PAPER No. 314

"Planning of Tubewell Projects"

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INTRODUCTION

Tubewells have so far been chiefly utilised to feed the public water supplies, requirements of the railway and meagre industrial demand in our country. Except for a solitary example there are no instances where large scale tubewell planning has ever been thought of to utilise the groundwater resources for irrigation purposes. It is a matter of the last few years since when there is some conception of large scale tubewell schemes to serve as means for supplementing the deficient canal water supplies and to check the food production waning down to the lowest limits in the years of drought.

Ever since the Universe came into being man has realised the worth of ground water which is a symbol of life. In fact the old civilisations have been developing around the points where dependable sources of water supply existed. It is quite interesting to read early attempts of Persians, Romans and Babilonians to utilise the subsoil water by their ingenious devices relics of which can be seen at some places even today. Subsoil reservoirs and flowing streams of groundwater are nature's hidden treasures below our feet which it is for us to utilise to our best advantage whether for drinking, for running our industrial or motive power or to cultivate our own food. So far we have not attempted to make use of even a fraction of this national asset which is flowing down to sea and becoming waste.

There is need to exploit this wealth of our country to achieve immediate self sufficiency in food but we must proceed according to a well set out programme. There is as much necessity for matured planning of tubewell projects as for any other schemes. In fact the element of uncertainty in dealing with a hidden source makes it all the more binding that any tubewell projects should be prepared after thorough investigations. This is an adventure where hazards can be avoided to a large extent provided we make use of others' experience in the same field. There may be very few projects like tubewell scheme where a prior knowledge of the technique, science and investigation procedure can serve to the maximum benefit. It may be an outcome of detailed coordinated efforts of a soil chemist, geologist,

groundwater development and water resources specialist, a hydrologist, land and water use economist, an agronomist, irrigation and drainage engineer, a reclamation man, a pump and a drilling engineer, a hydro-meteorological fellow, and a farming specialist that an economically sound tubewell proposal could be framed. Joint efforts of different specialists when pooled together will be able to convert the elements of " Gamble " and risk associated with tubewell projects into reality and make disparity between the results as expected and as achieved the minimum possible. Collection, appraisal and analysis of the existing data and new information to be acquired and their correct application to the specific conditions under study are the controlling criterion for success.

The most important link of a tubewell project is the survey and development of the underground resources because this constitutes the hidden element of the scheme on which its main success depends. The men incharge have to conduct thorough investigations to reveal the potential of groundwater storage, chances of its recharge and the dependability for basing a long range pumping sheme on it. Otherwise any recommendations derived from premature studies and sets of short-lived observations may lead to absolutely wrong results. Really speaking it is a methodical investigation which is responsible for compilation of accurate data on strength of which the future behaviour of the tubewells supply can be predicted with a reasonable accuracy. Any slips during this phase of the work may result in major deviations from the projected aim and bring about heavy financial losses by cutting short the useful life of assets. It is correct, therefore, that the maximum prior knowledge gained for comprehensive planning of a tubewell scheme, justified expenditure on its preliminary investigation work and time to be spent for the same within framework of the needs of the scheme are well justified from academic as well as financial point of view.

Scope :

This paper compiles some record to show various steps to be taken and procedure to be adopted for execution of a thought out tubewell project. It is to our advantage that other countries having a good deal of similarity to us in basic tubewell problems have gained experience at cost of considerable sums of money which is readily available for us. However we must have knowledge of what and wherefrom to look for, to learn from their ventures. Various sciences associated with different phases of a tubewell scheme are rapidly changing and it is essential for the men incharge to keep their knowledge abreast with the latest developments so as to make the best of such advancements. It is not within scope of this paper to go into full discussions and description of various aspects of the subject and the following pages therefore present a general investigation and survey procedure. This may help the authorities and private agencies not to be unmindful of various features, problems and remedies linked with tubewell schemes.

Some of the important considerations for planning a tubewell project may be broadly classified under the following main headings :—

(1) Object of the tubewell project ; irrigation, town water supply, de waterlogging or foundation drainage.

(2) Collection and study of available data.

(3) Field reconnaissance observations for geographical, meterological, and geological conditions.

(4) Land and water use survey.

(5) Groundwater investigations including the following :

(*a*) Water table variation.

(*b*) Test drilling and test pumping.

(*c*) Geophysical studies.

(*d*) Geological features record.

(*e*) Specific ground water problems and their soultion.

(6) Groundwater inventory and methods of its recharging.

(7) Drainage problems.

(8) Financial appraisal and project feasibility.

(9) Drilling method and design of tubewells.

(10) Selection of motive power, pumping machinery and design of pump houses.

(11) Typical tender procedure and clauses.

(12) Operation and maintenance schedule of tubewells.

(13) Propostd groundwater regions of west Pakistan.

(14) Groundwater law.

(15) Extension service for the public and the proposed authorization.

I. OBJECTS OF THE SCHEME.

The very approach to a scheme depends upon the purpose for which it is being planned. For instance a tubewell project for irrigation purposes cannot be called complete unless detailed soil survey for the land in view which is going to serve as the earning component is also carried out minutely. Tubewell supply for town water demand should take into considerations of water quality and quantity both for human and industrial use. The fire regulations might materially affect the design of pumping sets. On the other hand if tubewells are to be utilised for depression of water table to enable construction of foundation works in areas of excessive seepage the procedure for groundwater study will considerably change. Here the problem will not be to develop the groundwater source and to make it dependable for the maximum duration of time but to get rid of it in the shortest possible time and to maintain a pre-determined drainage. Some of the characteristics of these pumping schemes are cited here :—

(a) Tubewell irrigation schemes :

(*i*) As compared with a canal irrigation scheme a tubewell scheme is more elastic and under individual's control. Additional

capital and working costs of groundwater lift irrigation schemes can be considerably offest by reduced costs in levelling operations of rolling lands or soils with shallow fertile crust. There are no threats of canal closure or shortage and the system is more independent.

(*ii*) Economics of the tubewell scheme for irrigation have to be absolutely sound in view of the fluctuating prices of agricultural produce.

(*iii*) Tubewells have a collective strain on the groundwater over a large area and so phenomena such as interference, groundwater re-charging etc., deserve special attention.

(*iv*) Any existing surface irrigation close to the area will help building up the sub surface storage.

(*v*) Tubewells are generally planned for peak demands of 24 hours working.

(*vi*) Losses of water due to percolation, evaporation, conveyance and application add to working costs considerably.

(*vii*) Safe limit of sand and salinity contents of water from tubewells for irrigation purposes can be relaxed more than sanitary wells resulting in quicker wear of pumping machinery working the former.

(*viii*) Automatic control for worklng the tubewells is generally not practicable absence of which results in employment of more attendants. However if operations can be well controlled with alarm system, automatic control will achieve more working flexibility.

(*ix*) There is necessity to limit and decide the economic yield of the tubewells considering the length of water courses, water losses in application, and interference from other wells.

(*x*) There is more flexibility in location and spacing of the tubewells than other tubewells schemes.

(b) Town water supply schemes :

(*i*) Specifications of these tubewells have to satisfy the sanitary laws and are more rigid to demand better quality of water being pumped out. Cementation and sealing operations make their cost higher.

(*ii*) The feasibility of these schemes is easier.

(*iii*) Determination of size and output of the tubewells can be done with less rigidity.

(*iv*) Chances of failures of these tubewells are much more than

irrigation wells because their success is controlled not only by quantity but quality of the water being pumped out.

(*v*) If the aquifer is limited the tubewells have to work all the 24 hours to meet the daily requirements.

(*vi*) Recharging of the aquifer cannot be done so conveniently because of limitations of space and other facilities around the town sites.

(*vii*) The pumping heads against which pumps have to operate are more than irrigation pumps.

(*viii*) Standby arrangements have to be very efficient to avoid any shut downs.

(c) Tubewells to check water-logging :

(*i*) Location of the seepage source contributing to the excessive subsoil water storage is very important.

(*ii*) Proper spacing of the tubewells is one of the chief criterion for success of such a reclamation project.

(*iii*) If the quality of subsoil water or soil is unfit for irrigation the project benefits will be mostly indirect to check deterioration from spreading to other areas.

(*iv*) If further water-logging trouble is to be controlled and the menace does not exist in an area to start with the benefits of the tubewell scheme will be collateral,

(*v*) Tubewells have to be designed with bigger outputs, extensive draw down and for continuous non-stop operations. Pumping lifts will be considerably low.

(*vi*) Pumping machinery will have serious rate of depreciation because of non-stop working.

(d) Tubewells to allow sub-aqueous constructions :

(*i*) Fixing the size, spacing and number of these de-watering tube-wells is not so easy as in other tubewell schemes. Actual drilling tests and electrical analogy experiments have to be jointly utilized to fix the data.

(*ii*) The pumps selected for this purpose have to be very sturdy against wear and tear and of big capacities with low settings. They have to deal with turbid water with no control over water quality.

(*iii*) The pumps have to be efficient over a wide range of working characteristics depending on marked fluctuations of the subsoil water.

(*iv*) Tubewells are of temporary nature and so their specifications are comparatively cheaper.

(*v*) Electrical submersible pumps are better suited for this work because of ease of their installation and manoeuverability. Use of centrifugal pumps with old practice of masonry pumping sumps and difficulties of adjustment of pump stagings is becoming a matter of the past.

This paper concentrates on tubewell schemes for irrigation purposes meant to supplement the surface irrigation.

II. COLLECTION AND STUDY OF AVAILABLE DATA.

It is an established fact that the initial time spent on collection and study of existing tubewell data will result in an immense saving of money and un-wanted delays later on. An account of other difficulties and failures when examined in detail will help the new scheme considerably. Every effort should be made to convert the hidden aspects of the project into something sure and known. A preliminary reconnaissance survey is, therefore, necessary to probe into the following :—

1. Water table variations.
2. Particulars of the existing tubewells in the locality.
   (*i*) Well-logs.
   (*ii*) Discharge, draw down and rate of recovery original and present.
   (*iii*) Influence on other tubewells or open wells.
   (*iv*) Size of the existing tubewells in the area with details of the pumping machinery and its daily working hours.
   (*v*) Land cultivated on the tubewells both in Rabi and Kharif crops with average yield of various commodities per acre.
   (*vi*) Method of boring with its details such as ; cost, time, materials, with their sources.
   (*vii*) Taste of water being pumped out with any visible sand contents-whether water is fit for agricultural use.
3. **Open wells.**
   (*i*) Diameter, depth and staining perforation details.
   (*ii*) Static water level, depth of water.
   (*iii*) Rate of recovery and daily working hours.
   (*iv*) Areas being irrigated under different crops and yield as compared with Barani areas.
   (*v*) Taste of the water during working of the well and when standing.
4. Water use figures *i.e.* watering frequency for different crops and

water dips. Maximum and minimum consumptive use of irrigation water in terms of acre-feet of water/acre both monthly and yearly.

5. Available meteorological data if any.
6. Apparent geographic and topographic features.
7. Flooding effect.
8. Land erosion.
9. Water-logging and salt peter effects.
10. Likely proposals for canals, rivers, diversions, drainage, development, reclamation schemes etc.
11. Geological and soil features.
12. Existing groundwater law if any.
13. Land holding patterns and pressure of population.
14. Published reports as submitted by various enquiry commissions, international agencies such as FAO, TCA etc., on subjects related to tubewell schemes.
15. Reeords of different departments in particular study of the district gazetteers.

A typical sample proforma showing particulars of some areas in district Sialkot being proposed for tubewell schemes is given as an nexure No. 1.

III. FIELD RECONNAISSANCE OBSERVATIONS FOR GEOGRAPHICAL, METEOROLOGICAL AND GEOLOGICAL CONDITIONS.

After study of all possible data and record to aid in planning of the scheme detailed reconnaissance investigations have to be carried out in the field. This should bring on record pertinent features of the area such as geographical, meteorological and geological conditions, which are closely linked with the tubewell project at one stage or the other.

1. Geographical divisions.

Geographical features of the problem area should be obtained and exhibited in form of a block diagram. This should show the following :—

(*a*) Topographical features such as land unit boundaries detailed down to village boundaries, transport routes, existing means of irrigation, drainage system, natural water ways. Any future schemes affecting the existing features.

(*b*) Types of land whether plain level, rolling, sandy, broken, hilly and so on. Whether top crust fertile clay, loamy, sandy, marshy or strewen with shingle.

(*c*) Contours showing variations in levels.

(*d*) Location of relief features such as hills, valleys, ravines, forest

growth, erosion belts, sand dunes etc., The area should be divided into geographic divisions after the field study.

(*e*) Aerial maps of the area, if available, will be very useful.

2. Meteorological data.

Meteorological details of the area play an important part to influence the quantity of water for irrigation, type of crops and livestock, water demand in different periodic distribution and duration of the growing season. Relevant information about the following points may be useful :—

(*a*) Rainfall-minimum, maximum and average on monthly and yearly basis.

(*b*) Temperature and effective heat variation throughout the year.

(*c*) Durations of growing seasons.

(*d*) Climatic record.

(*e*) Weather station location on the index map.

(*f*) Frequency and intensity of dust storms or winter breezes with their direction.

(*g*) Monthly evaporation records.

(*h*) Climatic suitability for livestock.

3. Geological features.

Detailed geological record can be obtained from the point of view of groundwater features by actual drilling or geophysical methods. There are, however, some apparent points to look for :—

(*a*) Type of soil, its origin and suitability for irrigation.

(*b*) Signs of soil erosion with reasons.

(*c*) Geological classification of land.

(*d*) Surface study of rocks and alluvial cones.

(*e*) Any apparent faults, fractures, joints, stratification, thrust planes or outcrops with typical promising water bearing formations.

(*f*) Study of any springs, artesian, Karez, or signs of confined water out flow.

There are typical properties of different types of rocks a knowledge of which will enable better appreciation of drilling results in such formations.

(*i*) Sands and gravels are the best containers of ground water being at once porous and pervious. They yield fairly pure water but sometimes impregnated with ferringinous contents.

(*ii*) Sandstone : It is the second best medium to hold water. Quality of water is similar to sands and gravels but is sometimes adversely affected by nature of the cementation material.

(*iii*) Limestone: Due to large variation in type and location of the limestone its properties as an aquifer are not uniform. Water obtained from limestone is generally hard.

(*iv*) Clay and shales : They are useless as sources of groundwater. However hard shales at joints might yield water.

(*v*) **Crystalline rocks.**

Because of jointing, gneisses and schists these rocks might yield some water but otherwise they are not classed as water bearing.

It is difficult to lay any hard or fast rules about different type of formations as a water bearing media. The location, formation and weathering action very often play an equally important role to materially change their properties as groundwater containers.

IV. LAND AND WATER USE SURVEY

Pumping costs can be controlled under given conditions of working by economic use of water. Climatic conditions, quality of soil, type of crops and their rotation have all to be studied to fix the optimum quantity of water needed for maturity of different crops. Extravagent use of water may not only mean extra pumping costs but on tight clay soils will result in serious damage to crops due to scalding. In pervious textures of soils it will contribute excessively to groundwater thus raising the saturation and salinity limit to the root zone, which will seriously affect the crop yields. Land survey is necessary to determine the following :—

(*a*) Production capacity.
(*b*) Texture.
(*c*) Land development.
(*d*) Cost of production.
(*e*) Crop adoptability.
(*f*) Effect of climate.
(*g*) Shape and lie of the area.
(*h*) Quantity and quality of water.

A soil good for farming should have :—

(*a*) High water-holding capacity.
(*b*) Ready penetration by water to permit aeration and ready escape of excess water.
(*c*) Slow enough infiltration to check percolation losses.
(*d*) Enough depth to permit root development and drainage.
(*e*) No harmful salts.
(*f*) Reasonable slope not susceptible to erosion.

Soil stratum survey.

It is preferable if the soil stratum survey and test borings are conducted simultaneously to fix the profile representation and permeability by laboratory and field tests. The soil sample grid will no doubt be more extensive but test borings will help these studies and collaborate the permeagraph results.

A land classification map should be prepared to represent the results obtained graphically.

High costs of working of a tubewell scheme call for more extensive soil surveys to determine the productive power of a given land than a surface irrigation project. Similarly the figures for water use have to be fixed very very accurately.

The efficiency with which water is employed for irrigation depends on the methods and practices to a considerable extent. It is estimated that losses due to transportation, percolation, evaporation, application etc., vary from 20 – 30% depending on soil and climatic conditions besides the efficiency of use. Figures for the average annual irrigation and periodic requirements within the irrigation season are essential to be determined and provided to the tubewell engineer. There is no definite figures available for average allotment acre-foot per acre for our country which varies from 1 – 2 acres foot/acre as compared with 3.66 acres foot/acre in Columbian basin in U.S.A. The tubewell engineer will have to rate his pumping to about 22 hours/day with a tubewell of 1 cusec output to be able to supply this water allotment.

In America Lowry-Johnson Curve is adopted to fix the average consumptive use of water as related to effective heat. It is necessary for the tubewell engineer to know monthly variations of this consumptive use figure so that schedule of operation of the tubewells can be fixed, taking into consideration the precipitation and losses. Following table will give some idea of these figures as extracted from Bureau of Reclamation records for Mexico, U. S. A. :—

DERIVATION OF WATER REQUIREMENTS.

Month	Consumptive Use Feet.	Effective Precipitation feet.	Consumptive use of Irrigation water feet.	Farm Delivery Requirement feet.	Conveyance losses & Waste		Diversion Requirement.		Total Project Demand AC—FT.
					Percent	Feet	Feet	Percent	
Winter ..	0.35	0.16	..	..	..	..	..	..	....
April ..	.07	.02	0.24	0.37	56	0.47	0.84	17	3,100
May ..	.26	.04	.22	.34	47	.30	.64	13	2,400
June ..	.44	.01	.43	.66	30½	.29	.95	19	3,500
July ..	.46	.03	.43	.66	30½	.29	.95	19	3,100
August ..	.44	.06	.38	.58	32½	.28	.86	17	2,100
September ..	.23	.03	.20	.30	46½	,26	.56	11	700
October ..	.07	.01	.60	.09	55	.11	.20	4	....
Total ..	2.32	0.36	1.96	3.00	40	2.00	5.00	100	18,400

Note.—Net irrgated area = 3,680 acres.

For example let us assume that annual consumptive use figure is 30 inches and 20% or 6 inches is the monthly peak demand. Water holding power of the soil is 25% or 3 inches water interval = 15 days.

If yield of the tubewell is 1 cusec the acrea which can be irrigated/annum will be 150 acres.

These water use figures are essential for the project engineer to plan the tubewell scheme for irrigation of a given tract of land. There are many factors influencing economic size of the tubewells and purely irrigation use on theoretical grounds is not the only consideration. For example it may be possible to save considerable seepage losses by reducing the irrigation runs with bigger water heads especially on loamy type of soil. Such a practice which will permit bare infiltration into a tight clay soil will not be useful at all. Capacity of the tubewells may be further determined by influence of interference of group of tubewells on one another which will fix their spacing. Economics of bigger outputs versus longer water courses and slopes of the land have also to be taken into consideration.

V. GROUNDWATER INVESTIGATIONS

The real essence of a tubewell project and extent to which its success can be judged depends on the groundwater investigations. There are very few places on the earth's surface which are completely devoid of groundwater storage underneath. Job of the groundwater specialists is not to find this water but to enable its pumping out in sufficient quantities, of requisite quality and for an economically long duration.

1. Water-table study :

Perhaps the most important observation for ascertaining groundwater behaviour is the study of water-table and its fluctuations. If record of water table variations extending over many years is available it will be immensely useful to draw useful conclusions for the future forecast and influence under the tubewell scheme.

Piezometric observations which should be recorded at time of soil survey are very useful for recording the water-table pressures and establishing the States of artesian or sub-artesian flow in the subsoil. They will confirm the water-table studies or establish new ones if old record does not exist. It is possible to establish areas of water-table mounds or holes and also direction of flow from such water-table contours. It is customary to draw isobaths which show equal rise or fall for a given period under watch. These maps are useful to conduct the following studies :—

(*a*) Strata study.

(*b*) Direction of groundwater movement.

(*c*) Sources of percolation.

(*d*) Possible threats of waterlogging.

(*e*) Fersibility of a tubewell scheme.

Fxhibit No. 1 shows an index plan of part of Thal showing Isobaths. Point X marks an area proposed for a tubewell scheme. It is quite evident that movement of ground water flowing from rivers Indus and Jhelum to points of depression A, B, C etc., will be diverted towards X after pumping has lowered the water-table by about 15—20 feet. The area falls on a mound of water-table which will draw upon the periphery having shallower water depths below ground level. The countours are closely spread in the western portion of the block where the soil is richer in clay than the surrounding regions.

In the areas which are fed by seepage from canals or rivers water-table fluctuations both in low and high stages have to be studied. In the hilly areas water-table contours of alluvial cones formed on slope of mountain ranges, which serve as the water bearing sources for karezes, springs etc., are an important study. While taking observations of the water-table movements in a tubewell the effect of inlet friction of the screen etc., must be taken into consideration so as to remove the disparity between the levels inside and just outside the well casing. Study of confined water-table which generally contributes to artesian or sub-artesian flows is quite interesting for planning of tubewell schemes in areas like Baluchistan and N. W. F. P.

2. Pumping Test :

Behaviour of groundwater under a tubewell project can best be judged by carrying out pumping tests over a long duration. The pumping wells may be exploratory or existing regular service wells. The observation wells should be spaced and located properly so that the likely influences of various sources of re-cuperation or limitation can be studied with fair accuracy. These tests will enable study of the following :—

(1) Specific yield.
(2) Shape and area of cone of depression.
(3) Re-cuperation sources.
(4) Peremeability.
(5) Rate of recovery.
(6) Rate of draw down.
(7) Critical velocity.
(8) Draw down curves based on time.
(9) Interference phenomenon.

Shortlived tests are very often misleading and any data for specefications of pumping sets etc., derived from them will create disillusions later on. An actual example is cited here to explain things better.

A tubewell during a short test gave about 2000 g. p. m. at 30 feet draw down at a working water level of 60 ft. When subjected to 12 hours

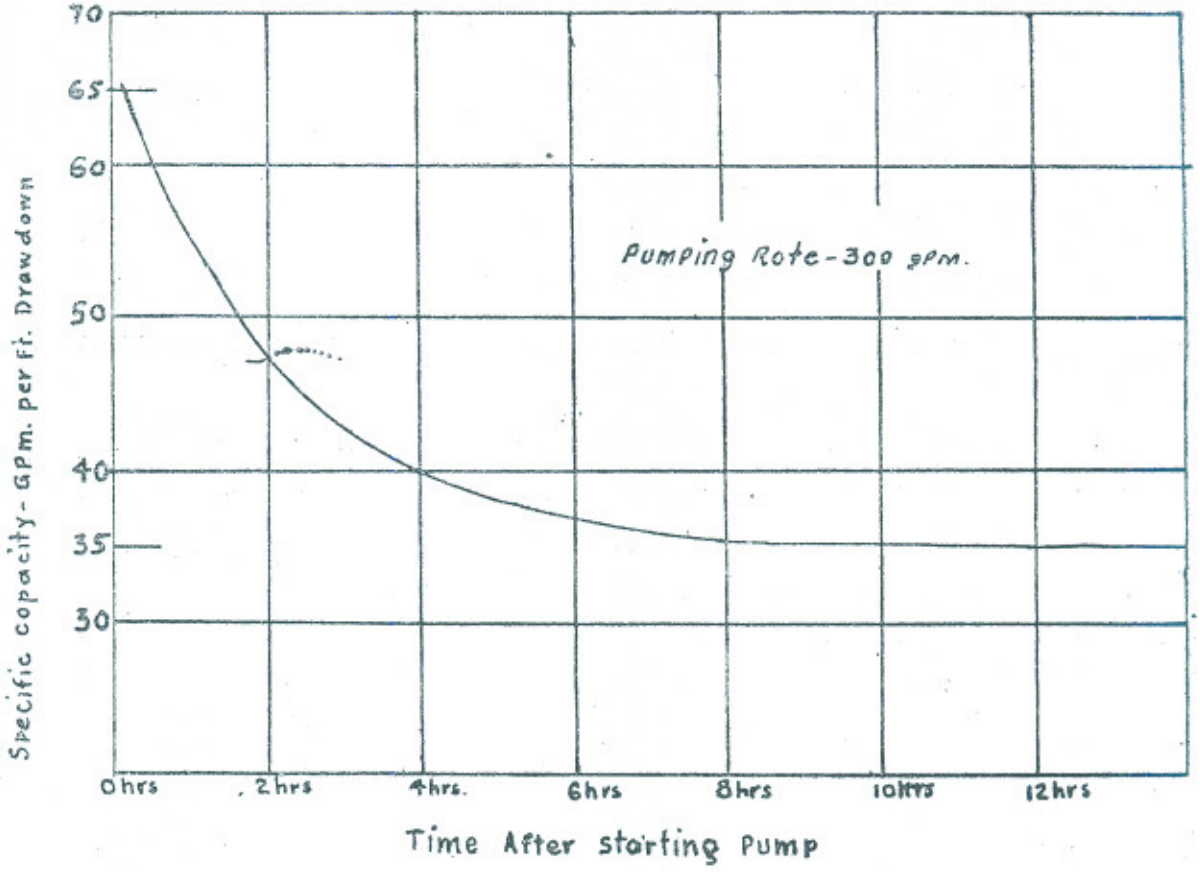
continuous test the same well gave 300 g. p. m. with a specific capacity of 35 g. p. m./foot as against 66 g. p. m./foot originally recorded. The pumping level was not stable at end of the test and was still going down. Following time-specific capacity curve will illustrate this case. Such a diagram will help to investigate the following in conjunction with geological study of the strata.

(*a*) Whether the aquifer has uniform permeability in all directions.

(*b*) If the rate of pumping is constant.

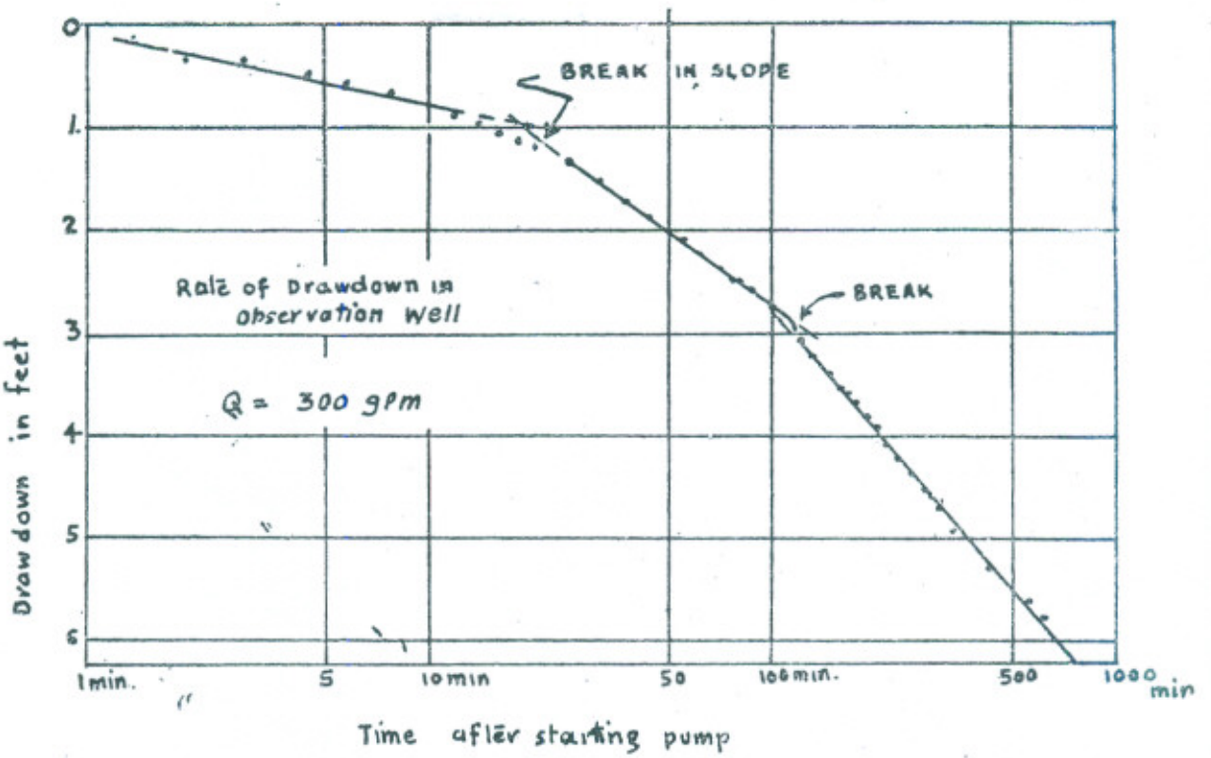
(*c*) If the aquifer is uniform in thickness.

(*d*) What are the sources of recharge and limitations of the aquifer.



Curve showing how yield per foot of draw down decreased during 12 hour pumping test
DIAGRAM No: 1

If a logarithmic scale is used for plotting the drawdown-time relation it will at once show whether the aquifer is behaving as normal or abnormal. The breaks in thc slope of the lines as indicated by the following diagram will show that the aquifer is limited on different sides by layers of clay and impervious bands. If the cone of depression would have extended unobstructed on all sides there would have been no breaks in the slope of the line.



Curve showing change in draw down in observation well during 12hour pumping test

DIAGRAM NO: 2

These results are utilised to estimate the excessive drawdown due to a limited aquifer and also to extend the result of pumping over hours to days' and months' continuous operation. This will enable calculation for the pump setting which must be based on tests of long duration. In this example if the pump setting would have been determined by first short test with 65 g. p. m./foot, drawndown and not 35 g. p. m /foot as revealed by 12 hours test the pump would have broken suction after a few hours of pumping the tubewell.

Hydraulics of flow of wells :

It is necessary to have some idea about the hydraulics of flow of the tubewells installed to tap both confined water table as well as free water table. Following diagrams will illustrate the two cases and also the formnlae used to calculate the permeability co-efficient which will enable study of the characteristics of the aquifer.

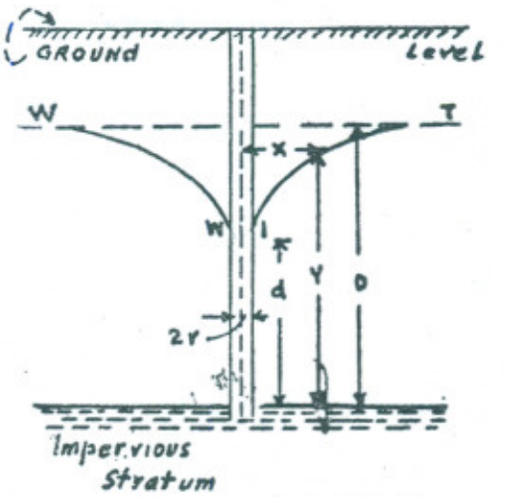


DIAGRAM No 3

Discharge from a tube well tapping free water table.

$$q = \frac{\pi \, P \, (D^2 - d^2)}{2.3 \log \frac{R}{10r}}$$

Where :—q = water pnmped in gallons/day. P = Permeability co-efficient according to Meinzer. R = Radius of circle of influence.

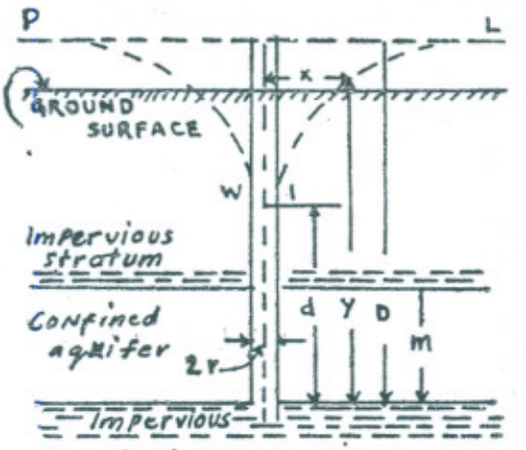


DIAGRAM No 4

Discharge from a tube well tapping a confined water table.

$$q = \frac{2\pi \, P \, m \, (D - d)}{2.3 \log \frac{R}{10r}}$$

D − d = draw down.

3. Further utility of groundwater investigations.

These investigations will be useful to ascertain following additional points:—

(*a*) Fixing type of the strainer best suited to the soil.

(*b*) Fixing slot size for the strainer.

(*c*) To determine the best technique of development of the tubewell.

(*d*) Best location of the tubewells for economical drilling. Exhibit No. 2 shows how position of clay lenses affects the depth of boring for the same length of screen. Prior knowledge about location of these lenses will help to achieve the same results by cutting down depth of boring.

4. Geophysical studies.

Geophysical studies are made on earth's surface to explore the subsoil strata without actual drilling. For groundwater investigations electrical resistivity is more economical and quicker than gravitational and siesmic methods. Electrical resistivity method is used to forecast the following:—

(*a*) Strata study.

(*b*) Location of groundwater.

(*c*) Salinity content of water.

(*d*) Location of clay or shingle lenses.

These results cannot be confirmed without collaboration of actual drilling work. They guide the drillers in advance about the approximate results to be expected. Cooperation between the geophysicist and a geologist fully familiar with geology of the area is essential for reliable interpretation of results.

A recent electrical resistivity investigation result is shown on exhibit No. 3. This was conducted near Quetta for a trial boring for S. B. Khan Sanatorium at Quetta. Distance between the outer electrodes is an indication of the soil depth and is generally three times the penetration. Potentio meter readings in terms of resistivity are plotted against the depth. The slopes of the graph so obtained at different points are an indication of the type of strata. For instance steep variation at point (A) shows presence of water table and zone of saturation which reduces the resistivity to minimum. This was confirmed by actual drilling. Unless typical standard resistivity curves are studied for reference it is sometimes very difficult to interpret the results.

5. Specific studies.

(*a*) The value of groundwater development depends on scarcity of surface irrigation means. This is the reason why in Baluchistan every drop of water taken out from subsoil is utilised beneficially. It is quite interesting to study the history and working

of Kerezes, springs and other means of utilizing precious ground-water in this area. Investigations of confined water table and means to conserve it, pump it out and recharge are really interesting. Without water land has literally no value in this region.

(*b*) In certain areas of N. W. F. P. like Kohat, tribal belt of Khajuri around Peshawar, Pakhli Plain in Hazara, ground water investigations are quite interesting. The flow is confined and chances of artesian or sub-artesian flow are qnite bright.

(*c*) Areas lying between river Jhelum and salt range in district of Sargodha and some areas in Mianwali district also near this range suffer from salt laden groundwater. It is possible that if fresh water is injected from the river backwards it may be able to build up suitable pressure to keep creep of the salt laden water way. Water Supply schemes for villages and towns in this belt call for detailed groundwater research.

(*d*) Area around Chakwal presents an interesting study. Here valuable information can be obtained by coordinating efforts of the grouudwater engineer with the oil geologist.

(*e*) Chittagong in East Pakistan and Karachi present typical problems generally met with in towns close to sea where intrusion of sea water has to be controlled to tap palatable drinking and irrigation water.

VI. GROUNDWATER INVENTORY AND METHODDS OF ITS RECHARGING

It is not possible to declare a tubewell project feasible unless the sources feeding the groundwater storage allowing for the pumpable water. An area has therefore to be minutely examined to find out the means adding to groundwater increment and those responsible for its decrement.

Additions to groundwater.

(*a*) Rainfall precipitation, snowfall and their proportionate contribution to the water table.

(*b*) Natural influent percolation from beds of rivers, lakes, streams, reservoirs etc.

(*c*) Artificial feeding from canals, spreading basins, injecting wells, reservoirs.

(*d*) Contribution of groundwater movement from one basin to the other or actuated by natural agents such as siesmic action.

Deductions from groundwater.

(*a*) Leakage of groundwater and discharge by surface flow.

(*b*) Outflow of confined water through springs, faults, abandoned wells etc.

(*c*) Artificial discharge from pumping.

(*d*) Leakage by sub surface discharge.

Inspite of best efforts it is sometimes very difficult to obtain correct basis for preparation of this inventory. The pumping results will establish very useful results at a point where equilibrium is achieved because the output will balance the input at this stage.

The area under study should be hydrologically and geologically confined on the extremeties. Sometimes depression of watertable makes the water holding capacity of the ground basin more defined and results in sealing off the effluent points. It also helps in the process of compaction which is of special benefit to alluvial cone formation.

Methods of recharge.

Very often the surface water which may be surplus in a particular area is diverted in the pumping zone so as to recharge the ground basin. If this is not done very big pumping lifts will result and pumping cost will jump up. An idea of the variation in pumping lifts in the 17 states of U. S. A. during the decade 1939-1949 with average pumping costs/acre of different forms of irrigation is shown on exhibit No. 4. No doubt the recharging operations and their maintenance mean cost but they may be much more economical than additional pumping costs brought about by increasing drops. Different methods of subsoil water recharging are given below :—

(*a*) Artificial underground basins are created by constructing impervious subsurface dams and dykes. Examples of such costructions exist in Baluchistan which serve to conserve the groundwater storage. This is an efficient means for indirect charging.

Water storage below the surface is sometimes better than surface storage because it eliminates evaporation losses. Perhaps this factor alone may justify additional cost on pumping for lifting the water to surface.

(*b*) *Water spreading basins.*

Water is spread in these basins bed of which is selected to be composed of perscious material. Surface spreading is achieved through basins, furrows following contour lines, or pits and shafts. A particular method is selected depending upon topography of the soil. levels, space available, conditions of water available for recharging and stream flow characteristics.

(*c*) *Injection Well.*

These are useful where underground pressure is to be created to keep out bad quality of water. This system is more costly no doubt but has its special applications which may well justify the cost in view of the benefits achieved. Some of the difficulties with working of these wells are :—

(1) Air entrainment.

(2) Bactereological growth.

(3) Silt deposit.

(4) Chemical encrustration.

Injection wells have to be supplemented by observation wells to study the effectiveness of their working and improvement in the groundwater. As stated under 'groundwater investigations' this system of groundwater feeding or rather improvement can be specially useful to improve subsoil water in the salt range areas of Punjab, certain areas of Bahawalpur State along Sutlej and areas remote from Indus, Lower Sind belts along Indus close to Hyderabad, Kotri etc , and at ports like Chittagong and Karachi. Such like experiments have to be extended over a long period before the results obtained can be relied upon.

(*d*) *River inducing Shafts.*

These shafts are constructed close to banks of rivers to encourage infiltration of their water especially during floods. This helps to build up the subsoil storage. Pumping induces such a flow and cone of depression touches these shafts as the recuperation zone which controls further depletion of the water table. River Jhelum offers many ideal places along Eastern fringe of Thal where such like experiments can be tried with success. Soil opposite the reach marked P-Q on exhibit No. 1 is ideally suited for this method of recharging which will be much more economical than extension of irrigation canals for non-perrenial flow and summer feeding.

VII. DRAINAGE PROBLEMS.

No pumping Scheme can be designed on a firm footing unless drainage problems of the area are fully known. The drainage characteristics of the soil and subsoil conditions are studied so as to ascertain the conditions prior to introduction of the pumping project and also to know its likely effects. Such an examination is essentially conncentrated on study of topography, soil, water table, water sources, quality and quantity of water. Some of the areas suffer with unwanted saturation in the crop root zone due to leakage of confined water table or internal building up of the pressure which can best be relieved by pumping. An efficient drainage scheme will achieve the following :—

(*a*) To remove excess water from the root zone.

(*b*) To keep the salts under control by teaching and not to allow them to rise up to the root zone.

(*c*) To release the artesian pressure from the cup-shape basins.

A thorough collection of the relevant data and its detailed study is necessary to keep the drainage efficient and to save the soil as well as quality of subsoil water from deterioration. Proper growth and yield of crops depends on successful drainage. The information gathered so far will be of considerable help especially the examination of water-table and groundwater characteristics, shape of land, gradient exits, groundwater

inventory etc. Growth of trees, crops and vagetation in general are sometimes indicaters of efficiency of drainage or otherwise.

Location of the tubewells should be properly planned with respect to sources contributing the seepage additions to groundwater. If waterlogging has already developed then tubewell water can be used for irrigation provided quality of water is fit and soil too has not been deteriorated by salt impregnation too much. In such a case perhaps major allocation of cost of the tubewell project can be debited to the dewater-logging and reclamation scheme. Such a scheme will enable achieve the following :—

(*a*) Vertical water conductivity.

(*b*) Good quality of an aquifer into which water should escape both downwards and laterally.

(*c*) To maintain an atmospheric pressure contact in the confined beds and check rising of the water-table.

Tubewell meant to achieve collateral benefits of irrigation of land and control waterlogging have to be liberally designed for bigger outputs and extensive draw downs in fact there is no question of development and conservation of groundwater in such cases but to get rid of excessive water. However a constent check over chemical composition of the sub-soil water is essential. Electrical conductivity tests are conducted from time to time to check up the salinity contents on a large scale.

VIII. FINANCIAL APPRAISAL AND PROJECT FEASIBILITY :

Project reconnaissance carried out so far will enable financial and feasibility tests. Before spending any money on a tubewell scheme and prior to fixing specifications for the machinery it is essential to estimate the cost-benefit ratio and return expected on the outlay not only at the moment but for the foreseeable future. Special peculiarities of such a project involving so many hidden features on which the entire working depends call for minute scrutiny to avoid disappointments, later on.

The feasibility will be examined under three main categories :

(*a*) **Engineering feasibility :—**

(1) It will be checked up that quality and quantity of water to be pumped out will be hopeful for the scheme to be based upon.

(2) Groundwater conditions and subsoil formations are all favourable.

(3) Soil and climatic conditions are suitable for agriculture and live stock.

(4) Means for tranport for marketting are favourable.

(5) The land is not vulnerable to attack of floods and other natural devastations.

(*b*) **Economic feasibility :—**

A detailed survey of benefits, tangible as well as non-tangible is carried out and compared with the cost to find out the cost benefit ratios. Some of the benefits of a tubewell scheme are given below :—

(1) Irrigation of otherwise uncommanded areas.

(2) To eliminate waterlogging and control its spreading.

(3) To control salinity contents in the groundwater.

(4) To define shape and capacity of the groundwater basin and to create its water holding potential.

(5) To reduce cost of development of rolling lands.

(6) To enable use of sprinkler type of irrigation which will preserve the top thin layer of fertile soil crust.

(7) Creating avenues of employment.

(8) Feeding indigenous industries like pipe, strainer making, rolling of brass sheets, M. S. sheets etc.,

(*c*) **Financial feasibility :—**

Object of examining this feasibility is to test whether project beneficiaries will compensate the reimbursable costs considering a certain preliminary development period generally taken as 10 years.

IX. DRILLING METHODS AND DESIGN OF TUBEWELLS :

1. Drilling methods.

At present there are hardly any satisfactory drilling methods in use for boring of water wells in the country. 99% of the job is done by hand boring and that too in a very slow and conservative manner. There is need to revolutionise the age old practice to meet demand of large scale ambitious tube well programmes in view.

Various factors to be considered for choosing a particular method of drilling are :—

(*a*) Subsoil conditions.

(*b*) Output desired.

(*c*) Availability of technical staff.

(*d*) Availability of funds.

The chief method of drilling are percussion and rotary with hand boring falling under the first category. With slight alterations and improvements on these two basic methods other systems of drilling have been devised. A brief description of these methods with relative merits and demerits is given below :—

(*a*) **Hand boring :—**

More that 99% of the wells are now being drilled by hand boring. Essentially ; the working consists in raising or lowering the bailer by hand pulling of rope to give the necessary spudding action. Wooden clamps support the loading platform to load the drill pipes upto about 30 tons weight.

Advantages :—

(*a*) Method is easy for unskilled labour.

(*b*) Equipment can be manufactured locally.

(*c*) No engine or other delicate parts which are liable to break down when rough handled.

Disadvantages :—

(*a*) For a 300′ well to yield on average 2 cusecs the time required on single shift is about 6 weeks. Of this time approximately half is spent in sinking 15″ and/or 12″ casing, 10 per cent. for setting screen and gravel packing and 40 per cent. for extracting the casing.

(*b*) The fixed loading platform on clamps necessitates unloading and loading for each pipe length.

(*c*) Drilling time is increased very considerably when clay is encountered due to the difficulty of penetration with the tools used for sand.

The above disadvantages could be largely eliminated by use of :—

(*a*) A normal winch suitably geared with free fall drum and brake.

(*b*) Power driven jacks with long stroke and top spiders and slips.

(*c*) Use of weight boxes with pull down winch and blocks so that load can almost instantly be changed from one length of casing to another.

(*d*) Hand operated lever type spudding arm to facilitate and lessen the burden of direct hand pulling of the line with bailer or tool.

However limitations of the method are there.

(*b*) **Power driven standard percussion drills.**

Advantages.

1. Can work in more range of strata especially with boulders.
2. Risk of skipping over the strata is not there.
3. Handling of machines easier than rotary.

Disadvantages.

1. Speed of drilling is slow.
2. Straightness of holes is not ensured.

3. Availability and use of casing pipes is a limitation.
4. For running sands and unconsolidated strata such as river gravels sometimes cable tools cannot be used.
5. Interruptions to drilling by loss of tools, fishing operations etc., are more.
6. Cost of drilling is comparatively more.
7. It is difficult to cross solid rocky formations with this type of drilling.

(*c*) **Rotary method.**

It is especially suitable for Indus valley basin.

Advantages.

1. Speed of drilling is much more which brings down the cost of drilling.
2. The holes are truly verticle.
3. Under reaming for converting test holes into main holes is very easy.
4. Exploratory borings can be economically done with these rigs.
5. Gravel packing along the entire length of bore to utilise discharge from all the zones of aquifers without setting of series of screens is a special advantage.

Disadvantages.

1. Lining of mud sometimes interferes with development operation.
2. Tapping of more than one aquifer with screens will require use of rig pipes,
3. Drilling with these rigs in sub-mountaneous areas of N. W. F. P., Baluchistan and some of Northern districts of Punjab with loose boulder formations is not feasible.

(*d*) **Winter wise reverse circulation rig.**

This rig has its usefulness limited to areas of high water-table. This is a modification of the rotary system. The advantages are that speed of drilling is fast and no drilling mud is required to line the holes to control caving in loose formations. However following are the disadvantages :—

1. Well trained crew of about 10 men required.
2. Large quantity of water reqnired for drilling (about 600 gallons/min) with make up water about 100 gallons/min. Any breakdown in water supply or of the engine is dangerous as the hole already drilled tends to break in.
3. Setting of screen and packing of gravel has to be done atonce.
4. Any lag in gravel supply stops work

(e) Benato Hammer Grab Systcm.

This method employs an orange peel grab to dig the hole. It is especially suitable for un-consolidated strata. While digging, the casing is turned forward and backward and sunk continuously. Holes up to approximately 60″ can be sunk in a matter of hours. The casing could be rolled from M. S. Steel plates and welded on the spot.

In actual practice sometimes a combination of various methods is followed to penetrate mixed type of strata. Very often limitations of a drilling rig are overcome by experience and efficiency of a driller. It has been reported that rotary rigs are being tried in Jammu (India) with big boulders in the subsoil to put up tubewells for the town water supply scheme. A thorough study of geology of the area and geophysical investigations conducted are essential to guide the drilling methods.

Exhibit No. 5 shows a typical progress chart for tube well drilling penetrating sub artesian conditions. Fluctuations in the water level give an indication to the mixed hydro static pressure of free as well as confined water in the aquifers.

2. Design of tubewells.

It is not possible to do full justice to this item here which needs an exhaustive account to give complete details. However some of the chief considerations for designing a tubewell are enumerated here :—

(a) Type of the strainer should be fixed depending on the type of soil and depth of aquifer it is possible to penetrate. At present brass type, slotted screen, pre-gravel packed type of strainers are being used out of which the brass type has the most universal utility. Continuous wire welded type of strainer most popular in America or Strainers out of synthetic material being used on the Continent are not used here. For soils with poor yield the technique of development has to be properly carried out so as to draw adequate discharge and keep the critical velocity of flow within safe limits to eliminate sanding.

(b) The slot size should be fixed by keeping sand retention ratio of 30—40%.

(c) The gravel layer around the screen should vary from 6″ to 9″. Less thickness of shrouding falling short of 6 inches is useless and so is excessive layer harmful to create clogging of water passages.

(d) Length of strainer and its position should be fixed on the output needed and the permeability of the soil determined preferably by field tests.

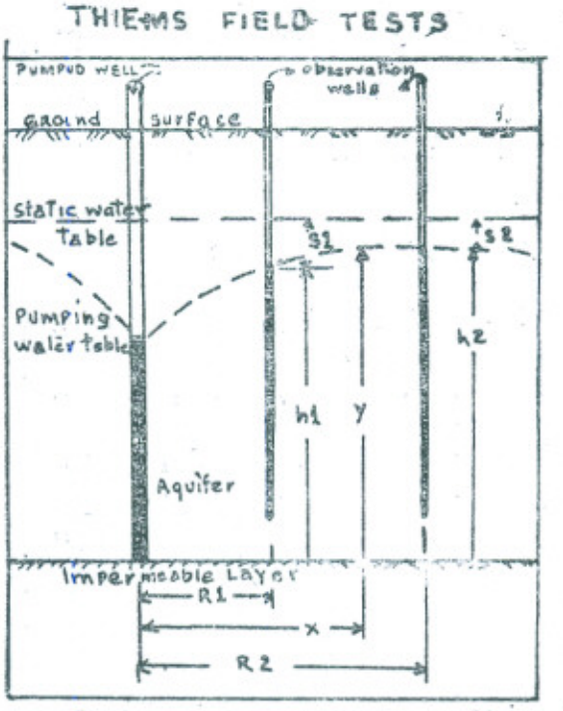


DIAGRAM NO. 5

(*e*) For alluvial soils of Indus basin valley it is recommended to keep the maximum draw down of tubewells not exceeding 30 feet. For submountaneous or mountaneous localities the drop can be safely increased to about 60 feet depending on the material constituting the aquifer.

(*f*) Diameter of the tube bore and size of blind pipe or the strainer should primarily be fixed to permit a pre-determined amount of gravel packing and not so much for the output considerations. It is a wrong notion that the discharge of a tubewell is increased proportionately to its diameter. Following table will give an idea that if the diameter is doubled the gain in discharge does not exceed 10—17% with all other conditions remaining identical.

Well diameters.	2"	4"	6"	8"	12"	18"	24"	36"	48"
	Yield increase in percent.								
	0	10%	15%	20%	25%	33%	38%	48%	55%
		0	5 ,,	10 ,,	15 ,,	23 ,,	28 ,,	38 ,,	45 ,,
			0	5 ,,	10 ,,	18 ,,	23 ,,	33 ,,	40 ,,
				0	5 ,,	13 ,,	18 ,,	28 ,,	35 ,,
					0	8 ,,	13 ,,	23 ,,	30 ,,
						0	5 ,,	15 ,,	22 ,,
							0	10 ,,	17 ,,
								0	7 ,,
(According to Bennison)									

(g) It is generally more economical to increase diameter of the housing pipe in consultation with the pump manufacturers so that most efficient type and an economical pump could be utilized for the specified duty. Size of the blind pipe and the screen should be kept smaller than the housing pipe. Length of the housing pipe should be fixed taking pump setting and any future extension into consideration.

X. SELECTION OF MOTIVE POWER, PUMPING MACHINERY AND DESIGN OF PUMP HOUSES.

Tubewell pumps are being operated on two chief types of motive power *viz.* diesel power or electricity, steam being a matter of the past now. Individual diesel engines are cheaper in the first cost than a central diesel power plant generating electricity and running a number of pumps. However the working cost is very much in favour of electric drive as is shown by exhibit 6. The aggregate capital and working cost of the individual diesel engine operation overshoots the figures for the electric drive between 2 to 3 years. Considering this Government of India have more or less banned use of diesel engines for their tubewell schemes. Question of Individuals who cannot form into co-operative societies or pool their resources is an sxception.

The general consideration in selecting the economical type of pumping machinery is the depth of working water table. Centrifugal type of pumps are quite suitable for low lifts and adoptable without any difficulties for

electric drive. For diesel engines above 10 H.P. the system of their installation on ground level with a sloping or vertical belt operating the pump down below in the sump well is not scientific and an efficient arrangement. Seepage due to rain or water course water is a constant threat for uninterrupted working of such a pump. Variations in water table will present so many difficulties. It is, therefore, advisable that for bigger outputs from tubewells the use of deepwell shaft type of pumps should be preferred provided the financial position is not absolutely tight. In cases of very high water-table where depression of the subsoil water is required with big drops the suction lifts may be beyond capacity of centrifugal pumps.

At those places where electricity is available it will be worthwhile to consider utility of submersible pumps. There is a trend these days to use more and more of these pumps. Even in America where these pumps have so far been imported from U. K. or the Continent some of the leading pump manufacturers have started manufacturing these pumps themselves. Sumbersible pumps are really economical with static lifts beyond 50 feet. Even though surface type of induction motors are more efficient than the sumberged "wet" type of motors yet considering the overall losses the total power consumption may be in favour of the submersible pumps. Following table shows the relative comparison of power consumpution of two types of pumps under identical conditions :—

Relative power consumprion chart for a submersible and a vertical shaft pump.

		Submersible pump.		Shaft-type pump.	
		I	II	III	IV
Well-int. diameter ..	inches	8"	12"	8'	12"
Speed	r. p. m.	2900	2900	2900	1450
Pump diameter ..	inches	6.5	8.25	6.5	9.5
Impeller diameter ..	inches	4.9	5.9	4.9	6.3
Number of stages ..	...	4	3	4	6
Pressure per stage ...	feet	44.5	59.4	49.5	29.11
Np-Pump efficiency ...	%	72	74	72	74
nm-Motor efficiency ...	%	84	84	85	88
Combined efficiency ...	%	60.6	62.2	61.2	64.2
Electric power consumption.	KW	13.5	13.2	13.4	12.75

Loss through power transmission in the discharge pipe.

Cable-cross-section	...	mm	3 × 10	3 × 16	...	...
Cable loss	...	KW	0.24	0.15	...	...
Shaft length	...	ft.	...	...	3.5	1.6
Number of bearings	...	...	...	...	11	25
Friction loss in bearings.		HP/KW	...	...	1.1/0.8	2.5/1.85
Power consumption at ground level	...	KW	13.74	13.35	14.2	14.6
Ratio of power consumption $\frac{N}{NIL}$	...	...	1.03	1	1.07	1.09

Hydraulic loss in the discharge pipe.

Discharge pipe	...	inches	3.9	3.9	3.9	4.9
Friction loss in (130 ft) pipe line	...	ft.	5.28	5.28	5.28	7.59
Percentage of friction loss	...	%	2.7	2.7	4.3	3.8
Ratio of power consumption with equal pressure at ground level.		$\frac{NI-1V}{N\ II}$	1.03	1	1.09	1.10

For selection of any type of pumps following points should be kept in view :—

(*a*) The specifications should be carefully drafted so that there are no omissions of essential accessories or spares. In addition the likely behaviour of the tubewells must be kept in view. It is very difficult to change the specifications every now and then which will result in serious delays due to foreign exchange and other restrictions at the moment.

(*b*) The working characteristics of the pumps should be carefully examined. Maximum efficiency at minimum price should be the aim. The discharge-H. P. curve should be non-overloading type.

FIG: 9 PAPER N

SHOWING PROGRESS OF RECLAMATION IN BL
UNDER VARYING CONDITIONS OF WATER SU.
ON MIAN ALI BR: (L.C.C. EAST) 1953.
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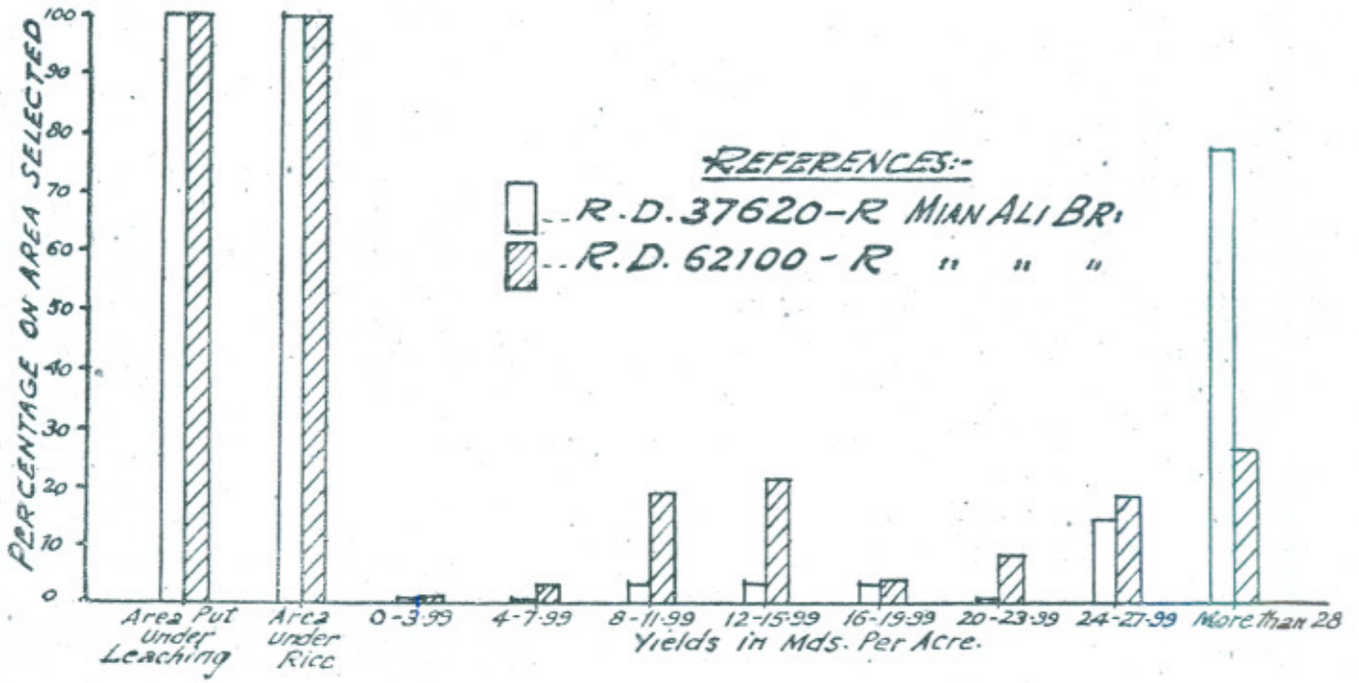
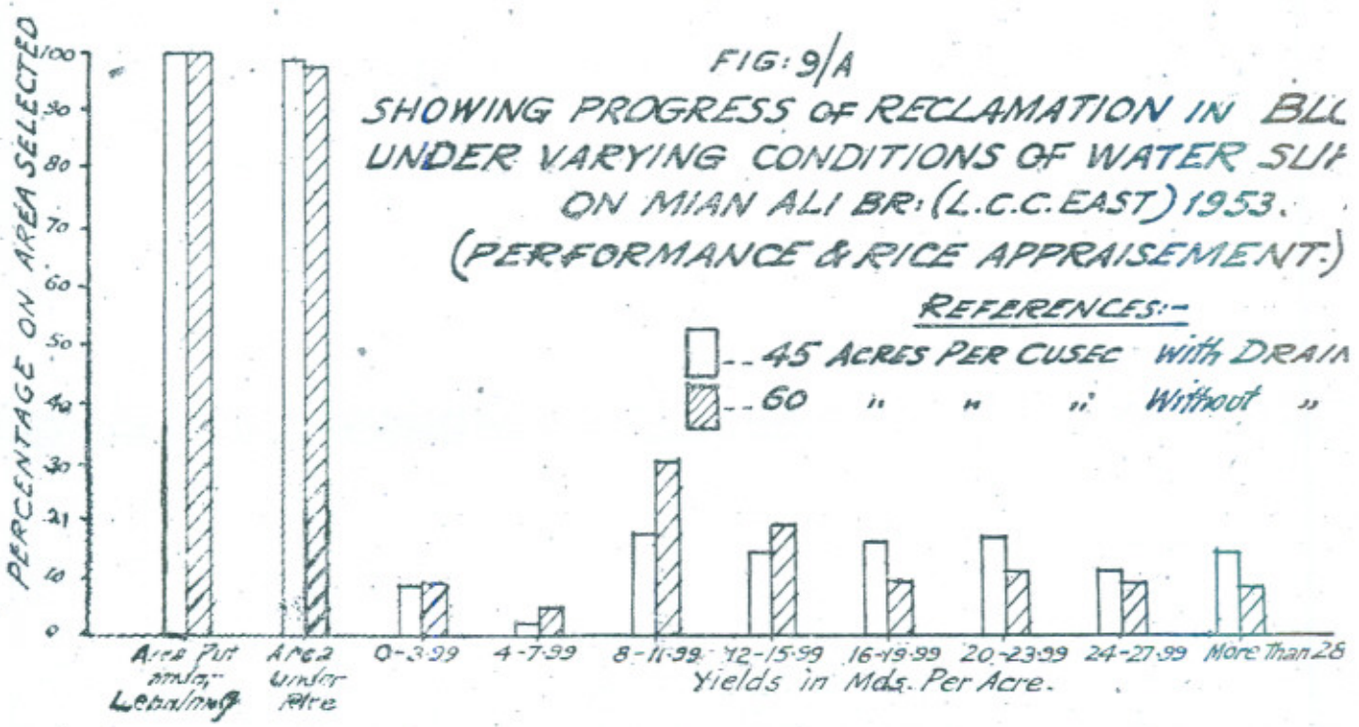


FIG: 9/A

SHOWING PROGRESS OF RECLAMATION IN BLC
UNDER VARYING CONDITIONS OF WATER SUI
ON MIAN ALI BR: (L.C.C. EAST) 1953.
(PERFORMANCE & RICE APPRAISEMENT.)



(*c*) The electric motor should be checked up to conform to temperature rise and ambient temperature characteristics.

(*d*) Schedule of various items of machinery on order must be construction and other characteristics.

(*e*) It is a good policy to order spares for at least 2 year working after the first 3 – 5 years along with the pumps.

(*f*) Specifications for the electric starters should be carefully drafted considering the simultaneous load regulations on electric feeders. Electric machinery should be planned considering the future development of hypro-electric power in the area.

Pump Houses :—

Every effort has to be made to keep design of the pump houses economical. Sometsmes temporary portable structures are erected on tubewells till such time that their working for a few months has confirmed that they will not be a failure. Essential features for design of pump houses will be as follows :—

(*a*) Dimensions to be fixed after knowing the machinery lay out.

(*b*) The size should be minimum possible but at the same time should provide enough working space.

(*c*) Arrangment for the top lifting gantry should or should not be made depending on type of the pump.

(*d*) Foundations of the machinery should be cast after machinery has been received at site and its alignment has been checked. Depth will vary with the bearing pressure of soil.

(*e*) For submersible pumps there is no need for a pump house except when the tubewells are utilised for public supplies. These shelters are constructed for security reasons.

XI. TYPICAL DRILLING TENDER PROCEDURE AND CLAUSES.

Very often wrong tendering procedure is responsible for causing serious delays in execution of a tubewell scheme. Because of omissions to include certain important clauses complications are created at later stages. It is advisable therefore that the tender notice should be a well planned and a comprehensive one so that as far as possible none of important features of project are left out. Following few points may serve to guide in this respect.

1. Generally speaking the foreign firms interested in drilling work are not familiar with the local conditions in the country because no tubewell work has been started on an appreciable scale as yet. In their efforts to cover unforeseen risks they quote unreasonably high costs when quoting on cost/foot basis. The safest procedure is to ask them to quote on fixed fee basis either with there own rigs or with the rigs to be supplied by the authorities.

2. Details of supervisors, foreign and local personnel, local labour, materials, field facilities to be provided should be mentioned in the notice.

3. Total amount of work involved with details of areas and schedule of progress with time intervals should be specified.

4. Investigation work tenders should be called separately from the main drilling job. In fact specifications for the latter should be based after knowing results from the former.

5. In case it is decided to supply the boring machines departmentally their number etc., should be so fixed that they could be charged off to the project. Their technical specifications should be supplied for information of the tenderers.

6. For the investigation job tender full details about results to be expected from such a work should be specified.

7. Quality of water to be acceptable should be given and also the required output from wells for which investigation are necessary. Maximum permissible contents of sand in the water should also be mentioned.

8. It is to be specified whether or not the test bores are to be converted into regular bores by under reaming.

9. The abandoned wells should either be converted into observation wells or thoroughly plugged.

10 Procedure for testing of tubewells and different observations to be recorded should be detailed.

11. Maximum draw down at which the given discharge is to be obtained should be detailed.

12. Size of the housing pipe, screen, pump setting should also be specified if the data has been compiled as a result of preliminary investigations.

13. Procedure for carrying out the job and contractor's responsibilties should be mentioned. It is also necessary to state the system for control of staff care of equipment etc.,

14. A clause for training of local personnel should also be added.

15. Responsibility for supply of consumables, spares etc., should all be fixed.

16. Indemnity clause for the wages act, employment regulations, labour welfare rules etc., should be added.

17. Arbitration clause for settlement of disputes is essential. It should be binding that laws of the country (Pakistan) are to be followed.

18. Payment procedure both for foreign as well as local payments is to be mentioned.

19. Clause for any advances and their recoveries shoul also be included.

It may be interesting to read a note written in 1908 concerning the terms of karez digging agreements in Baluchistan to bring ground water on surface which are perhaps the oldest on record in the country and compare them with modern well drilling agreements.

" Karez digging, which is an important occupation, is in the hands of trans-border Afghans, chiefly Ghilzais, who visit the district in the winter. They generally work in parties of four and, in addition to such other payments as may be agreed upon, usualy receive food from their employer. This ordinarily consists of one maund of wheat, one seer of salt and half-a-seer of tobacco per man per month. This owner also supplies the windlass (charkh), all necessary tools oil for lamps and loin clothes (lang). Arrangements for payment in a lumpsum (ijara) and the system known as Khatkashi, and contracts for payment by yard are to be found existing side by side In short a lumpsum is fixed to be paid on the production of a quantity of water sufficient to irrigate the area of land in which specific quantity of seed can be grown. Thus, Nazar Muhammad and others of Muhammad Khel in I904 entered into a contract with Gul Muhammad and other karez diggers to dig a karez near Panjpai, agreeing to pay them a lump-sump of Rs. 2,050 on the production of sufficient water to irrigate an area in which three maunds of grain could be sown. Under the khatkashi system a capitalist or gang of labourers engages to contract a karez in another person's land and, if successful, the water and land which it can irrigate are generally divided equally between the owner of the land and the excavator.

Payment by the pieces is, however, the most common method. The rates vary according to the nature of the soil in which the karez is excavated and the following, quoted by the tehsildar of Pishin, may be regarded as fairly representative :—

	Rs.
(*a*) For a well 9′ deep in soft soil (The diggers determine the size of the well and no regard is paid to it in fixing wages). ...	1/-
(*b*) Well in hard soil, 6′ ..	1/-
(*c*) Open channel in soft soil 9′ deep, about 4′ wide and 9′ long. ...	1/-
(*d*) Tunnel connecting well, 7½′ per rupee in soft soil, 6′ per rupee in hard soil, and 3′ per rupee in still harder soil. Height and width does not matter. ...	1/-
(*e*) Linning with a stone (sang chin). Open channel (about 1½′ wide) with a lining 15′ long, 2′ high and 1½′ thick. ...	1/-
(*f*) If the channel has to be covered in with stones, the rate is 10′ x2½′ x1.1/2′. ...	1/-
Note —If the height exceeds 2′, the rate is about ...	1-8-0

The stones for lining have to be provided by the owner, food is not supplied while the men are doing lining work. For cleaning karezes and channels, the Ghilzais are sometimes engaged on a daily wage which varies from 4 to 6 annas in addition to their food."

XII. OPERATION AND MAINTENANCE SCHEDULE OF TUBEWELLS.

Extensive investigations conducted and pains taken to implement them efficiently will all fall through unless the operation and maintenance procedure for the tubewells and pumping machinery is not set on systematic lines. There is a tendency at the moment to worry only about installation of the tubewells and then ferget about their efficient continued running. In the project feasibility tests certain life of assets is taken as the basis. By neglect in methodical working of the tubewells these figures will become imaginary and the entire forecast will be a dupe. It is binding therefore that proper working of the tubewells and care of tubewell maehinery should deserve the same care if not more as evinced at time of execution of the scheme. Tubewells and the pumping machinery should be considered separately for their periodical tests to ensure their good upkeep and trouble free running.

1. Tubewells:—

Following particulars should be checked.

(*a*) Discharge and draw down and specific capacity at recorded speed of pump and head with comparison with the last results.

(*b*) Rate of recovery.

(*c*) Drop in water table in the observation wells.

(*d*) Any sanding noticed.

(*e*) Water analysis both chemical and bactereological.

(*f*) Sounding of the tubewell to check up inflow of sand through rupture of the strainer which will be stopped by special rubber seals.

(*g*) Any settlement of floor, pump house structure noticed due to formation of caving around the tubewell bore.

(*h*) Any damage to well blind pipe which will be located by electrical logging and will be plugged by rubber seals.

2. Pumping set.

Working characteristics of the pumping set are checked on the following lines :—

(*a*) Efficiency test and its comparison with the last tests.

(*b*) Checking guaranteed characteristic curves.

(*c*) Checking clearance at bearings and impellar setting.

(*d*) Effect of sanding if in excess of 3 parts per million.

(*e*) Check of the speed.

(*f*) Behaviour of foundation of the pumping set.

(*g*) Any vibrations in the pump head.

(*h*) Working of the lubrication system of the pump.

The initial tests of the tubewell and the pumping set after completion of the erection have to be more intensive and rigorous because balance payment for machinery has to be made on these tests which are declared as the final joint tests conducted at site for which the makers guarantee certain working characteristics. A specimen proforma for such a test is illustrated on annexure No. 2.

XIII. PROPOSED GROUNDWATER REGIONS OF WEST PAKISTAN

There is need at the moment to utilise the available data based on geological survey, groundwater behaviour and tubewell logs to divide Pakistan into groundwater regions. As very little is known about East Pakistan so an idea is given here how West Pakistan only can be divided into such units.

(1) Baluchistan including States Union, Divisions to be based on geological formation provided groundwater properties are identical.

(2) Upper Sind, Southern Bahawalpur State, including Cholistan desert bordering with India.

(3) Remaining of Sind excluding hilly formations which are unpromising as regards storage of ground water.

(4) Upper Bahawalpur with districts of Multan, Montgomery, Lahore and part of Muzaffar Garh, Jhang and Central Punjab districts, with irrigation facilities in old practice.

(5) Colony areas of Punjab with more recent canal irrigation and brackish subsoil water.

(6) Northern districts of Punjab such as Sialkot, Gujrat, Jhelum, Rawalpindi, Campbellpur, Mianwali (Northern Portion) including some areas of N. W. F. P. across Indus.

(7) Salt range affected areas in Northern Thal and districts of Sargodha and part of Mianwali district.

(8) Thal especially heart of Thal.

(9) North Western Frontier Province—Division is to be considered based on geological conditions as controlled by groundwater behaviour. Fertile clay regions around Peshawar, Kohat, Bannu, D. I. Khan, D. G. Khan (Punjab) Jacobabad (Sind) and Sibi (Baluchistan) plains are proposed as one unit.

(10) N. W. F. P. States, hilly tracts and Plateaus.

These groundwater divisions with description of characteristics of each will be immensely useful in planning a tubewell scheme in any of these areas.

XIV. GROUND WATER LAW.

The need for groundwater law is created by circumstances in countries where soil is precious and highly productive but where groundwater is the only chief source for irrigation. Some of the continental countries like Yugoslavia, Danub valley have the oldest system of water district working and ground water law. Enactment of such a procedure in England and some of the states in U. S. A. is of a recent origin. In some countries it was too late to start provision of such a law because question of rights on use of groundwater had already created sufficfent complications. Pakistan for that consideration is fortunate to make start of its tubewell schemes and can frame its water law simultaneously. Such a law will be able to lay down definite ruling concerning utilisation of groundwater resources so that disputes in claiming priority of rights are amicably settled. This will also guide people in the drilling profession in that any particular tubewell work does not meet with a disappointment of being closed down under sanctions of law when in half progress.

The doctrines of 'Riparian' rights or 'Reappropriation' in their separate or joint application to surface water are generally being followed in the same sense for groundwater use. Perhaps the oldest groundwater law (which can hardly be called a law) in Pakistan is being followed in Baluchistan. Its essential provisions are :—

(*a*) Water rights belong to the owners of the land cultivated by the water and not to owners of the land from or through which the water flows. It is the re-appropreation doctrine which is being followed in this area.

(*b*) No karez may be sunk within 500 yards of an existing karez. In Quetta the same rules apply to sinking artesian wells.

(*c*) For acquisition of land in Baluchistan it is laid down that the cultivated area is limited by the amount of water available for irrigation and not by the area of land suitable for cultivation.

Provision (*b*) above limiting 500 yards as the distance between any two groundwater sources can hardly be called a sound and a scientific clause. The interference or "stealing" phenomena of aquifers particularly in case of confined watertable is to be determined by the merits of each case depending on geology and hydrological features of the subsoil and mere distance on the ground surface can never be taken as a universal safety clause. N. W. R had to face a number of disputes with Zamindars because of this defective groundwater Law. As in other countries the disputes regarding "stealing" or interference problems should be decided by actual long pumping tests and not by mere regulation of fixed distances. Some of the provisions of the proposed groundwater law which will vary from one groundwater region to the other or from one province to the other

depending on the changing subsoil water problems will be on the following lines :—

1. **Status of well drillers.**

(*a*) The procedure for registration of the well drillers has to be laid down with a view to encourage capable, resourceful and qualified people to enter the drilling line and not to impose restrictions on their working.

(*b*) All drillers should submit well logs with water analysis reports at end of each year before their permits are renewed. They should fill in a specified proforma for giving detailed particulars of the tubewells such as ; screens, casings, well temperature, working characteristics of the tubewells and specifications of the pumping machinery used.

(*c*) Pump installers should get themselves registered for erection of pumping machinery separately.

2. Lower limit of capacity of tubewells should be fixed above which water rights have got to be approved.

3. In cases of wells for de-waterlogging, recovery of canal seepage water no water rights are necessary.

4. Specifications for sanitary wells have to be rigidly laid down in consultation with medical authorities.

5. The abandoned wells should be efficiently plugged especially in zones of confined water which otherwise will mean considerable wastage of groundwater and also deterioration in its qualities.

6. Particulars and provisions of observation wells should be specified.

7. For domestic water supply use of open wells or well pits should be discouraged. Those already in use should be kept under a strict control for periodical bactereological examination of the water. This check should be exercised on water being pumped out from sanitary tubewells also.

8. It is to be specified whether " First in time first in right " or the ' Riparian ' doctrine has to be followed for use of groundwater. It should be seen however that this will not block the economic development of underground water resources.

9. Pumping levels and depression in the water table has to be controlled.

10. Rights for surface storage and diversion of natural water flows to augment the storage of groundwater have to be defined.

11. Recharging, damming and emptying out of groundwater basins have to be regulated.

12. Relation between use of surface and ground water has to be established to determine the rights of use of the latter.

13. There should be appreciation between the free water table and confined water table characteristics to specify the legal provisions regarding their utility as applicable to a particular area.

14. Likely interferences, stealing effects of aquifers etc., have to be defined and clauses put in to avoid controversies over vague interpretations.

15. Duration and details of pumping tests should be specified to decide any of such controversies.

16. Authorities who will be responsible for conducting such tests, for carrying out water analysis or any other tests should be named.

XV. PROPOSED AUTHORISATION AND EXTENSION SERVICE FOR THE PUBLIC.

There is need to set up a central organisation by the Govennment which should deal with groundwater problem of whole of Pakistan. The authorisation for issuing different types of permits under the law should be undertaken by such an authority. It will be better to coordinate the work concerning such problems under a central organisation owing to most of the connected problems and common relation of groundwater resources of the Indus basin valley for West Pakistan. Setting up of authorities on provincial basis will create further complications in matters relating to division of common underground water rights as in the supply of surface water. Such an authority should render all possible help for the extention surface to the public. At present considerable public money is being wasted because of lack of data and any agencies to help the people in installation of tubewells and purchasing of pumping machinery. This extention service will deal with various points to guide the common man in the technique of best and economic use of groundwater some of which are given below :—

(1) Educational programme to demonstrate correct procedure for tubewell execution and their operation.

(2) Economical use of the groundwater to be lifted from subsoil for surface irrigation or other purposes.

(3) Data to be made available to the public which should be of real use to them to make use of groundwater resources in different regions.

(4) To set up training institution for educating technical staff who could handle the tubewell schemes.

(5) To publish lists of recognised drillers from time to time so as to guide the public for getting their tubewell jobs done through reliable agencies.

(6) Standardisation of drilling rates and their modification from time to time under certain standard and known conditions.

(7) Publications and circulars to be issued off and on giving an account of the advances made in the tubewell activities, and

also giving an acconnt of problems encountered and how remedied. This will enable people to benefit from the experienee of authorities or private individuals in other areas.

(8) Agencies manufacturing tubewell material such as blind pipes, strainers etc., should be registered and their lists published for guidaace of the public.

(9) Proforma fcr testing and operation of tubewells and tnbewell machinery should be issued from time to time.

(10) Proceduee for setting up organisations to operate the tubewell particularly on eommunity basis should be drafted for guidance of cooperative organisatiohs.

(11) Standing enquiry boards should be set up to investigate into ground water problems for various tubewell schemes.

(12) Enquiries will have to be conducted into ground water litigations and special legal problems relating to use of this source.

(13) Coordination should be set up between such an authority, soil reclamation board, development authorities and any such bodies.

Conclusion.

Tubewell schemes like any other development projects call for methodical planning on a firm footing. Seepage and water logging problems, occasional dry years creating food shortage justify to put in this means for supplementing the canal supply shortages. Tubewells even though more costly to operate will ensure no deterioration of the soil by excesive salinity in the root zone or threatening rise of the water table. There is need at the moment to attach importance to the tubewell schemes on a long range basis and not as actuated by temporary food shortage in lean years of production and then forget about them in the years of normal rainfall. There are lacs of acres of virgin land which can be brought under plough provided tubewell lift irrigation means are made available.

It is necessary to pool our resources, compile a consolidated data with efforts of various departments and agencies and make out subsoil as well as groundwater characteristics ot the country known in the shortest possible period. This alone will enable a scientific and a sure approach to the tubewell problem in planning of which this paper may be of some utility.

Views and recommendations put forth by the author are purely his own and not connected with his official capacity in any manner.

ANNEXURE No. I

CROP AND GENERAL STATISTICS DURING THE LAST DECADE OF AREAS PROPOSED UNDER THE TUBE WELL SCHEME. TEHSIL PASRUR DISTRICT SIALKOT.

RABI

ba er va- n.	Average yied of wheat per acre.		Average cost per maund.	Average rainfall	Average yield per acre.						Average price maund			Efforts of floods if any		Is this area normally subjected to floods or was it a rare phenomenon	Effect on spring water level in wells.	Any large scale land erosion	Depth of water table below ground level	Remarks.
					Gur from sugarcane.		Cotton.		Maize											
	Chahi area	Barani area			Chahi	Barani	Chahi	Barani.	Chahi	Barani.	Gur	Cotton	Maize	Source of floods.	Percentage area affected.					
	Md. Srs.	Md. Srs.	Rs.		Md. Sr.	Md. Sr.	Mds.	Md. Sr.	Md. Sr.	Md. Sr.										
177	7—20	5—0	4 0 0	37.37	14—20	7—20	5	3—0	9—0	7—0	4—10	...	5/-	Heavy Rain fall and Nala Degh.	25%	Rare phenomenon.	...	..	23	feet	
601	7—15	4—15	4 0 0	19—12	14—0	7—10	3	2—10	8—30	7—30	5—0	...	5—8		...	...	...	..	23	,,	
425	7—10	4—20	4 8 0	36.02	13—10	7—8	3	2—15	9—0	6—20	5—8	...	6—0		...	...	...	..	23	,,	
256	7—25	4—35	4 8 0	25.42	14—10	7—6	3½	2—10	9—10	7—0	6—8	...	6—0		...	...	...	..	23	,,	
166	7—35	4—15	4 8 0	31.63	13—35	7—15	2¾	2—5	9—15	6—30	6—12	...	6—4		...	...	...	..	23	,,	
128	8—0	4—35	4 8 0	25.99	13—10	8—0	3	2—0	9—20	7—0	10—0	...	7—0		...	...	...	..	23	,,	
408	7—15	4—30	5 0 0	42.27	13—35	8—3	3¾	2—15	8—30	6—30	10—0	..	13—0		...	...	...	..	23	,,	
726	7—10	5—0	4 12 0	23.85	13—10	7—5	3	2 10	9—30	6—20	12—0	..	6—0		...	...	...	..	23	,,	
1705	7—5	4—20	4 8 0	48.21	13—20	8—4	2¾	2—20	9—0	7—0	14—0	..	5—0		...	..	6 ft	..	17	,,	Due to floods of 1950, water level has risen much.
1296	7—30	4—10	5 0 0	22.95	14—0	7—10	2½	3—0	9—20	6—20	14—0	..	9—0		...	..	6 ,,	..	17	,,	
1962	7—20	4—20	5 4 0	28.04	12—0	6—15	2¾	2—0	2—15	6—30	14—0	...	12—0		...	...	6 ,,	...	17	,,	

ces from where figures collected :—

Name of the official who produced the revenue record with designation. _____

Name of the official incharge of Market Committee with its place of working who gave figures for commodity prices. _____

Data compiled by _____

Checked by _____

Note.—(1) Those columns where no information can be obtained should be left blank.
(2) Every effort should be made to put in only the most authentic and reliable information.
(3) Average yield per acre of wheat, gur, cotton and maize is not available yearwise, therefore, the figures from Jhar Bando-Basti are given.

ANNEXURE No. 2

COMBINED TEST OBSERVATIONS FOR THE DEEPWELL TURBINE PUMPS AND TUBE WELLS.

Tube well

(i) Tube well No.....
(ii) Static water level below ground level.....
(iii) Location of aquifers.....
(iv) Diameter of strainer..... length.....
(v) Dia of pipe..... length.....
(vi) Dia of housing pipe..... length.....
(vii) Place .....
(viii) District.....
(ix) Date of installation.....
(x) Date of test .....
(xi) Duration of test..... hrs.

Pumping machinery.

(i) Type.....
(ii) Supplier's name.....
(iii) Guaranteed output.....G. P. M.
(iv) Against.....Ft. Head.
(v) At.....% efficiency.
(vi) Type of drive with details.....
(vii) Details of motive power.....

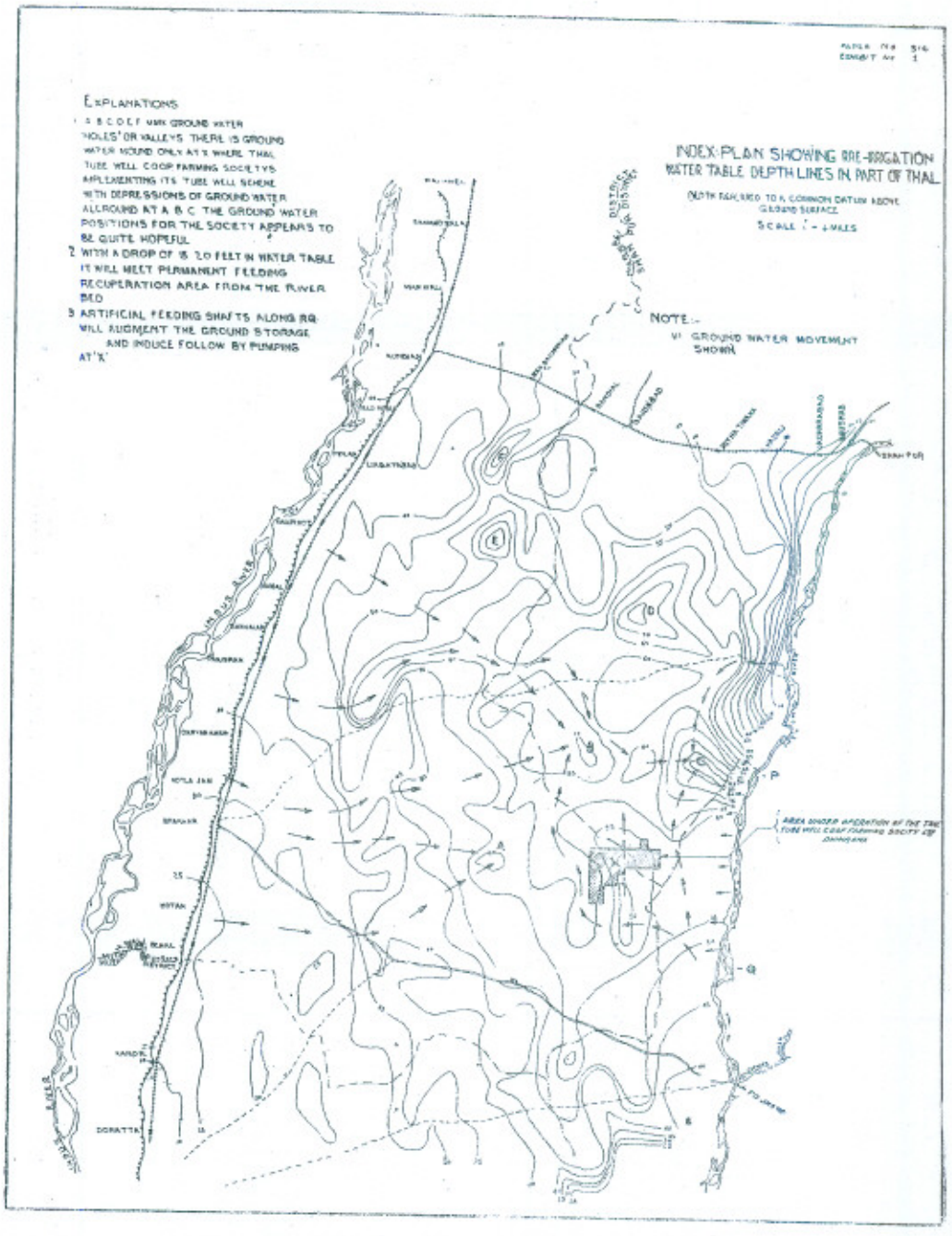
Speed :—

Normal.....
Maximum.....
Type and dimension of pump house.....

or very.	Working water level below CL of the pump based on depth gauge readings.	Draw down	Rate of recovery.	Out-put of water		Gauge readings and heads of pumping.			Total head against which pumping (x+y) assuming gauges at the same level.	Electrical consumption KWS	Pump efficiency.	Any sand particles or colour tinges noted in the water pumped out.	Any smells in the water.	Behaviour of the flooring and pump house structure during test.	Remarks.
				GPM	Cusecs.	Depth Gauge.	Delivery Gauge.								
						Feet of head (x)	Lbs./Sq" ×2.31	Feet of head (y)							
1															
2															
3															
4															
5															
6															
7															
8															
9															
10															

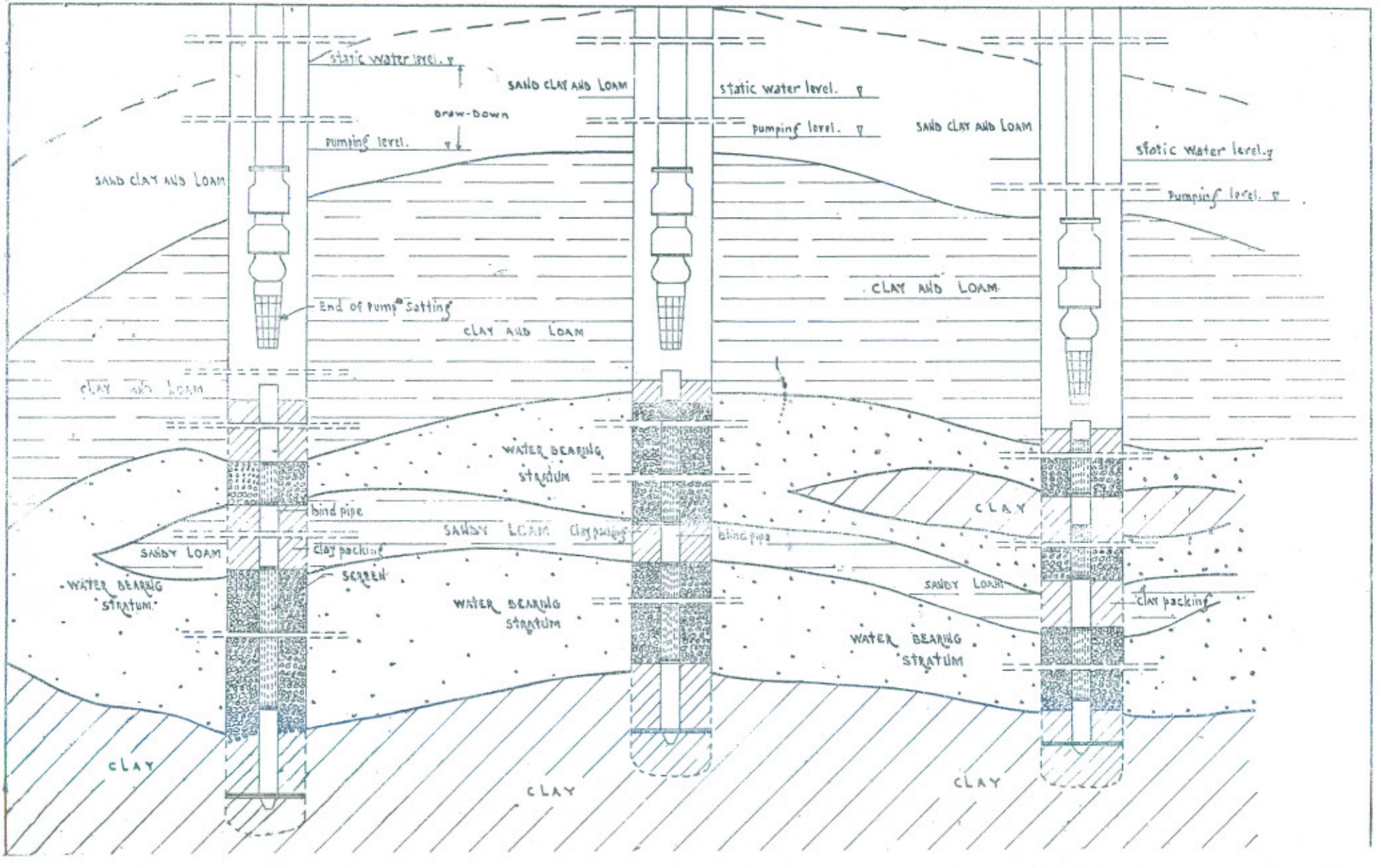
Officials incharge of conducting the joint test.

.....Designation.....Signature.....Dated.....


EXPLANATIONS
1 A B C D E F mark ground water holes or valleys there is ground water mound only at A where thal tube well coop farming society is implementing its tube well scheme with depressions of ground water all round at A B C. The ground water positions for the society appears to be quite hopeful
2 With a drop of 15 to 20 feet in water table it will melt permanent feeding recuperation area from the river bed
3 Artificial feeding shafts along RR will augment the ground storage and induce follow by pumping at 'X'
INDEX PLAN SHOWING PRE-IRRIGATION WATER TABLE DEPTH LINES IN PART OF THAL
(DEPTH REFERRED TO A COMMON DATUM ABOVE GROUND SURFACE)
SCALE 1" = 4 MILES
NOTE:-
VI GROUND WATER MOVEMENT SHOWN
AREA UNDER APPLICATION OF THE THAL TUBE WELL COOP FARMING SOCIETY LTD DARKHANA
DISTRICT MUZAFFARGARH
DISTRICT DERA GHAZI KHAN
DISTRICT LAYYAH
DISTRICT BHAKKAR
DISTRICT MIANWALI
DISTRICT JHANG
DISTRICT MONTGOMERY
DISTRICT SARGODHA
DISTRICT SHEIKHUPURA
DISTRICT LYALLPUR
DISTRICT TOBA TEK SINGH
DISTRICT MULTAN
DISTRICT KHANEWAL
DISTRICT JHANG
DISTRICT MONTGOMERY
DISTRICT SARGODHA
DISTRICT SHEIKHUPURA
DISTRICT LYALLPUR
DISTRICT TOBA TEK SINGH
DISTRICT MULTAN
DISTRICT KHANEWAL

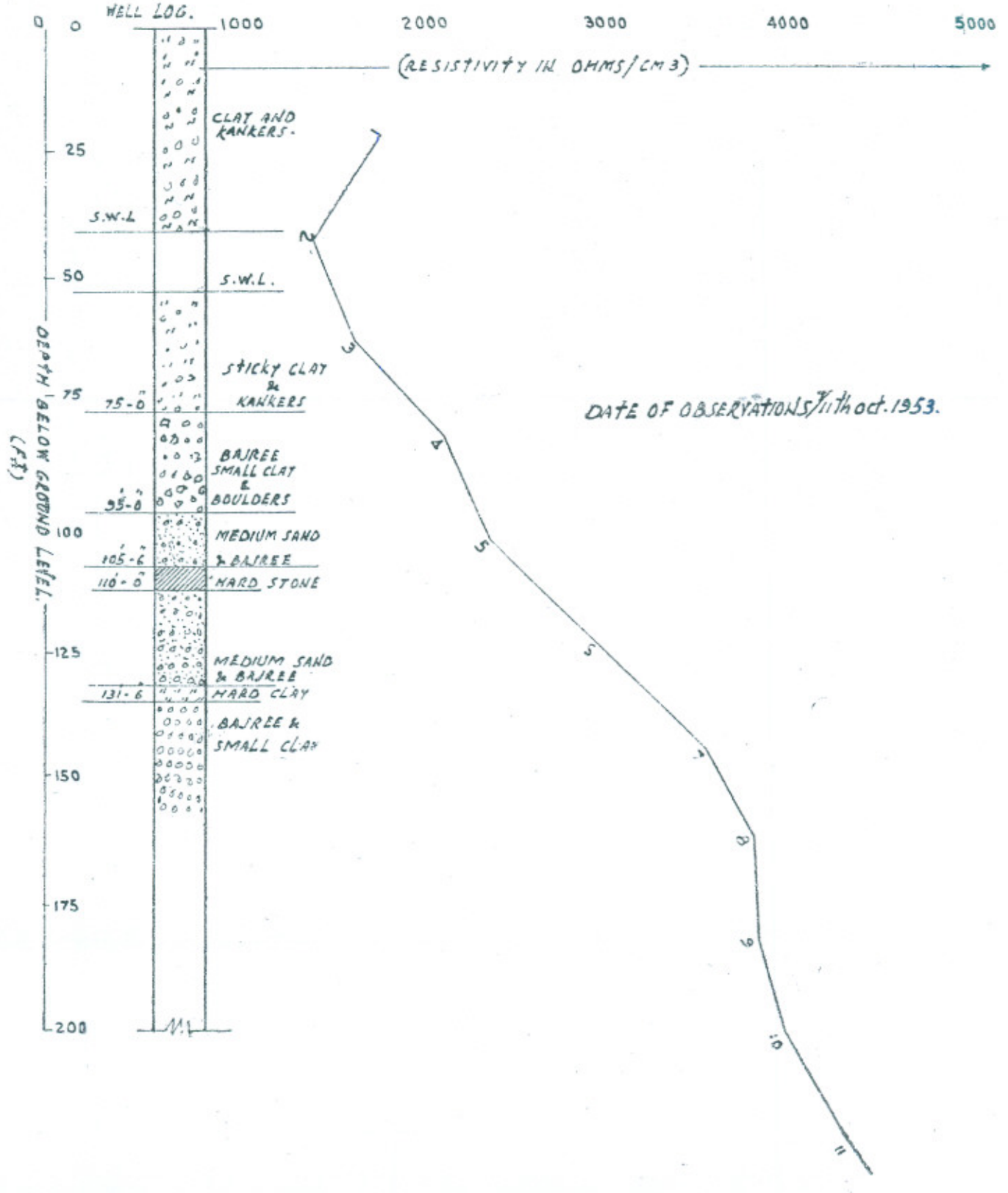
PAPER NO 314
EXHIBIT NO 2

SKETCH SHOWING EFFECT OF VARYING DEPTHS OF AQUIFER AND CLAY LENSES ON ECONOMICS OF TUBE WELL COSTS FOR SAME OUTPUT.



PAPER NO. 314
EXHIBIT NO. 3

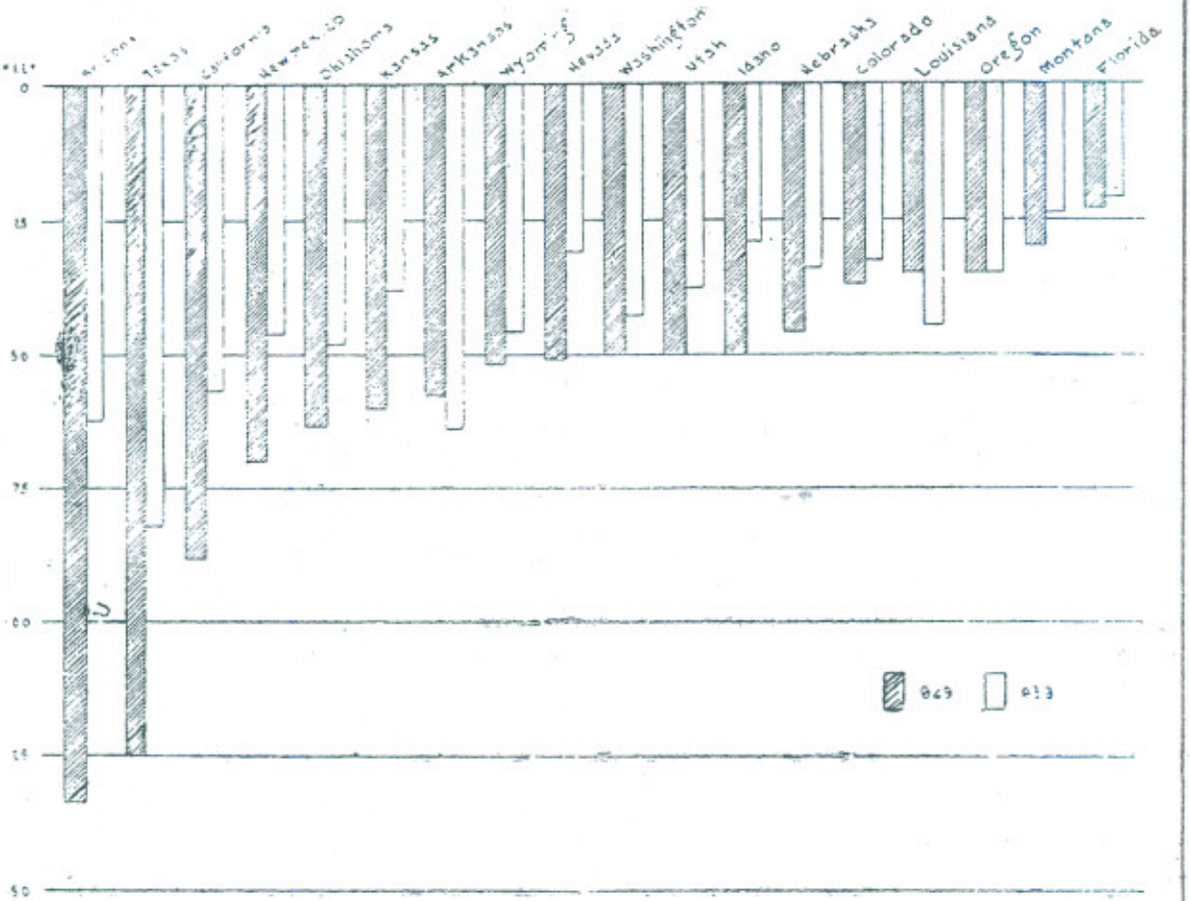
ELECTRICAL RESISTIVITY INVESTIGATIONS FOR TUBE-WELL BORING SITE FOR S.B. KHAN SAHATORIUM AT QUETTA.

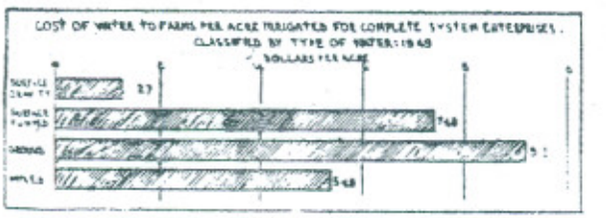


DATE OF OBSERVATIONS 7th to 11th oct. 1953.

PAPER EXHIBIT HR 319 4

AVERAGE PUMPING LIFT OF PUMPED IRRIGATION WELLS BY STATES 1949 AND 1939





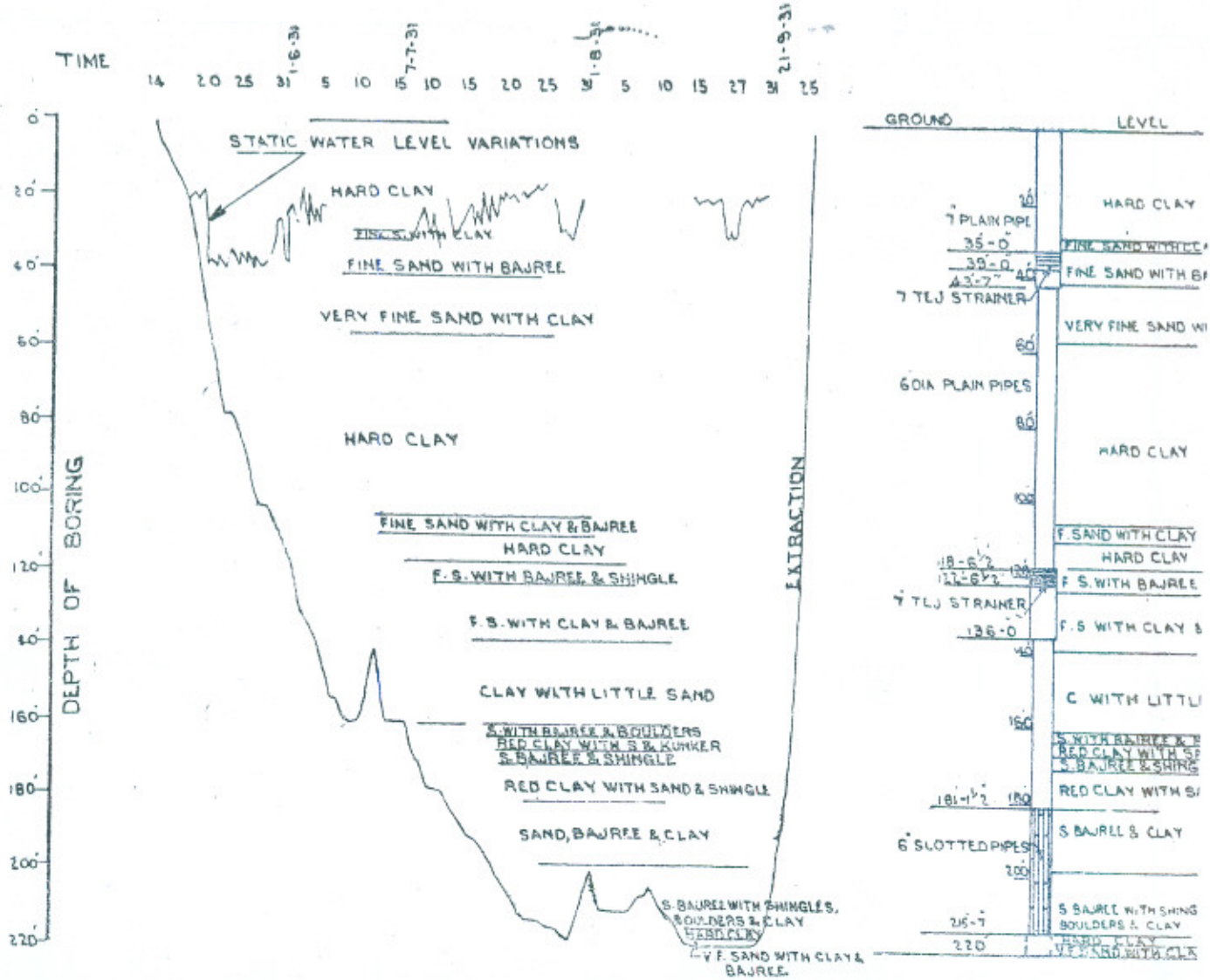
BASED ON REPORT OF U S DEPARTMENT OF AGRICULTURE BUREAU OF AGRICULTURAL ECONOMICS

PAPER Nº 314

EXHIBIT Nº 5

PROGRESS DIAGRAM OF 7 INCS MACHINE DRILLING AT SIMZAI (BALUCHISTAN) SHOWING WATER TABLE VARIATIONS AND STRATA SECTION

SCALE 1" = 40 FT



PAPER NO 314
EXHIBIT NO 6

INDIVIDUAL ENGINE VERSUS ELECTRICAL DRIVE COST COMPARISON ON BASIS OF PER HOLDING OF 150 ACRE EACH.

LEGEND:-

	SHOWN THUS
1. COST. TIME RELATION FOR DIESELENGINE DRIVE ON EACH T. WELL OF 3 CUSECS	○—○—○
2. COST. TIME RELATION FOR ELECTRIC DRIVE FOR OPERATING A COMBINE OF 100 T. WELLS FROM A CENTRAL ELECTRIC GENERATING STATION	○—○—○

