TUBE WELLS FOR IRRIGATION IN INDIA

by

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A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

in

Farm Mechanics

Department of Agricultural Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1963

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INTRODUCTION

India is mainly an agricultural country and about 80% of the population depends upon agriculture. The welfare of the nation depends upon that of the community and to uplift this nation it is but essential to uplift agriculture. In spite of being essentially an agricultural country, India has faced and has to face the increasing problem of food shortage. The population of the country is increasing but there is no equivalent stepping up in food production. This has upset the economic condition and to be in a position to feed the population, grain was imported in large quantities immediately after independence.

However, the increase in imports surely was not the solution. It was found imperative to step up food production which mainly depends upon irrigation, fertilizers and improved seeds. The combination of these factors can help to increase yields up to 100%.

The surface water resources in the country have been assessed to a fair degree of approximation and about 15 per cent of the resources are utilized for irrigation. After Independence, with the rapid industrialization and increasing demand for perennial irrigation, it was felt that knowledge of ground water resources is as important as the assessment of the surface water potential. At present, nearly 20 per cent of the ground water potential is being utilized for irrigational purposes. Keeping in view the diversity of the rock types in a sub-continent like India it is reasonable to expect large quantities of terranean water.

Looking to the importance of irrigation and the scope of ground water availability, the Government of India has planned a scientific approach for assessing the availability of ground water resources for utilization towards irrigation, industry and rural water supplies. Under this scheme, a co-ordinated effort by water engineers, drillers, geologists, hydrologists and geophysicists was made to ascertain the quality, quantity and depth occurrence of ground water. Economics of lift irrigation and harnessing of water by tube wells were also examined. As such the idea of utilization of ground water for large-scale irrigation is not new to India. In fact it has been in vogue in India since 1934 and presently, the Indo-Gangetic basin has as many as 6,500 tube wells irrigating over 2 million acres in a normal year.

The results of inquiries conducted by the planning commission and the states have established beyond doubt that tube wells can be fairly economic source of minor irrigation if the use of pumped water is properly planned.

The real problem therefore is to educate the farmer and develop suitable cropping patterns for tube well irrigation. This can be effectively done by starting special demonstration farms and projects for educating the farmer in the tube well areas in the use of water.

HISTORY OF IRRIGATION IN INDIA

Irrigation, or the artificial application of water to crops is an old art in India; in many parts it began with agriculture itself. Large numbers of the ponds found in the Deccan have been in existence for ages. The Cawery delta canals date back to the second century and the Yamuna Canals were constructed originally about the fourteenth century. In the 19th century during the British period three important irrigation works were remodeled and opened. They were the western Jamuna canal, the eastern Jamuna canal and the Cawery Delta system. These works were followed by many other works like the Upper Bari Doab Canal, the Ganga Canal and the Godavari delta system.

The report of the Indian irrigation commission of 1901-03 gave a good impetus to the construction of various kinds of irrigation works in India.

The first serious attempt to tube-well engineering dates back to 1912. In this year the first serious attempt in Punjab was made to draw water in quantity sufficient for irrigation from the subsoil by means of tube wells. The first attempt was made by Ashford on his wire wound principle and the well gave $\frac{1}{4}$ cfs. The outlook was, however, so promising that a larger and deeper well was sunk shortly afterwards which yielded 2 cfs; a volume of water astonishing at that time. From these beginnings sprang the present practice of tube well engineering. Today in India there are two statutory bodies at the centre known as the central Board of Irrigation and Power, and the Central Water and Power Commission. In addition a separate tube well organization is also functioning.

There are also a number of irrigation research stations in many states to solve the problems connected with irrigation and allied subjects.

Since independence in 1947, the Government of India and all state governments have constructed many major and minor irrigation projects to increase food production.

The scope of this paper will however be limited to minor irrigation with a special emphasis on tube wells.

The main object of this paper is to present the available information in a comprehensive form for the benefit of those interested in this subject.

REVIEW OF LITERATURE

Though the existence of ground water has probably been realized by man from the dawn of history, it is only in comparatively recent years that ground water has been scientifically investigated.

Tolman (1937), Bennison (1947), and Dean C. Mickel (1955) have studied the geological aspects of ground water.

Foster M. D. (1942) and David K. Todd (1959) studied the hydrological aspects and quality of ground water.

Peterson et al. (1955) and Corey (1949) investigated the hydraulic properties of well screens.

Darcy's (1856) well known formula for the flow of subsoil water through a porous medium has been proved very useful for derivation of mathematical expression.

Dupuit (1863) and Thiem (1906) developed the mathematical expression for analysis of hydraulic of wells.

Recently, Indian scientists and engineers have also studied the problem of development and utilization of ground water for irrigation purposes in India.

Ashford (1912) made the first attempt in Punjab on his wire wound principle. Leggett (1928) studied the economical aspect of tube well irrigation under Indian conditions.

Subba Raju (1956), Sanghi, A. (1957) studied the design and method of construction of wells in India.

Talati and Mehta (1959) and Agrawal et al. (1956) examined the problem of quality of ground water in the chambal commanded area of Rajastan and Alluvial tract of Uttar Pradesh.

The Central Board of Irrigation and Power (1961) and Exploratory Tube Wells Organization (1962), explored the ground water resources and have shown that there is good scope for utilization of ground water for irrigation purposes in India.

NEED FOR IRRIGATION IN INDIA

The outstanding feature of rainfall in India is its unequal distribution during the year and its variation from year to year in respect of quantity, incidence and duration. The average annual rainfall of India is 50 inches but it is only of the order of 5 inches in the desert in the northwest, increasing gradually across the plains of northern India from west to east until it is about 100 inches in Assam. In central India the mean rainfall is of the order of 50 inches a year and in the peninsula, except along the west coast the mean annual rainfall is of the order of 30 inches. Almost the entire rainfall in the country is due to the southwest Monsoons and is received during the four months from June to September with the exception of the southeast portion of the peninsula where the rainfall is heavier from October to November. In the winter, rainfall varies from $\frac{1}{2}$ to 2 inches except in the northeast Monsoon areas, and from March till the on-set of the southwest Monsoon, the country is almost rainless. Apart from its unequal distribution in the year, the rainfall shows considerable variation from year to year. It is not uncommon in many places for rainfall in a year to be less than half the normal; even one-fourth of the normal during a critical period in the crop rotation has been experienced (15). (See tables 1 and 2).

The importance of irrigation to the predominantly agricultural economy of the country needs no emphasis. Agriculture in India has to be content with a notoriously capricious rainfall. Droughts alternating with floods in one part of the country or another is a common feature resulting in famine conditions sometimes over very extended areas (36). Irrigation is necessary in one form or the other for successful farming in all parts of the country where the mean annual rainfall is less than 30 inches.

Table 1. Number of days of widespread rainfall. (33)

Sr. No.	Meteriological Subdivision	Winter period Dec.-Mar.	Pre monsoon period Apr.-May	S.W. monsoon period June-Sept.	Post monsoon period Oct.-Nov.	Whole year
1	Assam	3.3	15.5	52.9	5.1	76.8
2	Bengal	0.3	3.9	44.4	3.1	51.7
3	Orrisa	1.6	2.2	37.9	4.5	46.0
4	Chota Nagpur	4.3	2.5	46.2	4.6	57.8
5	Bihar	2.0	0.5	30.3	1.7	34.5
6	U. P. East	2.7	0.5	31.9	1.3	36.4
7	U. P. West	3.5	0.6	27.4	0.7	32.2
8	Punjab, East & North	4.9	0.7	11.7	0.1	17.4
9	Punjab, S. W.	2.0	0.2	2.3	0.0	4.5
10	Kashmir	9.7	4.2	2.2	0.8	16.9
11	Rajputana, West	1.2	0.8	8.5	0.4	10.9
12	Rajputana, East	0.2	0.3	15.0	0.5	16.0
13	Gujerat	0.1	0.2	12.8	0.1	13.2
14	Central India, West	0.6	0.2	33.1	1.7	35.6
15	Central India, East	2.3	0.6	28.7	1.1	32.7
16	C. P., West	1.3	0.7	42.9	2.9	47.8
17	C. P., East	1.2	1.2	38.1	2.1	42.6
18	Kokan	0.4	1.2	80.0	6.2	87.8
19	Bombay Deccan	0.3	0.5	14.2	2.8	17.8
20	Hydrabad, North	1.4	1.5	40.2	4.5	47.6
21	Hydrabad, South	0.6	1.0	19.8	4.3	25.7
22	Mysore	0.6	4.5	22.3	9.4	36.8
23	Malabar	0.9	9.8	71.9	13.9	96.5
24	Madras, S. E.	2.7	1.1	1.0	8.4	13.2
25	Madras Deccan	0.4	1.9	11.8	5.0	19.1
26	Madras Coast North	0.4	0.7	9.8	8.1	19.0

Table 2. Normal seasonal rainfall of India in inches. (28)

	Meteriological Subdivisions	Winter Dec.-Feb.	Summer or Pre monsoon March-May	Monsoon June-Sept.	Post monsoon Oct.-Nov.	Year
1.	Assam	2.38 (2.4)%	25.06 (25.7)%	64.26 (65.8)%	5.96 (6.1)%	97.66
2.	Bengal	1.53 (2.0)	12.42 (16.5)	56.01 (74.5)	5.17 (6.9)	75.13
3.	Orissa	1.82 (3.2)	5.62 (9.9)	44.49 (78.2)	4.98 (8.8)	56.91
4.	Chota Nagpur	2.57 (5.0)	3.64 (7.1)	42.71 (83.4)	2.26 (4.4)	51.18
5.	Bihar	1.41 (2.9)	3.30 (6.8)	40.96 (85.0)	2.54 (5.3)	48.21
6.	U. P., East	1.53 (3.9)	1.12 (2.9)	34.44 (88.0)	2.04 (5.2)	39.13
7.	U. P., West	2.27 (6.0)	1.36 (3.6)	32.98 (87.8)	0.97 (2.6)	37.58
8.	Punjab, E. and N.	2.76 (11.9)	1.89 (8.1)	18.23 (78.4)	0.37 (1.6)	23.25
9.	Punjab, S.W.	1.28 (13.7)	1.36 (14.5)	6.58 (70.4)	0.13 (1.4)	9.35
10.	Kashmir	9.12 (22.1)	9.09 (22.0)	22.19 (53.7)	0.94 (2.3)	41.34
11.	Rajputana, West	0.62 (4.8)	0.56 (4.3)	11.74 (90.0)	0.12 (0.9)	13.04
12.	Rajputana, East	0.96 (3.8)	0.78 (3.1)	22.91 (90.9)	0.55 (2.2)	25.20
13.	Gujerat	0.22 (0.7)	0.24 (0.7)	31.46 (96.2)	0.77 (2.4)	32.69
14.	C. India, West	0.85 (2.5)	0.47 (1.4)	31.56 (93.8)	0.75 (2.2)	33.63
15.	C. India, East	1.44 (3.7)	0.79 (2.0)	35.05 (90.9)	1.30 (3.4)	38.58
16.	Berar	1.01 (3.1)	0.96 (3.0)	28.10 (87.4)	2.07 (6.4)	32.14
17.	C. P., West	1.47 (3.2)	1.14 (2.5)	41.04 (90.4)	1.76 (3.9)	45.41
18.	C. P., East	1.58 (3.0)	2.10 (4.0)	46.37 (89.1)	1.99 (3.8)	52.04
19.	Konkan	0.28 (0.3)	1.85 (1.7)	102.45 (93.7)	4.75 (4.3)	109.33
20.	Bombay Deccan	0.51 (1.7)	2.13 (6.9)	24.41 (79.1)	3.82 (12.4)	30.87
21.	Hydrabad, North	0.67 (1.9)	1.53 (4.4)	29.51 (84.5)	3.20 (9.2)	34.91
22.	Hydrabad, South	0.37 (1.9)	2.10 (7.0)	23.38 (78.1)	3.88 (13.0)	29.93
23.	Mysore	0.73 (2.0)	5.47 (15.2)	22.27 (61.8)	7.54 (20.9)	36.01
24.	Malabar	2.73 (2.6)	12.61 (12.2)	71.47 (68.9)	16.93 (16.3)	103.74
25.	Madros, S. E.	4.76 (13.6)	4.53 (12.9)	12.01 (34.2)	13.80 (39.3)	35.10
26.	Madras, Deccan	0.74 (3.0)	2.42 (9.9)	15.27 (62.3)	0.09 (24.8)	24.52
27.	Madras Coast North	1.69 (4.2)	3.44 (8.9)	25.03 (62.3)	10.00 (24.9)	40.16

A crop requires a certain quantity of water after a certain fixed interval throughout its period of growth. If the rain water falling directly on land on which the crop stands can satisfy both these requirements, irrigation water will not be required for raising the crop. Thus in England the rain as it falls naturally satisfies both these requirements for practically all crops and therefore irrigation is not practiced in England. Irrigation is however, necessary in tropical and sub-tropical countries when the rain water falling directly on the land is either insufficient for the growth of crops or the rain does not fall at intervals as required by the crops. Further as the amount and frequency of rainfall varies from part to part of a country a certain crop may be irrigated in one part of the country but may not require irrigation water in another part of the same country (27). It is due to this that the major irrigation works are in the states of Punjab, Uttar Pradesh and Madras.

The area actually under cultivation in India in a year is about 277 million acres. The total area irrigated from all sources is a little less than 50 million acres or 18% of the total area sown in a year. There are thus very large areas which still await irrigation. With increased facilities for irrigation, large areas of land now laying barren and waste can be cultivated and put to productive use. In other areas the yield per acre can be greatly increased if there is an assured supply of water or two crops can be grown in a year instead of one. Moreover, where there is irrigation, the farmer has more incentive to improve his method of cultivation by using improved seed and manure and following proper crop rotation. By increasing production from the land and furnishing more employment for farmers, irrigation can change the entire agricultural pattern in large parts of the country. Indeed if the water resources of the country are utilized to the fullest extent practicable, India can produce all that is needed to ensure progressively improving standards of nutrition for its increasing population. To solve the food problem however, it will be necessary to double the area under irrigation within the next 15 to 20 years (15).

RESOURCES OF IRRIGATION IN INDIA

There are two main sources of irrigation water: surface water and ground water.

Surface water is provided by the flowing waters of the rivers or from the still waters of tanks, ponds, lakes or artificial reservoirs. Irrigation from rivers is mainly through canals drawn from dams constructed across the river and mainly seasonal i.e. during the flood season. When the dam is high enough to form a reservoir the water is available throughout the year. The possibilities of diverting normal flow of rivers into canals have almost been completely exhausted. The future development of irrigation aims at impounding the surplus river flow during the monsoon period for use during the dry season. Tanks which form an important source are mostly rain fed. They depend for their replenishment on the surrounding drainage area and watershed. As run-off water from the drainage area carries large quantities of sediment, tank sites are usually selected in watersheds that are protected by vegetation. Where this is not possible, suitable soil conservation practices are adopted to remove as much sediment from runoff water as possible (36).

The rivers of India may be broadly divided into two groups. (1) The snowfed rivers of northern India and (2) the rivers of central and southern India. The Himalayas give rise to three important systems of northern India: the Indus, the Ganga and the Bramhaputra. The chief rivers of central and southern India are the Mahanadi, the Godavari, the Krishna and the Cauvery flowing eastward into the Bay of Bengal and the Narmada and the Tapti flowing westward into the Arabian Sea. The Chambal, the Betwa and the Sona drain the northern edge of the peninsula and flow into the Ganga system. (See map showing rivers of India.)

The rivers of northern India rising in the Himalayas are snowfed and flow all the year round though the supplies available in winter are low. The rivers rise with the melting of snows in spring and with the break of Monsoons they swell further and carry enormous floods during the rainy season; the supplies falling again from October onwards. The rivers of central and southern India have no snow fields at their heads and their supplies depend entirely upon rainfall. Since this rainfall is confined to a small part of the year, the rivers carry large supplies in these months and the dry weather flow sometimes dwindles down almost to a trickle.

Detailed gauge and discharge observations are available for many of the major rivers of India for the last few decades. Most of these observations are however, mainly in connection with existing or projected irrigation works. There has been no attempt to make a complete hydrographic survey of the country. The task is one of great magnitude. The India Irrigation Commission of 1901-03 estimated that the total annual surface flow in the rivers in India (as it was then but excluding Burma, Assam and East Bengal) was 51 billion cuft. This is equivalent to 1170 million acre feet of water. A more recent appraisal of the water resources of the country based on an empirical formula correlating the river flow in each basin with its rainfall and temperature, gives the total annual flow as equivalent to 1356 million acre feet for the Indian union. Of this, only 76 million acre feet or 5.6 percent are at present being used for the purpose of irrigation; the rest of

MAP SHOWING RIVERS OF INDIA

the flow is wasted to the sea. The position in regard to utilization of water resources in the important river basins is set out below (15).

River system	Estimated average annual flow	Existing utilization and proposed projects
1. Indus	170 million ac. ft. for entire system lying both in India and Pakistan	Existing utilization in India is about 8 million acre feet. The Bhakra-Nangal project is the main project in this system. A mean annual utilization of 8 million ac./ft. is contemplated in this project.
2. Ganga	400 million ac./ft.	Only a small part has been utilized mainly by canals on the Ganga, Yamuna and Sarda rivers. The Damodar Valley Corporation (D.V.C.) is the major project in this system. This proposes to utilize nearly 2.7 million ac./ft. of water. Other schemes for development are under consideration.
3. Bramhaputra	300 million ac./ft.	Existing utilization is negligible. In general irrigation is not necessary on account of heavy rainfall in Assam.
4. Godavari	84 million ac./ft.	About 14% has been utilized so far.
5. Mahanadi	74 million ac./ft.	Small quantities are utilized for irrigation in delta areas. The Hirakund project will be the first major development on the system. The project will utilize about 11 million acre feet of water.
6. Krishna	50 million ac./ft.	Approximately 18% of the flow has been utilized. The Tungabhadra project will ultimately utilize an additional 6 million ac./ft. Schemes for further utilization are under consideration.
7. Cauvery	12 million ac./ft.	Over 60% of the waters are utilized for irrigation in Mysore and Madras.
8. Narmada	32 million ac./ft.	There has been no large project on either of the rivers. The Kakrapara project on the Tapti would be the first major scheme.
9. Tapti	17 million ac./ft.	

There are numerous other rivers and riverulets in which waters are available intermittently during the rainy season. Small irrigation reservoirs have already been built on many of them, but there are many more which could be constructed. Substantial water supplies for irrigation and for industrial and domestic purposes are also available from underground sources. Wells have been constructed in all parts of the country for domestic water supply and for the irrigation of land and have been in use from time immemorial; but large scale irrigation from this source is possible only with the help of tube-wells operated by power pumps. The information at present available suggests that such large scale irrigation would only be economical in parts of Uttar Pradish, Bihar, Punjab, Rajasthan and Gujerat (15).

An additional 13 million acres from large and medium projects and about 14 million acres from minor irrigation projects are expected. After making allowance for depreciation etc. the net irrigated area is expected to increase from 70 million acres (1961) to about 90 million acres in 1966 (31).

OCCURRENCE OF GROUND WATER

The source of the water supply of wells is the rainfall, which is absorbed by the soil and penetrates to underground reservoirs where it is retained more or less perfectly by natural causes. In some instances the rain water, as it falls, passes directly to the subsoil reservoir, but generally speaking it may be assumed that the main supply is derived from percolation through beds of depressions filled with rain water permanently or temporarily.

It will be understood that these underground reservoirs are not hollows filled with water, pure and simple, but consists of gravel, sand or any soil of an absorptive nature saturated with water which cannot pass away below on account of some retentive substratum and which can only pass slowly away at the sides on account of the natural, frictional and other resistances which the constitution of the soil offers to the free flow of water through it.

The portion of the rain water which is absorbed by the soil wets the surface of the openings and soil holds the moisture by molecular attraction. Under the force of gravity the excess water moves down to fill the pores, fissures and cavities of underlying rocks. On coming in contact with a layer of impervious material, the water starts to spread laterally filling up the pores of the material in its path as it spreads. These processes have continued for long periods of time and as a result have built up a supply of water which underlies large areas of land surface. The water with the exception of that held in closed basins is all moving towards points where it can escape into a spring, stream or swamp.

The permeable rocks that lie below a certain level are saturated with water under hydrostatic pressure. The saturated rocks are said to be in the zone of saturation. The water found in the zone of saturation is "Ground water." The upper surface of the zone of saturation is called the water table. The zone above the water table where the interstices of the soil or rocks filled with water that is held by capillarity is called the zone of aeration or zone of suspended water.

There are therefore two kinds of water in the interstices of the rocks: (1) ground water and (2) suspended water. The water that supplies springs and wells is ground water. If a well is sunk, its walls may be moist at various levels above the water table but water flows into the well only when the well enters the zone of saturation.

Deep down in the earth, where interstices are absent, there is no room for water to exist in its ordinary condition. There is some evidence that in the molten rock, the minerals are dissolved into one another and the water is believed to be a common constituent of these mineral solutions. Evidence that water occurs in molten rocks is afforded by volcanoes and hot springs. This water is called internal water and the zone where it occurs is called zone of rock flowage.

The zone of saturation forms a huge natural reservoir. It is from these great natural reservoirs that springs and wells obtain their supply of water. All openings or interstices in the formation in the zone of saturation are filled with water. The zone of saturation or ground water occurring in the pores and interstices of a formation varies from a few feet to many hundreds feet of thickness, depending upon the nature of the formation. Ground water may be found in one continuous bed or several separate sheets. The ground water may occur as free water or confined water depending on the geological formations of the water bearing strata and the strata lying over and below these.

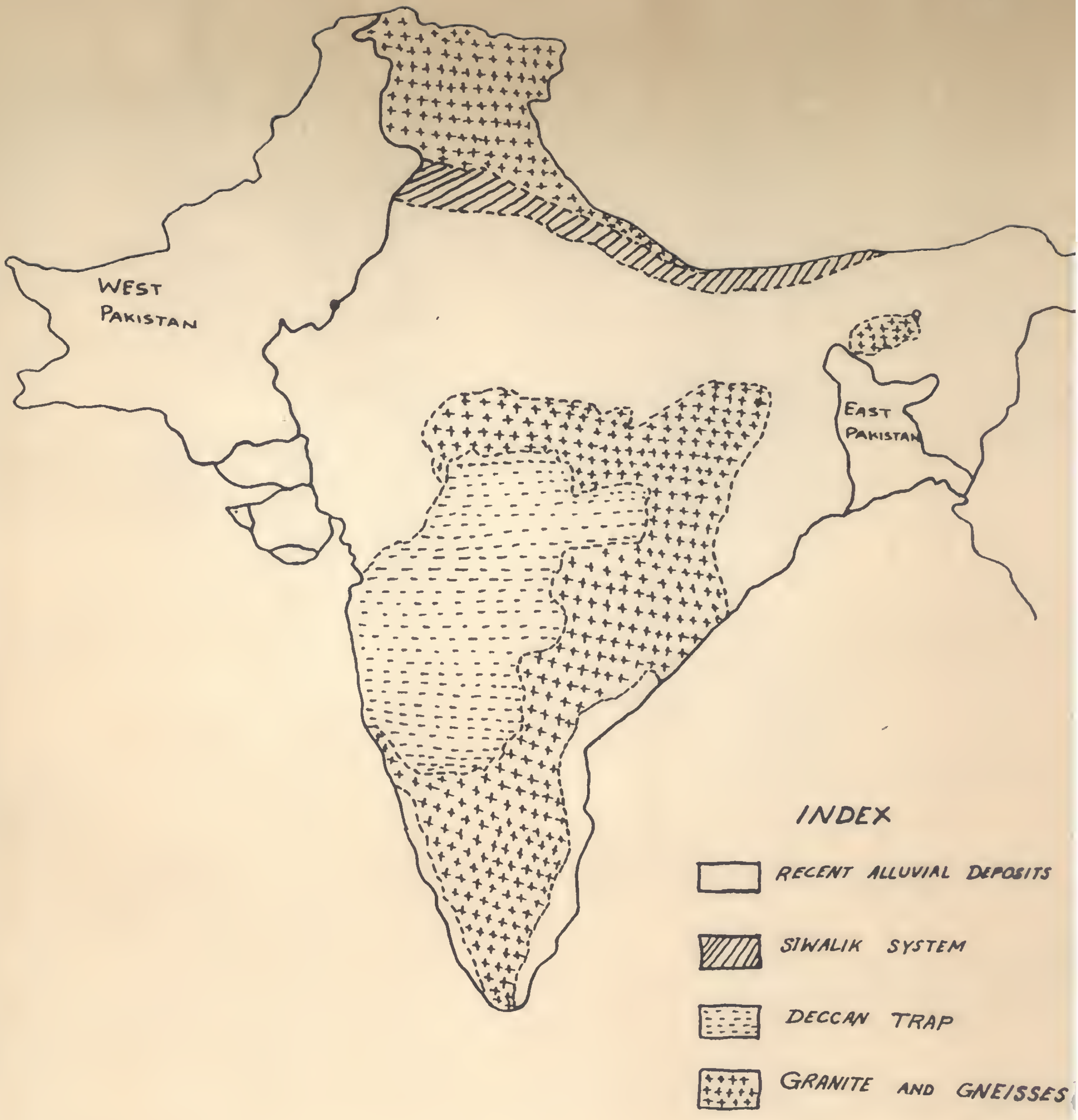
GEOLOGICAL FORMATION OF INDIA

Ground water is held in the substrata of the earth's crust and as such has an intimate relation with the medium of its storage. The storage capacity and the pressure under which it is held in the water bearing strata, or aquifers as they are called, depends directly upon the geological nature of the rocks in that stratum and the nature in which the strata are arranged i.e. their formations.

Four types of rocks are found to be occupying the surface and subsurface strata in India. At the north in the Himalayas and in the areas of Uttar-

Pradesh, Bihar, West Bengal and Assam which lie at the foot of the Himalayas, sedimentary rocks are found. The region is classified as the Siwalik formation. Adjoining these sedimentary rocks, and extending through the states of Punjab, Rajasthan, Uttar Pradesh, Bihar and West Bengal vast plains of alluvium are in existence. These alluviums are of recent origin from the geological point of view. Some of these alluviums are also found in parts of Gujrath and along the eastern coast of peninsula. These plains are very gently and uniformly sloping. In the peninsular region, towards the south of the river Narmada igneous rocks are found and form a very vast plateau region. This region extends over the states of Maharastra, Madhyapradesh, Orissa, Andhra Pradesh and parts of Mysore and Madras states. This deccan Plateau gradually merges into the metamorphic rocks, the rocks also of an igneous origin. Granite and gneiss are mostly found in this region. (See geological map of India.)

The igneous rocks by their character are very compact and the rainfall water has a very meager chance of penetrating them. Secondly they are found in a solid mass and layering is practically horizontal thus very little chance is afforded for water to percolate through. The storage capacity is determined by gaps and cavities created by geological processes. Thus water could be obtained where there are cavities, fissures or joints. In case of faults they give rise to surface storages such as tanks and ponds. If the joints or the openings in the underground mass open out in a valley we get temporary streams which may vary in their size according to the area of collection of rain water and the size of the water conduit. Both the deccan trap and the granite of southern regions have these water bearing characteristics. However where valleys have been formed by big rivers such as the Tapti, the Godawari, the Krishna, and the Cauvery, soils have been deposited by the flowing waters and absorb rain or flood waters and form a small scale storage of water which may



GEOLOGICAL MAP OF INDIA

be available for open wells in the proximity of the river streams. However, this does not form a perpetual supply of water.

Contrary to the above, in the Indo-Gangetic plain, which comprises great alluvium deposits of recent origin, we find the depositions in well defined layers of sand, gravel, clay, limestone, etc. All these layers are porous in varying degrees and allow infiltration of water in more or less quantity. Lateral percolation from the river stream, and well developed canal system is also abundant, through this medium. As such ground water is available almost anywhere, even in the Rajasthan (25) deserts and bores sunk into the water bearing underground strata yield economic quantities of water. The tube wells consequently have been most popular in this region of the country.

Attempts were made to procure water in the regions of Vidarbha, Andhra Pradesh, Mysore, etc; which lie in the region of igneous rocks, but were discontinued as sufficient water was not obtained. The only possibilities for irrigation in this area is by diversion of river water or by storage in tanks in suitable catchments. The irrigation from shallow open wells or shallow ponds is extensively practiced but there are strict limitations to the quantity available and hence to the area under command.

QUALITY OF GROUND WATER

All ground waters contain salts carried in solution. The kinds and concentration of salts depend upon the environment, movement and source of the ground water. Ordinarily higher proportions of dissolved constituents are found in ground waters than in surface water because of the greater exposure to soluble materials in geologic strata. Soluble salts found in ground water originate primarily from solution of rock materials (14). In areas recharging large volumes of water underground such as alluvial streams or artificial recharge areas, the quality of the infiltrating surface water can have a marked effect on that of the ground water.

Ground water passing through igneous rocks dissolves only very small quantities of mineral matter because of the relative insolubility of the rock composition.

Sedimentary rocks are more soluble than igneous rocks. Because of their high solubility, combined with their great abundance in the earth's crust, they furnish a major portion of the soluble constituents to ground water. Sodium and calcium are commonly added cations; bicarbonate, carbonate and sulfates are corresponding anions. Chloride occurs to only a limited extent under normal conditions; important sources of chlorides, however, are from sewage, connate waters, and intruded sea water. In limestone terrains calcium and carbonate ions are added to ground water by solution (9).

By and large, however, the subsoil water in Punjab is considered suitable for agriculture, except in some areas like those around Rajpur and Safidan, where it is said to be of poor agricultural quality. At some places, presence of calcium carbonate in the subsoil water leads to encrustation of the strainer slots in tube wells. At other places sodium salts are present to such an extent as to make the water harmful to agriculture. Therefore, while installing tube wells in the Punjab for agricultural purposes, special care needs to be taken in regard to the quality of water present in the subsoil (17).

The study on the usefulness of ground water in the intermonate valley from the quality point of view has suggested the existence of high carbonates and bicarbonates in the valley water, and to that extent a suitable soil and crop pattern is being suggested in the explored area (25).

Talati and Mehta (1959) found that underground waters in Bundi district are generally of an injurious nature and special care is necessary to check the rising of the water table while irrigating this area and to prevent the development of salinity and water logging problems (35).

Studies by Agrawal, Mehrotra and Gangwar (1956) show that the quality of well waters in Uttar Pradesh vary with the nature of the soil formation and its ground water levels. Immature and azonal soils contain well waters of doubtful quality and may present soil salinity problems. Well waters on mature soils are comparatively free from salinity danger (3).

DEFINITIONS

Definitions of some terms to be used in studying the hydraulics of wells:

1. Aquifer. It is a geologic structure or formation rich in ground water.

2. Cone of depression or depletion (23). The ground water table generally slopes towards the major drainage lines if a well or tube well is constructed and water is not pumped out, the ground water level will remain undisturbed. However, as soon as the pumping is started there is a steepening of the slope towards the well and the ground water surface gets slightly depressed. As pumping proceeds depression increases. If the well were in the form of a narrow, long, continuous box and the depth of the aquifer were to be infinite the surface profile will be two straight inclined lines. But as neither of the conditions are satisfied and the tube wells draw water from all sides and the area through which the water passes goes on decreasing, the surface profile takes a shape of a parabola. The "cone of depression" is the entire paraboloidal surface generated by the surface profile.

The water surface formed as the result of the continuously increasing downward slope toward the well is an inverted bell shaped depression which is known as the cone of depression. The base of this cone theoretically extends outward from the well to the limits of the equifer (10).

3. Depression head. The vertical difference between the normal undisturbed ground water table before pumping from a well and the level of water in the well any time after pumping is called the depression head. The depression head in a well goes on increasing with pumping. Recharge to the formation, may however, halt the development of the cone of depression by furnishing additional water, which will become a supply for the pumped well (5).

4. Porosity of rocks. It is expressed quantitatively as the percentage of the interstical volume to the total. A rock is said to be saturated when all its interstices are filled with water. In a saturated rock the porosity is the percentage of the volume of water contained to the volume of rock (29). In rocks this ranges from 0 to more than 50% (20).

Porosity determines the amount of water a rock or material will hold. It does not determine the amount it will yield.

5. Permeability. Permeability of an aquifer is its ability to allow water to pass through it under pressure. A high degree of porosity is no assurance of permeability. The moisture held in the soil which cannot be drawn out by pumping is called "specific retention." It is the ratio of the amount of water retained to the volume of water bearing material expressed as a percentage (29).

The specific yield of material is the ratio of the volume of water which (after the material is saturated) will drain out by gravity to the volume of such material. Specific yield plus specific retention is equal to porosity (10). Specific yield varies from 15% to 40% of water bearing medium.

6. Co-efficient of permeability or Transmission constant. Ground water

is not static, except in closed basins. It has a definite, though slow, velocity which depends upon the slope of the water surface and the nature of the medium through which the water is moving. The combined effect of these factors is expressed by what is known as a transmission constant or co-efficient of permeability. It is defined as the flow of water in gallons per day through a cross section of one square foot under 100 percent hydraulic gradient at a temperature of 60°F (10).

The term co-efficient of transmissibility is becoming more popular in ground water hydrology. It is defined as the rate of flow of water in gallons per day through a vertical strip of the aquifer one foot wide and extending to full saturated height under a hydraulic gradient of 100 percent at a temperature of 60°F. Thus the co-efficient of transmissibility is equal to the co-efficient of permeability multiplied by the thickness of the aquifer (29).

HYDRAULICS OF WELLS

The discharge or yield of wells depends upon the rate at which the water flows into the well from and through the surrounding water medium. The water bearing media which are permeable, act in two ways: (1) where little flow takes place and (2) where circulation of water is pronounced. The first is similar to reservoirs, while the second is like conduits. When a tube well is put down, into a layer of water bearing material, and water is pumped, the water in the casing is first lowered and water from the saturated material surrounding the casing flows into the well. If the pumping is continued the water in the well will continue to lower and the water coming from the saturated material will increase until it will just equal the discharge.

The movement of water flowing through granular material was first investigated by Darcy in 1856. He discovered that the velocity of water through homogenous media which are porous is directly proportional to the slope of water surface (23). It remains the basic law governing the flow of ground water (10).

It is mathematically stated as $V = \frac{Kh}{L}$ or $V = K\,i$ where K is the permeability constant, i is the slope of water in the water table underground, h is the head of water lost in friction and L is the length in which the head loss h occurs.

Darcy's law is true for very low gradients i.e. gradients up to which no turbulence occurs and the friction loss varies directly with the velocity. The friction loss after the inception of turbulence varies as the squares of the velocity (37). This velocity, when the turbulence gets in is called the critical velocity. Reynolds through his experiments found that the critical velocity varies inversely as the diameter of the pipe and temperature. Experiments have also shown that the critical velocity varies inversely as grain size in uniform material. Similar results may be expected with heterogenous permeable materials and the critical velocity may be assumed to vary inversely with the effective grain size.

Through formations in which wells of good yield may be developed, velocities of the order of 5 feet a day are usual. Velocities of 30 to 60 feet a day have been observed in the laboratory in well assorted gravel with hydraulic gradients of 5 to 10 feet a mile. Field tests to determine underflow have shown velocities as high as 400 feet a day.

In a well, as long as draw-off velocity, through the soil, is less than the critical velocity, there is no disturbance of the soil particles. When however the velocity exceeds the critical velocity, the finer particles are washed out from the portions of the soil in contact with the free water. This process of washing out the finer particles progresses into the soil up to the surface where the velocity of water through the soil is just equal to the critical velocity. A virtual cavity in the soil which is devoid of finer particles is thus formed. If the velocity of water at the exit is less than the critical velocity for the thicker particles left at the soil surface a stable condition will be established. Otherwise, even the thicker particles will be washed out gradually and failure of the well will occur. Draw off from a well should not be so great as to induce a velocity higher than the critical velocity of thick particles of the soil. In an ordinary soil consisting of 0.2 to 0.3 millimeter particles the critical velocity of half an inch per minute is a safe value. This velocity of half an inch occurs further into the soil where the virtual cavity starts. But at the bottom of any open well the velocity may be as high as three inches per minute which corresponds to the coarse sand between 0.5 to 0.6 millimeter diameter. In a tube well sand is prevented from entering the tube mechanically by filter and therefore permissible velocity can be 30 inches per minute (23).

Water Yield of Wells

Dupit, in 1863, utilized Darcy's law for the analysis of the hydraulics of wells. A modified analysis was developed later by Thiem in 1906. Equations explaining the fundamentals of flow of water into wells are given below (34).

The following assumptions are made in this analysis:

1. The aquifer is homogeneous and of infinite extent.

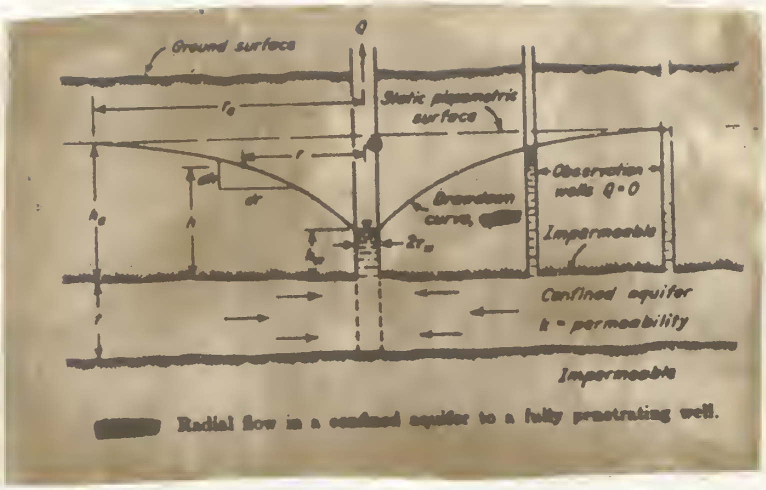
2. The discharging well penetrates the full thickness of the aquifer.

3. The co-efficient of permeability is constant at all points.

4. The flow is laminar and radial.

5. The pumping ratio is steady and the hydraulic system has reached an equilibrium stage.

A. <u>Water table conditions</u> (confined flow). (21)



Radial flow in a confined aquifer to a fully penetrating well.

Radial horizontal flow in a confined layer of thickness to a fully penetrating well is shown in the above figure. The flow Q into the well can be represented as Q = A V. The area A of a cylinder of radius r and height t is $2\pi r t$. The velocity V through the cylinder is given by the Darcy law:

$$V = K \frac{dh}{dr}$$

Where K is permeability and dh divided by dr is slope of the draw down curve at radius r. Therefore, the quantity of radial flow toward a well is:

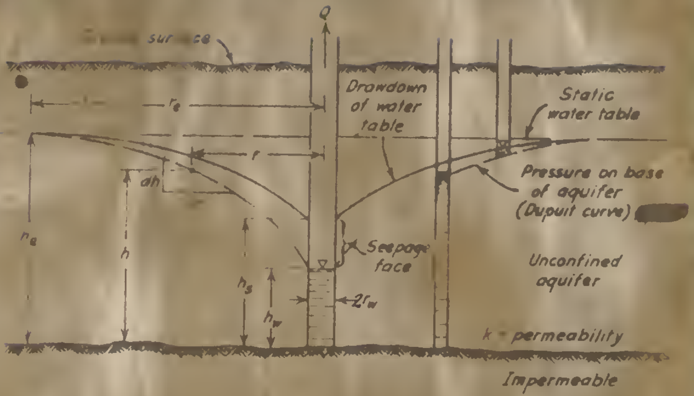
$$Q = AV = 2\pi r t K \frac{dh}{dr} \qquad \text{I}$$

Separating the variables and integrating this differential equation between limits of h_e and h_w in the vertical plane and r_e and r_w in the horizontal plane, the result is:

$$Q = \frac{2\pi k\ t\ (h_e - h_w)}{2\cdot 3\ \log_{10}\ (r_e/r_w)}$$

The draw-down $(h_e - h_w)$ substantially is directly proportional to the discharge, whereas the discharge varies as the logarithm of the well radius.

B. Unconfined wells (21)



[redacted] Radial flow to an unconfined aquifer to a fully penetrating well

A confined well becomes an unconfined well when the flow is not restricted by the impervious layer above the flow. In unconfined wells the surface of the flow is the water table, which is the plane of atmospheric pressure below which the pores of the aquifer are essentially saturated.

The hydraulics of the unconfined well can be developed in the same manner as that of the confined well, except that the constant thickness of the aquifer t is replaced by a variable thickness h. Hence equation I becomes:

$$Q = A\ V = 2\pi r\ h\ K\ \frac{dh}{dr}$$

and intergrating between the same limits, the classical Dupuit equation is obtained:

$$Q = \frac{\pi K \, (h_e^{\,2} - h_w^{\,2})}{2 \cdot 3 \, \log_{10} \, (r_e/r_w)}$$

The discharge Q now varies as the difference of the squares of h_e and h_w, whereas in a confined well discharge it varied linearly with h.

Limitations (34)

Several authorities have developed mathematical formula to show the relationship between discharge of a well, shape and the extent of the cone of depression and the characteristic of the material in which the well is drilled.

Tolman 1937, Bennison 1947, Dean C. Muckel 1955, and Raju 1956, agree to state that the formulas are not satisfactory for computing either the discharge or permeability. Numerical results are at best rough approximations which may be used to check preliminary estimates as to the possible yield of the well prior to actual pumping tests; due to the following limitations:

The water table is not horizontal. It is not certain that the well has penetrated the full thickness of the aquifer. The aquifer is not always uniform and there will be considerable variation in the value of co-efficient of permeability. Under water table conditions the flow is not completely radial. The rate at which the region of influence is recharged is ignored.

The concept of radius of influence is fallacious and misleading. The radius of influence may be many times greater than the value ordinarily assumed by the investigators.

It is assumed that all the discharge from the well flows horizontally into the zone of influence and no quantity is taken out of the storage. Further, the effects of the time factor on draw down is ignored.

Actual experience has shown that the draw down goes on increasing with time of pumping. Ignorance of this factor has resulted in the considerable lowering of the water table and consequent failure of many wells.

However, the above formulae will help in comparing the effects of different factors on the discharge.

1. Effect of diameter of well for same draw down.

$$\frac{Q_1}{Q_2} = \frac{\log \frac{r_e}{r_{w_2}}}{\log \frac{r_e}{r_{w_1}}}$$

Assuming a value of 1,000 feet for r_e, the radius of the circle of influence a well of 2 ft. diameter will discharge about 13 percent more than a well of one foot diameter (29). Bennison (5) states that other things being equal a 2 ft. well will yield about 19 percent more than a 6 ft. well.

The following table gives the relative increase in yield due to increase in diameter, the drawdown and the formation remaining the same.

	Tube-well Diameters					
	4"	6"	8"	12"	18"	24"
Relative yields	100	105	110	115	123	128
	---	100	105	110	118	123
	---	---	100	105	113	118
	---	---	---	100	108	113
	---	---	---	---	100	105

Though there is some increase in yield with an increase in diameter, it is only a small percentage. Bennison 1947 (5) and Dean C. Muckel 1955 (10) have also suggested that usually where depth of the water yielding formation is sufficient, no attempt should be made to increase the discharge of a well by increasing the diameter, rather the well is driven deeper. The tube well diameter may be increased only when it is necessary to make room for the installation of the pumping equipment.

2. Draw down and yield. Under artesian conditions the yield is directly proportional to the draw down. Under water table conditions if the draw down is small, the yield is approximately proportional to the draw down (5).

A majority of the wells constructed in gravel formation are non artesian, the non artesian relationship between draw down and yield is the most important. It is observed that 75% of the maximum yield is obtained by lowering the water level to 50% of the maximum depth of the aquifer. However it may be pointed out that it is impossible to lower down water by 100% as the pump ceases functioning before the bottom is reached and also other operating troubles will result (29). If the water level is lowered down by 50% there will still be left 50% of the depth of water for installing the screen. If the draw down is still increased it will result in a high velocity of flow causing failure of the well. It would be desirable to keep the velocity of flow at 0.10 to 0.25 feet per second (5).

3. Co-efficient of permeability, depth of penetration and yield. The discharge is directly proportional to the co-efficient of permeability K. There is wide range in the values of K for coarse gravel and fine silt. Due to difficulties in determining the value of K, large errors occur in computed results.

The following table (37) gives the average permeability of materials normally encountered in well drilling.

Type of material	Effective size in millimeters	Estimated permeability coefficient: gal./day	
		Average	Range
Sand very fine	0.05 to 0.10	50	10 to 300
fine	0.10 to 0.25	300	50 to 1,000
medium	0.25 to 0.50	600	100 to 3,000
coarse	0.50 to 1.00	1,500	300 to 5,000
Gravel fine	1.00 to 2.00	3,000	1,000 to 10,000
medium	2.00 to 5.00	6,000	3,000 to 20,000

In deriving the formula for flow of water into wells, it is assumed that the wells penetrate the water bearing formation to an underlying impervious stratum. Frequently the full thickness of the aquifer is not penetrated. The yield is directly proportional to the thickness of the aquifer and therefore it is most important that the well should penetrate as deeply as possible into the water bearing formation. The discharge is reduced to half if the well penetrates only half of the full thickness of the formation. Thus doubling the depth of penetration is much more effective in increasing well discharge than doubling the diameter.

4. Interference of wells. The amount of interference between wells depends upon the diameter, depth, spacing, draw down, and the nature of the water bearing material. Bennison (5) states that minimum spacing of wells is about 200 feet and the maximum may be as much as one mile.

From the tests conducted on interference, the following results were obtained (34).

Distance between wells	Reduction in yield
56 feet	14.2
73 feet	8.7
92 feet	7.5
148 feet	5.3
221 feet	nil.

Water flow in unconsolidated rocks such as alluvium formations found in the Gangetic plain or sand or gravel is capable of being interpreted scientifically, but there are no general principles applicable for wells obtaining water from consolidated rock formations such as Deccan trap and other igneous rocks. It is not possible to predict what will be found in fissures, solution channels or crevices in a rock well. The draw down is usually large and permeability is low in rock wells as compared to wells drilled in gravel formation.

Testing of Wells

The foregoing discussions regarding the theory of yield of wells is not of great use in preassessing the yield very correctly for various reasons pointed out therein. The general practice is to base the discharge on actual pumping tests. Tolman, C. F. and J. F. Poland (37) suggested five hydraulic observations of wells.

1. The quantity of water pumped in a given time, usually expressed in gallons per minute, per hour, or per day, can be measured. This is a quantitative figure for the yield of a well without respect to draw down or size of well.

2. The draw down during a selected period of pumping can be determined. If the pumping level becomes stationary after a period of pumping, the natural supply of ground water to the cone of depression is equal to the quantity pumped and information is thereby furnished as to the supply available.

3. The gallons produced per foot of draw down can be calculated. This value is known as the specific capacity and furnishes the best figure for comparison of yield from two or more wells. The specific capacity depends

upon two factors: the permeability of the aquifer and the frictional resistance at the entrance to the well.

4. The static level to which the water rises after cessation of pumping can be measured. Overpumping is indicated if the water does not rise to its original level after pumping stops, and safe yield is indicated if the recovery between pumping periods is complete.

5. The rate of recovery, which depends upon, and consequently indicates, permeability of the surrounding aquifer, can be determined by means of an electric measuring line which is lowered into the well to determine the rise of the water surface. It can also be measured by an airline and pressure gauge if the well is equipped with this device.

In summarizing the hydraulics of wells, the fundamental principles can be stated as to the general performance of wells under average conditions (5).

1. The yield of a water well is approximately proportional to the lowering of the static level by pumping.

2. The yield of a well is increased very little by increasing diameter.

3. The yield of a well is approximately directly proportional to the depth it penetrates a water bearing formation.

4. The yield of wells increases very rapidly with the coarseness of the formation and vice versa.

5. The yield of wells increases with the slope of the water table and the diameter of the circle of influence.

6. The yield is decreased if its cone of depression is overlapped by the cone of another well.

WELLS AND THEIR CONSTRUCTION

A well is a hole of certain diameter from the ground surface to a point below the subsoil water table. The wells can be classified in two ways: (1) according to the nature of the source of supply and (2) on basis of method of sinking.

1. According to the nature of the source of supply they are called as (a) spring well, (b) sub artesian well and (c) Artesian wells (Plate I, Fig. 2).

(a) Spring wells. In hilly regions or areas with rocky substratum the ordinary wells sunk in sand and alluvium are not possible. It is only the sandy and loamy soils which can contain sufficient quantities of water to be drawn out of wells. In rocky tracts the water moves along the fissures in small quantities. For a well to be dug successfully in rocky tracts, joints in rocks are to be located and the best position of the well is at the junction of the major joints. Such type of wells are known as spring wells. Marbles will be better than limestones, and slates are superior to shales. But in all these the fissures should be only in the upper layer of the rock while the lower layer should be water tight. Igneous rocks are usually disappointing.

(b) Artesian wells. The existence of these wells depend upon: (1) A complete enclosure of the aquifer or water bearing porous stratum between two impervious strata. (2) The height of outcrop of the aquifer through which rain water passes in the aquifer above the site where the well is to be sunk. (3) The continuity of aquifer from the outcrop to the well. Such wells are located in the valley and when a hole is bored to reach the enclosed aquifer water flows out of the bore of its own accord i.e. no lift is essential. Such wells are called artesian or flowing wells.

PLATE NO. I

Fig. 1

Fig. 2

(c) If through the bore sunk in the formation having characteristics as mentioned in (b) the water does not rise well up to the ground level, but has to be lifted for a certain height, the well is called sub-artesian.

2. The second criterian of classifying the wells is the method of sinking employed in constructing the wells. The wells then can be (a) dug wells or (b) bore wells.

(a) Dug wells. The dug wells are also called open wells, are larger in diameter. It is more or less a pit dug in the soil to varying depths. The economically feasible depth is limited to 100 feet below ground level. It may be in alluvial or non alluvial soil. In alluvial soil its construction and maintenance are comparatively difficult but the supply of water from it is greater and more reliable. The open wells are often lined with rock or rubble.

(b) Bore wells. The bore well is essentially of very small diameter from 6 in. to 24 in. A bore well may be artesian or subartesian in character and is usually much deeper than the open wells. They can be constructed to tap many water bearing strata below the ground. They are more successful in alluvial soils and are drilled when discharge of more than .15 cusecs is required. They are however more costly than open wells. These types of wells are also known as tube wells (Plate I, Fig. 1).

Before the start of tube well engineering in India open wells for irrigation existed by the thousands, some of them being very old and as much as 60 feet from ground to the water level.

Comparison of Open Wells and Tube Wells

There is a fundamental difference between the lined open well and the tube-well. The lining of an open well is very essential from the point of view of maintaining the well cavity. If not lined the open wells deteriorate faster unless they are in consolidated rocks. In consolidated rocks the supply is only by way of springs through joints. Otherwise a lined open well admits water only through the porous sand exposed at its base; the tube well on the contrary, has its base blanked off and water is taken in through its cylindrical outer surface.

The effect of this difference of principle is profound. An open well having a base area of 80 sq. ft. yields about 1/10 C.f.s., while a tube well with a cylindrical outer surface of the same area will yield 1/2 C.f.s. an amount five times as great.

The inferiority of the open well in respect to water yield per square foot of percolation surface is partly explained by the fact that it is not possible to take water rapidly from an exposed surface of sand, due to liability of sand to lift and pass away with the water but this action cannot account for more than 2/5 of the difference stated. The real cause of the relatively small quantity yield by open wells is to be found in the direction of the approach of water, vertically through the sand in case of the open well, and horizontally for the tube well.

Sedimentary deposits of sand and clay are always stratified horizontally. Even a thin stratum of clay presents a formidable obstacle to the verticle passage of water but not to horizontal flow. There is also good reason for believing that the subsoil sands offer less resistance to horizontal than to vertical travel.

The yield of water from any sort of well cannot be predicted with certainty although we have a general knowledge of the geology of the district where it is proposed to sink wells. There are always some blind spots shielded by ancient clay beds wherein very little water is found, consequently well sinking is speculative. The tube well is better in this respect than open wells, by reason of its greater depth and the chance of piercing good strata below the level at which the base of the open well must be situated. No data is obtainable concerning the proportion of failures with open wells, but it is estimated that one in ten, fail to tap the right stratum, resulting in financial loss and disappointment.

The risk of the tube well is considerably less. The sinking process permits exploration of the subsoil to depths of 300 feet below or more. The site selected must be very bad to fail entirely in these circumstances.

At the same time experience has shown that promising sites have not given the anticipated supply; while other sites have greatly exceeded expectations. Tube-well engineering has, however, now reached a stage when it is possible to forecast with reasonable accuracy the yield from various classes of sand after a boring has been made, but not before.

The other essential difference between the tube well and the open well is that the sand is prevented mechanically from entering the tube well and hence the critical velocity is increased many times. A cavity is formed as in the case of open wells, but in this case the cavity is round the strainer and it extends to a considerable distance. In other words the open well is in itself, a reservoir, while for a tube well the entire aquifer surrounding the strainer serves as a reservoir.

Tube wells are the most important sources of water for irrigation. The construction of a tube well involves the following operations.

1. Drilling deep holes of diameters normally ranging from 4" to 24", usually accompanied by insertion of a plain tube to avoid clogging of the hole.

2. Inserting casing pipe and strainers; and removing the plain tube inserted.

3. Development of wells.

There are, in general, two distinct systems of drilling.

1. Percussion system.

2. Rotary system.

A brief description of these two systems is given below.

1. Percussion System. The principle of operation of the percussion system is the breaking of the rock by the impact of a bit with a relatively sharp edge which is lifted and dropped at regular intervals. At the same time the bit is slowly turned so that the edge of the bit strikes on a different line at each successive blow. If the tools are sharpened properly and are turned carefully, the bit will cut a round straight hole, with the help of a bailer or sand pump, drill cuttings are removed.

Tools and equipment. A set of standard tools consist of a drilling bit, a stem, a drilling jar, and rope socket. A string of tools may weigh from 1000 to 5000 lbs. Special steel is employed for manufacture of tools so that they may withstand severe strain. The tools are joined together by tapered screw joints of the box and pin type. These joints are made very tight by special wrenches.

The bit is the most important part of the string of tools. It does the actual drilling and consists of the cutting edge, the body, the wrench square, the shank and the threaded pin head. The edge of the bit is of different forms. The regular bit is used for drilling fissured and sloping rocks. Spudding bits are short and thin and are used in starting holes in soft formation.

The drill stem consists of a round bar of diameter ranging from 2½" to 6" and length from 5' to 10'. It is connected to the drill bit by box and pin joint. The purpose of the stem is to add weight and length to the drill so that it will cut rapidly and straight.

The jars consists of a pair of steel links. It is connected to the stem on one end and a rope socket at the other end. The purpose of the jar is to provide a means for giving an upward blow to the tools. Rope sockets are for the purpose of attaching the rope or cable to the string of tools. They are made with or without a swivel joint with wire rope, they are made with a swivel joint for automatic turning of the tool in the bore.

The drillings are suspended by either wire cables or manila rope. The size of wire cables varies from ½" to 1" in diameter and manila rope from 3/4" to 2¼".

The drilling cuttings are removed by a bailer which consists of a pipe about 10 feet long with a valve at the bottom and a bail at the top for attaching the drilling cable or sand line. Bailers are equipped with flat or dart valves. The purpose of these valves is to allow the drillings to enter the bailer and keep them from running out after they have been caught. The flapper valve bailer can be emptied only by turning the bailer pipe. The dart valve bailer is emptied by striking the dart on some solid thing which forces the valve to open.

2. Rotary system. (Plate No. 2) The rotary system of well drilling consists of a rotating cutting bit, a mechanism for imparting a rotary motion to the bit, and a means of removing the material or cuttings displaced by the bit.

The bit is rotated by a hollow drill rods extending from the drill to a point above the ground. The drive rod is rotated by bevel gears. The speed of rotation is regulated according to the type, form and size of the bit and

PLATE NO. II

the formation to be drilled.

When power is applied to the drill rods, the rotating bit cuts a groove in the material under it. The string of tools consists of a shot bit, core barrel, rotation plug, matching coupling, silt barrel, and hollow drilling rods. Chilled steel shots are fed from the above through the hollow drilling rods and the shots roll down between the rock and the bit. The material loosened by the bit must be removed. This is done by a pressure pump which pumps water through the hollow rods. The pump forces the mud laden fluid upwards through the annular space around the cutting bit and the water of the well. As drilling proceeds the rock core fills up the core barrel. After the core has filled the core barrel to within a few inches of the top, grout is fed into the hollow rods. These will get themselves wedged between the barrel and the rock core. When the drill has been given a few turns, the core breaks and the string of tools is lifted to the surface. The grout is loosened by a few hammer blows and the core is taken out.

Rotary and Percussion Systems Compared (34)

The essential difference between the percussion (cable tool) method and the rotary method lies in the manner of abrasion and removal of material from the hole. In the rotary method, only an annular groove of material is cut by rapid rotation of the bit leaving the core in the centre while in the percussion system the entire portion of the rock in the bore is crushed to powder by the vertical oscillation of the bit. Material is removed by a bailer in the percussion system while in rotary system, circulating fluid, under pressure descending through hollow rods and ascending outside the tools, brings up the fragments of the formation to the surface in suspension.

Advantages of percussion method.

1. Less water is necessary for drilling operation.

2. Comparatively much lighter in weight and can be transported easily in rough country.

3. Cost per foot depth of drilling is cheaper in unconsolidated formations.

Disadvantages of percussion method.

1. Accurate samples of formation is not obtained.

2. Operations are very difficult in soft and sticky formations like shale, clay, quick sand, etc.

Advantages of rotary system.

1. The rotary system can handle alternate hard and soft formations.

2. Much bigger size of bores up to 60" in diameter is possible.

3. A correct sample of the underground formation is available.

Disadvantages of rotary system.

1. It needs a large quantity of water supply for operation; about 1000 gallons per 8 hour shift.

2. Its equipment is comparatively heavy.

The performance of these two systems is summarized in the following table.

Type of formation	Drilling performance	
	Rotary	Percussion
1. clay and silt	Rapid	Slow
2. loose sand and gravel	Rapid	Slow
3. baesalt, thin layers of sedimentary rocks	Slow	Rapid
4. lime stone	Rapid	Rapid
5. granite	Slow	Slow

The average speed of operations are given below.

1. Quick sand -- 30 ft. in a day of 8 hours working.
2. Gravel -- 30 ft.
3. Shale sticky -- 20 ft.
4. Clay sticky -- 30 ft.
5. Boulders -- 15 ft.
6. Sand stone soft -- 75 ft.
7. Sand stone hard -- 20 ft.
8. Conglomerate -- 20 ft.
9. Slate -- 80 ft.
10. Limestone -- 40 ft.
11. Granite -- 10 ft.

Well lining. While drilling through the upper formation, it is usually necessary to line the hole. For this purpose, flush jointed steel casing is used. The pipe is made very heavy to withstand heavy driving. After drilling 6' to 10' in subsoil, a length of casing is inserted and driven down with the boring tools. The object of lining bore holes is to prevent soft formation from falling in while the drilling is in progress.

Casing used in irrigation wells has to be perforated where it passes through the water bearing formation in order to let the water into the well. The perforated casing which is called strainer pipe, contains slots, the size and spacing depend upon the nature of formation and water supply.

If perforations are small, unnecessary entrance friction is developed which causes greater draw down and greater pumping lift increasing the cost of operation. On the other hand if the perforations are too large, the maximum amount of water will have full entrance to the well but difficulty will be encountered in flow of silt, sand and small pebbles. The sediment may come into the well faster than it is pumped out and partially fills the well, shutting off good water bearing formations. If too much material is pumped out from around the casing there is danger of collapse.

Bennison (5) stated that the losses can be decreased by increasing the amount of open area, the length of screen or the diameter of the screen.

The criterian is proposed that a velocity of less than .1 ft. per sec. to .25 ft. per sec. through the individual screen openings will keep sand movement and head losses to a minimum. A significant observation was made by G. L. Corey (8) in 1949, concerning the percentage of open area of a screen. Mr. Corey stated that there is a critical percentage above which the head losses are no longer a function of the open area.

The basic requirements for any well screen are that it:

1. be resistant to corrosion and deterioration;
2. be structurally strong enough to prevent collapse;
3. prevent excessive movement of sand into the well and
4. have a minimum resistance to the flow of water into the well.

An efficient screen must represent a compromise of several desirable characteristics. For example a screen with a large percentage of open area will provide a lower resistance to flow, but it will have less strength and will permit more pumping of sand than a screen with a smaller percentage of open area. The characteristics of well screen and the characteristics of the surrounding media influence the pattern of inflow and the losses (26).

Development of wells. The post drilling treatment of a well to establish the maximum rate of water yield is called "well development." It is accompanied by pumping, surging and bailing, to wash the fine silt and clay from water bearing formation immediately surrounding the well screen. The removal of fine materials opens up the pores and channels through which water enters the well and reduces the resistance to flow. Different methods of well development are detailed below.

1. Gravel treatment. The gravel envelope consists of a layer of screened gravel which surrounds the casing. The thickness of the layer is normally from 6" to 12". The gravel can be put in while the drilling is in

progress or when the well is completed it can be placed around the casing. In drilling through some fine sand formations a large quantity of sand is carried into the well. When a gravel envelope is used, the material taken out is replaced by gravel screen wells. The type of gravel used should be given careful consideration. The principal purpose of the gravel screen is to keep fine sand from coming into the well and to provide easy passage for water to enter the well. Screened pea sized gravel has been found to be most satisfactory in many cases. Mixtures of gravel of different sizes are unsatisfactory.

2. Developing by pumping. A turbine pump of sufficient capacity to handle the estimated discharge from the well is needed for this operation. The well is pumped slowly at first and gradually at higher and higher rates. At each rate of pumping, operation should be continued until no more sand comes into the well. This procedure is continued until maximum capacity of the pump is reached. After the pump has attained maximum discharge, it is run until water becomes clear. The pump is then shut down and all the water in the upward column will drain into the well and the water table returns to normal. Then the pump in starting and stopping stirs up the material to come into the well, until the passages for water are cleaned out. Usually it takes one day for this process.

3. Surging. Surging is a very effective method. A bailer loaded with sand to give more weight is moved up and down against the perforated portion of the casing. This process will alternately draw out water and push it into the surrounding strata. This will enable the fine material to come into the well without causing clogging. After sand has accumulated in the well, it is removed by a sand pump or bailer.

4. Development by compressed air. A compressor capable of developing

100 to 150 lbs. per square inch is necessary. Water is forced up by turning air into the air intake pipe and the rate of pumping is varied. Pumping is done intermittently to allow the water to build up to a static level. The pressure tank of the compressor must be filled to full capacity, while the water is rising in the well, and this large volume of air shall be released suddenly at the bottom of the well through the air line. There will be a brief forceful surge of water, then a "head" of water will "shoot" partly from the casing and partly from the drop line. If the air line is pulled back into the drop pipe as soon as the first heavy load of air has been released into the well, a strong reverse flow will be produced up the drop pipe which will quite effectively agitate the formation being developed. The well is then pumped and continued with occasional releases of "heads" of air until the well is thoroughly cleaned of the sand.

5. Back washing. The top of the casing is sealed by an air tight cap and forces water through perforations. When the pressure is released the water will flow back into the well through the perforations and bring fine sand from the area surrounding the well. This process is repeated until no more sand is brought in. The cap is removed and the sand is bailed out.

COST OF CONSTRUCTION OF TUBE WELLS

The cost of sinking a tube well depends upon the size and depth of the well, the characteristic of formation, the method of drilling employed, and also cost of labor, material and transportation.

Increase in diameter of hole not only increases the cost of sinking because of the additional material to be removed but also it demands larger and more expensive tools. The cost of each foot drilled increases rapidly with the depth, for more time is lost in cleaning the tools and cleaning the hole. Also progress is slower because of decreased speed at which tools are operated. Great labor and ingenuity are required for recovery of lost tools.

In working out costs the following prices of material are taken into consideration.

1. Cost of a portable rig capable of drilling 6" to 15" diameter holes up to 500 ft. . . . . Rs. 40,000.

2. Crew needed for operation:

   a. one driller . . . . Rs. 10.00 daily wages

   b. one assistant driller . . . . Rs. 6.00 daily wages

   c. one blacksmith . . . . Rs. 4.00 daily wages

   d. two helpers . . . . Rs. 4.00 daily wages

   Rs. 24.00 total daily wages

   The cost of labor for operation per day of 8 hours will be Rs. 24.00.

3. Operating charges of the machine per 8 hours of working.

   a. Fuel oils . . . . Rs. 15.00

   b. Lub. oil . . . . Rs. 3.00

   c. Greases and other items . . . . . Rs. 1.00

   d. Repairs and replacement of parts . Rs. 1.00

   Rs. 20.00 per day.

4. Depreciation and interest on equipment

   per day . . . . Rs. 16.00

   Total cost of operation per day is 24 + 20 + 16 = 60.00 per 8 hours of working.

5. Output per day.

   a. Granite . . . . 5 ft.

   b. Trap . . . . 10 ft.

c. Laterite . . . . 20 ft.

d. Soft rock . . . . 30 ft.

e. Rocky murum . . . . 40 ft.

6. Cost per foot of drilling.

a. Granite . . . . Rs. 12.00 per foot depth

b. Trap . . . . Rs. 6.00 per foot depth

c. Laterite . . . . Rs. 3.00 per foot depth

d. Soft rock . . . . Rs. 2.00 per foot depth

e. Rocky murum . . . . Rs. 1.50 per foot depth

The above figures hold good up to 200 ft. depth of boring. For every additional 100 ft. depth of boring, the rates will have to be increased by about 25% (29).

Total cost. The general break down of the cost of a 1½ c.f.t. tube well is as given below.

		Rs.
1.	Tube well construction equipment etc.	30,000
2.	Appurtemant works and other charges	15,000
3.	Electrical installation	20,000
	Total	65,000

Specifications. General criterian for accepting tube wells drilled has been a yield of one and half cubic feet of water per second with a maximum pumping lift of about 50 feet, involving a depression of about 20 feet. The wells consist of 12 inch diameter housing pipe and 8 inch diameter plain and slotted pipe appropriately placed according to the finding of different strata.

State tube wells in Punjab are built mostly to a specification requiring a gravel packed type well, bored generally up to a depth of 300 feet below ground. The gravel used for packing is mostly good, hard and well rounded stream gravel obtained from near Chandigarh or Dadupur. After the pipe assembly consisting of blind pipe and slotted strainer pipe is lowered into the bore centered by steel braces spaced through the hole at various depths, the gravel already screened to desirable size is shoveled into the annular space. Care is taken to assure a vertical shaft for pumping sets, which are mostly turbine type bore-hole pumping units. In a few cases, however, wells have been provided with centrifugal pumps. The pumping sets are generally of standard makes, like Jhonston, Jyoti, Layne and Sume (17).

ECONOMICS OF TUBE WELL IRRIGATION

Relation of size to cost/Ac. As is the case with most enterprise, the larger the scale on which it is conducted the cheaper the product. This axiom of commercial practice applies to tube well engineering with the same truth as it does to manufacturing. The capital cost, supervision expenses, labor and overhead charges, are all lower in relation to the water raised from large groups of wells, than from single wells of small output. These large installations would naturally require financing by public companies, Indian states, or by the Government, and managed and planned by experts to ensure the lowest possible cost to the farmer.

While it is desirable from financial considerations to group tube wells around a central source of power, the impression must not be conveyed that single wells privately owned, are not profitable investments. On the contrary the assistance given by a tube well to crops depending normally upon rain, often turns what might have been a season of loss into one of profit. The sense of security imparted by the knowledge that all is not lost in times of drought should lead to improvement of agricultural practice and reduce the conservatism so noticeable in India.

Tube wells are fortunately effective in all sizes; it is not necessary to be a rich man to own one.

Leggett (1928) studied economical aspect of the size of the well and found that:

	Discharge from well	Area irrigated Acres	Cost/Ac.
1.	.125 c.f.s.	30	16 Rs/Ac.
2.	0.35 c.f.s.	90	12.5 Rs/Ac.
3.	01.00 c.f.s.	250	11.5 Rs/Ac.
4.	2.00 c.f.s.	500	10.0 Rs/Ac.

Figures of cost/Acre are very old (1928). They are used only to show the relation of the size of the well and the cost/Acre.

<u>Tube wells versus surface or shallow wells</u>. The results of inquiries conducted by the planning commission and the states have established beyond doubt that tube wells can be a fairly economic source of minor irrigation if the use of pumped water is properly planned.

1. A tube well irrigates about 500 acres while a surface or shallow well can barely irrigate 5 acres.

2. The tube well cost about Rs. 65,000, depending on whether electric energy is available for running the pump or not. This is for $1\frac{1}{2}$ c.f.s. discharge.

3. Cost/Acre with tube well = $\frac{65,000}{500}$ = 130 Rs.

Cost/Acre with shallow well = $\frac{1500}{5}$ = 300 Rs.

It shows that the tube well is definitely a cheaper source of irrigation, than shallow surface wells.

Energy charges. The Government of Punjab has prescribed the rate per unit of electricity as 2 annas (12 N.P.) for 1960-61. As per arrangements between the irrigation department and the electricity department, the irrigation department accepts debit from the electricity board at a rate of 6.77 N.P. per unit and the balance of 5.23 is supposed to cover the cost incurred for working expenses by the irrigation department itself. It is to be seen that if the rate charged by the state electricity board could be reduced further, so as to be in line with their actual generator and transmission cost and no profiteering is allowed between the state irrigation department and the state electricity board that the cost to the consumer could be further reduced. This would help the irrigation department in finding more money for maintenance purposes and for working expenses.

In Uttar Pradesh the rate for 3200 tube wells operating on Ganga Hydroelectric Grid is 3.5 pies per unit (1.84 N.P.) plus an annual charge of Rs. 80 per B.H.P. while the rate charged for water is 16,000 gallons per rupee (with a rebate of annas three (19 N.P.) per rupee at present. This leaves a good amount with the irrigation department to meet the working expenses of tube wells.

Water Rate Structure (17)

An average tube well in the Punjab area gives a discharge of 1½ c.f.s. with a total lift or approximately 50 ft. It can irrigate an acre in two hours to a depth of three inches on an average consumption of energy of 10 KWs per hour. As such the cost of irrigating an acre of land is about Rs. 2.50. This in itself is not a high rate.

In Uttar Pradesh tube well water is supplied at about 19,690 gallons per rupee. A three inch depth on one acre works out to be 67,500 gallons and the cost per acre of three inches of water will be about Rs. 3.50.

As such the current Punjab rates are lower than the Uttar Pradesh. Their earlier unpopularity was on account of the Punjab Canal water rates being comparatively cheap.

Even if the rates of tube well water are brought closer to that of canal rates, some differences between the user of tube well water and the user of canal water must still exist. In respect of canal irrigation, water rates vary from crop to crop. In respect of tube well irrigation, the rate is uniform based on water consumption. Tube wells energized from the hydro-power have cheaper rates than those energized from combustion engines.

Comparisons made with charges at present on Eastern Yamuna Canal indicated that the tube well charges in Uttar Pradesh are close to the canal rates, as shown in the following table.

Crop	Canal rates per acre	Tube well rates per acre	
		Gallons	Cost at 16000 gallons per rupee
Sugar cane	Rs. 32	5,35,000	32.80
Wheat	Rs. 12	1,60,000	10.00

While in Punjab on the western Yamuna Canal, irrigation charges on sugar-cane and wheat are Rs. 16.50 and Rs. 5.84 per acre respectively as against

Rs. 32 and Rs. 12 per acre respectively on the Eastern Yamuna Canal in Uttar Pradesh, only a score miles away on the other side of the Yamuna. Since this disparity was unreasonable to the general irrigation economy of the tract, the authorities had to lower the rates for tube well assessment also.

Income. There is considerable disparity between the net income per acre derived by the farmer from irrigated and unirrigated areas. As per farm accounts in Punjab brought out by the state Economic and Statistical organization the figure for net income per acre from irrigated areas and unirrigated areas are Rs. 190.17 and Rs. 61.37 respectively, indicating a gain of Rs. 128.80 per acre in net income as a result of irrigation. In other words Rs. 128.80 represent the extra productive value of an acre under irrigation (17).

ADVANTAGES AND DISADVANTAGES OF WELL IRRIGATION

Disadvantages.

1. Working expenses are high. The cost of irrigation from wells is roughly three times that of flow irrigation from canals. If the cost of labor of men and animals is added to this, the excess cost will be still more.

2. Water from wells has to be lifted and lifting appliances have to be worked, either manually or mechanically. In case of manual lifting there is a possibility of the person who lifts falling ill and in case of mechanical lifting there is a possibility of energy supply being interrupted. The result will be that during the interval of interruption, the supply of water is stopped.

3. The water is clear and free from manurial properties of silt.

4. In case of tube wells, the tube well is liable to progressive

deterioration due to strainer getting choked or the tube well pipe getting corroded. Hence there is an additional cost of maintenance. Some sort of machinery has to be utilized for pumping water which again requires delicate care.

Advantages.

1. It is under owners control.

2. It permits isolated areas to be irrigated.

3. It helps lowering of the subsoil water level and thereby assists in drainage of irrigated land which might become water logged.

4. It is not likely to fail in seasons of drought unless the drought continues for several years and even in such cases the supply is only reduced and not totally stopped.

5. It enables perennial and hot weather crops being grown on such of the canals whose supply is likely to fail at times.

6. It economizes supply.

7. It is particularly adapted to intensive irrigation of high value crops and to the growing of more than one crop per year.

8. In colder weather it supplies water which is warmer and in hot weather the supply is cooler, thus making the water more agreeable to crops.

9. The supply is fairly constant.

10. Loss in transit is reduced and when the water is scanty, lining of field channels can be easily resorted to.

11. The wells may be sunk wherever desired.

12. In case of tube wells, assessment on volumetric basis of supply is possible or rather desirable and due to this, the water is likely to be used more economically.

UNDERGROUND WATER RESOURCES AND EXTENT OF IRRIGATION

It will take years before an accurate survey of the important ground water regions can be completed in any country. In some countries like the United States of America and United States of Soviet Russia geophysical surveys have been conducted on an extensive scale but no such survey exists in India (18). So we can only have a general division and account of the underground water resources.

Broadly speaking the underground water regions in India can be divided into

1. The Indus Basin
2. The Ganga Basin
3. The east coast
4. Godavary and Krishna Basins.

The other regions are either rocky or have plenty of rainfall or cannot be considered as continuous. Some isolated tracts may exist on the west coast of Bombay and Malabar, but they cannot be very extensive because of the mountainous nature and of the volcanic formations of the subsoil.

1. Of the underground basins, the Indus and the Ganga basins are the most important. Part of the Indus Basin is in Pakistan and part in India.

The Indus Basin in Pakistan is well suited for digging tube wells. In many areas tube wells have been installed to prevent the water logging caused by canal irrigation. The transmission constant of the subsoil is high. Some of the Northern districts of the plains of East Punjab have also a very high water table. There is as yet no tube well irrigation in these districts. The subsoil water goes deep down or gets obstructed near about Ambala. In this region the sub mountainous rocks of the Himalayan range seem to divide the Ganga and the Indus Basins.

2. To the east Ambala, Meerut the Jamuna-Ganga basin starts. This is a vast basin extending to the Bay of Bengal and there is plenty of water in the subsoil in this region. Geodetic evidence indicates that the alluvium of this basin attains a maximum thickness of over 6000 ft. in North Bihar. South of the Ganga the alluvium rapidly becomes thinner and forms a Veneer resting upon the old topography (4). The transmission constant of the subsoil varies very considerably but in many areas of this basin it is high enough to install tube wells. This basin runs through part of East Punjab, Uttar Pradesh and Bihar.

The source of the subsoil supply in this region is a flow from the sub-Himalayan regions through the underground. The river Ganga may also be contributing to the underground resources, but the main underground flow is from north to south through the subsoil.

While the Ganga Basin has been very suitable, the same cannot be said of Mahanadi, Krishna and Kavery basins, due to the unsatisfactory condition of the subsoil and also the undulating nature of the ground surface (18). There may be isolated regions in which tube well irrigation may be carried out but not on a vast scale.

The East coast is suited for tube well irrigation because the Eastern Ghats are away from the sea and thus is a wide strip in which the subsoil has enough water. The discharge obtained in the explored part of the coastal tract is of the order of 24,000 to 42,000 gallons per hour at a draw down of about 19 to 41 ft. (25). In digging wells and using them for irrigation there is one main point to be investigated in the East Coast. Coastal aquifers come in contact with the ocean at or seaward of the coastline and here, under natural conditions, fresh ground water is discharged into the ocean. With increased demands for ground water in many coastal areas, however, the seaward flow of ground water has been decreased or even reversed, causing sea water to enter and penetrate in land in aquifers. This phenomenon is sea water intrusion. If the salt water travels inland to well fields, underground water supplies become useless; moreover, the aquifer becomes contaminated with salt which may take years to remove even with adequate fresh ground water available to flush out the saline water (9).

It is therefore necessary to consider the point of sea water intrusion and the ways of protecting the coastal aquifers must be investigated before embarking on a tube well irrigation scheme on the East Coast. The permeability of the strata is not bad though systematic data does not exist. It can be presumed to be good becaue it must be formed of sea silt which has a good transmission constant on the average.

Mahavir Prasad (25) 1962, has stated that the quality of water in the coastal areas and the delta regions, in particular, has been generally and uniformly good for purposes of irrigation, industrial consumption as well as for human or stock consumption.

The West Coast of India is not fit for tube well irrigation because of the rocky subsoil.

Arid zone of Rajasthan. With the idea of exploring the arid and semi-arid tracts of Rajasthan the organization undertook an ambitious program in the 1956-57 season. On the basis of the explored area in the first phase, only one isolated pocket of good groundwater reservoir could be delinated in Rajasthan around Chandan. Small groundwater pockets of poor quality and quantity were also located near Bhotia in Barmar district and Sikar in Sikar district; which can stand development by low duty tube wells. The discharge sustained over long duration pumping of the only productive well of the first phase at Chandan was 46,000 Imperial gallons per hour at a steady draw down of 18 ft. the static water level being 119 ft. below ground level the quality of water is also found to be good for irrigation, domestic or industrial purposes.

Further work in the second phase has now established that certain areas in the Jaiselpur and Barmar districts are proven for their ground water reservoir in their deep sub-surface aquifers. The aquifers in Jaiselmer district in particular are confined to the Lathi Series. It is therefore, imperative to deliniate the productive horizon and the exploratory tube wells organization will before long present a correct picture of the productive horizon in the arid and semi-arid tracts of western Rajasthan. However the information brought out so far is of a great utility to the geologists and ground water engineers engaged in water problems in other similar parts of the world.

Water required for drilling in ground water exploration projects in the arid region of Rajasthan is a great problem due to acute scarcity of even drinking water in the region and has to be hauled over long distances of 20 to 30 miles (25).

Extent of Irrigation Tube Wells in India (16)

There were about 2500 tube wells in India prior to 1951, about 2300 of which were in Uttar Pradesh. These tube wells irrigated about a million acres. The first plan provided for the construction of 2650 tube wells under the Indo-U.S. Technical Cooperation Program, 700 tube wells under the grow more food program and 2480 tube wells in the development plan of the states. The number of tube wells to be constructed in different states and the progress made up to the end of 1955 are given below:

State	Indo-U.S. Technical Cooperation Scheme		G.M.F. Program		State plans	
	No. allotted	No.	Allotted	Completed	Allotted	Completed
Bihar	385	378	---	---	424	424
U. P.	1275	1094	420	93	1400	1165
Punjab	530	445	150	---	256	256
PEPSU.	460	369	130	---	---	---
Bombay	---	---	---	---	400	198
Total	2650	2286	700	93	2480	2043

The additional irrigated area by these tube wells will be about 2 million acres on completion and full development.

The program for the second plan provides for the construction of 3581 tube wells. The total outlay on these tube wells will be about Rs. 20 crores (200 million), which has been included in the provision under the minor irrigation program which forms part of the Agriculture Sector, and the irrigation expected therefrom is 916,000 acres.

The distribution of these tube wells by states is shown below:

Name of State	Number of tube wells	Estimated cost Rs. Lakh.	Area to be irrigated ('000 acres)	Approx. no. of exploratory tube well borings
Andhra	---	---	---	25
Assam	50	30	15	15
Bihar	150	10	15	1
Bombay	330	150	66	15
M.P. & Bhopal	98	70	39	30
Madras	300	75	6	50
Orissa	25	20	7	20
Punjab	466	280	77	46
U.P.	1500	1050	485	47
West Bengal	150	100	32	37
PEPSU	292	150	133	5
Rajasthan	50	35	16	5
Saurastra	70	25	14	10
Travancore-Cochin	---	---	---	5
Delhi	50	21.5	8	---
Kutch	---	---	---	10
Pondicherry	50	12.5	3	---
Other areas	---	---	---	14
Total	3581	2029	916	350

FACTORS WHICH HAVE HINDERED DEVELOPMENT

The Committee on planning projects (Minor Irrigation team) New Delhi in 1962 has studied the development of irrigation by tube wells in Punjab and Uttar Pradesh. They found the factors, which have hindered the development of tube wells, as given below (17).

1. Time lag between completion of different items particularly water channels.

It has been observed that a large number of tube wells had to wait for energization for long periods, up to a couple of years. This caused loss of interest on tied up capital on idle tube wells. The benefits from the irrigation potential created also remained unutilized.

Another important lag is on the completion of water transmission or distribution channels. In order to develop irrigation on tube wells it is essential to have well planned lined and unlined water courses. Unless these are done well in time, the development of irrigation is bound to suffer. In fact installing tube wells without providing a proper water distribution system is like opening a shop without a counter. Therefore the team suggested that the channels on tube wells should be treated as an integral part of tube well scheme.

2. Inadequate land and farm preparation. The team suggested that the plans for tube wells should if possible include provision for implementing the land preparation part of the project also. This will ultimately induce farmers to properly utilize water, which is most important on state tube wells.

3. Lack of assured tube well supply. On a number of areas in Punjab, rationing of electrical supply had been imposed. This had made electricity undependable, besides frequent shut downs of power supply and discontinuance of tube well supply. Such a state of affairs naturally comes in the way of tube well irrigation, as the cultivators cannot tolerate the failure of electricity, when need for watering their crops is the greatest. In other words, an irregular and uncertain electricity supply makes tube well irrigation a very risky financial venture. Probably, this will improve when Bhakra Dam Power comes into use.

It is also essential to provide a speedy repair services to deal with mechanical faults and defects, otherwise the tube well will remain out of operation too long and expose the area to unnecessary damage.

4. Reduced discharges. In some tube wells discharges are falling. In others there is sand pumping. It should be possible to put the wells

with reduced discharges and sand pumping in order. Unless this is done, we will not be able to win the confidence of the farmers for tube well irrigation and the tube wells with poor discharge may never succeed.

5. Seasonal variations like abnormal rainfall. Apart from the factors referred to above, there are seasonal variations, which will affect development of tube well irrigation. For example, it is gathered that during the past four years in Punjab, rainfall has been heavier than normal. Abnormally heavy rainfall undoubtedly hinders the development of irrigation.

SUGGESTIONS FOR FURTHER INVESTIGATIONS AND RESEARCH

1. Underground water maps. It is necessary to undertake a scientific study of the sub-soil for the development of ground water resources on a large scale. For this purpose a large number of bore holes in the whole area should be drilled and the underground water-levels should be compared with the topographic map of the area reducing the water surface to the standard reduced levels. These underground maps will indicate the direction of movement of ground water which is of course at right angles to the contour lines and will enable correct estimation of the underground water resources. Such surveys should be carried out at periodic intervals to indicate the effect of tube well pumping, if any, on underground water levels. Tube well pumping is often resorted to lower the water-levels in water logged and salt affected areas by intensive pumping. The effect of this, on lowering of water levels will be clearly brought out by the above mentioned maps.

2. Transmission constant. There is considerable scope in carrying out further research in the methods of determining the transmission constant in the field, especially the non-static method.

In the areas near the east coast, the problem is more complicated as the underground water-levels are affected by the rise and fall of tides, with a certain time lag and in order to design tube wells in such areas the transmission constant of the sub-soil will first have to be determined. Laboratories, especially on the east coast, can develop the technique by a series of observations and correlations.

3. Yield. A tube well engineer is conversant with the traditional methods of boring and obtaining discharge in the usual routine method. Changing the technique for making tube well digging easier and cheaper by direct explosives or by other methods, requires investigation. In advanced countries directed missiles are used for accelerating the digging of wells and it is necessary to keep pace with them to meet the increasing demand for irrigation waters to develop such methods in India also, especially in the southern regions of India which are rocky.

4. Strainers. It is the practice to carry out analysis of different strata of the tube sub-soil and then select the strainer with proper slit width. It is worthwhile that systematic investigations are done in order to find the relation between the slit width, the total area of the opening and the discharge of the tube well. It is generally believed that the larger the area presented to the water, the better the yield. But this will not be the case unless frictional forces through the slits becomes equal to or less than that of the surrounding strata. Qualitatively it is better to present the maximum area to the water front, but quantitative investigations would possibly make the cost of the strainers less if the actual relations are known, and the number of slots required are kept at the minimum.

5. Loss of water in tube well channels. Tube well channels are generally very shallow because they carry small discharges. Annual seepage

from such channels due to hydraulic pressure is very small, but due to capillary action, loss of water can be as much as 40% to 50%. Water gets absorbed into the capillary pores and the area for a few feet away from a channel remains moist. This moisture is drawn from the channel and is very rapidly evaporated from the capillaries of the soil. If the soil is very fine, the capillary affect extends to about 10 ft. away from the channel. It is necessary to find this capillary zone by independent experiments in glass tubes and then take steps to prevent the loss.

6. Lining of tube well channels. Many investigations have been carried out, but the proper type of lining for small channels is still not very satisfactorily solved from the point of durability and cost. Considering the amount of loss of water it is extremely urgent to devise cheap but durable types of lining for tube well channels.

7. Expansion of underground water resources. The eastern part of the Ganga Basin is still to be tapped fully, but with extension of tube well irrigation, these regions will also be tapped in due course. It is necessary to study the subsoil conditions and external investigations so that the underground supply can replace the surface water discharge.

The east coast requires investigation for the direction of flow from or to the sea in the underground water before developing tube wells in that area.

8. Shrouding. Material for shrouding should be carefully selected taking into account the subsoil profiles so that the shrouding material does not get clogged. Besides, the yield of a tube well with shrouding increases due to the indirect increase in the diameter of the tube well. It is worthwhile to carry out investigations in the field as well as the laboratory on these important aspects.

ACKNOWLEDGMENTS

The author wishes to express his gratitude to his major professor, Mr. G. E. Fairbanks and the head of the department Dr. G. H. Larson for their keen criticism and advice in the preparation of this report.

The author is very much thankful to his professors Mr. C. O. Jacobs, Mr. J. W. Funk, Dr. F. W. Smith and Dr. H. S. Jacobs whose human sympathy and interest in the author has been an inspiration and encouragement throughout.

The author is also grateful to Mr. M. B. Phatak, Assistant Professor of Agricultural Engineering, College of Agriculture, Poona, for his valuable timely help in sending the literature concerning the subject. The author would take this opportunity to extend his appreciation to his wife, Indumati Vanjari and daughter Maya Vanjari for their sacrifices, without which this endeavour could not have been accomplished.

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TUBE WELLS FOR IRRIGATION IN INDIA

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AN ABSTRACT OF A MASTER'S REPORT

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

in

Farm Mechanics

Department of Agricultural Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1963

India is an agricultural country. More than 70% of the people are dependent on agriculture. The average annual rainfall in India is 50 inches but due to the unequal distribution and variation in the quantity, incidence and duration from year to year, agriculture is a gamble. Irrigation is necessary in one form or the other for successful farming in all parts of the country where the mean annual rainfall is less than 30 inches. Irrigation is expected to increase from the 70 million acres now irrigated to about 90 million acres by 1966. About 20 million acres of land are irrigated by ground water obtained from wells.

In the Indogangetic Plain, which comprises great, alluvium deposits of recent origin, we find the water depositions in the well defined layers of sand, gravel, clay, limestone etc. All of these layers are porous in varying degrees and allow infiltration of water in more or less quantity. Lateral percolation from the river stream occurs. Ground water is available almost everywhere, even in the Rajastan desert and holes sunk into the water bearing strata yield economic quantities of water. The tube wells have been most popular in this region of the country. In most areas the quality of groundwater is good. Special care needs to be taken in regard to the quality of water present in the soil, however, before installing tube wells.

The flow of water into a well depends upon the draw down, thickness and nature of the water bearing medium, diameter of the well and the radius of the circle of influence.

The construction of a tube well involves: (1) drilling a deep hole of diameters normally ranging from 4 to 24 inches, (2) inserting the casing pipe and strainers, and (3) development of the well. Two distinct systems of drilling holes are followed in India, the percussion system and the rotary system.

The cost of a complete tube well varies from 60,000 to 75,000 Rupees. An average tube well gives a discharge of $1\frac{1}{2}$ c.f.s. with a total lift of approximately 50 feet. The area irrigated by one tube well varies from 250 to 500 acres. Therefore the cost of irrigation from the tube well per acre is less than that from the ordinary shallow well which can only irrigate about 5 acres with a cost of construction of 1500 Rs. However, the cost of irrigation water from tube wells is roughly three times that of flow irrigation. Water rates from canal irrigation vary from crop to crop. With tube well irrigation, the rate is uniform based on water consumption. Attempts are being made to minimize this difference in the cost of irrigation water by supplying electricity at a cheaper rate for tube well operation.

Some factors which have hindered the development of tube wells are: (1) time lag between completion of different items particularly water channels, (2) inadequate land preparation, (3) lack of an assured tube well supply, (4) reduced discharges, and (5) seasonal variations such as abnormal rainfall.

The following topics are suggested for further investigation and research: (1) preparation of water maps, (2) study of transmission constants of different aquifers, (3) study of coastal aquifers, (4) improvement in the digging technique, (5) design of cheap, strong and efficient strainers, (6) lining of water channels and other ways of reducing loss of water in channels, (7) expansion of underground resources by exploring the new areas, and (8) improvement in the shrouding method and material.

Lastly the author feels that if the farmers are fully informed and the water resources of the country are utilized to the fullest extent practicable, India can produce all that is needed to insure progressively improving standards of nutrition for its increasing population. To solve the food problem however it will be necessary to double the area under irrigation within the next 15 to 20 years.