 59% R.P. = 1%</td>
</tr>
<tr>
<td>83</td>
<td>180.72 to 182.92</td>
<td>Sandy clay with kankar and R.P.</td>
<td>Sandy clay = 35% Kankar = 63% R.P. = 2%</td>
</tr>
<tr>
<td>84</td>
<td>182.92 to 184.92</td>
<td>Greynish yellow silty clay with kankar and R.P.</td>
<td>Silty clay = 65% Kankar = 34% R.P. = 1%</td>
</tr>
<tr>
<td>85</td>
<td>184.92</td>
<td>Very fine greyish yellow silt</td>
<td>Silty clay = 53% Kankar = 48% R.P. = 2%</td>
</tr>
<tr>
<td>86</td>
<td>186.92 to 188.59</td>
<td>Greyish yellow clay kankar &amp; R.P.</td>
<td>Clay = 65%, Kankar = 32% R.P. = 3%</td>
</tr>
</tbody>
</table>
INTERPRETATION OF ELECTRIC AND GAMMA RAY:

Logs in Water Wells: A typical tentative logging for water wells consists of a normal or single electric resistivity; the sp. and some times Gamma ray measurements. The usual logging situation are classified into three gps. and simple interpretation procedures are outlined for each. Much useful information is provided by these records, especially when they are supplemented by the bit penetration rate and the other data. The logs can solve many common Groundwater problems.

INTRODUCTION:

Geophysical logging is an accurate and convenient way of obtaining sub-surface data that would be provided, otherwise only by coring or testing. Some of the data are read directly from the logs—depth and thickness of beds, other such as the water salinity be obtained only by analysing the records.

There are many geophysical logging tools, but the groundwater developer cannot afford the cost of running the comprehensive suite of logs used in the oil industry. Nevertheless, much information can be extracted from these records especially when they are supplemented by the drillers logs cuttings, knowledge of local geology and some experience.

CLASSIFICATION OF FORMATIONS:

The problem encountered in groundwater work are many,
8 geophysical logs can solve or help only part of them. A log may be a valuable tool in one locality use less in another, because the water may occur in a different kind of rocks. For log interpretation purposes it has been found convenient to classify formations among one of the following gps.

(1) **Clear Granular Aquifer;**

Comprise gravel, sand, sandstone of carbonate rocks having only granular type porosity. Silt must be added to this if provided that its particles are not composed of clay minerals.

(2) **Clayey Granular AQ;**

This gp includes granular aquifer that is in part composed of grains formed by clay minerals or contains clay material within its pore spaces.

(3) **Fractured AQ;**

Represented by fractured or jointed rocks having little or no granular type porosity.

(4) **Complex AQ;**

In which the porosity as in a type different from those specified above; eg. Carbonate Rocks that are both granular and fractured, lava etc.

(5) **Dense Formations;**
(5) **Dense Formations:**

Rocks having so little effective porosity that no water could be normally obtained from them. Besides some carbonate rocks, they include anhydrite, gypsum, salt as well as many kinds of Igneous and metamorphic rocks.

(6) **Clay:**

This group includes all formations like clay and shale that consist of very fine, surface active particles. All have very similar properties as far as electric and Gamma ray logs are concerned, they are called clay for both of simplicity.

For convenience specially in Gamma ray logging any formation of type (1) to (5) is called a "Rock." Unless specified otherwise it will be assumed that all aquifers are reasonably information in texture and fully saturated with water.

**Resistivity Log**

**Resistivity for Clear Aquifers:**

A clear aquifer is made up of a nonconductive rocks or skeleton, and water. Its resistivity is determined by

1) the resistivity of water (i.e. the water salinity)

2) the quantity of water that the rock contains, i.e. (rock porosity).
iii) the distribution and continuity of water within the pore spaces.

It has been found that the resistivity (Rt) of a clear aquifer can therefore be expressed as follows:

\[ \text{Rt} = F \times \text{Rw} \quad \text{(A)} \]

where \( \text{Rw} \) = water resistivity
\( F \) = constant, that represents the effect of pore spaces.
This constant called formations resistivity factor is given by the following formula

\[ F = A/m \quad \text{(B)} \]

where \( \phi \) is the effective porosity (Fraction of total volume) and \( A \) and \( m \) are non-dimensional holes that represent the effect of porosity distribution and continuity.
\( A \) and \( m \) vary from rock to rock and their values can be accurately determined from lab-measurements.

The resistivity of water (Rw) decreases when the salinity increases. At a given temperature, water resistivity is related to the dissolved solids content in parts/million (ppm) by the expression.

\[ \text{Rw} = K/\text{ppm} \quad \text{(C)} \]

where \( K \) is a factor that is nearly constant for a given salt when the salinity is low (less than about 3000 ppm of dissolved solids)
For the usual low salinity eaters, $k$ average 6500 at 25°C. Water resistivity decreases somewhat when temperature increases but this effect is small (2% per degree at 25°C) and will be neglected. Fig. (1) is a chart representing formula (C).

**CLEAN GRANULAR AQUIFER:**

For clean granular rocks having a porosity greater than about 10% $A$ and $m$ have the following average values rocks that are litter or not cemented: $A = 0.52$ $m = 2.15$

Rocks are more cemented $A = 1$ $m = 2$

Fig. 2 illustrates the relationship between function factor and porosity using above sets of values. The first set will be used for the numerical examples given below:

Combining formula (A) & (B) & (C) and using for $k$ the resistivity of clean granular aquifer.

$$R_t = \frac{0.62 k}{\phi^2.15 \text{ ppm}} \quad \text{(D)}$$

Fig. B is a chart based on the formula using for $k$ the value (6500). It gives the resistivity of clear granular aquifers as a function of their porosities (expressed in % of total value) and for a few water salinity values.

The geometry and continuity of the pore spaces in low porosity granular materials is rather irregular and it is not possible to assign two parameters parameters $A$ & $m$ average rock.
It is seen from fig.3 that all other factors being constant

1. The higher the porosity, the lower the aquifer resistivity.
2. The lower the salinity of water, the higher the aquifer resistivity.

The above upper x-hatched area of fig.3 correspond to clean fresh water aquifers, commonly their resistivities are of the order of 50 to 1000 ohm-m.

Brackish and salt water aquifer of good porosity have resistivities which are much less than 50 ohm-m.

**NON-GRANULAR AQUIFERS**

The pore spaces of non-granular aquifer is so variable and irregularly distributed that it would be illusory to seek an expression a chart relating resistivity to porosity. All that can be said with confidence is that resistivity decreases when porosity or water salinity increases, all other factors remaining the same.

**DENSE ROCKS**

Rocks that have non-effective porosity have extremely high resistivity, usually of the order of 100,000 ohm-m and more.

**CLAY**

As far as resistivity concerned, clay can be considered as a granular material whose pore spaces has a particular
geometry. Hence formula (B) applies, but the parameters $A$ and $m$ have values which probably are somewhat different from those previously specified. Although no numerical data are available, the resistivity of a clay can be estimated from formula (D) or fig. 3.

Clays have a high porosity and the marine clays at least generally contain brackish-water, two facts that make their resistivities low commonly these range from 2 to 10 ohm, i.e. they are lower than the resistivity of the fresh-water aquifers.

**Clayey Granular Aquifers:**

Clay dissolved within the pore spaces reduces the resistivity of fresh-water aquifers, fig. 4 gives the resistivity reduction for a granular aquifer as a function of its clay content.

The resistivity of the clay is assumed to be one-tenth ($1/10$) that of the aquifer water and the double layer effect, if any, is disregarded.

The lower curve applies if the clay particles surround the rock skeleton and the upper one curve is applied, if they do not touch it.

If the clay is randomly distributed, the geometric average of the two curves probably gives a better account of the
Fig. 3

Approximate permeability of granular aquifer vs. porosity for assumed water salinity.

Relationship between clay content, percentage loose sand content after granular aquifer, and clay content is assumed to be one-third (1/3) of water salinity.
resistivity reduction.

The average is shown by the dashed line. It will be observed that when the pore spaces contain 10% of irregularly intersected clay, the aquifer resistivity drops to about 60% of the value it would have if it were clean.

The drop would be greater if the resistivity contrast between water and clay were higher than 10, which is often the case for fresh-water aquifers.

**APPARENT RESISTIVITY:**

Resistivity logging devices ............average resistivity, called apparent resistivity, of a certain volume of earth material in the velocity of the logging problem. This zone intercepts a portion of the mud column and frequently the adjacent beds also; the larger the contrasts between the aquifer resistivity (on the one hand) and mud and adjacent beds resistivity (one to other), the larger the departure is between apparent and true values.

The departure is small, if the aquifers are thick and have high porosities, it is therefore of no great consequence if the log is used qualitatively, as is generally the case for water wells. The departure is large in high resistivity formations. And an aquifer of low porosity may be mistaken for dense rock or conversely on the strength of the resistivity curve, if the latter is used alone.
When qualitative data are desired true resist must be determined. The true resistivity of a bed can be obtained provided an appropriate electric log and the related analysis charts are available (Guyod 1961 & Prangin, 1961). Petroleum producing service companies run electric logs, that are sold to the heads of the petroleum geologists and to the real conditions, from these logs certain types of quantitative data can be divided. If circumstances do not justify cost of service to log or if logging service is not available the water well contractor desires quantitative data must provide his own log. The only equipment which is adequate, practical and reasonably priced is one giving two normal — preferably with 10-64 electrodes spacing fairly accurate resistivities can be derived from such a log provided following conditions are met.

1. The aquifer resistivity is not too large, thus reveals that the porosity be fairly high and the dissolved contents of the water be not less than about 100 pp.

2. The aquifer is at least 15 ft. thick and reasonably inform in tectured, and particular it should not contain clay or dense layers.

3. The mud invasion is small.

4. The hole diameter is less than 10 in and mud resistivity greater than about 1 ohm.m.

5. There are many areas where the area conditions can be met by aquifers in the depth material of interest.
EXAMPLES OF RESISTIVITY CURVE:

Fig. 5, 6, & 7 are artificial electric and gamma ray logs for three types of formations. These appearances are approximately those of actual logs for the formations shown, provided the hole diameter is less than 10" and borehole resistivity greater than one ohmm and the R.C. are those that would be obtained with a single electrode or a short normal probe; they correspond to the noted average resistivity of the material contained in a sphere having a diameter of approximately 3 ft. The internals marked "sand" or "sandstones" could represent greater carbonate rocks since these rocks have nearly the same resistivity, other factors being constant. The bed shown have informal texture 10-15 ft thick; there true resistivity are indicated to the ft R.C. of curves. Actual logs have more irregular shape because the curves reflect the base of non-uniformity commonly exhibited by rocks. No scales are shown semi apparent R values depend upon many factors such as porosity, water salinity, mud resistivity etc.

The resistivity curves illustrate the following factors:

1. Fresh water aquifer and dense rocks have much higher resistivity than most other formations.

2. The apparent resistivities of fresh water aquifers with low porosity are of the same order as those of dense rocks. In practice they can be differentiated by the reference to the bit penetration rate the character of the cuttings or some times the S.P. curves.
3. Aquifers which contain highly saline water have resistivity close to that of clay. In practice they can be differentiated from clay by using the S.P. or gamma ray curves.

4. Bed depths and thicknesses can generally be accurately determined from the resistivity curve, but the size of the individual fractures in consolidated rocks can not be.

In fig. 5, the apparent resistivity of the bottom salt water sand is shown to be less than that of the adjacent clay. This is frequently the case where there is only little invasion by the mud filtered. The S.P. is larger when the invasion is important.

Artificial ER and Gamma ray log approximately the appearance than an actual log would have in a sequence of clay bed and granular aquifer, having good porosity. Aquifers and are assumed to be non-radioactive. Fig. 6: Artificial ER and Gamma ray log approximately the appearance that an actual log would have in a sequence of clay bed and several types of rocks is assumed that water in the aquifer is fresh and the rocks are not resistively active.

**Estimating water salinity:**

Rearranging formula and gives the following expression for the salinity of the water in a clean granular aquifer.

\[
pp = \frac{0.62 K}{D 2.15 RF}. \quad \text{............(5)}
\]
This formula is applicable in practice only both the resistivity and the porosity of the aquifer are known that sensibility limit its applicability is unknown areas, unless an appropriate suite of logs is available. Further, some knowledge of the depth of water likely to be present is required so that the correct \( K \) value can be selected when this is not the case a value of 6500 corresponding to average waters is generally used and the formula becomes:

\[
ppm = \frac{60069 \times 4000}{\theta \times 2.15 \times R_t}
\]

... (6)

Fig. three based on the numerical values and in this formula, can be employed to obtain or estimate the dissolved solids ( ) in terms of \( R_t \) and porosity of clean water bearing formations. An outstanding example of water quantity determination from \( R \) and other data is the method developed by Johnes and Bueford (1951) for obtaining, not only the quantity of dissolved solids, but also approximate water analysis for the important water bearing formations Louisiana.

Artificial E. Gamma log approximately the appearance that actual log would have in a formation that do not contain clay bed. It is to fresh \( \text{H}_2\text{O} \) and that the rocks are not radioactive. It is assumed that the water in the aquifer is fresh and that the rocks are not radioactive.
ESTIMATING AQUIFER POROSITY:

Formula (5) or fig.3 can also be used to obtain or estimate porosity of the quantity of dissolved solids and the aquifer resistivity are known.

Quantities $\phi$, $A$ and used in formula (2) has no dimension. Fig.8, therefore $R$ are not directly affected by absolute grain size, which means the $R$ can not be directly used for determining permeability. In particular it is not possible to distinguish a fine sand from gravel, the discussion must be made by reference to the cutting s or other geologic data.

When aquifer permeability may be directly related to changes in porosity or clay content, that permeability changes are reflected on the aquifer resistivity. This permits semi-quantitative determinations of permeability for empirical data of true $R$'s can be derived from the log.

WATER TABLE:

Since air is more conductive the $R$ of a permeable rock is watered. However, some of the borehole fluids generally enter the rock and measurements made with probes having a small radius of investigation show only a small increase in $R$. the depth of water table is difficult to pick up especially if the rock is not of uniform textured.
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Formula (5) or fig. 3 can also be used to obtain or estimate porosity of the quantity of dissolved solids and the aquifer resistivity are known.

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WATER TABLE:

Since air is more conductive the $R$ of a permeable rock is watered. However, some of the borehole fluids generally enter the rock and measurements made with probes having a small radius of investigation show only a small increase in $R$, the depth of water table is difficult to pick up especially if the rock is not of uniform textured.
The best resistivity logging device for determining the depth of W.T. is the Gaurd tool because it has a deep lateral investigation and gives a great vertical detailed A combination of 1 normal devices, a log one and a short normal one, can also be used, but the depth determination is less accurate.

PRINCIPAL USES OF RESISTIVITY DATA:

To a water well driller the most tangible benefits that can be derived from a log one those obtained from a more interception of their record. In this respect, the R.C. curve even the recorded by the least expensive equipment is most rewarding. By glancing at it he can determine the depth and thickness of almost evenly bed except the thinest ones.

SUPPLIMENTING it with his own drilling observations or local experience, he can tell what most, if not all of these beds are. This will permit him to formulate an optimum screen setting programme. If he has to vent into brakishwater zone he finds the decrease in resistivity although not equivocal. A wellcome safeguard of the bit penetration rate remained exactly same for all the aquifers logged, he can assume that their positions are of the same order and therefore interpret a decrease in AP Resistivity as an indication of a salinity increase. Fig.8 (Ron et al, 1944 is a case in. It represents the lower portions of the electric logs of L. water wells which have penetrated a sequence of clays and
Electrical lay formation that probably does not contain bed.

...
clean unconsolidated sediments having proportions of the same order. Above 1375 ft, the sand apparent R. are nearly in same but below the fig. they decrease with depth. This decrease can be interpreted as increase in the water salinity. Incidentally, the bottom plogged bellow 1375 ft and the appear ones are producing waters averaging 500 parts/million of dissolved solids.

Conversely, when it is known that the quality of the water remains nearly the same for all the aquifers penetrated changes in resistivity can generally be interpreted as being caused by the changes in porosity, or by a clayey conditions. The simultaneous use of the SP or Gam ray curve will generally permit determining which of these situations exists. There are major applications of R. log. A few more an described in the section titled "Application of Geophysical logs to specific problems".

In practice the log interpretations are not made with the resistivity curves also the SP and all other variables data analysed simultaneously with resistivity.

EMPTY HOLES:

Good R curves can be obtained in increased empty holes provided a probe making good contact against the bore wall is employed. Because the borehole effects one greatly minimised, there is usually less departure between true and apparent R.'s. An example of an electrical log made in empty hole is given in fig.9 left, the log to the right was obtained after the hole was fitted with a thin drilling mud.
drilling mud portions of electrical logs of two water wells 1.60 apart (Honslon area) mud resistivities are 10 and 1.3 ohm.m in well (1) & (2) represented by comparison of log made in empty hole and in the same whole containing mud (Hot spring, South Delta).

CASED HOLES:

Resistivity measurements made in cased holes are not related to the formations steel being an excellent conductor, the resistivity obtained in a steel casing that is not too old is extremely low, its only usefulness is to permit determining the casing depth old steel casing are corroded the resulting iron oxides is non conductive and resistivity changes reflect the primarily the degree of corrosion of casing but the interpretation is difficult and usually problematic.

Resistivity measurements made in undamaged plastic casings are related to the resistivity of the fluids contained in the pipe. Large holes in casings cause local resistivity decreases.

RESISTIVITY MEASURING TOOLS:

The majority of the R logs recorded in water wells are obtained with a single electrode or short normal devices they give good qualitative data and some times semi-quantitative informations. Long normals and laterals are occasionally used, especially when the electric logs run by commercial companies. Other R measuring devices are also available each of the three mentioned below logs a particular
volume of formation.

The ground Electrode measures the R of the horizontal disk-shaped zone 6 to 20 ft high having a diameter of 6 ft., or more (Owen & Geer, 1951, Guyod 1964) logs gives good vertical detail and is valuable in a very broken formations. It is the best log for accurately determining the depth of the water level.

The micro log measures the R of the few cubic inches of formation situated indcately behind the bore wall (Doll, 1950). It gives still more vertical detail than the ground log and, in granular rocks, the data can frequently interpreted in terms of porosity.

The induction tool (Doll 1944) makes a measurement which corresponds to a foot vertical internal, it is little affected by the mud column and the invaded zone. It is a excellent tool for calculating formations, but its efficiency decreases while formational resistivity increases, for this reason the induction log does not permit quantitative determination fresh water aquifers; especially in those of low porosity. All these three tools are complicated to handle and expensive which are generally operated only by commercial companies.

**SPONTANEOUS POTENTIAL LOG:**

This sort of curve usually called the SP, is record of the natural potentials which occur in a borehole (Hnonrymons 1965-68 a) when the formation contains a clay bed it is generally observed that
these beds have approximately the same potential; on the SP curve this potential defines, an almost straight vertical line called the clay (or the shale), base line from which the SP deflections in the other beds are measured. These natural potential, are primarily caused by electrochemical reactions taking place between mud, formation water and clay, unless specified otherwise it will be assumed that no other source of potential.

CLEAN GRANULAR AQUIFERS INTERBEDDED WITH CLAY FORMATIONS:

If the water in the aquifers are much more salin than the drilling mud, the SP generally more -ve in the aquifers than in the adjacent clay and if the waters are much less saline than the mud the SP generally is more the in the aquifers than the adjacent clays. In these extreme cases the electrochemical potentials (SP) expressed in mill volts is approximately given by following formula:

\[ (SP)_c = -K \times \log_{10} \frac{R_{mf}}{R_w} \]

where

- \( R_w \) = formation water resistivity.
- \( R_{mf} \) = the resistivity of the mud filtrate
- \( K \) = factor which generally take equal to 71 at shallow depth

Conversely, an approximately volume of the formation water resistivity can be obtained from the SP curve and the application of above formula, because it is possible to closely estimate salinity from water resistivities, especially if the type of water is known. The SP seems to be a very significant tool in groundwater investigations. However, it has proved to be great disappointment in this respect. The main reason is the formation formula (7) is an approximation
which is permissible only if there is an extremely large difference in the salinity between formation water and mud. In water well practice it is generally applied when the waters contain less than 15,000 ppm of dissolved solids and rather expression has to be considered instead. This expression is based on the activities of the formation water and the borehole fluid and it is rather complicated (Wyllie 1949, Patten & B. Benn H, 1963). For low salinity solutions are Na, Ca, Mg, this expression reduced to the following formula (Gondowati et al, 1957).

\[
\left(\varphi\right)_c = -K \times \log 10 \frac{(aNa + aCa + aMg)a}{aNa + aCa + aMg)MF} \\
\]

The nominator of the fraction refers to the formation water denominator to the mud filtrate the \(a\)'s denote the activities due to the ions specified by the subscripts. The portion of activity due to a particular ion is approximately proportional to the ion concentration but the co-efficient of proportionately may very greatly with the type of ion if the valences are taken into account. This can be seen for example in the chart of fig. 10, which gives effective activities as a function of salinity for the three ion constant. As far as the \(\varphi\) value is concerned, a solution containing only 100 ppm of divalent ions is equivalent to a solution having 1000 ppm of the Na ions, but their resistivities are in a ratio of 10 to 1. Evidently this bars the applications of formula (7) to salinity determinations. Formula (8) should be used, but this is not possible in practice because all that the field measurements can give is the quantity \((aNa + aCa + aMg)w\) from which salinity can
not be derived unless the activities are known, unless any analysis of the water is available. The same conclusions are reached regardless of the ion types and concentrations. An empirical chart for estimating water resistivity has been developed by Gondouin et al. (1957), but is applicable only when the dissolved solids total less than 3000 ppm. The only possibility using the SP data for quantitative salinity determinations is fresh water bearing formations would be to establish beforehand empirical data for the waters of an area and use an appropriate chart or formula. This is actually what Jones and Bufor and (1951) did with resistivity, unfortunately the difficulties are considerably more numerous with the SP as will be understood from the following comments.

1. The numerical value of the and factor formula (7) can be accurately evaluated only when the clay formation bounding the aquifer is perfect cationic permeable membrane actual k values can be determined only from the lab. assurance.

2. The chem. composition of the borehole fluid must be taken into account.

3. A streaming potential is usually superimposed on the electrochemical potential (Gordonin & scale, 1958). Although the former is very small at shallow depth. Its relative value may not be negligible in deep water wells when the SP amplitude is low, and it is difficult to ascertain this fact.

4. Even if there is no strong potential, the measured SP is only a portion of the total electrochemical potential (SP) developed in the ground. The reduction, SP/(SP)c is a function of several of
factors, in particular the aquifer resistivity and thickness (Geyod, 1964 a). A correction can be made Worthington and Meldan 1958) but this difficulties practice, note that the depth of (SP) is analogues to that between apparent and true resistivities.

The unpredictable behaviour of the SP curve be demonstrated from the logs of fig. 8 (Ron et al, 1944). The distance between wells one and two only 160 ft. and the formation is nearly horizontal. The resistivity curves correlation wells which permit following each main sand from one well to the other. The dashed lines represent the clay base line - i.e. the line on which the SP falls in the thick clay intervals. The SP amplitude in sands is measured with reference to this base line. It is seen that the SP is negative in all sands of well 1, that the amplitude which is nearly uniform about 1375 ft. In well 2 the SP is either negative, +ve or nil in the sands of the same intervals, if we should are formula (7) to evaluate salinities we could only conclude that the water resistivities vary rather widely with depth in well 2 and that they are nearly constant in well 1. Considering the short distance between the two wells it is illogical to think that for every grain sand, the water in well two is different from that in well one.

**GRANULAR AQUIFER, INTERBEDDED WITH CLAY DENSE BEDS:**

In this type of formation both the shape and amplitude of SP are different from those obtained in granular aquifers. The
curve is usually distorted and difficult to use alone, even bed
boundaries can not be picked with certainty. A good review of the
subject is given by Doll (1948). Fig. 6 illustrates this situation
for some fresh water aquifers, in practice the curve may be still
more confusing when there are several in SP polarity.

CLAYEY AQUIFERS:

Clay or similar materials disseminated within the pore
spaces of an aquifer reduces the aquifer SP. Approximately
correction can be made for granular formation (Le Witte, 1955;
Pirson, 1957), but the procedure is involved and the accuracy
uncertain.

PECULIAR SP CURVES:

Actual SP curves do not always conform to the patterns
illustrated in fig. 5, 6 & 7. The most notable exceptions are
described and explained below.

1. Drilling the clay base line in commonly the clay base line
is essentially sandstone and vertical, especially below a few
hundred feet, as illustrated by the logs of fig. 8. But in certain
wells at shallow depths the SP curve gradually wanders, either
as or whole or only in the clay intervals and generally to the
left as the depth decreases. No satisfactory explanation has been
offered for this phenomenon which appears to be more prevalent
in arid areas.

2. Shift in clay base line. This is frequently observed when
there is a rather fast change in salinity of formation waters. An example is given in fig.12 (Jones 1965). A shift can also be caused by a change in the nature of the clay (Doll, 1948).

3. Unstable SP - This is obtained in the upper part of the holes in which there is an appreciable movement of water, as an artesian well or above these many zones. The signal changes constantly even if the logging electrode is kept stationary. This condition is due to an unstable electrode potential caused by the water flow. This is stability disappears below the zone of water movement.

4. Polarity reversals - Numerous polarity reversals in the aquifers of a given well are sometimes noted even though the waters have salinity of the same order. These reversals are usually due to changes in the type of ions or in quantities of some of the ions. An example is found in the log to the right of fig.8. above the depth of 1375 ft.

ESTIMATING POROSITY AND PERMEABILITY:

Although the presence of permeable rocks, rocks having intergranular porosity and situated between clay beds, can generally be offered from the shape of the SP curve formulas (7) & (8) show that neither curve shape nor the amplitude provides a basis for direct calculations of porosity or permeability.

When the change in the permeability of the rock are used by the presence of some clay material within the pore spaces, they can be quantitatively established for the resulting changes in SP.
amplitude by using empirical data obviously the method is applicable only if there are the changes in water composition within the formation of interest.

**EFFECT OF POROSITY:**

Although the electrochemical potential (SP) is not porosity the amplitude of SP curve is directly affected by porosity changes. In fact, a decrease in porosity increases the rock resistivity and this in turn reduces the SP amplitudes as was previously pointed out. In particular, dense beds situated in clay exhibits no memorable SP reflections.

**PRINCIPAL USES OF SP CURVE IN WATER WELLS:**

The SP curve is at its best in formations comparing clay and granular aquifers, especially below a few hundred feet. For the SP is always analysed simultaneously with resistivity curve and other available data.

When formation waters are much more saline than the drilling mud the SP generally more -ve in aquifers than in the adjacent clays. This permits using the curve for formation, identification, correlation purposes, and for determining the depth and thickness of certain beds.

Supplimented by curve, the SP indicates when the formation water changes from fresh to brakish.

The SP is generally meaningless when there are no clay formations in the sequence of beds penetrated by the well of interest.
The SP curve in a plastic casing is practically at straight vertical line.

**Gamma Ray Logging:**

The only borehole geophysical methods giving dependable data on the formation situated behind casing are those based on radiation measurements. They can also be used in open holes with the added advantage that the measurements are not much affected by the nature of the borehole fluid. There are two basic radiation logging methods.

**Gamma Ray and Neutron:**

Gamma ray logging equipment is fairly simple, not too expensive and valuable in investigations, neutron logging equipment will not be discussed here.

Radioactivity of clay and rocks - The atoms of a few occurring elements spontaneously disintegrate. This integration is slow but continuous, and it is accompanied by the production of radiation, alpha rays, B rays, V rays. X-rays, and B rays are stopped after travelling less than one inch through matter, but V ray can go through two feet of water less than 6 of common formation contain some radiation isotopes of the following elements, generally K, Th, and/or U in varying amounts, this property makes gamma ray measurements valuable for formation logging.

It is convenient in Gamma ray logging to classify sedimentary formations into two groups only clay and rock. The later will be called rock. Although there is no hand and fast rule regarding the
amount of radioactivity that a given formation may have, rocks
as a hole are less radioactive than clay, regardless of porosity
and fluid contained, but a few rocks have a radioactivity which is
some in times of the same order as that of clay or clayey aquifers.

The gamma ray intensity of clay varies from area to area.
In the tertiary deposits and more recent formations, it is of the
order of 5 micro roentgens/hr. It is twice as great for older
clays. Some organic clays have a much higher intensity than the other
clays of the same area.

EXAMPLES OF V-RAY CURVES:

V-ray curves are shown to the right of figs. 5, 6 & 7. In
these examples only the caly is assumed to be radioactive.

Interpretation of V-ray curve — The interpretation of the V-ray
curve in water wells is based on the following observations.
1. In a given area, only the relative intensity measured for the
various formation is of significance.
2. Formation exhibiting a low V-ray intensity are clean sediments,
gravels, sandstones, limestones, dolomites, anhydrites, shale,
lignite or coal. A low V-ray reading may indicate a very porous
and permeable aquifer or it may indicate an impervious rock,
geological information is needed to remove the ambiguity.
3. It is known that the rocks in the area of interest have only
a very low radioactivity, all the intervals of the log exhibiting
a high V-ray intensities are probably clay. The intervals of
intermediate intensity correspond to rocks generally aquifer.
Containing some clay materials the clay extent can be assumed
to increase nearly in proportions with the V-ray intensity.

4. If nothing is known on the R.A. of the rocks of the area, it
is not possible to interpret the intervals of the logs that exhibit
a high intermediate V-ray intensity. Some of the resulting
ambiguity can be removed if an electric log is available.

5. The V-ray curve should always be correlated with a lithologic
log and all other data available.

A few exceptions to above rules are noted below:

INTERPRETATION DIFFICULTIES:

When water, instead of a property conditioned mud, is used for
drilling, clay and other cuttings, silt and may increase the
V-ray amplitude in the bottom 5 to 10 ft. of the hole. Thick
drilling mud may have been left behind the casing, or there may be
some clay material on the face of certain non-radioactive rocks.
This increases in V-ray intensity at these levels make them appear
on the log as sandy clays or clayey sands. In a gravel packed
well the gravel stops an important amount of V-rays that would
normally reach the detector. This reducing the V-ray amplitude.

If the material selected for the gravel packing is R.A.,
if certain volcanic granitic rocks are used, the V-ray log does
reflection show primarily the presence of thickness of the material.

PRINCIPAL USES OF V-RAY CURVES:

1. The main application of the V-ray curve is in cased wells
for which only insufficient or unreliable data are available. Water wells that do not produce enough water, or that produce a water that is unfit for its intended use; generally can be rehabilitated after the presence of other aquifers is determined from the V-ray measurements.

2. The V-ray curve is also useful for logging of open holes when an electrical log would not be up to standards (brakish or salty borehole, fluid, large hole size) or could not be run because of the lack of an appropriate (empty holes).

3. The depths and thickness clay and non-clay beds can be obtained from the V-ray curve, but the accuracy in measuring the thickness of those less than 2 feet thick generally poor.

4. The V-ray data are valuable as a supplement to help indentify clay layers and porous zones in dense rocks.

MISCELLANEOUS FACTORS AFFECTING THE LOG RESPONSES:

1. Borehole effects inasmuch as as the logging probe is placed in the mud column, bore fluid and hole size usually affect the measurements.

2. **Sediment Boundary Effect** — The sharp formation changes, eg. from clay to a fresh water aquifer does not result in sharp changes in the curves of a log, the read of and for the electric log, the reading is particularly important when the whole is large or the mud brakish.

3. **Thin bed effect** — The curve amplitudes are reduced when the thickness of the bed of interest decreases, all other factors being
constant. This is illustrated in fig. 13 which represents for a simple electrode resistivity curve for a number of the beds. The effect on the cp and V-ray curve is very similar.
Aquifer in clay.

Clay bed.

Artificial single electrode reservoir was formed from a formation containing the bed of aquifer which has low salinity.
HYDROGRAPHY

Necessity — For any irrigation project it is necessary to know two things — (a) The requirements of water for particular area, (b) Quality water available from various sources.

Having known the requirement of water it is now necessary to deal with the method of ascertaining the quality available. The best method of knowing this quantity is by actual discharge measurements from the well in the case of well irrigation and from streams when the irrigation to be done is from river water. Various methods of discharge measurements are used in both the U.J.P. and Ghaggar but I shall describe only those methods which we saw their at Rania Gauge Station.

GAUGES:

They are meant to register variations in water level and are made of wood and more usually of enamal iron; with graduations in feet divided into decimal parts for recording water level at tails of channels and in laboratories for determining the surface slope, centesimal gauges; i.e. those giving reading correct to one hundredth of a foot are used.

The gauges are either fixed vertical against wooden posts or on a slope usually 1:1, in the later case the markings are elongated so as to give readings corresponding to vertical differences in feet. When there is much fluctuation due to wind or pulsations caused by structure across a channel gauges are usually installed in wells which are connected with the streams.
by horizontal pipes, one on each for about two feet height.

There are three types of gauges:

1. **Plain gauge** — which is usually provided.

2. **Hook gauge** — mostly used for lab work where very accurate measurements of water level is required, which is operated by a tangent screw and vernier is usually fixed to it. Gauge is lowered in water and gradually raised till the hook point appears, just at the surface when the reading is taken.

3. **Automatic Recording Gauge** — (or graphic water level recorder) which we saw in the field. There is a float and a counter weight attached to a metal belt hung over a pulley which actuates a drum through some gearing. As water level goes up and down taking with it the float, an ink point draws a line on the graph paper round the drum. The point is actuated by a clock-work, which releases the rope wound round a pulley. If the gauge reading is needed at long distance the pulsations from graphic recorders are transmitted through a transmitting set to a reservoir which indicates the gauge on a dial and chart.

These records are useful in giving continuous record of water levels. For correct reading they need to be checked up occasionally electrical operated alarms which work on simple system of making and breaking contact, just as an electrical bell does, are sometimes necessary to be coupled with automatic gauges to give a warning when water level goes beyond a certain safe limit.
Gauges by themselves can not give any idea of discharges unless some discharge observations are made. Gauges reading when supported by some discharge observations will help in plotting a gauge discharge curve from which discharge for any gauge can be read. Gauges are useful in correcting discharge at different sites.

The very important object of measuring discharge is the regular record of the discharge passing through the streams and canals will be valuable for future reference, may be used for various purposes one of which is setting disputes between nations.

There are many other instruments for measuring depths and velocities etc. by we have seen one called currentmeter. Current Meter — Consists of wheel containing blades or cups which are rotated by flowing water. It is made to face the current by means of a tail on which cross veins or fines are attached. Electrical current is passed to the wheel from a dry cell battery fixed in a box kept above the surface of the water on a bridge or boat. The current is carried by a leading cable. A computer is fixed to the staff of the revolving blade. It makes and breaks the contact and disconnects the circuit. A revolution counter is worked by this cam and ticks of the cam are heard by the observer through a telephone. The Amster current meter which we saw had provided with two contacts recording every fifth revolution or every single revolution. The instrument is attached a heavy circular weight at the bottom. The instrument is then fixed to a vertical rod or a cable. The meter is lowered to...
a particular depth at which the velocity is measured.

The current meter can register velocities at any depth for more precise observations. Any of the three following methods is followed.

(a) $V$ is observed at two points, one fifth and four fifth of the depth below the surface at each section and the average of the two $V$'s is taken as the representative mean $V$.

(b) The meter is lowered to the bed gradually and again raised at a uniform speed. This way meter automatically integrates and records the average velocity at each section. Apparently the method (b) appears to be more accurate.

(c) $V$'s at intervals of one or two ft along the depth of each station are observed and averaged.
Evaporation is a physical process by which water vapours escape from any free water surface or wet surface at a temperature below boiling point of water. Water is also lost by transpiration from vegetation covering the soil or water surface. "The combined loss from vegetation and the earth surface surrounding it is known as Evapotranspiration".

The evaporation/evapotranspiration losses are controlled by 2 factors namely the moisture availability at the earth surface and the evaporative power of the air. If supply of water is unlimited, loss of water in the form of evaporation or evapotranspiration is termed as potential evaporation or potential evapotranspiration.

The actual rate of evapotranspiration, however, varies from plant to plant and also varies during different stages of their growth. No measured data on actual evapotranspiration rate from various crops raised in Upper Yamuna Basin are available. It has therefore, to be estimated on the basis of studies done elsewhere, which may be applicable to the situations prevailing in this basin. A good and reliable method appears to have been furnished in Technical series No.2. entitled "A guide for Estimating Irrigation Water Requirements" of the Water Management Division, Ministry of Agriculture, Govt. of India, New Delhi.

It is proposed to adopt this very methodology for estimating Evapotranspiration losses in UJP. In this method consumptive use coefficient i.e. ratio of evapotranspiration to pan evaporation, for average conditions, have been suggested for various crops during different
stages of their growth. Multiplying these coefficients with the appropriate pan evaporation values gives evapotranspiration losses from various crops during entire period of their growth would be known. These losses multiplied with total areal cover under different crops during entire period of their growth would be known in the project area would yield total evapotranspiration losses per season/year. However, this method suffers from obvious limitation that it will not provide daily values of actual evapotranspiration losses, but would provide an average estimate of these losses which may be good enough for early water balance studies.

To assess the evapotranspiration losses under this scheme, basic data requirements would be as follows:

1. Pan evaporation data at a No. of places
2. Land utilization statistics of the project area.

In the area under study, there are only three observations located at (a) New Delhi, (b) Karnal, (c) Muzaffarabad, which record daily pan evaporation. The data at these sites is available from the years 1959, 1971, and 1967 respectively. In order to arrive at a reasonable representative value of evapotranspiration losses in the basin, two procedures as enumerated below can be adopted.

The mean value of the three pan observations and assume it to be representative of the whole area. The record of annual mean temperature at various points in and around the project area would be utilized to prepare an isothermal map of the basin. This
map will be utilised to earmark the areal extent of influence of each of the three point measurements. Within each influence zone, it would be assumed that the respective pan value operates uniformity. It is proposed to adopt the second method for UY basin.

The 2nd important factor for assessment of evapotr- losses in the data regarding land utilisation statistics of the project area. Information regarding land use are available at various Tehsil. Head Quarters at the lowest level. These statistics gives information regarding classification of area on the basis of different uses, and details of total area under various crops.

With the above data of land use at Tehsil level it would, be possible to work out Evapotr- losses for Tehsil as a whole. It is not possible to break evapotr- losses at various points; therefore, Tehsil will be the smallest units for assessment of evapotr- losses in the basin.

In case of evapotr- losses from water bodies in the area, the recommendation of I.M.D. to use a value of 0.8 as pan coefficient for the area receiving more than 100 cm of rain per annum and 0.7 for the areas receiving lesser annual ppt- will be adopted. The surface area of the large water bodies lying within the project boundaries will be collected and total evapor losses determined on the lines discussed above.

A sizeable part of the project area falls under the following broad gps -

  1. Area under non-agricultural use.
2. Barren and unculturable land.

As the evaporation losses from these surfaces cannot be exactly determined by any of the methods discussed above, it is proposed to adopt the water budgeting technique on daily basis considering daily rainfall and daily potential evaporation values. The actual evaporation rate will be governed by the daily ppt and limited to the potential value of evaporation.

So we shall briefly discuss here some physical theories on evaporation and evapotranspiration so that we can understand the importance and use of these methods.

THEORY OF PENMAN:

Which he presented it in 1948 a theory of free water evaporation $E_0$ based on the application of the energy-balance condition (Evap. requires supply of heat) and the vaporation gradient condition (a gradient must exist to remove the vapor once produced).

The former condition can be expressed by the formula

$$E_0' = 60 E_0$$

where $E_0' = \text{Heat required in}\ \frac{\text{Cal}}{\text{cm}^2 \text{ days}}$

$$E_0 = \text{Evaporation in}\ \frac{\text{mm}}{\text{day}}$$

$E_0'$ is estimated from the incoming solar radiation after deduction of the "losses".

The second condition is expressed by the application of
Dalton's law.

\[ E_0 = c(e' - e) f(u) \]

where \( e' \) = saturation vapour pressure at the temperature \( t' \) of the boundary layer between water and air.

**POTENTIAL EVAPOTRANSPIRATION**:

Evapotranspiration \( E_p \) from a short, closed and green vegetation with adequate water supply, is comparable to the evaporation from a wet and green surface. Differences with free water evaporation are:

1. The albedo is greater because of the green colour,
2. The stomata are closed at night. Hence we can expect \( E_p \) (potential evapotranspiration) to be smaller than \( E_0 \) (free water evaporating) or \( E_p = E_0 \times 0.8 \) for the growing season.

In recent years this matter has been explored further. Penman and Schofield have produced a formula taking into account the transpiration process in the plants.

**MASS TRANSFER METHOD**:

This method does not consider the loss of water from a surface but rather the transfer of water through the air to the atmosphere ("invisible vertical vapour flux"). The theory has been developed by Prandtl, Sverdrup, Rosby and Montgomery and investigated in practice by Thornthwaite and Holzman.
The relationship of evapotranspiration to pan evaporation has long been used in the computation of irrigation requirements. This relationship is available for some crops from many diverse depth parts of the world, such as Israel - U.S.A. and India etc.

Consumptive use coefficients K, for computing evapotranspiration Et, from either computed or in ensured evaporation Ep. These coefficients are suggested as representing in average conditions and are proposed for use the formula:

\[ Et = K Ep \]

The eight crop groups are as follows:

A). These crops fit a fairly even bell type curve and have a modal grouping of an average value of 1.00 is used. Most important crops include Peas - Maize - Cotton - Potatoes - sugar beets - Jowar and Peas.

B). This gps consists of the deciduous fruits and some field crops. Some gp (A) crops that fail to produce maximum vegetative cover and maximum growth ratios will best fit in this gp.

It includes: Dates - Olives - Plumes - Walnut - Tomatoes and hybrid jowar.

C). The crops include - Melons - Onions - Carrots - Hops and Grapes with a maximum Et/Ep ratios of about 0.60. The general pattern is again that of a bell type curve.
D) Maximum Et/Ep ratio is about 0.90 and usually occurs at about 75 to 80% completion of the crop vegetative cycle. The crops included are Barley - Celery - Flax - Wheat and other small grains.

E) These crops have fairly flat curves. Ratios of Et/Ep range from 0.70 to 1.10. The modal gp ratio is about 0.90. The crops include - pastures - Orchard with cover crop and plantation.

F) This gp includes the citrus crops; Oranges, Grape fruit. The Et/Ep and ratios are fairly constant throughout the year and average about 0.60.

G) Group (G) includes sugarcane and alfalfa. Et/Ep values increase with crop and generally vary from 0.66 to 1.00.

Rice: The Et/Ep ratios present a fairly flat curve. A maximum values of 1.30 and a minimum of 0.80 is representative of average conditions. Sugar-Beets are shown as fitting a typical bell curve with maximum ratios at 50 to 55% completion of the crop growing season.
In such a complicated systems of like multipurpose water development projects one has to deal thoroughly with every component, solve its problems and intricacies.

To study the inputs, outputs and storages of water, a systematic plan is made. As we have many water releases at various points in U.J. Canal, we mainly measure the discharges at JAJAWALA.

There are two main canals in the basin called eastern Yamuna canal and western Jamuna canal. The western Jamuna canal has a branch canal called Augmentation canal which is a lined lined.

Many methods have been devised for study the hydrological problems.

1. Water shed Mode, i.e. only surface water response.
2. Sub-surface water Models.

The sub-surface water contributes throughout the year to the streams. In the river there is also some sub-surface flows. But all such types of flows have been stopped contribute by putting pumps in the main Jamuna again into the canal back.

To know the amount of water put to river Jamuna from under surface aquifer is necessary thing. The first method which
we apply to this is the Water Balance Equation

\[ I = Q + S \]

we have here to see the regenerated flows.

**Input** - Tajwala release rainfall, groundwater regeneration, other escapes etc.

**Output** - At Hatwala discharge measurements are noted evaporation and infiltration etc. are to know.

We can know unknown components if we know other two.

Suppose we need to calculate the storage then we must add the outputs and inputs and automatically the rest less will be the amount of water infiltrated down the surface.

Next method is the concept of WATER storages - This too is the concept of a method to analyze the flow rates. The determination of Base flow upon the linear depletion curves, which is defined as the hydrographs of a river during rainless periods when the flow is sustained by the outflow of water from aquifers. The flow in the river is indicated as sustained flow or minimum flow or Baseflow.

We here consider only groundwater run off as the supply of water during rainless periods. Such types of curves are used for forecasting the minimum flows; gives the flow today, to forecast the minimum flow in the absence of rain in 10, 20, 30 — days from now. Depletion curves form the link between surface water and groundwater and provides information on the
recharge and the characteristics of aquifers. These curves represent the outflow of groundwater in storage. This process is examined in theory of the non-study flow of groundwater.

If \( Q_0 \) is the outflow at time \( t = 0 \)

\[
Q_t = Q_0 e^{-t}
\]

\( Q_t \) = discharge at beginning, \( e \) = characteristics of basin

\[
\log Q_t = \log Q_0 - t
\]

which is usual form of equation.

If there are various aquifers in a canal basin with different values of \( \theta \), the depletion curve will not plot as a straight line. Depletion curves assume special shapes when the outflow from aquifer is affected by \( E_0 \) in seepage zones or when seasonal variations of the outflow is small owing to the considerable aquifer capacity.

**MASTER DEPLETION CURVES:**

Indicate rate of decrease of base flow with time starting from any initial flow value. If the base flow would behave like the straight line with the slope indicated by the value of the parameter \( \theta \). There are aquifers with different characteristics, under these conditions the master depletion curve may slightly differ from a straight line on semi-logarithmic paper.
To find the best approximation the following graphical method can be used:

a) select the longest flow periods without rains, (b) plot these segments on paper with time on a linear and discharges on a logarithmic scale, (c) shift the segment horizontally until the various segments coincide in their lowest parts, (d) do not change the vertical position of the segments (e) assign the greatest weight to periods of considerable length, (f) check whether the D.C. differ systematically according to the second.

We take straight line to form a one recession ensure or master recession curve after measuring the Basin Flow we analyse statistically.

The calendarical fluctuations have been removed by moving average method which shall give the straight line. At Hatwala - Tagiwali, Indri release and baseflows are three main components. There are three system independent on each other. Tajwala data are also analysed and observed whether there is trend or not and same at Aandri and no trend is found thin in present data. Hatwala no trend occurs. So no down or fall in base flow.

Wazirabad — we have 20 years data present. The data is required to be homogeneous and constant. After that the time series analysis is checked. We study and components of time series (1) Trend, (2) periodicity, (3) stochastic component, (4) and Randomness, by stochastic component analysis we can generate future predictions. Suppose at Hatwala if there is
100 cu sec baseflow and some how 100 cu sec. more is added
to the river at up stream automatically we shall get the
100 + 100 cu sec at down stream and then we shall superimposed
then and we can find the both amounts seperately.

Another method which we apply is we take flow readings
at distant stations, go on increasing the days interval till
becomes the straight line. By this method we can clearly observe
that the water moved at point a shall reach the station B
and also can knew that the travel time. We can then plot the
whole situation on log papers what we are required is wether
the data is random or non random. We shall know it by parametric
and nonparal parametric analysis which are most convenient. This
data called is called serial correlation coefficient. We too
should know the components which cause river flow, then we see
consistency and homogenity again which depends upon the
quantity of available data for random data we feed probability
data, log normal data, poisa distribution etc.

If the data is non random then their is trend, in that
case we have to analyse it in four parts whether there is
inclination or declination in trend.

1) Canal flow, (2) tubewell, (3) R. fall, (4) Flood flow.

These are factors which cause trends. We find all the
20 year values of each above four factors.
Recharge of aquifer increases the outflow

Effect of seepage zone and seasonal variation

Log A

Marine depletion curve
MULTIPLE LINEAR REGRESSION (ML RE) EQUATION:

If in the area there is rainfall and recharge.
(Recharge - dependent, rainfall is dependent). We can develop the equation between the two variables. By this regression equation, we can form the coefficient correlation and can see whether the correlation between two is bad or good. If the variables are large we have to develop the (ML RE) and to adopt the technique and we can know the variance, and shall find which variable is dominant.

SYSTEM APPROACH:

Here main interest goes not some such to what is actually happening in the system or box but to correct conversion of the input diagram into the output diagram.

The river basin system is so complex that in most cases a division into at-least three subsystems is necessary to obtain manageable solutions. These are:
- the surface and the shallow strata where a quick response of the flow to the rainfall occurs;
- the unsaturated zone with the soil moisture storage governing the recharge of the subsoil;
- the subsoil with a slow response of the groundwater flow to the recharge.
Attention will be focussed in the first place to the subsystem referring to the surface runoff. There are two approaches to the conversion problem.

a) **Conceptual model**: (lumped approach).

A limited number of operators is used which have the same effect as the numerous subsystems in the prototype. It is logic to prefer operators which reproduce actual processes in the prototype. Basically there are two: - translation (travel of water through the system) - storage (retention of water on the surface, in channels, lakes etc.).

b) **Black box**: (system identification).

In this case no attempt is made to describe in one way or another the actual processes in the box. The system is identified by the response of the system to a given input. This response has to be measured, with certain assumed properties of the system the response can then be computed for any other rain.

\[ p = \text{precipitation} \]

\[ p_e = \text{"effective" precipitation generating surface runoff} + \text{interflow} = Q_s \] (direct runoff)

\[ R = \text{recharge} \]

\[ Q_g = \text{groundwater outflow} \]