Ground Water

In Hyderabad & Khairpur Divisions

M. H. Panhawar

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HYDERABAD

&

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By

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PREFACE TO SECOND EDITION

The first edition of the book came out in 1964 and went out of print the same year. As theories in the book were based on geology, geography, history, archaeology, chemistry and civil engineering, large scale criticism and controversy was anticipated, but fortunately the specialists in these fields showed appreciation for the work. I had however to wait for voluminous report of Messers Huntings technical services, who had put in above five years work in the same area on ground water. Their report came out in 1966 stating clearly that my ground water maps were remarkably accurate. I had done no detailed work on Nara command. Messers Huntings stated that area along both sides of Nara canal was unsuitable for ground water development. To verify the truth of above statement we had to carry out a two years detailed investigation which showed contrary results as discussed in the additional notes of this book.

Since the first edition did not need any change in text, instead of revising it new findings have been incorporated in additional notes. Due to increase in the number of tube wells, there is more interest in chemical composition of water. For the interest of general reader this aspect has been discussed in details. An experimental wind mill was installed at Tandojam in 1965. After three years study some conclusions about its application could be drawn which have also been incorporated in the additional notes.

The publication had its economic repercussion. The sweet and brackish water areas being well defined tube-wells installation was no longer a chance or gamble. No prior test boring was needed. In six years since the first edition, 2,000 tube-wells have been sunk and interest is on the increase. The price of land in sweet water belt has also shot up.

In the end I must offer my thanks to Mr. M. M. Siddiqui, Director of Agricultural Research for the help extended not only in analysing the samples, but also rendering useful advice. Thanks are also due to M/S Kamal-ud-Din Qureshi, Agricultural Engineer, Khemchand, Assistant Agricultural Engineer and Zulfiquar Ali Khan, Store Officer for their going through the text and proofs. I am also grateful to Mr. W. A. Mirza for full co-operation in publishing the book in the West Pakistan Government Press Khairpur of which he is Manager. Lastly thanks to Mr. Abdul Aziz, Draftsman for preparation of maps, charts and diagrams and to Iqbal Shaikh a well known artist of Hyderabad for designating the cover

Khairpur MOHAMMAD HUSSAIN PANHWAR
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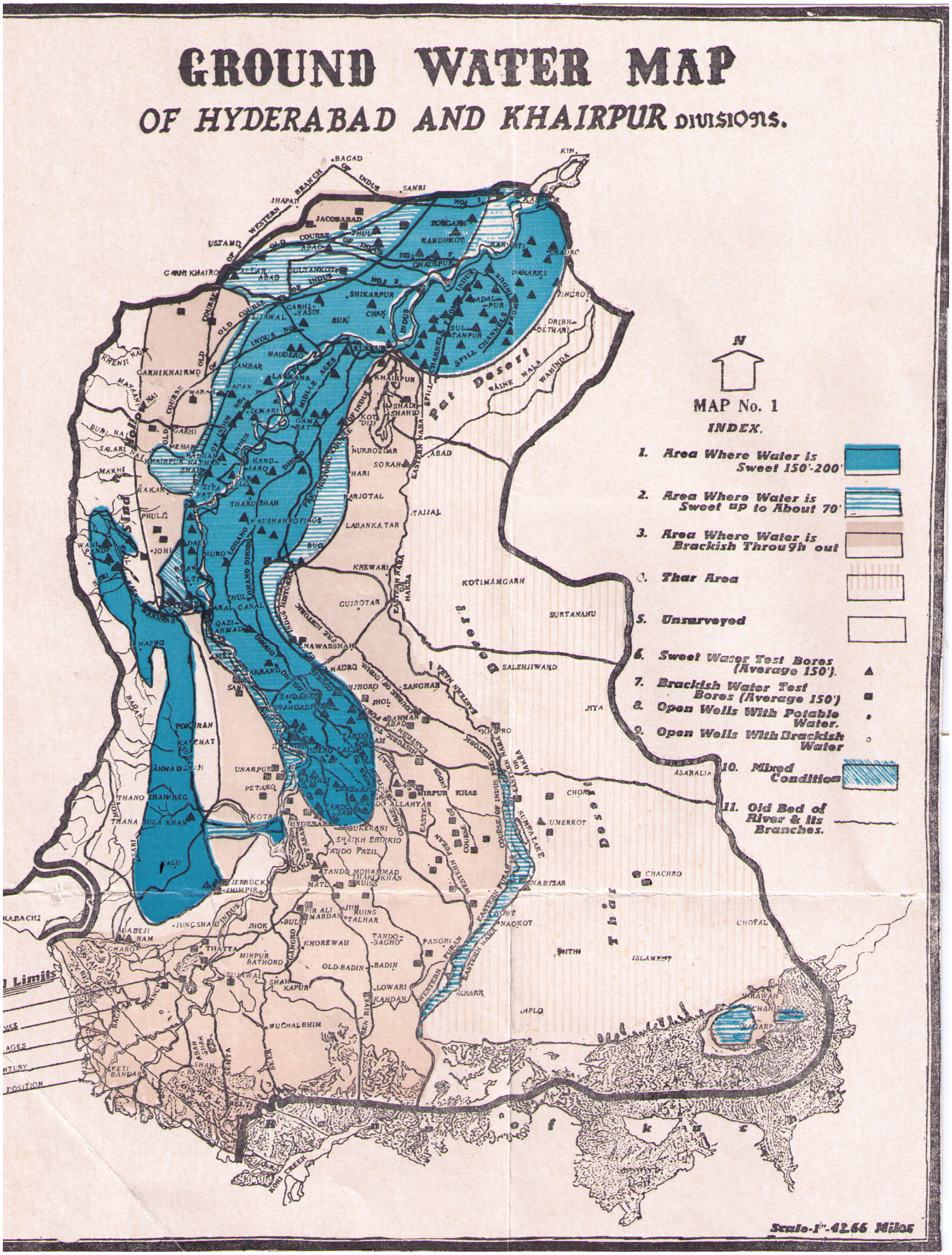
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CHAPTER I
INTRODUCTION

I joined the Sind Agricultural Department as Agricultural Engineer in Sind in 1953. It was part of my job to install, develop and promote tube wells for the purpose of irrigation in this region. That time, one could hardy count one dozen tube wells in the whole area. Since the department was working on commercial basis, we could not carry out any test bores at Government cost. The land owners were not willing, to spend on test bores: being unfamiliar with tube wells, their performance and advantages, they could not be blamed. Only in a few isolated cases, when hard pressed for water, they were willing to invest. Many of the people, interested in water definitely wanted to go in for tube wells, provided somebody assured them of sweet ground water, otherwise their expenses, they felt, would be a waste. This meant that I should do water divining, if I believed in it, and could do so.

In order to have an idea of some broad indications of sweet water, I turned to the writings of O.E. Meinzer, who a quarter of a century ago, had suggested that plants could indicate ground water, and its quality and quantity to some extent. This method could not be applied to the lower Indus Basin (i.e. Hyderabad and Khairpur divisions), because from the irrigated tracts the original plantation had been mercilessly removed, in the early days of the North Western Railway, the locomotives of which used wood as a fuel. Whatever wild growth remained was removed as the development of Sukkur Barrage lands progressed. The new plantation that followed, were the gift of human hand and barrage water and, therefore, could not indicate the ground water conditions. Meinzer had done the work in a climate, which was colder than what prevails in this region, and the plant species he discussed were also different. Applications of that theory, therefore, to this area could not give proper results. His theories could at the best be applied to the desert tract of the region, which in any case, is devoid of high water table and where shrubs showing no leafy growth thrive. Nevertheless, a separate chapter on plants as indicators of ground water has been incorporated in the book. It will definitely be of interest, if some student of botany, in collaboration with agricultural engineering section, started research on this protect and came out with a finding on the relation of various plants to the ground water table, its quality and quantity, in our prevailing conditions and circumstances.

Having failed in this method at least partly, I made an attempt to survey the shallow wells in the region. Shallow wells or the open surface wells, used for Rabi irrigation prior to commencement of Sukkur Barrage, have lost their utility. After 1932, majority of the wells in the Sukkur Barrage area were abandoned. Due to continuous evaporation from them, they show high salinity, which is not representative of the ground water of the area. Some how, a few wells, in some villages, have survived for drinking purposes and have been worked regularly. The depth of these wells, when originally constructed, must not have been more than 6' to 10' below the water table, but with the advent of the Sukkur Barrage, the water table has risen considerably, and some wells, though not cleaned for many years, still contain 20' of water column. The wells, which are still being utilized, show indication of the quality of water, existing only in the shallow depths varying between 20' to 40'. But we were interested in depths of 100' and above, so as to install tube wells giving at least more than a cusec discharge.

At a number of places, people have installed hand pumps, which at times are sixty feet deep, but information about the exact depth is not known even to the owners. From this information, however, I could at least segregate the areas, where one should not look for sweet water at greater depths. It was also seen that the quality of water in general was better, when we moved closer to the river Indus. This made it clear that the sweet water in the region was mainly due to the presence of river Indus, from which, it seems, enormous quantities of water are seeping on both sides. Simultaneously, it occurred to me that in the past when the river changed its courses, it must have diluted the original brackish water on both of its banks, and unless this water is drained out, or encroached upon by the former, these reservoirs could remain intact for centuries. Of course, some of the water from these reservoirs must have been lost due to the transpiration from the plants, but this would only be a very limited quantity, as the trees can send their roots to shallow depths only. There was also a possibility that water from these reservoirs may have seeped out to the sea, but rates of seepage under, normal conditions which exist here, could not exceed a few hundred feet per year. It was worthwhile, therefore, finding out basically the location of river Indus from time to time. Obviously I was not interested in the location of the Indus at the time of Mohenjo-Daro or in 3000 B.C. and before or immediately after. But information about the last 1000 years or so, could definitely be useful and serve as a guide for future, even for other arid zones under similar conditions.

To find out the old beds of the river, it required the study of historic historical geography of Hyderabad and Khairpur divisions, and unfortunately there was lack of information on this subject. Two books, one by Raverty and another by Haig, printed in 1892 and 1894 respectively, were, however, on hand for reference. The former had started under a misconception that Eastern Nara was one time the bed of Sutlej, which he called Mehran of Sind. According to him, Indus with all other rivers of the Punjab discharged into Mehran and all these were the tributaries of the latter. Though a good work, running into 350 pages, its greatest defect was that the author came out with theories, which were discarded at one time or the other, by engineers, hydrologists and historians. Major General Haig, who seems to have been aware of the controversy, limited himself to the investigation of the lower Delta, the portion lying below Hyderabad and now commanded mostly by Ghulam Mohammad Barrage. The latter's work though it has only been partly superseded since, was not of much use for my investigations, because in Ghulam Mohammad Barrage tract ground water is brackish any way. I, therefore, started studying the old beds of river Indus, as I physically saw them existing in different parts of the two divisions, and tried to check them with rare historical books including those of Raverty and Haig. As a cross check, I also examined the contours of these beds and the adjoining areas.

I knew that some useful information could be had from the archaeological sources, and tried to go through their works too.

The work done by Indian Archaeological Department was started nearly a century ago in 1861. In the first phase the policy of the Government was preservation of the old monuments, and the work there under can be called "Monumental Archaeology". During this period, the work produced by Henry Cousens, completed in 1907 and printed in 1929, is the only work worth mentioning for our purpose. He had taken pains to locate ruins of various towns in Sind, and he was a firm believer that the destruction of these old towns in this region could not have been due either to the ill-famed and mostly imaginary tyrant King Dilu Rai, who is popularly believed to have always been running after beautiful maidens, or to the earth-quakes, ascribed to the wrath of God. He felt that most of the towns in this region were destroyed or abandoned due to desertion of the river Indus. From his studies, clues to seine courses of River Indus could thus be had, facilitating further investigations in the problem.

In the second phase of life of the Indian Archaeological Department, the work, which was started in 1902, had behind it the strength, vigour, view, and fore-sight of Lord Curzon, who laid down the aims of the department of archaeology to be "To dig and discover, to classify, reproduce and describe, to copy and decipher and to cherish and conserve". Unfortunately, during this phase, it was the search for classical monuments like Mohenjo-Daro and other sites of pre-historic Indus valley civilization, which claimed the sole attention. Thus the archaeological work done during this period does not help us in our search for the courses of river in historical times. In Thirties, Majumdar, a young archaeologist, started explorations in the Kohistan area between Thano Bula Khan and Shahdadkot, looking for pre-historic sites. His information printed in 1934, has, on the other hand, definitely helped in the understanding of ground water in Kohistan tract.

In the third phase, which started with Wheeler in 1944, new foundations of archaeology were laid down: After the Independence, he became for some time the Director of Archaeology of Pakistan. According to him, the purpose of archaeology is digging up not things, but people. During this phase, however, only one site has been unearthed in this area to date, which too cannot, throw much light on the beds of river Indus. This place; Bharnbhore, is given out to be a small congested trading centre, very populous in its heyday, on the right bank of the very mouth of Gharo, a channel of river Indus then, but so located that it could be considered to be placed, both on the north and the east of the river. It is also believed to be a port, and its importance is thus said to be mainly due to its being a harbour. Historians and travellers have, however, never mentioned such a place (unless it be Debal).

As archaeology could not offer much information, I turned to the classical historians and ancient travellers, who came and visited this area in the past, and whose works were printed during the last century and later translated. It is not necessary to go into the details of their works, but it may be mentioned that most of the Muslim writers like Al-Idrisi, Istakhari and Ibn Haukal were really poor geographers. Ptolemy (150 A.D.) who preceded them by 1000 years, had a better picture of lower Indus basin, than they have left. To these Muslim geographers, the river has either flowed in a perfect straight line, or a perfect circular curve. To them, the distance was measurable in terms of a day's journey, which could really be any thing. Some times they have described the journey in parsangs, the standards of which are neither fixed nor uniform. Though maps drawn by them were inaccurate, they give a good clue to the course of river in 9^{th}, 10^{th} &11^{th} centuries.

During this study, quite a good bit of information was, however, collected about the old beds of the Indus through the region. It was my belief that in arid zones there is always seepage from river, and that this water could remain there for even a thousand years. I, therefore could easily forestall presence of ground water and even make a sort of estimate of its quality and quantity, if I had a firm grip on an old course of the river and the bearings of a particular place on it. In 90% of the cases when actual drilling was done the results were surprisingly closer to those already predicted.

After I958 more and more people got interested in tube wells, and over a period of last five years, we drilled at no less than 800 places in the region with surprisingly good results. Some bores were also put in the rocky area, and after finding success in a few such cases too, the study of geology of western Sind was done in due course to understand the natural formations and behaviour of water in them.

Mr. B.B. Desai, Deputy Director of Agriculture, Sind. (1940) who had been in the Thar desert in connection with the locust campaign, had indicated sweet water supplies in Nagarparkar Area. A survey of the Thar area was therefore undertaken, samples of water collected, analysed and the results plotted on, maps.

On the basis of the data, collected from the bores drilled over a period of five years (1958-63), a ground water map was finally prepared. The map showed that water from Kashmore to Sehwan on the right bank and from Ubauro to Miani Forests (8 miles north of Hyderabad) on the left bank was sweet. The width of this belt varied. A close study of the material in hand, showed that generally speaking wherever Indus had flowed for more than two centuries or so, it left sweet water in a very wide belt, sometimes five miles on either side. Even where the river deserted the place a thousand to twelve hundred years back, the water was sweet. If the river had flowed at a particular place for shorter period, or was a non-perennial channel, flowing in the inundation season only, water was sweet in a narrow belt and to a shallower depth. It was also found that the quality and quantity of water was affected by many other factors, like calcareous and agrillarious formations. Further study revealed, that in the delta area, which has emerged out of sea only recently, the salt contents of the ground water were so high, that the river water had failed to dilute them except to shallow depths, and in a very narrow belt, which was probably not beyond the present protective embankments.

The Sukkur Barrage commands 7.8 million acres of land, out of which only 4.1 million have been put under cultivation so far. The rest of the area is not being cultivated, primarily because of shortage of water, though there are other contributory factors also. In order to increase the intensity from the present more or less 55% to at least the designed intensity of 81%, more water is needed, which could in part be acquired in the shape of ground water. Gudu Barrage is a non-perennial system. Ground water in 90% of area commanded by this barrage on its left Bank, is fit for cultivation. This water could be exploited for Rabi crops.

In the Kohistan area, people depend on grazing of cattle for their livelihood. They are nomads in the true sense, and there are no permanent villages or towns worth the name. With location of sweet water in that area, permanent settlements could be established. Nagarparkar is another area having great potential of ground water development.

The occurrence of ground water in any area depends on the geological and geographical conditions. The quality of water is affected by the salt contents of the geological deposits and the drainability of the area. The geography of area governs the subsequent flow of water over the surface, the rate of evaporation, transpiration and percolation in the ground. The original water, therefore, slowly keeps changing, depending on in-take and off-take.

Geographically, Hyderabad and Khairpur divisions are divided into three main areas. Geologically also the region in general, is divided in the same three groups—the geology of each group being different from the other. These three groups occupy approximately 1/3rd of the area of each of the two Divisions. In the following chapters, these groups are separately discussed in details.

Wind is a natural energy potential, which can be utilised to some extent, in drawing ground water in some parts of Hyderabad division. The subject is discussed in a separate chapter.

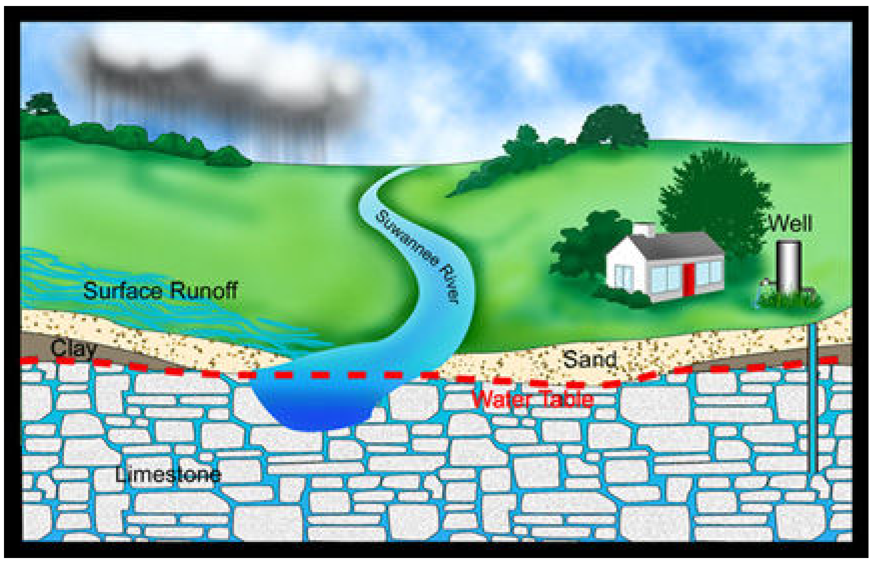
Before concluding the introductory paragraphs, I must offer thanks to Mr. Mohammad Ibrahim Joyo, Hon. Secretary of the Sindhi Adabi Board, who very kindly supplied me with a press copy of Lambrick's book "History of Sind" Vol. I, still under print. This book helped me a great deal in giving last touches to my studies of the courses of river Indus through the ages. I feel deeply indebted to the learned author of this book for this. My thanks are also due to the staff members of Agricultural Engineering Section, who collected information for me on ground water wherever they went for a visit. My thanks are also due to the following libraries for lending me the use of their books on history, archacology and other allied subjects

1. Sind Provincial Library, Hyderabad,
2. Sind University Library, Hyderabad.
3. Frere Hall Library, Karachi.
4. Liaquat National Library, Karachi.
5. Library of Geological Department of the Universoty of Punjab.

I also thank Mr. Syed Ahsan Ali Shah, Controller of Examinations, Board of Intermediate and Secondary Education, Hyderabad, and my friend Mr. Joyo, for checking the manuscript and doing its proof reading as it went through the Press.

CHAPTER II
THE KOHISTAN AREA

In the geological times a mighty river named Siwalik was flowing from the present Assam westwards to Potwar, where it changed its course and ended in the present Arabian sea. The river brought lot of gravel, silt and sand with it, which was deposited in the lndo-Gangetic plains. However, the Potwar area slowly rose up, and in time, the river changed its course eastwards. The western part was taken over by the Indus and its tributaries.



About 60 million years back, the Cretaceous rocks in the Laki range rose, throwing up the present lower Dadu district from the Tethys sea. This happened when Himalayas had not risen above the ground. When Himalayas started rising, the river Indus went on cutting them like a saw and maintained its original level. The Alluvial plains of this region, which then were under the sea, slowly started silting up by finer material brought by river than already deposited. Due to this, if we dig 15', 20' or 30' below the ground level, we find sand layers. The top layers were deposited later on. The top material was brought partly by the river and partly by inundating rocks of Kohistan.

The geologists, geographers and archaeologists agree that it was not river Indus alone but possibly Jamuna in late geological times, and some portion of waters of Sutlej, which flowed through the lower Indus plains. This water passed through the river called Nara or Hakra and was flowing through the lower Indus plains, as late as thirteenth century.

During this epoch, the Kohistan hills took the shape which belongs to different geological periods. These rocks are classified as under:-

(i) *Manchhar Series:*—Gray sand stones:- Extending from Shahdadkot taluka through Manchhar lake, valley of Baran river to Thano Bula Khan.

(ii) (a) *Nari Calcareous rock series:*—Starting from Kute-ji-Kabar to the West of Manchhar lake, and down to Hub river in Karachi District.

(b) *Nari Gray sand stone:* Which extend from Nari river to Laki range, upper Baran river and lower portions of ground from Thano Bula Khan to Junghshahi.

(c) *Nari Lime Stone:*—Found at Kute-ji-Kabar and northern Khirthar range.

(iii) *Khirthar Range white lime stone:*— Found along the main axis of Khirthar and Laki ranges. The shally layers at Meting and Jherruck belong to this class. Makli, Pir-Patho and Aban Shah hills, also belong to the same class.

(iv) *Ranikot sand stones:*— Around Ranikot and plains of Leilan.

(v) *Deccan Trap Basalt Rocks:*—Found in some parts of Laki range.

Thus it will be seen that the entire area is covered with rocks of different classes belonging to different geological periods.

Lime stones contain calcium salts soluble in water, and therefore they usually contain brackish water, unless their cracks and fissures are big enough to allow quick passage of water through them or the lime stone is pure and not impregnated with salts and does not decompose fast. Basalt usually gives fresh water supply and is not soluble in water. The sand stones being porous, will normally hold water, and in Kohistan area sweet water is mostly associated with sand stones.

The Khirthar range in its upper portions, being made of lime stone, contains brackish water, except in a narrow strip of Nari range in Kambar and Kakar Talukas. In its central portions i.e., around western Johi, the Khirthar rocks themselves contain brackish water, but down in the valley, along the Nari Series, the water is sweet partly because the river Gaj is traversing its whole length, and partly because down below lie sand stones. The Agriculture department has installed some tube-wells in this latter area at Wahi Pandhi and Thano Bala Khan and have found sweet water.

Below Manchhar, the rocks run in parallel ridges which, at places, are 25 miles apart. The valley is made of either Nari or Manchhar sand-stones. This area is also traversed by a number of *Nais* namely, Naing, Baran, Suk, Mari, Mol, Sari, Kalu and upper reaches of Malir. These rainfed rivers are responsible for seepage of some water in the ground, adding to the water table. In this zone, as indicated in Maps No. I and 7, chances of getting sweet water are quite bright. The prospects are further explained in connection with Thatta, Dadu, and Larkana districts.

CHAPTER III
ALLUVIAL OR LOWER INDUS PLAINS

This zone is formed by the silt deposited by the old rivers. The Siwalik may have contributed to lower beds only, but upper beds are formed in recent and sub-recent geological times. The formations could in brief be described into three categories:-

(a) *Old Alluvial,* which is in general on the west of the bed of Western Nara. Though the silt from Indus is responsible for its formation, the denudating Khirthar rocks are also a contributory factor to this alluvial.

(b) *Sub-recent formations,* about 200,000 to 400,000 years old, which are somewhat younger than the formation. (i) In general, the area above Hyderabad is of sub-recent formation.

(c) Recent formations, not more than 100,000 years old, and which have emerged from shallow sea (possibly Rann of Kuchh) very recently, and some parts below the line connecting Thatta, Badin and Gujo as late as last 5000 years. The rivers responsible for the formations are Indus, since geological times; Jamuna, till recent geological times; and Sutlej with whole of its volume till pre-historic times and partially till 13th century.

The rivers bring silt with them, which is partly deposited in their bed and the sides, and the rest is discharged into the sea at the delta, where it slowly raises the sea bed, emerging new land. The silt carried by river Indus in the high flood of about 100 days is calculated as 6%. The silt slowly raises the valley and the river starts moving on the ridge. Once the ridge is formed, unless controlled artificially, the river moves off the ridge, forming another ridge and so on, raising the general level of the country. The river Indus has changed its course from one end of plains to the other throughout the ages, and at none of the times has it kept the same course for very long.

A study of contours of the plains will clearly indicate the courses the river has taken through the ages. Flying over the valley one can easily see the winding courses of the old beds. The excavations at Mohenjo-Daro have clearly indicated a surface rise of 13 ft. in 5000 years i.e. approximately 7" per century. The rise near the river bed is much more, say 12" per century, and further away from it, it is much less.

Water from the rivers seeps into the ground in the arid zones and accumulates there for long times. The movement of the ground water under natural conditions is very slow, depending on permeability of the ground. It could be as low as 3' per year. A few hundred feet per annum may be considered as a good average. Under natural conditions in medium and fine sand stratas as we have, and with such a poor drainability, the water left by a river may remain there for many centuries, till it is either drained away, or diluted by brackish water from the surroundings. With this theory in mind, I started with study of different courses of Indus, and Hakra or Eastern Nara as they were changing courses in historical times, through this region. The study revealed that in addition to these two rivers, there was a branch of river Indus (I should call it Western Nara for convenience sake), which, in pre-historic times even, took off from the river north of Kashmore, and in historical times first below Kashmore and then opposite to Gauspur, and in the recent times, 25 miles below Bakhar, and in the early part of this century, 8 miles north of Larkana.

This stream flowed sometimes as one branch and at other times as two branches. The western-most branch flowed to Manchhar through Sind Hollow starting from Ghari Khairo, and the other ran its course close to the present Western Nara (abandoned in 1932, after Sukkur Barrage), which also ended in Manchhar. From there, the two offshoots re-discharged their water in the Indus via Aral canal. These branches of the river, whose position at different historical times has been explained in chapters IV and V, were responsible for seepage of water in the ground. Unfortunately, both Eastern and Western Naras were non-perennial, particularly the former, which in historic times was carrying spill waters of Indus and Sutiej. They also did not carry very big volumes of water as the main river, Another unfortunate factor was that they passed through the alluvial which contained calcareous materials, with the result that their diluting effect on the ground water below was not adequate, and in the dry season, when they partly acted as seepage channels, they were rather draining their original water. The Eastern Nara had practically ceased to flow even in the inundation season for nearly 600 years since its drying up in 1226. Only in 1859 it was converted into a perennial canal. The Western Nara and least kept flowing till 1932. It was a branch used for navigation in the inundation se son as late as 1840.

From the above data, it is obvious that one could look, with a reasonable amount of confidence, for sweet water along the Indus and both the Eastern and Western Maras. And, nearly 800 test bores carried out in the defined areas during the last 5 years have definitely strengthened the theory that along old beds of old rivers sweet water could be located. The matter is discussed in details in subsequent chapters. However, it may here be affirmed that: -

(i) On the left bank of the river, from Ubauro upto Miani forest, in a width of about 20 miles (With a few exceptions for which there are special reasons), ground water upto the depth of 200' or even more at many places, is fit for cultivation.

(ii) On the right bark of river Indus, from Kandhkot upto Sehwan, water is sweet in depth varying from 125' to 200', in a width of even 25 miles north of Sukkur, and to a width of only 10 miles in Dada district.

The reason for this variation on the left and the right bank is that the river has really not westerned much beyond the present location in historical times at least except north-west of Sukkur where water is sweet, upto the width of 25 miles or so. In the case of left bank, the river has slowly moved west wards by about 20 miles, during the last 2000 years, thereby creating better conditions.

(iii) Along the ridge of Western Nara, which perhaps was always non-perennial, water is sweet only in depth of 30' to 70' and to the width of a few miles on either side.

(iv) In the case of Eastern Nara, whose bed was denied water by the river 700 years back, sweet water can be located only in a thin strip of about one or two miles, on either side, to a very shallow depth and perhaps not more than 70' at some isolated places only.

On the basis of the test bores carried out, a ground water map has been prepared (see Map I). This happens to coincide, except in a few points, with the old beds of river Indus and its branches. The total area in the Alluvial plains, where water is fit for deep tube wells (125' and above) will roughly be 6000 sq. miles.

The chapter that follows deals with the details relating to the changing beds of river Indus and its branches, in the region.

It would thus be clear that sweet water in the region is mainly the outcome of seepage from the river and its branches, in the historic times.

CHAPTER IV
DIFFERENT COURSES OF RIVER INDUS IN HISTORICAL TIMES

1. The search for old beds of River Indus based on historical and scientific lines started when General Cunningham, Director Archaeological Survey of India, started following the route of the traveller Hiun Tsiang (Yuan Chwang) of 7th century A.D. His search resulted in the location of a large number of Buddhist stupas. He produced a map of old course of river Indus & its tributaries 1871. He thought that Eastern Nara was the bed of river Indus. His predecessors like Mcmurdo, Burnes and Pottinger, who had visited this area before the British conquest, were of the same opinion, though J.G. Fife, the Superintending Engineer then, who surveyed Eastern Nara in the mid-fifties of last century, thought that it was merely a spill channel fed by Indus.

2. In 1874, C.F. Oldham of Survey of India wrote in Calcutta Review (Vol. CXII) that Sutlej was discharging in the bed of Eastern Nara, and continued to do so till about the first quarter of 13th century, and that the Eastern Nara was not the bed of river Indus.

3. Another anonymous writer, preferring for himself the name of Nearchus (the name of Alexander's General who had written details of his voyage), stated (Calcutta Review Vol. LX, 1875) that Sutlej never flowed into Hakra or Nara, but flowed westwards directly into Indus. It was Jamuna instead that once flowed westwards and fed Hakra . He supported the view that east of Rohr', Indus passed through the bed of Nara.

4. In 1887 A.D., Oldham of Geological Survey of India, who was familiar with behavior of rivers and hydrology, said that Indus could not have flowed into Eastern Nara at all. It was Jamuna in recent geological times' and Sutlej later on, that fed Eastern Nara.

5. On this topic, Raverty wrote "Mehran of Sind and its Tributaries" in the Journal of Asiatic Society of Bengal-1892, which ran into 350 pages. His theory was that Eastern Nara or Hakra was the main river in which Sutlej and other Ambala streams were discharging in Eastern Punjab area, and Indus too, carrying the combined waters of Jhelum, Chenab, Ravi and Beas discharged in it, below present Khanpur (in Bahawalpur division) at the time of Arab conquest. He names the Eastern Nara as Mehran and calls the Indus as its tributary. He supported his theories with historical references, and indicated the position of rivers in this region at six different periods.

Though his theory is completely incorrect, the information and historical evidence collected by him has been most useful to future writers of historical-geography, history and archaeology of the region.

6. In 1887, Major General Haig wrote chapters I and II of his "Indus the Delta Country" and traced the route of Alexander's march through lower parts of previous province of Sind. In 1894, his complete book "Indus the Delta Country" was printed, which covered the courses of Indus in delta area from Alexander's times upto the times of the British conquest of Sind. He knew the controversy that had arisen on the Eastern Nara and successfully avoided touching the northern area of this region and only dealt with deltaic region south of Hyderabad, but he too believed that Eastern Nara was the bed of river Indus.

Though the course traced by him about Alexander's route, today stands completely superseded, the rest of his chapters give valuable information, and his map of delta country, except in a few particulars, remains unmatched.

7. Col. Minchin and J.N. Barnes, in 1904, after study of physiography of Bahawalpur state, concluded that bed of Hakra was too narrow to have carried whole of Sutlej water through it. They were the first to suggest that flood waters of Sutlej and Indus escaped into Hakra in the inundation season. However, their theory did not make it clear how then such a uniform bed was formed.

8. Henry Cousens, whose work "Antiquities of Sind," completed in 1907, was printed in 1929, had done quite a considerable archaeological exploration in this region, which caused him to believe, that, at the time of Arab conquest in 711 AD., old course of the river was between the river's present course and the Eastern Nara. This is a major deviation from Raverty's theory. Cousens however did not involve himself into Sutlej-Nara controversy, and made use of Haig and Raverty's writings only wherever they suited his archaeological sense, but he too, somehow, believed that Nara was one time the bed of Sutlej.

According to his map, the river Indus, at the time of Arab conquest, passed between the following modern towns: To the West—Kandiaro, Tharushah, Naushahro, Nurpur, Tando Adam, Shahdadpur, Thul-Mir-Rukhan (14 miles south-west of Bandhi Railway station and 8 miles south-east of Daulatpur), and towards its east were Pad-idan and Kot-Lalu. The towns of Kingri (in Khairpur district) and Sakrand were just on the river.

9. In 1932, Mr. Whitehead in an article printed in the Indian Antiquary (Vol. LXI-1932), concluded, on the basis of hydrological data of the Punjab rivers, that river like Sutlej could not have oscillated 70-80 miles. According to him, Hakra or Nara dried up due to diminished rainfall in the Punjab and consequent loss of Ambala streams. He located a large number of ruins of old towns on the bed of this river extending almost to Delhi.

10. Sir Aurel Stein of Archaeological Department in his article (in 1942), after study of a number of sites in Bikanir and Ambala, came out with a theory that the mighty Ghaghar or Hakra at one time carried combined waters of a number of streams including

one or two branches of Sutlej river in Bahawalpur state and those- of a channel of Indus, through Aror gap near Rohri.

11. From the study of Sir Aurel Stein and Whitehead's theory, it can be concluded that Hakra was the original bed of River Jamuna in recent geological times, and later on, it was being supplied by rain-fed streams (or small rivers) like Ghaghar, Thangri, Saraswati, Drishad,Wadi, Wahund or Rainee and Markanda. The spill water from Sutlej also supplied water to Hakra every season and so did the Indus from Panjnad to Bakhar. Its drying up could be attributed to decline in rain fall, which definitely was caused by excessive deforestation in Bikanir and Ambala and also due to un-controlled grazing.

There is even evidence of a rainfed stream from Jaisalmir joining eastern Nara near Khipro. Several *dhands i*n Khipro Taluka are proof of this. It is also certain that Indus had never flowed through the bed of Nara, and if it had done, the river could not have westerned without silting up the low line through which Hakra passes.

On the basis of available research the following paragraphs may finally be laid down on this highly absorbing subject of the bed of river Indus as it must have been in the historical times.

It is impossible to trace out the pre-historic location of river Indus, but it would suffice to say that Indus flooded Mohenjo-Daro at least three times if not more, and so was the case with Naru Daro and Chhanhi-jo-Daro.

INDUS IN ALEXANDER'S TIMES (327 B.C.)

12. The Indus passed north-west of Sukkur close to Ghauspur, north of Shikarpur, and down south to Ruk. It then crossed the present course of river and was practically running parallel to it at a distance of about 18-20 miles east of it, till it reached Patala the then capital of Sind, a place in southern Nawabshah Taluka, but not much to the east of Shahdadpur, where delta head started. Here, one branch turned south-east and the other southwest. The former ended in the sea possibly by present Western Duran, and the western branch again bifurcated into two near present Tando Mohammad Khan—one branch going down south, and the other to the west, above Makli hills, into the sea. The hill on which Gujo stands was probably close to the sea coast. The hills eleven miles south of Pir Patho, now on left bank, and called Aban Shah hills, were an island in the sea where Alexander had landed. These hills are now 75' above the surrounding land and 1½ miles long.

There was a channel of the western branch of Indus, which is described as course No. I of the western branch of river Indus in the next chapter. This channel certainly issued somewhere in Jacobabad district and went down to Shikarpur, where it took southern course to Ghari Yasin, Mirokhan, Mahota and Warah etc., and finally to Manchar, wherefrom it made a loop south-east to meet the main channel mid-way between Sehwan and Patala. The loop channel must have been Aral.

INDUS IN 150 A.D AT TIME OF PTOLEMY'S VISIT

13. Ptolemy, a geographer, who came to India about 150 A.D., wrote about two branches of Indus: one which passed below Kashmore, probably near Ghauspur, then south of Jacobabad and near Garhi Khairo and ended in the western depression or Sind Hollow, which drained to Manchhar lake. This branch also got water from flood streams of the Bolan river of Baluchistan.

The other stream also took off from Indus, west towards Arbita (Khirthar) mountains. This might have been the Western Nara or Ghar. One of these streams, by which he probably meant Western Nara, joined the main river above Patala, the then Sind capital. This must have been via Aral below Sehwan.

INDUS IN SEVENTH CENTURY AT THE TIME OF YUAN CHWANG'S VISIT AND DURING THE TIMES OF CHACH

14. In the upper reaches, there was not much change since Ptolemy's visit, except that the river had westerned somewhat, and was closer by another couple of miles. In 632 A.D., the river passed near Dahiyat (Dehat) 17 miles east of present course. Chach crossed the river near this place to suppress at revolt. The place is situated on northern border of Kandiaro taluka and the old bed is visible here. Below Bahmanabad .(possibly old Patala), it bifurcated into two branches, the south-east branch met the Eastern Nara just below Naukot and the western branch flowed to Debal. The Eastern Nara continued to flow possibly as a non-perennial river.

The western branch (Western Nara) is not mentioned, but cannot have been non-existent because important Buddhist stupas existed near Badah and Dhamraho which must have been on it. Sehwan also survived, which could depend, for its water and food supplies, on this branch.

INDUS AT THE TIME OF ARAB CONQUEST (8TH CENTURY)

15. For this period, I believe Henry Cousens' map, with slight modifications, could give a fair picture.

The Indus then was only a couple of miles west of Mirpur-Mathelo. Further south above Bakhar, it turned south-west, then headed south passing close to present. Sukkur on its west, then through Lohano Dhoro which was 5-6 miles west of Kot Deji, 10 miles west of Kot Lalu, 2-3 miles east of Naushaharo, 3 miles east of Thul Rukan, about 10-20 miles east of Sehwan (at both these places there are abandoned beds of the river), 2 miles east of Sakrand, and 16 miles east of Nerun or Hyderabad. Hala was on the west of the river. The water for Nerun (Hyderabad) came by a channel in the inundation season and was possibly stored in some lake or depression, as the ground water was brackish around Hyderabad. The general course of the river was about 17 miles east of its present course in Kandiaro Taluka, as in previous century. Mansura built on the site of Bahmanabad is in line with the Lohano Dhoro.

The western branch took off mid-way between Mathelo and Alore and followed the usual course to Sehwan, wherefrom it made a south-eastern bend to meet the river near about Sakrand. Sehwan was about 10-20 miles west of the river. There are old beds at both these places. A branch took off from near Sakrand (probably Western Puran), supplying water eastwards to Bahmanabad and Mirpurkhas (Dhaliya) or Kahu-joDaro and discharging in eastern Nara about 30 miles south of Naukot. A central branch took off the river, 13 miles below Sakrand and had important towns like Bahrur (Tharri) and Rawar (Talhar) on it.

The third and western branch taking off below the level of Matli from the central stream, had Debal on it. One branch (or a delta mouth) of the river passed through Deh Bukerani or Kakar Bukera, which, according to "Chach Nama" was assigned to a certain chief for his maintenance, by Governor of Debal. This bed is still traceable through that Deh.

It appears from Arab writings that the main stream of Indus flowed through Aror (Alore) by about 950 A.D. The Aror gap through which the Nara canal passes is just too small to allow the large volume of river water to pass through it. It was either a small spill-channel of the river or a stream but not the river Indus, which was then flowing north-west of Sukkur. This channel seems to have deserted Alore by about 950 A.D.

One important change that seems to have occurred during this period was destruction of Bahmanabad, (probably due to an earthquake according to Henry Cousens), and Mansura a new capital was built on its site in the year of 734-735 A.D., named after the abasside Khalif Mansur.

INDUS IN THE 9TH AND 10TH CENTURY

16. As stated in the introduction of the book, it is difficult to rely upon the Arab maps and the location of towns etc. mentioned by these writers. Al-lstakhri (951 A.D.) and Ibn Haukal (960 A.D.) were the two Arab geographers who wrote in the 2nd half of the 10th century. From their writings quoted by various authors with their own interpretations, it appears that Indus was flowing north west of Sukkur, where it made a loop south-east to Lohano Doro (about 17 miles east of present channel), but at a place known as Kalari about 40 miles north of Mansura, the river bifurcated into two branches, to meet again below Mansura. This channel must have started somewhere opposite present Moro, made a loop west-wards reaching to the proximity of Sehwan, (though not less than 7 miles and more than 10 miles close to it) and united with the main stream 12 miles below Mansura where the delta head started. The main south-eastern channel must have passed .15 miles, or more, south of Umerkot (then Amarkot) into Hakra, which at that time was flowing as a separate river. From there it passed to the sea via Koree creek.

The western branch passed to Debal which, in Ibn-Haukal's words, in 961 A.D., was a confined place, but for the sake of trade, people took their dwellings there. From this description Bambhore may probably be Debal. It is a small harbour and is congested.

(No other harbour except Lahori, which belongs to late perk has even casually been mentioned by Arab writers).

In the upper reaches, the branch of the river, which passed through Alor gap, possibly silted up leaving the Alor without water, and this town was no longer mentioned after the 10th century. Hyderabad was on the west of Indus and so was Hala.

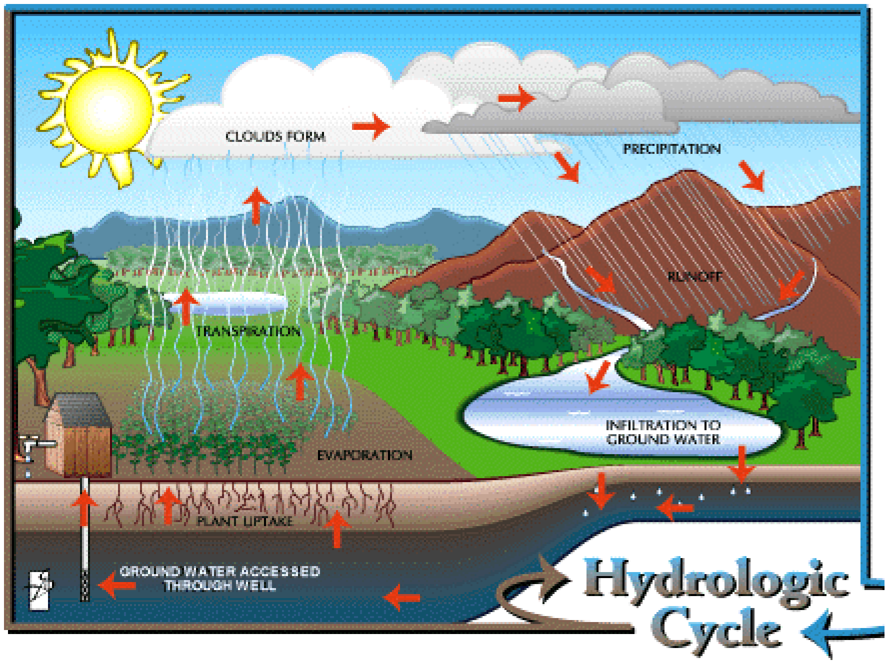
The main branch still continued to flow practically through the old course, i.e. it left between Kashmore and Ghauspur towards north of Shikarpur, then down to Ruk where it made a turn east-wards, and, after wandering in Khairpur District, passed into Lohano Dhoro. Still another western branch took off from it, passed near Jagan between Shikarpur and Jacobabad and reached Sind Hollow near Ghari Khairo. (This channel was later on utilized for what is known as Begari canal now).

South of Ghari-Khairo it passed to Manchar via Sind Hollow, wherefrom it discharged in the main stream via Aral, taking south-eastern direction and meeting the Indus, many miles down stream. Sehwan at this time was at least 16 miles west of the main channel.

A COURSE OF RIVER INDUS IN THE 11 TH AND 12TH CENTURY

17. During 11th century two Arab writers visited Sind, namely Alberuni (937-1048) and Al-Idrisi. The former had lived in India, and studied Sanskrit. He was comparatively scientific in his investigations. The latter has been considered a better geographer than his predecessors of the previous century. From their accounts it appears that there was not much of a change in the course of the river during the previous two centuries. According to Al-Beruni, the united waters of Punjab meeting at Panjnad bent west-wards from the city of Alor (He means between Alor and Kashmore) and were received in "Nahr-i-Mehran" (through the famous Lohano Dhoro), which flowed through the midst of the country (as it actually did) and formed a number of islands, till it reached Mansuriyat (Mansura or Bahmanabad). One such island between Kalari and Mansura was also described by the geographers lbn-Haukal and Ishtakhri.

The city (Mansura) is situated among two branches of the river. The united waters reach sea by two branches the first westwards to Lahori Bunder, and the other bends towards east, in the confines of Kuchh, there called "Sind Sager." Al-ldrisi puts Mansura on the west of the main branch of Indus. This shows another hydrological change during this century.



As regards Alor, Al-ldrisi says that this town was to the east of the river. This was also a hydrological change which deprived. Eastern Nara of part of Indus waters passing through Alor gap.

At delta head, the route taken by the eastern branch was probably the same as taken at the time of Arab conquest (possibly Western Puran), when it met Eastern Nara some 20 miles south of Naukot. This was the main branch of the river, and was in the Sumra territory.

On the western branch Lahori seems to be gaining more importance as compared to Debal, as a harbour.

The first Sumra capital, Tharri, was on the main branch of the Indus, called the Western Puran. The ruins of this town are 6 miles south by west of Mohbat Dero in Matli Taluka. This capital town was built in early 10th century and was abandoned later on, and a new Sumra capital, Mohd. Tur, was built (probably in 13th century on Gungro branch, as by that time Indus seems to ha deserted the Western Puran as its main branch.

As regards the Sind Hollow, Al-Idrisi has pointed out that the tract to the west of Indus i.e. south of present Shahdadkot to Manchar, was full of lakes, depressions and *dhands,* In his words he calls it "marshy area in the west (from Kashmore) to Sewistan". This clearly shows that the western branch was definitely flowing through that area the same way as it did before, in previous two centuries or later on.

CHANGES IN THE COURSE OF INDUS US IN THE 13TH CENTURY

18. The most prominent change in river Indus was its passing through Bakhar gorge, in the last years of 12th century or early 13th century. How Indus carve to occupy

this place, and why it passes through this gorge and has never abandoned it since, looks mysterious. The reason is that the river brings silt which is deposited in its bed and on sides, raising its level. In due course of time it starts flowing on a ridge. Once the ridge is formed, the river soon breaks away from it and takes to lower, area which again gets silted up and elevated in its turn. Thus time was reached when the area upstream of Bakhar got silted up above the level of the gorge. At Bakhar gorge there is a sudden fall (depth 60' as compared to 20'-24' normal river bed, during high floods). So the river came to occupy a permanent position, wherefrom it could not escape for centuries. The main stream of Indus having thus passed through the Bakhar gorge for the first time joined Lohano Dhoro slightly down below.

Sultan Muizud-Din Muhammad-i-Sam of Ghazni invaded Sind in 1177-78 A.D. and passed via Indus, but Bakhar is not mentioned. Later on in the days of Malik Nasir-uddin Kabaja (1205-1227 A.D.), Bakhar had become a strong fortress. In 1333-34 A.D., when Ibn-Battuta visited Sind, he wrote that Bakhar divides a branch of Indus in two parts, the one being a western one, by which he had gone to Sewistan or Sehwan. The fortress at Bakhar was re-inforced by Mirza Shah Beg Argun in 1558-59 A.D., from the old materials of Alor fort.

The western branch (Western Nara or some other channel) continued to flow, but its volume was definitely reduced, and was probably then only a seasonal channel it continued down south, and south of Sehwan via Aral joined the main stream. The Aral definitely took south-eastern direction. The river probably was 10 miles east of its present course at this point. In 1297-98 A.D., when Sultan Saldae the Moghul invaded Sind, Sultan Allaud Din's son Nusrat Khan, the ruler of Multan, Uch (Bahawalpur Div.), Sehwan and Bakhar, took his troops to Sehwan via river. This does not mean that Sehwan was on the river then. This Sultan either came along the Western course or came up-stream to Sehwan, via Aral. Mir Masum saw the same river about 6 Kuroh (7 miles) west of Sehwan in 1585. However, possibility of its being very close to Sehwan also cannot be ruled out as old Pat and Talti were not on the right bank but on the left bank of river Indus, in 1541 A.D., at the time of Humayun's flight to Sind, and that being so, the river could have been closer to Sehwan at least in 1541 A D.

At delta head which no longer was near Mansura the Arab Capital (which was not heard of since the 2nd decade of 13th century, and in the next century was already in ruins) but was much down below, the river took two channels, one eastern called Western Puran, which joined Eastern Nara or Hakra, and another took a western course. The spill water from Indus did not flow into Hakra or flowed less, and so did Sutlej, resulting at least in partial drying up of Hakra or Eastern Nara, on which depended prosperity of south eastern part of this region, the stronghold of Sumras. This resulted in decrease of their power in that area, as a consequence of which they lost Umerkot to Sodas in 1226 A.D. The Hakra however kept flowing only partially from occasional overspills of Sutlej and Indus till the 16th century.

Of these two, the western branch took more water than the eastern branch, the Puran and therefore Sumras shifted their capital from Tharri (onWestern Puran) to

Mohammad Tur (Shah Kapur) on Gungro channel, which may have been the river's main stream to the sea then. This town was sacked by Allauddin Khilji around 1299-1301. However, one branch of Indus was definitely passing through Debal in this century.

In the last quarter of 12th century, Sultan Jalaluddin Khurasani took over Debal, sacked it and acquired wealth. The same Sultan took shelter in Debal in 1223 A.D., when chased by Changiz Khan. Debal is however not heard of, since then. lbn-Battuta who travelled through this area in 1333-34 A.D., never mentioned it, proving that the river probably had already deserted it.

From the above it is clear that during this century the river had westwarded more. It was passing through Bakhar, and was closer to the present course of Indus than in the previous centuries. The delta head was much below Mansura. Mansura seems to have decayed in the first half of 13th century. The date is not known but should coincide with shifting of Sumras' capital from Tharri to Mohammad Tur. This seems to be an important hydrological change of the century. However Henry Cousens believed that Mansura was destroyed by Sumras who sacked it. The Sumras may even have sacked Debal which was no longer heard of, in the next century. The western branches of the river like Ren, Gungro and Baghar had established themselves, at the cost of Western Puran and new towns like Fatehbagh, Jun and Lahori, were getting more importance.

The western branch of Indus passing through Sind Hollow, down to Manchar still survived. Lahori *Bunder* mentioned by Al-Beruni existed in this century, and was possibly on Baghar.

INDUS IN THE 14TH CENTURY

19. Some more revolutionary changes seem to have taken place in the course of Indus during this century.

The river seems to have established its course north of Makli hills, when Samas built their capital, Samui three miles northwest of present Thatta in years about 1338-40 A.D. Kalri was the main stream then, and Baghar a secondary stream, though definitely perennial, as Lahori *Bunder* was on it. The bifurcation now took place 10-12 miles east of Thatta, which point some years earlier was between Jhok and Bulri, where the beds are still traceable.

The river along Kalri or Baghar branch had not quite established itself, by cutting its bed deep enough. Sultan Feroz Shah (1351 A.D.) who attempted to attack Thatta from Baghar side (south-west), finding the river too wide sent forces up-stream to attack from Kalri side (northwest), and even here the river was too wide. Kalri remained the main channel till 1519.

The Ren and Gungro continued to flow. In the early part of this century Samas seem to have over-thrown the Sumras. The main reason for their loss of power probably was the change in the course of the river west-wards, which rendered the eastern parts of their country desolate and led to the weakening of their power.

Debal seems to have been deserted by the river by this time for good, and has not been mentioned by Ibn-Battuta, who visited Lahori Bunder in 1333-34 A.D.

In the central area, the river flowed 16 miles east of Hyderabad near Nasarpur, a town established under that name by Sultan Feroz Shah, ruler of Delhi in 1350 A.D.

To the north of Bakhar, the Western branch of Indus took off south of Kashmore, following its usual course to Manchar and met the main stream south-east of Sehwan.

INDUS IN THE 16TH CENTURY

(in 1542 at the time of Humayun's flight *from Delhi to Sind* and Khan Khanan's campaign against Mirza Jani Beg Tarkhan in (1590-92).

20. Exact information about the position of Indus during this period is not known. But it was passing through the Bakhar gorge. Old Pat (now in ruins), where King Humayun married Hamida Begum, was on the left bank of river Indus and so was Talti (both towns are now on the right bank). This old bed of the river is still traceable between west of old Pat and close to new pat a village in Dadu Taluka, about a mile to the west of the old Pat. This westerning of the river seems to have helped that territory very much and made it more fertile. As affirmed, by Mir Masum, this country was a mere waste, at the time when Taluka, about a mile to the west of the old Pat. This waste Sumra country (south-east Hyderabad and south west Mirpurkhas) was fertile, but by 1621 that part (the Sumra territory) grew waste and this part (the Pat area) turned fertile instead.

The Indus at this period probably passed close to Sehwan, but after going 10 miles south, made a turn eastwards to Sakrand, and on the way passed near the present Lakki, Amri, Sann and Manjhand (though at a considerable distance from this place than is the case now) and Unarpur. Hala was to its east and so was Nasarpur. Hyderabad was 16 miles to the west. At a place 20 miles south-east of Hyderabad above Tando Mohammad Khan, it divided into two branches: the main branch going westwards, and the other, a minor branch called Ren (probably non-perennial), due south. The Ren was converted into Guni channel later on. This branch had the town of Jun on its left bank (ruins 10 miles northwest of Talhar) and Fatehbagh on its right bank. The latter, also in ruins, is 5-6 miles northwest of Jun. During his flight from Sher Shah, Humayun wanted to conquer Sind, and so in 1543 AD., he made his headquarters at Jun, while Shah Hasan Arghun the ruler of Sind, to stop his crossing the river and capturing boats, made his headquarters at Fateh bagh. Old Badin (now in ruins) was down south on this same minor branch. Gungro took off from the western branch at a distance of about 12 miles southwest of its bifurcation with Ren. The capital town of Sumras, Mohammad Tur and Mughal-Bhim (Jati) were located on it.

The main river still kept flowing westwards. It bifurcated 8-12 miles east of Thatta into two branches, Kalri and Baghar. The Kalri which was the main branch in 1519 A.D., flowed westwards into the Chard creek. Baghar flowed upto Pir Patho hills, made semi-circular loop around them, and then flowed towards Sakro. It made a turn 5 miles south of Sakro and discharged into sea, via Lahori Bunder. According to Mir Masum, Kalri was the main channel then, and was to the north of Thatta town. The old bed is still visible on Thatta-Jungshahi Road a few miles north of Makli hills.

21. One more change took place during the years 1700-1750. Sattah and Shah Bunder branches, took off from Baghar stream. The latter had already become the main stream since 1519 A.D.

CHANGE IN THE BED OF RIVER INDUS IN 1758

22. In 1758, the river changed its course near Hala and started flowing west of Hyderabad. There were hydrological changes between 1755-59 causing flooding and destruction and consequently the change in the course of river Indus. Due to these changes, the river abandoned about 100 miles of its old channel. The Ren branch which also dried up, was another stretch of 70 miles. Due to these floods and hydrological changes, Muradabad, the capital town, built by Murad Khan Kalhoro in 1756-57 near Nasarpur, was also erroded. After the river established west of Hyderabad, Ghulam Shah Kalhoro started his ambitious programme of canals and irrigation works, and also built his new capital at Hyderabad in 1770 A.D.

A branch of Indus, taking off from Moro and reaching Puran, was irrigating rice fields of Kuchh. This was permanently dammed in 1762-63 A.D. Alexander Burnes who was East India Company's envoy to Kuchh, and had visited Sind in 1831, has attributed this to Ghulam Shah's taking revenge from Kuchhees, at whose hands he lost a battle, some years earlier. The same ruler had also dammed a spill-channel from Indus to Eastern Nara about 8 miles south-west of Yaru Lund in Rohri Sub-Division. This *bund* mentioned in the saint-poet Grohi's prediction was constructed, four centuries after the said writing of these verses. According to legend It is connected with the story of Saiful Muluk a rich merchant, whose beautiful maiden Badi-ul Jamal caught the fancy of Dilu Rai, the tyrant ruler of the time, who wanted some how to possess her. Saif-ul Muluk, however, got three days grace from the king, constructed the bund diverted the water down the main channel, and safely sailed away, with his wealth and the maiden. Dilu Rai's country also became a desert. This of course is only one of those stories attributed to the legend of Dilu Rai.

How hard this change in the course of the river must have been to the people, is quite clear from the fact that thereafter there was continuous political unrest, decline in agricultural production, trade, and small industry. The economists like Chhablani blame Ghulam Shah Kalhora and his successors for it, but the real cause was that Lacs of acres of land (which are now being reclaimed by the G.M. Barrage after two centuries) went out of production due to this abrupt change in the course of the river, crusting the economy of the country.

CHANGES IN THE 19TH CENTURY

23. Due to silting up, Kairi branch of the river dried up between 1779 and 1780 A.D. It was converted into a canal in 1859. In 1820 the Baghar which until 1809, at the time of Pottinger's visit was the main outlet to sea, also silted up. It was also converted into a canal in 1884.

In 1859, the Eastern Nara was converted into a perennial canal by Fife the then Superintending Engineer. Thus it again started irrigating for the first time since it dried up completely or was left as an un-important spill-channel after 1226 A.D.

The Western Nara, which existed at the time of Alexander's invasion and even before, had its head near Kashmore in pre-historic time and near Ghauspur later. Due to westerning of Indus, however, its head was 20 miles north of Larkana by 1860 and only 8 miles north of the same in 1902, when it was converted into a canal. This was the oldest channel of the river, and Sehwan, the oldest town in the region situated on a low rocky hill depended on it for its water supply. The river and its floods never destroyed this town. There is a large number of ruined towns on the banks of Western Nava—Stupas at Mohen-jo-Daro and Dhamraho, and ruins of Fatehpur and Khudaabad being the most important ones.

Ghar, an old branch of Indus, through which water discharged in the depression to the west , was converted into a channel by Kalhoras. It kept serving the area till Sukkur Barrage took over in 1932.

Phulleli canal started 10 miles north of Hyderabad in the 18th century and it ended near Tando Mohammad Khan in the old bed of river called Ren, on the banks of which at one time Humayun and Shah Hassan were watching each other's movements in the 16th century, and which was still flowing upto 1758. The upper reaches of it were called Phulleli, and the lower reaches, Guni, Gungro, a bed of river in the 13th and 14th century, was also converted into a canal.

The above courses of Indus have been shown in the various district maps.

These maps also show the sweet ground water zones. It can easily be seen that in the area where the river has flowed in the historic times, the water is sweet, but along its pre-historic courses the quality of water has changed and is no longer fit for irrigation.

CHAPTER V
THE COURSES OF WESTERN BRANCHES OF RIVER INDUS

The contours of the area show five depressions, three of which are above Bakhar, one opposite to Bakhar, and one below Larkana. The first three pass through an area known as *Sind-Dhoro* (Sind Hollow); for reference they have been marked on the map of Jacobabad, Sukkur and Larkana districts. All these courses belong to historic period. The first four of these are definitely the beds of old course of western branch and lead into Sind-Hollow, which is a depression between Shahdadkot and Manchhar Lake. The same depression drains the water of Bolan *Nai* Sibi plains, as well as that of *Nais* of Larkana and upper Dadu districts. The Sind-Hollow is caused due to heavy load of alluvial plains supported by hills. None of the western channels, flowing to the Sind Hollow, was perennial.

COURSE NO. 1.

There is an evidence of an old course along the northern border of Jacobabad district. It branched off westward from Indus between Kinkot (about 20 miles North of Kashmore, in D. G. Khan District) and Kashmore, passing 6-7 miles north of Kumbri two miles south of Sanri and Sundree, then north to Khanpur (in Sibi district), and within 7 miles of Uchh (in Sibi district), after which is bent southwards, passed at a distance of 11 miles west of Jacobabad (near Jhat-Pat) to Ghari Khairo, and from there through Sind Hollow to Manchhar lake, where it made a south-eastern loop and discharged into main channel, many miles below Sehwan. It did pass near Sehwan definitely, which got its supplies of water from it. Major part of this course in Jacobabad district is now being utilized for Desert canal alignment. This branch may have flowed at Alexander's times and earlier.

COURSE NO. 2

It starts near Murho Mari opposite to Karampur, and follows the present bed of Begari Canal, but leaving it at Khanpur, it makes north-westernly bend, and after passing north of Shikarpur, makes south-western turn to Waris-Dino Machhi, the junction of Jacobabad Larkana and Sukkur districts. At this point, it makes more south-westernly turn, and passing between Shahdadkot and Miro Khan, leads into Sind-Hollow near Garhi Khair Mohammad (not Ghari Khairo). The exact date of this course is not known, which, however, may have been the 9th and 10th century A.D.

COURSE NO. 3

It starts near Ghauspur, then passing through Mirpur it makes slight north-west bend, and passes near Abad about 10 miles south of Jacobabad. Here it makes southwestern turn to Ghari Khairo, from where it passes straight down to Shahdadkot and then to Sind Hollow. This may have been at Ptolemy's times. Ptolemy has also described another branch of Indus, going west-wards to the Arabita mountains (Khirthar hills). This was either Nara or Ghar or a combination of both.

It is interesting to note that from Gauspur to Mirpur, the Nasir branch has been aligned on this bed; and from Abad to Ghari Khairo, the present Began has been aligned on the same bed.

COURSE NO. 4

It starts opposite to Bakhar but at a point about 14 miles west of it, goes to Drakhan, and from there, moves south-west to Ghari Khair Mohammad into Sind Hollow. This must have been prior to Indus passing through Bakhar gorge, when Indus was 14 miles west of Bakhar.

COURSE NO. 5

It starts south of Larkana, passing near Bakrani, Dokri, Sehar, Radhan and Balishah, wherefrom it moves direct south to Pat.

Part of the course is along the present rice canal alignment (Dokri to Radhan) and part along the alignment of Dadu canal (Bali Shah to Pat).

These courses have from time to time formed western branch of Indus and were navigable. The exact date of flow of each of the course is very difficult to determine, but it seems likely that the first course is pre-historic and was there also at the time of Alexander's conquest when the Indus was passing north of Shikarpur, and then flowed south-east, crossing the present river bed into Lohano Dhoro. The famous pre-historic site, Limo-jo-Daro, must have been on this course.

The 2nd, 3rd and 4th courses might have come up at different times during the period of about 1000 years after Alexander's conquest. Ibn-Buttuta must have passed along one of these courses to Sehwan. The 5th course seems either independent of these or may have been a branch of them possibly since 3000 B.C., as important pre-historic sites like Mohenjo-Daro; Jhunkar, Dhamraho-jo-Daro, Lonam-jo-Daro, and Mahota (6 miles north of Larkana) must have flourished on it between 3000 B.C. to the 6th century A.D.

The Western Nara, Ghar, Dadu Canal, Rice Canal, Desert Canal, Begar *Wah*, and Nasir *Wah* are on the alignments of the 5 western courses discussed above.

The Sind Hollow was frequented by floods. The elderly people, of Dadu and Larkana districts always talked about floods from Kashmore. They specially remembered the flood of 1874, after which construction of a bond from Begari to Kashmore was started and completed in 1879. The last two of these floods came in 1942 and 1948. The path of 1942 flood which started south of course number 3 at a distance of a few miles, covered the whole area to the south, which was previously being covered by courses 2, 3 and 4. The path traversed by the 1942 flood was as follows:

To the right-Rustam, Shikarpur, Ghari Yasin, and to the left-Chak, Habibkot, Madeji. A bifurcation of the path took place near Ghari Yasin, having Rato-Dero to the right; from where one current flowed to Shahdadkot, & down through Sind Hollow to Manchhar lake. The other current had Madeji, Naudero, Mahotra and Larkana to the left. It took practically the same course as western Nara, from Larkana upto Kakar, where it entered Dadu Taluka and ended in the river Indus between Talti and Sehwan. The total overflow was carrying 50,000 cusecs, which clearly indicates the size of western branches when they flowed.

Though contours of the area do not show it but the presence of sweet water in Kandhkot Taluka to greater depth & brackish water to the eastern sides in Kashmore Taluka adjoining to the present course of Indus, clearly shows that these waters (in Kandhkot Taluka) must have been diluted by the river Indus which at least in prehistoric times, may have flowed through this area in the neighbourhood of Risaldar, west of Kandhkot and Haibat, near Ghauspur, and Shikarpur where it make a southeastern turn to Khairpur state and then to Lohano-Dhoro. There could be no other reason for a wide sweet water belt in the centre of Jacobabad district away from the river, but this. Western Nara must have been a branch of the river, since then.

CHAPTER VI
OLD SETTLEMENTS AND GROUND WATER

The old settlements in this region must have been founded where assured supply of water both for drinking and irrigation purposes was available. Before advent of Sukkur Barrage, we did have a net-work of canals, and it is within our living experience that their water could reach to a maximum distance of 20 miles only, from the course of the river. In cases, therefore, where these settlements were not located on river Indus, the people must have depended for water supply on wells in the winter season when water could not flow through the canals. The sites for these settlements had therefore in any case to be within the sweet water zone. Below is a brief account of some of the important historic and pre-historic sites. Except a few of them in the delta area, the rest of them are still located within the sweet water zone though the river deserted some of these places even more than 1000 years back.

SUKKUR DISTRICT

(i) Vinjrot in Sukkur district, 5 miles east of Red Railway station on Hakra.

(ii) Dribh Dethari about 20 miles south of the former near Hakra.

(iii) Alor (or Aror) flourished on a small eastern branch of river Indus, which passed through Aror gap upto mid 10th century. Water being brackish in the area, the town was deserted in the 10th century.

(iv) Bakhar was established in the early 13th century when Indus passed through its gorge. Ground water being brackish, the triple towns, Rohri, Sukkur and Bakhar, got established only after the Indus passed through this gorge.

KHAIRPUR DISTRICT

Old towns namely Kasur, Kot Deji, De-jji-Tokn exist near the old river bed in which Indus was discharging, after making a loop round Ghauspur, Shikarpur and then crossing the present course south of Sukkur. With change In the course of the river, the towns were reduced to ruins.

NAWABSHAH DISTRICT

Thul Mir Rukan is an old bed of River Indus possibly the Lohano Dhoro; so is *chanhu-jo-Daro*, which is about 1/2 mile south of modern village of Jamal Kerio near Sakrand. The river is 12 miles west of it now, but in the 3rd millennium B.C. the river flowed near it and more than once caused its destruction.

SANGHAR DISTRICT

Patala the capital of Sind at Alexander's times was probably on the same site as Bahmanabad. Mansura was also built on the old site of Bahmanbad. The site claiming such historic names is on the old bed of the river. In the 9th century, the river seems to have bifurcated 40 miles north of Mansura, and the two branches met south of it. Later in the 12th century, the Indus changed its course, and Mansura was not heard of much longer. It met its final destruction probably at the hands of Sumras. It could otherwise have survived, as a small town though-as it had its situation in the sweet water zone.

Deper Gangro, another place a few miles north, by east of Bahmanabad, was on a pre-historic course of the river, and when the river changed to a new course about 7 miles west, it probably continued getting its water supply by some channel. Being in brackish water zone, its survival otherwise was out of question.

THARPARKAR DISTRIC

Kahu-jo-Daro, near Mirpurkhas was definitely on Eastern Puran, which in Alexander's time was the eastern branch of Indus, starting at patala. From the 6th to 12th century, the same branch left Bahamanabad or Mansura south-east to meet the Eastern Nara south of Naukot. Amar-kot (now Umerkot) on a branch of the Eastern Nara was getting water from it, till it dried up around 1226 A.D., but the town continued to get its supplies from a lake, called Sumra Dhand, which lay parallel to and on the west of the bed of the Eastern Nara.

Naukot, another Buddhist site, was on the Eastern Nara, and so was Nohto on the east of Puran above Allah Bund. The water in the whole district is brackish (except in small pockets), and therefore the old settlements perished as soon as deserted by the rivers.

HYDERABAD DISTRICT

Nasurpur was founded in the 14th century on the river Indus. Nerun (Hyderabad), 16 miles west of Nasarpur, was getting water by a canal.

Suden-jo-Daro was also on an old bed of river Indus at the junction of Guni and Phulleli. Places like Tharri, Jun, Fatehbagh, Mohammad Tur, Old Badin, and Bulri on Renn and Gungro have been described in Chapter IX. Their rise and decline went with the change in the course of the river. Since water in lower Hyderabad district was brackish, all old settlements were deserted as soon as the river deserted them.

DADU DISTRICT

Leaving aside the sites in the Kohistan hills, which are described in Chapter IX, Amri is an important prehistoric site. The river is close by it now, but, in the olden days, it was a great distance away from this settlement; which instead was situated then on the Aral canal, the western branch of Indus. Water being brackish all around, this pre-historic site could not have survived as long as it did, without Aral being close to it.

Loham-jo-Daro a site near Piarogoth railway station was too far away from the Western Nara, but west of this site there are old lakes and depressions called Sutyaro dhand, Kenjhar dhand etc. This settlement possibly was at one time on a branch of the western Nara from which it was getting water supplies. North of Loham-jo-Daro near Rukan, there is still a lake which may have supplied water to it. Sehwan, possibly the oldest town in the region (or even in West Pakistan) has survived, because the western branches of Indus, after making a loop near Manchhar, had to pass near it, to discharge into the main branch. The other two places, Chakar-Kot and Kot-Drigh Mathi, respectively 17 and 13 miles west of Johi, were getting assured water supply from Sind-Hollow. Even in the recent times two cities Fatehpur (Ghari), 8 miles north-west of Kakar, and Khudabad, were built on the Western Nara in the 17th and early 18th century respectively.

THATTA DISTRICT

Bhambore, a small harbour which possibly existed from 7th to 14th century, was on river Indus. Its brick lined wells now giving brackish water must have been sweet then.

Helai (now Hilaya point), 16 miles N.E. of Thatta was on some old channel, (possibly the channel on which Debal stood).

Lahori Bunder, established in early 11th century, existed till the river changed its course in 1758.

LARKANA DISTRICT

Prehistoric town of *junkar-jo-Daro* is on Ghar. Mohenjo-Daro is close to the western Nara, a non-perennial channel, but the town itself was located in the sweet water belt.

Another Buddhist stupa near Dhamraho must also have been on the western Nara and is located in the sweet water zone. *Mahota* on Ghar channel or possibly on old Nara must have been a place of great importance in former times.

JACOBABAD DISTRICT

Lime jo-Daro, is an old site near Ghari Khairo. The ground water at Ghari Khairo is sweet to a depth of about 150' or more. In historic times, the western branch of river Indus has passed from Kashmore to Kandh Kot, south of Jacobabad to Ghari Khairo and then into Sind Hollow. The drainage waters of Bolan *Nai* from Baluchistan hills also passed near this place into Sind Hollow. This is an isolated place which has sweet water to a great depth, though in the surrounding area water is almost brackish.

The above sites clearly show that though some of them were on non-perrenial streams, the seepage from the latter had diluted ground water, some 2000 years back . The quality of this water has remained unchanged (except in lower depths) and therefore there is no fear of water turning brackish for many centuries to come, if draw-downs do not exceed replenishment excessively.

CHAPTER VII
SEEPAGE OF WATER INTO THE GROUND

Once it is proved that sweet water exists in areas where the river, particularly its main channel, has flowed for centuries, an, immediate question arises that, if this water is pumped out, will brackish water from the sides, both to the right and to the left, not rush in? To answer this question, let us examine what actually has since happened to most of these beds of the river.

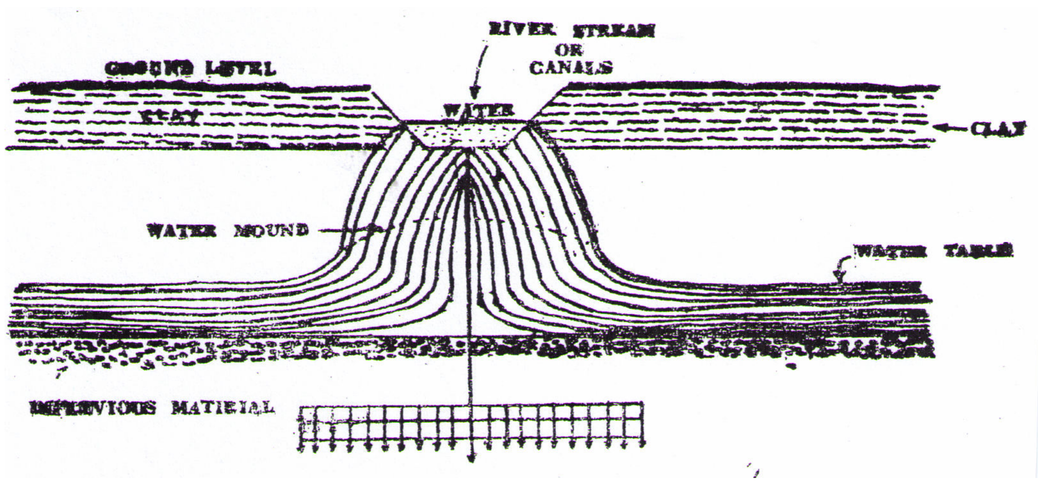


FIG. NO. 1

Principal of seepage of water from canals, streams and rivers to ground which raises water table and also dilutes the brackish water down below.

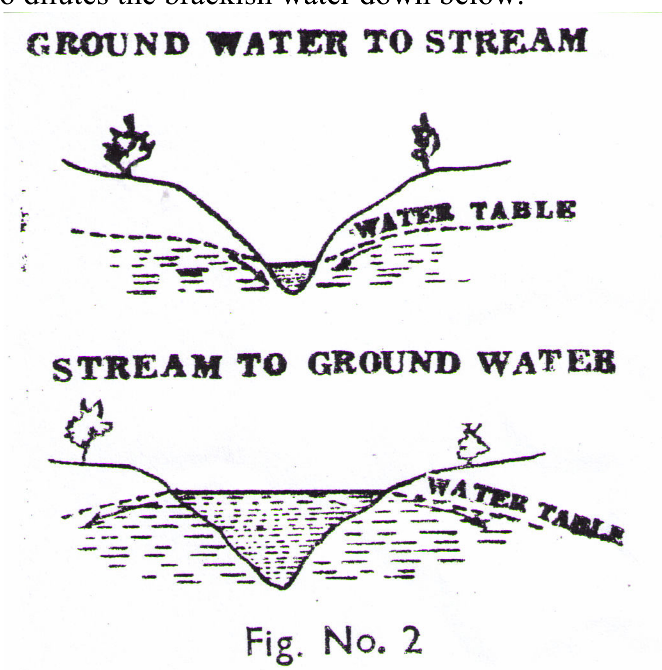


Fig No. 2 (a) & (b)

GROUND WATER TO STREAM, STREAM TO GROUND WATER

Figure (a) showing how some canals and rivers act as drainage channel when water level in them is low and in case of (b) from the some canals or rivers, seepage takes place to surrounding areas. The river Indus and non-perrertial canals of Guddu, Sukkur and G.M. Barrage act as drainage channels in winter while they are responsible for seepage in the inundation season.

We have seen that in the case of Jacobabad & Sukkur Districts, the old beds of western stream of the river have been converted into the desert canal, Nasir wah and *Begari Canal*. These three canals have flowed in the past, and will continue to flow as a part of Guddu Barrage irrigation system in the future.

In the case of Larkana and Dadu districts, the easternmost bed of western course of river Indus (course No. 5, Chapter V) is taken over by the Rice Canal and Dadu Canal. A part of the old channel was converted into *Ghar Wah* by Kalhoras about 250 years back. They also constructed *Dato Wah* from Larkana to Shahdadkot along an old alignment. The old bed of western Nara below Radhan, forms a part of Rice Canal system. Aral still continues to flow as it did 5000 years back, practically for 6 months. The canals *Dato-ji-Kar* (20 miles) and *Shah-jo-Kar* (20 miles) were absorbed in the *Warah* branch.

The Sind Hollow, where water is brackish except in a part of Khairpur Nathan Shah and western Johi Talukas, still gets water from Bolan *Nai* (of Baluchistan) and several other *Nais* of this region, though not to the same extent as before. The Manchhar Lake still fills up in the summer months inspite of its being silted up gradually.

In the case of Khairpur district, we have three old beds of the river Indus. Rohri Canal lies on the alignment of the central one. The seepage from this canal is so much that reclamation of the waterlogged lands has become a problem.

Coming down to Nawabshah district, the *Naulakhi, Nasrat, Dad and Dambhro Wahs* are on the alignment of an old bed of the river. Nasrat was constructed by Nur Mohammad Kalhora and Naulakhi (consisting of *Murad Beg and Phiroz Wahs*) was a canal in pre-Kalhora days. These canals now form part of the Rohri canal system.

In Hyderabad district, the *Gharo Mohumdo* canal consisting of *Gharo-Rano, Gharo-Bhanot, and Gharo-Muhamdo* itself, was on an old bed of the river starting south of Hala. These Wahs have been merged into Rohri Canal system.

The Eastern Nara was also converted into a perennial canal by Fife in 1859, about 600 years after it dried-up.

The old river beds in G.M. Barrage area were converted into canals like *Phuleli, Guni, Baghar, Kalri, Sattah, Phito and Khante,* by Kalhoras, Ta{purs and the British.

However, ground-water in G.M. Barrage area is too brackish to be diluted by these channels, when river Indus failed to do it in centuries.

The Eastern Puran is now a drain channel casually taking some water, but the Western Puran carries drainage water most of the year.

The seepage is taking place from all these canals and from the river Indus, and from the fields fed by them, at a much higher rate than ever before. According to Chhablani's estimates, the cultivated area in the 16th & 17th century was about 15 lac acres, rising by mid 18th century to 21 lacs, which again declined to 10 lacs in the early 19th century. The annual cultivation figures in alluvial plains are in the neighbourhood of 65 lac acres now, and are going to reach 85 lacs or more by the end of 1970. Such a vast irrigation system, more or less constantly submerged in water, would again mean more and more seepage into the ground.

The water table has already been rising in the whole area. By pumping water from the ground, we will be increasing storage capacity of the underground reservoir, which in turn will be fed and replenished by seepage from above. The river is flowing at the ridge, and ground water has a gradient away from the river water. By pumping the ground water, we will induce seepage from the river, and therefore there is no fear that the ground water reservoir will be exhausted by pumping, specially in case of sweet water zone on both sides of the river.

My opinion is same about the area, where water is sweet to shallow depths in Jacobabad, Larkana, Dadu, Khairpur and Nawabshah districts.

CHAPTER VIII
THE DESERT ZONE

The Desert Zone may be divided into three distinct parts known as (i) *Rann*, (ii) *Thar,* and (iii) *Pat.*

THE FORMATION OF RANN OF KUCHH

The Rann has played the most important part in the formation of the whole desert. According to some geographers and geologists, the Thar desert was formed by sand blown across the Rann from the sea. Had that really been so, the Rann of Kuchh itself would have been covered with sand hills first. In the Rann, however, we find deposits which are of much finer material than the coarse sand found in the desert, and therefore-the sand blown from the Rann's surface could not have formed the desert.

Some investigations were carried out recently in Rajisthan by the Development Commissioner of the area, a professional chemist, who came to the conclusion that the salts found in the ground water in the area were of the sea origin, rather than the calcareous salts. From this, it has been concluded that a branch of the Arabian Sea extended in the interior of Rajisthan, possibly along the Luni river, upto Panchabordra in the recent times, and probably upto Samber lake in the pre-historic period. An in-land sea described in Mahabharata was probably this arm of the sea.

My own conclusion is that in pre-historic times a branch of Rann of Kuchh, extended as far north, as present Rohri. I have based this on the following facts:—

(i) The water in the Thar desert is not so brackish as that on the west of the desert, at some places to a distance of even 20 to 30 miles, in alluvial plains.

(ii) In the desert *dhands* or lakes, some marine bacteria abide, which exist only in the sea, and therefore, these *dhands* must have been connected with the sea at some time even after their formation.

(iii) Salt lakes are common only on western border of the desert, which fact clearly shows their origin from the sea.

The silting of present Rann started in the recent times by both Hakra and Indus flowing into it. At the time of Alexander's conquest, according to Greek writers, the Rann was a shallow sea. When Mahmud Ghaznavi was returning from his march to Somanath, pursuing a Hindu chief to the islands north-east of Kuchh in 1006 A.D., he was told that sea waves will wash away his boats. This clearly shows that the Rann of Kuchh was not dry in the early eleventh century. The town of Pari Nagar, a sea port in Nagarparkar Taluka, was destroyed in 1226 A.D. This was the year when Hakra dried up near Umerkot also, clearly showing that the Rann of Kuchh was an arm of the sea, and was fed by Hakra. Feroze Shah Tughlak crossed the Rann in 1361 AD., when it was dry. His army on retreat from Sind to Gujrat nearly perished from heat and thirst. According to historians, "no tree was to be seen, no bird ever flapped in the howling desert, there was not a blade of grass, not even a miserable weed." Two centuries later, Abul Fazal in *Ain-i-Akbari* called it depression 90 Kuroh in length & 30 to 80 Kuroh in width, which represents nearly the same size as it has today, after another four centuries. Balmir was a sea port or Luni River near Nagarparkar in historic times, which shows that in those days Luni was also navigable. All this proves that the Rann of Kuchh, at one time a sea creek, was silted up slowly, possibly due to silt brought by Luni from Rajisthan, and Hakra and Indus from the north. Some geologists have said that the Rann is creation of earthquakes and slow elevation of the land, but the historical and scientific evidence is against this.

It is not possible to lay down exact location of the Rann of Kuchh, but it seems likely that it extended over the whole area now covered by G.M. Barrage and over the area commanded by Sukkur Barrage in the Tharparkar District. A projection of it must have extended upto Rohri or a little further up. In all this area, we should not, therefore, expect any sweet water for irrigation purposes. Small quantities of water, for domestic and small scale irrigation purposes could however be located along the banks of old Hakra or Eastern and Western Purans, to shallow depths of 40' to 50' at isolated spots.

Today the Rann of Kuchh is a dry barren country which turns into swamp after rains, when waters brought by Luni from the east, Puran from the north, and some stream of Kuchh from the south fill it up, to the depth of a few feet. The water does not dry till about November. There is no vegetation in the Rann. It is an abode of wild ass, occasional deer and constant mirage; Some desert bushes and tamarisk etc. grow in odd patches near the Thar border.

FORMATION OF THAR DESERT

Underneath the Thar Desert at the depth of about 1000' rock has been located, out-crops of which appear at Aravalli hills and Nagarparkar. On the top of this rock, lies the 1000' mass of earth which has continuously blown from the Rann of Kuchh, which, as described above, extended to the west, south and south-east of the great, Indian desert, and on Pakistan side upto Rohri. Due to south-west winds, the silt, sand and tiny sea shells were blown from the Rann, which have formed this mass of earth. The sea shells, decomposed and formed calcareous grains, which are saline, and are responsible for brackish water in the desert.

In due course of time, calcareous shells and the sea salts were dissolved and re-deposited in the form of *kankar* and saline concentration. In places, sand became cemented giving rise to soft sand-stone. The soft sand-stone and *kankar* are scattered in the whole desert, and are encountered at various depths, while drilling or digging. Being impervious, they hold water above them, known as "perched" or "trapped" water. This water will obviously be some-what brackish, depending upon contact with *kankar* etc. The actual ground water lies much below this, possibly 500'-1000' deep.

In this area, no wells have been sunk below 300' and therefore nothing could be said about the quality and quantity of its ground water. At Gadra Road Railway Station, across its Pakistan border on the Indian side, a well 350' deep was sunk by the J.B. Railway. The quality of water is said to be good, and the well is yielding substantial quantities of it. It is very much desirable, therefore, that a number of test bores to a depth of 350'-500' are sunk at different places in the desert area. These should penetrate the perched water zone, and the *kankar* and sand stone beds, to see the quantity and quality of water down below.

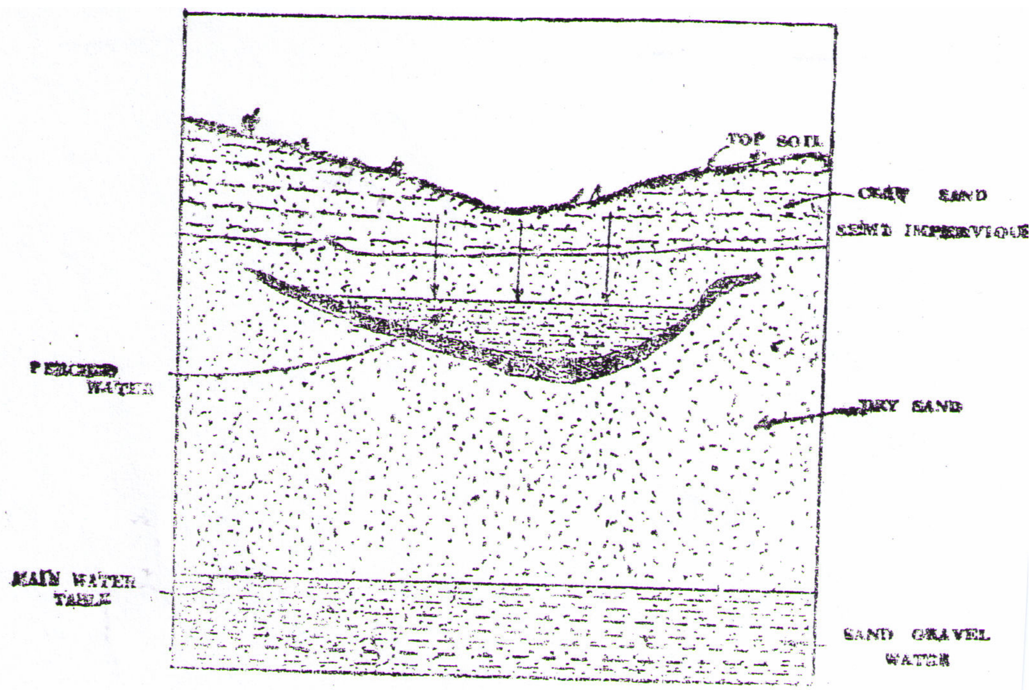


Fig. No. 3

PRINCIPLE OF EXISTENCE OF PERCHED WATER

The fig. shows cup-shaped bowl made of impervious clayey material of calcareous origin, met in Thar and Pat areas. It holds small quantities of water above it. The real water table lies at much lower depth. Almost all wells in Thar area are in perched water.

NAGARPARKAR AREA OF THE THAR DESERT

The Parkar part of Nagarparkar area is altogether different from the rest of the Thar desert. From the pattern of ground water in this area, it seems certain that at one time river Luni was flowing across the peninsula between Virawah, and Dinsi. Parkar possibly was an island then.

In Nagarparkar, Southern Mithi and Southern Diplo near the Rann of Kuchh the water is located in many wells. The figure shows the brackish water of Rann of kuchh on which sweet water floats. The brackish water is heavier than sweet water by 8½% and more. The sweet water being lighter floats on brackish water and the height of sweet water, above the level of brackish water of Rann is governed by formula t =H (g—l) where H is total depth of water, g the specific gravity of brackish water.

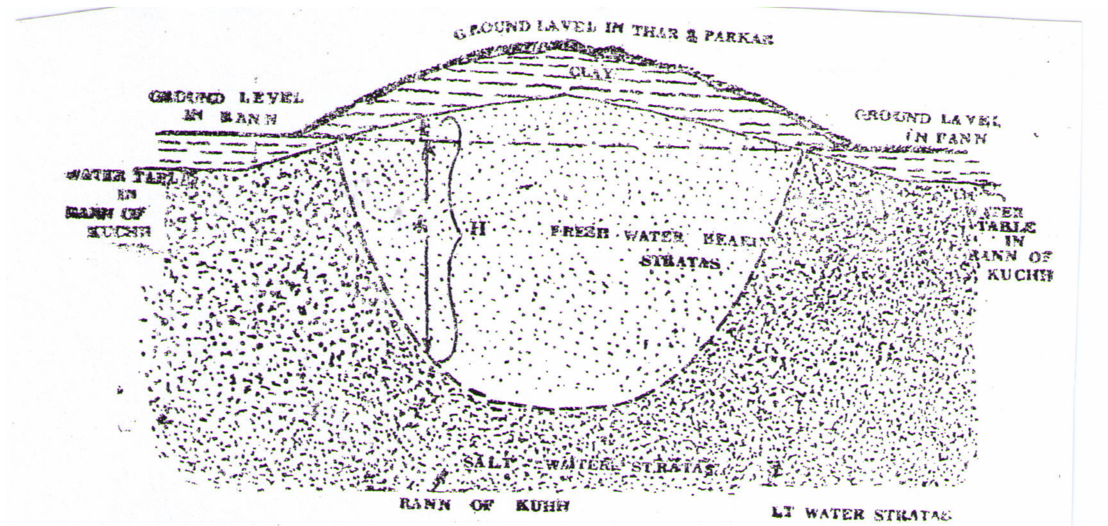


Fig. No. 4
PRINCIPLE OF FLOATATION OF SWEET WATER ON BRACKISH WATER

A special phenomenon is observed in some islands; even though surrounded by sea, they contain sweet ground water. The phenomenon can scientifically be explained, and even the precise depth of the sweet water determined mathematically. Even if Parkar was not an Island, it was, and is, surrounded by the Rann of Kuchh (old sea creek) along almost 85 to 90% of its borders The Rann of Kuchh still contains brackish water. The fresh water which seeps in, floats on it. This theory is further supported by evidence in as much as in the centre of peninsula, water to greater depth is sweet whereas away from the central region, water turns brackish with depth.

The out-crop of the rocks is almost in the centre of this island or peninsula. The depth of sand clay over it is not so much as in the desert. The sand is porous and absorbs huge quantities of water. Even the rocks which are pre-Cambrian of Archean & Purana group, are igneous and not soluble in water. They are impervious but hold water in fissures and cracks. This water slowly moves under the ground and is available in the wells. Near these rocks, artesian conditions can be expected. There are no changes of artesian conditions in the rest of the desert. The appended map No. 12 shows the sweet and brackish water zones of Parkar area.

PAT AREA

The desert area lying in Khairpur division is called *Pat.* Its main difference with the *Thar* is that vegetation and rain—fall is comparatively less and the *Bhits* or sand hills do neat lie S.W. to N.E. but to SSE-NNE in the southern portion, and north-south in the northern portion, along the usual direction of wind. The sand hills are not only a function of wind direction but also wind velocity, and when velocity decreases, the sand hills tend to lie across the wind directions. The sand hills here are also smaller than those in Thar. The area is otherwise flatter and therefore called Pat (i.e. flat ground). The top sand lies on impervious clay layers and the rain water, after seeping through the sand, collects over clay and comes out in the low spots as 'Sim' or spring water. Though the rainfall is only 4", luxuriant grasses grow, on which cattle thrives.

Like Thar, the Pat rests on rocks which lie about 1000' deep.

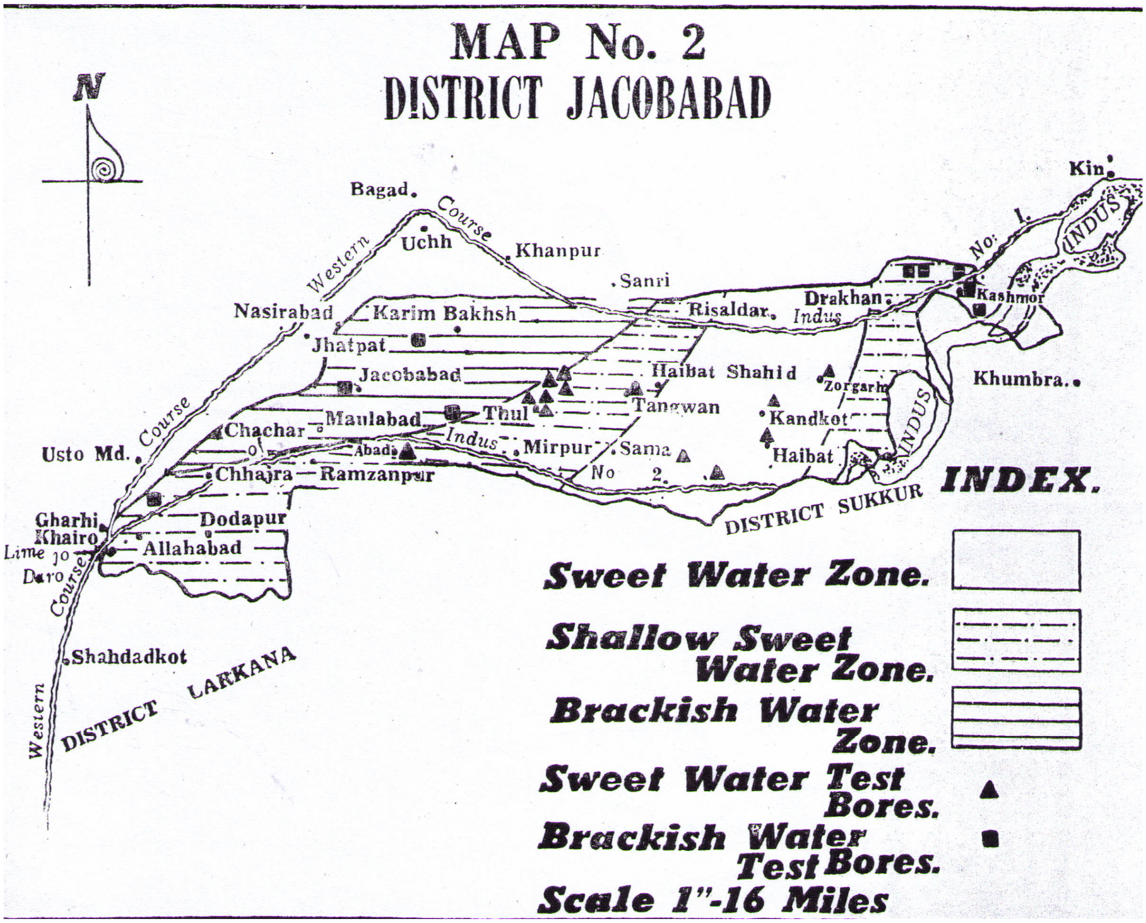
In Khairpur district, on the west of the *Pat*, lie Kot-Di-ji hills, which are Eocene lime stone (Khirthar-hills group). An outcrop of these hills appears near Jaisalmir. Down below in Hyderabad District near Badin, at the depth of 950', the Standard Vaccum Oil Co., while drilling for oil, located Khirthar lime stone. This clearly indicates that most of the Pat area and the western part of Thar is underlain by Khirthar hills, and the eastern Thar by Pre-Cambrian rocks of Aravalli group.

Up north in Sukkur district, the Pat is geologically of the same formation as the Desert Zone of Ambala and Bikanir. The depth of alluvial is 1000° or more. The whole tract is traversed by beds of old Hakra and the spill channels to it from Indus and Sutlej. The soil lying below the sandy desert, is hard alluvial. The water in the shallow depths is brackish, but so is the case in similar formations up north in Bikanir area. Deep drilling upto 1000' or more is necessary to determine if there is any water down below. It may be mentioned here that Geological Survey of India in 1926, while drilling located substantial quantities of sweet water on the Indian side of Pat area in Ambala at depth of about 1000'.

CHAPTER IX
DISTRICT WISE POSITION OF GROUND WATER

JACOBABAD DISTRICT

The map No. 2 gives details of ground water in Jacobabad district. The district has been divided in four zones of ground-water.



(a) The riverine area inside the protected bond,

In the southern part of riverine tract, water is sweet upto the depth of approximately 200' but in the upper reaches near Kashmore, only upto the depth of 30-70' or so. The southern area is suitable for tube wells or open wells. In the northern area, only open wells can be installed, There seems to be an extension of some lime-stone sediments underneath, near the head-works of Guddu Barrage and south of it, which has made the water brackish in the northern part. The tube wells, 100'-150' deep, can give yield of 1.5 cusecs, and open wells 30' deep and having 40' long filters, about .33 cusec or more in the riverine areas.

(b) Sweet water zone.

The strip representing sweet water zone, as shown in the map, extends throughout the width of the district and covers Kandhkot and parts of Thul and Kashmore Talukas.

The water is sweet upto the depths varying between 100'-150' and in some areas even upto 200'. The sand in water bearing strata is medium grained and can yield high quantities of water, as compared to other districts of the two divisions. In this zone, tube wells having 6" diameter and only 100' deep have given discharge of 1.75 cusecs. Open wells 30' deep with 40' filters can yield 1/3 to 1/2 a cusec of water. Water table varies between 8 to 12' at the start of inundation season in April.

(c) Shallow sweet water zone.

This belt extends to the west of sweet water zone. Here the water is sweet up to the depth of 30' to 70'. The area is suitable for open wells. In case water is sweet to the depth of 60'-70', boring in the open wells is recommended—discharge of .33 to .5 cusec may be expected, depending on the depth of the well, length of filters and design of the well. There is also a shallow sweet water zone parallel to the river in Kashmore Taluka east of the sweet water zone and west of river Indus, where similar results can be expected.

(d) Brackish water zone.

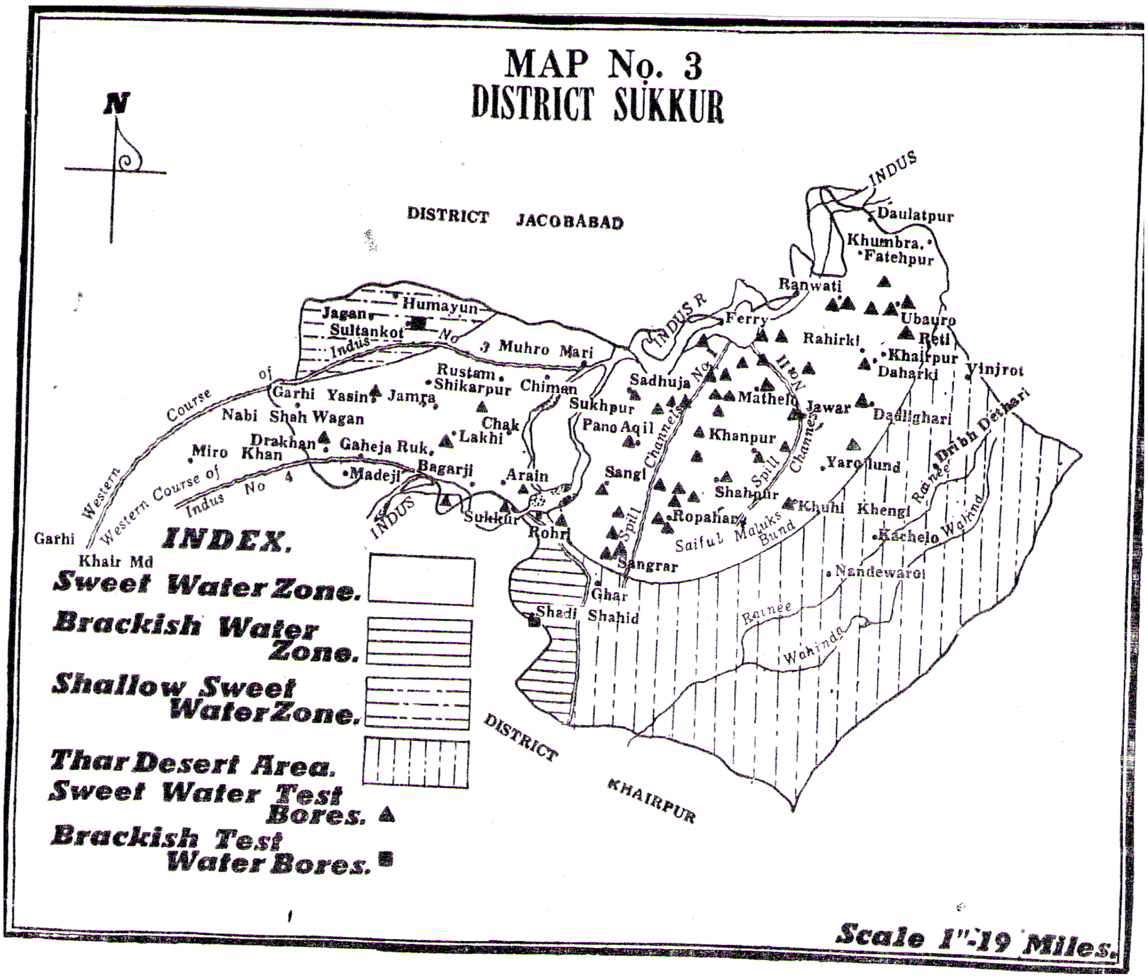
West of the shallow sweet water zone is "brackish water zone". The origin of brackish water here is not known. No detailed analysis of salts has been done. The salts may be the original sea salts or may have resulted from Baluchistan hills.

In the whole of Jacobabad district, water table is very high. The water table at the time of rice cultivation is just near the surface. In the months of April and May, it falls down by 7' to 8'. For tube wells, ordinary centrifugal pumps, kept in a few feet deep pit, are recommended.

SUKKUR DISTRICT

(i) Sukkur Sub-Division. The sub-division is divided into 3 different zones of water: the *sweet water zone* where water is sweet upto the depth of 200' or more, the *shallow sweet water zone* where water is sweet upto about 70’ and *brackish water zone*. The zones are shown in map No. 3.

It is appropriate to mention here that in Shikarpur and Sukkur Talukas, the quality of ground water is very good, and possibly better, with very low salt content than found anywhere in the whole of Hyderabad and Khairpur divisions. While tracing the courses of Indus through ages, we have seen that before the river passed through Bakhar gorge in the early 13th century, its main course tilted somewhere above or below Ghauspur crossing the present course of river near Ruk, and ending into Lohano Dhoro. We have also seen that even afterwards the flood waters have passed through this area. This has obviously diluted the brackish water of sea-origin. Accordingly, we sometimes get as low salt content in the area as 250 parts per million, which could be considered as the most excellent water. Even to-day had the river flowed in a straight line after leaving Kashmore, it would have passed through the centre of this area rather than through the Bakhar gorge. It seems that the seepage water from the river is draining through this area rather than under the present bed of the river. This deflection is probably caused by the Rohri hills. Open wells and tube wells of the same type may therefore be recommended for this area as for Jacobabad district. Discharge of wells and water table of the two areas also show similar pattern.



(ii) Rohri Sub-Division. Rohri sub-division may be divided into three ground water zones:

(a) Riverine area.
(b) Alluvial plains.
(c) Desert area.

(a) In Riverine areas, conditions are exactly similar as in alluvial plains described below.

(b) The detailed survey of alluvial plains was done by the Agriculture Department in 1960 by drilling a number of test bores. On the basis of this information, a definite area, containing sweet water at an average depth of 24' to 40', was located, which is shown in map No. 3. The quality of water is good, and sweet water extends upto a depth of 200' and even more. A few tube wells and a large number of open wells already exist in the area.

This area had the eastern Nara or Hakra or Rainee to the east and Indus to the west. Eastern Nara was getting water from Jamuna in recent geological times. At times Sutlej also contributed its spill-water to it. Regular over-spills have also flowed from Indus into Hakra in Rohri sub-division as well as in Bahawalpur area over a distance of 120 miles. Some spill-channels are still traceable from Indus to Hakra, two of which are shown in map No. 3. Due to such a long and widespread spilling of water over the area and seepage from the Indus, the tract holds considerable quantities of sweet ground water.

Incidentally 90% of this area will soon be irrigated by Guddu Barrage, but the water supply will only be seasonal. The area, therefore, is most suitable for tube well irrigation to increase intensities and to grow Rabi crops.

(c) No survey of desert area of this district called Pat has been done. In the desert, there are old beds of Hakra (or the Eastern Nara river), which dried up in 1226 A.D. But the chances of getting sweet water in the upper strata are limited. Below the sands at depth of 1000' or so lie the rocks. Since the Hakra had flowed over the desert sands for centuries, there are, however, possibilities of water having seeped down and accumulated over the rocks. Deep drilling may give clue to this. There are shallow wells in the area, but water in these wells is mostly brackish. Geological survey of India carried out deep boring (1012') in 1925-26 in Ambala district, and found sweet water at great depth. Geological formation of this part of Pat is closely connected with Ambala formations. Test boring to the rock level may therefore be worth while in the area.

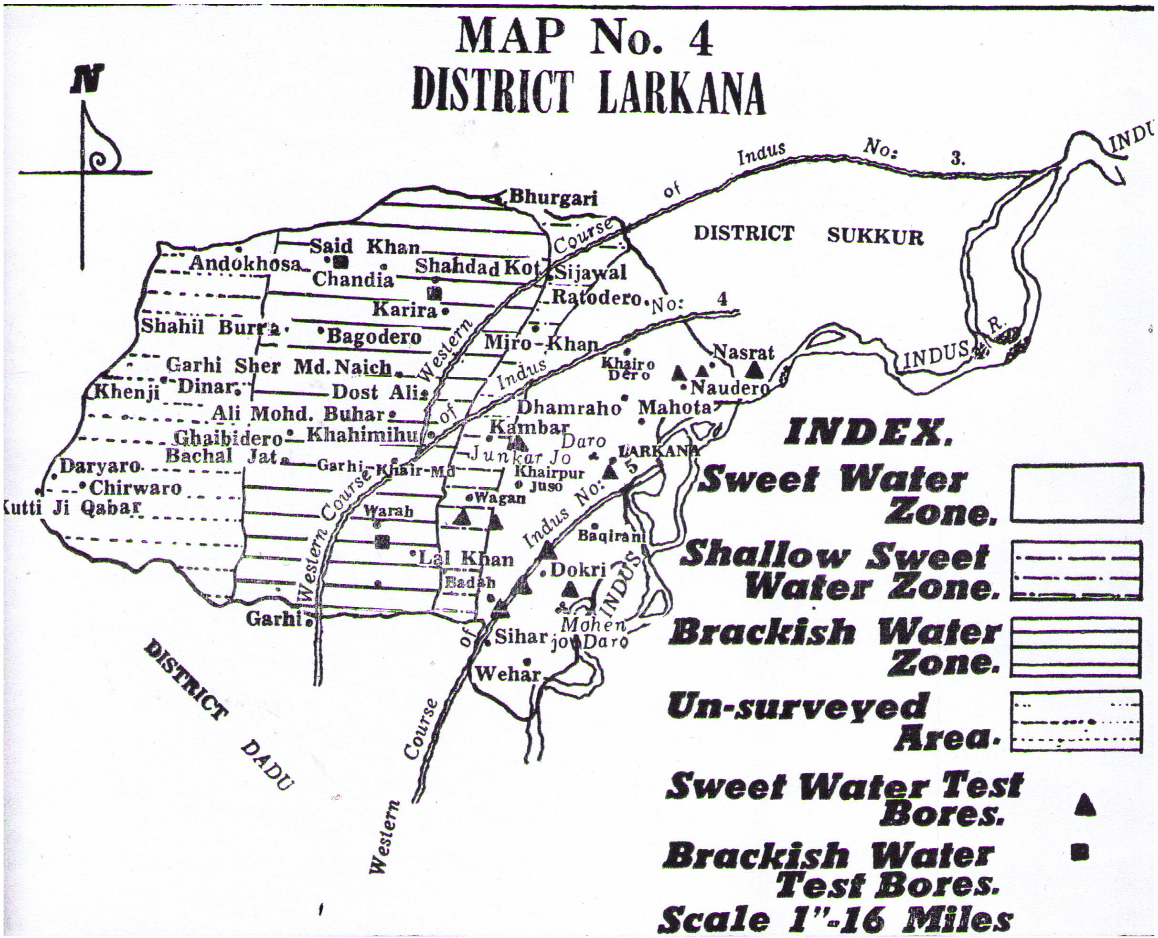
LARKANA DISTRICT

From the view point of ground water, Larkana District could be divided into five zones: (refer map No. 4).

(a) Riverine area, where the conditions are the same as in the Riverine areas of Sukkur District, described above. Similar wells and tube wells are recommended here. The water table in this area never falls below 8'.

(b) Sweet water zone, similar to one described in the case of Jacobabad district. The sand in certain places is slightly finer than that in Jacobabad district. Practically the same discharge of water can be expected by going slightly deeper in this area. Water is

sweet upto the depth of 150' and at places to even greater depths. A 150' tube well can give discharge of 1.5 to 1.75 cusecs.



(c) Shallow sweet water zone, where conditions are the same as in the corresponding zone in Jacobabad district similar types of open wells are recommended for this area too.

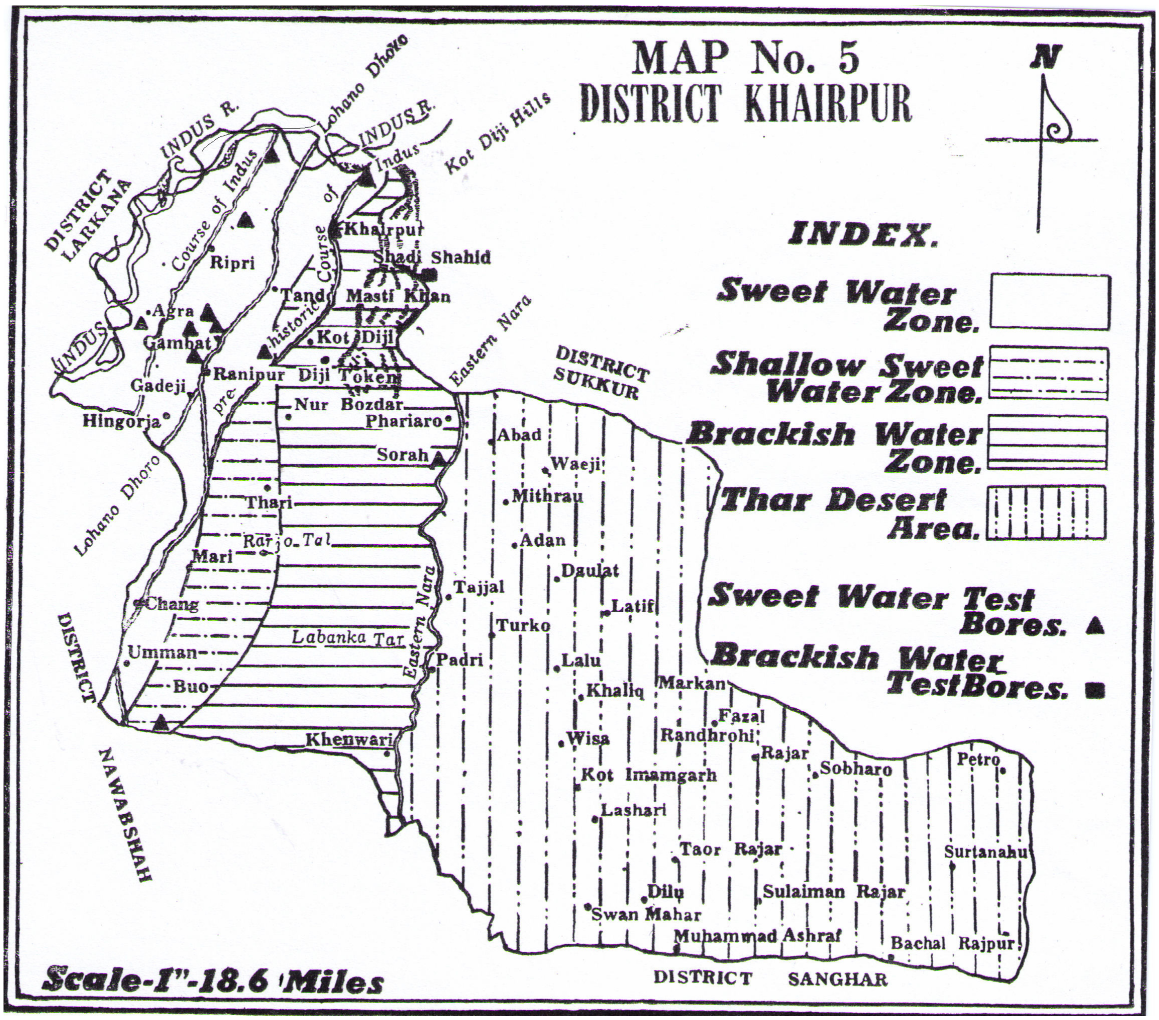
(d) Brackish water zone, similar to that in Jacobabad district. It also _formed under the similar circumstances here.

(e) Hilly tract, which consists of calcareous white lime-stone formations. The chances of getting sweet water in this tract are almost negligible, except in a narrow strip of sand-stone, known as *Nari* series. There is a number of rain fed rivers, like Sain, Khenji and Mazrani, which drain rain water from the hills. Some possibility of sweet water in the bed of these rivers could be investigated. However, even if there is no ground water in the bed of these rivers, the water carried by them could be utilized by spreading it for *sailabi* type cultivation. This type of cultivation to a limited extent is already being practised on these *Nais*. There are plateaux near Kute-ji Kabar and Daryaro in this tract, where some tilting is being done.

This aspect of agriculture in hilly tracts is discussed elsewhere in the book in connection with similar sites in Dadu district. Meanwhile, it is appropriate to mention that there are several natural depressions in the *Kaachho* tract in Larkana district, which form lakes. They are mostly preserved as *Shikargahs.* Some of these lakes have silted up. They could be cleared of the silt and filled in with water in summer, which could be used for winter cultivation. The origin of these lakes is of course due to Sind Hollow.

KHAIRPUR DISTRICT

Broadly speaking, this district has five ground water zones (refer map No. 5).



(a) Hilly tract: The hills in Khairpur district are extention of Eocene series of Khirthar hills, which start 3 miles north-west of Sukkur and reach 40 miles southeast-wards in this district, with maximum width of 15 miles. The Bakhar hills are a part of the same series. This lime-stone is in decomposed state, and the rain-water while passing through these rocks carries salts, which drain to the plains all around making water in

them brackish. This is specially the case in zone (d) adjoining the hills and also in the alluvial plain on the eastern side of hills. This alluvial plain, though in the proximity of Eastern Nara, accordingly, holds brackish water. These hills extend under ground to a considerable area, and their outcrops are visible near Jaisalmir too.

The west of Khairpur District was the area, through which the river wandered for centuries. After making a turn-around north-west of Rorhi-Sukkur hills, it went as far east as Kot-Diji hills. Three courses of the river are shown in map No. 5, two of which belong to recent historical times. The quality of water therefore should normally be good throughout the area, but as the Kot-Diji lime-stone hills have been draining brackish water westward. The above is the case only west of present Rohrl canal which is on the alignment of the central course of river Indus on the famous Lohano-Dhoro.

(b) *Riverine areas,* where sweet water exists upto the depth of 250' or more. Open wells and tube wells in these areas will give the same discharge and are recommended on the same pattern as In the case of Jacobabad district.

(c) *Sweet water zone.* In this zone, sweet water exists upto 250' or more. The area is suitable for tube wells and open wells on the same lines as in Jacobabad district.

(d) *Shallow sweet water zone,* which has the sweet water zone to the west, fringes of desert to the east, and Kot-Diji hills to the north-east. Open wells 30' deep are recommended for this zone. They should be fitted with filters upto 60' or 70', depending on availability of sweet water. Discharge of about 1/3rd of a cosec may well be expected from these wells.

(e) *Desert Zone.* Here the water is mostly brackish at least in the upper strata. There is some chance of getting sweet water from wells close to the Eastern Nara, but it will be more economical to pump water from, Nara for irrigation rather than putting in the wells, at this stage. A time is however going to come when the barrage authorities will no longer allow pumping from Nara. At that stage, wells will have to be put in. The desert zone is covered with a large number of lakes which are either saltish or alkaline. Since these lakes are bye-products of ground water, they are briefly described in the following paragraphs:—

It has already been explained that the Thar in Hyderabad and Khairpur divisions is formed by sand, silt, salts, and fine sea shells, blowing from Rann of Kuchh, which extended as far as Rohri in the recent geological times. In Tharparkar district due to high wind velocities, the sand hills, which are some times 300' high, lie south-west to north-east along the direction of wind. In southern Khaiprur, where wind velocity decreases, the direction of sand hills changes slightly and becomes south-southwest to north-north-east. In northern Khairpur and Sukkur districts, the sand hills lie south-north. The sand hills of Khairpur are not so high as those of Thar. Among the sand hills there are, at places, lakes or *dhands,* which are formed by rain water seeping down the sand mounds. In the neighbour-hood of Nara, there is also seepage from the canal into these lakes. The rain water percolates down the sand, where it is held by impervious clay which lies under the sand. The water so "trapped" or 'perched" comes out in the form of springs or as locally called‘‘Sim". All lakes in the desert area are formed by this process called *"Sim"*. The salt content in these lakes depends upon the salts dissolved by rain water and appearing as *"Sim"*. Water in most of the *dhands* is brackish, as the salts keep on accumulating in them year after year, unless these salts are removed by human hand when water evaporates leaving cakes of salt behind. In some cases, water from wells in the neighbourhood is available at higher water table than in the dhands and is potable. This is actually the *"Sim"* water, which instead of seeping into lakes seeps into the wells. The *dhands* are shallow, but some of them extend about a mile in length. Local belief, however, is that these lakes are unfathomable. Actually they are hardly 10' to 12' deep. At one time, these lakes yielded soda ash. This industry slowly disintegrated as old Hakra was converted into a canal and embankments were raised on its sides, so that water from it no more wandered into the desert lakes away from it. *Dhands* close to Nara are even now always full of water due to seepage from the canal. But this water, no longer so brackish, has instead become an abode of crocodiles and water loving reeds and canes like *‘Sarr’*. The lakes away from the canal are highly saline. In general, the Khairpur lakes are alkaline as compared, to the Thar lakes which are saline. There is always a dispute about the causes of this phenomenon. It is believed that the salts of the lakes, whether in Khairpur or Sanghar district are basically of similar ingredients, but in the Khairpur lakes, due to presence of some bacteria or organic material, the sodium salts are converted into soda ash.

In the desert area of Khairpur district, normally similar ground water conditions, should be expected, as in the desert area of Sukkur district. The deep drilling can give clear indication if there is water at the lower depths in the area.

NAWABSHAH DISTRICT

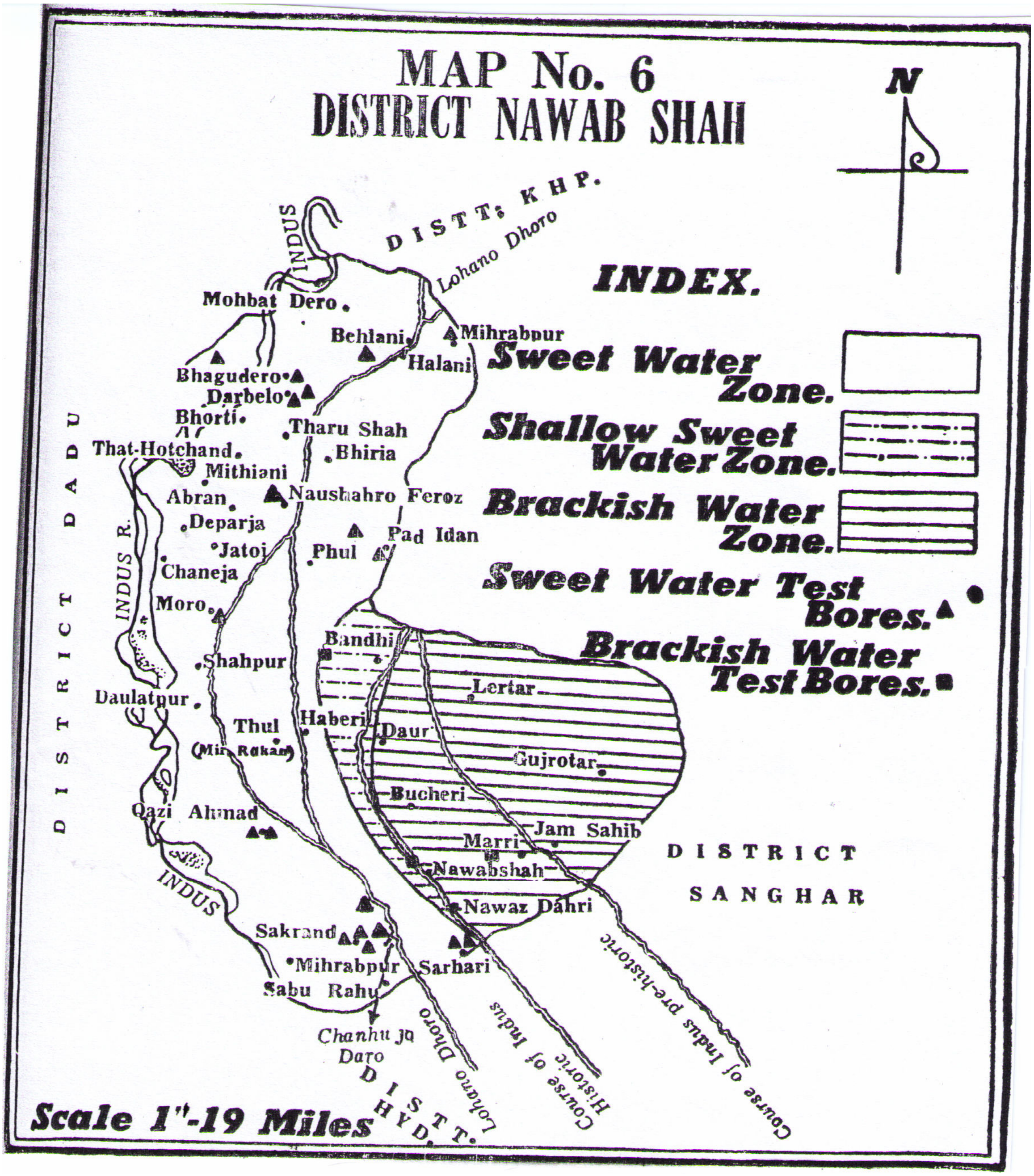
Nawabshah district has been the main stage of activities of the Indus through the ages. Since Alexander's time, it has westerned at least about 18 miles. The famous Lohano-Dhoro is situated in this district, which runs through the length of Naushahro Taluka in the form of either a deep continuous bed of sand or low tract. Along the western edge of Nawabshah and Shahdadpur (district Sanghar). Talukas runs a belt of *dhoras,* ravines and mounds, marking the old beds of river Indus. Beds of the river are traceable near Daulatpur and Sakrand too.

The settlers of this district since pre-historic times must have suffered the ravages of Indus. But today when we are facing shortage of water, Nawabshah district can reap the harvest of water left by the river in the ground, much more than any district in the region.

Nawabshah district from ground water view point can be divided into following three belts (Refer map No.6).

(a) *Riverine areas,* where water is sweet upto a depth of about 200' to 250' or more. The area is suitable for tube-wells and open wells, the former giving about 1.5 to

1.75 cusec discharge and the latter 1/3 to 1/2 a cusec if filters upto depth of 70' or more are lowered in it.



(b) *Sweet water zone.* As indicated in map No. 6, here the water is sweet to depth of 200' to 250's and the area is suitable for tube wells and open wells with the same discharge prospects as in (a) above.

(c) *The Brackish water zone,* which lies to the east of sweet water zone, and extends upto fringes of the desert.

The eastern part of this district classified as brackish water zone was part of Thar desert originally, but flood waters from the Indus in pre-historic times, and human hands later on, have reclaimed large portion of it.

(d) *Shallow sweet water zone.* On the western edge of brackish water zone, there is a strip, where water in shallow depths is fit for irrigation. The zone is suitable for open-wells.

DADU DISTRICT

Geologically and geographically, the district could be divided into two main divisions:

(i) Kohistan.

(ii) Alluvial plains.

(i) The Kohistan area could again be classified as follows:

(a) *Khirthar range* of white lime-stone, found along the main axis of Khirthar and Laki ranges. Shaley layers at Metting and Jheruck, belong to this class, and so do the Makli hills. The rocks emerged between 50 and 60 million years back.

(b) *Deccan trap,* or basalt existing in some parts of Laki range was laid 55 million years back.

(c) *Nari grey sand-stone,* found parallel to main Khirthar range and in the valleys of upper Baran and Nari rivers. The most of low ground from Thano Bulla Khan to Jungshahi is also covered by these series. These sandstone deposits were laid by river Siwalik about 20 million, years back.

(d) *Nari calcareous rock series,* laid 10 million years back, forma ridge parallel to the main Khirthar range, and extend down to Hab River in Karachi district. The rocks are visible near the western boundary of Manchhar Lake.

(e) *Manchhar series,* consisting of grey sand-stone, which extends from Shahdadkot Taluka of Larkana district to Manchhar lake and down to the valley of Baran river. They are also seen in the valley of Karchat and Thano Bulla Khan. They cover a vast area between Laki range and Khirthar range, bordering Lasbella district. These formations are about 1000' thick and were laid about 7,50,000 years back by the river Siwalik

(f) *Gaj series,* consisting of a narrow ridge between Khirthar and Nari series up to south of Tando Rahim and reappearing near Karchat and extending south and west into Thatta and Karachi districts. These were laid before Manchhar and after Nari formations and consist of lime-stone.

All these rocks look barren and desolate from a distance, and after the rains, only bear small shrubs, which grow up adopting the cream yellow colour of the rocks, and serve as an excellent grazing to sheep, goats & Ibex.

Dwarf palm is found on the western flanks of Khirthar, and at higher altitudes wild olive grows; cactus Is also found but mostly in lower Dadu and Thatta districts (southwest Kohistan).

(2) *Alluvial plains:* Alluvial plains in Dadu district were laid in recent geological times between 1 to 4 lac years before the present times.
The plains in general could be divided in 3 classes:

(i) *Kaachho,* which is a barren desolate tract, adjoining the hilly country and is conspicuous for its being devoid of vegetation, and consists of heavy clay and fine material. Though partly formed by river Indus, the denudating hills have contributed greatly to its formation since the recent geological times.

(ii) *Old alluvial,* which practically extends to the present old bed of western Nara. This soil contains more calcareous material than the soils to the east, which have been lately deposited by the river.

(iii) *Recent alluvial,* deposited mostly by river Indus.

BEHAVIOUR OF GROUND WATER IN VARIOUS GEOLOGICAL FORMATIONS.

(i) *Lime-stones:-*They contain calcium salts soluble in water, and therefore water in them is usually brackish, unless their cracks and fissures are big enough to allow quick passage to water through them. Once water reaches the water table, there are less chances of its absorbing lime-stone salts.

In the case of Khirthar range of white lime-stone, the ground water is mostly brackish.

(ii) In case lime-stone is pure and is neither decomposed nor impregnated with salts and does not decompose fast, the water underneath may contain less salts and may be fresh. Such conditions are expected in Nari calcareous series and Gaj formations.

(iii) Sand-stones usually supply fresh water. Sand stones are porous, and at times their porosity may be as high as 30-40%. The ground water in Dada district is associated with Nari grey sand-stone, and occasionally Manchhar sand-stone formations.

In western Johi and western Sehwan Talukas, the Khirthar lime-stone rocks themselves contain brackish water, but down in the valley along Nari and Manchhar formations, the water is sweet. The same way, in the vast area between two main ridges of lime-stone i.e. Khirthar range and Laki range, the ground water is sweet. This valley is traversed by a number of rain-fed streams, namely Gaj, Nari, Naing, Baran, Sukh, Mari, Mol, Sari, Kalu, Dilan, Buri, Salari, Makhi, Shol and Malag. These rain-fed rivers are responsible for seepage of some water in the ground, adding to the water table. Thus there are good chances of getting sweet water in this area.

There is a large number of springs at Pokran, Karchat, Khajur, Shahjo, Arabjo, Thano Ahmed Shah, Osman Buthi, Bachran, Wahi pindi, Ali Murad, Lakhjo, Tando Rahim, Pir-jo-Goth, Pir Gazi, Gorandi, Naing and Diso etc., on which some cultivation is being done, specially at Buthi, Naung and Taung where the spring waters irrigate 200-300 acres. At all these places, pre-historic ruins (3000 B.C.) of Indus valley civilization have been located. The spring water alone could not have been the source of irrigation during those times. Possibly, the rainfall was more, but spring water must definitely have been a perennial source of water for irrigation on small scale and for drinking purposes. Since the sites are not well explored, it is not certain whether those people were employing wells for water, which were so much in use with their contemporaries at Harapa and Mohenjo-Daro. At one site, Ali Murad, a stone well having inner diameter of about 5' to 6' and outside diameter of about 9' was, however, found by Mujamdar in the early thirties. The existence of these historical sites shows that the potential for development of water in Kohistan existed, and it was partially utilized even in pre-historic times. As said above, some cultivation is done on these springs even now, though some of them are hot springs with temperature reaching upto 126° F. Geologists of the last century, who surveyed this area from 1774 to 1776, have also recorded existence of cultivation on spring water. There is no evidence whether the ground water was developed in this area for irrigation in the historical times on the lines of ancient Egypt and Iraq by open wells, or as in Iran by *karezes.* Such information could only be had after large scale excavations of these archaeological sites. The Arabs traded with Sind via this route, and until recently, the road from Karachi to Sehwan passed through this area, as there was an assured water supply for caravans along this route. In fifties of the last century, this hill route from Karachi to Sehwan was improved by the British, and at the distance of every 10-15 miles *Landhies* were built and mile stones laid for guidance and easy movement. Lt. Col. J. Holland in his paper, "Roads from Karachi," written in 1847 has mentioned some sites, where potable water was available. Reopening of this road could easily hasten not only the development of ground water in this area, but also that of its mineral resources.

On the western ridges both in Dadu and Larkana districts, there are plateaux at Lakhani, Daryaro, Kute-ji-Kabar and many other places. The elevation of some of these places is about 5000', and important fruit crops can certainly be grown on them as are grown in the Quetta valley. Some cultivation is already being done on these plateaux.

(iv) *Alluvial formations:-* In alluvial formations, the behavior of ground water depends upon the salt contents In the formations when they were initially laid down, and subsequent drainage of these salts. Given enough time, salts, usually leach out with reasonable amount of natural drainage. In the case of Dadu district, the western branch of river Indus (the western Nara) has traversed the whole width of its upper, section from time to time. This has already been described in Chapter V. As late as 1840, this branch of Indus was even used for navigational purposes, in the inundation season.

The original lower formations were laid by fresh water rivers in the bed of the sea, but the upper formations were laid over the dry land. The upper formations were laid partly by silt of the river and partly by decomposed material from the rocks to the west. The latter contained calcium salts, which added to the alluvial. The net result was accumulation of salts over the alluvial plains, which required to be leached out. The western branch or branches of the river traversed the length and wandered through the breadth of the district through the ages, and large quantities of water seeped in the ground, leaching down the salts and diluting the original brackish ground water. When the river changed the course, the brackish water, however, encroached upon the sweet water again, converting it into saline.

It is doubtful whether the ground water left by the river along the old beds could remain there for so many centuries, but the Western Nara continued to flow as a branch of Indus River and was converted into a canal only as recently as 1901-1903. The supply to the ground water was thus maintained at least partly. The result is that, with a few exceptions, all along the banks of this old channel of river Indus, i.e. the Western Nara, water Is sweet upto a depth of 70' or so, even today.

(v) *Seepage from the river Indus.* The river Indus passes along eastern border of the district. There is water seepage into the ground from the river. Investigations have shown that in the riverine are as, in the month of October, water table is only 2'-3' below the ground level and it gradually slopes to wards the sides. The influence of this seepage exists to a minimum width of 10 miles (with the exception of a few places) and maximum of 20 miles in the strip, water upto a depth of at least 150', and at places even 250' or more, is fit for irrigation.

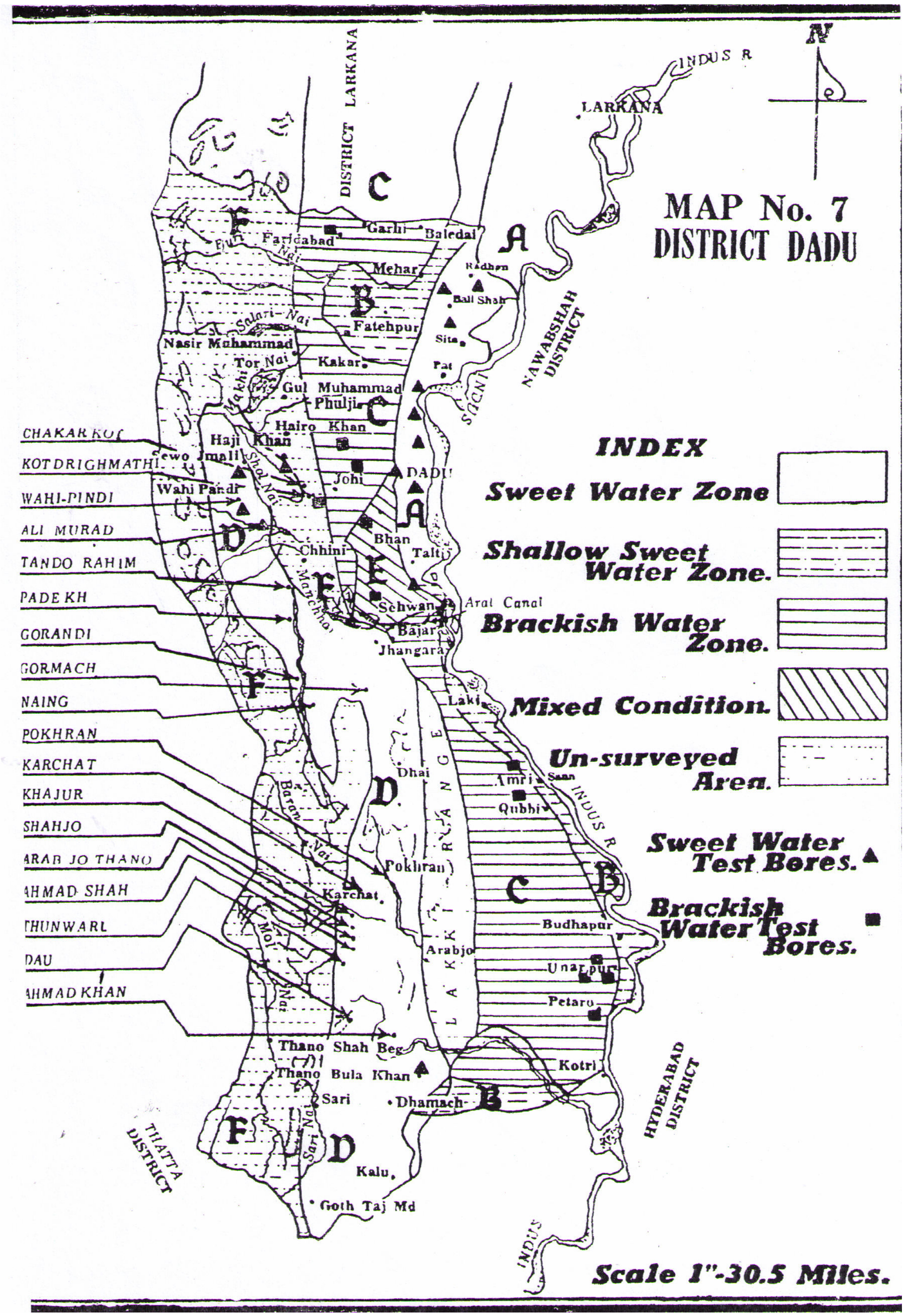
(vi) *Riverine areas of alluvial formations.* In lower Dadu, in the south of Laki range, the rocks are very close to the river, and the thickness of alluvial is only 100' or so. The drainage of salts from the rocks is also towards the river. Under these circumstances, water in a narrow strip of only 2-3 miles from the river bed at some places, is sweet and this again to a depth ranging between 40 and 80 feet only. Below this depth water is brackish, even in the bed of the river.

It is difficult to segregate sweet and brackish water areas in the strip of 2-3 miles.

In upper Dadu north of Sehwan, there is an area between protective embankment and the river; which at times is even 5 miles wide. This tract also contains sweet water upto the depth of 200' or even more. Due to nearness of the river and almost annual flooding, salt contents are as low as 0.03% or 300 parts per million.

GROUND WATER MAP OF DADU DISTRICT

On the basis of the above data, and on the basis of the logs of tube wells installed or test bores carried out, a ground water map of Dadu district (refer map No. 7) has been prepared. As far as possible, use of local knowledge regarding the condition of water in open wells, has also been made. Broadly speaking, the area has been divided in seven zones namely:-



(a) *Riverine area,* shown as "G" on the map. Here the water is sweet upto the depth of 200' or more. The area is suitable for installation of tube wells, giving a discharge upto 1.5 cusecs, and open wells with filters upto 70' depth, and giving 1/3 to 1/2 a cusec discharge.

(b) *Sweet water zone,* shown as "A" on the map. Similar conditions are noticed in this zone as in (a) above. As one proceeds to the western fringes of this zone, water may however be sweet upto 125' only, or at times even upto 100' only.

(c) *Shallow sweet water zone,* which lies to the west of sweet water zone, and through the centre of which at one time flowed the Western Nara, a branch of river Indus. On this branch stand a number of old archaeological sites. Here, water is sweet upto the depth of 70' in most of the area. Open wells 30' to 40' deep with strainers upto 70' depth are recommended. Open wells can give discharge of 1/3 to 1/2 a cusec of water, if properly constructed.

(d) *Brackish water zone,* shown as "C' in the map.

(e) *Mixed water zone,* in the south-west of Dadu Taluka and bordering Sehwan and johi talukas, where at places water is sweet upto 70' and at others upto 200'. Test boring on large scale is necessary to demarcate sweet and shallow sweet water areas in this zone.

(f) *Sweet water zone in the hilly tracts of Kohistan,* marked as "D" on the map. The geology of the area has already been described. Vrendenburg, a geologist, who visited the area in the first decade of this century, produced two papers entitled—"The Tertiary and post-Tertiary fresh water deposits of Baluchistan and Sind", which were printed by Geological Survey of India in 1909 and 1910. According to these papers, the post-Tertiary, upper Siwalik, lower Siwalik and upper Nari Series, were fresh water deposits. In other words, they were not in the sea then, and therefore there are good possibilities of sweet water being there in these formations. There are very great chances of getting artesian conditions, if drilling to the depth of 500' to 1000' is done in the above formations. Normally, open wells, about 80' deep, should give discharge of about .5 cusecs, and tube wells, if deep enough, a discharge of 1 to 1.5 cusecs of water.

(g) *In the Kacho area,* between Laki and Kotri, there is a wide strip of a few miles, which is inundated by river Indus almost each year (shown as B on map 7). This extends throughout the right bank. Water in this strip, upto the depth, varying between 30' to 70', is fit for cultivation, and a discharge of 1/3 to 1/2 a cusec can be expected from open wells, depending upon their depth and the permeability of stratum.

QUANTUM OF WATER

(i) *Alluvial plains:*—Through out the alluvial part of the district shown as areas "A", "B", "C" and "G" in the map, the water is contained in the sand-strata which start at 10’ – 15’ below the ground level, and extend upto 300’-400’ or more. The sand is classified as medium in majority of cases. The water content varies between 25 to 35% of the total volume of earth. The water, in these plains, therefore, is in abundance, and one can safely tap approximately 2.5 cusecs per square mile, without lowering the table substantially.

(ii) *Kohistan area:*— Kohistan area, though the possibility of developing the ground water is very good and at least 1/3rd of the rain water seeps into the ground, the rain-fall is scanty and therefore the rate of recharge of the ground is very low. Average rainfall is about 6" in the lower, 5" in the central, and 4" in the upper part of Dadu.

Assuming that only 2" of rain water percolates into the ground, we can pump 1280 acre-inches of water per square mile. This is approximately equivalent to 1/7th of a cusec of water pumped continuously for 24 hours daily all the year around. In other words, we can pump only one cusec of water from every 6 to 8 square miles. However, the total rocky area in Dadu district is so much, that one can tap approximately 500 cusecs of water without lowering the water table substantially. On this water, one can safely bring 1,50,000 acres of land under ordinary crops.

At present, we have some four tube wells working in the Kohistan area, and all the four are about 200' deep. Three of them are giving discharge of 1.5 cusecs and one of them about one cusec. All are fitted with centrifugal pumps, which have a limit to the pumping capacity in rocky areas due to excessive draw-down. A better picture can be had by installing deep well turbine-pumps.

KAREZES OR KANATS

The *Karezes* or *Kanats* probably originated in Persia or Iraq, in the ancient times, and spread to Afghanistan, and the present Quetta and Kalat region about 3000 years back. They are in fact a series of unlined open wells, dug upto a few feet below water table, and connected at bottom by a tunnel. The tunnel some times is a few miles long. Being on the sloping ground, the horizontal tunnel ultimately finds its way to the ground where the water becomes available as flowing water. In Quetta area, the average *karez* is about a mile long, having shafts (or open wells) at maximum of intervals of 150' (i.e. 30-40 shafts per mile). The cost of the *karez* is between Rs. 50,000 and Rs. 100,000. The average discharge is about 1/2 a cusec.

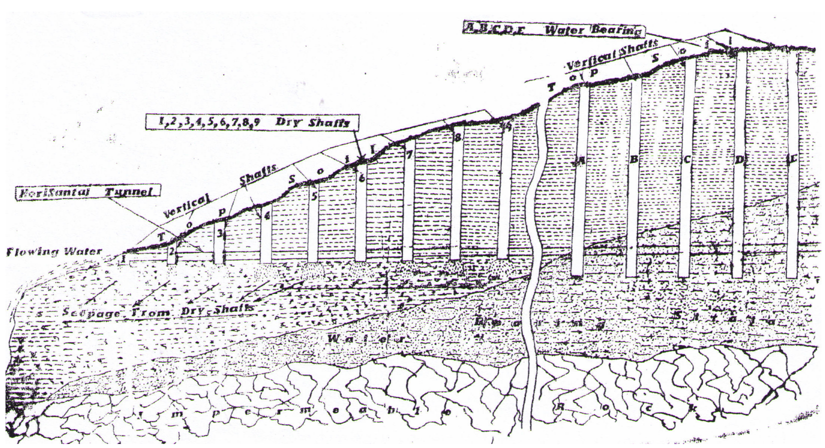


Fig No. 5
Principle of a Karez

With development of diesel pumping sets, the *karez* is the most out-dated method of exploiting ground water. Karez is initially 5 to 10 times as costly as the open well fitted with diesel engine. The maintenance and running cost of diesel operated pumping sets (½ a cusec capacity), fitted on open wells, will approximately be Rs.7000-annuaally, if pumped 24 hours a day. The *karez* on the average costs more than that, only on annual cleaning, if there are heavy rains, *karezes* collapse, and cost of renovating them becomes too high. Occasionally, there are even fatal accidents, while cleaning a *karez.* Recent studies at Quetta show that in *karezes,* there are heavy losses of water due to absorptions or seepage in the dry shafts. The exposed surface area also increases due to large number of shafts, and therefore there are excessive evaporation losses. The karezes being perennial streams, flow even when water is not required by crops. The total losses are thus estimated as 42%. On the above grounds, this type of exploitation of ground water should be ruled out totally in the Kohistan areas of Hyderabad and Khairpur Division.

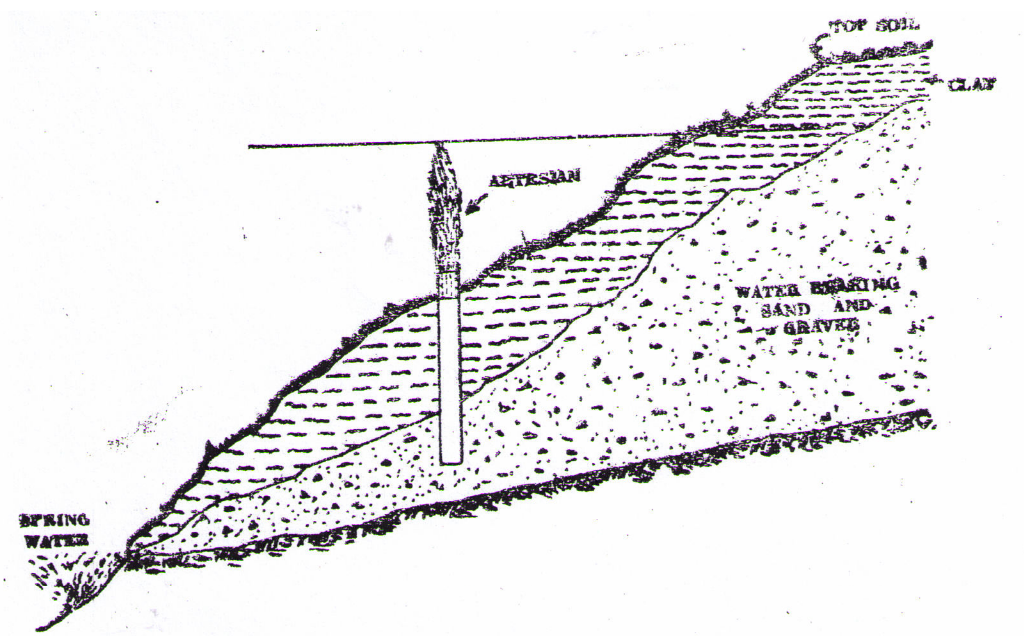


Fig. No. 6
PRINCIPLE OF ARTESIAN WELLS AND SPRINGS.
(Chapter II and Chapter IX Dadu, Larkana and Thatta districts).

ARTESIAN WELLS

The existence of springs is a clear indication of ground water in a particular area. In hilly tracts, we have springs at Rani-jo-Kot, Wahi-Pindi, Tando Rahim Khan, Pir Gazi. Naing, Pir Ari, Tong, Pokran, Gorandi, Phadeh, Kandhar, Garmach and Osman Bhutti etc. In fact, a spring is nothing but a natural artesian well. Artesian condition does not mean that water should start flowing freely against gravity. If by digging an open well or drilling a tube well, after cutting particular strata, the water table rises, the condition is considered as artesian. By drilling 200'-300' or more, we may meet artesian conditions at many places in the whole rocky region, classified as "D" in map No.7. Figure No. 6 explains principles of spring and the artesian well.

DEVELOPMENT OF WATER IN THE BED OF STREAMS

The rocky zone is intersected by a large number of rain-fed streams known as nail. The most important of these are:—

1. Gaj (which at times of high flood discharges 1,50,000 cusecs of water).
2. Dillan.
3. Burl.
4. Salari.
5. Makhi.
6. Shol.
7. Nari.
8. Malag.
9. Naig.
10. Baran (High flood discharge has sometimes hit, 2,50,000 cusecs).
11. Suk.
12. Marai.
13 Sann (Ranikot).
14. Mot.
15. Sari.
16. Kalu.

Some of these, *nais* flow only for a short period during rains, but the major ones like Naig, Gaj and Baran keep: flowing sometimes even upto February. On excavation in their bottom, they are found to contain water at a depth of a few feet. On both the banks of these streams, there are chances of getting sweet water. Their banks could be developed on the lines of Malir River at Karachi by putting in open wells or tube wells. Open wells could also be sunk in some of the more dry streams. Right in. the bed of these nais or along their banks in the Zone, "D" there are almost 100% chances of getting water. In case of zone "E", streams, like sann river and, lower baran (after leaving Thano Bulla Khan) pass through lime-stone rocks. The quality of water in these streams is therefore bound to be affected by local conditions, and water should be tested before use. Chances in the case of Sann *nai.* are that ground water is brackish, though in the case of lower Baran nai chances of sweet water are more, specially on its right bank.

SAILABI OR SOIL AND WATER CONSERVATION

In Quetta and Kalat divisions the rain water is conserved by putting temporary or permanent earthen check dams in the bed of rain-fed rivers. Rain water during flood is diverted across these check dams, and spread over a large area prepared in advance for cultivation.

The area so prepared has an embankment 3'-4' high, and is arranged in plots of different sizes governed by the contours of and. The water so accumulated gets slowly absorbed in the land, raising its preserved moisture. This water also deposits silt in the plots, adding to their fertility. Wheat crop is raised on such plots, the yield of which sometimes is as high as 20 to 25 maunds per acre. The entire Kohistan area (including that of Thatta and Larkana districts) is 7000 square miles, out of which only 2000 acres are cultivated on an average by this method annually.

The entire population of Kohistan is nomadic, ever moving with their flocks, in search of fodder and food. No sooner a particular area ceases to provide grazing to their flocks, than they shift to new pastures. There are only a few permanent villages in Kohistan. In dry years, when rains fail, the population moves to adjoining plains. They make their mobile dwellings from reeds tied together into make-shift tents with ropes made from brushes, and earn their living from cattle produce like ghee, butter and wool, out of which they sometime make woolen carpets, and loading bags etc. For colouring their wool for carpets etc; they use the indigenous material known as *lakh*, which they extract from *babul* plant. They breed sheep and cattle in lower Kohistan (including Thatta), and camels in Kaachho, a desolate, tree-less tract, east of the rocks and west of Sind-Hollow.

Along the *nais,* plants of alluvial plains like tamarisk, *kandi,* (poplis) and panpas grass are common. On hard patches, *ber* tree is also found. All these plants are indicators of fair quantities of ground water of good quality. Occasionally in low patches, where there is accumulation of salts due to seepage etc *Ak* and *Khabar* plants are also found.

Typha reeds and canes also grow along the *nais*. The typha is used for making boards for dwellings and so the reeds, Brushes, sedges, and other wild grasses are used as horse and cattle feed. Baskets are made from typha, which, at one time found almost a ready market in Sind villages. Some grasses like are used for making ropes, which also find good market for packing as well as for netting of cots. Cheaper type mats for floor covering called *tada* are also made from the reeds. In some of the depressions in the area, perennial water in the shape of ponds is also encountered. Crocodiles are many times found in such places, which are a danger to both human beings and the cattle. In some cases, fish is also found in these ponds.

The hilly tract of Dadu, Larkana and Thatta districts having rain-fed rivers or even streams, could be developed by the water-spreading or *sailabi* method. Water-spreading has still another advantage. Part of water percolates down in the ground, to add to the water table. If the water down below is fit, it could later on be pumped out and used for irrigation.

SCOPE FOR WIND POWER DEVELOPMENT IN DADU DISTRICT

In southern area f Dadu district, around Thano Bula Khan, there are high wind velocities. No data for Thano Bula Khan is available, but the data for Hyderabad and

Karachi would suggest that the wind velocities of 10-20 miles per hour are prevalent in the area for about 2,000 hours, 13-18 miles per hour for about 800 hours, and 18-24 miles per hour for another 200 hours annually. A wind mill in the area can therefore operate 3000 hours. The wind blows for longer hours in summer as compared to winter. This is all the more an advantage, as water requirements of the area are at their maximum in summer.

Wind mills, though not as economical as diesel power, have relevance in the Kohistan area, where means of communication being poor, transport of oils and greases will be a serious problem, and mechanics for maintenance or repair of diesel engines would hardly be available in time. In this part of Kohistan, there are quite a number of small villages, constantly facing difficulties of water supply for themselves and their cattle. The area, being important grazing land for cattle, does deserve attention, so that livestock industry receives proper encouragement, wind mills, at a few sites, could be easily installed as an experimental measure for pumping out water, which could then be stored in small surface tanks, for use by man and his animals. Similar installation can be done in the Kohistan area of Thatta district as well.

The cost of a wind-mill of 25' diameter on a 60' tower would be Rs. 20,000, and the cost of open well approximately Rs. 7,000.

THATTA DISTRICT

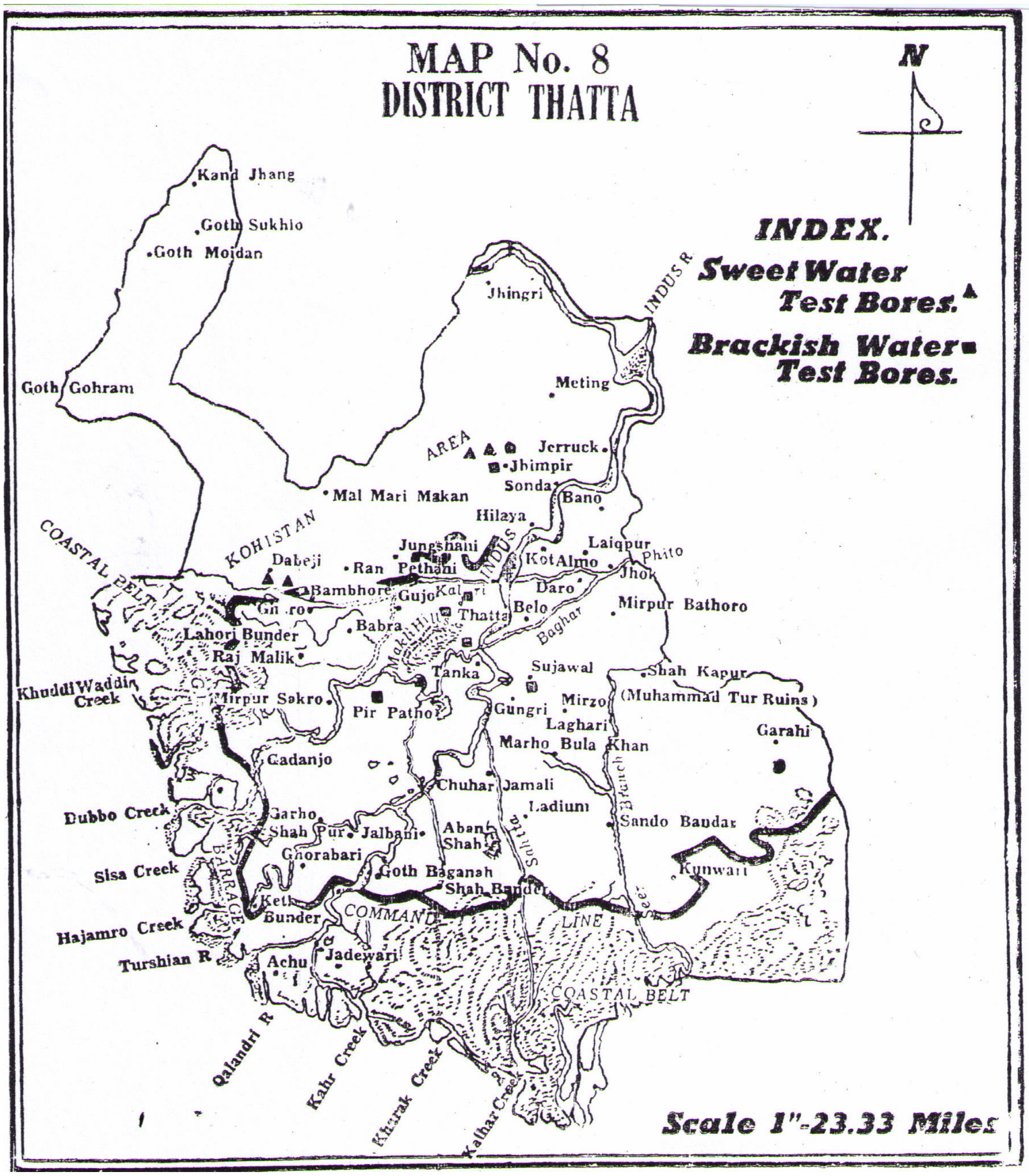
Thatta district could be divided in the following four ground water zones.
(Refer map No. 8).
(a) Kohistan area.
(b) Plains of G.M. Barrage.
(c) Riverine area.
(d) Coastal area.

(a) *Kohistan area.* From ground water view point, Kohistan area of the district may again be divided into three groups:

(i) *Meting shale,* which consists of white pale-coloured lime-stone, seen at Meting. It extends to Jhimpir on the east, to Jherruck on the south, and appears at Makli again. The same hills are again visible at Pir-Patho, and still down, south of Pir-Patho, on the left bank of the river Indus near a place called Aban-Shah, where Alexander had landed in 326-27. B.C., when this hill was an island in the sea. This area contains very little water and is highly impregnated with salts.

(ii) *Nari sand-stone,* which extends from Thano Bula Khan to Jhimpir and Jungshahi. The valley is covered with sediments of other rocks also. Test boring was done in a small area around Jhimpir in 1959. In about 50% cases, all in Nari formations, water was found fit for cultivation. Large scale test boring is necessary. There are chances of getting sweet water in the whole tract covered by these series, i.e. area north-west of Jhimpir and north-east of Jungshahi, extending all along to Thano Bula Khan.

(iii) *Laki lime-stone series.* In the Laki lime-stone series, existing north of Jhimpir, there is brackish water. The shaly lime-stone, which is impregnated with saline matter, will impart salinity to water existing in its belt; but where-ever water exists in the pure lime-stone, it is expected to be comparatively fresh.



(iv) *Nari formation.* These formations consist of clay and sand stones of Tertiary formation. These may contain sweet water, but as they are made of finer material, the yield of water will be low, unless deep drilling is done and deep well turbines are installed. The area extends from Jungshahi to Ran Pathani. Two tube-wells, with centrifugal pumps, installed at Ran Pathani in 1958 and 1959, are yielding 1/2 a cusec of water each. A deep well turbine would probably give a much higher yield.

The other conditions in Kohistan are similar to those in the Kohistan area of Dadu district. There are large numbers of rain-fed *nallas,* which traverse the hills. Water in the bed of these rivers may be suitable for irrigation.

The rain water from *nallas,* specially from Kalu *nai,* which passes near Jhimpir, could be spread over the land and cultivation carried out on preserved moisture. Approximately 10 miles north-west of Jhimpir, this *nai* has a loop, where it could be dammed, and water spread over an area of approximately 25 sq. miles of land, which is a good quality alluvial soil, and at present lies barren except for a few dwarf *kandi* trees scattered all over. The people are nomadic, and living conditions are similar as in the Kohistan area of Dadu district.

(b) *G.M. Barrage area.*

The alluvial plains of G.M. Barrage in Thatta and Hyderabad have emerged out of Rann of Kuchh in the recent times due to silting up. During maximum flood, the silt contained in the river Indus is about 0.6%. Taking 100 days as good average of high flood, the silt carried to sea will approximately be 120 million cubic feet, which will cover 38 square miles to a depth of a yard. Thus the river will form 22 square miles of new land each year, considering the present depth of the beach.

The delta is therefore advancing every year. At the time of Alexander's conquest, the sea extended upto Gujo, and the area from Gharo to Ibrahim Hydri was covered by sea. From Gujo to Gharo, and perhaps to the north it was dry, but to the south-west it was definitely under sea. The map No. 1 shows the delta limits at the following periods of history:

1. Greek times (Alexander's conquest - 327 B.C.) (36 miles average). At this time the sea extended upto Gujo area.
2. Arab times 71 l A.D. (16 miles average).
3. Middle ages (l0 miles average).
4. Eighteenth Century (2 miles average).
5. The present time.

It could thus be seen that the sea is receding at an approximate rate of 1 mile per century. This would also indicate that the whole G.M. Barrage command area must have been under the sea, ten or twenty thousand years ago. Under such conditions water in the plains of G.M. Barrage, whether in Thatta or Hyderabad districts, must be brackish. No wonder that the "Chach Nama" refers to the report about conditions in the Sind delta area, said to have been laid before the Khalif to the effect that "the water in lower Sind was dark and dirty, its fruit was bitter and poisonous its land was stony and rough and its earth saltish."

The Indus kept on changing its courses in this delta from time to time. Major General Haig's "Indus, the Delta country" is a good study of the subject. The river Indus and Hakra (or the Eastern Nara), while passing through a given area must have diluted its brackish water down below, but with change in their courses, the salt water advanced again, turning the fresh water deposits saline. Phulleli and Puran, however, have maintained their present course for a long time, and therefore fresh water to shallow depths could be expected along their banks, but that too would be in small quantities and for drinking purposes only. The Agricultural Department installed three tube wells in Tando Mohammad Khan in 1960, out of which two are still supplying sweet water while the third has already turned brackish. Same was the case with two tube wells installed at Fauji Sugar Mill farm in 1955-56. They were put in near a lake on an old bed of river Indus, but turned saline after a very short time. The two existing sweet water tube wells on Mir Ghulam Ali's farm have so far shown no change, possibly because of their closeness to Phulleli and to an old branch of river Ren, which is visible at a few hundred yards from them. Some open wells also exist along the banks of Phulleli in its upper reaches. A few hand pumps have been installed about half a mile from Puran, which also have kept up their supply of sweet water. Search for sweet water in the district could therefore be fruitful only along the old channels and beds of the river. With the exception of upper reaches of Phulleli and Puran, large quantities of sweet water should not be expected in the whole G.M. Barrage area.

(c) *Riverine area*.

Study of ground water in the riverine area of G.M. Barrage tract has not been done, but in all probability, water upto the shallow depths of 30' or so could be sweet. In many villages out-side the river protective bond, there are shallow sweet water wells only 15'-20' deep for potable purposes. If sweet water is at all located, due to fineness of sand in the area, discharges of not more than 1/8 a cusec could be expected from open wells. Further investigation can be done by test boring.

(d) *Coastal belt.*

The water near the coast is bound to be brackish. The coconut plants alone can stand saline water to some degree. Investigation of the quality of this water could be fruitful for judging the prospects of coconut plantations in the area. The-coastal belt of Thatta district comes within the zone of high wind belt. Since the water table in the coastal belt is high, and the wind velocity is also higher than in other areas, and with much longer duration, a 25' wind mill costing Rs. 20,000 could be utilized to pump 1/8 of a cusec for approximately 4,400 hours annually. Such a capital investment is obviously too high, but on long term basis, it may be worth while, if the coconut plantations prove successful in the belt.

SANGHAR DISTRICT

A small area of Sanghar district holds sweet water. Three courses of river Indus can be distinctly located in this area, one of which leads to the Eastern Nara and is definitely pre-historic. Two other courses, one of which ends into the Eastern Puran and the other into Western Puran, belong to the historic period - the first to the times of Alexander, and the western-most to the time of the Arab conquest. The courses are shown in the map. The last course of Indus was near Shahdadpur. The old bed is still visible nearby. The ruins of Mansura stand on its banks. The river left large quantities of sweet water underground, which have not yet been encroached upon by saline water from the east. Only limited drilling has been done in this district so far.

There should be a zone of shallow sweet water in the district between 2nd and 3rd old courses of the river, belonging to historic times. Test boring and survey of existing wells can help in getting more information about this area.

Further to the east is the desert, the conditions of which are similar to the Thar desert, with the only exception that it is less grassy, and gets less rainfall.

HYDERABAD DISTRICT

Geologically and geographically Hyderabad district is divided into two parts:

(i) The Ganjo Taker hills, which are an out-crop of the Khirthar lime-stone, and are seen around Hyderabad. The hills extend below the ground to a considerable area. An extension of similar rocks was located at Badin, at the depth of 950', by Standard Vaccum Oil Co,. while drilling for oil, a few years back.

(ii) Recent and sub-recent alluvial formations, which cover rest of the district.

The Ganjo-Takar hills (shown in map 10,) which are in partial decomposed state, absorb rain water, which goes down into their cracks and fissures up to a depth of about 200'. The water absorbs salts from the rocks and turns brackish. This water is totally unsuitable for crops, or human consumption.

The water does not remain static in the rocks, but drains slowly towards all sides. Investigations show that the influence of this water spreads to a width of approximately 8 to 9 miles on all sides. Thus, on Hyderabad-Mirpurkhas road, water is brackish upto the 9th mile, on Hyderabad-Hala road upto Miani forest, and on Hyderabad-Tando Mohammad Khan road it is brackish throughout. On the western side, sweet water should not be expected even in the bed of the river except at very shallow depths.

However, in 9 miles around the hills, the zone covered by alluvial formations holds sweet water in shallow depths upto 40' or so, which is fit for cultivation and for human consumption. This water could be exploited by open wells, on small scale. Putting down large number of open wells will lower the water table, which will in due course be replaced by brackish water from the hills, rendering the whole area saline.

ALLUVIAL PLAINS

Alluvial plains of the district could be divided into two distinct formations:—

(i) Recent alluvial.

(ii) Sub-recent alluvial.

These could further be divided into geographical zones of Kacha (riverine) and Pacca areas respectively.

Sub-recent formations are about 2,00,000 to 4,00,000 years old, and the recent formations are less than 1,00,000 years old.

The area south of Tando Fazal is of recent formation, and was covered by Rann of Kuchh till recent geological times. It was a shallow sea, and went on slowly getting silted up, due to sediments brought by river Indus and the Eastern Nara. The coast line was as near as in the vicinity of Badin and Jati, only 2500 years back, and Aban Shah now a hill, was a sea island at the time of Alexander's conquest, as already mentioned. These facts would indicate how late has been, the deposits of these formations.

Spill-waters of Sutlej River, till 1226, were flowing in the present Eastern Nara and Puran beds. The Western Puran borders Hyderabad district south of Pangrio. Because the formation is of very recent origin, the salts contained in the sub-soil have not leached out and therefore ground water is highly saline or brackish. The salt contents increase with the depth and sometimes reach 70000 parts per million parts of water. This is more than twice the salt content of sea water. The logs of a bore carried out by Standard Vacuum Oil Company at Badin for oil, show the existence of alluvial formations containing brackish water having salinity of 30,000 parts per million at depth of 950' Beyond this there is rock, which contained water having salinity of 100,000 parts per million from 1762' to 6533'.

Old River beds. The map No. 10, shows the old beds of river Indus through the district in the historical times. The river has wandered across the entire district from time to time. The periods during which the river flowed at different places have been explained in chapter IV.

AN IMPORTANT RIVER BED

The Indus was flowing down south till it changed its course near Unarpur during the days of Ghulam Shah Kalhoro in the year 1758. Prior to that it was flowing from, present Unarpur, straight south of Nasarpur and Tando Mohammad Khan. The old bed is traceable from Hala downwards, by a large mass of sand dunes and depressions which pass Nasarpur, and down south to Shaikh Bhrikio. Below this point, the old bed is not well defined. From Tando Mohammad Khan the river was flowing south to the Rann of Kuchh and was called Ren River. A western branch of it, near Tando Mohammad Khan, known as *Phito*, made a loop towards Jhok.

At Jhok, it branched off into two different channels, one of which passed south of Thatta, and the other north of it, both again meeting near Mirpur Sakro One of these branches was called Kalri, and the other Baghar.

HISTORICAL TOWNS NEAR THE OLD RIVER BED

Old towns like Nasarpur, Bukerani, Khokhar, Tando Mohammad Khan were thus on the main, river, whereas Matli, Jun (now in ruins) Lowari and Kadhan were on the Ren river, Bulri and Jhok were on Phito and Pir Ali Mardan, Khorwah and Jati were on another branch of it known as seer. Mohammad Tur (Shah Kapur) was also on the Seer branch.

GROUND WATER D EPOSITS OF THE RIVER IN RECENT FORMATIONS

The water from the rivers in the arid zones always seeps into the ground on both sides and remains there for many centuries, as the natural rate of drainage of soils in, arid zones usually is very low. However, since the formations through which the water seeps happen to be of different geological times, the chemicals present in the formations have an influence on the ground water. In case of recent formations, the seepage water from river acts with salts present in the soil and slowly runs brackish. Over the centuries, this is what has happened in the whole area.

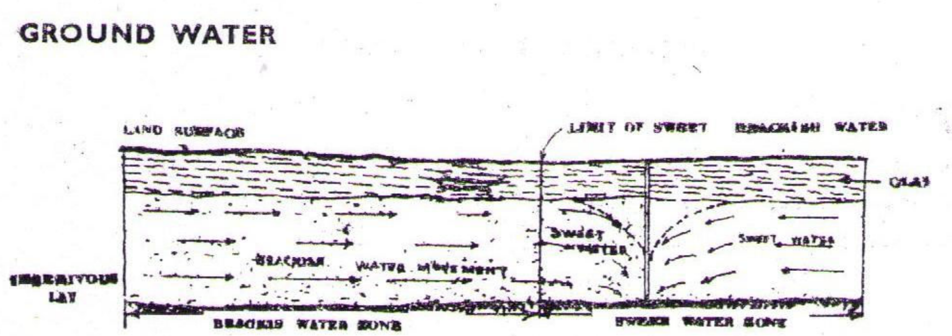


Fig. No. 7

Principle of encroachment of brackish water on sweet water when the rate of pumping exceeds the rate of replenishment

The figure shows the brackish or salt water on the fringes of sweet water zone. As the fresh water is pumped, draw-down occurs which induces flow of water from brackish water zone and slowly sweet water turns brackish.

WATER IN THE SUB-RECENT FORMATIONS

(a) *Water due to old rivers.*

Sub-recent formations in the area are known to lie to the north of latitude 25º-20º passing east to west, between Tando Fazal and Khokhar village. South of it, the formations are recent, and have been reclaimed from Rann of Kuchh due to silting up. The water in the sub-recent formations (2,00,000 to 4,00,000 years old) is sweet, as they have been drained of the salt initially contained in them. A large number of borings have been carried out in this area, and the water encountered is sweet to a depth ranging- upto 350', depending on the distance from the old river. As distance from the old river bed increases, the depth of sweet water decreases. At a distance of approximately 7 miles, it falls to 150'. The ground water is sweet at Uderolal, Herolal, Jhandomari, Mushaikh, Hoti, Sultanabad, Tando Aliahyar, Nasarpur, Palijani, Bukerani, Khokhar and Tando Fazal, as it is the water left by the river Indus, which was flowing through this area upto 1758 A. D. There is some percolation from the present irrigation channels and the fields into the area, and the water table is continuously rising. However, on fringes of the sweet water zone (as shown in map No. 10), there is brackish water on the south and the east, in the recent alluvial formations, which as described above are remnants of the Rann of Kuchh. On the west there is seepage of brackish water from Ganjo-Takar hills. Thus the water on 'fringes of the area will slowly start turning brackish as pumping is done. This has already been demonstrated by the increasing salt contents at Tandojam, which lies on the margin of this belt. However, exploitation of the whole area on this account should not be avoided, as there is enough seepage from the channels and the fields, and the area as a whole will not be badly affected except possibly at the fringes.

(b) *Water due to seepage from the present river.*

There is a continuing seepage of water from the river Indus on both sides to an approximate width of 10 to 15 miles, and in this area, the water is accordingly sweet. The water at Saidabad, Hala, Bhit Shah, Sikhat, Khaibar, Matiari and down upto the Miani forest is sweet, because of the seepage from the, river. At isolated places near Matiari and above the Miani forest, there are pockets of brackish water, which are due to underground drainage of salts from hills near Khanpur on the other side of the river in Dadu district.

The whole area has a very great potential for development of ground water, which is sweet upto a depth of more than 250' in most cases.

WATER IN RECENT FORMATIONS

In the recent formations, the old river courses must have left huge quantities of water, but these slowly turned saline, as the brackish water of the surrounding area encroached upto it. The sweet water could be located at the same places only along the old river beds, upto the depth of 20'-70'. A number of towns namely Jhok, Bulri, Pir Ali Mardan, Tando Mohammad Khan, Matli, Badin, Lowari & Khorwah, get their supplies from these deposits, and so is the case with Jati in Thatta district. Recently, few hand pumps were installed near the bed of Western Puran, south of Pangrio, and sweet water struck upto a depth of 70' or 80'. But all these are isolated pockets, and can supply sweet water only when some water flows in the old beds of the channels. Any large scale pumping will disturb equilibrium, and due to lowering of water table at the pumping site, brackish water from the neighbouring area will displace it, converting the ground water brackish. Any attempt for exploitation of ground water for irrigation purposes in the area, should therefore be discarded, except possibly in the case of very small scale cultivation for kitchen gardens.

There is some seepage from the present river on both the banks in the recent formations, but the salt contents in the existing ground water are so high, that except a few pockets water is brackish all along the river.

The river Indus passes through the upper western boundary of the district. West of the river there is the range of Khirthar lime-stone hills, the base of which is in the Dadu district. The brackish water from the hills drains towards the river, but in all probability we should expect sweet water in the riverine area upto the depth of 200' from Hala upto Miani Forest, except in small pockets near Matiari. South of Miani Forest and down upto Jamshoro, due to heading up of water on account of the G.M. Barrage, sweet water can be expected upto the depth of 30' to 60'. Below the Ghulam Mohammad. Barrage headworks and upto Jherruck, water is brackish except in isolated pockets. No investigation of this area has been done.

WATER BEARING STRATA

Throughout the alluvial formation, there is waterbearing sand at the bottom. On the top there is a clay and silt layer which is about 25' thick in the sub-recent alluvial formations and only 12'-15' thick in the recent formations.

The sand is medium in upper parts of the district and gradually becomes finer as it reaches the coast line.

The medium type of sand, when met, will give a yield of about 1.5 cusecs of water, if the, tube-well is 150', deep, and will yield 1/3 to 1/2 a cusec from open wells 40' deep, with 30' filters.

The entire sand layer is saturated, with water. The, water table in the, whole area is along the sand line, and no dry sand is encountered anywhere. The recent alluvial, where water table is, between 8' and 12' can therefore be considered as, water-logged, as this water, can rise any time by, capillary action through 8' of the top clayey layer.

RESULTS OF THE TUBE WELLS, ALREADY INSTALLED IN THE AREA.

Map, No. 10, shows the, area of sweet, and brackish, water and the location of various test, bores and their results. The map shows the existence of sweet water tube-wells at Jhandomari and Tando Mohammad Khan, in the, brackish water zone. Here the water is sweet because the wells are installed in the bed of old river Renn, which at a later date became a canal known as Phulleli from the Indus. The water is sweet upto 190’ or so. Only a mile away from these tube wells, water is brackish. These wells are on fringes of the sweet water zone, and at least one well has already, turned brackish, though two more at Tando Mohammad Khan and one at Jhando Mari are still supplying sweet water.

SCOPE FOR WIND POWER DEVELOPMENT

In Hyderabad district, the wind, pattern is such that the wind velocities of 10 to 12 miles are prevalent for about 2000 hours annually; of 13 to 18 miles for about 800 hours and 18 to 24 miles for another 200 hours. The wind mills can therefore operate 3000 hours annually. The wind blows for longer hours in summer, as, compared to winter. This is all the more favorable, as water requirements in the area are maximum in summer.

However the wind mill is not as economical as diesel power, and it should be encouraged only at those places where the transport of diesel oil may be a problem. For municipal needs, it is indeed preferable to diesel power, as it cuts down the red tape in repairs and maintenance.

A 25' dia wind mill on 60' tower shall give an approximate discharge of 1/8th of a cusec (as much as the Persian-wheel) against a head of 40' and will cost Rs. 20,000 including installation. A few wind mills could be tried: for town water supply, to start with.

SUGGESTED METHODS FOR DEVELOPMENT OF GROUND WATER

(i) *Sweet water zone*---open wells about 30' to 35' deep, with strainers upto a depth of 70' to 80' and tube wells 150' to 200' deep.

(ii) *Along beds of old rivets*---open wells for drinking water only and irrigation wells on very small scale near existing channels.

(iii) *Riverine area north of Miani forest*---tube wells 50' to 200' deep and open wells as in area (i).

(iv) *Riverin area south of Miani forest, upto Ghulam Mohammad Barrage Head works*---open wells as in area (i).

(v) *Riverine area south of G.M. Barrage head works*---open wells, if sweet water is available.

THARPARKAR DISTRICT

As explained in the preceding chapter, the Pat, Thar, and Parker were formed by the action of southwest winds which blew sand, tiny sea shells and salts over the desert area. There is some contribution of denundating hills between Budhapur and Karachi including Ganjo-Takar also, but most of the sand came from the old sea (the Rann of Kuchh which extended upto Rohri). The occasional sand-stone layers are met, but there seems to be the sands formed sand-stone. These two are responsible for the "perched water zones" in Pat and Thar.

In Nagarparkar, an 1100' rock out-crop lies in the centre of the peninsula, and the soil is not so deep. Occasional sand-stone layers are met, but there seems to be absence of calcareous formations, particularly in the sweet water zone.

In Thar, sand hills formed due to south-western winds lie parallel to each other. The rain water flowing down the sand hills does not move as run off, but is absorbed in the ground. It is subsequently lost largely in the atmosphere, by evaporation and transpiration, and the rest percolates down in the ground in small quantities. There are no rain-fed streams in Pat and Thar. In Parkar area there are a few streams, which flow for a few hours after rains. Only in the southern parts of Mithi and Diplo, near the edge of the desert, water collects and flows to the Rann of Kuchh in nominal quantities. Since the absorbed water remains there for some time, wheat crop is raised in isolated patches, on the preserved moisture of the soil.

There are low valleys between the high sand hills, lying in high wind belt near the lower Indus delta, in which cultivation to a limit is done on rain water. These sand hills grow smaller further east. *Bajra* is the main crop in these valleys. Mostly the land is not prepared in advance. Only after the first shower, some ploughing is done. Even a small quantity of rain suffices to grow a surprisingly good crop, and profuse green vegetation crops up immediately all around. The crops grown on rain water are *Bajra, Till, Sarseem, Jambho* and castor.

In the Thar area only those places, where ground water for human and cattle consumption is available, are populated. The Economy of Thar depends on grazing. Complete failure of rains in one year or partial failure in two successive years often causes famine. The cattle which is the only capital and mainstay of the people when overtaken by such conditions, cannot cross 150 miles of the desert, and perish almost entirely. Goats and camel alone which live on the desert shrubs, survive such conditions. Many tracts are un-inhabitable mainly for want of drinking water, which lies buried as deep as 300 feet.

There are approximately 3,50,000 heads of cattle in Thar desert. Their life, as much as the life of their human masters, depends on rain water. In every 11 years there is a cycle of about 2 years of scanty rain-fall, when famine conditions exist, and the cattle perish for want of food and water. The water from wells is to be raised by human beings, who under such circumstances, migrate, leaving their cattle behind.

WELLS IN THAR AREA

A large number of small diameter wells exist in the Thar area (Ref: map No. 11). The largest number of them is in Chhachro Taluka, which gets less rain fall than Mithi, Nagarparkar and Diplo. The average rain fall in the desert Talukas is as under:-

1. Nagarparkar	14”
2. Mithi	11”
3. Diplo	11”
4. Chhachro	10”
5. Urnerkot	8”
6. Khipro	6”

7. Ubauro	4”
8. Mathelo	4”
9. Rohri,	4”
10. Khairpur District	5”

Along the edge of Rann of Kuchh, water is found at the depth of only 26' to 30', whereas, away from the Rann, the water table becomes deeper. It is difficult to generalize but in the case of limited areas there seems to be a general co-relation between the depth of water and level of ground. The level as a rule rises towards Aravalli hills, and therefore in the Thar area it rises as one goes east-wards from the Indus plains or northwards from Nagarparkar. The water depth also seems to increase on the similar lines. In the case of Pat area, reverse will be the case. Deepest wells are in Khipro Taluka, on the Indian Border. Near the western fringes of the desert along Eastern Nara or old Hakra, water is available in plenty at shallow depths. This water had its origin from the river Hakra, which remained dry for atleast 6 centuries, and as such the original sweet water turned brackish. 30 miles eastwards from Nara bed, water is reached at the depth.of 200'. Near the Indian border in Chhachro and Khipro Talukas.one must go 300' or more to get some water. This water is being utilized for drinking purposes, but invariably salt contents are too high to make it fit for irrigation.

On both the sides of Hakra or old Nara, water up to a depth varying between 50' to 70' is sweet. The Department of Agriculture carried out some borings near Umerkot, where sweet water was located upto approximately 60' to 70'. This is the residual water due to seepage from the old Hakra River. In Diplo Taluka, along the bed of old Hakra or Eastern Puran, in a width of 2 miles or so, some, open wells have been dug, which contain sweet water. Similar pockets of sweet water may be expected along the whole length of Hakra, though water is brackish in the surrounding areas. This is a special phenomenon. The sweet water being lighter than brackish water floats on it. So long the water supply in the Nara bed is main-tamed, water on both the banks, in narrow width, and shallow depths, shall remain fit for drinking, and even for irrigation, though for the latter purpose the quantities available would be too small.

EXISTING WELLS IN THAR AREA

Wells are usually of 3' to 4' diameter, and are dug 3' to 4' below the water-table. Their depth sometimes goes upto 300'. Because of small diameter, they do not collapse. Below this depth, due to small diameter, further excavation becomes impossible. The portion below the water table usually contains the coarse gravel and sand and is apt to collapse by caving in, unless protected by some artificial means. This is usually done by lowering a circular frame, made from the branches of Laee or other bushes. it looks like a 3' to 4' diameter circular ring. A number of rings each. 6" in height are piled over one another and wooden pegs are driven through them. The space around the whole frame is filled with bushes, etc. This works as a filter and its life is approximately one to two years. Some times bricks are used in place of the above mentioned wooden ring. But in absence of proper curb and binding cement, the bricks usually give way. Being very shallow, below the water table, the wells usually dry up after a few dozen gallons are lifted from them, and people have to wait hours, till water, again percolate into the same. If a small water bearing stratum is encountered, it is choked up by bricks and cement etc. If the wells were of bigger diameter, it would be possible to go 15' to 20' below the water level, and then alone it will be possible to lift large quantities of water, from them. Because of the scarcity of water, many areas in the desert have become uninhabitable for human beings and for their cattle, though in those areas luxurant grasses grow.

A survey of the existing wells in a limited area of Diplo Taluka was carried out around Diplo town in 1959. The results showed that in approximately 40% cases, water was sweet and fit for irrigation. The phenomenon could only be explained on the basis of the theory that sweet water floats on brackish water below it. It has already been mentioned that open wells in the bed of Puran, in Diplo Taluka, can yield smaller quantities of water, fit for irrigation.

Perched water can definitely not be a perennial source of water. One has therefore to look for deep seated water, which may be available at a much lower depth. This water could only be tapped by tube wells. Sand in the desert is coarser than that existing in the alluvial plains, and therefore is more suited for tube wells, if large volumes of water are discovered. No artesian conditions exist in the desert area.

In order to protect, and further develop, cattle industry in Thar, the ground water investigation, and conservation of rain water, wherever it may collect, is necessary. The areas being inaccessible, wind mills probably will be the only practical power unit in the Thar area. Their application is described in Chapter XII.

SALT DEPOSITS

Salt industry in Thar is a bye-product of ground water. The water at places collects by process called 'Sim'. Near Rann, the brackish water from the rain-fed river Luni fills the ground. This water evaporates, leaving salts behind. Over, thousands of years, these deposits have become voluminous. All along the border with Rann in Diplo and Mithi Talukas or elsewhere in Sanghar and Khipro Talukas, and Khairpur district, there are salt deposits formed by the above process. Some of these deposits probably will be economical to develop. The matter is worth investigating. These salts, being of sea origin, may not be inferior to any sea salt.

EXISTING WATER RESOURCES OF NAGARPARKAR

There is a number of wells in the whole area called Parkar, in each village there being at least one According to a rough estimate, their number reaches as thousand. A survey of these wells was carried out in 1959 to find out suitability of ground water for irrigation. The depth of the well, depth of water table, total soluble salts and PH. value of 60 representative wells from the whole area is given in the table No. I. On the basis of this data the ground water map of the area has been prepared. (Refer map No. 12). The water table in the wells, varies between 10' to 60', the average being 30'. From these results it was found that 60% of the wells were fit for irrigation, 10% marginal and 30%

unfit. The survey was carried out in: the later part of May, when water table was at the lowest, and the brackish water from Rann of Kachh had done maximum encroachment upon the sweet water of wells. It was learnt that after the rainy season, water in many wells towards the southern border changes for the better. This local report could not be verified by actual investigation of the conditions after rains. The sweet water zone in the area extends to approximately 1,50,000 acres, which could be put under well-irrigation. The population is almost 90% Hindus of Soda Rajput, Kucchi or Gujrati origin. The more advanced and educated Thakurs migrated to India after partition, leaving behind backward class of Hindus, Koihies, Bhils and Menghwars etc. These people lack initiative and never construct lined wells. The unlined wells collapse after a year or two, due to caving in. It was with very great difficulty, that the department of agriculture installed some open wells there, in 1960-61. To this day, locals have not added a single lined well, and unless the initiative comes from some outside agency, there are rare chances of developing ground water in the Parkar area.

The Nagarparkar soil is also better than that of the desert. There is more silt and clay in it than in the desert, though sand still is dominant. In Parkar area they grow *Mung, Gowar, Til, Methi, Urid, Turia, but* important cash crops are castor and onion. Wheat is also grown on well-irrigation, on a limited scale. The Parkar area grows more than 50 thousand maunds of castor sped and an equal- quantity of Til, annually. If proper communication facilities are made available in that area, castor cultivation could be increased considerably. It may be worth while mentioning here that Parkar, unlike Thar desert, is a flat country, with no sand dunes. Its land is of a good quality and has enough ground water. It can easily be converted into greenary.

The wells as a rule being unlined, usually collapse as mentioned above, due to caving in from sides, after a few months or at the most a year's: service. The water for the purpose of irrigation is lifted from these wells, by means of leather buckets (locally known as *Bokas*), which can lift 40 gallons at a time. *Boka* is pulled by a pair of bullocks or four donkeys. The camel is not used for this purpose. Persian wheels and diesel pumping sets were unknown in this area till they were introduced by the Department of Agriculture in 1960-61. The *Boka* seems to be originally a device adopted from Central India. It is similr to the one used in Daccan and Madhya Pradesh. *Boka* has an advantage to the Persian heel in as-much-as it does not spill water back into the well. It has the form of a tea kettle with a spout. It is raised or lowered from its top, with rope over a pulley. Another rope is attached to the spout which passes over a small pulley kept at a lower level. When the bag passes over the level of the smaller pulley, the spout is pulled horizontally and the water rushes out from the spout into the outlet already built.

The disadvantages of *Boka* are:-

1. The animals for each turn have to walk forward and get back in the reverse. This walking back in the reverse is a very hard and slow job for the animals.

2. At least one person is needed all the time to guide the animals, and another to watch the lower pulley and to guide the rope over it.

The capital outlay on the *boka* devise is much less than that on the Persian wheel. But its hourly discharge does not match with that of the latter. After introduction' of the Persian wheel in the area in 1960, local people therefore seem to have at once preferred Persian wheel to the *boka* system, for it reduced all the drudgery both on the man and the animal. The chief advantage of a Persian wheel besides is that even a child could keep the animals working once they were yoked and got going.

While carrying out the survey for wells in the area, it was expected that the wells like those in the lower Indus valley will give discharge of 1/8 to 1/6 of a cusec of water, but at the time of constructing open wells in this area, it was found that the permeability of the sand was very high, and at one place excavation of an open well further down was even abandoned as the dewatering pump of one cusec capacity could not dry it up even after 24 hours pumping. The average wells in this area thus can give about 1/2 a cusec of water. Were it not for the difficulty of transporting diesel oil, the 6-7 h.p. pumping set would be most ideal unit. The area happens to be outside the high wind zone, and, data about the wind velocity in the area is not known. If wind velocities of 10 to 12 miles per hour were available, a 25' diameter wind mill could replace a Persian wheel, as water is available at shallow depths. The cost of wind mill of this size, including tower and installation, would be about Rs. 20,000.

There is no danger of wells drying up in the Parker area. Average rainfall is 14", which is the highest in the southern zone. Though the rain-fall in 1957 was scanty, still the wells did not dry up in 1958. The rain-fall during 1958 was 12.99 inches, and at the time of survey in May 1959, none of the wells had dried up, though as locally reported, the water table had fallen down generally by 10' in 10 months. This figure shows a rather too exorbitant natural drainage. It could therefore be assumed that most of the wells got initially fitted up due to rain water and seepage from surrounding area, rather than by the actual rise of water table by 10'.

The sweet water perhaps extends up to the depth of 100' or so in the centre of the Parkar area, and this depth slowly decreases till near the Rann of Kuchh water turns saline. To investigate this, test drilling is necessary.

Open well 40' deep, with 20-30, feet of filter in it can easily yield 1/2 a cusec or more water. A hundred feet deep tube well fitted with a turbine pump can give 1.5 cusecs in suitable areas. However for this area an open well instead of a tube well will be preferable, until such time the area is properly connected by metal road with the plains.

S. No	Details	Total depth in ft.	Depth of water in ft	T.S.S. as P.P.M.	P.H.	Remarks
1	Vethakioo Ramji Mehta	65	17	910	7.3	Good
2	Tarachani-Veri	46	8	665	7.3	Good
3	Careoramji Veri	39.5	36	1400	7.5	Good
4	Govt. L.B.Well.	38.5	3.5	2100	8.0	Poor
5	Bhatiani Barwaro Khuh	50	14	1330	7.3	Good
6	Ramawah	52	12	1050	7.0	Good
7	Waghawah.	52	17	805	6,5	Good
8	Souraji-Veri.	394	34	1120	8.3	Doubtful
9	L,B. Wetl	38	3	7.1		Good
10	Dameji Khuh (Nagarparkar),	40 1/6	7 7/8	3220	7.5	Poor
11	Loveji Lohano (Nagarparkar)	35	10	1750	7.4	Fair & Poor
12	Ashram well	26	salt/water	1470	7.2	Fair & Poor
13	Govt. well	42	16	2205	7.0	Poor.
14	Krishan Lohami	55	35	1645	7.7	Fair.
15	Gordharo (I)	42	25	105	7.4	Good.
16	Gordharo (II)	30	10	910	7.6	Good.
17	Khariro	30	1 1/6	3360	6.8	V. Poor.
18	Ramat Sam Khuh	28	7	840	7.1	Good.
19	Lakar Khadio	12	1	3500	6.8	V. Poor.
20	Sahensan	15	1	2532	6.9	V. Poor.
21	Sudran	48	3	805	7.2	Good.
22	Maljijo Vandhio (Nathuram Suntar)	28	3	1550	7.1	Fair.
23	Maliijo Vandhio (Gangaram. Lohano)	28	2	1400	7.4	Fair.
24	Mallijo Vandhio (Pamjijo Santar)	27	3	1260	7.2	Good.
25	Maljijo Vandhio (Channba Maleji)	3I	3	1400	7.2	Fair.
26	Dreh.	32	4	2830	7.3	Poor.
27	Baka Talao	35	6 1/3	6300	7.0	V. Poor.
28	Un	28	7	1260	7.1	Good.
29	Un Sarupo Sautar.	49	10	735	7.2	Good.
30	Swachand Surla Khuh	43	11	1190	7.5	Good

S. No	Details	Total depth in ft.	Depth of water in ft	T.S.S. as P.P.M.	P.H.	Remarks
31	Hamirji Jo-Goth	43	10	2100	7.3	Poor.
32	Rampur	40	16	3150	7.2	Poor.
33	Rampur Saran.	57	17	1890	7.2	Fair
34	Phulpro Govt. Well.	45	10	11200	7.7	V. V. Poor.
35	Bartala	21	1	1190	7.4	Good.
36	Bartala II	24	8	595	7.2	Good.
37	Bartala III	25	7	665	7.3	Good.
38	Chruio	47	1	910	7.1	Good.
39	Virawah	38	3	665	6.1	Good.
40	Gadro VVatchumal	20	3	3325	7.2	V. Poor.
41	Karku.	23	10	7000	7.5	V. Poor.
42	Ghanido	28	4	7700	7.5	V. Poor.
43	Dungri.	25	7	910	7.2	Good.
44	Wadampa	20	8	1120	7.5	Good.
45	Jamamadar-Jo-Goth.	46	1	560	6.3	Good.
46	Vadharui III	18	5	3500	7.3	Poor.
47	Padamsar Talao	12	3	1750	7.4	Fair.
48	Virwah Chachhro Road.	23	1	4410	7.8	Poor.
49	Virawah Watasar L.	18	4	5250	6.5	Poor.
50	Virawah Ditcher.	50	2 1/2	2275	5.8	V. Poor.
51	Vial.	22	2	4900	7.7	Poor.
52	Bartalao VI.	26	6	630	7.6	Good.
53	Kasbo Narumal	27	10	700	7.3	Good.
54	Kasbo Chiman Sangh.	23	3	1225	7.3	Good.
55	Vadhrai II Pucca.	27	12	2450	7.4	Poor,
56	Mandrio Ramsar Chandio.	47	1	1400	7.7	Fair to on.
57	Mandro Shamir Khan Chandio	46	2	1400	7.7	Fair to on.
58	Kasbo Chaman Sangh.	29	9	875	7.4	Good.
59	Kasbo Dergi.	27	--	805	7.4	Good.
60	Barkalao.	20	3	560	7.2	Good.

CHAPTER X.

PLANTS AS INDICATORS OF GROUND WATER.

The knowledge that plants indicate ground water is not new to man. It was being utilized even at the dawn of human history for crossing vast expanses of deserts.

There seems to be a basis on which plants and vegetation could be used as indicators of depth as well as quality of ground water. The indications would, however, vary from place to place, soil to soil and according to climatic conditions.

The indications as to quality of water would not be so definite, as to its presence under ground, and may in any case be regarded merely as a probability. Some plants have ability to send roots deep enough to reach water table and may, as such, indicate the depth as on surer lines.

Quantity of water is indicated by the vegetative growth of the plants, trunk girth, height etc. Larger and more leafy trees will allow more water to transpire to the atmosphere, which would mean larger ground water supplies.

Below are some of the plants, which may indicate ground water table.

1. *Brushes, sedges and cattles* (*Typha*) Sindhi: (*Naru)*.

These plants grow on margins and borders of shallow water and on pools. Such growth shows presence of water at small depth and the quality of water it indicates is also usually good. The growth is abundant in low lying *dhands* and ponds in this region. This type of growth also indicates that the ground water is perennial, since such plants cannot survive temporary dry periods.

We cannot rely upon these plants as indicators of ground water, while we think in terms of pumping for irrigation, as they indicate water only at shallow depths.

2. *Reeds and cane.*

Common reed and giant reed grass (Sindhi *sarr*) is found along streams and ponds, where there is no surface water, but where ground water is not far below the surface. It is the most reliable indicator of shallow ground water (at depth of 3' to 4').

3. *Wild rye, salt grass and sacaton.*

These are wild grasses looking like wheat and barley etc., and attain a height varying from a few feet to even 10' or more.

They indicate water table between 5’ to 8’ on the average, and in exceptional cases, even upto 12 or 15’.

They indicate fresh water supplies, but can also thrive on alkaline soils and brackish water, though in such cases the growth will not be so luxurant.

4. *Salt brush* (Sindhi: *Khabar*).

This plant thrives in alkaline soils, and in those containing sulphates and gypsum. They also indicate water table varying between 10' to 30'. Rise of table above 10' affects the plant growth. They thrive on brackish water.

5. *Mesquite* (Sindhi: *Devi*).

This plant in post-barrage period has wildly expanded in irrigated tracts of Sukkur Barrage. It is not found in areas of high water table, but is only come across where water table is below 15'. The plant seems to thrive well where water is sweet, though it can establish in ditches, etc., where sweet water accumulates for longer periods, even if in such cases ground water is brackish. It has established itself along Karachi-Hyderabad road in ditches and depressions, where ground water is brackish and the water table more than 60' deep, but under such conditions its growth is usually very poor.

6. *Prospis* (Sindhi:*Kandi*).

It is normally an indicator of sweet water, but thrives in northern Parkar area too, where water is brackish and is usually 50' to 60' deep. It is a poor species of prospis in such conditions.

7. *Acacia Arabica or Babul* (Sindhi: *Babur*).

This plant shows the same habits as 5 above. Basically it is a sweet plant, but, is found in Thar desert area in depressions where ground water though slightly brackish is not very deep (50'-60' or so). In some cases there is no regular water table, but it thrives on perched water at similar depths.

8. *Poplar* (Sindhi: *Banhan*).

It grows in localities, where water table is not below 20'. It grows better if water table is higher than that, and can survive even when water table rises to 5 to 6 feet below the surface. It usually indicates fresh, ground water and in large supplies.

9. *Palm trees.*

Unfortunately they do not always indicate good water and some times even grow near springs where water is bad. A healthy clump of palms means that water is drinkable. They indicate shallow water table within a few feet.

10. *Cactus Plants* (Sindhi: *Thoohar*).

They depend upon moisture from scanty rainfall, supplemented if rarely, by occasional flood. They have no relation to water table and do not habitually utilize ground water. In brief they are not ground water plants.

11. *Tamarisk* (Sindhi: Laee).

This can grow quickly on light soils having preserved moisture and is found along canal beds and riverine tracts etc. However, for a thick and, large growth, it must have permanent sweet-ground water supplies even at depths of 20' to 30'.

Unfortunately, in the arid zones of Pakistan and India no research work worth notice has been done on this subject. A study of plant growth and vegetation as related to water table, its quality and quantity and soil condition,' can help us in locating water wells, at least for drinking purposes, in Thar area, and possibly for irrigation, in Kohistan area.

I found large wild growth of babul, prospis and tamarsik in the Rohri sub-division, which meant that large supplies of sweet water should exist here. In 1960 we put in 24 test bores in the area from Ubauro to Rohri and in the width of 20 to 25 miles. The bores were on the average 150' deep. We found that in 90% cases the water was sweet and fit for irrigation.

In the same year we carried out survey of some parts of Thar desert and found that though prospis and babul species did survive there, the growth was poor, they had less girth, and their leaf-growth was not enough, all because, the ground water was brackish.

In most of the Thar area, we have leafless growth like *Khip, Phog, Lani* and *Akk.* In some depressions where the water stands for longtime, *Kirir,* tamarisk, *Tali, Kandi,* and *Ber* also grow, but they do not attain the size of their counter-parts in the plains.

In G.M. Barrage area, the wild growth is mostly *Khabar,* which indicates alkaline soil and brackish water.

In some depressions tamarisk also grows, but these depressions are annually flooded by inundation water or Pancho water from rice fields. Since water down below is brackish, tamarisk has never attained considerable size or height in G.M. Barrage zone. These indications should suggest that search for sweet water in that area has to be abandoned. Along Puran in Dehs Kotadao I and II and towards south in Mithi I, II and III, a thick wild babul growth was observed which indicated sweet water at least upto 50' or so. Hand pumps installed upto depth of 70', proved this to be correct, but width of this sweet water belt was hardly a mile on both the banks.

Wild growth of indigo indicates *kalar* soils. This on checking proved to be true in case of Khairpur division.

The subject of plants as indicators of ground water requires further study and investigation by hydrologists and botanists.

CHAPTER XI

GROUND AND SURFACE WATER AND ITS CONSERVATION

Supplies of ground water are definitely exhaustible and unless natural or artificial recharging is done at a rate same as that of pumping the wells & tube wells might dry up.

(a) *ALLUVIAL PLAINS.*

In the case of alluvial plains, there is no fear that the water table will go down if large scale pumping is done. The water table is already too high, and the development of ground water will on the contrary help solving water logging problems.

The alluvial plains of the two divisions are irrigated by the three barrages, namely Gudu, Sukkur and G.M. It is apprehended that it may not be possible to achieve the designed intensity in these barrages. The designed intensity of Sukkur Barrage is 81% whereas in actual practice this has hardly reached 60%. Attainment of 55% intensity may be considered as good average in the case of this barrage.

The reason for this is that the designed intensity has been fixed on the basis of total volume of water discharged by a canal annually, and volumetric water requirements of crops, ignoring the peak water requirements of different crops. The area under cultivation has automatically been adjusted as per peak water requirement of the crops and availability of water. Of the peak demand, the water is wasted or certain crops are unnecessarily given over doze of water. Since the canals cannot be designed to take different quantities of water at different times of the year, there is in fact no remedy to this The only solution lies in supplementing the water by tube wells in areas, where extra demand for water arises.

(b) *KOHISTAN AREA.*

The rainfall in the area varies between 6" at the southern end to 4" at the northern end. We really cannot pump more than 1/6th of a cusec of water per square mile of area continuously for 24 hours a day and 365 days annually.

In Kohistan however the rocks are bare, devoid of natural vegetation, and fissured. Most of rain water finds its way to water table, and evapo-transpiration rate is minimised. The replenishment to ground water table is maximum in fissured lime-stone series namely Khirthar, Gaj and Nari formations. Where the rocks are not decomposed the water is fit for irrigation as explained in connection with Dadu and Thatta districts. However as we move down from mountains to less permeable areas of Kachho or alluvial plains the rate of infiltration becomes low and some times is entirely lost by evapo-transpiration. But water that infiltrates, in rocky areas adjacent to Kachho finally reaches the alluvial plains by seepage through permeable strata, which lie some 50'-60' below the top alluvial. During this process it absorbs salts enroute, turning saline. It is therefore that water in the rocks is of better quality than that in the plains downhill.

Luckily there are very few or no shrubs in the Kohistan hills and therefore evapo-transpiration losses are negligible. This water could be developed by wells and tube wells, but if excessive pumping is done, the water table may lower down sufficiently to dry up the wells and tube wells, and ultimately make happy and fruitful life only impossibility.

Conversely by proper recharging of ground with water, it may be possible to pump more than the theoretical quantity and still keep the water table at reasonable depths. This could be achieved by following methods:-.

(i) *Extending soil and water conservation practice*, as suggested, to the whole area. This will help absorption of more water in the ground.

(ii) *Creating under-ground barriers in the rain-fed rivers or nais*. The experiment has succeeded at Damloti in Malir River. These areas being of rocks having fissures, water up-stream definitely penetrated 'the banks, and was absorbed or drained away slowly, but the water level in the wells up-stream not only rose but supplies became more abundant, and were assured even in the dry season.

(iii) *Creating water absorption basins.* The damming of river Baren at Dau or Darwat is being objected to on the ground that rocks around have fissures and the water is bound to leak out. But even if these basins, when dammed, do not hold all the water instead of its being lost as run off, it could be absorbed there and thus add to the under-ground reservoir.

(iv) *The water flowing in streams could either be dammed, or directed to spreading areas,* then it will not be lost as run off, but absorbed. The ground in Kohistan. area is highly porous. The water can easily find its way down, if it is allowed to stand on it for sufficient time. Some low lying areas could artificially be converted into ditches for absorption of rain water.

In the Kohistan region the nallas or rain fed river beds, are filled with very porous gravel. The re-charge rate in such formations will normally be 5 times or more than even the fissured rocks of the same region. The rate of recharge in these streams could further be increased by bunding them at different points, so that natural slope is reduced and water stands there for longer time.

(v) *Open wells in the bottom of nais* properly protected on sides could also act as recharge wells at the time of flood. The wells have as much capacity to absorb as they have to yield water, Kohistan area is intersected by a number of rain fed rivers, some of which like Gaj keep flowing even upto February. Water from some of these rivers is used for irrigation to a limited extent though not scientifically. On Dilan river for example they cultivate a big area of land. On Gaj also, cultivation is carried out. Same is case with Naig, and some other minor rivers.

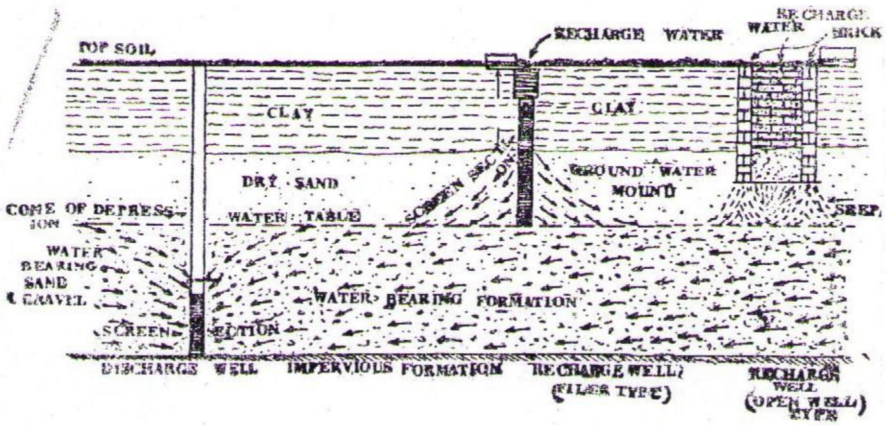


Fig. No. 8

PRINCIPLE OF RECHARGING OF WELLS

It is important in that case of recharge wells (whether open well type and filter type or so called inverted tube wells) that:—

(i) the formation opposite to filter slots or the bottom of open well should be highly permeable.

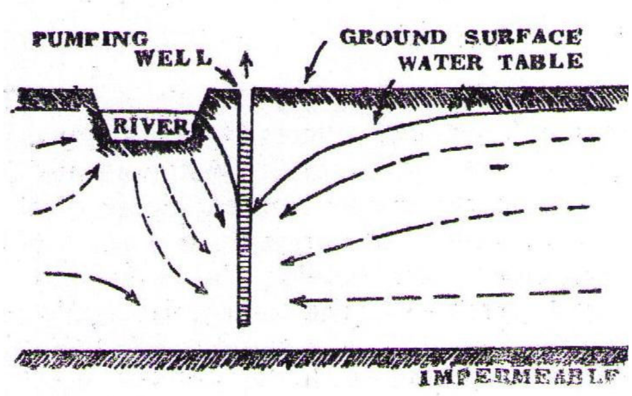
(ii) there should be no impervious layers between the filter and the stratas to be replenished.

(iii) the recharge water should be free from any sediments which may choke up the water bearing strata.

(iv) for a good rate of recharge the water head in the recharge well should be maintained at maximum height.

(v) periodical cleaning of the well bottom or filter slots should be done.

By putting wells and tube wells along the banks of these *nais* the induced recharge zone is created as shown in Fig No. 9.



Induced re-charge resulting from a, well pumping near a river, canal, lake or stream; showing flow pattern of water (Refer chapters VII, XI, XIVand XV also).

Fig No. 9

In Quetta and Kalat area they have been conserving this water by the spreading or the so-called sailabi (moisture preservation) method. The water from the *nais* at time of flood is diverted into plots, which are properly embanked. Water stands there for many days and is absorbed in the ground. On this they grow bumper crops. Vast Kohistan areas of Larkana, Dadu and Thatta districts could be, put under cultivation by this method. Diverting of *nais* by earthen bunds at places will be necessary. In a few cases even small concrete dams may have to be built to obstruct the water or to divert it. By proper planning, most of the water drained by these *nais* could thus be utilized for raising crops.

(c) DESERT ZONE:

In this area there is in fact very little run off water. Some times it flows and collects in depressions. In these depressions locally called *tarais,* water stands for two months or some times even more. Some of the *tarais* cover a few sq. miles and only a small portion of these is flooded by water. By dividing the *tarais* into smaller plots of say 4 acres each, the rain water could properly be diverted and spread over the basin. Later on, the area could be developed on the lines of Sailabi cultivation.

Following are the main *tarais* of the area.

1. Daki Dahar.
2. Chhachhi-jo-Dahar.
3. Wachheray-jo-Dhar.
4. Harkal Kori.
5. Menchho Dahar,
6. Dhokari Dahar.
7. Lathi-jo-Dahar.
8. Bay-jo-Dahar.
9. Dhar Sano Dahar.
10. Posarki-jo-Dahar.
11. Way-jo-Dahar.
12. Bhikoi-jo-Dahar.
13. Tanpi-jo-Dahar.
14. Chhaho Dahar.
15. Ghogharo Dahar.
16. Unand-ji-Tarai.
17. Gadro Talao.
18. Kathoo Talao.
19. Kainsar Talao.
20. Mithi Talao.

Lined wells could also be put in the *tarais* for supply of water for drinking, and at the time of rains, the rain water could be allowed to go in them. If the wells are properly lined with bricks and cement, and the water is thus diverted into large number of wells in an area, the general water table will slowly rise in the whole area. If diverted in a few wells, it may not be of particular advantage to that locality, but in the long run it will still be beneficial for the whole area.

In humid areas the precipitation causes the leaching of lime, whereas in the arid zones, the lime does not leach and forms an impervious layer or pan which stops further percolation. In Thar desert the clay layer at top forms impervious barrier and therefore percolation in the ground is retarded. The rain water though held in top sand layers for some time, giving rise to luxurant vegetation, is ultimately lost by evaporation.

Finest earth particles of sediments are carried by rain water in taras or depressions. These slowly form impervious layers. It is important that rain water may be diverted to areas of coarser material to recharge ground water. Muddy water will seal up the coarser material. The recharge water should therefore be desilted before spreading for this purpose.

(d) *NAGARPARKAR AREA.*

In the Nagarparkar area, where the conditions are, different and rain fall is more, the run off water could be conserved by diverting it over the adjoining lands and there-by increasing the preserved, moisture of the soil.

In this, there are natural lakes near Surchand, Virawah and Sindhuri, which could be converted into artificial basins for cultivation. The most-important lake is Sanghasar near Virawah, which covers approximately 4 sq. miles, If proper embankments are constructed the depression will be the biggest artificial lake in Thar.

RANASUR RESERVOIR IN NAGARPARKAR HILLS

South-west of Nagarparkar there are Kalingar Hills. Between them there is a natural depression, the total catchment area of which is about 15 sq. miles. It is surrounded by impervious, pre-Cambarian igneous rocks on all sides except an opening of about 125'. This was dammed by Ranas in the early 16th century. The dam now has been damaged and is leaking all over By raising the dam, it still can hold some water, but unless the provision for desilting is done, the renovating of it may not be Beneficial. This reservoir having catchment of roughly 15 sq. miles, with the average rain fall of 14" and 30 per cent annual losses by evaporation can still hold seven thousand acre feet of water, which can irrigate about 2,500 to 3,000 acres under Rabi crops, if supplemented by small winter rains.

In addition to above, there are about 45 *tarais* fed by rain water from Kalingar hills of Nagarparkar. These could also be developed on the lines suggested for *tarais* in the Thar area.

CONDENSATION

In arid conditions of the Thar and Kohistan region maximum and minimum temperature difference is 40° F or some time even more and therefore there is condensation or heavy dew, which at times reaches 1/16" to 1/4" but this evaporates within a few hours of bright sun and is most insignificant factor in ground water discharge. However, it probably helps certain desert and Kohistan species to survive.

CHAPTER XII

SCOPE FOR USE OF WIND POWER IN THE REGION

BACK GROUND

We should always talk with caution about wind mills. In their home country i.e. Netherlands, they have disappeared very fast between 1920 and 1950. Hardly 7% to 8% of those existing in 1920 have survived. These have been protected by the efforts of society for preservation of wind mills, which in turn is being helped by Government, and the National Tourist Bureau. The wind mills have ceased to be economical as compared to diesel or electric power. Most of the wind mills in Holland, Denmark and other European countries were huge monsters having diameter of 100 feet, and stood on massive towers of the height of more than 60'. With the highest wind velocity, at the best they could develop only 20 H.P. Such structure, if constructed now, will cost Rs. 1,00,000. Though the maintenance cost is negligible, still it cannot be considered as economical as a diesel engine, which will at the most cost Rs. 7,500 initially for the same H.P.

For some time, it was thought that wind mills will possibly become extinct, but the new development in wind mills in desert zones of Australia, again revived interest in them. In the fifties, wind power research organizations were established in most of the advanced countries. Even Government of India in 1952, established a Wind Power Research Committee to carry put surveys and to determine the most favourable areas. The advantages of wind mills are their comparative simple construction, freedom in choosing the location, and in the most in-accessible place, the problem of transport of oils and greases, which will be needed for other types of power units, is completely solved. The main disadvantage is the unpredictability of wind, even in the very windy places there is no certainty that it will blow sufficiently strong, for power production at a particular time, when it is needed the most. This is more important, if wind mill is used particularly for agricultural purposes. In most of the areas where it is sufficiently windy, the windy season may not coincide with the time when crops need the maximum water. This limits the use of wind mills for irrigation.

EXISTANCE OF A WIND BELT IN HYDERABAD DIVISION.

In Hyderabad division, there is a belt of high wind velocity, where the velocity at times reaches even 30 miles per hour, but this velocity is limited to a few hours annually. On an average, 10-12 miles per hour may be considered a good figure for reasonable period during the year. This high wind velocity zone is roughly bounded by two parallel lines, one passing through Shah Bunder, Mithi, and extending to Rajisthan desert, and the other passing from Karachi to Hyderabad and going into the desert beyond Chhor.

This belt is shown in Map. No. 13. In this zone the following important stations are located:

1. Karachi.
2. Damloti.
3. Thatta.
4. Mirpur Sakro.
5. Gharo.
6. Sujawal.
7. Mirpur Bathoro.
8. Tando Mohammad Khan.
9. Matti.
10. Golarchi.
11. Tando Bago.
12. Tando Ghulam Ali.
13. Kunri.
14. Hyderabad.
15. Tandojam.
16. Tando Allahyar.
17. Mirpur Khas.
18. Jamesabad.
19. Pithoro, and further down, all desert stations like:-
20. Chachro.
21. Diplo.
22. Chotal.
23. Chhor, and
24. Khokharapar etc.

On the Indian side of the desert the belt includes Jodhpur.

WIND VELOCITIES IN THE WIND BELT.

Meteorological Department of Pakistan has no wind recording stations in this belt except at Karachi and Hyderabad. They have collected some data for Chhor. The data shows that the wind velocity of 20 miles per hour exists for 1,800, 15 miles for 2,200, 10 miles for 5,000 and 5 miles for 65 hours annually at Karachi.

Outside this zone in Nawabshah, they have an observatory which shows a wind velocity of 15 miles for 200, 10 miles for 1800 and 5 miles for 3200 hours annually. The Indian Meteorological Department has an observatory at Jodhpur. The wind velocities there, for different months in the year, are given in the table No. 2 below. It shows that wind velocity of more than 5 miles per hour exists during most of the hours of the day, and more than 10 miles only during the month of June, July and August for only a few hours daily. For Jodhpur, therefore one has to design a wind mill of wind velocity between 5-7 miles per hour. It seems that wind velocity decreases from Karachi to Jodhpur, but is between. 5-7 miles per hour at Jodhpur itself for most of the time. Considering the figures of Jodhpur, Nawabshah, Chhor, Hyderabad and Karachi (see tables No. 2,3,4,5 and 6), one can safely assume that the wind velocity of approximately 12 miles per hour will exist for over 2,000 hours in most of the desert area of Hyderabad division. Therefore, the wind mill is to be designed for that wind velocity. It is also to be concluded that wind velocity of between 15-20 miles will be available for another 700 hours or so. In other words, the wind mills if erected, will be operative, on the average, about 7.5 hours daily. The wind velocities are favourable for summer months, when human and animal or plant consumption of water is at its maximum.

HORSE POWER DEVELOPED BY DIFFERENT WIND MILLS AT DIFFERENT WIND VELOCITIES.

A thorough analysis of the output of the wind mills has been made. The H.P. developed by different size wind mills is so small that their utility for agricultural purposes on large scale has to be ruled out. They could only be used for kitchen-gardens or a few acres only. The table No. 7 gives the H.P. developed by different size slow speed wind mills of comparatively good design at different wind speeds. The table also gives the gallons pumped per hour against average head of 100 feet. It may incidentally be mentioned that a cusec of water is equivalent to 22,500 gallons per hour.

HORSE POWER THAT CAN BE DEVELOPED BY WIND MILLS IN WIND BELT ZONE OF HYDERABAD DIVISION.

As mentioned above, the average wind velocity in the wind belt area in Hyderabad division is about 12 miles, at which the H.P. developed by 18' wind mill will approximately be .337 to .59 . If we build a wind mill of bigger diameter, say 25', the H.P. developed will approximately be twice as much i.e. one H.P.

The output of wind mill varies as the cube of wind velocity, and therefore at a velocity of 5 miles per hour, it will hardly develop 1/8 H.P., barely enough to keep it moving.

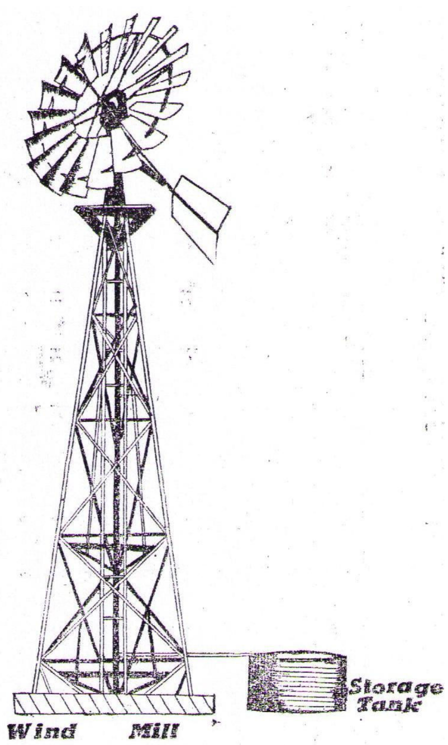


Fig No. 10
Wind Mill
SLOW SPEED WIND MILL AND STORAGE TANK
(Suitable for wind belt zone of Hyderabad division shown in Map No. 13.)

TABLE NO 2

DATA ABOUT WIND VELOCITIES AT JODHPUR

WIND VELOCITIES GREATER THAN MILES FOR HOURS DAILY IN DIFFERENT MONTHS OF THE YEAR

Station: JODHPUR

Greater Than	January	February	March	April	May	June	July	August	September	October	November	December
1	24	24	24	24	24	24	24	24	24	24	24	24
2	24	24	24	24	24	24	24	24	24	24	24	24
3	24	24	24	24	24	24	24	24	24	24	24	24
4	24	24	24	24	24	24	24	24	24	15	17	24
5	24	24	24	21	20	24	24	24	19	0	9	22
6	19	20	14	15	18	24	21	21	10	0		12
7	11	5	7	8	11	24	14	14	8	0		10
8			3	6	10	19	12	12		0		0
9				1	5	12	10	10		0		0
10						7	9	9		0		

TABLE NO 3

MAIN FREQUENCIES OF WIND VELOCITIES IN VARIOUS RANGES BASED ON SIX HOURLY OBSERVATIONS

Station: KARACHI

Months	0	1-3	4-6	7-10	11-16	17-21	22-27
January	235.2	159.6	96.0	189.0	54.0	12.0	0.6
February	241.8	144.0	78.0	156.0	18.6	9.6	0.6
March	210.6	162.0	78.6	179.4	89.4	19.8	1.2
April	157.8	130.8	94.2	198.6	118.2	16.8	2.4
May	70.8	97.8	94.2	261.6	175.2	41.4	3.0
June	38.4	71.4	81.6	292.8	169.8	52.2	10.8
July	30.6	49.8	68.4	279.0	231.6	71.4	11.4
August	31.2	49.8	67.8	358.2	190.2	42.0	4.2
September	71.4	79.2	105.0	280.8	162.0	18.0	1.8
October	294.6	120.6	79.8	189.0	52.8	6.0	
November	316.2	126.6	86.4	162.6	25.2	1.8	
December	269.4	181.8	93.6	169.8	29.4	1.2	
Total (Annual)	**1968.0**	**1373.4**	**1023.6**	**2716.8**	**1316.4**	**292.2**	**36.0**

TABLE NO 4

MAIN FREQUENCIES OF WIND VELOCITIES IN VARIOUS RANGES BASED ON SIX HOURLY OBSERVATIONS

Station: HYDERABAD

Months	0 IN KNOTS PER HOUR	1-3	4-6	7-10	11-16	17-21	22-27
January	188.4	326.4	106.8	115.2	7.8		
February	215.4	295.8	91.8	60.0	4.8	0.0	1.2
March	207.6	324.0	105.0	96.6	13.2	1.2	
April	160.2	226.8	122.4	163.2	43.2		
May	62.4	136.8	136.8	298.8	96.6	15.0	
June	16.8	90.0	108.6	271.8	190.2	36.6	
July	56.4	85.2	97.8	258.6	190.8	51.6	
August	75.0	103.2	107.4	298.2	141.6	17.4	
September	122.4	151.2	120.0	233.4	76.8	11.4	
October	298.4	234.6	102.0	103.2	6.6		
November	296.4	309.6	66.8	35.4	3.6		
December	207.6	318.0	136.2	78.6	3.0		
Total (Annual)	**1907.0**	**2601.6**	**1301.6**	**2013.0**	**778.2**	**133.2**	**1.2**

One Knot - 6020' or approximately 1 - 1/7 miles.

TABLE NO 5

MAIN FREQUENCIES OF WIND VELOCITIES IN VARIOUS RANGES BASED ON SIX HOURLY OBSERVATIONS

Station: NAWABSHAH

Months	0 IN KNOTS PER HOUR	1-3	4-6	7-10	11-16	17-21	22-27
January	544.4	253.2	88.8	48.0	7.2		
February	363.0	187.8	65.4	56.4	6.0		
March	304.2	263.4	85.2	67.8	22.2		
April	264.0	207.6	90.0	180.2	26.4	1.2	
May	166.2	192.6	151.2	178.2	44.4	9.0	
June	63.6	116.6	153.0	261.6	104.4	18.0	1.2
July	103.8	121.2	146.4	301.2	69.6	1.2	0.0
August	118.2	151.8	171.0	233.4	64.2	3.0	
September	202.8	254.4	132.6	115.2	13.8		
October	324.6	237.0	94.2	84.0	4.2		
November	408.6	223.8	64.2	23.4			
December	394.8	231.6	81.6	34.8			
Total (Annual)	**3258.2**	**2441.0**	**1323.6**	**1584.2**	**362.4**	**32.4**	**1.2**

One Knot - 6020' or approximately 1 - 1/7 miles.

TABLE NO 6

MAIN FREQUENCIES OF WIND VELOCITIES IN VARIOUS RANGES BASED ON SIX HOURLY OBSERVATIONS

Station: CHHOR

Months	0 IN KNOTS PER HOUR	1-3	4-6	7-10	11-16	17-21	22-27
January	378.6	162.0	112.8	82.8	6.6	1.8	
February	338.4	168.0	94.8	55.2	14.4	3.6	
March	296.4	187.2	120.0	106.8	24.6	4.8	
April	206.4	168.6	159.0	141.6	40.2	3.0	
May	79.2	121.8	157.2	273.6	99.6	11.4	
June	37.2	84.0	112.8	326.4	135.6	20.4	0.0
July	39.6	83.4	136.8	307.2	151.8	25.8	
August	102.0	108.6	139.2	300.0	84.0	9.6	1.2
September	156.6	157.8	178.2	184.8	42.0		
October	357.6	232.2	90.6	58.8	4.2		
November	441.6	194.4	57.0	26.4			
December	460.8	180.6	60.6	39.6	1.8		
Total (Annual)	**2894.4**	**1848.6**	**1419.0**	**1903.2**	**604.8**	**80.4**	**1.2**

One Knot - 6020' or approximately 1 - 1/7 miles.

TABLE NO 7

PUMPING RATES AND H.P. FOR DIFFERENT DIAMETERS OF WIND PUMP 9WITH 100 FEET HEAD0 OF AVERAGE EFFICIENCY

Wind	6 feet		8 feet		10 feet		12 feet		14 feet		16 feet		18 feet	
Speed m.p.h	h.p.	gals/hr.	h.p.	gals/hr.	h.p.	gals/hr.	h.p.	gals/hr.	h.p.	gals/hr.	h.p.	gals/hr.	h.p.	gals/hr.
5	0.0047	10	0.0083	17	0.0125	25	0.019	38	0.025	50	0.033	66	0.042	84
7	0.0128	25	0.0228	42	0.036	72	0.51	102	0.069	138	0.091	182	0.116	232
10	0.372	75	0.066	132	0.1	200	0.15	300	0.2	400	0.266	532	0.337	674
12	0.064	128	0.115	230	0.18	360	0.26	520	0.35	700	0.46	920	0.59	1180
14	0.102	204	0.183	366	0.29	580	0.41	820	0.56	1120	0.73	1460	0.93	1860
16	0.153	306	0.273	546	0.43	860	0.61	1220	0.83	1660	1.09	2180	1.39	2780
18	0.218	438	0.389	778	0.61	1220	0.87	1740	1.2	2400	1.56	3120	1.99	3980
20	0.297	594	0.53	1060	0.83	1660	1.19	2380	1.6	3200	2.12	4240	2.7	5400
22	0.398	796	0.71	1420	1.11	2220	1.6	3200	2.2	4400	2.84	5680	3.62	7240

QUANTITY OF WATER PUMPED, AND COST

The quantity of water pumped by wind mill varies indirectly as the water head. When the water table is 44', a 25' wind mill may be able to pump 1/8 to 1/6 cusec of water which is the output of a Persian Wheel". A 25' diameter wind mill, including a pumping unit, a 60' tower and installation, may cost approximately Rs. 20,000. The annual recurring cost on maintenance etc. may not exceed even 1%, but even then, it is not worthwhile having such a costly unit to produce only one H.P. During the course of the year, the wind velocity goes up from 16 to 20 miles per hour for 700 hours only, when we may get an approximate output of 4 H.P. from the same. It is doubtful if any private party will be willing to purchase such a unit, and therefore, its use on a large scale, at least in settled areas of Sukkur and G.M. Barrage, may be ruled out. Wind mills of smaller diameter, say 10' to 12', cost only 1/4th as much, and may be utilized for kitchen-gardens and domestic purposes etc. Their output is limited to a few gallons per minute and can suit any individual for these purposes.

APPLICATION OF WIND MILLS IN THAR AREA.

In Thar desert area, where conditions are altogether different, where water is available at depth of 150' or more, and where people from all over bring cattle for drinking water at appointed places, wind mills with storage tanks may be of considerable help in small towns like Chachro, where approximately 5,000 souls reside, and the water requirement including that of their cattle is approximately 50,000 gallons per day, three or four wind mills of 25’ diameter may solve the town's water supply problem. Similarly, if wind mills are installed on open wells in the desert area, each may pump 12,000 gallons of water daily and may solve water problem in an area of 100 square miles, of course depending on its human and cattle population at a given period. The total number of wind mills required in the wind belt zone will be 120, if installed on wells and at an approximate distance of 10 miles from each other.

TYPES OF WIND MILLS.

There are two types of wind mills, the slow speed and the high speed. The slow speed wind mill operates after the wind velocity reaches 5 to 6 miles per hour, and. will keep on operating upto 20 miles or so. If the wind velocity increases beyond this, the mill changes the direction so that there is impact of only 20 miles component. The high speed type will operate only in high wind velocities. It does not rotate till the wind speed reaches 15 miles or so. This type of wind mill is out of question in the wind belt existing in Hyderabad division, as we do not have high wind velocities for sufficiently long time. The high speed wind mill is still in the experimental stage in all advanced countries. When properly developed, it may compete with diesel power in windy areas, but its application in Thar area is ruled out due to low wind velocities.

WIND MILL LOCATION

By erecting bigger towers, or by installing the wind mill on the top of a hill, there is the advantage of getting more wind velocity. The benefit of 10% increase in wind velocity may increase the output of the wind mill by 30%, since the output varies directly as the cube of wind velocity.

In the Thar desert, at some places in the wind belt, water is available at the depth of 150'. Sand hills some times are even 300' high. If a wind mild is erected on a hill, say 150' high, the water table will be 300` below the point of installation, and therefore, the advantage gained by erecting a wind mill on the top, of the hill wilt be off-set by spending extra power on lifting the water through a greater height. In the Thar desert, wind mills should be erected in the plains rather than on the hills. The valley between the hills, in fact, has the wind passing through it in the same manner as water would pass through the cutting at high velocities. Since the pumping unit is directly attached to the wind mill, it has to be erected over the well. It has also to be ensured that the well supplies enough water, so that the pump does not operate dry. The well on which the wind mill is erected, has therefore to be scientifically built, and in case the water strata are shallow, horizontal tunneling, (Ref. Fig. 11) must be done to increase the water-supply. With each wind mill, a tank has also to be built to store water. Water, being costly and scarce, can not be allowed to run waste.

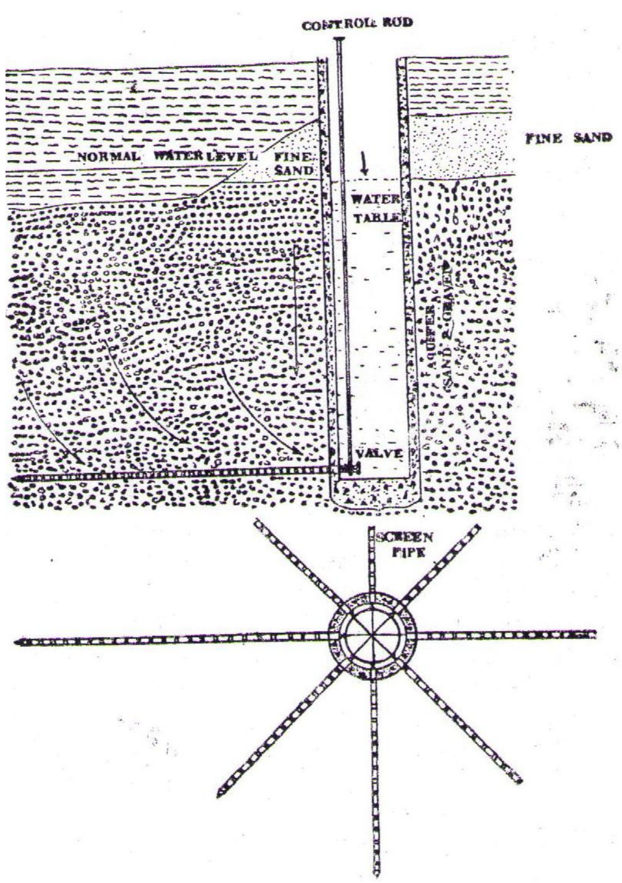


Fig No. 11

This type of well if put in rocky area may give very high discharge of even 5 cusecs or more. Similar wells could be put in perched water table zone if water bearing stratum is not thick enough and yields are low.

METHOD OF PUMPING WITH WIND MILL.

It has been suggested that wind mill should drive a compressor or an electric generator with storage batteries so that electric power or compressed air is used for pumping, whenever water is needed. These devices are more costly than the directly coupled pumps, and off-set all the advantage in favour of wind mills as against complicated power units and diesel engines etc.

COMPARISON OF COST OF WIND MILL WITH SMALL DIESEL ENGINE.

Pumping sets 1 to 3 H.P. for lifting small quantities of water by a small diesel engine through large heads are very costly to maintain. The over all pumping cost with these units will probably be the same as with a wind mill. Wind mill therefore should be preferred to small pumping units in desert areas, where the water head is very high say 100' or more.

CHAPTER XIII
SOLUBLE SALTS IN GROUNDWATER AND SALT TOLERANCE OF CROPS

Plants vary in their tolerance of salts. According to established practice, the salt contents of water should not exceed 1200 parts per million parts of water. If they do, water is considered to be unfit for irrigation. The following is the general classification recommended by Agriculture Department:-

1. Upto 500 parts per million: 1st Class.
2. Upto 800 parts per million: 2nd Class.
3. Upto 1200 parts per million: 3rd Class.

However, the U.S. Department of Agriculture, recently in their Bulletin No. 217 (salt tolerance of field crops) published in March, 1960 have given salt tolerance of various crops, which is reproduced in Table No. 8.

UNESCO in their publication "Utilization of saline water" has given the tolerance salt contents suitable for irrigation, which is reproduced below:-

TABLE NO. 8
SALT TOLERANCE OF VARIOUS
CROPS

Tolerant	Moderately tolerant	Sensitive
Electrical conductivity of soil 8 to 12 milliohms per CN at 25° C (One milliohm is usually equivalent to 640 per million of salts in solution)		
Barley (grain)	Rye (grain)	Field beans
Sugar beet	Wheat (grain)	
Rape	Oats (grain)	
Cotton (upland)	Sorghum (grain)	
	Sorgo (Sugar)	
	Soybeans	
	Sesbania	
	Broadbean	
	Corn	
	Rice	
	Flax	
	Sunflower	
	Castrobean	

TABLE NO. 9

USE OF WATER OF DIFFERENT SALT CONTENTS

Proportion of chlorides, expressed as NaCI in gramems per liter in the irrigation water.	Sustainability for irrigation
Less than 0.5 (i.e. 500 parts per million)	Suitable for all irrigation
0.5 to 1.0 (i.e. 500 - 1000 parts per million)	Suitable for most irrigation
1.0 to 1.5 (i.e. 1000 - 1500 parts per million)	Slightly high chloride content, usable for most irrigation but precautions needed for use on sowing of delicate varieties.
1.5 to 2.0 (i.e. 1500 - 2000 parts per million)	Definite chloride bias but useable for irrigation except for sowing of delicate varieties.
2.0 to 2.5 (i.e. 2000 - 2500 parts per million)	High chloride content, but useable with suitable precautions.
2.5 to 3.0 (i.e. 2500 - 3000 parts per million)	High chloride content, but still useable for certain crops.
3.0 to 4.0 (i.e. 3000 to 4000 parts per million)	Very high chloride content, practically unusable for irrigation.
Above 4.0 (Above 4000 parts per million)	Salt water entirely unsuitable for irrigation.

These two tables require study by specialists as according to this information we can use water with three to four times the salt contents than what is otherwise being recommended now. If salt contents to the extent recommended by UNESCO and U.S. Department of Agriculture do not affect some of the crops substantially, we can easily use most of the ground water available in the region for irrigation. The matter needs a thorough investigation.

CHAPTER XIV
SUGGESTED METHODS FOR DEVELOPMENT OF GROUND WATER AND COST

In the chapter No. IX two methods of ground water development have been recommended:—

(i) Tube wells.
(ii) Open wells.

The tube wells and open wells will again be of four categories. (a) Alluvial plains type, (b) Kohistan type, (c) Thar type, and (d) Nagar Parkar type.

(a) ALLUVIAL PLAINS

(i) *Tube wells:*—Tube wells with average discharge of 1.5 to 2 cusecs, shall be 125'-200' deep, with 6" filter and a 20 H.P. diesel engine, or a 15 H.P. electric Motor. Cost with diesel engine, pumping set and pump house etc. Rs. 17,500; and with electric operated sets including a pump house etc. Rs. 10,000 (Refer Fig. 12).

The discharge of the tube well: 1.5 cusecs.

(iii) Open wells with filters: Total depth 30'-40' filter of 6" diameter. The cost will be as under:—

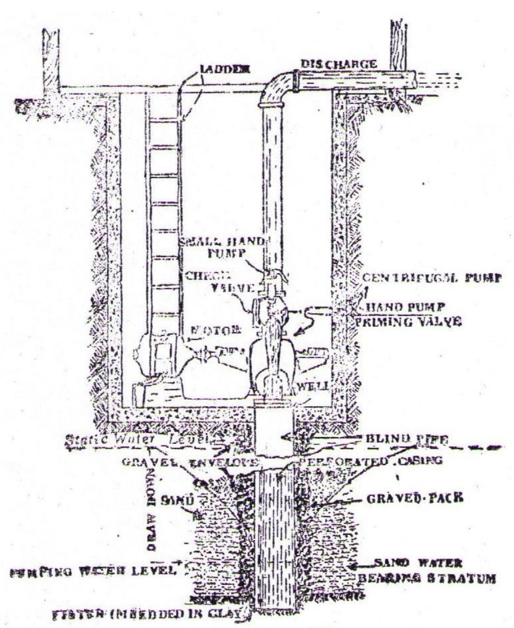


Fig. No. 12

Fig No. 12

TUBE WELL FOR ALLUVIAL PLAINS WHEN WATER TABLE IS UPTO MAXIMUM OF 40'

Diagram showing conventional type of tube well with horizontal electric motor driven centrifugal pump. Recommended for alluvial plains of this region. The diagram shows necessary components like; check valve, priming pump (useful though not common); ladder for going down, lined pit to house the pump and keep it close to water table, gravel envelope, water bearing strata occasional clay lenses, static water level, pumping water level, draw down, metallic filter and discharge pipe.

In case of diesel pumping unit: (Refer Fig. 13).

Open well	Rs. 2,500
Drilling and filters	Rs. 500
5 H.P. diesel engine and pump etc.	Rs. 4,500
Total	Rs. 7,500

Where electric power is available, it will be cheaper to use electric motor instead of diesel engine.

In case of electric pumping unit:

(1) Open Well	Rs. 2,500
(2) Drilling and filters	Rs. 500
(3) Electric motor and pump etc.	Rs. 1,500
Total	Rs. 4,500

(iii) Open well without filters with 1/8 cusec discharge and Persian wheel or flow pump:—

(1) Open well	Rs. 2,500
(2) Persian wheel or flow pump	Rs. 1,200
Total	Rs. 3,700

The discharge of an open well with filter and pump will be 1/3-1/2 a cusec, and that without filters only 1/8 of a cusec.

(b) *KOHISTAN AREA*

(i) Tube Wells— Since quantity of water in a rocky area is small and the draw-down is too much, ordinary, centrifugal type pump will not work, and therefore one has to install a deep well turbine pumping set. Cost, Rs. 30,000, including filters, pump and pump house etc.

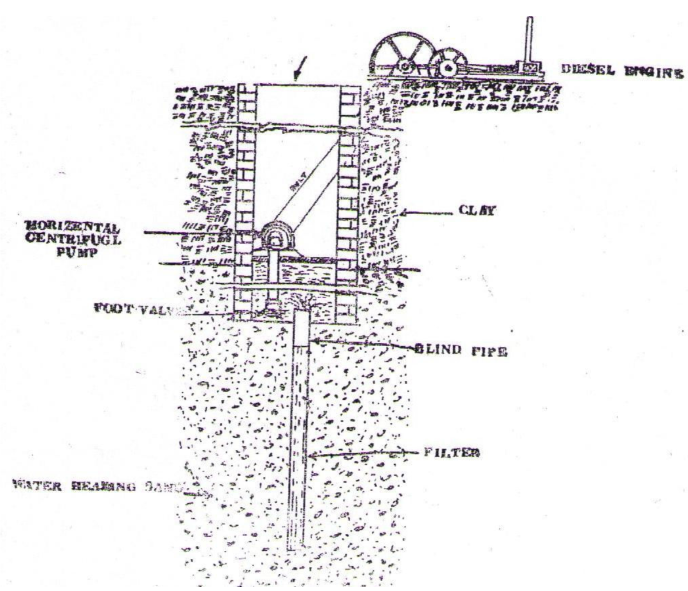


Fig No. 13

DUG WELL OR OPEN SURFACE WELL FITTED WITH HORIZONTAL CENTRIFUGAL PUMP AND DIESEL ENGINE

The well has a filter at the bottom which increases its capacity two to three times. This type of installation is very popular in West Pakistan.

Discharge: 1 to 1.5 cusec of water.
Refer figure No. 14 for deep well turbine pump.

(ii) Open Wells. 58'-80' deep with 15 H.P. Diesel pumping set are recommended. Cost will be as under:—

(1) Open Well	Rs. 7,500
(2) Diesel engine with pumping set etc.	Rs. 7,500
Total	Rs. 15,000

Discharge: 0.5 cusec of water.
Refer figure No. 15 for special type of pump recommended for Kohistan conditions.

(c) *THAR AREA.*

In this area till test bores are carried out to see the quality and quantity of water, open wells having small discharge only and depth between 100'-300' will be installed.

The cost will be as under

(1) Well 100 ft. deep, 12' diameter	Rs. 10,000
or 200 ft. deep, 12' diameter (Telescoping)	Rs. 25,000
or 300 ft. deep, 10715'020' diameter, (Telescoping well)	Rs. 40,000
(2) Wind mill, pump and installation etc.	Rs. 20,000

(d) *NAGAR PARKAR AREA.*

(i) *Open Wells.*

(i) Open wells 50' to 60' deep
Rs. 7,000
(ii) Persian wheel (discharge: 1/8 cusec)
Rs. 1,200 or
6/7 H.P. diesel pumping set with accessories.
(Discharge: 1/2 cusec)
Rs. 5,000

(ii) *Tube Wells.*

Same cost as that in the alluvial plains: Rs. 17,500 Discharge: I to 1.5 cusecs.
However, in Nagarparkar, test boring on a large scale is necessary before tube wells may be

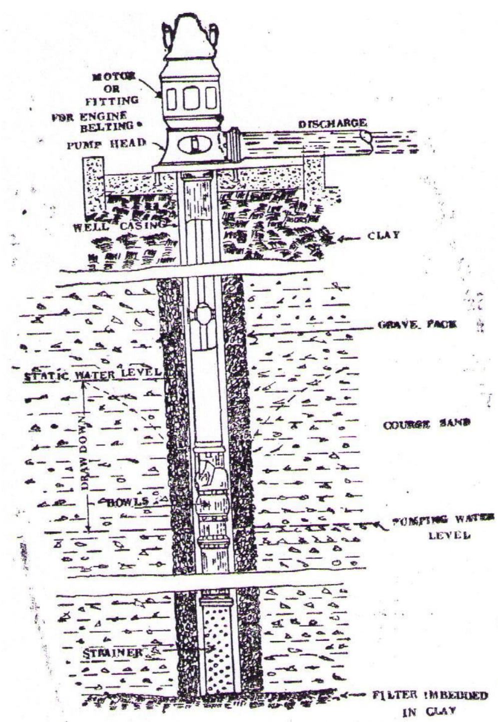


Fig No. 14

DIAGRAM OF A DEEP-WELL TURBINE PUMP
Recommended for areas where water table is deep or draws down is excessive. Suitable for Kohistan and Thar Desert areas.

recommended.

Water movement in some formations is very slow. Recent observations in Sahara desert have shown that water has travelled through about 200 miles in 500,000 years. It is therefore possible that water left by old Siwalik and other rivers may be encountered at greater depth in Thar, but it is very doubtful if this shall show artesian conditions.

PLANS FOR PROPER DEVELOPMENT OF KOHISTAN AREA

There are a number of springs in the rocky zone, which could be classified as:—

(a) Springs in the high mountains
(b) Springs at the foot of hills
(c) Springs in plains, valley fill, and those which appear and disappear in the *nais.*

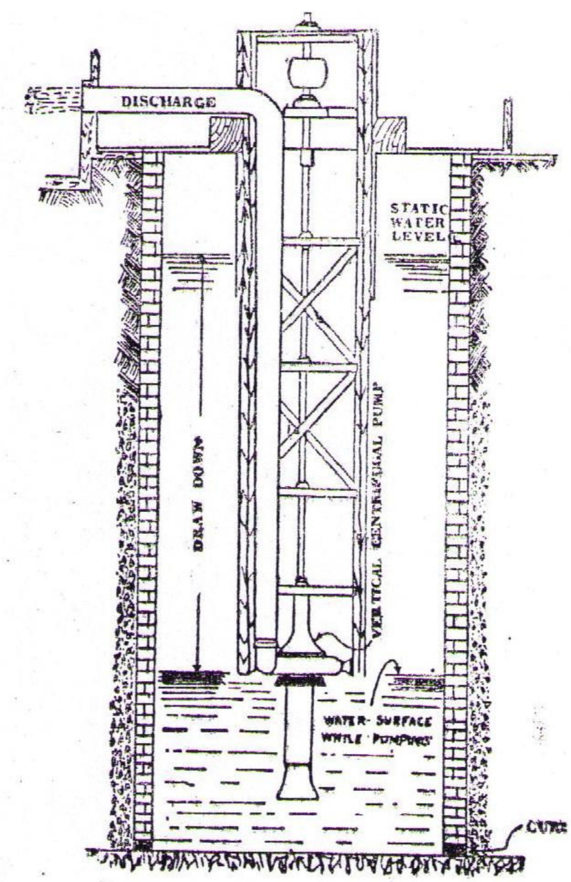


Fig No. 15

OPEN WELL FITTED WITH VERTICAL CENTRIFUGAL PUMPS
This type of installation is not known in Pakistan, but is most ideal for open surface wells of Kohistan area, where due to excessive draw-down the centrifugal pump cannot pump beyond a certain capacity and become inefficient and un-economical. Their initial cost including installation will be much less than that of horizontal diesel operated centrifugal pumps of the some capacity.

As regards quality of water i.e. percentage of soluble salts, it is minimum in first case and maximum in the last, as the water in latter two categories, is mostly seepage from uphills and will carry lot of salts en-route.

Usually there is no agricultural land in case of (a) except at, few plateux in the Larkana and upper Dadu, but in case of lower Dadu and Thatta the hills are not so high and the spring water is useable directly.

When open wells and tube wells are put in the rocky area the springs and *karezes* will dry up gradually. It will therefore be a wise policy to give up development of springs, *karezes* water galleries in favour of wells and tube wells. It need not be emphasised here that the quantity of water that can be tapped from wells will be many times that from springs and *karezes.*

Another aspect of development should be to start development from up-hill side down wards so that the whole quantity of water on the up-hill side is utilized. Instead of its coming out as springs, riverlets and being lost by evapo-transpiration.

In the upper portion of Kohistan i.e. Larkana and northern Dadu districts there is no agricultural land in the mountains and therefore the best area for development shall be sub-montane tract. In Kachho area, because of thick clay layer at the top and deep water table, harnessing of ground water by any method other than deep well turbines will be difficult. In such cases if ground water is available in sub-montane tract, it could easily be pumped out and brought to Kachho by streams.

The development of sub-montane ground water has another advantage that an underground storage will be created which will later be replenished by water from up-hills, thereby even reducing evapo-transpiration and run-off losses up hills. This will also help in reducing water coming down in form of stream-lets and spring-channels most of which ultimately form swamps and then water evaporates to atmosphere.

There is another good reason for developing the land at the foot of hills first because the salinity of ground water will rise progressively as one moves away from the rocky zone.

In the zone shown as unsurveyed in the Kohistan area the rocks are usually of lime-stone. Lime-stone has fissures and cracks through which water circulates. If this stone is- covered with dis-integrated vegetative growth the latter imparts CO^2 to rain water which helps dissolution of salts. If the rocks are bare, and not decomposed the rain water which takes CO^2 only from atmosphere in very small quantities, is just incapable of dissolving rock salts beyond depth of .003" and therefore fresh ground water can be expected in Khirthar lime-stone ridge or the Laki lime-stone. The chances of getting sweet water in the unsurveyed zone therefore need not be ignored.

CHAPTER XV
ANALYSIS OF WATER AND WATER BEARING STRATA AND CONCLUSION

There are different methods, and standards, laid down for investigation of ground water and the water bearing strata. Due to limited, staff, and lack of facilities for carrying out detailed analysis of water, we had to adopt simple methods which would ensure how far water was useable for irrigation and what type of strainers and pumps etc should be selected. The water analysis consisted of total soluble salts, per million parts of water and its p.H. value. The water was usually associated with sand, therefore only, 3 categories of sand were determined.

(a) 1 m.m. and above, coarse sand.
(b) 0.5 to 1 m.m., medium sand.
(c) 0.1 - 0.25 m.m., fine sand.

The analysis did not cover very coarse sands, gravel, very fine sands, clays and silts etc.

From the information collected, it was found that in the sweet water zone created by seepage from river Indus and its branches, the sand was of medium class in almost 60% of cases and fine in 40% of cases. The coarse sand or gravels were met only occasionally and in thin layers. By experience of the first five years (1953-58) work, it was seen that almost all tube wells with coir rope filters had failed in this area, and therefore we recommended brass filters, with 0.016” and 0.010” slots for medium and fine sand strata. These required gravel packing, but since the biggest size bore we could drill with hand rigs was 10", we could only give a gravel pack of 21” or 2" by putting 5” or 6" filters. The gravel was 1/8” to ¼” size. This worked alright, as only one tube well failed during the, last 5 years due to filters getting colgged with sand, but this also was reclaimed later on. We knew that the question of filters had raised controversy elsewhere, but since these functioned well for us, the work of evolving better and cheaper filters was left to other organizations (Ref. fig. 16 for gravel packing).

The only exception to medium sand was in Kaachho area i.e. west of Kamber, Khairpur Nathan Shah and Johi Talukas along the Sind Hollow, where clay layers at top some times were as thick as 60'-70', and down below thick gravel was not an uncommon feature.

In Jacobabad District near Thul, the sand met with was of coarse or even of very coarse type, and therefore in a few cases, no gravel packing was done. Surprisingly enough none of these tube wells pumped out any sand.

In the plains the top layer is usually clayey and sand starts after 15' to 30', but sand layers at top 10' to 20' are usually dirty, mixed with clay and silt, and the sand is finer in many cases. It was therefore decided not to put any filters in top 15' to 20' of sand strata. While

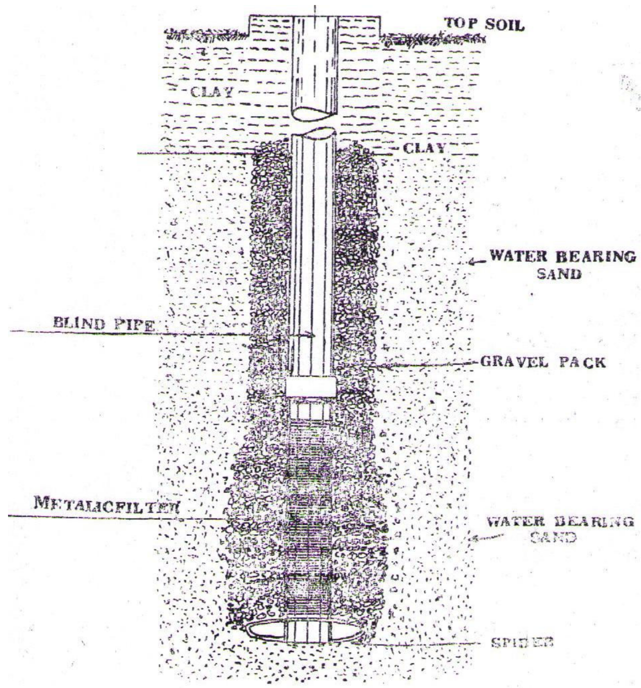


Fig No. 16

SECTION OF GRAVEL PACKED WELL

In case of metallic filters, the gravel acts as an additional filter. In ideal conditions the gravel-pack layer should be 6" thick and gravel size between 1/8" to 1/4" drilling, many times clayey layers are met at various depths, but they are a few inches thick in most of cases. These are local, and therefore their presence is ignored. Only rarely 10' to 20' thick layers of clay are met, but they too seem to be local lenses. Thick layers of clay are choked by blind pipes, while lowering the filters.

As regards the discharges, we were keen to get maximum water from shallower depths. It was found, that in Jacobabad and Larkana districts and Sukkur sub-Division of Sukkur District which is the rice area, the water table in April is hardly 8' below the ground level. A 100' deep tube well, with 30' filters, in this area, yields upto 1.75 cusecs of water. In limited cases, drilling was done over 125' depth. The pumps used were centrifugal 6"x6" and having capacity of about 1200 gallons per minute, but discharge measured by V-notches, showed only 1.5 to 1.75 cusecs. The centrifugal pumps have limit to their suction capacity. Fifteen feet is about the normal. It was concluded that pumps, which were about 4' above the water table, and give 1.75 cusec discharge, showed that we could pump one cusec of water for 15-4/1.75 i.e. approximately 6.5' draw-down. The actual draw-down were not measured by putting down the air lines, as none of the land-owners was interested in getting air lines installed. To get more discharge one has to put in a deep-well turbine. This will cost at least double the amount but will not give the proportionate discharge, and even the running costs will not be lower, as higher discharge creates more suction heads and therefore water has to be lifted through greater height, which in turn increases power consumption costs proportionately. Conditions in Khairpur district particularly are the same.

In Rohri sub-division, Nawabshah and Hyderabad district, water is available at depth of about 20'-30', and above it are the clayey strata. The tube wells about 125' deep have given discharge of approximately 1.5 cusecs. It was felt that in Hyderabad district sand is finer than in the other districts, and therefore its permeability was also expected to be low. In such cases we went about 200' deep to get assured supply of 1.75 cusecs.

All these wells could give a discharge of 1.75 cusecs, but some-times, unfortunately, the pump impellers were not properly designed, and the land-owners concerned did not care to replace them to suit the suction head, resulting in slightly lower discharges of 1.3 to 1.5.

It has therefore been concluded that in the plains of Hyderabad and Khairpur divisions, the centrifugal pump tube wells will prove to be the most ideal and economical. To increase the discharge beyond, 1.75 cusecs, firstly one has to go deep, and as we go down, salinity increases and quality of water becomes poor. Secondly, by pumping more water, draw-down or suction heads increase, and therefore the power required to lift water is more. Thirdly, the ordinary centrifugal pump has to be replaced by a deep well turbine, and these pumps can not be lowered in 6" filters. In other words, we have to put bigger bore, say 14" to 24", which would need power drilling rigs, and not ordinary hand drilling rigs. Lastly, the capital cost of deep well turbine tube well, shall be Rs. 30,000 to Rs. 35,000, as compared to 16,000 to 17,500 for ordinary centrifugal pump tube wells.

The figures about recharge rate are not available, though the April and September water table difference is about 6'. The porosity of medium sand we encounter is about 30% to 35% which means that about 2 cusecs of water are seeping in the ground per sq. mile, and this quantity of water can therefore be pumped out without lowering water table, which is already high in these areas.

As regards salinity, it is the experience that as one goes away from the present bed of Indus, the salinity keeps increasing. A number of bores were drilled in Tando Allahyar Taluka near the old bed of Indus (bed prior to 1758). Even in this case, salinity kept on increasing as one went further from the river bed, and after going 6 to 7 miles away, the salinity exceeded, and the tolerable limit.

This evidence further suggests that the ground water is due to seepage from the river Indus. By pumping ground water, therefore, the chances are that the river water will replenish it during the high flood period. Therefore pumping more than even two cusecs may not affect the area adversely.

The open surface wells built in the area are very defective in their construction. The brick lining is laid in mud plaster, which is not really any binding agent, specially in presence of water, which.; spills , all over on the walls, due to the use of Persian wheels. Some of the wells are near water-courses, and water from the latter seeps into them, causing weakening and caving in of the formation all around. These wells can not yield adequate quantity of water. The open wells must be laid in cement mortar, and should be taken at least I0-15 feet below the top sand, which is usually impregnated with impurities like silt and clay. At present, 2" to 2½" diameter filters are being put in these wells. 5"-6" filters instead of small filters, which soon get clogged, will be better. The filters should be put as deep as possible.With these improvements, one can easily pump 1/3rd to 1/2 cusec of water from the wells, but if the wells are not laid in cement, the chances of caving in and the collapsing of wells on pumping more than 1/4 of cusec are almost 95%.

It has been suggested to dig the wells deep enough, and fill them partially with graded gravel, so that, on pumping sand does not come up with water. Theoretically this is possible so long as the weight of gravel plus water above it equals to the weight of total column of water, if there were no draw-down, and no gravel In actual practice, such construction will be highly uneconomical, and sooner or later, When sand slowly comes up, its cleaning, and re-filling with graded gravel, may involve lot of expenditure.

METHOD FOR TAKING SAMPLES.

All the 800 bores drilled were by hand or power percussion rigs. They are slow but accuracy of method cannot be denied. At every 10', water and soil samples were taken. In many cases analysis was done by chemical section at Tandojam, at our own request, but in the cases where land-owners got the analysis done on their own, the results were not supplied to this section. It is therefore difficult to give the detailed logs -and salinity data for each of the wells. A few representative data are however attached in Appendix I. One thing was clear that salinity increased with depth. This gives another justification for not going very deep but instead put in shallow tube wells of 1.5 cusec capacity and between 100' to 150' deep.

It may be admitted here that we had intention of fixing Ca, Na, Mg, CI_2 CO_3 SO_4 and HCO_3 from the beginning and no such analysis was done, specially due to lack of facilities and the cost involved. Detailed analysis has definite advantages, specially when salt contents exceed 1.200 p.p.m. but salts may not be injurious to crops. However such occurrences are comparatively rare.

DESCRIPTION OF SOME BORES SHOWING ABNORMAL BEHAVIOUR

DISTRICT JACOBABAD

A number of tube wells have been installed in Thul Taluka, which is in the shallow sweet water zone. On pumping, it was found that one of them after three years showed salinity of over 1400 pp.m. The tube well was shifted to another site. It was noted that the tube wells were in proximity of Nasir Wah and Unar Wah which have been flowing for over 250 years and have diluted the water down below in limited pockets. It has been concluded to put not more than 70' deep tube wells in this area.

Another tube well near Abad (R.S.) in brackish water zone showed sweet water when installed. This well was worked 22 hours daily during the dry season. At the end of May, salinity increased to 1200 ppm, but in November when pumping was re-started, salinity fell down to original level. The location of tube well is only one furlong from Noor Wah constructed by Mian Noor Mohammad Kalhora 250 years back. Even in brackish water zone, water in shallow depths is sweet due to continuous irrigation of rice. After conquest of Sind, John Jacob found that water in Jacobabad town was brackish and therefore he constructed a tank for city water supply. Today there are a large number of open surface wells in Jacobabad town giving sweet water. This is due to rice irrigation around Jacobabad for a century.

Gharhi Khairo is another place in the district, where water is sweet upto the depth of 200' or so. The western branch of Indus has always passed through Ghari Khairo and so has the drainage channel of Bolan and other rivers of Balochistan. Nothing could be said about the capacity of the reservoir but it should be substantial.

In Kashmore Taluka, specially near northern area, water is brackish in all bores. This is probably the under ground drainage area of the Bugti hills to the north, which contain brackish water.

SUKKUR DISTRICT

In Sukkur district a tube well, approximately two miles south of Sultan Kot to a depth of 125' in shallow sweet water zone, showed salinity of 1150 ppm. This tube well is in proximity on the course number 3 of the western branch of the river Indus (Chapter V). This well was bound to go brackish, and therefore the land owner was advised to go only 70-80 feet. In the same district, in the neighbour-hood of Sukkur town, within a radius of approximately 2-3 miles, it is not advisable to put in tube wells more than 100' deep, as down below we may encounter the lime-stone of Rohri hills or water drained by them.

LARKANA DISTRICT

In Larkana district, in the areas shown as un-surveyed to the west, there are *dhands* (Lakes) and rain-fed rivers. The famous plataeux of Daryaro and Kutte-ji-Kabar are also in this area. The area requires thorough investigation.

KHAIRPUR DISTRICT

In Khairpur district one tube well was installed, near Sorah, on the old bed of Eastern Nara. Its water is sweet because of nearness to Nara. A shallow tube well 80 feet deep, near village Bagodero in Khairpur district, also showed sweet water. It was possibly due to proximity with Nasrat branch, which one time was bed of river Indus; later on an inundation canal and now a part of Rohri canal system.

HYDERABAD DISTRICT

In Hyderabad district, only in the upper portions, consisting of Hala Taluka and some parts of Tando Allahyar and Hyderabad Talukas, water is sweet. This has been shown in map No 10. On the fringes of the belt, some tube wells have been installed, specially near Tando Jam. The salinity of these tube wells keeps on increasing gradually However in the centre of the area, there is no rise of salinity even where the tube wells are 200 feet deep. It is concluded that on the fringes, heavy pumping may turn the water saline. A few bores at Matiari specially, close to the river, showed high salinity. This is mainly due to drainage of salts, from the Manchhar hills, between Unarpur and Petaro, on the other bank of the river. It cannot be said at present whether the salts from the rocks on the right bank will drain in the whole area north of Hyderabad. Similar phenomenon was observed near Daulatpur where salts were probably draining from Manchhar formations of Baghothoro hills.

Some tube wells were put in Tando Mohammad Khan near the bed of Phulleli canal. One of these turned saline after some time. If any tube wells are to be put near Tando Mohammad Khan on the banks of Phulleli, they should be shallow. In case of deep wells, the danger is that they will quickly get saline. The bifurcation of river before 1758 took place between Tando Moharnmad Khan and Shaikh Bhirkio. Since then Phulleli has been flowing through the same area. It is therefore concluded that in the area bounded by Tando Fazal, Shaikh Bhirkio and Tando Mohammad Khan shallow tube wells of less than 70' depth may supply water fit for irrigation.

THARPARKAR DISTRICT

In Tharparkar district, two tube wells installed at Government fruit Farm, supplied good water, but in the rest of the surrounding area, even in the town, water is brackish. The Eastern branch of river Indus passed near Mirpurkhas, on which once flourished the famous Kahu-Jo-Daro. The water at the fruit- farm may have been sweet because of the proximity of the old course. Since the rate of pumping at the farm is limited, there is no reported increase in the salinity. Two shallow bores at Umerkot and Nabisar showed sweet water. The reason for this is that they were near the bed of Eastern Nara, one time the mighty Hakra River.

A number of wells around Diplo showed sweet water suitable for irrigation at depth of 50-60 feet or some time more. They could be exploited for irrigation. During the visits, a number of wells between Naukot and Nagarparkar via Mithi and Islarnkot showed potable water. This water in a few cases was analysed and though apparently potable, had high salt content. Besides, the supplies of water were in-adequate. The potable water wells have been marked on the map of Tharparkar district.

THATTA DISTRICT

In Thatta district, there are no chances of getting sweet water in the plains. Five test bores were put in Kalan-Kote Lake in 1957. The lake has always remained a source of water supply for Thatta town. It was at one time probably the bed of a branch of the river. Though the lake may have dried up only occasionally during the last 600 years, the ground water is brackish, even upto a depth of 150'-200'. Below this level there is rock. In the rocky area of Thatta district, there are chances of tapping sweet water in Loki, Nari, and Gal formations.

SANGHAR DISTRICT

There is sweet water in a limited area near Shahdadpur and Tando Adam. In the bed of Eastern Nara near Khipro, water is sweet to shallow depths. In the rest of the area, water is brackish.

INTRODUCTION

The quantity of water available in this region is not finate. Estimates have shown that it will be safe to pump about 12,000 cusecs (2 cusec per sq. mile of sweet water zone extending to 6,000 sq. miles. M/S Huntings technical series have estimated these 3.1 million acre feet i.e. 8,500 cusecs. But they have not included Kacha area which has sweet water zone of about 2.000 sq. miles. In order to maintain this supply the hydrological factors should remain practically unchanged. Under Indus Basin water treaty the waters have to be diverted. This will reduce rechange rate and pumping limit will be affected considerably.

Study and exploration of ground water involves many sciences like geology, engineering, geophysics, geochemistry, hydrology and mathematics. It is impossible for one man to do just to the subject. The following notes discuss some important problems and questions which have been raised since publication of first edition 5 years back.

The purpose of introductory chapters I to VIII was to give the reader a thorough back ground of groundwater regime i.e. natural historical process representing individual stages of its formation proceeding under the sum influence of interacting and changing factors consisting of climatic, hydrological, geological, soil, biogenic and artificial, in the Lower Indus Basin. These chapters interested many readers. It was therefore felt that further work must continue to satisfy growing questionnaires.

It was in this contest that study of ground water regime of Nara canal and its main branches Jamrao and Mithrao was undertaken as conditions controlling its existence, climate, size of catchment, discharge had not changed in about century.

Another study was undertaken in Kacho between the protective embankments of river Indus and just out side. It was found that rapidly changing hydrological factors in the surface waters cause wave like changes and fluctuations in ground water regime, which have their maximum, minimum and mean variable time values. These surfaces water changes are annual and they influence hydrodynamic conditions, resulting in unsteady flow to ground water table. The changes were prominent in Guddu Barrage command, tract under rice canal and riverine areas but though they were less prominent in other areas of Sukkur Barrage command, still were sufficient to make many tube wells inoperative due to increase in suction head.

Kacho is considered more unpredictable. In general for whole hilly range there is actually no limit to historical outlook, and whenever time changes of water regime are discussed, one is forced to leave the present past and traverse into the geological times.

The variations in chemical composition of ground water in adjoining areas separated by short distances are difficult to describe to farmers installing tube wells. They could be attributed to soil forming processes, which exercise their influence on the rate of replenishment' of ground water or to biogenic process particularly micro-flora activity.

Transpiration caused by trees and agricultural crops over centuries has definite influence in change of quality of water.

Hither to artificial factors were not considered but pumping of ground water in certain areas has either improved or deteriorated the quality of water.

Unfortunately the farmers have kept no records of long term fluctuation of ground water of their tube wells. The Engineering Section of Agricultural Department is not adequately staffed to check this up periodically and to study, the ground water regime.

The ground water temperature beyond the depth of 60' is nearly constant throughout the year and in no case variation during the year is more than one degree. Temperature of ground water at Tandojam is 84° Advantage of this can be taken for heating or cooling the houses if located close to the-tube well. The fluctuations in atmospheric temperatures have no effect on water table.

The fluctuations in atmospheric pressures have quite insignificant effect on water table. Natural springs show erratic behavior due to changes in pressure. The discharge increases when pressure falls down. Exact measurements have not been taken. The conclusion is based on local knowledge and personal observations rather than scientific measurements.

GEOLOGICAL FACTORS AND THEIR INFLUENCE ON WATER BEARING STRATA.

Probably intensified action of oxygen and carbon dioxide in presence of water causes rock solution and formation of bicarbonates and later on precipitation of carbonates of iron, calcium, magnesium and potassium. This causes cementation of all cracks and fissures and clogging of filters.

The gravel of Khirthar range is unsuitable for packing around the filters as it contains soluable lime-stone and invariably clogs them in course of time. The gravel from Baluchistan hills is equally unsuitable as calcium carbonate dissolves in water containing carbon-dioxide. The gravel from Nagarparkar hill belonging to pre-Cambrian age is the answer, but transport difficulties have to be solved. Another solution is basalt layer on top of Laki hills.

EARTH-QUAKES.

Seismic factors change the hydrodynamics and resilient state, thermal regime and chemical composition of ground water and some times its occurrence and quality. Old springs disappear giving rise to new due to joining and intermixing of various water bearing strata. No measurements have been made, but earth quakes some times are preceeded by rumbling noise in the wells and rise of water table which continues for many hours even after the seismic shocks have subsided. At places wells can even run dry temporarily or permanently. The formation of Allah Bund in Rann of Kuchh, disappearance of fort of Sindhuri, appearance of a number of cracks in earth from which sulphuric waters and silt erupted for 3 days, after the famous earth quake of 1819 A.D. has been recorded. Even in Badin & Jati Talukas many miles from its epicentre, water gushed out from wells till it flooded surrounding country to a depth of 6'-10'. Mud gysers appeared at many places in the delta of Old Hakra or Nara.

Rann of Kuchh and lower Sind is in an active sesmic zone. History has recorded following earth quakes in Lower Indus Basin.

1. 962 A.D. towns of Bahmanbad and Alore were said to be destroyed by an earthquake, though it is very much doubtful.

2. 16th June 1819, A.D. earthquake in Rann of Kuchh was responsible for destruction of Sindhuree, formation of Allah Bund, uplifting earth by 20' in the north and depressing 10' in south along the vertical fault plain, which had width of 50 miles.

3. Minor topographical changes of same type as that of 1819 occurred in earthquakes of 1844 and 1845 A.D.

4. Between 1845-1861 A.D. seven earthquakes have been recorded.

5. On 15th October 1895 A.D. area from Shah Bander to Tharparkar was affected.

6. On 14th January 1903 A.D. an earthquake caused fissures in Badin and Jati Talukas and erruption of warm waters from beneath for 12 hours

7. Makran earthquake of 27th November 1945, destroyed many fishing villages near Karachi.

8. Due to Earthquakes in Quetta and Sibi Kachhi plains shocks were felt in upper Sind in 1909; 1928,1930, 1934, 1935 and 1960.

The earthquake can knock out tube wells more completely than an atomic attack. Usually the casing string breaks into two parts and, the top portion is shifted by a few feet. In 1964 in an earthquake in Anchorage city U.S.A., 60% of tube wells went out of commission and in some wells the top string separated by as much as 10 feet.

BEDS OF RIVER INDUS.

Study of various courses of river Indus was done by reconstructing map of old bed of river Courses based on aerial photographs and a map 7'X4' has been constructed to study the regime over period of 5000 years Following factors were kept in view:-

1. Wherever river flowed in last 1500 years ground water is sweet, as there is usually ni5 impermeable bed excepting in Sinjhoro Taluka where an impermeable clayey strata of 100' was met. This strata seems to extend to Eastern portion of Nawab Shah Taluka. ln such cases water is brackish.

2. The Ground water is continuously being replenished from river Indus. The rate being high during summer floods and low in winter for many centuries.

3. Seepage to river bed from Kacha area occurs only in winter months, but this is More so after construction of Sukkur Barrage.

4. On the up-stream side of the barrage works, water is headed up in a distance of many miles and there- fore the river continuously recharges the ground in that area.

This phenomenon has helped improving quality of water on the left bank above the Barrage head. 15 years back the water near Miani forest was brackish, which now keeps improving as pumping proceeds. Similar phenomenon is taking place about 6-7 miles north of Sukkur Barrage head-works.

5. The change in river level is transmitted to the ground water and table of latter along the riverside experiences considerable instability, frequently amounting to, many feet. This extends not only to Kacho but many miles out-side. Due to this, almost all centrifugal tube wells in Guddu Barrage and Kacho area are being provided with two foundations, one for high and other for low water tables.

6. Due to the same reason, not only the direction of flow, but rate of discharge and chemical composition of ground water in these areas are subject to sharp irregularities. The alternating discharging and recharging tends to improve quality of ground water.

7. The temperature of ground water in these zones does not remain constant, as in remoter areas but varies, depending on the temperatures of river water and is higher than other areas.

8. It was observed that rate of rise of ground water table in Kacho and adjoining zones was not the same through out the length of river. The only plausible explanation is that permeability of bed of river at some places is substantially inferior to that at other places. No drilling has been done in the river-bed to verify this fact. Annual changes in ground water table within the zone of river influence, under natural conditions not disturbed by man, should in majority of cases be negligible, but due to artificial irrigation, in whole of rice tract water table rises 8'-10' by end of October and falls down to original level by about May, because of evaporation of water rising to the ground surface due to capillary-action.

9. A question has always been brought up by tube well owners in rice tract that though rates of precipitation, evaporation climatic conditions and delta of irrigation in adjoining area were the same, the time lag between fluctuations of ground water table varied. This happens due to increase in zone of aeration caused by thick or thin clay-loam layer above the water bearing sands.

10. In Ghulam Muhammad Barrage commands pockets of sweet water were met with specially along the old bed of Kalri Branch of Indus which bifercated from river near Tando Muhammad Khan and passing near Bulri went to the north of Thatta hills where Samas built their capital town Samui in 14th century.

11. The salts on the surface of land in some areas were artificially leached down in order to restore and improve fertility of the soil. Heavy dozes of such salts added to the salinity of ground water. In general where the soil is saline mineralization of ground waters during the irrigation at first experiences a sharp and continuous rise followed by a reverse cycle. In some areas where soil is not saline the trend is towards reduction in mineralization through desalination of soil and desalting of ground water by additional layers of filtration.

Hydro-chemical studies have not been undertaken and probably they cannot be justified.

GROUND WATER IN NARA COMAND

In the first edition of this book little was discussed about water in upper reaches of Nara canal above Jamrao head and impression was that ground water in area below Jamrao head was definitely brackish. M/S Huntings do not seem to have put in any test bore above Jamrao head. They however suggested that strata tap; streams of Jamrao head were not suitable for tapping ground water. To verify the truth of this statement, we put in 40 test bores each 100' deep at distance of every two miles from Rohri to Jamrao head in 1967. The statement of M/S Huntings has to be reconsidered in light of these test bores which showed that ground water in the first 22 miles (definitely due to nearness of Eocene hills of Rohri and Kot Dijji) was brackish but beyond this point right upto Jamrao head was sweet. The water bearing strata starts at depth of 50' and continues beyond 100'. It consists of coarse sand and lime stone gravel. The width of sweet water belt could not be checked but apparently it was ' more than couple of miles wide on either side of river. The source of this water was seepage from Nara canal which has been flowing as Perennial stream since. Fife opened it in 1859, more than 600 years after it had dried up. Any water pumped from the ground will be replenished by Nara canal, which then, must be supplied with extra water at suitable times to store it in the under ground reservoir.

The results below Jamrao head were equally interesting. Water on both sides of Jamrao canal was sweet upto a point a few miles south of famous ruins of Mansura or Bahamanabad. The sweet water column is more than two hundred feet deep near Jamrao head and it tappers off slowly as one moves south wards to Sanghar where depth of sweet water column was only 100 ft. Map number 14 shows sweet water Zone in the Jamrao Mitharo command. This is an important finding since the first edition was printed 5 years back. This map (based on aerial photographs) also gives old beds of river Indus and Hakra on which flourished old capitals of Sind Patala, Bahmanabad Mahfuza and Mansura.

GROUND WATER IN GHULAM MUHAMMAD BARRAGE COMMAND

Search for ground water was started in Ghulam Muhammad Barrage command from Tando Mohammad Khan to Jhok, specially in Gaja Command in 1964 at request from Agricultural Development Corporation. The old bed of river Indus in which, the boats, of Muhammad Bin Tughlaq and Feroz Shah plied runs parallel to the present Jhok-Bulri-Tando Muhammad Khan road and is traceable by presence of large number of Dhandhs, Dhoros, ravines and depressions. There is vast area where sweet water in a number of pockets varying from 80'-150' depth is available and could be tapped, though water bearing sand is fine, impure, impregnated with silt and clay and yield is low. This, area is bounded by following geographical marks:-

North East:— Tando Muhammad Khan.

South West:— 3 miles North of Bulri.

North:— Dadu

North West:— 2 miles West of Dhandhi

South East:—about mite East of Jalalani regulator.

Southern most point: — 3 miles from Jalalani regulator towards Bulri.

The quality of water is 2nd class.

Study of aerial photographs showed presence of three old beds of river which cut through this area and they definitely are responsible for sweet water pockets. Map No. 15 shows sweet water area and the courses of river Indus in this small area.

SEEPAGE OF WATER TO THE RIVER IN DADU DISTRICT.

In Chapter VII, general principles of ground water flow to and from river have been discussed. Dadu and Sehwan Taluka show exception to this rule. The ground water level here is above the average level of the river Indus. The ground water therefore continuously seeps towards the river. If this process is allowed to continue, the brackish water belt of Kachho and Western Dadu and Sehwan Talukas will push out sweet water in the river and the present narrow sweet water belt adjoining to the river will also turn brackish. Pumping out of the brackish water can reverse the process.

RIVER THROUGH ALORE GAP.

Arab geographers had mentioned that Indus passed through Alore gorge in 10th century but this statement is not accepted by geographers and scientists, who consider that the Alore gorge is too narrow to allow the whole volume of river water or even substantial part of it, through its gorge and therefore only a small stream could have passed through it. Study of aerial photographs tells a different tale. There are at least two very prominent old beds of Indus above the gorge, which must have discharged its waters through it. Below it there are two beds one western which ends into Lahano Dhoro and other more eastern which passes close to Kot Dijji hills but ultimately discharges in Lohano Dhoro. Besides this evidence, there is unusual sight which indicates as if very high volume of water at high pressure has passed through the gorge and at exit end due to reduction in pressure has spread in the valley creating fan shaped stream, the silt of which has created continuous series of wave like dikes as seen from a height of 20,000 feet. The aerial photographs indicate in un-ambiguous terms that bulk of volume of water must have passed through the Alore-gorge. This could be verified by deep drilling in the bed of Nara, which has not been done so far.

COURSE OF RIVER INDUS IN 17TH CENTURY:-

Well defined course of Indus as it existed in the first half of 17th century has been rebuilt on the information of Hisamud-Din Rashdi's recent publication of Tarikh-i-Mazahar Shah-Jehani, supplemented by the records of East India. Company's factories in Sind between 1635-1662 A. D. A situation of political confusion and economic uncertainly lead to the most indispensible writings, which show that:-

Bakhar was an island between two banks of Indus, the right one of which had not eroded the gorge completely upto present barrage head works and Many boats were wrecked by invisible cliffs projecting beneath the water. Sukkur had not gained importance sand was eclipsed by Rohri.

River passed west of Kandiaro, which had gained importance in trade.

Pat was no longer on the left bank and had lost its importance, its inhabitants were Khawajas' new converts to Islam.

South of Pat River was following more westerly course upto Sehwan. It touched Talti town which was on left bank and proceeded southwards upto northern outskirts of Sehwan, where it looped around the town to the east and touched Laki Hills. River had west-warded to these hills before 1592 cutting off old land route and making it necessary for Mirza Jani Beg to cut a route through the hills. This route through the hills still forms part of main road between Kotri and Dadu the other portions of road were abandoned only a few years back. Present Villages of Khabroth, (near Sehwan) Sukhapur (in Talti Tappa) and Bhutra (near Sehwan) which also existed then, were on right bank. On the opposite bank were villages of Daulatabad (possibly Daulatpur), Deh Shaikh Momah Lanjar and Saidan Karach. Other Villages mentioned are; Babri on the right bank which has survived upto now. Kaka village now in Dadu District was on left bank then, and was a well known Pattan. Mandeji was a river port on the right bank just two miles south of Sehwan.

Tappa Lakhat was on left bank, but still included in Sehwan Sarkar indicating that change of course was comparatively in more recent times then, and old administration was still governing the areas. Lakha village was on the left bank of river then.

Sann having a strong fortress was on edge of water and opposite it on the left bank was Gujar village which has survived for 3½ centuries and is now known for Shrine of "Mai-Ojhi Rani".

Khasai-Shora now small village and an important centre of rebellious Shoras on the right bank of river then, was burnt by Moghal governors. It was first time erroded in 1956 and rebuilt at a new site.

Nasarpur was, on left bank and so were Vinjhar and Said ,Garh, all three of which were fortified. The last has survived as a small village and Nasarpur has lost much of its importance.

Kalri was still branch carrying the main water of river, leaving Thatta on left Bank. Kalan-kot was already in ruins. It was then that Sain Dina a Hindu hearing of Mirza Ghazi Beg's death, rebelled, crossed the river near Thatta and moved through hill country towards Sehwan.

Puran the Eastern branch of Indus was then called Sankra, a word on which Raverty was to lead a controversy 250 years later.

ARTESIAN WATERS:-

Due to lack of the means communications in the rocky zone where the artesian conditions are met with, large scale study hither to has not been possible. Forecasting levels of artisian wells is important for water supply. Western hilly region is rich in springs. Of all important springs Indo Pakistan sub-continent recorded by Geological Survey, this area contains about 70%. Many of less important springs have not been recorded. After Blanford (1874-77) no survey has been done. Some springs give substantially high discharges. The one in Ranikot yields about 5 cusec of water even in the driest part of the year. This spring probably was main source of supply to the occupants of fort in its hay days 1600-2000 years back and continued to remain so during various periods of its occupation till last century. Most of springs including this one, yield water fit for irrigation and some irrigation is being carried out on them.

Although the fluctuations in level of spring water to natural causes is insignificant, it is never the less important for calculation purposes,

Wells in the whole region show arteisian condition i.e. water table in the casing pipe rises as drilling proceeds. This is only 2-3 feet in the Indus plains, but in Kachho, Thar and Pat it is some times a few score feet.

Where the arteisian conditions are responsible for free flow of water above the ground or rise in level of water is high, rational controlling of discharge rate will help in reducing the expenditure on pumping. In such cases it may be economical to install a small pump and run in it for longer time or vice versa.

By artificial rechange of ground water, the discharge of arteisian wells or spring could be raised in many cases in rocky area. The rain fed rivers can serve as best rechange basins. It must be admitted that at present in large number of cases the accurate location of natural Irainage areas for deep lying artisian waters (both springs and wells) is not known and unless proper roads are built first, this investigation can not be under taken.

If irrigation is the purpose in mind the examination of artesian waters with reference to the content of rare elements, gases and microflora is of no small importance. Of particular importance when on analysing the regime of ground water is relationship between water-table fluctuations and dynamics of water delivery. This is known for the Indus plains, but there is no information on Thar, Pat Kacho, Kaachho and Kohistan.

In the irrigated tracts over a long period of time water-salt balances is characterized by process of natural desalination. The shallow sweet water zone throughout the region is mostly out come of this process. It is accepted that over a long period of time the brackish water may turn suitable for irrigation. The process can be hastened by installing drainage tube wells.

In non-perennial areas the canals act drainage channels, and carry water which in most case is suitable for irrigation but is not being utilized for Rabi crops. Pumping of these waters will further induce the seepage and save lands adjoining the canal banks from possible deterioration. In low lying areas where canal bed may be high; this water may seep into the lands even in winter and may possibly make them totally unfit for cultivation.

Belts 50'-200' or more in width along the banks of canals and distributaries invariably show lenses of desalined waters, over lying brackish water. This water usually has same composition as irrigation water differing from latter only by its high sulpher content due to decomposed organic material.

FORESTATION:-

Forests prevent the rise of ground water and thereby prevent salinization of soil. Forestation done along the canal banks in a narrow belt promotes lowering water table along in this belt.

BARRAGE HEAD WORKS AND GROUND WATER:-

The construction of dam on rivers causes two kinds of filtration, first under the dam always under-pressure, other along the bank on up stream side usually free of any pressure. The other infiltration sooner or later merely by passes the dam and discharges back into the river on the tail side as shown by diagram below:-

We have three such dams in this region and 4th one is proposed to be constructed.

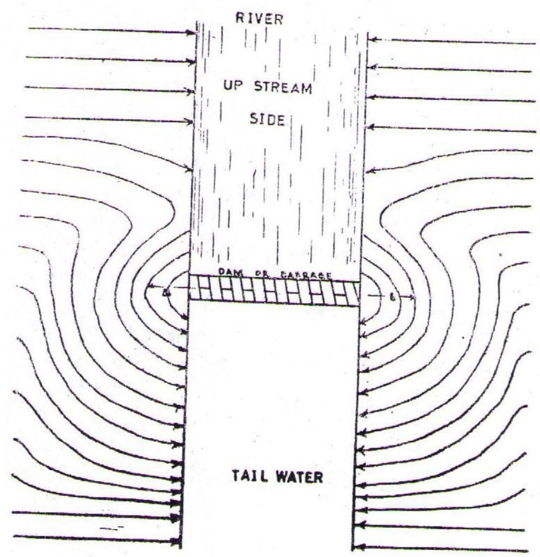


Fig No. 17

In case of Ghulam Muhammad Barrage the right bank is rocky and depression between the river and low hills is filled with impervious sediments from the hills. Infiltration along this bank is out of question. As regards left bank the space between Ganjo Takar hills on one side and the river and dam on the other side is also filled with impervious material to the depth of 100’ or more and below that is beds rock. The infiltration therefore must take place on the east of the three canals, Phuleli, Pinyari and Line Channel, closely following the alignment of Phuleli upto Tando Mohammad Khan and then following old bed of river Indus touching Bulri and Jhok, finally discharging in the river somewhere opposite of Sonda. The width of the infiltration bed shall be about 15 miles. Luckily this will have important economic repercussions. At present water in most of this belt is brackish. By pumping the brackish water out, in filtration can be induced and ultimately water in the whole area could turn fit for cultivation. Left to itself the process may take a century or two, but artificially induced infiltration could complete process, in a few decades. One other advantage shall be that water to the east of this belt which is sweet and is being pumped will be saved from encroachment by brackish water. The task however is too gigantic and at this stage is only of academic interest. Infiltration has already started taking place between Matiari and Miani Forest and quality of water in tube-well on pumping keeps improving.

In case of Sukkur Barrage head works, there are hills on both banks. Those on right bank extend to a few miles only and infiltration has already taken place. Water along the foot of these hills to a width of about 2-3 miles is still brackish but pumping can definitely desaline the water. On the left bank the situation is much more complicated. Rohri and Kot Dijji hills are interconnected and infiltration if at all possible will be to the Eastern Nara at point many miles below the head works.

Though the area has not been examined, in the opinion of writer there appears impervious layer between the two.

In case of Guddu Dam the two banks are not impervious and the infiltration can easily establish. On the right bank will water is brackish. Infiltration will definitely change its quality. Pumping brackish water can induce the process, On the same principal barriers can be put in the beds of rain fed rivers to cause filtration in the wells on adjoining banks.

Immediately after construction of the dams ground water table on the down stream side is depressed which is slowly counteracted by infiltration. Some times the process takes many years. It is possible to make forecast of phreatic back water development by various methods of calculations if co-efficient of filtration, saturation deficit and amount of rechange by percolation due to irrigation or rainfall are first worked out.

II. STUDY OF CHEMICAL COMPOSITION OF UNDER GROUND WATER

The method so far used by the Department of Agriculture is based on pH. value and total soluable salts. This gives general picture but in some case can also lead to wrong conclusion. For example It was seen that water around Shikarpur has a low value of total soluable salts, but these salts were of harmful nature, containing bi-carbonates which will have adverse effects on soil. The detail analysis and period i.e. study of ground water, to find changes in composition will help in:-

(a) Finding the laws which govern the quality changes chronologically and positionally (time & space)..

(b) Influence of artificial irrigation, canals, rivers springs and other acquifers on water from wells.

(c) Effect on corrosive action of water on strainers pumps and structures.

(d) Determining whether pumped out water could improve or deteriorate soils or has tendency of converting white alkali soils into black ones etc.

(e) Studying of laws which govern the development of chemical composition of ground waters.

(f) Forecasting changes in chemical composition of water.

SAMPLING WATER FOR ANALYSIS.

(i) When ground water is exposed to atmosphere it changes due to release of pressure & exposure to air. It looses gases specially carbondioxide. Oxidation occurs transforming iron etc. to their oxides and changing pH value, as consequence of these two factors. The samples collected should therefore be sealed and taken to laboratory in shortest possible time.

(ii)Water that stands in open surface wells or even casing pipes for long times suffers the same process as discussed in (1) above. Besides there is reduction of sulphate which results change of ions of magnesium, calcium, carbon dioxide etc. In open surface wells evaporation tends to increase percentage of salts. The water samples therefore should be taken after sufficient pumping or bailing out. Before collecting sample at least twice as much water should be pumped out, as the total water content in well or casing pipe.

(iii) Chemical composition of water column in the same aquifer varies with depth. In case where soil over lying the water is not thick enough, there is evaporation of water due to capillary etc. and top portion of aquifer therefore to will have higher mineralization, but if there is sufficient percolation or infiltration, the water in the top layer is diluted and has low degree of salt content. This is observable through out the region and variations are observed between bore holes located even a few hundred feet apart. It is therefore essential to take large number of samples. In doubtful areas samples are being collected at every 5' as, against at every 10' or 20' normally.

(iv) The lower Indus Basin emerged from sea due to silting up by the river Indus in recent geological and even historical times. The water in the lower strata is of sea origin and upper water have been diluted by water percolating from the river. This has given rise to sweet water only in upper strata and it keeps getting more and more saline with depth. Water below 600' depth in the whole area is brackish. Sweet water depth varies depending upon when the river, visited the locallity last and time period it flowed at that point. In most of sweet water zone shown in map No I, fresh water is available to depth of only 200'.

(v) In a few cases when water was stored in bottle some portion of consisting of magnesium, calcium, and iron salts precipitated. In such cases both water and precipilates were subjected to analysis.

(vi) Even the glass of bottle can dissolve in some waters resulting in formation of silicic acid.

There are special methods for preservation of water samples, but they can only be handled by a scientific personnel and therefore these are being left to specialists.

WATER USEFULNESS AFFECTED BY MINERALS.

Ground water contains no suspended material and is free from bacteria. It is clear and colourless in contrast to surface waters which are usually turbid and coloured and contain considerable quantities of bacteria. But it always contains salts in much higher proportion to surface water and therefore for various applications following factors should always be kept in view:-

(i) When total dissolved solids are less than 500 p p m water is generally satisfactory for domestic use and many industrial purposes. Water with more than 1000 p p m of dissolved solids usually contains enough of certain minerals to give it dis-agreeable taste or make it unsuitible for industrial and domestic uses.

(ii) Corrossive action of minerals in water increases with salt content. At 1000 p p m the water becomes good conductor of electricity and since corrosion is electro chemical action it is accelerated at a high rate.

(iii) Ground water in this region being associated with lime-stone hills contains dissolved calcium and magiessium, bi-carbonates, sulphates, chlorides and nitrides, which give it hardness and are cause of incrustation discussed further in the book.

(iv) Water that has hardness of less than 50 p p m is considered soft. Water containing 50 to 100 p p m is tolerated. Water containing more than 150 p p m should be softened chemically for industrial and domestic purposes.

(v) Water containing more than 350 p p m chlorides is objectionable for irrigation. For drinking and domestic purposes limit is 250 p p m. At 500 p p m it has disagreeable taste. Cattle can tolerate 3000 p p m of chlorides occasionally.

(vi) Nitrates in water usually are not related to geologic formations. The nitrate built up is from various sources like plant residue animal waste, seepage of fertilizers in the soil, sewage wastes, manures, barnyards and urine etc.

Water containing nitrates may be tasted for presence of bacteria. For domestic purposes water with more than 45 p p m is undesirable. Water containing 90 p p m is toxic for infants. It does not precipitate by boiling. The only solution is distillation.

DETAILED CHEMICAL ANALYSIS.

Lower Indus Basin ground waters show presence of following ingredients:-

(a) Chlorides-These are in-variably present in ground water of this region, their origin being sea water.

(b) Sulphates.

(c) Carbonates and bi-carbonates.

(d) Sodium in form of chlorides,-carbons, bicarbonates.

(e) Calcium as sulphate and carbonates.

(f) Magnesium as silicate.

(g) Silicates.

(h) Iron as hydrocarbonate, carbonate, suplhate, and chloride.

(i) Aluminum as oxide.

(j) Maganese.

(k) Free gases like carbon dioxide, oxygen, hydrogen, sulphide, methane.

(l) Trace elements like titanium, beryllium.

There are different classifications for representation of above ingredients like hydrocarbonates, sulphates and chlorides of calcium, magnesium and sodium etc., but these are meant for specialists only.

It is essential that immediately after completion of well it should be run for several days continuously and at the end, samples collected for test purposes. Samples should then be collected every 6 months in May and October, which mark lowest and highest water table. If there is increase in salts, the agricultural engineering section should immediately be consulted. In absence of record over a number of years it will be difficult to diagnose the trouble.

SCALE OF pH VALUES.

pH value indicates hydrogen concentration' or in other words it indicates whether the water will act as weak acid or as an alkaline solution. When amount of hydrogen ions is excessive in relation to other ions in the solution it will have acidic reaction and will attack metals.

A pH value of less than 7 indicates an acidic condition and pH greater than 7 correspond to an alkline solution. Each unit represents ten fold in hydrogen-ion concentration.

Distilled water has pH of 7-pH-8 has 1/10th hydrogen ions of distilled water and pH 9 1/100th of hydrogen ions. Some way pH-6 has 10 times and pH-S has 100 times ions of distilled water.

pH value of ground water is controlled by amount of dissolved carbon dioxide gas and dissolved carbonates and bi-carbonates. In other words pH is controlled by carbon dioxide-bicarbonate relation, but as carbon dioxide escapes with change of pressure and temperature, and therefore while pumping water from tube wells, due to release of pressure at the filter slots, the pH value changes.

pH value of water samples stored for some time decreases due to absorbtion of carbon dioxide if it is below 7. When pH value is already above 7 it further increases due to absorbtion of carbon dioxide.

pH values of less than 7 are met in humid areas like East Pakistan. In the lower Indus Basin pH values between 7 and a little over 8 have been encountered. Only at one place in the whole region- in wells near Virawah in Thar desert pH values of between 6 & 7 were met. This small area is a bridge which has made Nagarparkar islands a peninsula. It seems that rain water from Thar desert and Luni river, rich in atmospheric carbon dioxide percolates into the ground giving it acidity. On the same analogy pH values of less than 7 can be met all along Rann and Thar border.

OXYGEN

Oxygen content in ground water of this region is quite low. It can be presumed that oxygen dissolved in surface water that percolates into the soil is used up in oxidation of organic matter. Water dissolved oxygen can corrode metallic parts of tube wells rapidly if pH value is low. Fortunately if water has high temperature, the dissolved oxygen is very low and pH values become pretty high. The corrosion therefore is comparatively less in lower Indus Basin. Dissolved oxygen also removes zinc from brass alloys leaving metal porous and weak.

HYDROGEN SULPHIDE

Ground water having hydrogen sulphide of even 5 p p m. can be recognized by its rotten smell and I p p m is definitely of excessive. Hydrogen sulphide is present in water of open wells which are not being worked regularly and are surrounded by irrigated fields.

Hydrogen sulphide forms a weak acid and water is usually corrossive. Appreciable amount of it will attack well screens resulting in incrustation.

SODIUM

Sodium does not produce any hardness, Sea water contains more than 10,000 parts of sodium. However it increases pH value of water if is in form of carbonate and bicarbonate.

High concentration of sodium salts develop alkali soils in which little or no vegetation will grow. This is, due to exchange of calcium and magnesium ions for sodium. The exchange alters the physical characteristics of soil. Soil that carries a good excess of calcium or magnesium ions tills easily and has good permeability. If same soil takes up sodium it becomes sticky when wet and has low permeability. When dry it shrinks into hard clods which are difficult to break.

If irrigation water contains magnesium and calcium in quantity that equals or exceeds the sodium, the soil will retain sufficient concentration of magnesium and calcium and the good tilth is maintained. Even if total soluable salts become high this water can be used. This lead to development of a formula:-

$$SAR = \frac{\text{Sodium+}}{\dfrac{\sqrt{\text{Calcium++ + Magnesium++}}}{2}}$$

Where SAR is Sodium absorption ratio the equivalents for 3 ions are:-

Calcium++ —	.04990
Magnesium++ —	.08224
Sodium + —	.04350

These have to be multiplied by total ppm of each mineral and SAR worked out.

Value of SAR over 18 is considered high, 10-18 is considered as medium and below 10 it is low and is not dangerous for creating sodium problem.

WATER FOR HUMAN CONSUMPTION

In England and U.S.A. a maximum 570 ppm are tolerated for human use. World Health Organization considers 1500 ppm as excessive and not desirable as potable water. In Thar Desert people have been drinking water having more than 5000 ppm and definitely with ill effects on health. In Kohistan waters vary from place to place in their salt content. As the life is nomadic and there are no permanent settlements people are exposed to highly mineralized water danger. Development of ground water can reduce nomadic conditions and its hazards.

III. DRINKING WATER STANDARDS

For drinking water Public Health Service of U. S. A. has laid down standards which are reproduced below:-

Disolved Chemicals in Water	Recommended maximum amounts in ppm		Mandatory limits for rejection of water in Ipp	
	1946 Standards	1962 Standards	1946 Standards	1962 Standards
Iron	0.3	0.3	-	-
Manganese	-	0.05	-	-
Nitrate	-	45	-	-
Detergent (ABS)	-	0.5	-	-
Copper	3	1	-	-
Arsenic	-	0.01	0.05	0.05
Fluoride	-	1.7	1.5	3.4
Lead	-	-	0.01	0.05
Selenium	-	-	0.05	0.01
Silver	-	-	-	0.05
Narium	-	-	-	1
Cadmium	-	-	-	0.01
Chremium	-	-	0.05	0.05
Cyanide	-	0.01	-	0.02
Magnesium	125	50	-	-
Zinc	15	5	-	-
Chloride	250	250	-	-
Sulphate	250	250	-	-
Chloroform-soluble Extract	-	0.02	-	-
Phenol	0.001	0.001	-	-
Total disolved Solids	500	500	-	-

WATER FOR ANIMAL USE

Dairy cattle can tolerate water upto 3,000 p p m. Sheep can stand higher salt content provided water with 7000 p p m is used in emergencies only. The Kohistan and Thar waters fall with in the limits.

KOHISTAN AREA

Since 1964, a number of wells and tube wells have been installed in Jhimpir and Wahi Pandhi areas. Recently there is heavy demand in Kachho of Johi Taluka. The number of tube well is still small and they are being exploited at full capacity day after day. But as the number of tube wells increases, the, ground water reserves will deplete, the water table will fall down and only intermittent pumping for limited number of hours daily will be possible. The yield will also deteriorate to about 200 gallons/min (About 1/2 cusec). The ground water table will rise considerably after heavy rains, only to be depleted during subsequent dry years. Malir area of Karachi is facing similar problem due to greater withdrawal than infiltration. Past experience shows that in every eleven years there is one year of extremely heavy, three years of average, three years of a little below average rains. Rest of four years are dry. In order to save wells from drying up a well planned re-change programme has to be laid.

In both Jhimpir and Wahi Pandhi, luckily large tracts of Agricultural land are available which could be used for suitable crops and vegetation and water could be sprayed over the area by diverting specially from Kolu river whose waters go-waste into Kalri lake.

Main difficulty in using flood waters for recharge is often their suspended load of silt which when deposited soon reduces in filtration capacity of ground. There are special methods to treat the water before being lead into the wells.

THAR AREA

Human beings vary in their tolerance to waters of different degree of salinity. In Thar area consumption of water containing 5000 parts per million parts of water is not unusual.

CORROSION & CHEMICAL COMPOSITION OF WATER

Corrosion is different from incrustation. It is chemical action exerted by out side factors which cause eating away or destruction of metals. In tube Wells metals like iron, brass bronze etc. having different electric potential are joined and put in. Salts being present, water acts as electrolyte and current passes from one metal to another. If the two metals are brass and steel, current will pass from steel to brass and iron will start eroding or corroding. New steel pipes have higher electric potential than old ones and so have the threads of pipe joint as compared to coated surface of rest of the pipe. Corrosion is thus a continuous process and cannot be stopped. In due course of time the pipe is eaten away leaving holes of one or two inch diameter, through which sand gets in, causing failure of tube well.

One way of facing the problem is by using G.I. (zinc coated iron) pipe. Zinc protects steel in two ways. Where coating is continuous and unbroken it prevents direct contact of steel with water, but if coating is broken, current passes from zinc to iron i.e. zinc is corroded or sacrificed first to protect iron. This continues till nearly all zinc is consumed, and then iron will start eroding.

The elements that speed up corrosion of tube well components are:-

(a) pH less than 7 indicates acidic water which is corrosive. Water in the lower Indus Basin has pH higher than 7.

(b) Dissolved oxygen, which is usually present in shallow waters makes it acidic.

(c) Even less that 1 ppm dissolved hydrogen sulphide is corrosive.

(d) if total soluble salts are above 1000 ppm water is highly corrosive even if pH value is high.

(e) More than 50 ppm of dissolved carbon dioxide make water corrossive.

(f) Over 500 ppm of chlorides makes it corrosive.

(g) Combination of any two or more of above in fewer quantities will make it corrosive.

As against this the indicators of incrustation or deposition of minerals on the screen are:-

(a) More than 300 ppm of carbonates causes deposition of calcium carbonates.

(b) Iron content of more than 2 ppm will cause deposit of Iron.

(c) If manganese content is more than 1 ppm pH is high and there is oxygen present, magnese is precipitated.

(d) pH value of over 7 accelerates incrustation.

BACTERIAL DEPOSITS.

Bacteria non-injurious to human health, can survive in water containing dissolved iron and magnese. They oxidize and precipitate iron and magnese. This precipitate as well as the organism plugs the screen openings and voids. The process takes only 3-12 months to completely choke the filters

Treatment in case of incrustation consists of adding hydrochloric acid and in case of bacterial deposits, first burning up the organism with chlorine and then: removing iron and manganese salts by hydrochloric acid.

In Pakistan there is no choice in selection of filters. Monel, supernickel, Silicon-bronze, stainless, pure iron double galvanized, and double galvanized steel filters have such range of properties that even for worse conditions one or other filter could be adopted, minimizing breakdowns. In absence of choice left to us brass filter will be better than coir rope as it could be cleaned and salvaged.

MAINTAINING THE YIELD BY PREVENTING AND CORRECTING CORROSION AND INCRUSTATION

Progress of incrustation can be measured by collecting data consisting of draw down bi-annual chemical analysis, and variation in rate of discharge. We have been advising every tube well owner to put 14" pipe about 20' deep to act as peizometer. A float could be mounted on it to give direct reading of draw down. If the above three data are collected at regular intervals and made available, half of the problem is already solved.

The methods used for treatment of corrosion and incrustation are mechanical and chemical. As for as possible mechanical methods should be avoided, primarily because no coir rope filter can stand surges produced mechanically and the brass filters have only li"-2" gravel packing which will give away due to surging or jetting. Chemical treatment will be the easier and best result can be expected. A large number of chemicals both dry and liquid are used for the purpose. Of these hydrochloric acid is easily available in Pakistan. As used in the wells it has strength of about 28%. The acid is placed uniformly in the filter, over its whole length for about six hours and then it is either surged in mildly, before pumping out, or is pumped out without surging. Other acids recommended are Suphanic acid (not sulphuric) and hydroxyaccetic acid which are comparatively mild and are allowed to remain inside filters for 24 hours. To burn bacteria chlorine gas in the form of sodium hypochloride is added.

When silt and clay plug the screen, the most suitable material is sodium haxametaphosphate, a highly soluable chemical which does not dispurse clay but breaks it into small particles which become easy to remove by pumping. When using cleaning chemicals wells close by should be shut down for best results.

III. RECORDS

Except for a few farmers, no well logs and well records are being maintained. The tube wells are bound to develop some other trouble which could be diagonised after the case study. Some countries have enacted laws making it compulsory to provide useful data. Though there is no compulsory to maintain records in Pakistan, still it is in the individual’s interest to preserve the following information on a chart. A copy of it should preferably be framed and kept in pump-room.

Name of Zamindar and address.

Name of Village , deh, Tappa, Taluks

Date of Start of bore.

Date of completion of bore

Depth Drilled.

Diameter of bore.

Water quality. (fit or unfit)

Results of chemical analysis of water and sand.

Initial water table.

Final water table

Discharge in gallons/min.

Motor type and discharge

Pump type and discharge.

Total Suction head.

Delivery head.

Filter length.

Filter type and dia.

Gravel pack-thickness.

Results of annual/hi-annual chemical analysis.

Diagram and logs of the bore.

In the most advanced countries there is legislation to ensure proper collections and recording of hydrological data of all bore holes. In absence of any law, it is much more desirable that farmers installing the tube-wells preserve necessary records.

Once the data on tube wells in a particular area. are collected and compiled, a valuable public service is provided to aid water development and control. In fact such data was the basis of first edition of this book.

Later on M/S Huntings technical services Ltd. collected similar data for their investigation. Though the data available then was for 1000 test bore spread over , some 52,000 sq. miles, yet the approach was scientific and the book and its ground water map has stood test of the time. However the data available by end of 1963 were not adequate to prepare vertical salinity maps. Agricultural Engineering Organization now has cell in each district to provide advice on ground water based on data so far collected.

IV. COST FACTORS IN TUBE WELLS

Life expectancy of a tube well depends mostly upon the type of filter. A superior filter can increase its life even to 40 years. Various factors which govern its life and economical operations are:-

(a) Size of bore- By doubling the diameter the discharge can be increased only 5-10% but life can almost be doubled.

(b) Larger diameters reduce the velocity of water at the slots and therefore sand does not pass through the filter.

(c) Shallow tube wells, even if provided with adequate slot area to reduce velocity, still have high draw down as compared to deep tube wells having same slot area. The increased draw-down consumes more power, increases running cost, puts more loads on the pumping equipment, and reduces its life.

(d) If a tube well has low yield, the cost per unit of power in terms of capital investment and operating, cost are higher than a high yield tube well.

(e) High yield tube wells have greater draw-down. But even these wells are cheaper per unit of water delivered as compared to two or more tube well giving same total discharge.

(f) High capacity tube wells are pumped for less hours thus the staff for field irrigation is reduced considerably.

(g) Private drilling contractors have been putting tube wells at much cheaper rate than Department of Agriculture, but they use inferior type filters, shallow depths short screen lengths, smaller diameter pipes and pumps, and no gravel packing, resulting in low yield. The capital cost per unit of water and operating cost of the contractor's tube wells are much higher.

(h) Centrifugal pumps are more popular, due to low initial cost, portability and adoptability to any motor or engine. Since their suction is limited to 15' and there is draw-down of 6'-7' per cusec of water, the centrifugal pumps under no circumstances can yield more than 2.to 2.5 cusecs of water from a tube well. The average discharge of a tube well for this region is only one cusec. Deep well turbines on other hand though initially costly and require large diameter bore, can yield 3-4 cusecs easily from 250' deep tube well and will prove much economical. It has been observed that due to inferior construction the draw down in contractor's tube well is very high with the result than they yield less than a cusec for full draw-down of l5' in many instances.

The deep well turbines could only be lowered in large size casing pipes. They will necessarily need power drilling equipment for well installation and therefore centrifugal pump will predominate for a long time till large number of drilling rigs are imported and people are familiarized with the advantages of deep well turbines.

(i) Coir rope filters which are main source of trouble and are singly or doubly wound, in fact have very small slot area, which causes water to pass through it at a high velocity and consequently making it possible for sand to pass. Even if sand does not pass small slot area causes high frictional losses coir rope used in these filters cannot be precisely spaced and this again results in flowing of sand through the strings. The coir rope filters have reinforcing rings and strips of iron bars or flats on the inside which reduce the total slot area. In other words the effective slot area is much reduced. Contractors invariably fit in Coir-rop filters as they are comparatively inexpensive.

(j) The contractors to cut down expenses and to avoid trouble of making strong foundation have been installing pumps many feet above the water level. In Guddu Barrage majority of tube wells installed by them have pumps some 8'-10' or more above water table. These tube-wells hardly yield 1/2 .cusec of water.

(k) Twin-bore or multi-bore tube-wells are used where water is sweet in shallow depths, for what is called skimming of sweet water. The frictional losses in this type of arrangement due to large number of bends and fittings are heavy and this system should never be adopted where sweet water column is reasonably long.

(l) Contractors do not use metallic filters and in case these are used gravel packing is not done. With gravel packing the effective well radius extends up to exterior of annular packing and therefore frictional losses are reduced considerably.

(m) The cost difference between tube well installed by the contractors & the government agency is hardly Rs-2000-2500, but this amount can be recovered within a year's time on saving in operational cost and high yield.

V. THE FAILURES OF TUBE WELLS

In Southern Zone in past 5 years some failures were reported and remedied. The type and nature of failures were:-

(i) Gradual decrease in discharge.
(ii) Sinking of tube well structure in the ground causing damage to the tube well.
(iii) Pumping of sand with water.
(iv) Excessive power consumption after some time.
(v) Increase of specific capacity (draw down per cusec of water pumped.)
(vi) Increase in suction head with time.

Almost all these failures could be traced back to some or other fault with filters. Filter occupies the same status in a tube well as heart in human beings. Unfortunately the filter is not assigned proper status and care by the owner. Following types of filters are in use.

1. Coir rope filters, in which coir is wound on steel cage in a single on double turn, in fact have very small slot area and the coir strings are not uniformly wound. Once a sand particle passes through the winding, it being abrasive acts like a saw and cuts the string, resulting in pumping of sand and finally in failure.

2. Brass filter with slots varying from 008" width to 016" width and gravel packed to about two inches all around.

Little is known that most of troubles with metalic filters are caused by gravel available to West Pakistan tube well owners. The gravel is cause of formation of hard, brittle, cement like deposit around the slots, choking them partially or completely. The formation of this type is known as incrustration. Water always contains some free carbon dioxide which has been absorbed by it from atmosphere when it falls either as rain or as snow in northern hills. The carbon dioxide mixed with water forms carbonic acid which can easily dissolve lime stone. The gravel we use in West Pakistan is not free from lime stone. Except Nagar-Parkar hills and some formation in Kohat-hills rest of the rocks in West Pakistan contain lime stone in one or other form. This gravel dissolves in the water while latter passes through it. When this water reaches at the slots, the pressure on it is reduced. Due to reduction in pressure held carbon dioxide is released leaving the mineral salts (Calcium salts) which precipate and deposit at the slot in a thin sheet. This process is known as incrustration.

Once incrustration develops chain reaction starts. The pump keeps sucking quantity of water through less opening area in the filters. This means greater velocity at the entrance of slot, which accelerates release of still greater qualities of carbon dioxide and more incrustration results.

It has been observed that once the process is set in, the discharge falls down to 50% in 2 to 3 months and complete failure may take another 5 or 6 months.

Little is realized that gravel we use for packing around the filter is so dangerous. Gravel from NagarParkar or Kohat-hills or Basalt layer on top Khirthar range can solve the problem.

3. Steel filters. They have slot width of 1/16 " to 1/8" and because of larger slot area per inch of circumference a small length of filter is to be used. They have however to be given a gravel pack of 6" or more around them. In addition to incrustation they suffer from corrosion and oxidation.

4. Plastic filters having slot widths of a few thousand to 1/8" can be available. Plastics in general suffer from age hardening and unless they are thoroughly tested their use cannot be recommended.

RECLAMATION OF FILTERS.

With the increasing number of tube wells, certain failures of filters due to corrosion and incrustation were, reported and filters had to be removed. It is not possible to salvage coir rope filters, but metallic filters being costly have to be extracted. Two methods are commonly employed:-

(i) PULLING BY A HOOK INSERTED. IN THE BAIL PLUG FROM ABOVE

The method is very defective as almost any screen that has been in place for a period of time is certain to be set very tight in the formation. The pulling force is not uniformly spread over the screen length and hook usually straightens out.

(ii) PULLING BY SAND JOINT

In this method a good quality pipe of smaller diameter with a sack attached securely to the lower and is lowered up to the bottom of filter and annular space filled with sand to about 2/3rd of total length. The upper end of small pipe is then jacked up slowly.

Care has to be taken that sand is uniformly poured, the pulling pipe sockets well screwed and sacking consisting of 2' — 4' wide strips tightly secured. It will be preferable to have a socket at lower end of pulling pipe to avoid slipping of sack. The pulling pipe should approximately be 50% of diameter of filter. Same arrangement could be used for pulling out casing pipes.

WATER TURNING BRACKISH IN MARGINAL AREAS

Since 1st edition of this book went to press, 5 years back a number of wells went brackish. There were two main causes. The introduction of saline water in aquifer from the adjoining brackish water zone and rise of brackish waters down below into sweet water column. The ground water maps clearly indicate the border between the sweet and brackish water. The sweet water area near this line is always prone to encroachment of brackish water both from the brackish water side and down below. The farmers intending to install tube wells in such areas must consult agricultural engineers.

HOW TO SAVE TUBE WELLS FROM TURNING BRACKISH

In the lower, Indus valley the sweet water column lies above the brackish zone. The tube well screen therefore does not penetrate upto the bottom of aquifer but is kept much above it. Such a well is called-partial penetrating tube well. The specific capacities of such wells are much lower- than fully penetrating wells. In other words discharge for the same draw down is much less. This increases the pumping cost. In addition to this there is very serious disadvantage, that it will suck water from lower strata and in time the tube well will supply brackish water.

Fig. below gives profile of partially penetrating well how it pumps brackish water.

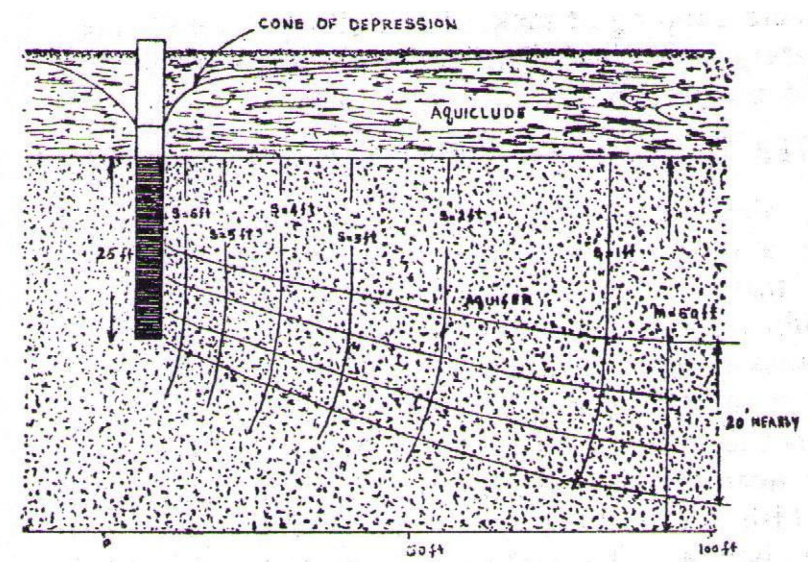


Fig No. 18

The problem could be solved by having the screen divided into shorter lengths and alternated with blank pipes. Figures 19 and 20 below give the pattern of reducing the convergence of flow.

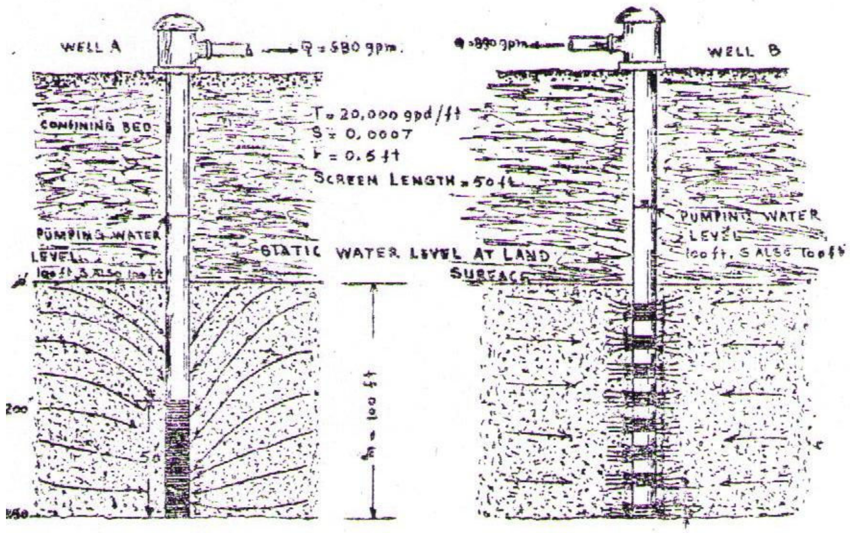


Fig. No. 19 Fig. No. 20

Hither to the department has worked out total length of sweet water column and developed only 60 %of it. Care has been taken to put a long filter, but theoretically it appears that breaking of filter and alternating it with blank pipes is better. Such a tube well can increase specific capacity by even 50%

VALVE TROUBLES

Frequently foot valves give trouble due to leakage of seals and priming becomes a major and serious problem. When the pump is shut off water column in the delivery pipe due to gravity, falls down with impact causing leakage of seals.

Spring loaded valve has -been developed at Tandojam Agricultural Workshop to reduce the frequency of troubles. Another solution is to put an inexpensive check valve (also made at Tandojam), a few feet above the pump. This valve will take all the impact saving the foot-valve.

YIELD OF TUBE WELLS AND WATER LEVEL RECOVERY

(i) The draw-down of a tube well increases with the time it is in use. This is quite obvious that full cone of depression cannot be established immediately on starting tube well but will enlarge as water in the vicinity is pumped out. To reach full draw-down it may take about 120 hours or more.

(ii) A test was carried out on 750 gallons per minute discharge pump. The draw down kept increasing and in 24 hours reached 14 feet but by that time the discharge had started falling down. At end of 48 hours the draw down was 16 ft and discharge had decreased to 710 gallons. The tube well was shut down for 48 hours and rate of recovery recorded. It did not recover fully and there was residual draw down of 2 feet i.e. the water did not recover to original level. Below is a typical graph of the draw down recovery curve.

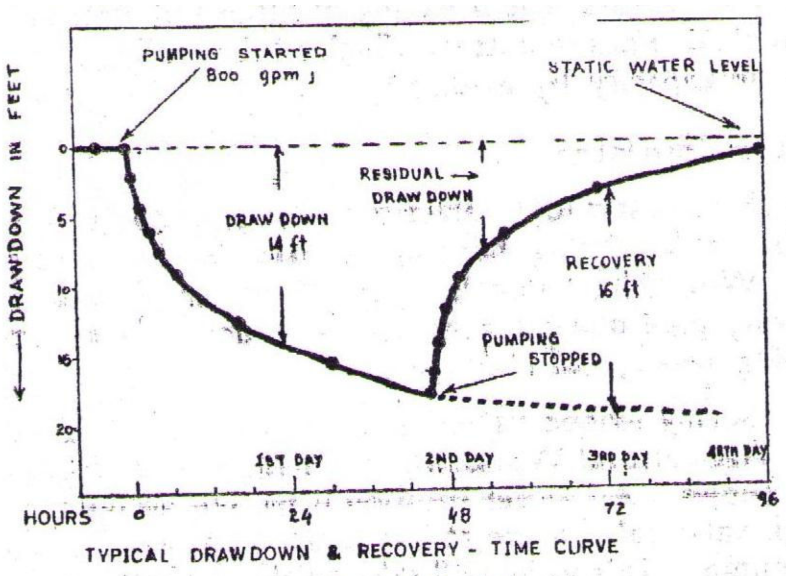


Fig. No. 21

TYPICAL DRAWDOWN RECOVERY - TIME CURVE

In hot weather and during closure of canals, many tube wells are worked continuously for some days. The discharge during the period falls down by 10 to 20 percent or more depending on the design of tube-well. There should be no cause for alarm and process should be considered normal. If after a few days rest the well does not recover fully and still give less discharge, other causes of low yield May be investigated.

LAND SINKING DUE TO TUBE WELLS

In different places all over the world land Subsidence due to removal of ground water is reported. Most alarming report is about Mexico City. Same phenomenon is going to take place here. Almost in all tube wells sinking of tube well floor, cracks in pump room pit and walls (for centrifugal pump type tube wells) and setting of foundations are noticeable. In few cases the pipe filter string has sunk and some times filters have broken and detached themselves from the top line. If large scale tube wells are installed for municipal needs, damage to drainage and sewage system, roads, pipe lines, bridges and buildings cannot be avoided. This occurrence was first noticed in Kazi Ahmed while over-pumping from open surface well, which caused not only caving in of well, but also cracking of adjoining bungalow. Since then care is being taken to put tube wells sufficiently away from houses and other structures.

When large scale pumping is done in big area it will always be accompanied by subsidence of land surface.

VI. METHODS OF DRILLINGS

It is beyond the scope of this book to go into the details methods of drilling. In brief they are:-

(a) HAND DRILLING

This method has limitation, as to diameter of the bore. It is not practical to drill beyond 10" diameter with this equipment as labour requirements become excessive. The great disadvantage, of method is that filter diameter is limited to about 6" and adequate gravel packing cannot be done. This reduces the over all life of the well. Due to lack of power drilling rigs, know-how to operate them and difficulty in their mobility, hand rigs form the major part of drilling equipment in the country.

(b) PERCUSSION RIGS.

They are as slow as hand drilling rigs and in rocky area the progress on the average is 6' per day. For rocky areas they are still the most economical machines. In the plains hand drilling rigs can compete with them fairly well except when large diameters are to be drilled.

(c) ROTARY RIGS WITH MUD CIRCULATING PUMPS

They are fast operating machines and in soft formations of the Indus plains can drill 200' daily. Their chief advantage is larger diameter, and speed. In rocky areas they are slow unless costly tools (diamond and rock bits) are used which make the operations uneconomical as compared with percussion rigs which are more suited to rocky formations, conglomerates and boulders.

(d) REVERSE ROTARY RIGS.

Their main application is 40”-60” diameter bores in soft formations. They are much faster and cheaper than ordinary rotary machines, when larger diameters bores are to be drilled. If larger diameter and gravel packing are aimed! at method b, c, and d, have to be resorted to.

(e) COMBINATION PERCUSSION AND. ROTARY

As straight percussion or rotary these machines are very useful but in combination they are cumbersome, difficult to transport, and change over from one system to other. They will also require operators with better skill to handle the two systems of drilling efficiently.

SAMPLING IN CASE OF ROTARY MUD CIRCULATION MACHINES

The drilling fluid usually has 2000 parts per million of salts. Samples from different water bearing strata will reflect the salts of circulating fluid. If salt content of ground water is over 2000 p p m the sample will show lesser salts than actual but still above 2000 p p m. If it is under 2000 p p m, the sample will show high salt content, but below 2000 p p m.

DANGEROUS CASES IN THE WELLS

Typical cases of deaths occurring in open surface wells and karazes while cleaning them are reported periodically. This is attributed to presence of certain harmful gas like carbon dioxide or hydrogen sulphide arising from decomposed organic matter or even the exhaust fumes from pumping engines. The gases are detected by lowering a lamp or torch, in the well and are removed by stirring up the air by some means, usually umbrellas.

DRILLING IN QUICK SAND

Quick sand seen in movies or read in novels, usually swallowing evil characters, is no fable or myth. It is some thing real and mighty dangerous. I encountered this material in Thar Desert of Sanghar district. I was informed that the swampy areas swallow men and animals during a particular part of year only and rest of time they turn into hard ground or water pool. According to stories current locally it was said, that during Hur movement of 1941-42, the Hurs used quick sand as strategic move, against the troop who had no knowledge of deadly traps scattered all over.

We encountered quick sand in the Tandojam Workshop premises while drilling for a tube well in 1956. After reaching 100' depth it was found that sand rose by 68 ft. in the casing pipe over night. Whole day's clearance took us to 100' depth and intervening night merely reversed the process. Every night the sand rose by exactly 68' and in 7 days we were not able to penetrate a foot extra. The operations we abandoned to study the scientific explanation. E. R. Smith Professor of Geology of De Pauw University, Indiana's research papers gave clue to the causes of phenomenon. His explanations and explorations showed that:-

(a) quick sand is caused by water rising upwards due to some pressure, through a layer of fine sand and lifting action of quick sand was 1-1/7 times that of water. In Tandojam bore water column in the pipe was 78' and water table was at 22'. The sand rose by 68' clearly showing that rise of sand was by 1 divide by 1 1/7 times that of water column.

(b) If the flow of water upwards (under pressure) is stopped sand is no longer quick. The quick sand in Thar is caused by seepage of water from near by lakes under pressure below the sand and when water in mother lake dries up or level of water in two areas attains some height sand is no longer quick.

(c) Most common form of quick sand is kind found along shores and in the bottom of rivers, due to upward pressure from under lying springs.

(d) Quick sand cannot exist where the water flow is large in volume or is under high pressure. In such cases sand is usually washed away.

(e) Quick sand occurs in hilly country near springs. Its occurrence is rare in plain country. In Thar it is connected with lakes located high in sand hills from which water seeps in low lying pools, but its occurrence in such areas is comparatively rare and un-common, specially after drying up of many lakes.

(f) Quick sand for all purposes is ordinary fine sand (.004 inches size) and is in no way different from it. It becomes quick as water under pressure passes upwards through it.

In drilling when quick sand is encountered, following practices are adopted to over come its upwards movement.

(a) Filling the casing pipes with water. Since this water will be absorbed in the strata below, water is pumped in continuously.

(b) If the water table is very high the casing pipe string is extended above ground level to maintain water pressure in the column.

(c) Additives like drilling mud are added to this water to increase its weight.

Since in many parts of the Hyderabad district water bearing sand is of .004 in size, it acts quick in at least 10% of cases. The filters used in such cases have slots width of .008 inch and with gravel pack of a minimum of 2" thickness, they are able to retain major portion of sand.

DUEL OR MULTIPLE-AQUIFER WELLS

Strange phenomenon was noticed while tapping water from a well at Chhachhro. The well 408 deep had two water aquifers one between 320 feet to 336 feet other 372' to 408'. While drilling the water table in case of 1st aquifer stood at 64 ft. When casing pipe was further driven through 2nd aquifer it stood at 108 ft. This was not carefully taken in view and when filters were lowered water table stood at 110 ft.

Only when on pumping the yield was poor the problem came for analysis. It became clear that due to hydrostatic pressure differential water from aquifer I was flowing in aquifer II. Solution lies in tapping one aquifer only.

This shall be normal pattern for most of wells in Thar area and some of deep wells in Kohistan.

Fig. below explains the phenomenon.

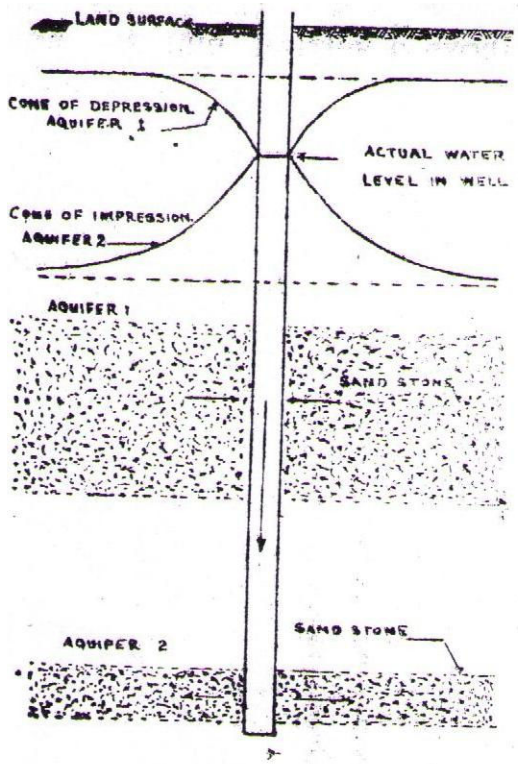


Fig. No. 22

VII. MEASUREMENT OF DISCHARGE OF WATER

In order to watch performance of tube wells, in addition to biannual analysis of water, the discharge should be measured and record maintained. For any noticeable variation Agricultural Engineering section should be consulted. It is difficult for tube well owner to install and maintain elaborate water discharge measuring equipment. Two very simple though approximate methods are:-

(A) Measuring the discharge from height to which water rises above a vertical pipe as shown in diagram below:-

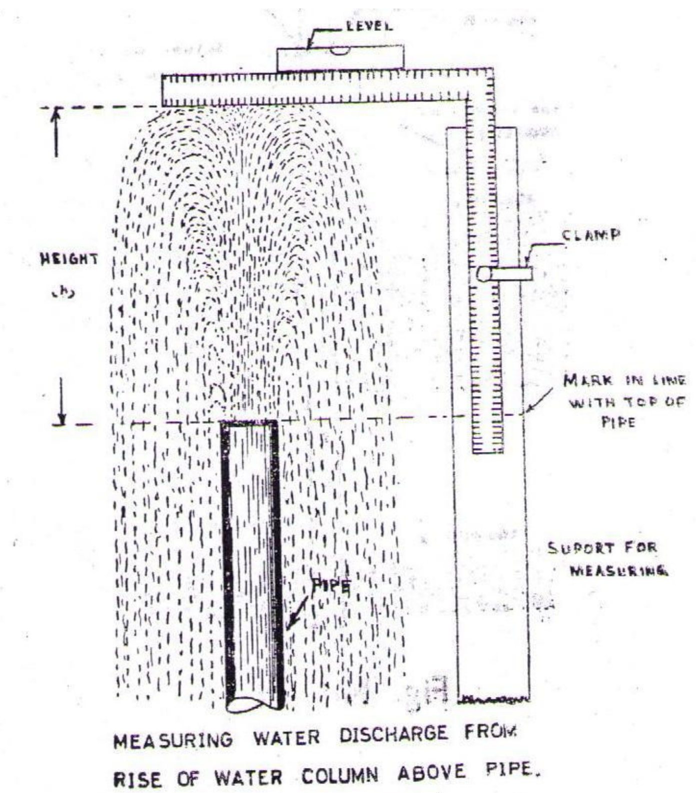


Fig. No. 23

MEASURING WATER DISCHARGE FROM RISE OF WATER COLUMN ABOVE PIPE

Once height is known discharge is measured by use of following table:

Approximate flows (in imperial gallons per minute) for vertical standard pipes.

Height (h) inches	**Nomind liamentor of pipe inches**					
1	2	3	4	5	6	7
1 1/2	21	43	68	85	110	160
2	26	55	93	120	160	230
3	33	74	130	185	250	385
4	38	88	155	230	320	520
5	44	99	175	270	380	630
6	48	88	190	300	430	730
8	56	152	225	360	510	900
10	62	112	255	400	580	1050
12	69	128	280	440	640	1150
15	78	175	315	500	700	1300
18	68	195	350	540	780	1400
21	93	210	380	595	850	1550
24	80	230	400	640	920	1650

(B) Measuring from a horizontal pipe is shown in fig. 24 referring to the table below:-

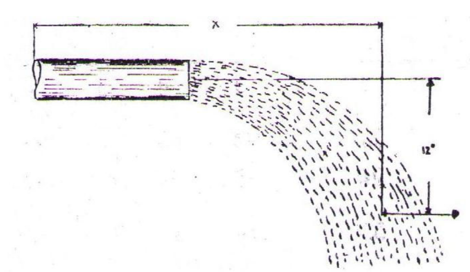


Fig. No. 24

Muliplier is used in estimating flow from pipes for which the inside diameters are shown. Distance X (inches) times the multiplier equals flow in U.S. gpm.

Pipe Diameter (Inside)	Multiplier to be used	Pipe Diameter (Inside)	Multiplier to be used
5.761"	27.2	10.136"	84
6.065"	30.2	10.250"	85.7
7.625"	47.5	11.750"	113
7.981	52	11.938"	117
8.125"	54	12.000"	118
12.090"	77.7	12.090"	120
12.250"	81.8	12.250"	123

(C) In case the pipe is not flowing full as shown in figure below, make use of attached table.

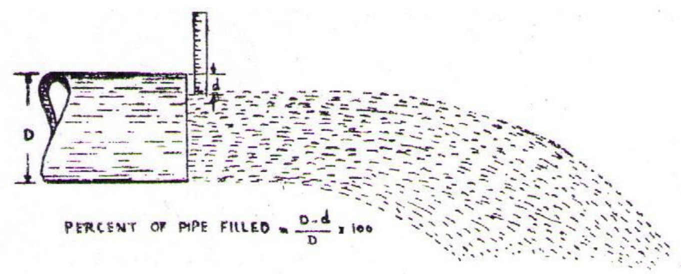
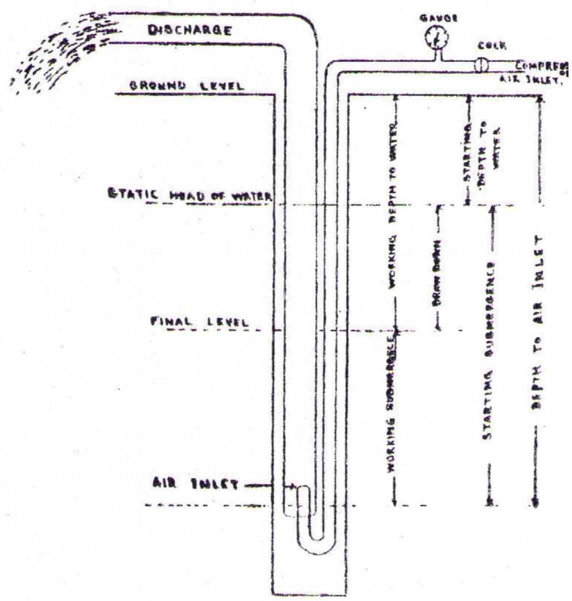


Fig. No. 25

Percent of pipe filled	Correction factor	Percent of pipe filled	Correction factor
25	0.20	60	0.63
30	0.25	65	0.69
33 1/3	0.29	70	0.75
35	0.31	75	0.80
40	0.37	80	0.86
45	0.44	85	0.91
50	0.50	90	0.95
55	0.56	95	0.98

VIII. AIR LIFT PUMPING METHOD

When diameter of filters and casing pipes is small or the water requirements are intermittent and limited and it is not practical to install a deep well turbine. It may be cheaper to pump water by air lifting. The figure below gives diagrammatic view of arrangement.



PUMPING BY COMPRESSED AIR

Fig. No. 26

In order to work out requirements of H.P. air pressure, pipe size and efficient use, following two tables are utilized.

Lift ft.	Submergence below pumping level ft.	Percentage	Gal water per cu. Ft. of air	Length of air line	Rating
1	2	3	4	5	6
25	29	54%	4.55	54	Minimum
	53	68%	8.34	78	Optimum
50	52	51%	2.5	102	Minimum
	93	65%	4.35	143	Optimum
100	89	47%	1.43	189	Minimum
	150	60%	2.7	250	Optimum
150	113	43%	1.05	263	Minimum
	183	55%	2.04	333	Optimum
200	139	41%	0.85	339	Minimum
	216	52%	1.54	416	Optimum
300	176	37%	0.6	476	Minimum
	115	47%	0.96	566	Optimum

TABLE
PIPE SIZES FOR AIR LIFTS

Pumping rate gpm	**Size of well casing**	**Size of eductor pipe**	**Size of air line**
30 to 60	4" or larger	2"	1/2"
60 to 80	5" or larger	3"	1"
80 to 100	6" or larger	3 1/2"	1"
100 to 150	6" or larger	4"	1 1/4"
150 to 250	8" or larger	5"	1 1/2"
250 to 400	8" or larger	6"	2"
400 to 700	10" or larger	8"	2 1/2"

IX. WATER RIGHTS

In the irrigated plains of the region there is no law or custom regarding water rights. The ground water is plentiful and is governed by common law rule recognizing ownership of ground water by the owner of overlying land. The number of tube wells as yet in the area are too small to cause government intervention.

In certain area like Gudu command left bank, or Hyderabad and Halla. Talukas where the number of tube wells is fast increasing; soon we will be confronted with question of rule of reasonable use of ground water. Tube wells have their own cones of depression. If two tube wells are located close together their cones of depressions may over lap resulting in low discharge of both tube wells. The tube wells have therefore to be located sufficiently apart so as not to interfere with each others performance. Under this doctrine also called doctrine of correlative use the tube well has to be installed: in a way that interference with neighbouring wells is eliminated. Under the conditions prevailing in our alluvial plains the distance between two tube wells has to be about 1200' to stop any interference what so ever. Below are some of values for the radius of cone of depression for various formations:-

(a) Fine Sand 100' to 300'
(b) Fine medium sand 300' to 600'.
(c) Coarse Sand 600' -1000'
(d) Gravel 1000' - 2000'

To avoid interference spacing has to be twice the radius of cone of depression.

In Thar and Kohistan area the people by custom have water right in certain tracts. In Thar it is not unusual for a man owning a well to earn a few thousand rupees for allowing water to be lifted from his well for human and animal consumption. In Kohistan the rule is not as rigorous, but there is strict right in case water is to be used for cultivation. In absence of enactment of law the local administration has been respecting customary or tribal law. When large scale development of ground water is under-taken, the question of rights on water has to be settled in these water scarcity areas.

In Malir area when the underlying strata do not contain sweet water, people with permission of revenue authorities have put in wells in the bed of Nallas or rain-fed streams, where sweet and abundant water is available. Large scale permission of this nature will cause water deficit and question of water rights will have to be settled legally. Till such a situation comes up, the party in need of water must be encouraged.

In case of the plains there will be no question of control on ground water for another 15-20 years. Water deficit will come up in Thar and Kohistan as soon as large block of land is developed, but till area approaches full development the control and restrictions should be kept to minimum.

Period or system	Estimated time of beginning in millions of years ago	common map symbol
Quaternary	1	Q
Tertiary	65	T
Cretaceous	135	K
Jurassic	180	J
Triassic	230	R
Permian	280	P
Pennsylvanian	310	P
Mississipian	345	M
Devonian	405	D
Silurian	425	S
Ordovician	500	O
Cambrian	600	C
Precambrian	3000 to 5000	P

X. WIND MILL

First edition of "Ground Water" was published in 1964. In this chapter on wind mills based on theoretical considerations was included, which in brief stated:-

(i) Slow speed wind mills are no longer able to compete with the diesel and electric power and are practically vanishing in Europe where they are now being subsidized by Tourist Bureau to attract tourist rather than produce power economically.

(ii) The initial cost per horse power developed for these wind mills is 10-20 times those of slow speed diesel engines and 30 to 50 times those of electric motors.

(iii) They are used in desert areas of Australia to pump water for sheep which move from place to place for grazing.

(iv) The wind mills cannot be relied upon as only source of power for irrigation due to un-predictability of winds fluctuations and wind velocities. Some times non-coincidence of wind with the time when crop need maximum of water.

(v) In Hyderabad Division there is High Speed Wind belt roughly bounded by two paralleled lines one passing through Shah Bunder and Mithi and other passing from Karachi to Hyderabad both extending to desert and to the Indian territory.

(vi) From the wind velocities at various places namely Hyderabad, Nawabshah and Chhore it is concluded that the, average of wind velocity of 12 m.p.h could be expected for about 2,000 hours annually and 15-20 miles for an other 700 hours in Hyderabad Division. This wind will be available from April to October for longer hours daily and for a few hours in winter months.

(vii) The H.P. developed varies as cube of wind velocity or a square of blade diameter. At normal speed of 12 m.p.h a 25' to30' dia wind mill can develop only one horse power. Looking to initial cost of about Rs. 10,000 for a 25'-30' wind mill it will not be worth while to use it for irrigational purpose. A diesel engine costs about Rs. 300/- to 400/- per horse power and electric motor from Rs. 75/- to 100/-.

Its economic application for irrigational purposes therefore was out of question except if supplemented by diesel electric or animal power.

(viii) Wind mills could successfully be utilized in the Thar desert area of Hyderabad Division, for lifting water for human and cattle needs but again not for irrigational purposes. The need for such installation is great as this could do away with complete nomadic conditions and bring about settled life. No other pumping unit will be so economical and low in the capital cost when the level of water is 100° or more.

This paper interested some commercial concerns. 1964 M/S Southern Cross of Australia made offer to supply a wind mill free of cost for the trials. It was suggested to them to supply 30' wind mill with 90-100 gallons per minute (approx. ¼ cusec discharge) pump at wind speeds of 10 miles an hour. At that speed it was supposed to develop one horse power. The firm agreed but later on supplied one 21' dia. wind mill. As compared to former it would produce only ½ =H.P. The discharge per minute was expected to be about 1/8 cusec, almost equivalent to a Persian wheel. A Steel Persian wheel or uniflow pump operated by one bullock only could give the same discharge. The capital cost of farmer including transportation and installation, custom duty, sales tax etc. came to Rs. 10,000 as compared to Rs. 1,000 for uniflow pump or Persian wheel and a bullock would cost another Rs. 500 On this assumption we started the trials.

The wind mill was received in 1965 and installation completed in October, 1965 but at that time the wind velocity was too low to give appreciable results. In April, 1966 the wind velocities rose sometimes to 20 m.p.h or even more and data were taken.

The Wind Mill was installed on an open surface well having diameter of 10' and 42' deep. The water table was maintained at 24' throughout the period of trials. This was done by allowing the water pumped out to be returned back to well.

The measuring of discharge was done by a right angled V-Notch which was fitted at the end of a tank 16' X 4' X 1'-7". The tank was divided in 4 compartments which were connected by a regular hole. The water was discharging in compartment number I and from there through compartment 2 to compartment 3 and then to compartment 4. This arrangement made possible that in compartment number four water was flowing without any wave action and the measurements at V-Notch were accurate.

Throughout the year pumping was done against constant head of 31-9". The discharge pipe was 8’ -9” above ground and water table 23' below ground level.

The measuring of discharge was done by a right angled "V" notch, which was fixed at end of the tank divided in 4 compartments. The discharge from "V" notch was recorded continuously day and night at intervals of every 5 minutes for 3 continuous years. This gave accurately the discharge throughout the day. From these readings, hourly & daily discharges have been calculated & plotted on the graphs.

The average daily has been plotted on a separate graph and from this graph, average discharges throughout the month and year have been plotted. As the Agricultural Workshop had no facility and equipment for finding out the wind velocity, these readings were taken from Agriculture College, Tandojam.

Since the distance between wind mill and college is about one mile, it is assumed that there was no difference between wind velocity at the two places. The wind mill tower was 60' high where as College wind velocity, was recorded at height of 10' only, but this error was eliminated for all practical purposes. The readings taken for wind velocity were at 8 hours, 14 hours and 18 hours i.e. 3 times a day, from this a corresponding graph discharging in g.m.p versus wind velocity in m.p.h were plotted. On the basis of this the wind velocity and discharges were plotted as on a graph.

From this, graph folio wing conclusions are drawn;

(i) The maximum discharge occurs when velocity' of wind is 14 m.p.h and this is 80 g.p.m.

(ii) As the wind velocity increases, the automatic governing takes place, thus smaller area of wheel vanes is exposed to the wind and the discharge decrease. The governor is not properly adjusted and cuts off early' otherwise discharge could increase. However we decided not to temper with original arrangements.

(iii) The average daily 'discharge throughout the year is 38 g.p.m i.e. approximately 1/10 of a cusec.

(iv) The average quantity of water period available' during May to September is 51 gallons per minute or 0.132 (1 /8th) cosecs.

(v) During rest of months the discharge and quantity of water is below average i.e., 29 gallons per minute or 0.075 (1/13th) cusecs and is intermittent and nor reliable::

(vi) The maximum wind velocity during the season reached to about 22 m.p.h, but discharge was reduced to about 40 g.m.p., with proper adjustment of governor the discharge could be increased to 1/2 cusec at this velocity.

From above discussion it will be seen that for half of the year i.e., during summer the quantity of water available from wind mill is sufficient i.e. 1/8 cusecs. By proper adjustment of wind mill it is possible to raise the discharge. But even it is 1/8th of cusec for 6 months it can command about 12½ acres of land and since there are no recurring costs the wind mill can successfully, be utilized in areas where water table is not more than 25'-30' deep. In other areas the wind mill can supply water: for human and cattle consumption only.

XI. SOME USEFUL DATA

1. HEAD OF WATER IS SUM OF:-
(a) Suction head.
(b) Delivery head.
(c) Head lost due to friction inside pipes, filters, slots, foot valves, bends, pump etc.
(d) Velocity head at the discharge end.

2. POWER REQUIREMENTS OF PUMP:-

(a) Wt. of water/min X head in ft. = 33000 X efficiency of pump.
(b) Cusec discharge X total head in feet divided by 8.8 X efficiency of pump.
(c) Gallons/min X total head in ft divided by 3300 X efficiency.
(d) Thumb rule for power requirements is: one cusec of water and 44 ft. head will need 5 Horse power.

3. HORSE POWER TABLE.

Horse power table for 40 percent efficiency.

(a) Electric motors.
(b) For Diesel engine add 50% to this

Discharge in cusecs	**Lift in ft**				
	20'	**25'**	**30'**	**40'**	**50'**
	Horse Power Required				
0.02	114	0.14	0.17	0.23	10.28
0.04	0.227	0.38	0.34	0.46	0.57
0.06	0.342	0.48	0.51	0.68	0.85
0.08	0.454	0.57	0.68	0.91	1.14
0.1	0.568	0.71	0.85	1.14	1.24
0.2	1.14	1.4	1.7	2.3	2.8
0.4	2.27	2.8	3.4	4.6	5.7
0.6	3.42	4.3	5.1	6.8	8.5
0.8	4.54	5.7	6.8	9.1	1.4
1	5.68	7.1	8.5	11.4	14.2
1.2	6.8	8.5	10.2	13.6	17
1.4	7.9	9.9	11.9	15.8	19.8
1.8	9.1	11.4	13.7	18.2	22.8
1.3	10.2	12.8	15.4	20.5	25.6
2	11.4	14.2	17	22.7	28.4

4. LOSSES IN THE POWER UNITS

(a) Electric motors have efficiency of about 90% and they can be run continuously at 75-80% of rated out put.

(b) Diesel engines have mechanical efficiency of 80% and can be run at 70% rated load continuously.

(c) In use electric motor do not loose power, but power of diesel engine falls to 50% due to wearing of some components.

(d) Belt losses are about 8-12%.

(e) V-Belt losses are less than 5 %.

5. PUMP EFFICIENCY:-

At the designed head, pumps of reputed manufacturers have efficiencies of 80-85% but at half this head it falls down to 35%. For good performance the head should be specified accurately and impeller replaced periodically.

6. PUMP CAPACITIES.

(A) For Centrifugal Pumps Running at Speed of 1450 rpm.

Size of pump suction	**Head**					
	20 ft		**30 ft**		**40 ft**	
	Capacity in gallons and cusecs					
	Gls	**Cusecs**	**Gls**	**Cusecs**	**Gls**	**Cusecs**
2"	187	1/2	150	3/8	95	1/4
3"	360	1	270	3/4	180	1/2
4"	540	1 1/2	400	1 1/2	270	3/4
5"	720	2	540	1 1/2	360	1
6"	1080	3	720	2	540	1 1/2
7"	1260	3 1/2	1080	2 5/8	630	1/3/4
8"	1440	4	1260	3	720	2

(B) Deep well turbine pumps.

4" Casing 1/8 to 1/4 cusec
6" Casing ¼ to 1 cusec.
8" Casing ½ to 1¼ cusec.
10" Casing ¾ to 2 cusec

12" Casing 1 to 3 cusec.
14" Casing 2 to 4 cusec.

7. WATER REQUIREMENTS:-

A cusec of water flowing for twenty four hours in equal to 60x60x24 cubic ft. of water i.e. 86,400 cubic ft. This is spread over an acre of land i.e. 43,560 sq. ft. will give a water column of about 2' i.e. about 1" per hour. This may be remembered as thumb rule for all practical purposes.

The tables below give useful information for those interested in depth of water over different areas in different timings from different size streams of different discharges.

8. DEPTH IN FEET OVER ONE ACRE FOR DIFFERENT STREAMS AND TIME

Discharge in Cusecs	12 hours	24 hours	48 hours	96 hours
0.1	0.1	0.2	0.4	0.8
0.2	0.2	0.4	0.8	1.6
0.3	0.3	0.6	1.2	2.4
0.4	0.4	0.8	1.6	3.2
0.5	0.5	1.0	2.0	4.0
0.6	0.6	1.2	2.4	4.8
0.8	0.8	1.6	3.2	6.4
1.0	1.0	2.0	4.0	8.0

9. NUMBER OF HOURS REQUIRED TO COVER DIFFERENT NUMBERS OF ACRES TO A DEPTH OF ONE INCH.

Discharge in cusecs	1 acre	2 acres	3 acres	4 acres	5 acres
.1	10 hours	20 hours	30 hours	40 hours	50 hours
.2	5	10	15	20	25
.3	3.3	6.7	10	13.3	16.7
.4	2.5	5	7.5	10	12.5
.5	2.	4	6	8	10
.6	1.7	3.3	5	6.7	8.3
.8	1.3	2.5	3.8	5	6.3
1.0	1	2	3	4	5

10. NUMBER OF HOURS REQUIRED FOR DIFFERENT STREAMS. TO COVER ONE ACRE TO VARIOUS DEPTHS.

Discharge in cusecs	Depth of irrigation. 1 inch	2 inches	3 inches	4 inches	5 inches
.1	10 hours	20 hours	30 hours	40 hours	50 hours
.2	5	10	15	20	25
.3	3.3	6.7	10	13.3	16.7
.4	2.5	5	7.5	10	12.5
.5	2	4	6	8	10
.6	1.7	3.3	5	6.7	8.3
.8	1.3	2.5	3.8	5	6.3
1.0	1	2	3	4	5

11. FRICTION OF WATER IN PIPES:-

Loss of head in feet per 100 ft. of pipes.

Class per minute	2 inches	3 inches	4 inches	5 inches	6 inches	8 inches
16.66	1.8	0.25	2.09	• •	• •	• •
25	3.8	0.54	0.13	• •	• •	• •
33.33	6.6	0.91	0.22	• •	• •	• •
41.66	9.9	1.4	0.34	0.11	• •	• •
83.30	35.8	5.0.	1.22	0.41	0.14	0.04
166.6	• •	17.8	4.4	1.48	0.61	0.15

Loss in each 90% elbow = loss in 8 ft. of pipe.
Loss in each valve= loss in 25 ft. of pipe.
(10) HP = 746 KW

Giving data about location, p.H. value, salt contents, depth, filter type and discharge etc. of some representative tube wells.

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