SOME PROBLEMS OF GROUNDWATER RESOURCES OF WEST PAKISTAN

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SYNOPSIS

Large-scale utilization of groundwater is being planned in West Pakistan. It is envisaged to pump out about 43 *maf. of groundwater by* 1985 *in addition to our present usage of about* 41 *maf. by crops from the* 83.5 *maf. of surface water diversions.*

At present (1969) *about* 20 *maf. of water is being pumped out. More than half of it is being exploited by tubewells installed by farmers.*

In this paper, based upon certain meteorological assumptions, the life of the formation of the Indus plains has been estimated and some ideas about the accumulation and movement of salts in soils has been put forth. It has been explained that centuries of salts accumulation from the river water was washed away into certain pockets which have been kept in position under the pressure of fresh water from all sides.

The origin of the existing saline water is explained and the causes for its accumulation, only in certain regions, are put forth.

It is pointed out, in the end, that the present planning of groundwater exploitation needs a careful review, otherwise there is every possibility to add more salts on our lands and saline water moving into zones of fresh water.

An Estimate of Water being Utilized for Irrigation

Large-scale utilization of groundwater is being undertaken in West Pakistan. The local farmers have discovered the advantages of pumping groundwater by cheap type of tubewells to increase their yields of crops. Foothill areas of Sialkot and Gujrat which used to depend only on rain or open wells now use large volume of pumped out groundwater. Riverine areas along the main rivers which had not been provided with irrigation canals or where the canals were non-perennial, are now being irrigated by tubewells of the farmers or those of Irrigation Department. Wapda is undertaking large-scale reclamation and drainage schemes, by pumping out groundwater in the canal irrigated areas. Actually large-scale exploitation of groundwater has now started.

The total surface water resources of West Pakistan from its present (before 1970) potentials of 164.5* (or 167.0)† maf. will be reduced[I a, b] to 140* (142)† maf. by 1970 as a result of water treaty with India.

At present after nearly 90 years of efforts, we have succeeded to divert about 83.5* (79.0)† maf. of water from the rivers to irrigate about 25 million acres of land.

The climatic conditions of the area permit double cropping, both during the summer season (Kharif) and the winter season (Rabi) but the water diverted is sufficient for about 25 per cent cropping intensity during Kharif and 50 per cent during Rabi, in all 75 per cent cropping intensity per year, though with the modern utilization of fertilizers and mechanical cultivation, cropping intensity can be raised to 150 per cent.

The greatest handicap has always been the shortage of water. At present out of total diversion of 83.5* (79.0)† maf. hardly 41* (54)† maf. is utilized by crops.

Even when we succeed to use more water from Mangla and Tarbela Dams, the diversion will reach about 90* (85)† maf., the crop utilization will increase to 58.2* (65)† malf. which will include beside surface diversion of 90* (85)† maf. about 26.9* (30.0)† maf. withdrawn from groundwater.

These estimates of water resources are due to Harza Master Plan and of World Bank Consultants. The details of the estimates of the two organizations can be seen in Table 1.

After 1970 when nearly 27 to 30 maf. will be pumped out from the ground water resources, and which being less subjected to conveyance losses, will increase the volume of water for use of crops. Thus a large utilization of groundwater resources is to be developed in a very short period much less than that it has taken to divert 83.5 maf. from surface resources.

Groundwater being Utilized at Present

There are different estimates of the total number of private tubewells in operation as installed by the farmers. In Table 2, a districtwise estimate of tubewells on the basis of data collected by Pakistan Developing Economics, is put forth.

In the sixteen districts of the Punjab nearly 53,000 tubewells were found in operation by 1967. At the end of 1968, this number was estimated to have reached above 60,000 tubewells.

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*Harza's estimate.

†World Bank Consultants estimate.

TABLE No. 1.—*Water budget in canal commanded areas. All values in maf.*

Items	Harza Master Plan	World Bank Group	Harza Master Plan	World Bank Group
River Balance	Before 1970		After 1970	
Total surface water supply ..	164.5	167	140.0	142
Net percolation to groundwater ..	−4.0	−6.0	−3.1	−19.0
Other losses ..	−16.1	−6.0	−11.9	
Drainage return to rivers ..	..	..	5.0	1.0
Flow to Arabian Sea ..	−60.9	−76.0	−39.9	−39.0
Total surface water diversion ..	83.5	79.0	90.1	85.0
Canal Balance (incl. W/course)				
Total surface water diversion ..	83.5	79.0	90.1	85.0
Pumpage from groundwater ..	2.0	10.0	26.9	30.0
Evaporation losses ..	−8.0	−8.0	−10.2	−22.0
Percolation to groundwater ..	−23.0	−20.0	−28.6	
Total delivery to farms ..	54.5	61.0	78.2	93.0
Farm Irrigation Balance				
Total delivery to farms ..	54.5	61.0	78.2	93.0
Surface losses ..	−5.4	−6.0	−8.0	−35.0
Percolation to groundwater ..	−8.2	−7.0	−12.0	
Rainfall contribution ..	..	6.2	..	7.0
Net crop use ..	40.9	54.0	58.2	65.0
Groundwater Balance Recharge to Aquifer				
Percolation from rivers and canal systems ..	35.2	33.0	43.7	..
From rainfall ..	1.2	..	2.5	..
Total inflow to groundwater ..	36.4	33.0	46.2	49.0
Discharge from aquifer ..	2.0	10.0	31.9	30.0
Balance ..	34.4	23.0	14.3	19.0

TABLE No. 2.—*Number of private Tubewells installed by Farmers up to 1967, data compiled by Pakistan Development Review.*

S. No.	District	Tubewell run by		Total
		Electric	Diesel	
1.	Multan ..	1870	8080	9950
2.	Sahiwal ..	2920	6660	9580
3.	Gujranwala ..	3200	4150	7350
4.	Sialkot ..	1150	3520	4670
5.	Lahore ..	2460	1120	3580
6.	Jhang ..	1450	1820	3270
7.	Lyallpur ..	1080	2100	3180
8.	Rahimyar Khan ..	130	1050	1180
9.	Sheikhupura	420	970	1390
10.	Muzaffargarh ..	140	1020	1160
11.	Gujrat ..	750	570	1320
12.	Bahawalpur ..	340	890	1230
13.	Mianwali ..	390	300	690
14.	D. G. Khan ..	10	630	640
15.	Bahawalnagar ..	60	490	550
16.	Sargodha ..	460	300	760
17.	Other Districts ..	1170	1330	2500
	Total for the Northern area of W. Pakistan. ..	18000	35000	53000

At present full data about the capacity and efficiency of operation of these wells are unknown. Nearly two-third of the tubewells operate on diesel. With the increase in number of tubewells the tendency of selling water to neighbours is decreasing. With these considerations it is assumed that the average yield of these tubewells is 0.75 cusec and these operate at 30% efficiency. According to these assumptions about 9.5 maf. of ground water is being withdrawn by the farmers' tubewells up to the year 1968.

Wapda is installing tubewells for its reclamation and salinity projects. The schemes which have been approved to be instituted giving the number of tubewells and their pumpage capacity is given in Table 3.

TABLE 3

Scarp No.		No. of Tubewells.	Capacity provided, maf.	Capacity proposed to be utilized, maf.
1.		2040	4.2	2.50
2.		3311	6.6 (9255.5 cus).	3.96
3.		1550	4.3 (6100 cus.)	1.34 (1868 cus.)
4.		3273	9.29 (13103 cus.)	4.11 (5754 cus.)
5.	(*a*)	1876	5.29 (7412 cus.)	2.95 (4130 cus.)
	(*b*)	418	1.0 (1350 cus.)	0.64 (1896 cus.)
Khairpur		572	1.13 (1589 cus.)	0.379 (530.8 cus)
Rohri North		1196	2.90 (4053 cus.)	2.68 (3758 cus.)
Total		14236	34.71	19.36

According to the proposals for development of groundwater as put-forth by the World Bank Consultants, Wapda will instal 8138 tubewells in its four ongoing schemes of scarps *i.e.*,

2830 Tubewells in Scarp No. 2.
1470 Tubewells in Scarp No. 3.
3270 Tubewells in Scarp No. 4, and
568 tubewells in Khairpur.

It is also proposed to instal 11403 more tubewells in twelve new schemes. Thus by the end of the fourth plan, 14541 tubewells will be in operation. These additional (11403) tubewells will have 36980 cusecs installed capacity.

The estimate of World Bank Consultants for the number of public and private tubewells and their pumpage capacity up to the year 2000 is given in Tables 4 and 5.

TABLE 4

	1965	1970	1975	1980	1985	2000
Public Tubewells						
Usable groundwater area	2900	9600	20200	32200	34300	35000
Saline groundwater area	Nil	Nil	500	4500	9800	15000
Total	2900	9600	20700	36700	44100	50000
Private Tubewells						
Canal commanded area	29000	46500	38000	3000	Nil	Nil
Outside area ..	5000	9000	14000	20000	25000	25000
Total private tubewells	34000	55500	52000	23000	25000	25000

TABLE 5.—*Estimate of groundwater development in maf.*

	1965	1970	1975	1985	2000
Canal Commanded area					
Public Tubewells ..	2.7	10.0	22.0	36.53	44.00
Private Tubewells ..	5.3	8.0	7.0	3.5	Nil
Persian-wheel ..	1.7	1.0	1.0	Nil	Nil
Outside area private Tubewells	1.0	1.8	1.8	2.8	5.0
Total ..	10.7	20.8	31.8	42.8	49.0

Thus the Consultants have estimated the utilization of about 10.0 maf. of groundwater by Public Tubewells by 1970. At present about 6.0 maf. is being utilized which is made up of 2.5 maf. in Scarp-1, 3.00 maf. for Scarp-2 and about 0.38 maf. from Khairpur area. The private tubewells by 1970 will pump out about 9.8 maf.

Irrigation Department Utilization of Groundwater

Irrigation Department started its programme of Tubewell installation in 1938 when 20 tubewells of Karol Project were completed. A big scheme of Irrigation Branch tubewells was undertaken in 1945 under the name of Rasul Project when 1525 tubewells were installed by 1951 and put into operation by 1954. The department has been installing tubewells for land reclamation schemes as prepared by Soil Reclamation Board. Such schemes were called Chuharkana, Jaranwala, Chichokimallian, Pindibhattian, Central Rechna, Shahkot Tubewells etc. These tubewells have since been taken over by Land and Water Management Board under its operational charge of Scarp No. 1.

A few minor schemes such as Border Area Tubewells, Dera Ismail Khan Tubewells, Haripur Area Tubewells have also been installed by the Irrigation Department.

Recently, Irrigation Department has moved in the riverine and non-perennial areas to pump water for the grow-more-food schemes. Actually at present Irrigation Department is operating nearly 2137 tubewells as per details given in Table 6. These tubewells pump about 2200 cusecs and at 60 per cent efficiency of operation withdraw about 1 maf. of groundwater.

Utilization of Groundwater for Human Consumption

In all big cities one can see utilization of groundwater for human consumption; but its quantity is insignificant as compared to that being used for crops. For instance, in the city of Lahore, consumption of water per day per person is hardly thirty gallons. If we assume 5 cu. ft. of water used by a person per day then a population of 1500000 uses about 90 cusecs of water. The requirements of smaller cities are much less and those living in the villages hardly require a cu. ft. of water per day per person. Thus the groundwater being utilized by a population of 50 million is hardly one maf. These figures have been put forth to give an idea of the present utilization of groundwater.

TABLE No. 6.—*Present output of Irrigation Tubewells in Pakistan*

S. No.	Name of Scheme	No. of T/Wells	Present Discharge in cusecs.
1.	Rasul Scheme ..	1334	825
2.	D. I. Khan ..	83	118
3.	Mianwali Riverine Scheme ..	90	160
4.	Border area (Batapur) ..	92	130
5.	Islam Qaim Scheme ..	25	37
6.	Niazbeg, Jalleke and Thatti Minor ..	88	58
7.	Multan Grow-More-Food	58	84
8.	Halla Scheme ..	30	52
9.	Campbellpur Scheme ..	15	30
10.	Haripur Scheme ..	6	10
11.	Central Project (along drains, Sheikhupura Sub-Division) ..	135	270
11*a*.	Multan Grow More Scheme No. VIII ..	25	37
12.	Bet area T/Well Project ..	18	30
13.	U/S Marala H/W Tubewell Project ..	18	36
14.	D/S Marala H/W Tubewell Project ..	28	56
15.	Depalpur Disty Tail ..	20	38
16.	Jatri T/Well Project ..	15	30
17.	Narowal T/Well Project ..	20	15
18.	Bucharkhana T/Well Project ..	12	25
19.	Sailab area T/Well Project on the right bank of River Sutlej ..	18	36
20.	Mopalke T/Well Project ..	19	38
21.	Hassanabdal Haripur Road ..	30	45
22.	Right Bank of Kabul River ..	8	10
23.	Left ,, ,, ,, ..	5	5
	Total ..	2137	2193

Present Withdrawals from Groundwater Resources

The following is the present estimate of utilization of groundwater by different agencies :

Agency		Water being withdrawn in maf.
Private Tubewells	..	9.8
Wapda Tubewells	..	6.0
Irrigation Department Tubewells	..	1.0
Public Health Tubewells	..	1.0
Persian-wheels	..	1.0
Total	..	18.8

Thus at present about 20 maf. of groundwater is being utilized and there is ample scope for further development of usable groundwater.

Building of the Groundwater Resources

According to the geological history of Indo-Pakistan, sea existed in the area now constituting the plains of the Indus and the Ganges. The sea extended up to Attock. In the present Punjab area its bed was formed of ridges being the extension of Aravalli mountains of India. At places the depth of bed rocks was more than 10,000 ft. A few out crops extended above the level of the sea. These were the tops of the buried mountains which are still visible at Shahkot, Sangla Hill, Chiniot and Kirania hills.

It is said that a huge river of geological times originated near the present Assam and flowed all along the foot of the Himalayas. This river is now sometimes called the Swalik, after the hilly formation of the same name. It was more than 1500 miles in length and received large volumes of water, drained out from the mighty Himalayas. The debris and the alluvium brought down from the mountains were transported and deposited in the sea, where this river discharged its water.

Many geological changes must have occurred in the area. One of the important changes was the eruption of Potwar Plateau and the formation of the Salt Ranges. The great Swalik river ultimately split up into several big and small streams, some discharging into the sea where now exists West Pakistan, and others in the sea of the Rajputana area and yet others discharged into the sea where now exist Uttar Pardesh, Bihar and Bengal Provinces and East Pakistan.

Just a few million years ago the mighty Himalayan rivers built up the lands of West Pakistan, East Punjab (India) and Rajputana. The land formation below the salt range, above the elevation of sea, seems to have been formed under similar conditions as exist at present. No doubt there must have been several geological and meteorological changes but the similarity of the deposits having only clay, silt and medium sand, up to a depth of 1000 feet and in some cases up to the bed rocks, point out that the alluvium depositions took place under very similar conditions as exist now. One can assume that at least for some lakh years ago the climatic conditions resulting in the discharge of water and the carriage of sediment might have been nearly similar to as exist now. The deposition of sediment started in the sea reservoir. The boring carried out now up to bed rocks shows deposits of clay at the rocks. These got covered by later deposits of sandy materials. Once the land appeared above the elevation of the sea, it was built up by river spills, by their shifting and meandering action on the flat plains. The land building in the delta area of East Pakistan is a good example of the land formation of the Indus Plains.

How Long it took to Fill the Reservoir

The uniformity and similarity of the alluvium deposits in the vast plains of the Indus, can suggest that the building of the formation took place under identical conditions as they exist now. No doubt during the several million years in which the vast Indus Plains have formed many changes in natural streams must have taken place but similarity of conditions of deposits suggest that the discharge and sediment inflow was similar to as is occurring now. With this fundamental assumption we can draw useful conclusions about the land formation, its nature of groundwater and salinity position.

At present the three Western rivers, the Indus, the Jhelum and the Chenab carry an annual[2] sediment load of about 325,000 acre ft. with their annual flow of about 140 maf. The discharge of all six rivers, including the three Eastern rivers, the Ravi, the Beas and the Sutlej is about 167 maf. and their total sediment load is thus about 390,000 acre ft. This quantity of sediment when spread one foot thick can cover an area of 600 sq. miles, and can fill a storage 800 miles long 400 miles wide and 10,000 ft. deep in about 5.53 million years. The sediment deposits occurred both in the pond as well as it deposited on the upstream land surface. Certain regime changes also occurred in the portion of inflowing rivers. Above the delta, the land continued to be built up by the usual method of river deposition during flood spills and their meandering and shifting beds building up the land surface, 800 miles long, 400 miles broad and on the average 400 ft. high. It will take about 0.21 million years to build up this much deposit. Considering the volume of deposit and the period of depositions, it is estimated that the Indus plains were formed at the rate of 1.5 inches per 1000 years provided the sediment was of the same order as brought down by the six rivers. Thus very roughly the Indus plains took more than 5.5 million years to fill the sea reservoir as well as to build up the present land surface.

Fresh Water Head on Land, Washed the Salts out of the Deposits

In Figure 1 a section of the land formation just above the sea pond is

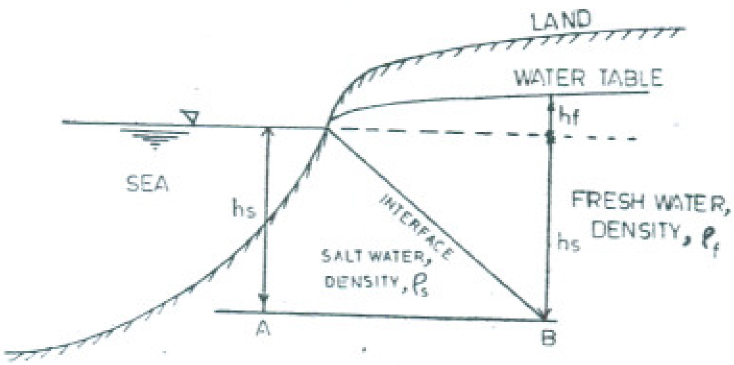


Fig. 1. Formation of an interface of fresh and saline water due to pressure of fresh water

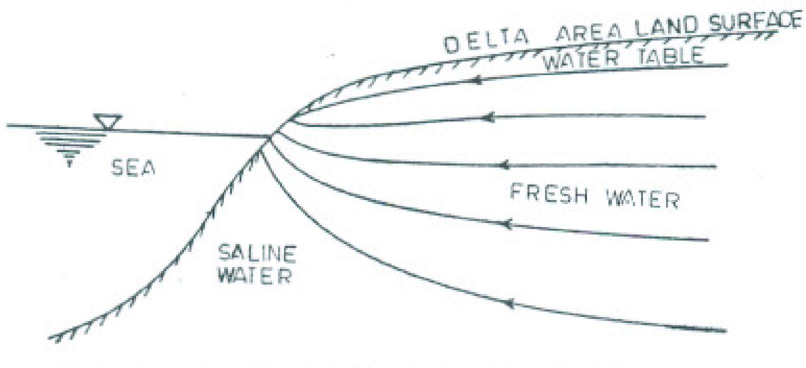
shown. The alluvium was deposited in the sea water. With the appearance of the land surface above the sea level, the fresh water head was built up in the land with its level higher than the water level of the sea. The formation close to the edge of the reservoir is usually made up of coarse grades of sand and is thus very pervious. The deeper deposits away from the water edge are of finer materials and in certain cases may be formed of pure clays.

The fresh ground water being at a higher head than the sea water exerts a pressure on the saline water. An interface of fresh and saline water as shown in Figure 1 is formed.[3] The density of fresh water is about one gram per cu. cm. The sea water is heavier and its density is 1.025 gram per cu. cm. The pressure of water at the interface at a point **B** is given by

$$h_s = \frac{\rho_f}{\rho_s - \rho_f} h_f = \frac{1.00}{1.025 - 1000} h_f = 40 h_f$$

In this equation ρ_f or ρ_s are the densities of the two waters and h_s, h_f are the pressure heads as shown in Fig. 1.

It has often been noticed that at the interface of the land and the sea, there is flow of fresh water through the soil. Flow lines as depicted in Fig. 2 are established.[4] The fresh water thus flows through the soil formation containing sea water. It washes the soil of its original saline water which is pushed to deeper depths and a sort of saline water wedge remains under the pressure of fresh water.



FLOW LINES WHICH WASH THE SEA WATER FROM THE LAND

FIG. 2

This type of flow in the delta area replaces the saline water by fresh water to a considerable depth proportional to the head of water.

Obstruction to the Subsoil Flow by Impervious Deposits

It is well known that delta close to sea is of recent construction. It has a deposit of coarse materials overlying the bed rock or the finer grades originally deposited at deep depths.

In comparison to this, land further away is built by the meandering rivers which shift from place to place, so that at the same level deposits of clay, silt and sand take place. The shifting rivers repeat the pattern of the deposition from place to place. This is the type of land formation farther away from the sea coast. There are, in existence, clay deposits different depths, haphazardly located in the formation as shown in Fig. 3. They work as barriers and obstruct the subsoil flow occurring through the flat lands.

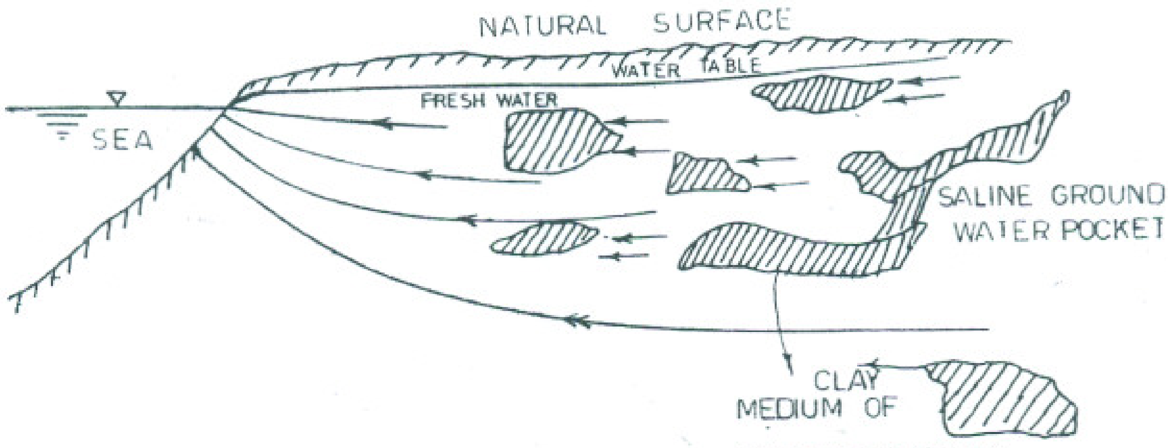


Fig. 3. Clay Deposits obstruct the subsoil flow and Create Saline Ground Water Pockets.

Rivers can Cause Obstruction to Subsoil Flow

The rivers of the Indus plains are perennial and have sandy beds. Their seeping water saturates the medium underneath. The percolating water is thus under a high water head than the surrounding areas. The flow pattern from rivers is shown in Fig. 4. It could restrict the flow of groundwater to the lower elevations. Such conditions generally existed in the Punjab where two perennial sources of water sometimes running parallel to one another, obstructed the flow of water from in between the enclosed lands. This conception gets support when we consider the rise of groundwater level in the doabs which got additional recharge from irrigation canals system.

In Chaj and Rechna Doabs, groundwater started rising with Irrigation practices but in the adjacent doabs like Thal, deep groundwater continued to exist. This is shown in Fig. 5 which depicts the groundwater level of 1960. The conditions in Sind and in Bahawalpur where the source of water was only on one side, were different. The fresh water seepage moved to a certain distance away from the rivers and the existence of obstruction to subsoil flow limited the zone of washing of the saline water.

Evaporation as a Factor Stabilizing the Level of Groundwater

Evaporation of water occurs from a soil surface. A common type of curve showing the variation of evaporation with depth is plotted in Fig. 6. It shows that with water-table deeper than 10 feet, the rate of evaporation follows an asymptotic curve with depth. It means that groundwater can be withdrawn by evaporation from very great depths although the quantity will be exceedingly small. This is very clear when we study the rise of groundwater levels in the Indus plains after the introduction of irrigation. So long the groundwater was deeper than 20 feet, the rate of rise was nearly uniform but above this depth it started to decrease suggesting thereby the increased influence of the evaporation forces. It is thus concluded that evaporation was one of the causes which helped to maintain the groundwater at the level of pre-irrigation.

In Rachna Doab for instance the sub-soil gradient was 1 in 2500. This flat gradient in combination with evaporation had stabilized the groundwater levels under the prevailing conditions.

Distribution of Salts in the Formation of the Indus Plains

We have stated that the Indus Plains took about 5.5 million years to be built. The land was built by transported materials which contained about 0.02 per cent of soluble salts. If these had continued to accumulate then during 5.5 million years, they could make the land too saline. Actually salts in ground

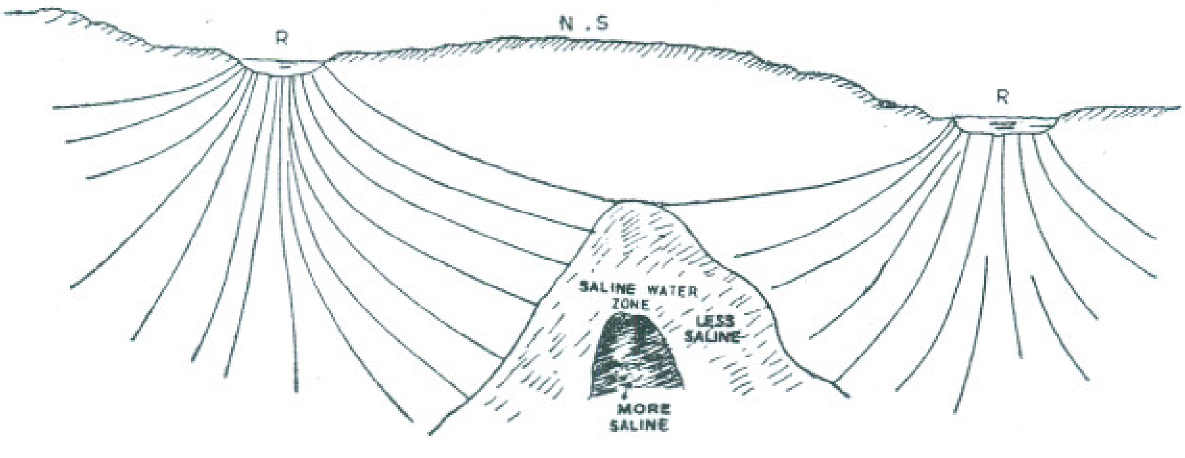


FIG. 4. GROUND WATER AS IT EXISTED BEFORE DEVELOPMENT OF IRRIGATION SYSTEM

Fig. 5. Contour Showing Depth to Water Table in Ft. Below Land Surface, 1960

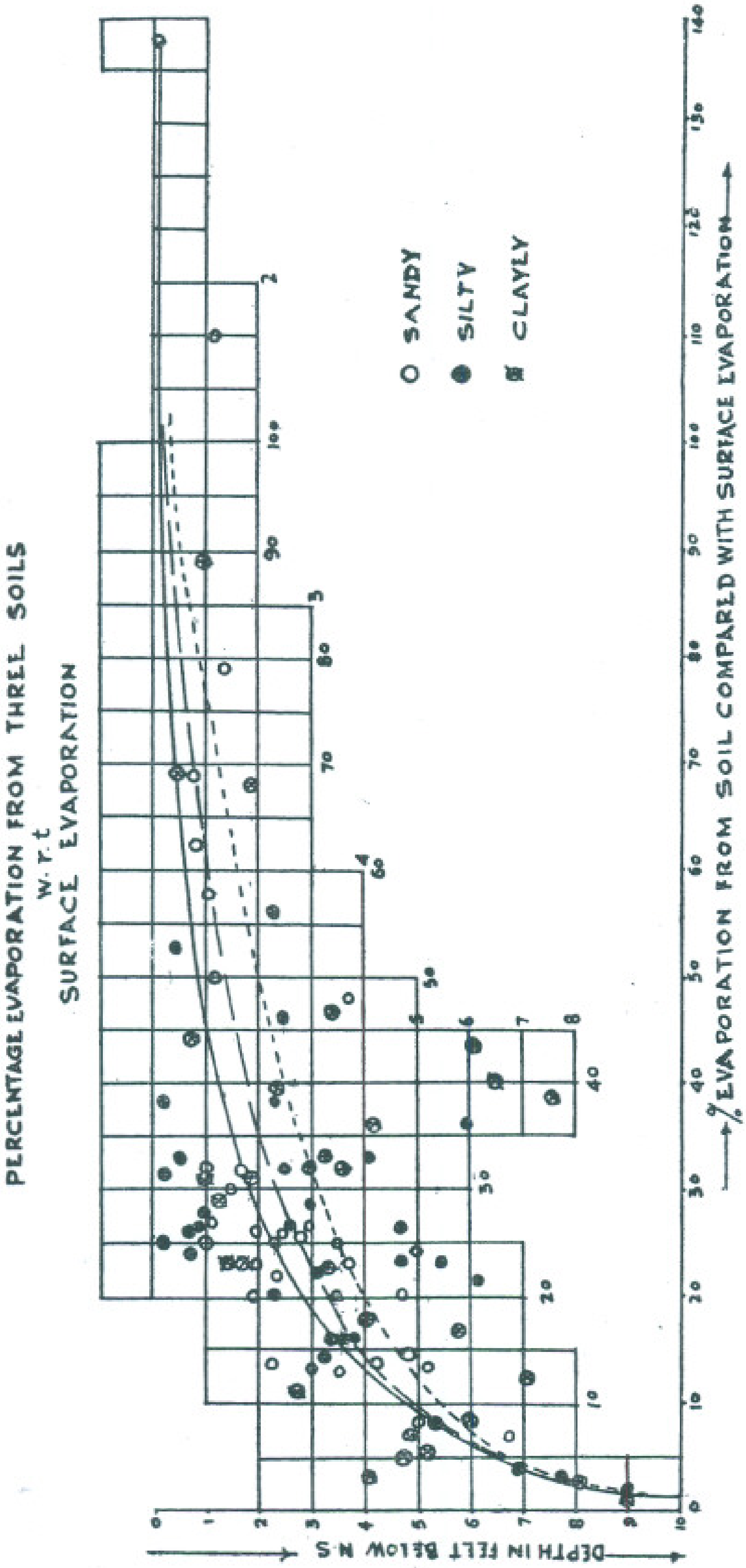

PERCENTAGE EVAPORATION FROM THREE SOILS
W.R.T
SURFACE EVAPORATION
O SANDY
● SILTY
⊗ CLAYLY
% EVAPORATION FROM SOIL COMPARED WITH SURFACE EVAPORATION
DEPTH IN FEET BELOW N.S

Fig. 6

water are much less than those accumulated during this long period.

The salt accumulations and their distribution or disposal can be considered under the following four heads :—

1. Deposition of salts and their disposal during the delta formation.
2. Salts distribution with spill of rivers.
3. Salts added with seepage water.
4. Salts added with the irrigation water.

Deposition of Salts and their Disposal during Delta Formation

Referring to Figs. 1 and 2, the existence of fresh water head was helpful to create interface of fresh and saline water. The seeping of good quality water for hundreds of years washed the remnants of sea water from the lands adjacent to the delta. This hydraulic phenomenon was thus very helpful to improve the land deposits by the removal of the saline water. The alluvium deposition in the delta close to the sea shore is of uniform coarse grade. The fresh water thus washes off all the sea water of the land to a great depth. When the delta extends into the sea, the washing phenomenon continues to progress so that land at a considerable depth than the sea water level is washed off. The saline sea water, further deposits take place on the land surface. The nature of deposition changes so that the salts depositing within the alluvium are those drawn from the water of the rivers.

2. Salts Deposited with River Spills

The salts content of river waters can be assumed to be of the same order in the early stages as it is now. Whenever the alluvium was deposited, the soluble salts also remained in the formation. Their accumulation and distribution occurred according to the physical and chemical nature of the alluvium.

Particles of sand have generally little affinity to absorb salts by the molecular forces of the minerals contained in them. There is no molecular bond among the salts and the sand particles. The permeability of the sand formation is also high, so that salts deposited along with the alluvium can easily be washed off. In case this deposit is subjected to evaporation, salts get concentrated often close to the surface.

The nature of clay deposits is, however, quite different. Clays have low permeability and insignificant flow occurs through them, so that there is less possibility for soluble salts to be washed off. Clay particles have a complex molecular structure. Its minerals have a great affinity to form a close bond with the cations and anions of the salts. These bonds between the ions of salts and clay minerals are much stronger to be washed off by the flowing water.

These are thus the causes for a high order of salts contained in the clay deposits.

There is, however, a limit up to which salts can be absorbed by the molecular forces of the clay minerals. Salts in excess to this limit remain free and are removed by the percolating water. The salts accumulated at the surface as a result of evaporation can be washed off either by the flood water or by the rainfall run off. The spills generally find their way back into the river during their low stages. Some salts, however, flow away with the seepage of the subsoil water.

It is thus concluded that salts deposited with river spills and concentrated due to evaporation, decrease with the flow of water to a great extent.

3. Salts Accumulation along with the Seepage

It is estimated that presently about 19 million acre ft. of water seeps form our river system. This order would have varied according to the prevailing conditions of the rivers with regard to their discharges, location, type of bed formations and the difference of the source and the sink etc. This seeping water could either be disposed of as evaporation or as subsoil flow into the regions having deep groundwater.

This seepage occurring for thousands of years can build up high order of salts concentration. The disposal of these salts was by two methods mainly along with the seeping water which got accumulated in the deeper regions or that washed off by rainfall run off which carried away the salts accumulated on the surface due to evaporation.

The fresh water was at a high head. It exerted pressure on the saline water which was slowly pushed to the central regions of the doabs. There was always a tendency of movement of water from the rivers towards the deep groundwater level. The flow pattern was similar to as depicted in Fig. 4. The saline water was wedged in a certain zone with the pressure of fresh water alround. The water with high salt content being heavier, sank deeper. Washing of larger areas also gave high salt concentration to the water. The waters with low salt content being lighter remained at shallow depths. These observations are confirmed by the investigations conducted by Wasid.[4] In Fig. 7, the saline groundwater zones as these exist in the Northern region are depicted. In Rachna and Chaj the saline groundwater has accumulated in the centre of the doabs where existed the deepest groundwater at pre-irrigation period. In Bari Doab, conditions are nearly similar although a few pockets of high order of salinity exist. In Thal, the deepest point of groundwater is not the zone of high order of salinity. It is accumulated in places other than the deepest groundwater as the seepage accumulation took place in these regions.[5]

Bahawalpur area shows the pushing away of saline water to one side under the pressure of seepage from the Sutlej river. In fact better conception about the accumulation of salts can be had by referring to Fig. 8, which depicts the cross section of water quality in all the four doabs. Similar results are illustrated in Figs. 9 (*a*, *b*, *c*, *d*) showing the quality of groundwater in the doabs. In Chaj Doab, the deepest groundwater existed round about Sargodha. This region has highly saline groundwater. The salinity increases with the depth. Large areas in the north of the doab have good quality groundwater.

The same conditions hold for Rechna Doab which has saline groundwater in the zone which had originally the deepest groundwater or in those areas which were highly stratified with plenty of clay deposits so that their obstruction did not allow the washing of saline salts of the formation.

The action of clay lenses is better understood when we study the conditions of Bari Doab. In this area, very complicated location of saline and good quality water is noticed. A study of Fig. 9*d* will show that in certain sites groundwater is fresh and saline water exist either at top or in middle with good quality water at bottom. There are two or three pockets of highly saline water surrounded by good quality groundwater. At certain sites, location of saline groundwater is similar to that existing in Chaj and Rechna Doabs. In fact the location of fresh ground water at deep depth supports the conclusion that the present saline water is that accumulated from seepage-water. It has no connection with the saline water of the sea.

The pockets of saline water are due to the non-washing of the zones by the fresh water. These saline groundwater pockets are remnants of salt accumulated as a result of seepage from rivers.

The surface salinity contours as exhibited in Fig. 7 do not give a true picture of the position of water of different qualities.

4. Salts Accumulation after the Modern Diversion of Irrigation Waters

When the Irrigation system started to be developed in this country, more water was spread on the lands. It resulted in greater infiltration from canals and from the irrigated fields. This caused a quick rise of groundwater levels. Major portion of the contribution was from the seepage of the Irrigation canals. This additional head of water helped to wash down the salts from certain pockets and redistribute the accumulated saline water with an all round pressure

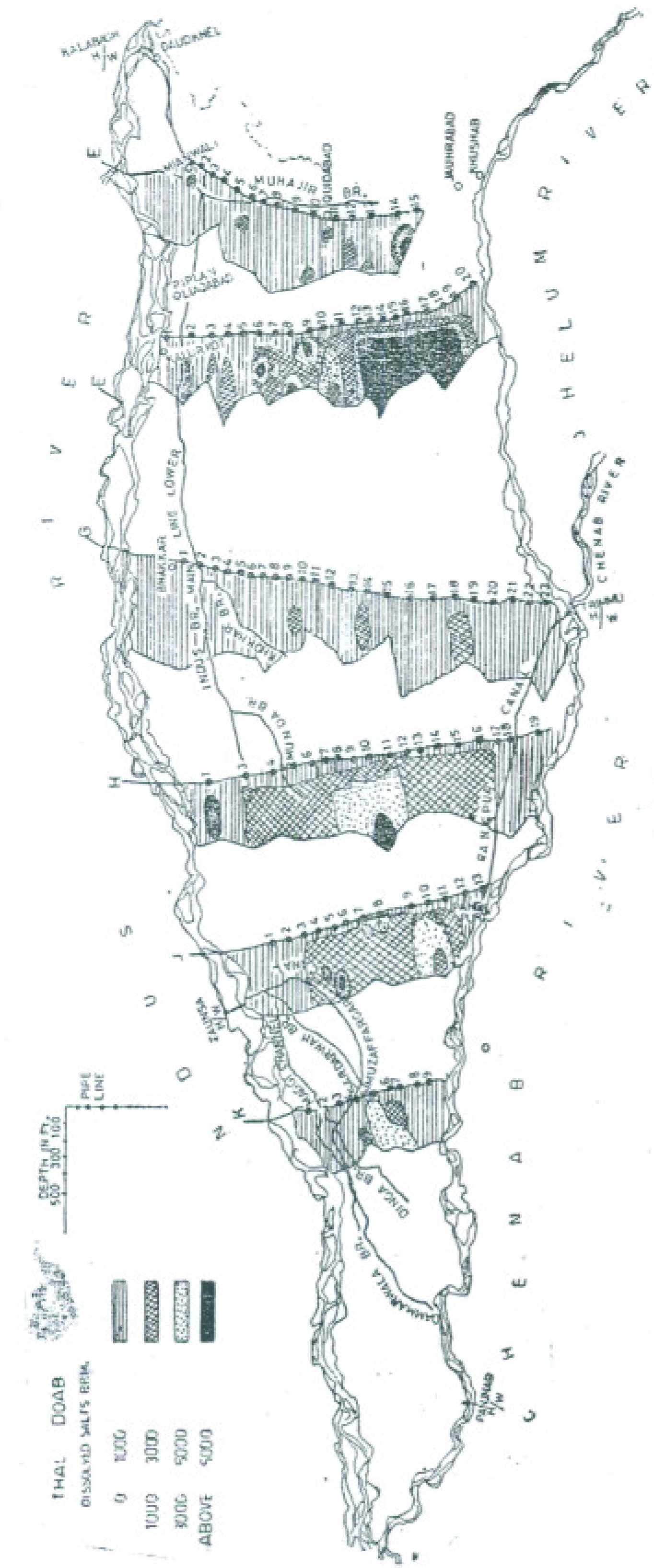

THAL DOAB
DISSOLVED SALTS P.P.M.
0 1000
1000 3000
3000 5000
ABOVE 5000
PIPE LINE
KALABAGH H/W
MUHAJIR BR.
KHUSHAB
CHENAB RIVER

Fig. 9a

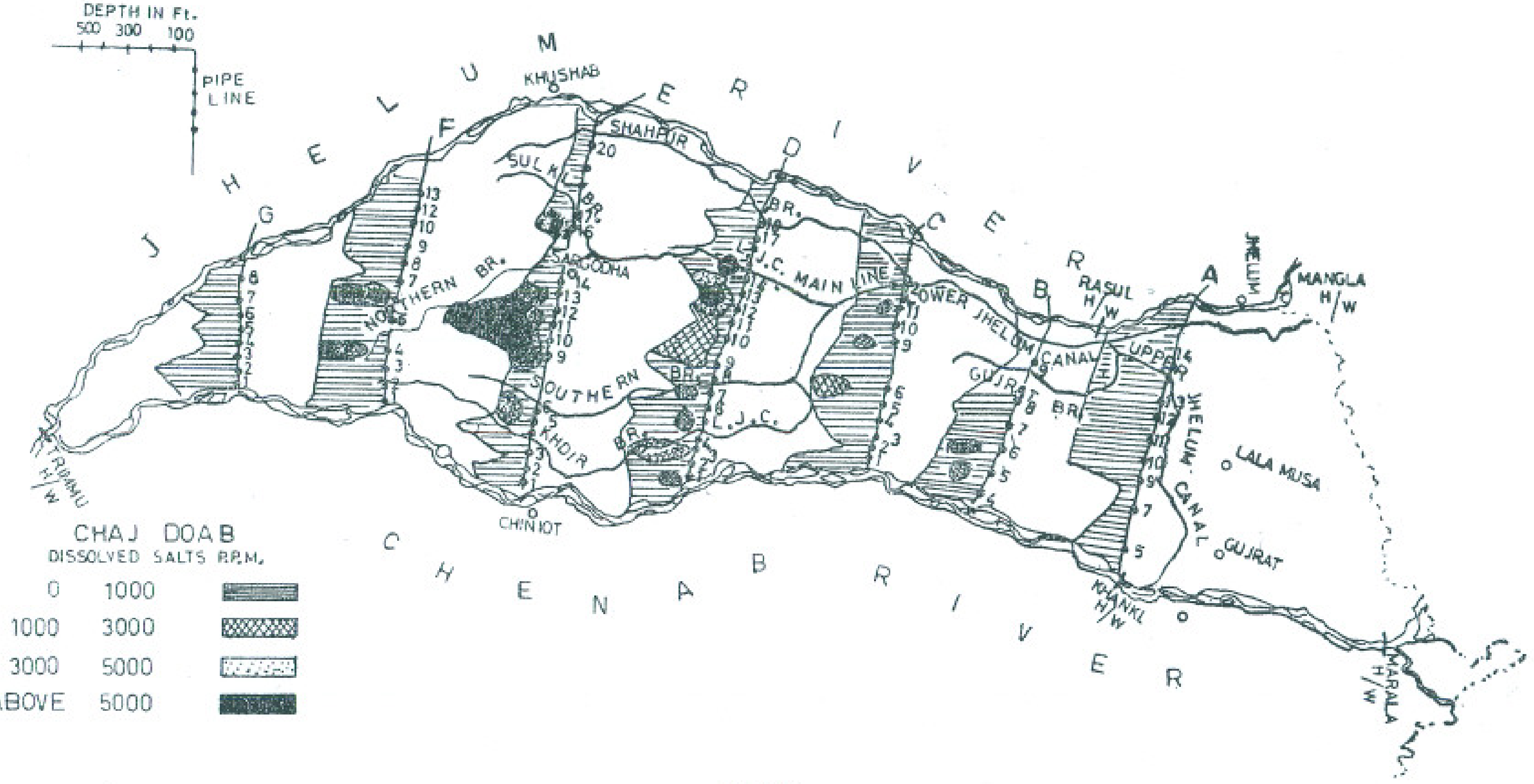

DEPTH IN Ft.
500 300 100
PIPE LINE
JHELUM RIVER
CHENAB RIVER
KHUSHAB
SHAHPUR
SARGODHA
CHINIOT
NORTHERN BR.
SOUTHERN BR.
KHOIR BR.
L.J.C. MAIN LINE
L.J.C.
LOWER JHELUM CANAL
UPPER JHELUM CANAL
GUJRAT BR.
RASUL H/W
MANGLA H/W
KHANKI H/W
MARALA H/W
TRIMMU H/W
LALA MUSA
GUJRAT
A
B
C
D
F
G
CHAJ DOAB
DISSOLVED SALTS P.P.M.
0 1000
1000 3000
3000 5000
ABOVE 5000

Fig. 9b

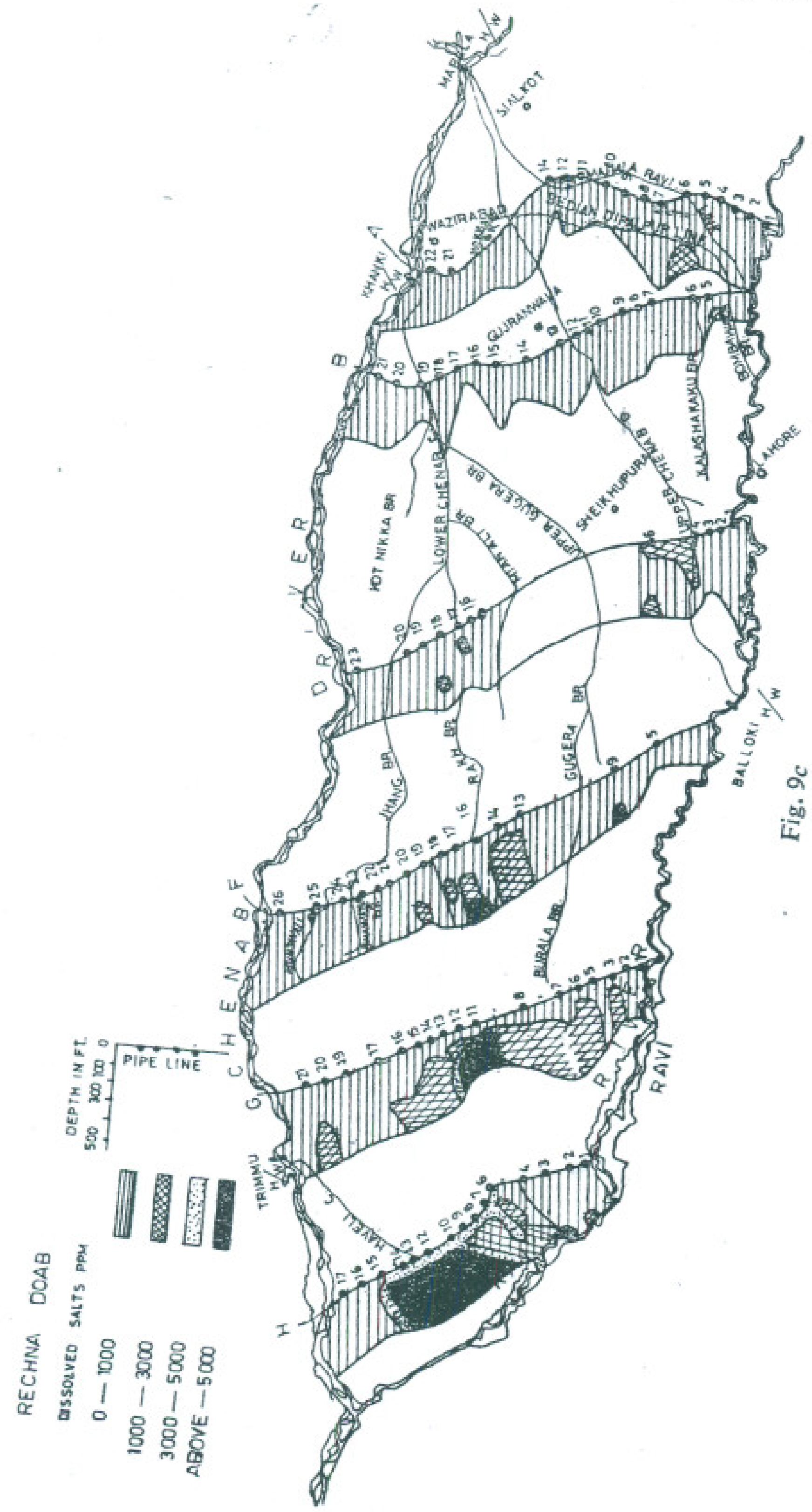

RECHNA DOAB
DISSOLVED SALTS PPM
0 — 1000
1000 — 3000
3000 — 5000
ABOVE — 5000
DEPTH IN FT.
500 300 100 0
PIPE LINE
CHENAB RIVER
RAVI RIVER
TRIMMU H/W
KHANKI H/W
SIALKOT
WAZIRABAD
GUJRANWALA
SHEIKHUPURA
LAHORE
BALLOKI H/W
KOT NIKKA BR
LOWER CHENAB
JHANG BR
GUGERA BR
UPPER GUGERA BR
UPPER CHENAB
HAVELI

Fig. 9c

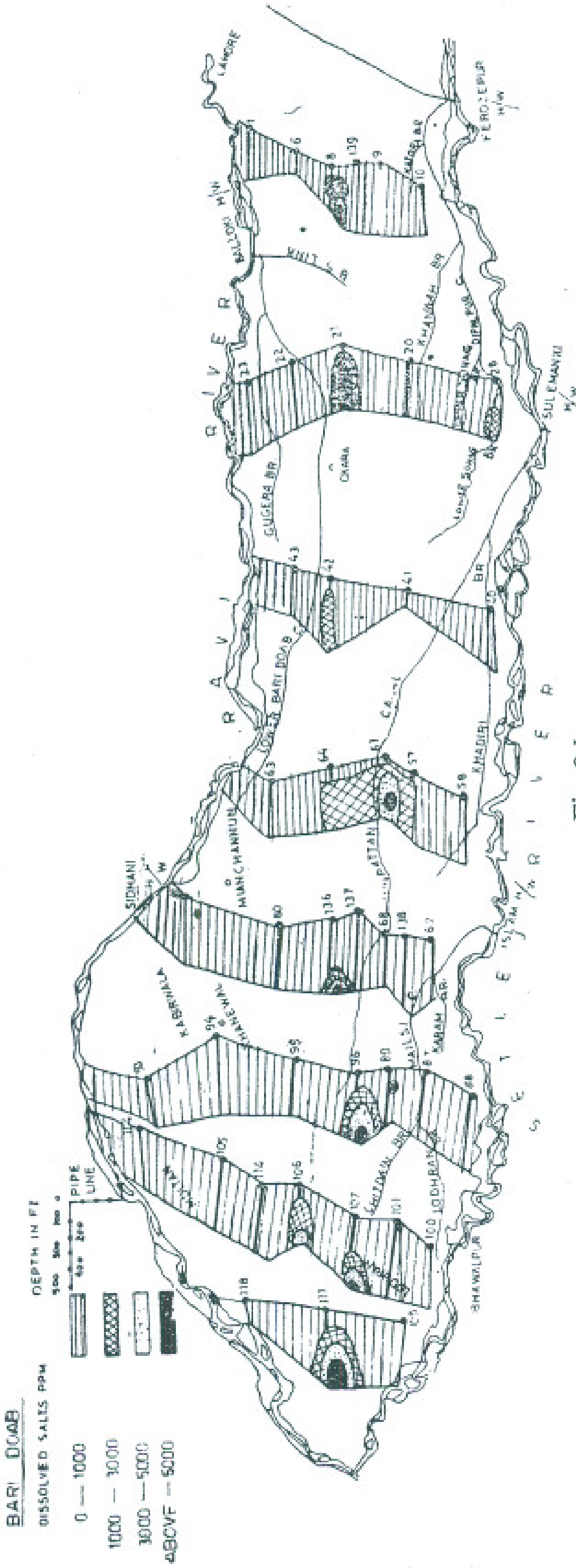

BARI DOAB
DISSOLVED SALTS PPM
0 — 1000
1000 — 3000
3000 — 5000
DEPTH IN FT
PIPE LINE
LAHORE
FEROZEPUR H/W
SULEMANKI H/W
SIDHNAI H/W
RAVI RIVER
MIANCHANNUN
KABIRWALA
OKARA
GUGERA BR
BHAWALPUR
LODHRAN

Fig. 9d

of good quality water. The salts accumulated at the land surface were to a large extent due to evaporation.

Dangers of Redistribution of Saline Groundwater with the Present Utilization of Ground Water

We have put forth that it took about 5.5 million years to create hydraulic conditions under which saline water was pushed in certain pockets enveloped by the pressure of good quality water.

Any change in the hydrological conditions could cause a redistribution of the saline and fresh water. Although no data are available about the extent of saline water zones after the imposition of additional water head from irrigation development but there is every reason to believe that this extra head of water must have slightly modified the location of saline water.

Now with the pumping of groundwater we are planning to upset the hydraulical conditions which have been established during the last several million years. If we pump extensively from good water quality zone and reduce the enveloping pressure, the enclosed saline water will spread out. Under this condition the saline water located downwards of 60 to 100 feet can spread into the water of good quality lying close to the rivers, to a considerable depth. At present the largest withdrawals of groundwater are from the fresh water zones. All the farmers' tubewells and those of Irrigation Department are located mainly in the fresh water. Their pumping will decrease the enveloping water pressure.

In the schemes of WAPDA much consideration has been given to groundwater potentials but the possibility of movement of saline groundwater into good quality water and the effects of withdrawing highly saline water and its use on the lands, has not been given due considerations.

In Scarp No. 5 for instance, water from good quality zone will be extensively pumped out. It will cause a decrease of enveloping water pressure. The zone with saline groundwater is to be subjected to greater irrigation intensity causing additional infiltration and water head. It will exert additional pressure on saline groundwater to move it into good water quality areas.

In Scarps No. 2, 3, and in Khairpur Scheme saline groundwater is to be pumped out and disposed of into rivers or into canals to spread these salts on land surface which nature has previously removed and accumulated in certain zones where these have remained least harmful to the dwellers of this land.

In Scarp No. 1 the deep lying saline water is being directly pumped on land.

A rough estimate of the salts proposed to be pumped out by implementing the Scarp schemes of WAPDA was put forth recently.[6] These data are reproduced in Table 7.

In the five Scarp areas of the Northern Region, we have been irrigating with 18,000 cusecs of river water carrying about 3.0 million tons of salts per year. These salts are to some extent instrumental for the acute conditions of salinity in the areas.

Now under the five Scarp schemes, we will pump out 21,400 cusecs from groundwater containing about 20.0 million tons of salts per year. Thus by increasing the water supply to nearly double we will be adding nearly 23 million tons of salts per year, nearly eight times more than that spread out during the previous years.

Similarly for the Southern Regions where we used to spread 0.5 million tons of salts with 2500 cusecs of irrigation water, now with about a 1000 cusecs pumped from groundwater we will add 2.24 millions tons of additional salts. Thus we will increase the spread of salts by 4.5 times with the addition of only 40 per cent more water. These are serious problems.

How to get Additional Water and keep the same Hydrological Conditions

In our country we must have to use groundwater, which is essential for our existence. At present our irrigation and river system is losing about 50,000 cusecs. This is going to increase to about 70,000 cusecs in the near future. We must recover as much of this natural resource as possible. If we can maintain our groundwater at a depth of 15 to 20 feet, we can largely reduce the wastage of this water. This level of groundwater can be attained by pumping.

The second problem is with regard to the maintenance of the present hydrological conditions. There is certain balance between the location of saline and good quality water due to the existing water levels. This balance can be maintained by pumping both from areas having deep saline water and good water quality. In the saline water zone shallow multiple wells can pump large volume of good quality water and yet maintain the same conditions of water pressure.

Our planning should be such as never to pump the deep saline water and yet maintain the existing hydrological conditions of the source and the sink.

At least up to the year 2000 we can pump our requirements equal to the seepage losses and maintain the hydrological conditions.

TABLE NO. 7.—*An estimate of salts delivered to land water by canal and that proposed to be pumped with tubewell water*

No. of Scarp	Historic canal water supply in cusecs	Salts content in m. tons assuming 200 (ppm)	Capacity provided (cusecs)	Tubewell Water				Total salts of canal and pumped water (m. tons)	Remarks
				Av. salt content	Total salts (m. tons)	Capacity pumped, (cusecs)	Salt pumped, (m. tons)		
1	2	3	4	5	6	7	8	9	10
1. Central Rechna	2500	0.40	(*i*) 950 (*ii*) 5000	1500 700	1.30 3.05	570 3000	0.78 1.83	3.01	
2. Chaj	3738	0.65	(*i*) 366 (*ii*) 2325 (*iii*) 5000	10000 600 2000	3.16 1.20 8.67	366 1737 3000	3.16 1.72 5.80	.. 11.33	For drainage into drain and river.
3. Lower Thal	2887	0.50	(*i*) 5600 (*ii*) 500	700 3500	3.44 1.54	1868 109	1.14 0.31	1.95	For drainage into river.
4. Upper Rechna	2156	0.31	13100	500	5.72	5754	2.50	2.81	
5. Lower Rechna	(*i*) Non-saline, 2856	0.50	7412	1000	6.55	4130	3.60		
	(*ii*) Intermediate, 1470	0.244	1350	2000	2.37	896	1.58	6.26	
	(*iii*) Saline, 2175	0.34	..	..	..	..	..		
Grand Total	17783	2.94	41603	..	37.00	21430	22.42		*For Drainage.*

TABLE NO. 7. (*Contd.*)—*An estimate of salts delivered to land by canal water and that proposed to be pumped with tubewell water*

No. of Scarp	Historic canal water supply in cusecs	Salts content in m. tons assuming 200 (ppm)	Capacity provided (cusecs)	Tubewell Water				Total salts of canal and pumped water (m. tons)	Remarks
				Av. salt content	Total salts (m. tons)	Capacity pumped (cusecs)	Salt pumped (m. tons)		
1	2	3	4	5	6	7	8	9	10
6. Khairpur West.	992.8	0.44	..	(*i*) 600	..	531.0	0.26	2.68	Will be let in Rohri canal carrying 10000 cusecs and 2.2 m. tons of salts.
Khairpur East	1312.5		..	(*ii*) 10000 to 1600	..	565.0	1.98		
7. Rohri North	..	..	4000	500	1.75	1400	0.57	0.57	
8. Gaja area	182.0	0.043	..	1500	..	437.5	6.10	6.14	For drainage.
Total for items 6, 7 and 8	2487.3	0.483	..	..	..	2933.5	8.91		

Main Conclusions

1. There is a great necessity for exploitation of the groundwater resources of West Pakistan. Several organizations are working towards this end. At present the private farmers are pumping and utilizing about 10.8 maf. of water. WAPDA'S tubewells have started to pump about 6.0 maf. Irrigation and Public Health Tubewells pump about 1 maf. each. It has been estimated by the World Bank Consultants that by 1970 with the completion of the proposed schemes in hand, the groundwater pumpage will rise to about 21 maf. and during the next four years it will attain an order of 32 maf. The estimates of groundwater utilization are 43 maf. by 1985 and 49 maf. by the year 2000.

2. It is estimated that the land formations of the Indus below the salt range have taken nearly 5.5 million years to build up and establish its present position and quality of groundwater.

(*a*) In all these years, the sea water contained in the deposits of the land has to a large extent been washed off to a considerable depth by the pressure of fresh water.

(*b*) Salts deposited by the river spills on the land have largely been disposed of by rainfall run off, regeneration into rivers, into depressions or as seepage into deep-water zones.

(*c*) The salts accumulation in certain regions of the Indus plains is a result of subsoil flow of seepage water, accumulation of salts after evaporation and washing of salts from the formation.

(*d*) The imposition of pressure of water accumulated as a result of irrigation development must have slightly modified the location of saline water zones, but no records are available to know the changes caused as a result of this additional pressure of water.

3. The present accumulation of saline water is a result of washing of the formations. These salts are drawn from waters of the rivers. It is argued that these salts are not the remnants of sea water which have been washed down to much deeper depths under the pressure of fresh water.

4. The waters with high order of salinity are heavier and thus sink deeper. This fact is confirmed by the existence of saline water in the centre of each doab. Some pockets of saline water also exist. These were formed by the obstruction to flow by the clay formations. This saline water is out of earlier accumulation of salts which have not been washed off. This condition

is very obvious in Bari Doab where fresh and saline water exist in quite a complicated manner.

5. The saline water in the doabs has always remained under an enveloping pressure of fresh water. This pressure is a result of seepage from rivers which have kept the saline water enclosed and enveloped by fresh water. This saline water cannot find its way from under the rivers the seepage of which forms a high water pressure zone.

6. As a result of intensive pumping from the fresh water zones and increase of irrigation practices on the area containing saline groundwater, the age-old balance of fresh water pressure enveloping the saline water is bound to be upset resulting in redistribution of saline water towards the good water zones.

7. The Scarp schemes need special considerations. In practically all these schemes either the saline water is to be pumped out and spread on land or a reverse pressure gradient may be expected to be established. It will cause saline water to flow into good water quality areas.

In the five Scarp schemes of the Punjab where annually 3 million tons of salts used to be spread with 18,000 cusecs of irrigation water, now with the pumping of 21,000 cusecs from groundwater, additional 20 million tons of salts will be pumped out.

8. It thus calls for urgent action to revise our conception of pumping groundwater. Our present seepage order is about 50,000 cusecs which will increase to 70,000 cusecs. Steps can be taken to recover a part of this huge volume of water, by keeping the hydrological conditions similar to those as exist now. Simple but proper planning can be helpful to attain this condition otherwise we will not only spoil our land but also our reserves of fresh groundwater.

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