A Study of the Rise of Ground-water and its Salinity in the Irrigated Areas of Indus Plains

By

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Synopsis

In the year 1959, West Pakistan Engineering Congress held a symposium on the waterlogging and salinity problems of the country. The author put forth, a conception that ground-water in Rechna Doab was accumulating in the aquifer having insignificant sub-soil flow. The existence of innumerable haphazardly existing clay barriers, obstructed the flow which had a greater chance to accumulate and fill the reservoir rather than to flow away into the lower regions or to the sea.

It was also noted that the ground-water in the northern region of the doab was rising even before the construction of the Upper Chenab Canal. Similar was the case in the region served by the Haveli Canal. After the introduction of the irrigation, the deep ground-water unaffected by evapotranspiration rose in an extensive area, at a uniform rate, irrespective of the depth to ground-water, rainfall or irrigation etc.

The author has extended his investigations to the whole of the Indus Plains. The rise of ground-water in the Thal, the Chaj, the Rechna and the Bari Doabs of the Upper regions and Khairpur, Larkana-Shikarpur and Ghulam Mohd. Barrage Command of the lower regions. In this paper, results of the Ex-Punjab are only given. The results previously reported in 1959 are confirmed for the rest of the regions. It is noted that in certain doabs in the early stages when the ground-water was very deep and the gradient towards the deeper regions was more than the surface slope, the rivers at high stages contributed to the aquifer.

With the rise of ground-water and with the flattening of the hydraulic gradient, as compared to the surface, the canals became the major source of feeding the aquifer.

The absence of salinity from the flood plains in general is attributed to the washing away of the soluble salts into the deeper regions and increasing their concentration. The contribution from the rivers to the aquifer when the water table was deep, supports this conclusion.

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Introduction

Agriculture has been the main occupation of the dewellers of the Indus plains since ancient times. Uptill the 18th century, it was restricted mainly to the areas of the rivers spill and later on several inundation canals were dug to irrigate the land farther away from the flood plains. Some of the important canals, irrigating the Punjab plains, were the Upper and Lower Sutlej Canals, Shahpur, Chenab, Indus and Bahawalpur Canals. Upper Bari Doab Canal and Jumna canals, were the oldest of the Mughal times. In Sind, the 19th century inundation canals, were the Desert, Begari, Sukkur, Fuleli, Pinyari and Kalri canals. The Indus flows over a ridge, therefore, conditions were very favourable for these seasonal canals.

Inspite of the working of these inundation canals, the earliest recorded ground-water was fairly deep. The British engineers started to regulate the rivers and thus to feed the canals throughout the year. The first canal so constructed was the Western Jumna Canal opened in 1837, followed by the Upper Bari Doab in 1850-59 and the Sirhind Canal in 1870. After the opening of this canal, waterlogging appeared and stagnant water resulted in spread of malaria. At that time due to the foresight of Sir Thos. Higham, a series of well observations were instituted to record the rise in ground-water. He got selected a number of open wells, usually five miles apart and established well lines, across the rivers and the Punjab plains. These were called the Provincial Lines of wells so that twelve such lines covered the whole of the Punjab. At the time of opening of a canal, several new wells constituting Circle Lines were also selected. The observations of wells were recorded in June and October of each year.

This valuable record, in some cases dating back from 1895, is a useful source of information for all those interested in the rise of ground-water and the salinity problems of the country.

This practice of well observations was slightly modified in the Sind Province. Here pipes were installed to record the water levels. This note is thus based upon the records of ground-water collected during the last sixty-five years.

THAL DOAB, ITS EXTENT

Thal Doab is enclosed between the Indus and the Jhelum rivers. It constitutes an area of about 12,000 sq. miles. In the north, it is bounded by the salt ranges. Here the width of the doab is about 62 miles which widens to 78 miles about 50 miles lower down. For a length of about 125 miles, the width of the doab remains nearly the same. Lower down for another 130 miles, the doab narrows down till the two rivers meet together.

A portion of this doab, close to the Indus river, constituting about 3,200 sq. miles is irrigated by the Thal Canal taking out from the Indus at Daud Khel, An area of about 6,500 sq. miles, known as the greater Thal, is covered by sand dunes and is a waste desert. So far it has no arrangement for water supply. A narrow strip of land on the side of the Jhelum is irrigated by the Rangpur Canal, taken out, at the confluence of the Jhelum and the Chenab at Trimmu.

At the tail of the Thal Canal, Taunsa Head regulator has been constructed on the Indus, out of which Muzaffargarh canals have been taken out to feed the lower regions of the doab. The main outlines of the doab, its canals, head regulators, etc., are shown in Fig. 1.

Ground-water Observation Wells

Six Provincial Lines of wells pass through this doab, covering about 150 miles of its length. In Fig. 1, the location of these lines is shown. Each line has 10 to 12 observation wells, the total number of which in the main doab is 59. These lines cover the full length of the Thal Canal. Four well lines No. V, VII, VIII and IX, lie in the area above the Rangpur Canal, well lines No. X and XI cover the Rangpur Canal. The Taunsa head regulator lies south of these lines.

Source of Infiltration

Rangpur Canal carries 3,000 cusecs. It was constructed in 1938.

The Daudkhel Headworks was started in 1940 and a portion of the Thal Canal, a few miles below the town of Mianwali, was completed and water started to flow in 1945. The construction of the remaining portion of the canal was started in 1947 and water was let into it at the end of 1954. The whole of the Thal Main Line and some of its important branches are lined.

Lower down, beyond well line No. XI, Taunsa Barrage was completed in 1960, to feed the Muzaffargarh inundation canals. After the construction of the barrage all the old inundation canals were changed into weir control canals. This region has always been under irrigation, much before the construction of Thal or Rangpur Canals.

Available Data of Wells

The records of ground-water considered are from the year 1935. In Fig. 1 contours of the earliest ground-water below natural surface are plotted. The R.L's of the natural surface are also shown. In 1935, the deepest ground-water was at 62 ft. below surface and near the Jhelum river in the widest portion of the doab. Ground-water even very close to the rivers existed at 25 to 40 feet below surface.

The surface of the doab in between the well lines VII to XI is at R.L.625 to 450 giving a fall of 175 ft. in a length of about 112 miles. This gives an average slope of the land surface equal to 1.6 ft. per mile.

The position of water level recorded by wells of each line during the last 27 years, is discussed below :

Well Line V

This line has 11 wells. All these are located nearly 4 to 6 miles south of the Muhajir Branch of the Thal Canal. Well No. 1 exists close to the Thal Canal, nearly 10 miles away from the Indus. Well No. II lies very close to the Jhelum. Records of water level in wells were studied (Table I). It was noted that ground-water during 1935 to 1946 in all the eleven wells was rising at a rate of about 0.36 ft. per year. The rise of water towards the Jhelum side was slightly less as compared to that towards the Indus side. The depth of water in 1935 was at 40 to 48 ft. so that in 1946 when the Muhajir Branch was opened, a rise of about 2.0 ft. per year started (Table 2). Practically all wells recorded this order of rise from 1947 onward. In 1960 water level in some wells had approached within 10 ft. of surface. In Fig. I-a, the position of ground-water in all the eleven wells of this line, during 1935 , 1947 and 1961 is plotted.

Well Line VII

This line also contains 11 observation wells. Well No. 1 lies between the canal and the river. Well No. 2 is very close to the Thal Canal. The remaining nine wells are located at the end of the distributaries issuing out of the Muhajir and Dulliwala Branches. Well Nos. 10 and 11 are situated close to the Jhelum.

A study of the record of the rise of ground-water as given in table 1, shows that :

(*i*) From 1935 to 1946, all wells recorded a rise of water level. The average rise being 0.22 ft. slightly less than that shown by wells of line No. V (Table 1).

(*ii*) From 1947 onward, a brisk rise of water started at the average of 1.74 ft. per year (Table 2).

(*iii*) Water table in 1935 was at adepth of 40 to 50 ft. In well No. 6 it stood at 62 ft. At the time of opening of the canal this well had water table at 59 ft. Depth of water from the ground surface in the rest of the wells, was at 38 to 40 ft. Uptill 1960, all wells continued to show a regular rise (*see* Fig 3 in which rise of a few selected wells is plotted). The position of water table in wells of this line during 1935, 1947 and 1961 is shown in Fig. 1 (*a*).

(*iv*) The wells having deep ground-water did not show greater rise than the rest having water at shallow depth.

Well Line No. VIII

This line has 11 observation wells. It is about 16 to 20 miles downstream of well line No. VII. Except well Nos. 1, 2, 3 and 4, all the rest are located far away from the Thal Canal. In this portion, of the doab, the canal started operating in 1955-56. When the data of the rise of ground-water in these wells was studied, it showed that :

(*i*) Ground-water was rising from 1935 to 1953 at the rate of 0.13 ft. per year before the canal was opened. The average rise of water 20 miles upstream was 0.22 ft. and in wells 40 miles upstream it was 0.36 ft. (table 1).

(*ii*) As soon as the canal was opened, the average rise in these wells became 0.99 ft. per year (table 2).

(*iii*) The wells having the deepest water did not show greater rise than those in which the water was shallow [*see* Fig. 1(*a*)].

(*iv*) This rise was less than that recorded by wells of the upper two lines Nos. VII and V.

Well Line No. IX

This line has 12 observation wells. It is situated about 40 miles below well line No. VIII, towards the Jhelum side and about 24 miles downwards, towards, the Indus. It has its first 5 wells close to the branches of the Thal Canal. The rest of the wells from 6 to 12 has no source of surface supply close by. In 1935 all wells showed deep ground-water which varied from 54 ft. to 35 ft. The depth in wells towards the Indus was shallow being 23 to 30 ft. [*see* Figs. 1 and 1 (*a*)].

The data of rise given in table I shows that :

(*i*) all the eight wells towards the Indus showed fluctuations, both fall and rise from 1935 to 1954. During the 8 observation years the net rise was zero.

(*ii*) Well Nos. 1 to 5 within the influence of the canal started to rise from 1954 onward when the canal was opened. The rate of rise per year was 1.77 ft.

(*iii*) Well Nos. 6, 7 and 8 away from the canal showed an average rise of 0.33 ft. per year, while the rest four wells, No. 9 to 12 still farther off from the canal gave a rise equal to 0.024 ft. per year.

Well Line No. X

This line of wells is situated about 45 miles below well line No. IX. Here the distributaries of the Thal Canal spread out to cover a considerable width of the Doab. Well No. 9 is very close to the Rangpur Canal. A study of the rise of ground-water showed that :

(*i*) Uptill 1954 there was practically no effect on the ground-water (Table I).

(*ii*) All the seven wells within the distributary system of the Thal Canal showed an average rise of 2.27 ft. per year from 1954 onward. The last two wells Nos. 8 and 9 lying close to the Jhelum showed no change.

(*iii*) In this region the maximum depth of water was 30 ft. towards the Jhelum side. It was shallow towards the Indus. At present, the water level on this side is very close to the natural surface (Fig. 1-*a*).

Well Line No. XI

This is the last provincial line crossing the doab, about 25 miles downstream of well line No. X. Here the width of the doab starts narrowing down. It has only eight observation wells. Practically all wells lie at the end of the distributaries taken out of Thal Canal, Rangpur Canal also flows close to well No. 8. The rise of ground-water studied from 1935 onward is shown in table I, which points out that :

(*i*) Uptill 1955 there was no change in the ground-water level.

(*ii*) From 1956 a steady rise equal to 1.67 ft. per year started.

(*iii*) The original water table in the first 5 wells was at 20 to 25 ft. and now it is within 10 ft. of the surface. The ground-water in wells Nos. 6 and 7 is still deeper and in these the rise per year was also less. In well No. 9, the rise was greater than the rest and the ground-water is now within 9 ft. of the surface.

A few typical water level rise curves are shown in Fig. 3. The present ground-water contours are plotted in Fig. 2.

Discussion of the Results

Four L-section along the length of the Thal are plotted in Fig. 3-*a*. These show the natural surface, the position of ground-water in 1935, 1947 and 1960-61. The position of these lines is marked on Fig. 2, so that the wells of which the levels are plotted in these lines can be noted with reference to this figure. The cross section through this doab along the six wells lines are plotted in Fig. 1-*a*. A careful study of all this data and in particular the figure 1-*a*, 2 and 3-*a* leads to the conclusions that :

(*i*) The ground-water slope along the length of the doab followed the slope of the doab. Its depth, however, varied from place to place.

(*ii*) The cross section through the doab shows that the slope of ground-water was towards the Jhelum. In the year 1935 to 1947, in well line No. V, close to well Nos. 8 and 9, there was a depression with a possibility of water accumulating over there.

There appeared to be some depression along well line No. VII close to well No. 10 and the rest of the well lines showed that the general slope of ground-water was towards the river Jhelum. It is clear that ground-water flow in the doab was not accumulating into the deepest position.

Rise of Ground-water before the introduction of Thal Canal

It is shown that water in all the wells of line Nos. V, VII & VIII was found to be rising before the introduction of the canal. Water level in wells of line IX, X and XI during this period was either fluctuating or steady.

It is concluded that water was being added to the northern portion of the doab even before the construction of the canal. Maybe, after the construction of rail and road from Khushab to Mianwali, changes in the natural drainage of stream below the salt range, took place. This may cause obstruction to the surface flow, resulting in percolation of the underground.

As will be shown further in this paper, similar conditions appeared in the other two doabs also. If this percolation had been taking place before the construction of the roads and the rails, the water table by this time should have come up close to the surface. The fact that in 1936, the ground-water existed at 35 to 50 ft. below surface points to the fact that the rise noted in the wells before the construction of the canal must have been a result of obstruction caused by the construction of rail, road and other obstructions. The wells of line No. V exist just at the foot of the salt range. Evidently this region received greater charge as compared to the regions lower down. The observation proves this contension.

There is a possibility of the saline water of the salt range moving down in this region. Usually rain water is lighter and depresses the heavy saline water. Due to the existence of underground clay deposit as for instance below Jauharabad, the top aquifer can be washed by rain water and the bottom aquifer may remain saline.

The natural surface slope is far from the Indus near Mianwali towards the Jhelum and there is a possibility of sub-surface flow, from the Indus towards the Jhelum; the saline water could be washed towards the Jhelum River side.

These arguments are supported by the conditions existing at site. The top ground-water is of good quality. The deeper water generally below the sub-surface clay layer is saline and salinity is greater towards the Jhelum.

As the intensity of rainfall run-off decreases towards the lower regions, the rise in wells correspondingly is less.

The non-existence of the highly saline water in the zone of deepest ground-water of the Thal doab also points to the fact that in this area water was not accumulating.

The rise in wells of the region, even those which are far off from the influence of the canal points out that water infiltering into the formation is being held up and is filling the aquifer.

The rise is more in wells of line V as compared to wells of line Nos. VII and VIII. Similarly wells of Line No. X also showed a big rise. The rise is noticed in wells of the full doab. Maybe, the seeping water from canals and distributaries is being held up in the region resulting in quick rise of ground-water.

The existence of high order of underground salinity in this region may have some connection with the greater rise as exhibited by wells of line No. X.

Rise of Ground-water after introduction of Thal Canal

Water in Thal Canal was let in the Muhajir Branch in 1947. From that very year, the wells of line No. V started to show a rise.

The lower portion of the canal started operating in 1954-56, so that, the wells of the rest of the region started showing a rise after that period.

The average rise in wells of each line was as under :

Well Line No.	*Period in years*	*Rise per year in ft.*
V	1947-61	1.9
VII	1947-50-61	1.74
VIII	1954-61	0.9
IX	1954-60	1.77
X	1954-60	2.27
XI	1954-60	1.67
	Mean	1.71

After the inception of the Thal Canal, the rise in the whole of the doab has been considerable. Area very close to big lined canal and in the region of small distributaries have all shown a uniform rise.

In some cases watertable has risen to within 10 ft. of surface and is now slowing down. The present position of depth of ground-water is shown in Fig. 2.

In this doab the rise has been slightly more than the Rechna or Chaj Doabs. It may be that the big canals and distributaries are all percolating heavily and adding to sub-soil probably due to the lighter nature of the formation.

TABLE I

Yearly changes in ft. of ground-water in wells of Thal Doab before the Thal Canal started operating. For well lines Nos. V, VII and VIII, period of observation is 1935 to 1946 and for well lines Nos. IX, X and XI period of observation is 1935 to 1954

Well No.	1	2	3	4	5	6	7	8	9	10	11	Mean
Well Lines												
V	0.5	0.46	0.45	0.35	0.35	0.38	0.28	0.33	0.33	0.35	0.2	0.36
VII	0.7	0.25	0.17	0.22	0.11	0.28	0.29	0.51	0.1	0.23	0.17	0.22
VIII	—	0.12	0.15	0.44	—	0.18	0.18	0.03	—	0.2	0.02	0.13
IX	0.01	0.2	—	—0.28 (fall)	—0.14 (fall)	0.04	—	0.09	—	—	—	—
X	—	0.2	—	0.76	—	—	—	—	—	—	—	—
XI	—	0.13	—	—	—	—	—	—	—	—	—	—

TABLE 2

Mean rise in ft. per year in ground-water of Thal Doab after the canal started operating. Rise during 1947 to 1961 for wells lines VI, VII and VIII and during 1954-55 to 1961 for wells lines Nos. IX, X, XI.

Well No.	1	2	3	4	5	6	7	8	9	10	11	Mean
Well Lines												
V	1.5	0.89	1.85	1.6	1.9	1.9	1.9	2.5	2.5	2.7	1.49	1.89
VII	0.39	1.17	1.6	1.9	—	1.9	1.5	1.1	1.0	2.6	1.84	1.74
VIII	—	0.82	0.87	0.61	—	1.25	0.75	1.07	—	0.92	—	0.9
IX	0.89	1.3	2.08	1.0	1.6	—	—	—	—	—	—	1.77
X	1.12	2.15	3.11	2.97	3.17	1.68	1.73	—	—	—	—	2.27
XI	1.4	1.6	1.5	2.7	—	—	—	—	—	—	—	1.67

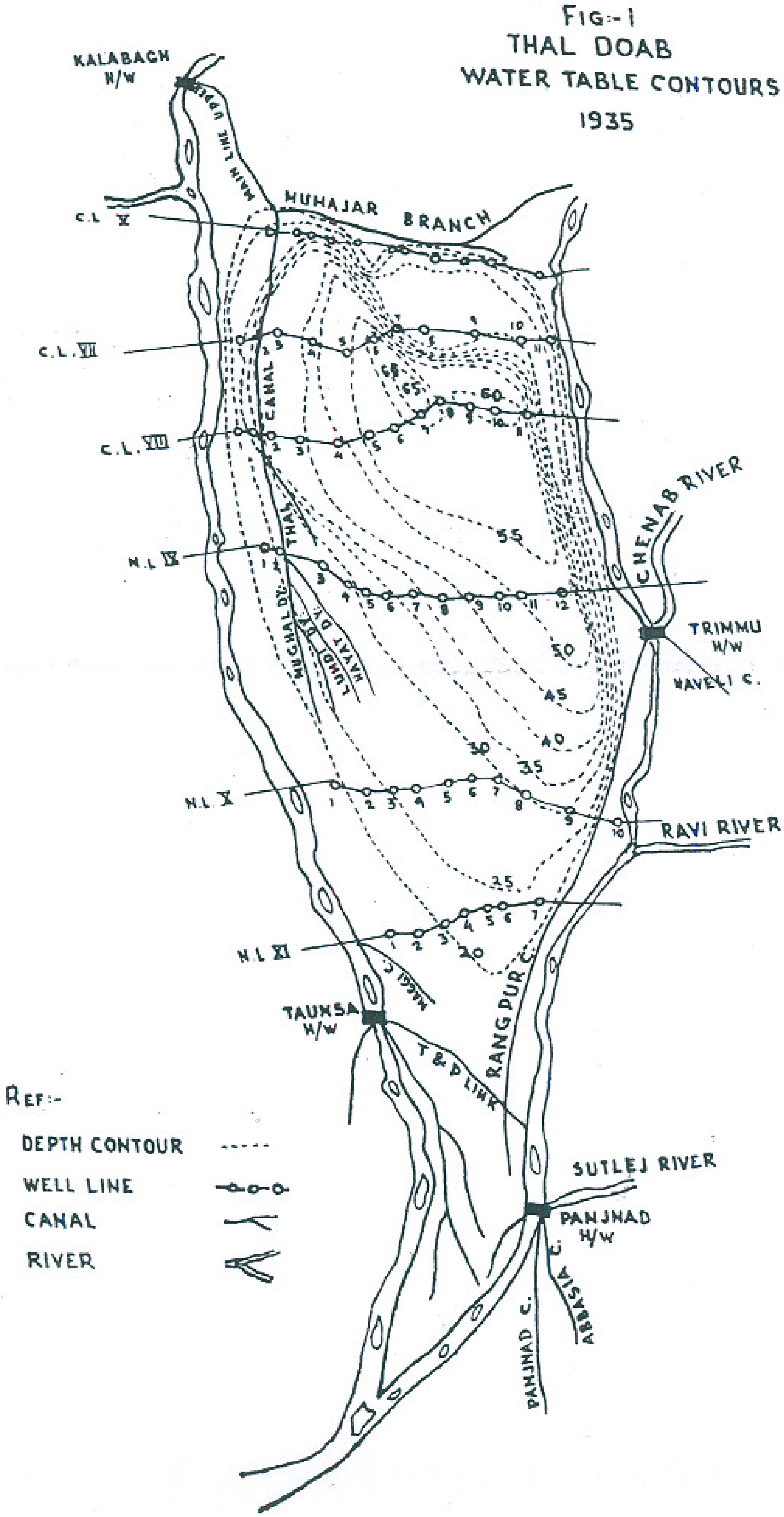


FIG:-1
THAL DOAB
WATER TABLE CONTOURS
1935
KALABAGH H/W
MAIN LINE UPPER
MUHAJAR BRANCH
C.L X
C.L. VII
C.L. VIII
N.L IX
N.L X
N.L XI
THAL CANAL
MUGHAL DY.
LUNDI DY.
HAYAT DY.
CHENAB RIVER
TRIMMU H/W
HAVELI C.
RAVI RIVER
TAUNSA H/W
T&P LINK
RANGPUR C.
SUTLEJ RIVER
PANJNAD H/W
PANJNAD C.
ABBASIA C.
REF:-
DEPTH CONTOUR
WELL LINE
CANAL
RIVER

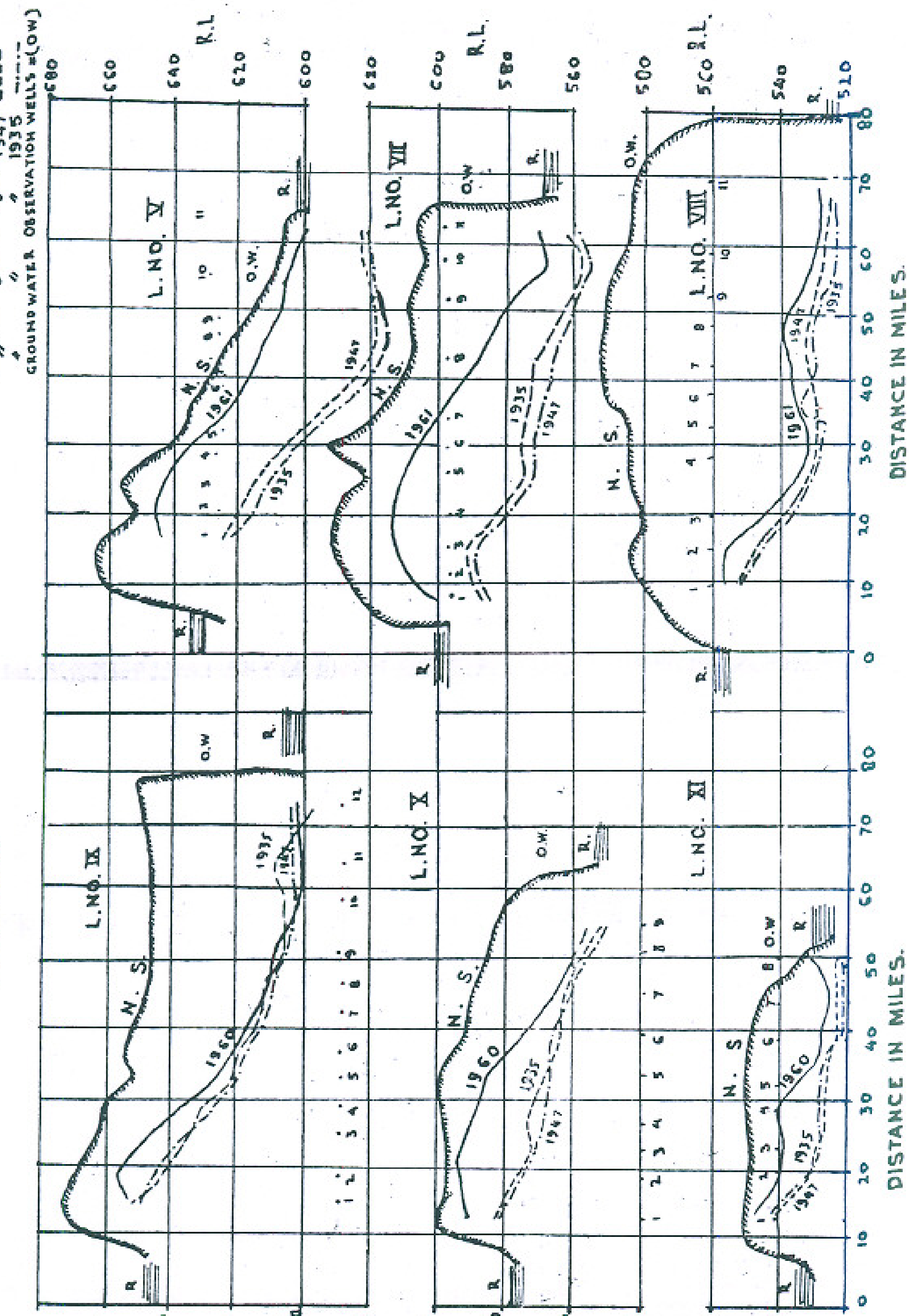


FIG:- 1(a)
N.S. & W.T. ALONG VARIOUS WELL LINES OF THAL DOAB

Fig:- 2.
THAL DOAB
WATER TABLE CONTOURS
1960

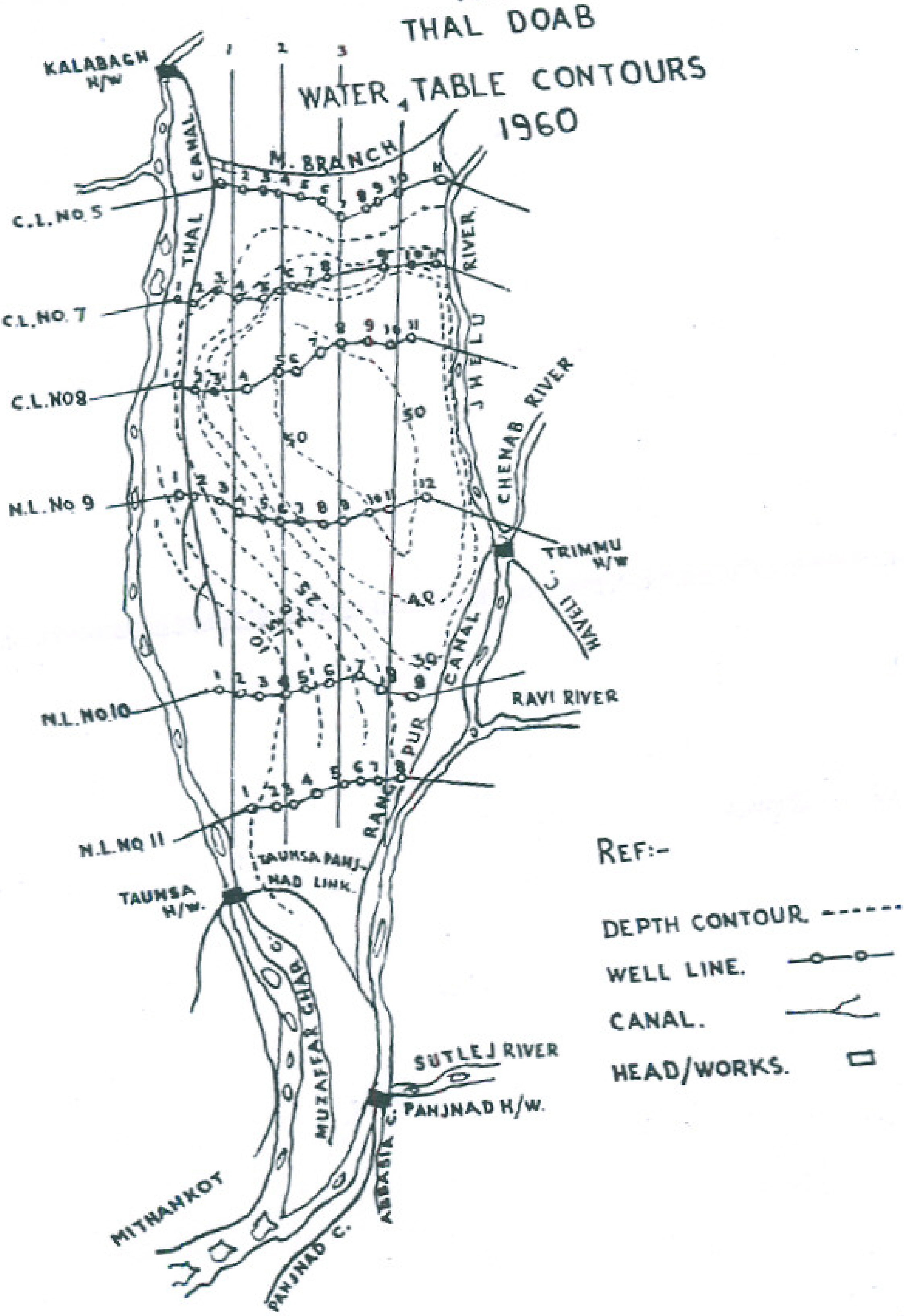


FIG 3 140-62-1

RISE OF GROUND WATER IN WELLS LOCATED IN THAL DOAB

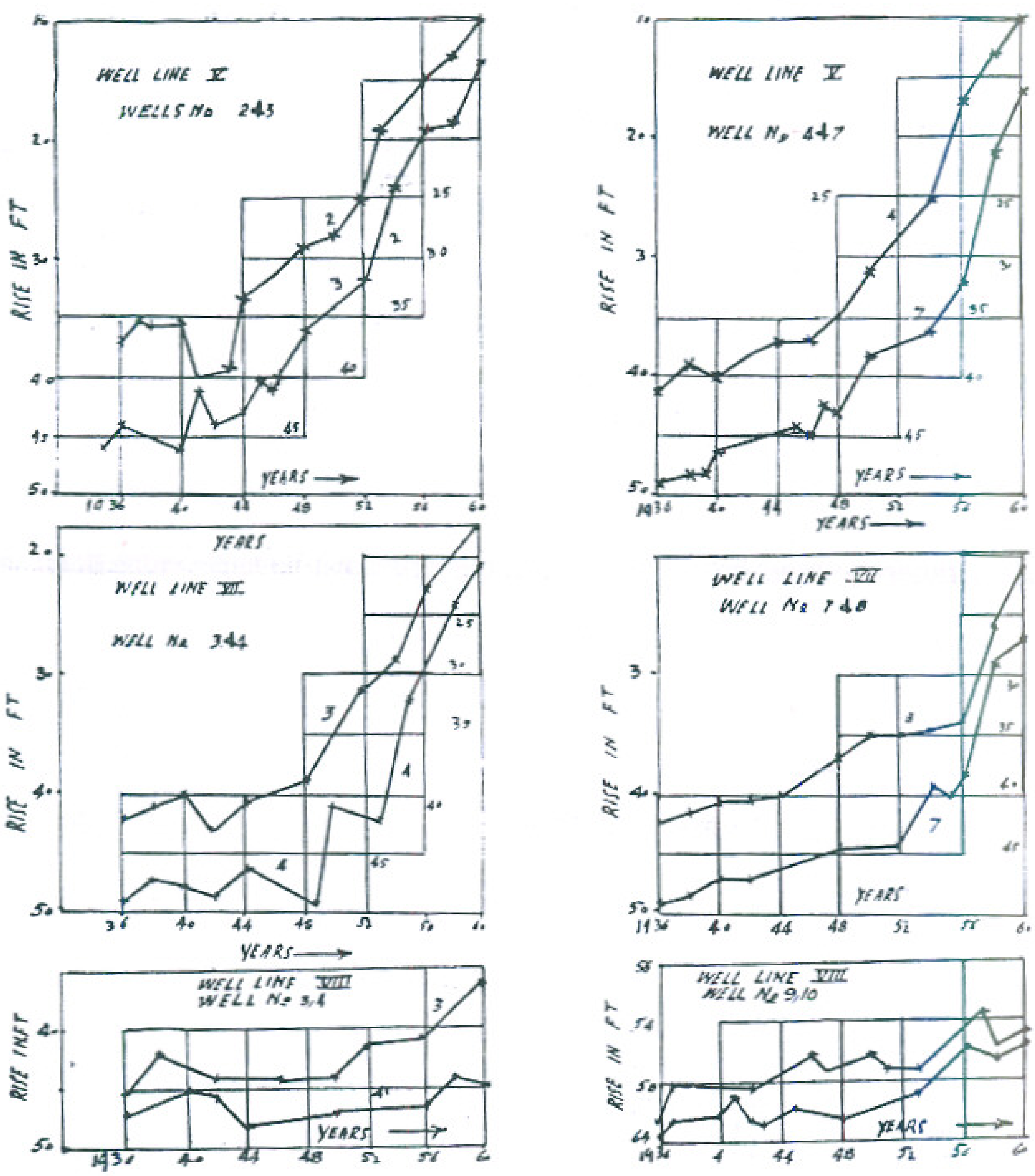
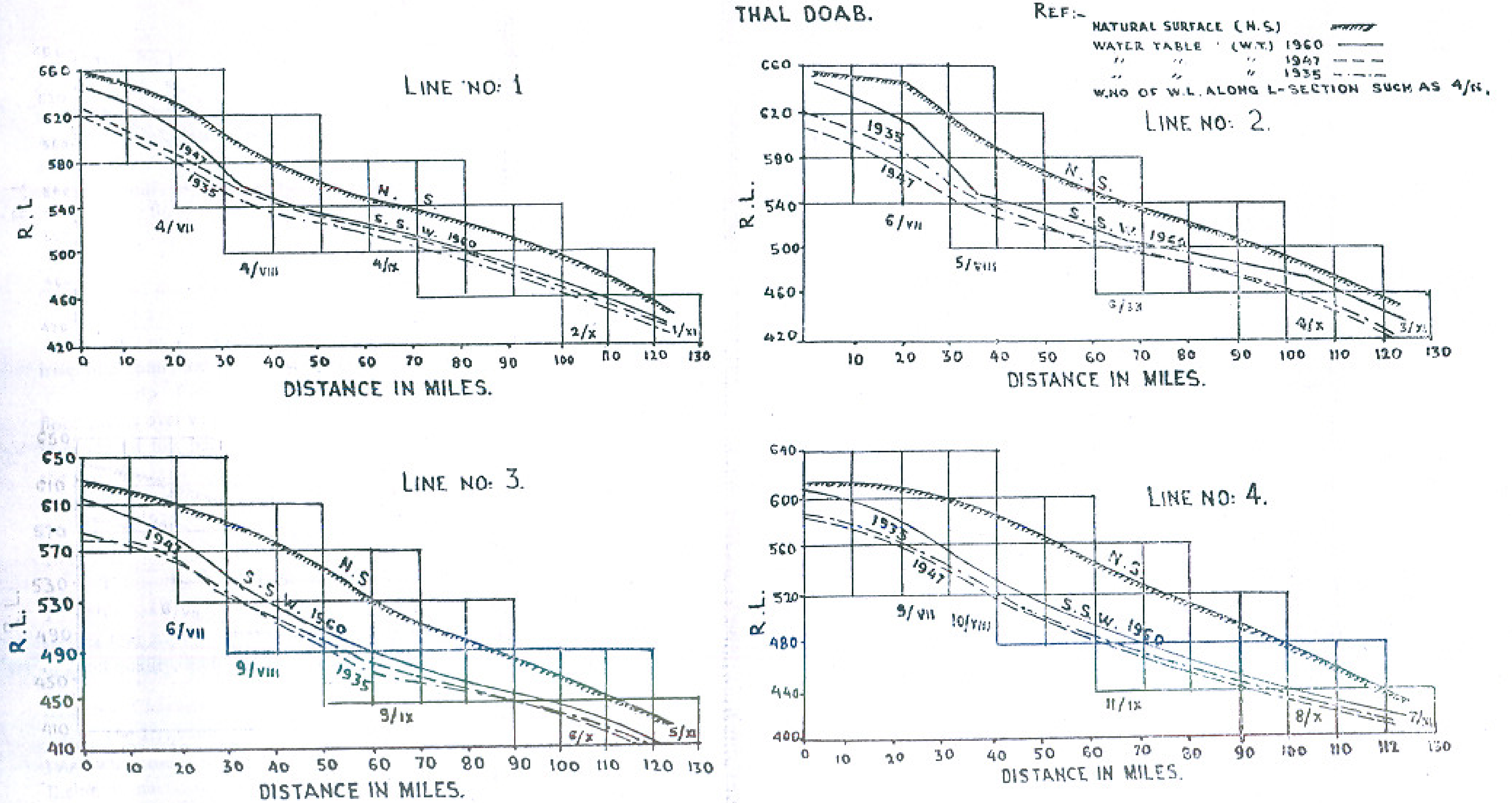


FIG:- 3(a).

N.S. & W.T. SLOPE ALONG FOUR L-SECTIONS OF THAL DOAB.



CHAJ DOAB, ITS EXTENT

This doab is bounded by the River Jhelum in the North West and the Chenab on the South East. It is the smallest doab constituting about 175 miles in length. The maximum width in the middle of the doab is about 55 miles. At its tail end for a length of about 25 miles, the two rivers are hardly 12 miles apart. The distance between the two rivers increases upstream of the tail end. About 50 miles above the confluence, the rivers are 25 miles apart after which the distance increases and it attains the maximum width of 55 miles within the next 25 miles. The rivers again start coming closer to within 27 miles and remain at the same distance apart for the next 70 miles. In Figure 4 the extent of the doab is shown. It constitutes an area of about 3.4 million acres of which about 0.5 m. acres are occupied by Pabbi Hills and the salt range. The rest 2.9 m. acres are culturable flat plains. About 2.2 m. acres are under irrigation command of Lower Jehlum and Upper Jhelum Canals.

A strip of about 2 to 5 miles on both sides of the rivers constitute the flood plains over which the rivers spill during high floods. This land from times immemorial has been the most fertile region, extensively cultivated, utilizing the ground-water with persian-wheels or the moisture left by the rivers during their spill. Before the advent of weir controlled Irrigation system, there were a few innundation canals through which water was lead to irrigate the land farther away from the flood plains of the rivers.

The north east region of the Gujrat District are the foot hill plains. This area has a steeper land slope as compared to the rest of the doab and has several rain water Nullahs draining through it. It has always been a region of good quality, high ground-water which is used for irrigation of the land.

Irrigation Channels

The Irrigation system of the doab was started to take shape in the year 1900, when the first weir controlled canal started operating. It was the Lower Jhelum Canal (L.J.C.) taken out from the river at Rasul. This canal irrigates 1,623,300 gross acres of which 1,500,000 acres are culturable. Its capacity at head is 5,280 cusecs.

Another canal was taken out of the Jhelum at Mangla during the years 1912-17. It is the Upper Jhelum Canal (U.J.C.) carrying a discharge of 9,031 cusecs which has now been increased to 12,031 cusecs. It is mainly a feeder channel bringing 8,783 cusecs of water of the Jhelum to the Chenab at Khanki. Only the Gujrat branch is taken out of this to irrigate about 580,000 gross acres of the doab un-irrigated by the Lower Jhelum Canal and thus utilizing about 2,100 cusecs of perennial and 1,450 cusecs of non-perennial supplies. The gross area irrigated by the two canals comprises 2,203 m. acres of which 2.041 m. acres are culturable. This area is irrigated by 3.818 m. acres ft. of supplies consumed per year.

Ground-water Level

It is said that some information of ground-water level of this doab is available for the year 1856, but this must be for a few wells, perhaps close to the river spill, the land which had then been inhabited. The regular observations of ground-water were started in the year 1899 when 27 circle lines (CL) of wells were established crossing the doab.

The first eight lines passed through the Gujrat branch of the Upper Jhelum Canal. Line Nos. I and II exist on both sides of the Upper Jhelum Canal but unfortunately data for a few wells of these lines are available.

Circle Line No. IX to XXVII cross the doab served by the Lower Jhelum Canal. In addition there are nine Provincial Lines (PL) which cross the doab. These usually overlap the circle lines with addition of a few more wells. The data for these wells is usually from the year 1917 onward.

After the Upper Jhelum Canal we opened, a few more lines of wells which were marked from 1920 onward. Eight ofthese crossed the Upper portion of the Canal (Jhelum Lines, JL) north of pubbies having only 3 or 4 wells in a line.

Six lines of wells were selected crossing the north of the Upper Jhelum Canal through the Gujrat District (named GT lines). These wells show the condition of ground-water in the foot hill area. Records for these are from the year 1927 onward.

Earliest Ground-water Depth

The earliest records of ground-water are from the year 1899 when the Lower Jhelum Canal was opened. The deepest water level was at 75 ft. below surface. Incidentally deepest points were those where the doab was the widest. Watertable on the north of the doab was at 20 ft. below surface. The ground-water in the flood plains was at a depth of 10 to 20 ft. with the deepest point in the mid-doab being 75 ft. below surface, so that in a width of about 25 miles, drop in ground-water was about 55 to 65 ft. This showed that in certain regions, the ground-water slope was more than 2 ft. per mile. The usual slope of the land being 1.6 ft. per mile. The slope of ground-water toward the deepest point was thus steeper than the general slope of the land.

Rise of Ground-water

Wells of Circles Line (CL) Nos. IX to XVII cross the area irrigated by L.J.C. Circle Lines No. III to VIII and Provincial Lines Nos. IIIto VI lie in the region served by U.J.C. Data for these wells are available from 1920 onward.

A study of the rise of water table in the wells showed that the water depth was between 40 to 75 ft. at the time of opening of the L. J. Canal. It showed a steady uniform rise every year. Rise of a few typical wells is shown in

Fig. 5. The average rise during 20 to 30 years remained uniform giving per year rise equal to 1.7 ft.

In table 3 we have tabulated the earliest depth of these wells and their rise. The ground-water started to rise from the deepest point at a uniform rate as soon as the canal was opened. Although some wells showed a rise of more than 2.0 ft. per year, the average worked out equal to 1.7 ft. as mentioned above.

Rise in Wells with Depth at 20 to 40 ft.

In table 4, data of all those wells is given in which water table started to rise from a depth of 40 ft. The rise up to a depth of 20 ft. below surface is considered. The average rise was found equal to 1.23 ft. per year which was slightly less than the position of water table when it started to rise from a depth of 75 to 40 ft. With water table 40 ft. below surface, the sub-soil slope was slightly less and so was the rise of water per year.

In some other wells, the rise from depths less than 40 ft. as it come up to 15 ft. of the surface, is considered. Data of such wells is given in table 5. These wells also showed an average rise of 1.26 ft. per year.

Rise of Ground-water from a Depth of 10 ft.

In table 6, data of wells having ground-water nearly 10 ft. below surface are given. The rise works out equal to 0.1 ft. per year. In sixty years the watertable has come up to within 5 ft. of surface. The water table stabilized at this depth.

The present position of water table is shown in Fig. 6 which shows that now very little area of the doab has water table deeper than 15 ft.

Rise of Water table in the North Region of the Doab

There are five lines of wells on the eastern side of the U. J. Canal. These are located in the foot hill region which has no irrigation channel. The records of these wells are available from 1927. All these wells showed a rise in ground-water since the period of observation. This data are given in table 7. The mean rise per year is of the order of 0.22 ft. It seems that some sort of obstruction was causing rise of ground-water. Maybe, it is a result of rail and road development which resulted in longer retention of flood water from hill streams or the imposition of U.J.C. which did not allow the ground-water to flow to lower regions. The former reason seems more appealing as the ground-water is still rising and the canal has been in existence from 1916.

Ground-water in the Region of U.J. Canal upstream of Pubbies

There are eight lines of wells, each having three or four wells. These wells have shown a rise of 0.13 ft. per year since the construction of the canal. The data of these wells are shown in table 8.

Discussion of the Results

As a result of the examination of the rise of ground-water in wells of Chaj Doab it appears that:

(*i*) As soon as the Lower Jhelum Canal started operating, ground-water in the whole region served by the canal started to rise.

(*ii*) In the initial stages, the water table was at 75 to 40 ft. below surface, the deeper water rose at an average rate of 1.7 ft. per year and in some cases up to 2.0 ft. per year. This rise was more in wells having deep water than those having shallow depth. It can be interpreted that when ground-water was deep, the flow from rivers accumulated in the deeper regions.

(*iii*) The general rise from a depth of 40 ft. to 15-20 ft. was at the rate of 1.23 ft. per year in the whole of the region irrespective of the depth to water table and the position of observation. Both the regions served by L.J.C. and U.J.C. showed the same order of rise of water table.

(*iv*) The rise in wells having water table at 10 ft. below surface was hardly 0.1 ft. per year. It seems to have stabilized at 5 ft. below surface.

(*v*) A study of the slope of ground-water levels shows that there was flow from high water table towards the deeper regions and this helped to wash away the salts of the soil and get them accumulated in the deeper zones. This may be one reason for the high order of ground-water salinity in the Chaj Doab and its accumulation in the central regions of the doab. This salinity may have got accumulated since ages.

(*vi*) The uniform and equal rate of rise of ground-water in a big area of the Chaj Doab needs special consideration. Such sort of uniform rise of ground-water is only possible if there is limited sub-soil flow. A study of boring data of Rasul tubewells or the deeper boring, as carried out by Wasid points out the existence of extensive clay lenses probably obstructing the sub-soil flow to lower regions. An instance of strata formation as per Wasid explorations is shown in Fig 7. It appears that in this doab there are more clay obstructions affecting the sub-soil flow.

(*vii*) It appears that imposition of obstruction to the sub-soil flow either by the construction of the roads, rail or the moisture pile conception of U. J. Canal is causing the rise of ground-water in the Upper regions even though there exist no canals. Upsetting of the natural balance of drainage thus results in rise of ground-water. This has been the cause of rising water table in the foot hill regions of Chaj Doab.

(*viii*) The flood plains along the rivers had always been the region of high water table and these have remained at this level only being affected by a few feet after the reorientation of the surface flow.

TABLE 3

Rise of ground-water in Chaj Doab from depth 75 *to* 40 *ft. Period of Observation* 1900 *to* 1920, *except for wells of line No. (P.L.) III and VI the period for which is* 1920 *to* 1930. *Average rise per year*=1.7 *ft.*

	P.L.			C.L.			
Well Lines	III	IV	VI	VII	VIII	IX	X
Well No./ rise per year	8/2.6	11/1.2	4/1.5	—	8/1.6	5/2.2	5/2.4
	10/2.2	13/1.3	—	—	9/1.9	7/2.2	5/2.1
	12/2.1	—	—	—	10/1.0	9/1.9	8/2.1
	—	—	—	—	—	10/1.5	8/2.1
	—	—	—	—	—	13/1.9	9/1.4
	C.L.						
Well Lines	XI	XII	XIII	XIV	XV	XVI	XVII
Well No./ rise per year	8/1.8	6/1.8	8/2.1	3/2.6	4/1.7	6/1.0	6/1.0
	9/1.8	7/1.7	9/2.1	4/1.8	—	7/1.2	—
	10/1.1	8/1.7	10/1.6	5/1.3	—	—	—
	12/1.8	9/1.6	—	6/1.3	—	—	—
	—	10/1.5	—	7/1.1	—	—	—

TABLE 4

Mean rise of ground-water in Chaj Doab, starting from water table depth of 40 *ft. and rising to* 20 *ft. below surface. For provincial line (P.L.) Observation period is* 1920-1930 *and for Circle Lines (C.L.) Observation period is* 1900 *to* 1915. *Mean rise per year is* 1.23 *ft. per year*

	P.L					C.L	
Well Lines	I	II	IV	V	VI	V	VI
Well No./ rise per year	8/2.5	10/1.7	8/1.1	7 wells from No. 13 to 22, average rise 1.3	9/0.9	4/1.2	3/.9

			C.L.					
Well Lines	IX	XI	XIV	XV	XVI	XVII	XVIII	XX
Well No./ rise per year	4/.0	8/1.1	9/1.2	7/1.0	4/1.2	3/.8	2/1.5	4/.8

TABLE 5

Rise of ground-water in Chaj Doab starting from depth below 40 ft. and rising up to 15 ft. below surface. The Data for P.L. is from 1920 to 1930 and for C. L. is from 1900 to 1915. The average rise is again 1.26 ft. per year.

Well Lines	P.L.					
	I	II	III	IV	V	VI
Well No./ rise per year	5/3.5	6/.9	9/1.8	10/1.6	12/1.6	5/1.0
	7/.8	7/1.6	13/1.6	12/2.1	19/1.0	2/.7
	9/.9	8/.4	14/1.4	13/1.3	24/.9	8/2.0
	10/1.0	11/1.1	15/1.1	15/1.3	—	—
	11/1.1	—	16/1.1	16/1.5	—	—
	—	—	—	—	—	—

Well Lines	C.L.						
	III	IV	V	VI	VIII	IX	X
Well No./ rise per year	1/3.2	1/1.5	1/1.1	2/1.0	1/1.7	6/1.4	3/.8
	—	2/.9	—	—	7/1.0	7/.7	4/1.4
	—	—	—	—	11/1.1	14/1.2	11/.9
	—	—	—	—	12/.7	—	—

Well Lines	C.L.							
	XII	XIV	XV	XVI	XVII	XVIII	XIX	XX
Well No./ rise per year	5/.9	2/1.1	3/.4	3/1.0	1/1.0	1/1.0	2/.9	1/.8
	—	—	5/1.0	5/1.0	—	3/1.0	3/.1	7/.7
	—	—	—	8/1.0	—	4/1.0	4/1.7	—
	—	—	—	—	—	5/.8	5/1.10	—

TABLE 6

Rise of ground-water in Chaj Doab from 10 ft. depth below surface. Average rise 0.1 ft. per year. Data for both P. L. and C. L. was generally from 1920 to 1960 except in a few wells of C. L. for which the data was from 1900 onwards.

	P.L.								
Well Lines	I	II	III	IV	V	VI	VII	VIII	IX
Well No./rise per year	1/.8	4/.1	13/.11	1/.09	3/.03	1/.1	4/.12	4/.01	1/.3
	4/.1	5/.2	16/.13	2/.11	7/.05	3/.1	7/.05	7/.05	4/.1
	7/.2	13/.17	—	5/.03	10/.05	—	—	—	5/.11
	10/.1	16/.1	—	15/.13	27/.05	—	—	—	—
	11/.2	18/.08	—	25/.1	—	—	—	—	—

	C.L.								
Well Lines	IV	VI	VII	VIII	IX	X	XI	XII	XIII
Well No./rise per year	3/.3	1/.07	A/.07	2/.06	1/.14	3/.1	4/.05	1/.08	2/.07
	5/.1	—	B/.1	11/.1	2/.13	4/.07	5/.6	3/.03	3/.07
	—	—	D/.08	13/.07	13/.03	6/.13	—	5/.05	4/.01
	—	—	—	—	—	12/.04	—	17/.15	5/.08
	—	—	—	—	—	13/.09	—	—	7/.12

	C.L.								
Well Lines	XIV	XV	XVI	XVIII	XIX	XX	XXIV	XXVI	XXVII
Well No./rise per year	1/.2	3/.09	5/.2	4/.07	6/.06	1/.05	2/.11	1/.1	1/.2
	2/.12	4/.34	7/.33	—	—	—	4/.2	—	—
	11/.05	—	11/.05	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—

TABLE 7

Rise of ground-water in Chaj Doab in Northern Region not irrigated by canals mean rise per year is 0.22 *ft. Period of Observation from* 1927 *to* 1960

Well No.		1	2	3	4	5	6	7
GT Lines	I	.15	.05	.39	.15	—	—	—
	II	.41	.03	.08	.03	.45	.34	.13
	III	.52	.27	.23	.19	.28	.19	.19
	IV	.1	.1	.19	.53	.41	.19	—
	V	.08	.64	—	—	—	—	—

TABLE 8

Rise of ground-water in Chaj Doab along Upper Jhelum Canal north of Pubbies, mean rise 0.13 *ft. per year. Period of Observation* 1921 *to* 1960

J.L.	I	II	III	IV	V	VI	VII	VIII
Well No. 1	.37	.04	.04	.16	.09	.11	.35	.03
2	.06	.05	.02	.16	.04	.02	.12	—
3	.05	.08	.37	.6	.01	.007	.11	—
4	—	—	—	—	—	—	.08	—

TABLE 8A

Region of L. C. Canal, Rise of ground-water from 50-60 *ft. below surface, observed from* 1905 *to* 1916-20. *Average rise* 1.4 *ft. per year.*

No. of Well Lines	9	10	11	12	9-14	Remarks
No. of wells Observed/mean rise in ft. per year.	4/1.9 3/1.4	4/1.2 —	9/1.5 2/1.4	13/1.1 —	46/1.1 —	81 wells of the region gave an average rise of 1.4 ft. per year.

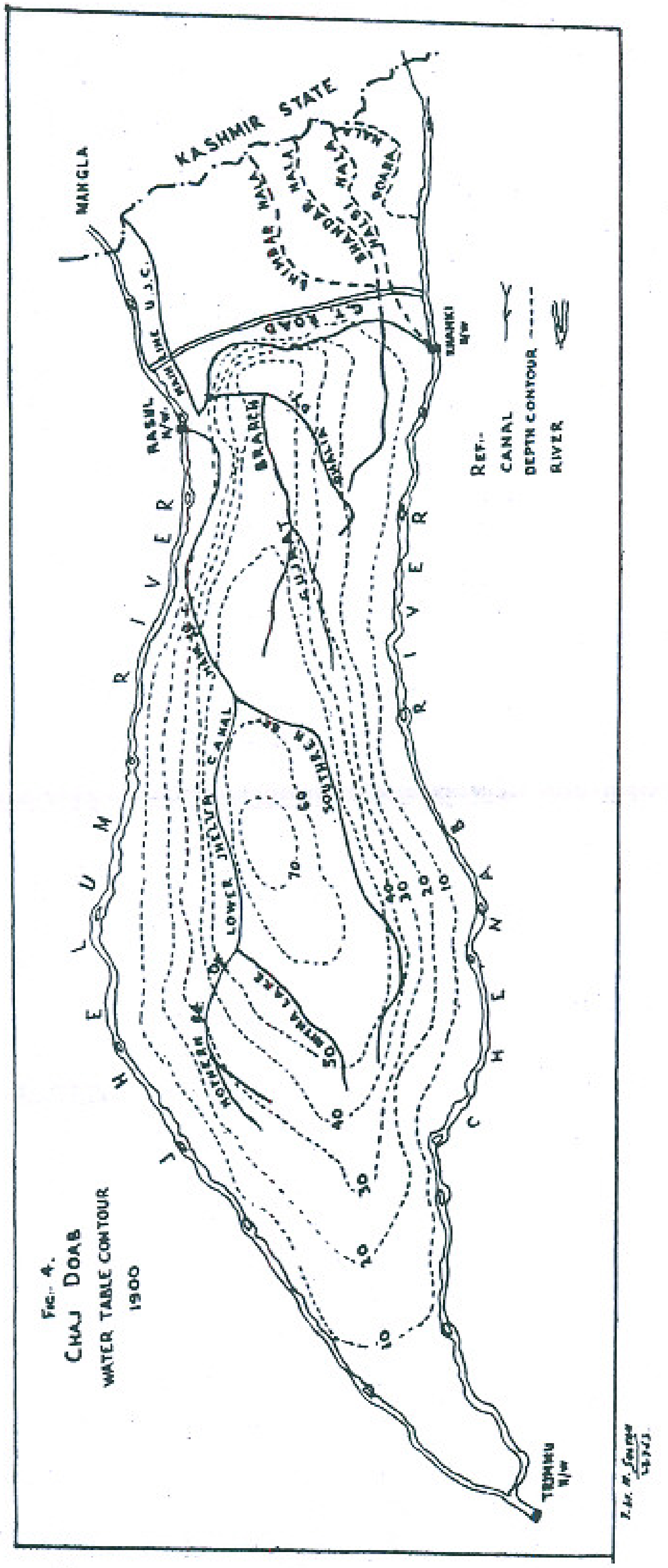


FIG. 4.
CHAJ DOAB
WATER TABLE CONTOUR
1900

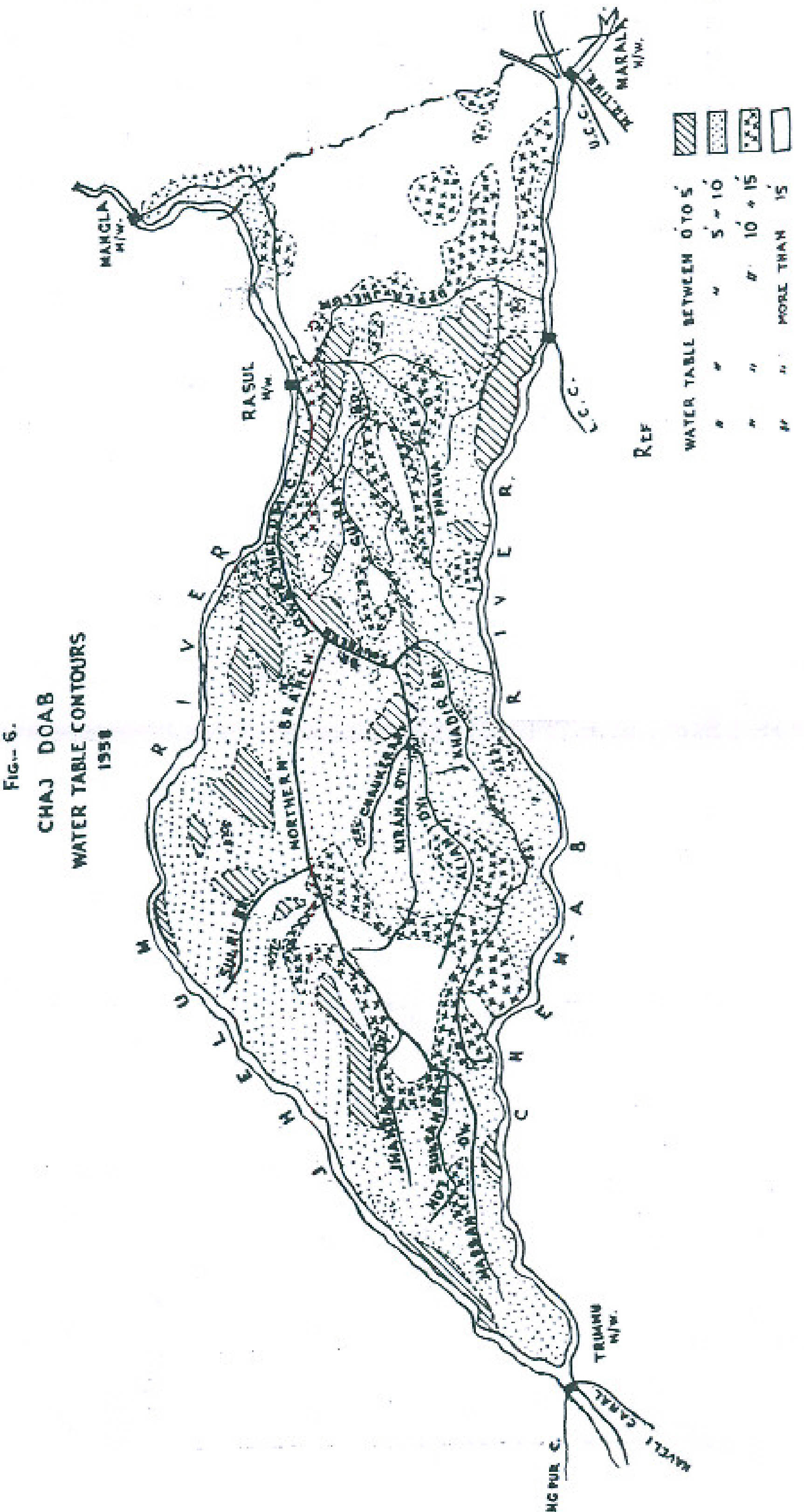
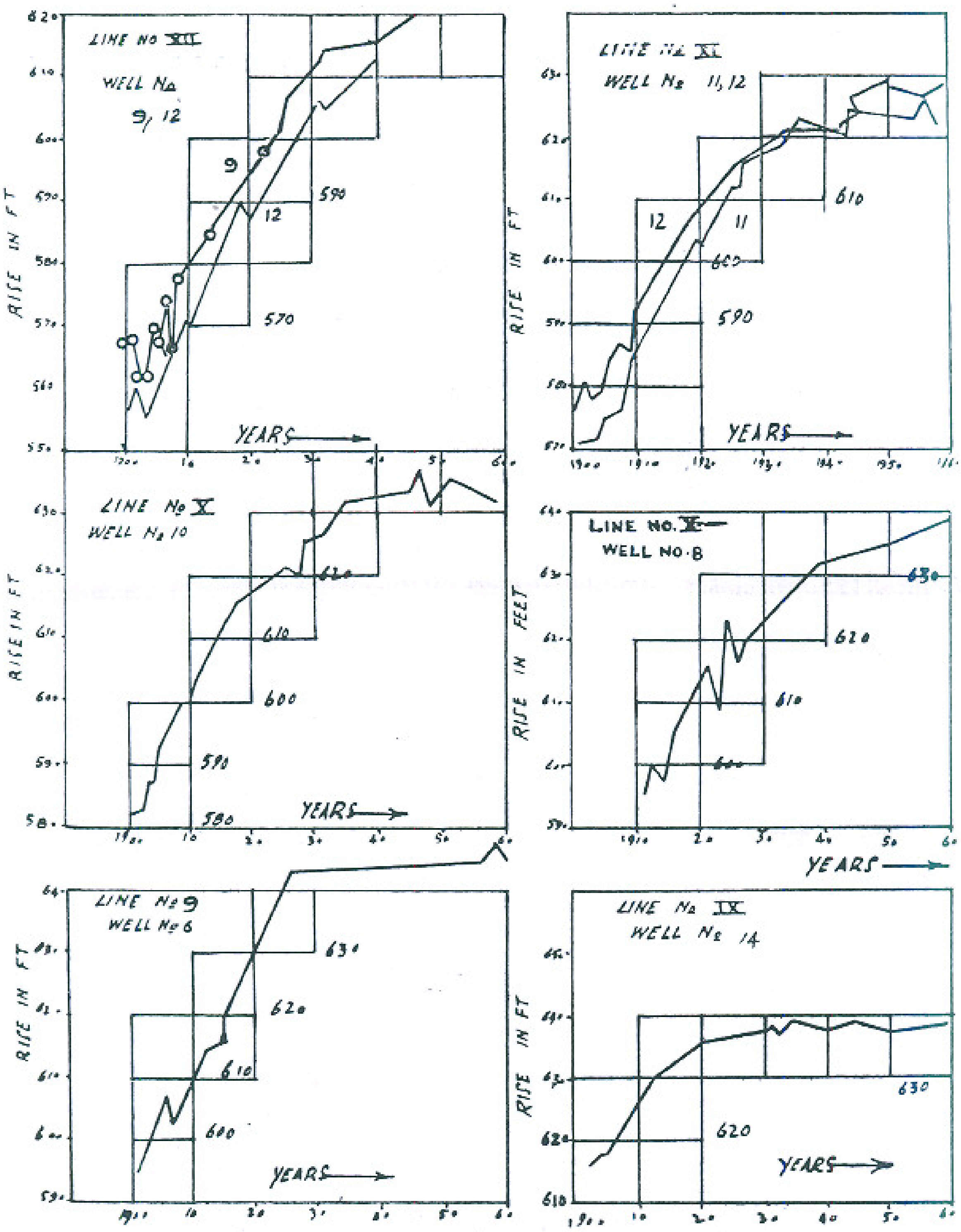


Fig. 6.
CHAJ DOAB
WATER TABLE CONTOURS
1958

FIG 5
RISE OF GROUND WATER IN SELECTED WELLS OF CHAJ DOAB



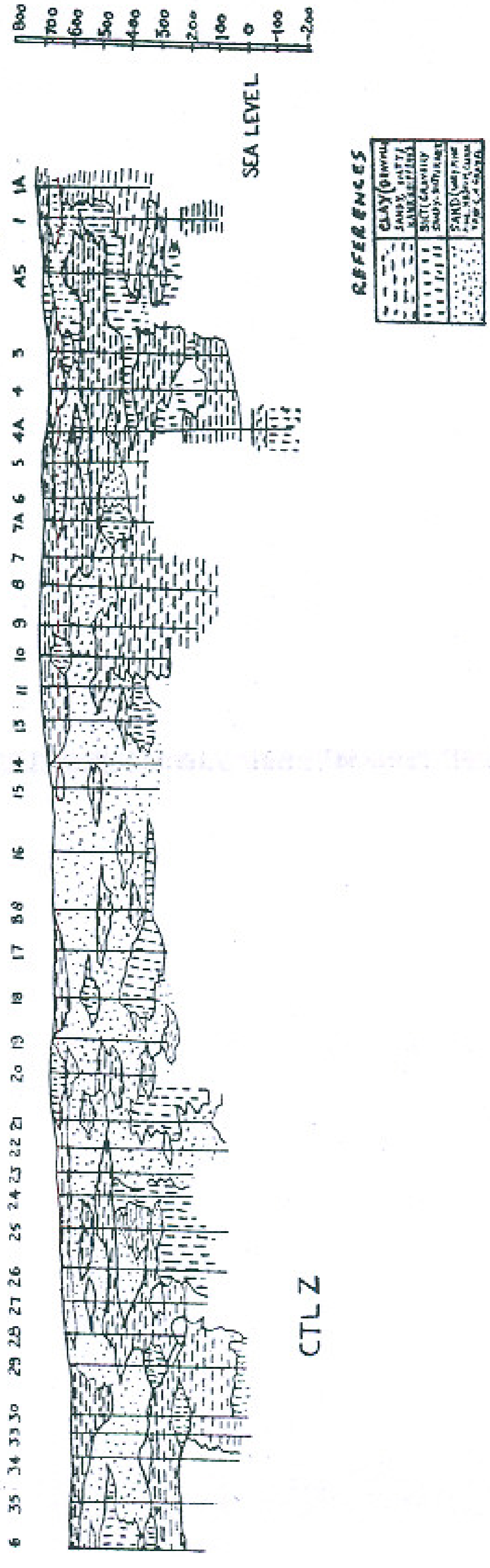


Fig 7(b)
GEOLOGIC SECTION
CHAJ DOAB

RECHNA DOAB, ITS EXTENT

Rechna Doab is bounded by the River Chenab in the north and the Ravi in the south. It comprises about 11,600 sq. miles, being 200 miles in length just below Marala in Sialkot district and having an average width of 65 miles. After the confluence of the two rivers, the doab widens out and within a distance of 16 miles, it attains the width of 60 miles.

At present, it has got the biggest irrigation system of the country. The first canal was completed in 1896. It is the Lower Chenab Canal (L.C.C.) and is taken out of the Chenab at Khanki. Its authorised supply is 11,000 cusecs and it irrigates a gross area of 3.703 million acres. The approximate length of its main lines and main branches is 454 miles.

In 1912-14 another canal was taken out at Marala from the Chenab. It crosses the doab and delivers its supply to the Ravi at Balloki. This canal is called the Upper Chenab Canal (U.C.C.) and is the second canal of the triple canals system transferring water of the Chenab to the Ravi. It irrigates about 1.511 million acres. Its discharge is 13,500 cusecs and it delivers about 6,500 cusecs at Balloki through a channel about 120 miles long.

In 1934-37 another channel was dug through the doab linking the Chenab at Trimmu to the Ravi at Sidhnai. It is called the Haveli Canal. It is 56 miles in length and carries about 5,250 cusecs of water. It is a lined canal.

In 1957-58, a new link canal called the Marala Ravi Link was completed. It follows an alignment in the Upper research of the doab and is designed to carry about 25,000 cusecs through a 63-mile long channel. It is a seasonal canal running only during the summer months.

Raya branch of the U.C.C., originally a non-perennial canal has now been widened to carry additional discharge required to feed the canals which were the branches of the Upper Bari Doab Canal and the Depalpur Canal. Due to location of the headworks of this canal in India, its branches in Pakistan are now to be fed by this link canal.

Recently in connection with the replacement works, waters of the Indus are to be brought to Sutlej to feed the Sutlej valley canals. There will thus be two feeder canals, one running parallel to the Haveli and the second running along the Upper Gugera Canal, a big branch of the Lower Chenab Canal. These additional canals are yet in the process of construction.

Ground-water Studies

The earliest ground-water levels recorded are from 1905 onward although some information from the year 1882, is also available. These observations were started by recording the water level in open wells. The region of Lower Chenab is crossed by well lines No. 1 to 14.

Similarly the zone of Upper Chenab Canal has a number of observation wells and the circle lines are marked from A to O. These cover the full length of the canal. This data also date from the year 1907, although the U.C.C. was opened in the year 1912-14.

The tail of the doab through which the Haveli Canal passes has also observation wells. These were started to be observed from 1915 although the canal passing through this area was dug in the year 1936-37.

In Fig. 8 are depicted the earliest ground-water contours as these existed in 1882. In the central region of the doab, water table was deeper than 90 ft. In the upper reaches of the Doab, the ground-water was at shallow depths so that in Pindi Bhattian, Chuharkana, Sangla Hill and Shahkot, the earliest recorded water table existed at 50 ft. Further upward in the doab now served by U.C.C., the ground-water was still closer to the surface being at a depth of 40 ft. only. The district of Sialkot being at the foot hills, has many rain water hilly streams, flowing through the region. These have caused a high ground-water which existed at 20 to 35 ft. below surface. The depth of ground-water close to the Haveli Canal near the confluence of the two rivers also existed at the same depth as that in Sialkot district.

The ground-water within the flooding regions was within 10 to 30 ft. below surface.

Slope of the Natural Surface and that of Ground-water

The slope of the natural surfaces of the Rechna Doab is about 1.6 ft. per mile. The ground-water slope in the Lyallpur Region before the construction of irrigation system was more than 2 ft. per mile. There was thus a tendency for the high ground-water close to the rivers to flow towards the deeper regions. Maybe, water had been flowing toward this depth and carrying away the soluble salts of the formation from the pre-irrigation times.

After the construction of the canals, the water table started to rise and till the level approached 40 or 45 ft. below surface the flow directions would have remained towards the deeper depths.

At the time of undertaking of the irrigation projects, the level of ground-water in the Upper reaches was at 40 to 50 ft. below surface. At this depth the sub-soil water slope being the same as that of the land, the possibility of flow into this region was not as much as into the deeper zones.

Rise of Ground-water after the introduction of Canal Irrigation

As soon as the L.C.C. was put in operation, all the wells located in its region started to show a rise of ground-water. The records of wells are available from 1905 onward, about 18 years after the canal had been opened, it is difficult to say about the earliest position of the ground-water. From 1905, all wells located in deeper regions away from the river spills started to show a rise of ground-water levels. This rise observed in 81 wells is shown in Table 9-A. The average rise per year was 1.40 ft. and it was for those wells which had water table deeper than 60 to 80 ft. In the other 122 wells which had water table at 60 to 30 ft. below surface, the rise as shown in Table 9-B was slightly less equal to 1.3 ft. per year. With ground-water at great depth, the gradient of ground-water being steep more in flow was expected. The rise from depth of 30 ft. and less was hardly 0.6 ft. per year. (*see* table 9). Wells with depths 10 ft. showed practically steady level, the rise being only 0.07 ft. per year. (Table 10).

A few typical ground-water rise curves are shown in Fig. 9.

Rise in the Region of the Rechna Doab served by U. C. C.

(*a*) *Condition of ground-water before the construction of the canal :* The data for this area also dates from 1905 onward, although the U. C. Canal was opened in the year 1912-14. A study of the records of wells from 1905 to 1914 showed that several of the wells were showing a rise of about 0.3 to 0.5 ft. per year (*see* table 11). The L.C.C. flows along the slope of the land and existed very far off. It could not have affected this rise. In the upper reaches of the Rechna Doab, there are several natural flood water streams. This rise may be a result of the retention of their water by rail and road constructions. The reason of excessive rainfall does not hold gr ound as at the time of opening the canal, the ground-water existed at 30 to 40 ft. below surface.

(*b*) *Condition of ground-water after the construction of the canal :* As soon as the U.C.C. was put in operation in 1912-14, a brisk rise of ground-water started in the whole of the region served by this canal. This rise close to the canal was about 2.2 ft. per year (*see* table 12). The well farther away from the canal rising from a depth of 15-18 ft. showed slightly less rise as shown in table 13. Maybe, the high order of rise of water table close to the canal was. a result of the combined effect of the infiltration from the canal and the obstruction casued to the flood water of the natural drains.

It was again noted that there was insignificant rise exhibited by wells which originally had water table at a depth of 10 ft. below surface (*see* table 14). Similar was the order of rise exhibited by wells located in the region of Haveli Canal. Construction of this canal had no modifying effect on the rise already exhibited by wells located in that region.

As a result of infiltration from canals and accumulation of water in the doab, the existing position of ground-water in the year 1955 is exhibited in Fig. 10. It may be noted that the similarity of rise of ground-water in the whole of the doab served by two different canals has some significance about the nature of sub-surface drainage. The similarity of the rate of rise in big canal area and smaller distributaries, in the region of deeper water and the shallower one, in the Thal, Chaj and Rechna Doabs, does suggest that the formation of the Indus plain is identical and affected the sub-soil flow in a similar manner.

TABLE 8B

L. C. Canal Rise of ground-water from 60 *to* 30 *ft. below surface. Period of Observation* 1905 *to* 1920-25

No. of Well Lines	3-4	5-8	9	10	11	13	14	9-14	Remarks
No. of wells Observed/ Mean rise in ft. per year	3/1.4	8/1.5	4/1.3	4/1.2	2/1.0	10/1.1	2/.7	14/1.0	Record of 122 wells gave an average rise of of 1.3 ft. per year.
	7/1.3	24/1.5	5/1.4	3/1.1	—	—	—	—	

TABLE 9

L. C. Canal. Rise of ground-water from 35-30 *ft. depth to* 20-15 *ft. depth below surface. Period of Observation* 1920 *to* 1945-50

No. of Well Lines	9	10	11	12	13	14	9-14	Remarks
No. of wells Observed/ mean rise in ft. per year	4/.75	3/0.6	9/.68	13/.5	10/.43	6/.73	42/.63	Record of 93 wells gave an average rise of 0.6 ft/year.
	2/.65	—	2/.7	—	—	2/.67	—	

TABLE 10

Rise of ground-water in the region of L. C. Canal. Rise of ground-water from 10.0 *ft. depth upward. Period variable from* 1905-1930 *to* 1955

No. of Well Lines	1-2	3-4	9	18	Remarks
No. of wells Observed/ mean rise in ft. per year.	7/.03	6/.04	3/.08	1/.09	42 wells which rising from 10 ft. upward showed an average rise of 0.04 ft. per year.
	7/.15	7/.05	—	1/.08	
	5/.04	5/.07	—	—	

TABLE 11

Rise of Ground-water in the Region of U.C.C. before the opening of the canal from 1907 *to* 1914 *from average of* 35 *ft. upward*

Well No.	J_8	L_3	EF_8	CC_3	H_6	H_2	J_5	G_6	H_5	K_7
Rise per year	0.3	0.31	0.43	0.43	0.43	0.43	0.60	1.03	0.63	0.60
Well No.	D_7	D_6	D_3	B_4	B_3	E_6	F_6	E_5	G_2	E_3
Rise per year	0.24	0.51	0.31	0.52	0.25	0.31	0.55	0.58	0.62	0.48

TABLE 12

Brisk Rise of Ground-water as soon as U. C. Canal was opened. The position of wells being close to the Canal. Year of observation is 1913 *to* 1920-23 *and depth* 30 *ft. upward*

Well No.	H_7	H_6	EE_8	CC_8	DD_7	DD_6	DD_3	B_4
Rise per year	1.62	1.70	1.60	1.06	2.10	2.75	2.92	2.55
Well No.	E_6	F_6	E_5	G_2	E_3	J_5	H_5	K_7
Rise per year	2.50	2.40	2.40	2.32	2.32	2.63	2.53	2.10

TABLE 13

Brisk rise of Ground-water as soon as U. C. Canal was opened. The position of wells being close to the canal. Year of Observation is 1913 *to* 1920-23 *and depth* 30 *ft. upward*

Well No.	H, H-A, J, J-A, K, K-A, L, M, N, O.			DD, E.F.G & H			AA, BB & CC.
Rise per year	23/1.25	23/1.26	23/0.75	11/1.60	11/1.60	11/1.40	13/1.00

TABLE 14

Rise of Ground-water from a depth of 10 *ft. in the region of U. C. Canal. Period of Observation* 1925 *to* 1955

Well No.	EE_8	H_7	H_6	9	7	7
Rise per year	0.06	0.075	0.05	0.088	0.062	0.125
Well No.	3	4	4	5	4	4
Rise per year	0.105	0.05	0.08	0.043	0.058	0.075

TABLE 15

Bari Doab. Rise in the region served by U.B.D. Canal. Period of Observation 1895 *and* 1920 *to* 1960. *Average rise in* 85 *to* 60 *years is* 0.28 *ft. per year. Water table rose from* 30-40 *ft. to* 15-20 *ft. below surface in part A and from* 15 *ft. to* 10 *ft. in part B*

No. of Well Line	XV	XVI	XVII	XVIII	XIX	XX	XXI
Part -A							
No. of wells observed/ rise in ft. per year.	—	5/.06	5/.04	—	5/.8	12/.2	8/.2
Part-B							
No. of wells observed/rise in ft. per year.	11/.03	11/.06	3/.04	8/.02	3/.04	—	—

No. of Well Lines	XXII	XXIII	XXIV	XXV	XXVI	Remarks
Part-A						
No. of wells observed/rise in ft. per year.	7/.3	5/.2	3/.2	2/.2	4/.4	56 wells gave an average rise of 0.283 ft/year.
Part-B						
No. of wells observed/rise in ft. per year.	—	—	—	—	—	36 wells gave an average rise of 0.05 ft. per year.

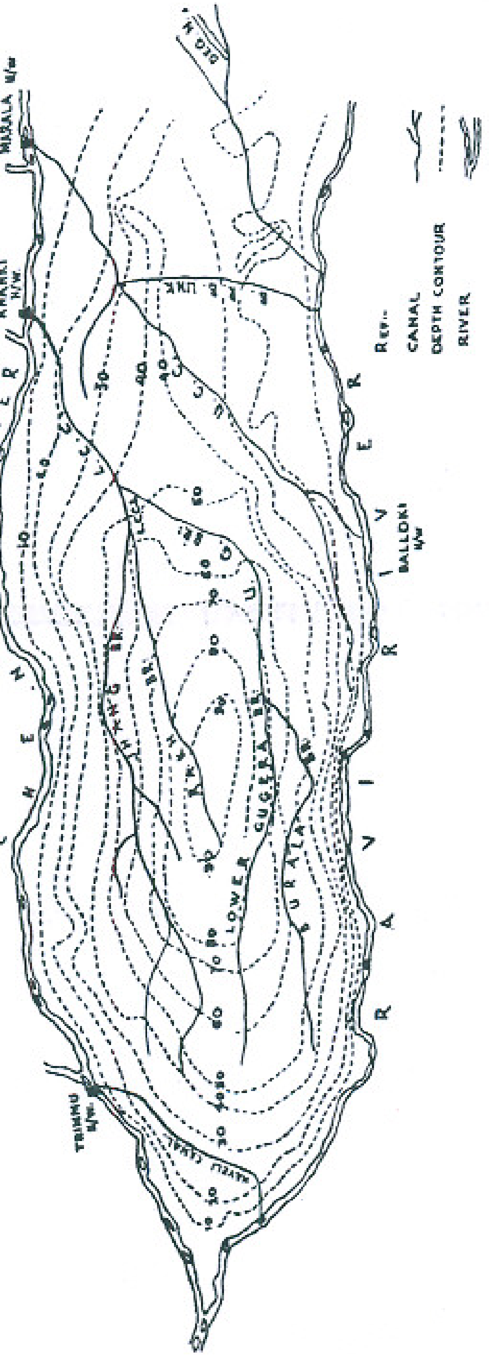


FIG. 8.
RECHNA DOAB
WATER TABLE CONTOURS
1882

Fig. 9

RISE OF GROUND WATER IN SELECTED WELLS OF RACHNA DOAB

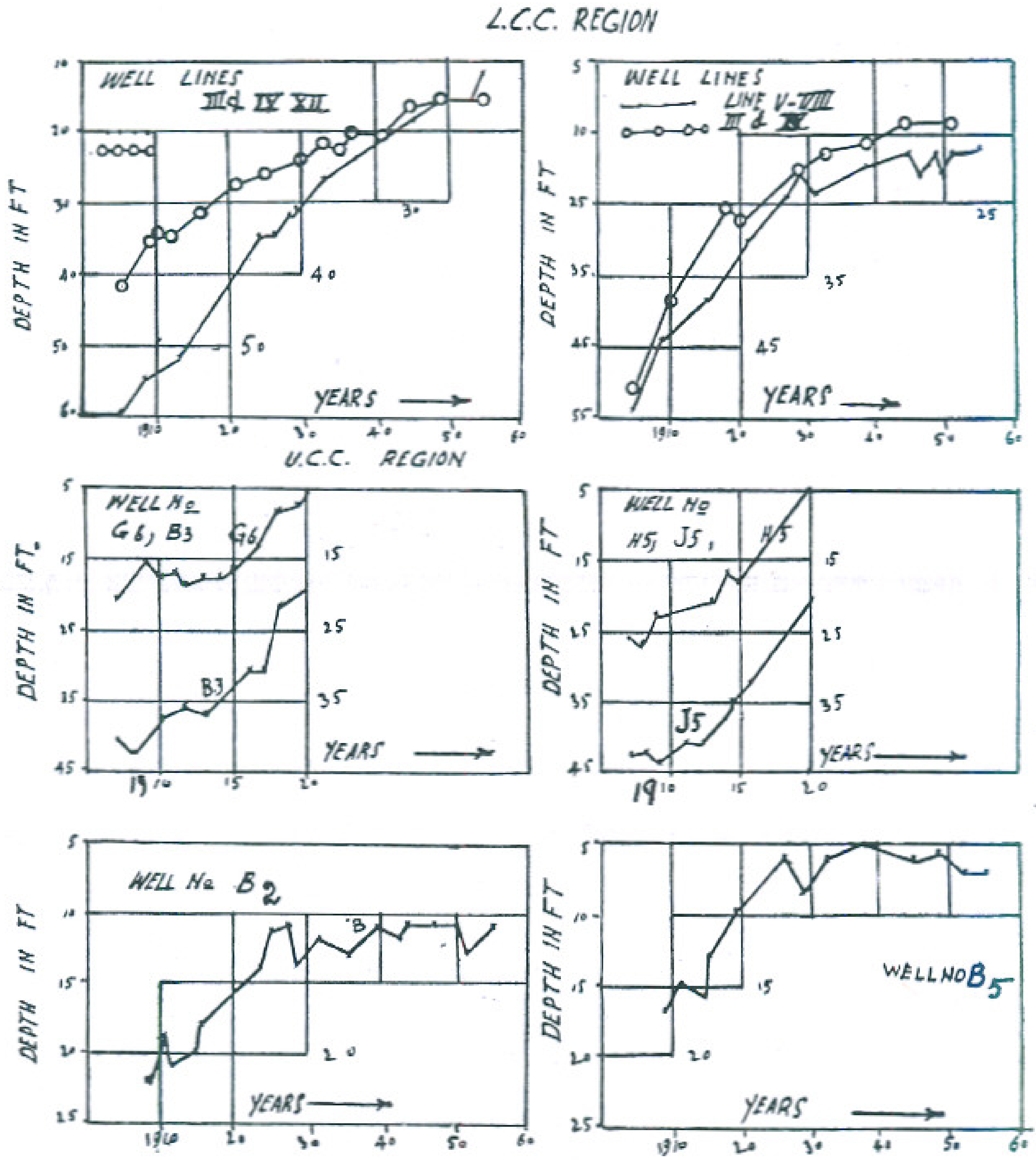
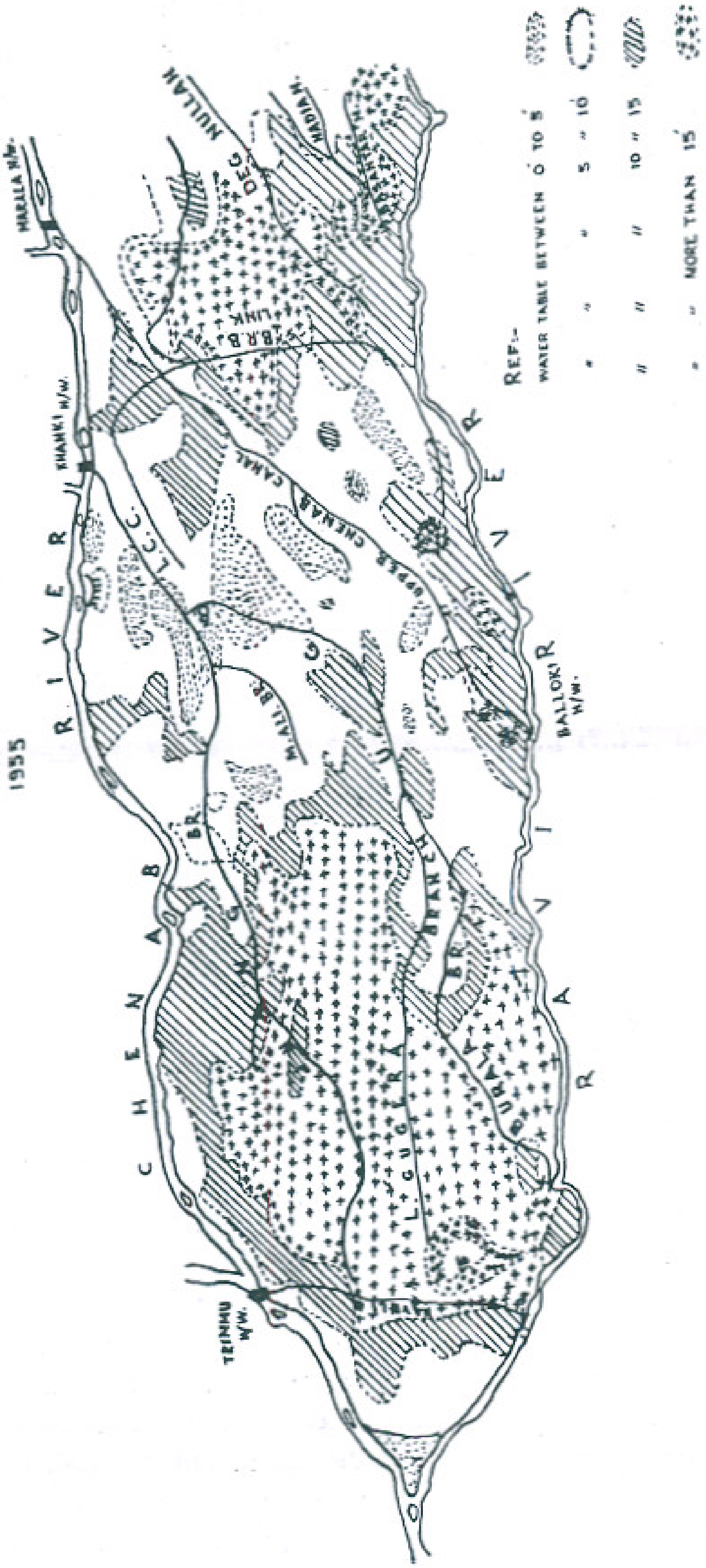


Fig- 10.
RECHNA DOAB
WATER TABLE CONTOURS
1955



BARI DOAB, ITS EXTENT

This is the 4th doab, ground-water studies for which have been carried out. This doab is enclosed between the Ravi in the north and the Sutlej in the south. It constitutes about 11,000 sq. miles. The length of the portion of the doab existing in Pakistan is 276 miles and the width which is more or less uniform, is 52 miles. It gives an approximate gross area equal to 7.06 m. acres. In fact it is a combination of two doabs. A few centuries back river Beas used to flow through the middle of this doab. Its old abandoned course is now occupied by the Rohi Nullah. At present Beas meets the Sutlej much upstream and exists in India.

Another feature of this doab is that the portion in Pakistan is not the foot hill region like the rest of the three doabs. A considerable flat land lies beyond the boundaries of Pakistan.

This doab has six different canal systems opened at different periods. These are given below :

Name of irrigation canal	Year of opening	Capacity of canal at Head	Gross area irrigated in 1000 acres
Branches of Upper Bari Doab ..	1857-61	6,900	704
Sidhnai Canal fed by Haveli Canal.	1886—1938	5,242	1,123
Lower Bari Doab Canal ..	1913-16	7,000	1,822
Depalpur Canal ..	1933	6,950	1,045
Pakpattan Canal ..	1933	6,594	1,396
Mailsi Canal ..	1933	4,883	751
Total ..		30,669	6,841

(not including Central Bari Doab Canal).

The northern 0.704 m. acres are irrigated by branches of Upper Bari Doab Canal. These started receiving irrigation after the opening of the canal in 1857.

Sidhnai canal was opened in 1886 but it always suffered from acute shortage of water. It started to get the required supplies after the construction of Haveli Canal which delivered practically its whole discharge of 5000 cusecs at the Sidhnai Headworks to feed the canal. In 1913-16, Lower Bari Doab Canal started flowing after the completion of triple canal project. In fact it received its supplies from Marala through Upper Chenab Canal. This canal delivery is 7,000 cusecs to irrigate 1.822 m. acres of land lying along the Ravi.

None of its branches cross over the old bed of the Beas. The area of the doab along the Sutlej was brought under irrigation by Sutlej Valley canals. These are, the Depalpur, the Pakpattan and the Mailsi. These are taken out from the right bank of the Sutlej from the three Headworks, namely, Ferozepur, Suleimanki and Islam. The capacity of these canals irrigating 6.84 m. acres is 31,000 cusecs although during winter, the Sutlej Valley canals have always suffered from shortage of water. The Sutlej Valley canals irrigate area along the Sutlej and their branches do not cross the Rohi Nullah.

Ground-water studies

In figure 11 the earliest known ground-water depth contours are plotted. Except for the areas very close to the influence of the two rivers, in the northern region of the doab and along the rivers within their spill zones, the ground-water was very deep. At the deepest point, the water was 70 ft. below surface and a stretch of about 180 miles long and 30 miles wide had water table deeper than 40 ft. All along the rivers there was a very steep gradient of the order of 4 ft. per mile in the central region of the doab. The slope of the doab is about 1.6 ft. per mile so that before irrigation there existed a tendency for the seepage water from the rivers to flow into the deeper regions and perhaps to take the soluble salts into this zone.

Records of Ground-water after the imposition of Irrigation

(*a*) *Upper Bari Doab Canal Zone* :

In this doab there are as many systems of well lines as are the canals. The earliest canal was the Upper Bari Doab Canal and the ground-water records for the area irrigated by it, are available since 1895. There are number of circle well lines of the canal which cross the area lying in Pakistan. These lines of wells are numbered 15 to 26. Each line has 10 to 16 wells so that quite an extensive records are available for the area.

In 1897, in the northern region irrigated by this canal the water table existed 10 to 15 ft. below surfaces. In the tail end of the distributaries, the ground-water was 25 to 40 ft. deep. A study of the known records of individual wells of each line was carried out. In case of wells which originally had water table at 25 to 40 ft. during 65 years of the operation of the canal, the water has come up to 11 or 25 ft. of the surface.

This rise observed in 56 wells of ten lines of wells is shown in table 15-*a*. It is hardly 0.28 ft. per year.

In the next table 15-*b* the rise from shallow depth is shown. This gives a record of 36 wells located along five well lines. Their original water was at 12 to 20 ft. below surface. In forty or fifty years it has risen only 2.0 ft., rising at the rate of 0.05 ft. per year.

(*b*) *Haveli Canal Circle*

The region served by Sidhnai Canal is included under Haveli Canal Circle. There are eight circle lines which cross the area served by Sidhnai Canal. The available data is from 1920 onward. In this year the water table existed at about 27 ft. below surface. During 40 years, it has come up to 17 ft. from surface rising at the rate of 0.3 ft. per year. The average rise of the well is shown in table 16.

(*c*) *Lower Bari Doab Canal*

This canal was opened in 1916. The data are available from 1920. At the time of the opening of the canal, ground-water in a vast region of the canal, existed at 30 to 45 ft. below surface. The records show that from 1920 to 1940, the water table has risen by 20 ft. The areas close to canal showed a higher rise than those farther off.

In table 17-*a* data of rise of ground-water are shown. Wells lines passing through the region were No. I to XIX. These wells exist above the Rohi Nullah. The average rise in the first 20 years was about 1.04 ft. per year. The initial depths recorded in many wells was below 40 ft. and in 20 years it has come up to 22 ft. below surface.

In table 17-*b* data of those wells are shown in which the original water depth was at 30 ft. and during 30 years the water has come up to 15 or 20 ft. below surface. The average rise per year was less than half a foot.

It is true, stability has not yet been attained and, maybe, the water table will continue to rise yet at a very slow rate. Some of the wells having water-table less than 20 ft. has given a rise of only 0.23 ft. during 20 years of the operation of the canal (*see* table 17-*c*).

(*d*) *Dipalpur Canal Circle*

This canal takes off from Ferozepur Headworks and irrigates area lying in between the Rohri Nullah and the Sutlej. It thus irrigates the southern half of the doab whereas the northern half is irrigated by the Lower Bari Doab Canal.

Circle well lines II to X cover a portion of the land up to the beginning of the Pakpattan Canal taken out of the Sutlej at Suleimanki. Dipalpur Circle lines from X to XVII cover a portion of this canal also. After this circle well lines of Lower Bari Doab from 12 to 18 cover another portion of Pakpattan Canal.

Uptill well line No. IX, the data of ground-water records are shown in table 18. A study of this table shows that in 1920 at the time of opening of the canal, the water table existed at 15 to 20 ft. below surface. During 20 to 40 years of the operation of the canal, the rise has generally been from 0.1 to 0.3 foot per year, so that the present water table in vast areas lies at 8 to 15 ft.

below surface. During 40 years it has risen by 4 to 10 ft. only.

(*e*) *Nili Bar Circle*

This circle covers the area served by tail of Pakpattan Canal and the Mailsi Canal. In this study data of well lines No. 25 to 29 are considered. In table 19-*a* and *b* which give the observed records of 32 wells from 1940 to 1960, the rise per year has been 0.25 ft. although the water table existed at 22 ft. in 1940 and now after 20 years, it lies at 18 ft. below surface.

In the second table 19-*b*, records of those wells are shown which had shallow water table at 12 ft. below surface and in 20 years the rise had been only 2.0 ft.

The present position of ground-water in this doab is shown in Fig. 12. After several years of irrigation, the position of ground-water is not as serious as in the rest of the doabs. After a study of this section it is concluded that:

(*i*) In Bari Doab six canals were opened at different periods, so that no one single canal served the whole area of 7.0 m. acres.

(*ii*) The earliest ground-water before irrigation existed at 50 to 70 ft. below surface and both the rivers were probably the regular source of feeding into the deeper regions.

(*iii*) The records for the region served by the Upper Bari Doab Canal are available since 1895. At that time ground-water existed at 15 to 40 ft. below surface. Even after sixty-five years of irrigation, the ground-water is still deeper than 10 to 15 ft.

(*iv*) The opening of Sidhnai Canal and even after its feeding by the Haveli Canal, there was an insignificant rise in ground-water in the area served by this canal.

(*v*) The opening of Lower Bari Doab in 1916 caused a brisk rise of ground-water in the zone served by the canal. The rise was at the rate of a foot per year. The rise took place from depths more than 40 ft. and in 20 years, came up within 20 to 25 ft. of surface. During the last 40 years of irrigation, water table still existed at 10—15 ft. below surface in this area.

(*vi*) The openig of Dipalpur, Pakpattan and Mailsi canals, did not cause quick rise in the ground-water.

(*vii*) The slow rate of rise in the doab can be attributed, mainly to the thick and relatively impervious soil crust which exist generally in this doab. As an alternative, one can argue about the free drainage of the underground formation of this doab. At present it is difficult to disprove it but it cannot be an exception to the general nature of the Indus plains.

(*vii*) In this doab unlike the other two doabs, the ground-water salinity is not exactly in the middle of the doab. It exists in big patches. In fact the doab has been under changing sub-soil flow conditions. The present Rohi Nallah is the old bed of the Beas and as a result of infiltration from this river the saline water should have accumulated in between the region of the Ravi and the Beas and in the second doab formed by the Beas and the Sutlej. After the shifting of the Beas, the sub-soil flow pattern might have changed the location of the salinity in the ground-water as it exists now.

TABLE 16

Bari Doab, Sidhnai Canal Region. Period of observation earliest 1920 *and latest* 1960, *Depth earliest* 25-30 *ft. Depth present* 15-20 *ft. Mean rise in* 37 *wells of* 8 *wells line is* 0.29 *ft. per year*

No. of Well Lines	I	II	III	IV	V
No. of wells/rise per year.	6/.25	4/.25	5/.42	6/.42	4/.27

No. of Well Lines	VI	VII	VIII	Remarks
No. of wells/rise per year.	5/.42	3/.2	4/.07	Rise per year is 0.29 ft.

TABLE 17

Bari Doab. Rise in region served by L. B. D. Canal. Period of Observation earliest 1920, *latest* 1940 *for rise from deeper depth (part A) and* 1940-60 *for shallow depth (part B). Deeper water started to rise from* 45-50 *ft. and shallow from* 25-28 *ft. In part C, with original level at length* 20 *ft., and the period of rise from* 1920-40 *to* 1960.

No. of Well Lines	I	II	III	IV	V	VI	VII	VIII	IX
Part-A									
No. of wells/rise per year.	1/.6	2/1.4	2/.8	3/1.4	3/1.2	4/1.6	4/1.2	6/1.4	4/.6
Part-B									
No. of wells/rise per year.	—	—	1/.6	1/.25	2/.5	2/.9	2/.8	5/.3	1/.4
Part-C									
No. of wells/ rise per year.	1/.07	2/.15	1/.15	1/.2	2/.4	2/.25	2/.2	2/.05	1./05

No. of Well Lines	X	XI	XII	XIII	XIV	XV	Remarks
Part-A							
No. of well/rise per year.	4/.8	2/.8	4/1.3	3/.4	2/1.1	3/1.1	15 wells gave an average rise 1.04 ft. per year.
Part-B							
No. of wells/rise per year.	6/.3	3/.5	5/.4	3/.9	1/1.1	11/.15	30 wells gave an average rise of 0.47 ft. per year.
Part-C							
No. of wells/rise per year.	3/.2	3/.25	2/.4	1/.8	1/.08	1/.07	33 wells gave an average rise of 0.23 ft. per year.

TABLE 18

Bari Doab. Rise of Ground-water in region served by Depalpur Canal. Rise recorded from 1920 *to* 1960. *Wells considered* 108. *Average rise per year* 0.29 *ft.*

No. of Well Lines	I	II	III	IV	V	VI	VII	VIII
No. of wells/rise per year.	9/0.2	5/.12	8/.02	11/.12	6/.09	8/.12	8/.2	9/.15

No. of Well Lines	IX	X	XI	XII	XIII	Remarks
No. of wells/rise per year.	9/.03	7/.25	11/.6	7/.4	10/.5	Total wells 108. Rise per year 0.29 ft.

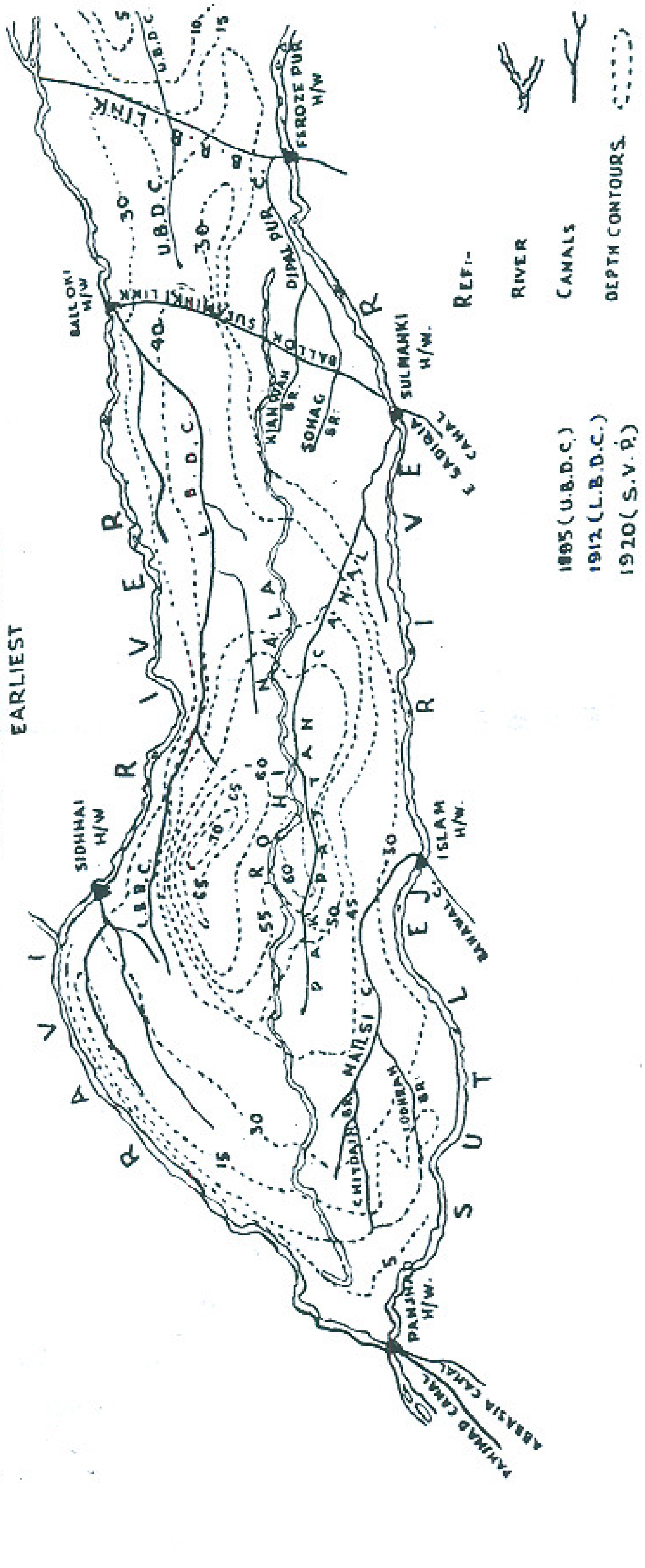
TABLE 19

Bari Doab. Rise of Ground-water in area served by Mailsi and Pakpattan Canals 'Nilli Bar Circle'. Initial depth in 1940 *for part-A was* 20-25 *ft. and for B at* 15 *ft. and final depth in* 1960 *for A at* 18-20 *ft. and for B* 10-11 *ft.*

No. of Well Lines	XIV	XXV	XXVI	XXVII	XXVII	XXVIII	A	B
Part A								
No. of wells/rise per year.	2/.25	11/.25	9/.2	3/.2	5/.56	—	—	—
Part B								
No. of wells/rise per year.	—	—	—	3/.05	5/.1	3/.15	5/.15	2/.15

No. of Well Lines	C	XXIX	A	B	C	Remarks
Part A						
No. of wells/rise per year.	—	—	—	—	2/.05	Part-A for wells with Ground-water at 20-25 ft. depth and average rise 0.25 ft. per year.
Part B						
No. of wells/rise per year.	3/.15	1/.2	1/.2	2/.15	2/.15	Part-B for wells with Ground-water at 18-20 ft. and rise per year equal to 0.13 ft.

FIG-11
BARI DOAB
WATER TABLE CONTOURS
EARLIEST



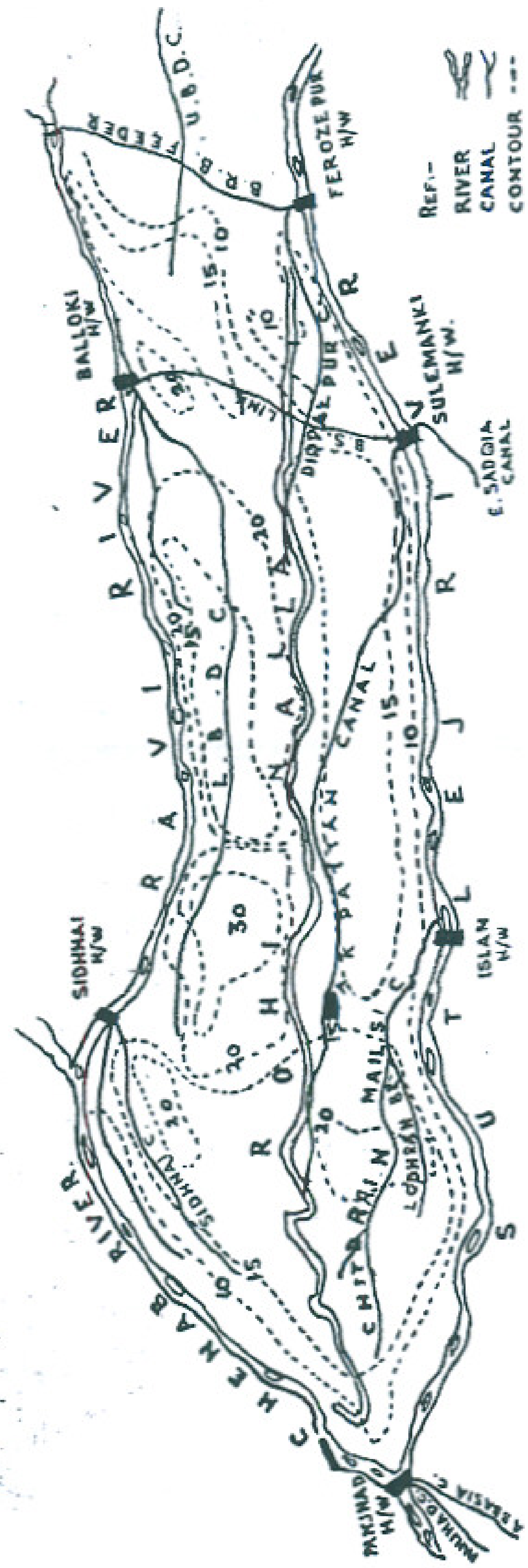


Fig. 12.
BARI DOAB
WATER TABLE CONTOURS
1960

MAIN CONCLUSIONS OF THE STUDY

The rise in ground-water in the Ex-Punjab and Bahawalpur regions has been studied since the canal irrigation was introduced. The rise in each doab has been a characteristic of the canal irrigation system and the nature of the land surface, its extent and its original ground-water level. The common features noticed in all areas are that :

(*i*) After the introduction of canal irrigation, ground-water, from a depth of 30 ft. and more, rose at the rate of 1.0 to 1.7 ft. per year.

The ground-water from a depth between 15 to 30 ft. rose at the rate of 0.3 to 0.7 ft. per year.

If ground-water was less than 10 ft. deep then it rose at the rate of 0.1 ft. per year. At a depth of 5.0 ft., the ground-water stabilized showing only seasonal fluctuations.

(*ii*) Rise of water in one doab served by a given canal system has been of the same order in extensive area. Deeper regions have not shown in general greater rise, the exception being those doabs in which the ground-water was so deep as to give a steeper gradient as compared to the natural surface slope. As soon as the gradient was reversed with the rise of water table, the water started rising in the area as a whole.

(*iii*) Canal irrigation in one doab resulting in rise of ground-water has not affected the ground-water of the adjoining doabs. May-be, the rivers have been working as moisture piles and do not allow high ground-water of one doab to move to the adjacent doab having deeper ground-water.

(*iv*) Rise in ground-water in Upper regions of a doab has not affected the rate of rise of ground-water in the lower regions, proving thereby insignificant underground flow.

(*v*) Obstruction to the natural drainage of streams and Nullahs by rail, roads and other developments, resulting in longer detention of the flood water, or by the imposition of canal crossing the doab, like U.J.C. has caused a rise in ground-water even before the introduction of canal irrigation. This rise has generally been in areas below foot hills such as those of Thal, Chaj and Rechna Doabs.

(*vi*) In certain cases the sub-soil water gradient between river water and the water of the deeper regions was more than the natural surface slope. This could cause infiltration into the deeper regions. It was possible in Chaj, Rechna and Bari Doabs, so that this flow washed the soluble salts in the deeper regions, raising their conductivity sometimes above that of the sea water. Such conditions existed before development of irrigation, so that the salts of the flood plains seem to have been washed down into the deeper regions having steep gradient of ground-water. Chaj Doab possessed the steepest sub-soil water gradient, followed by Rechna and Bari Doabs.

In case of Thal, the salinity in the northern area seems to be a result of infiltration from the salt range and washing of formation from Indus towards the Jhelum. In its south the saline zone is a result of washing of salts from the flood plains of the two rivers. Deep ground-water of Thal, did not possess such a sub-soil gradient as to accumulate the infiltering water into the deeper regions.

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Bibliography

1. Nazir Ahmad, Dewan Ali and Afaq Ahmad, "A new conception on the waterlogging and salinity problems of Rechna Doab." West Pakistan Eng. Congress (Symposium on waterlogging and salinity in West Pakistan Feb. 1959).
2. Wasid, Data release Vol. 24 No. 5, 1962.