saline ground water containing dissolved salts more than 3000 ppm. for northern area and 2000 ppm. for Sind, lies under 10.59 m. acres of culturable commanded area. The ground water of intermediate quality which can by used by mixing with canal water and contains salts between 1000 to 3000 ppm. for Punjab, Bahawalpur and 2000 ppm. for Sind constitutes another 4.55 m. acres. Thus out of a total of about 30 m. acres of culturable commanded areas of West Pakistan, nearly half the lands possess deep, good quality ground water which can be used on lands as such and another 4.55 m. acres (about 16 per cent) can be used by mixing with canal water. The area with saline unusable ground water constitute 10.6 m. acres nearly 1/3 of the total area.

TABLE No. 14—*Areas of Ground water Quality Zones*

Region	According to W. Bank Consultants						
	Million acres of Developed C.C.A.						
	Fresh	%	Mixing	%	Saline	%	Total
Vale of Peshawar	0.58	85.4	0.10	14.7	—	—	0.68
Thal Doab & Indus Right Bank	2.03	56.0	0.99	27.5	0.60	16.6	3.62
Chaj Doab	1.19	58.4	0.36	17.6	0.49	24.4	2.04
Rechna Doab	3.37	58.0	0.84	14.4	0.54	9.25	5.83
Bari Doab	3.95	69.0	1.34	23.0	0.54	9.25	5.83
Sutlej & Panjnad L. Bank	1.29	36.8	0.47	13.4	1.75	50.0	3.51
Sub-Total	12.41	61.0	4.10	20.1	3.87	19.4	20.38
Lower Indus	1.81	20.0	0.45	5.00	6.727	7.45	8.98
Total	14.22	48.4	4.55	15.6	10.59	36.4	29.36

Depth of Fresh Water Overlying Saline Ground Water

All the estimates of the area overlying fresh non-saline, intermediate and saline ground water have been made for such available depth of aquifer, where high capacity tubewells, pumping 3 cusecs and above could be installed. Average depth of aquifer for that capacity of wells is about 300 feet. The water is withdrawn by turbine pump, working in a housing pipe of 70 to 90 feet, with pump bowels located at 60 to 80 feet below natural surface.

TABLE No. 15.—*The depth of good quality and saline water.* (*Areas are in million acres*).

Regions	Areas or Doabs		Total area	Area with salt less than 1000 ppm.	Depth of good quality water in ft.	Area with salts more than 1000 ppm.	Depth of appearance of saline water
Northern (Punjab)	Rechna	..	4.7	4.00	400—600	0.70	50—100
,,	Chej	..	2.0	1.58	300—600	0.42	50—100
,,	Thal	..	5.3	3.84	200—400	1.48	100—200
,,	Lower Thal	..	1.3	1.12	500—700	0.16	200—500
,,	Bari	..	4.4	2.64	..	1.76	..
	Total of 4 doabs	..	16.4	12.06	..	4.36	..
Sind	G. M. Barrage area	..	2.33	0.28	40—80	2.05	25—50
,,	Sukkur Barrage	..	7.0	2.50	100—400	4.50	20—100
	Total	..	9.33	2.78	..	6.55	..

Recharge of irrigation operations takes place equally on the area possessing fresh or saline ground water. Similar problem of waterlogging and drainage of lands exist at the two sites. The suggestions of all consulting organizations have been to pump both the good quality and salined ground water zones, with deep turbine pumps of high capacity, to effect drainage and to adopt different measures for its disposal.

In practically all doabs of the Punjab, after the irrigation operation, fresh seepage water has accumulated over the saline ground water. Presently, baring the pockets of saline ground water, all the extensive zones of saline ground water possess a covering of fresh water at top. An estimate of the extent of area possessing different depths[13] of fresh groundwater in West Pakistan, and particularly in the three doabs of the Punjab, is given in Table 15. Practically all irrigated areas in the Punjab and Bahawalpur possess some shallow depths of fresh water.

A study was conducted[14] to determine the extent of the quality of shallow ground water for the Punjab and Bahawalpur area. The areas, possessing total solids up to 1000, between 1000 to 2000 and above 2000 ppm., were determined. The results of this study are given in Table 16. It was found that shallow ground water with salinity up to 1000 ppm. existed under 25.624 m. acres, out of the total area of 28.371 m. acres. The area with shallow ground water possessing salts above 2000 ppm. constituted only 1.347 m. acres. The chequered existence of the three range of qualities of shallow ground water are shown in Fig. 11.

TABLE No. 16—*Irrigated areas in the Punjab and Bahawalpur having different orders of salinities in Shallow Ground water*

Zone	Area in M. acres	Areas in m. acres with varying orders of ground water salinities in PPM within shallow depths		
		upto 1000	between 1000 to 2000	above 2000
Thal Doab	6.381	6.16	0.107	0.110
Chaj Doab	2.824	2.542	0.1765	0.1049
Rechna Doab	7.500	6.703	0.603	0.275
Bari Doab	7.80	7.103	0.366	0.330
Bahawalpur	3.785	3.116	0.1526	0.517
Total :	28.371	25.624	1.406	1.337

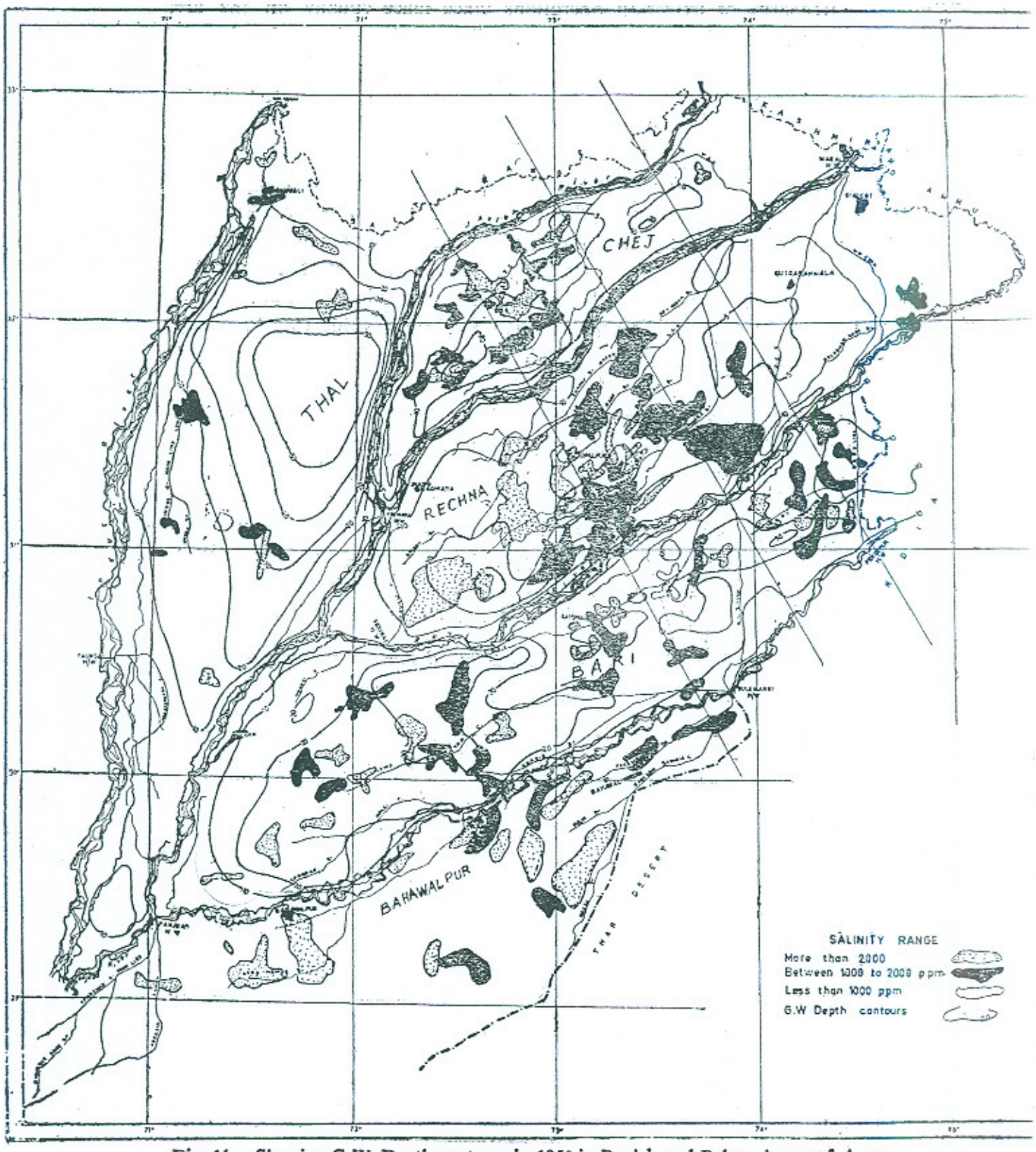


Fig. 11. Showing G.W. Depth contours in 1959 in Punjab and Bahawalpur and Appx. Location of areas with shallow G.W.

Shallow Depth of Fresh Ground water in Sind

Conditions in Sind have been slightly different from those of the Punjab area. Here the Indus is the only river. It has never been as tame and controlled as at present. In centuries past, it has been wandering about on the presently irrigated lands, forming innumerable distributaries. This shifting course of the Indus during the last 2000 years has been described by several persons[15a,b,c]. A recent paper was the presidential address of Mr. Memon[16] to the 1971 all-Pakistan Science Conference at Peshawar. A good description about the shifting distributaries of the Indus has been given by Hunting[17]. These shifting rivers have been building the lands as well as a reservoir of fresh ground water.

After the adoption of its present course through the limestone gaps of Sukkur-Rohri and Hyderabad-Kotri, during 16th century, the Indus has been building up fresh zone of ground water, mainly along its flow path. Still in the vast area where the distributaries had been roaming about, fresh ground water pockets have been left over.

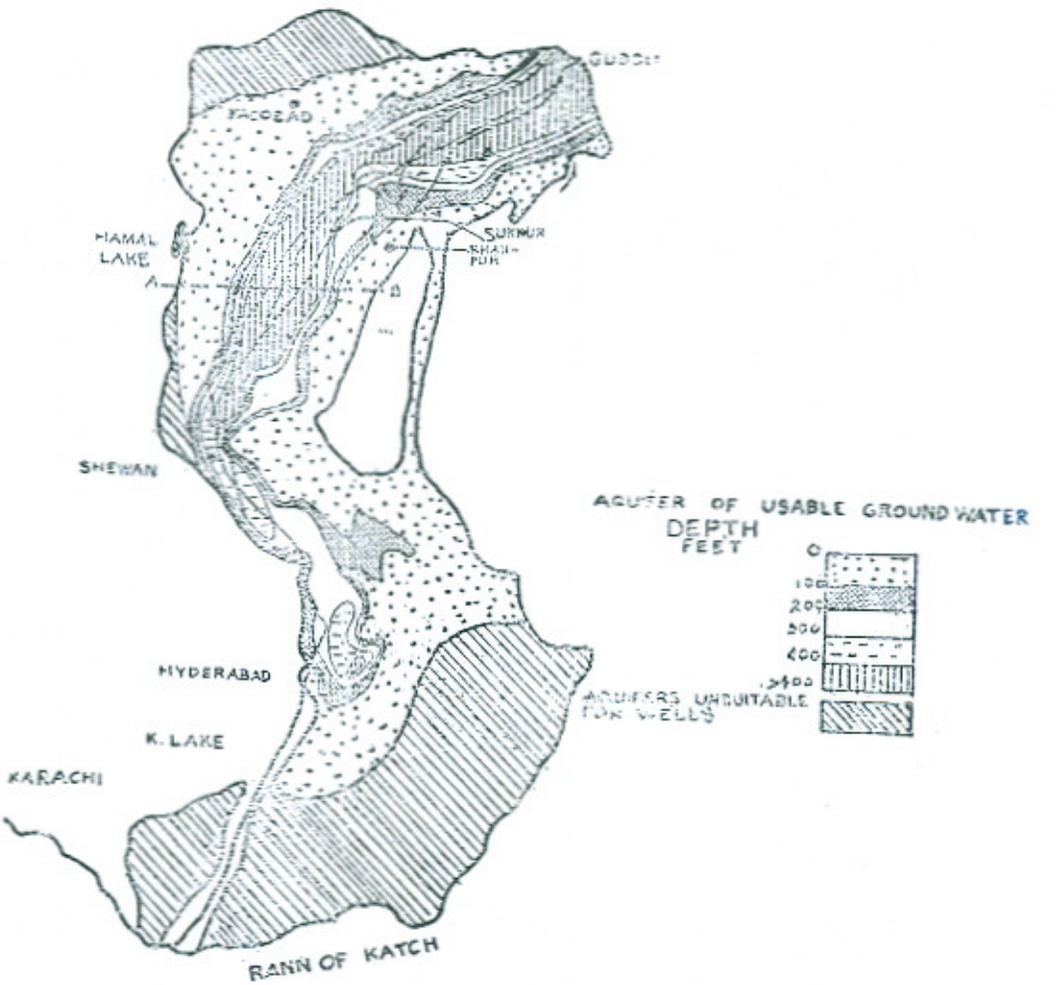


Fig. 12. Ground water quality 1200 ppm. in Sind, depth contours



Fig 12*a* Gudu and Northern Sukkur, showing extent of fresh Ground water (within hedge line) and Bunds along the Indus



Fig. 12*b*. Lower Sukkur and G.M.B. area showing extent of fresh Ground Water (within hedges)

Hunting has drilled several bores in the Sind irrigated area to determine the physical and chemical characteristics of the formation. Ground water samples from various depths were collected and analysed.

Similarly a number of tubewells were installed to determine the hydraulic properties of the formation. Chemical analysis of the ground water was also carried out.

In tables 16a and 16b, instances of 22 and 13 bores are put forth. These bores were drilled in the Central and Southern Rohri Command and G.M. Barrage area. These areas are generally included in the saline ground water zones. A study of these tables indicate the existence of considerable exploitable depth of fresh ground water.

In Fig 12-*a* & *b*, the extent of exploitable fresh water under the command of the three barrages is given. Fig 12-*a* mainly pertains to Gudu and a part of Northern area of Sukkur Barrage. In the command of Gudu Barrage about 2069 thousand acres, being 67 per cent of the total, possess usable ground water. As for Sukkur Barrage command the extent of usable ground water is shown in fig 12-b. Considerable fresh usable ground water area exist on the left side of the Sukkur Barrage. The southern area of Nora Canal command in particular has both unfit ground water and unsuitable aquifer.

The area of G.M. Barrage has not been fully explored. It was said to contain all unfit ground water but in 1960 when random exploration was carried out in Gaga area, 27 per cent for the sites were found to possess usable ground water. An approximate extent of area possessing usable ground water in Sind is given in table 16 C. It shows that 67 per cent area in Gudu Command and 26.3 per cent in Sukkur Command, constituting about 4.467 million acres possess usable water.

The data about the physical characteristics of the formation although not given in this paper but it proved invariably that each site was such which could yield economical discharge if a tubewell was installed in the area.

Another character of the Sind area is that fresh and saline ground water zones exist close by. Unlike the Punjab, extensive fresh water areas do not exist in Sind. For this reason rather than to locate fresh ground water areas surrounded by saline areas, the consultants have marked extensive area as saline. In this connection, example of Gaga area of G.M. Barrage is cited. This aquifer, underlying this barrage command, has always been included in the area with highly saline ground water, but in 1957 when drainage tubewells were installed in shallow depth of 80 feet, some were found to possess ground water of usable quality. The yield and ground water quality[18] of five wells is given in Table 17.

TABLE No. 16a.—*Central Rohri and SouthernRohri Command data of bore holes showing depth and quality of ground water.*

S. No.	Bore hole No.	Site	Central Rohri			
			Total Depth, feet	Shallow Depth feet	ppm.	Formation Character Total Clay%
1	2	3	4	5	6	7
1	LIPW 54	Kazi Ahmad ...	602	64 227	1030 1670	25
2	55	Nawabshah ...	450	64 141	1300 1850	15
3	109	Amerabad ...	770	89 235	352 480	40 Good up to 460 feet.
		Southern Rohri Command				
4	24	Sakrand ...	450	99 321	1300 950	20% Clay at 188
5	26	Sakrand to Nawabshah ...	298	174	710 1240	10
6	30	Fatehpur ...	359	98 252	590 2120	40E, Good for 43-263.
7	34	Tando Jam ...	435	76	640	25 Good up to 324
		Tando Allahyar ...	274	274 406	930 23000	
8	34A	Tando Jam ...	234	200	385	10
		Tando Allahyar		230	1200	
9	43	Tando Ghulam Ali ...	450	98	820	25

1	2	3	4	5	6	7
				242	25000	
10	35	Tando Allahyar to Mirpur Khas	450	398	860	25
11	44	Tando Ghulam Ali to M. Khan ...	450	54	960	60
				155	18000	
12	58	Sarhari ...	450	208	350	20
				309	1520	
13	61	Jamrao Canal ...	452	75	550	15
				186	650	
				262	22000	
14	62	Khelan ...	452	75	670	20
				209	390	
				373	1440	
15	88	Tando Adam ...	452	276	608	20 Very Good
				378	7000	up to 409
16	89	Maltari ...	452	76	480	Good at 16 to 152
				239	8000	
17	90	Tando Allahyar ...	452	98	1250	20
				200	8000	
18	95	Lundo ...	452	206	750	20
				283	5300	
19	96	Khesano Minor ...	452	76	1300	20
				303	410	
				400	2200	
20	97	Ghulam Leghan ...	450	76	1290	40
				198	30000	
21	98	Hadeki Dis. ...	450	277	1000	15
				353	10000	
22	104	Tando Allahyar ...	450	76	820	20

TABLE No. 16*b*—*G.M. Barrage Bore hole Data, usable Ground water*

S. No.	B. No.	Site	Depth, feet	Salinity, ppm.
1.	G. 1	Tondo Mohd. Khan	96	978
			140	832
2.	G. 2	Fauji Sugar farm	74	723
3.	G. 4	Bulri	84	986
			140	889
4.	G. 10	Pinyari Feeder	74	1000
			142	1104
5.	G. 11	Guni Canal Tando	74	474
		Mohd. Khan	162	429
6.	LIPW 64	Julalani	144	1240
7.	" 65	Bulari Canal	162	1430
8.	" 71	Tando M. Khan	98	470
9.	" 72	Mohd Seth	54	430
10.	" 74	Mulla Katiar Road	64	1040
11.	" 75	Jalalani	75	910
			165	380
12.	" 76	Gaja"	98	346
13.	" 85	Fuleli	54	1160

TABLE No. 16C—*Exploitable fresh ground water area in Sind. Basis is Fig.* 12-*a and b, and area is in* 1000 *acres*

Barrage or Command	Total Commanded area	Area between Bunds	Area underlain by river channel	Usable G.W. area	Exploitable area	Percentage of total area
Gudu	3100.0	566.0	71.0	2140.0	2069.0	68.8
Sukkur	8501	1012.0	147.0	2385	2238	26.3
	(Sukkur to G.M.B.)					
G.M.B.	—	—	—	160.0	160.0	—
Gaga	—	—	—	—	—	—
Total	—	—	—	4685.0	4467.0	

TABLE No. 17—*Performance Data in March* 1970 *of Tubewells Working in Gaja area of G.M. Barrage*

T/W No.	No. of bores working	Dis. in cusecs	Dep. Head in feet.	Quality of Ground water ppm.
4	2	0.94	18	443
5	2	0.66	18	454
15	3	1.24	10	384
16	3	0.94	8	467
17	3	0.94	10	896

A survey was also conducted in the same area to find sites of fresh water in shallow depths. It was noted, as shown in Table 18, that more than 27 per cent of the sites, possessed fresh usable water, within 100 feet of the depth of the mation.

TABLE No. 18—*Number of sites explored at Random in G.M. Barragge Area (Gaja) up to a depth of* 100 *feet, with range of Ground water quality*

	Total		Dissloved		Solids		
	0-500	500-750	750-1000	1000-1500	1500-2000	Above 2000	Total
No. of Bores	13	17	17	18	20	94	179
% of Bores	7.12	9.45	10.7	11.25	52.5	52.5	100

These random sites, with fresh ground water pockets, may have been built up by the roaming distributaries.

Hunting 6 has prepared a map (Fig. 12) depicting the depth of ground water with salt content up to 1200 ppm.

According to this figure, in a considerable area, on both sides of the Indus, deep good quality ground water is in existence except in the area under the command of G.M. Barrage and on the south-east side of the Sukkur Barrage, under command of Nara canal system, in some portion in Jacobabad and areas close to Sehwan. It is said that both the formation and the ground water are unfit for pumping.

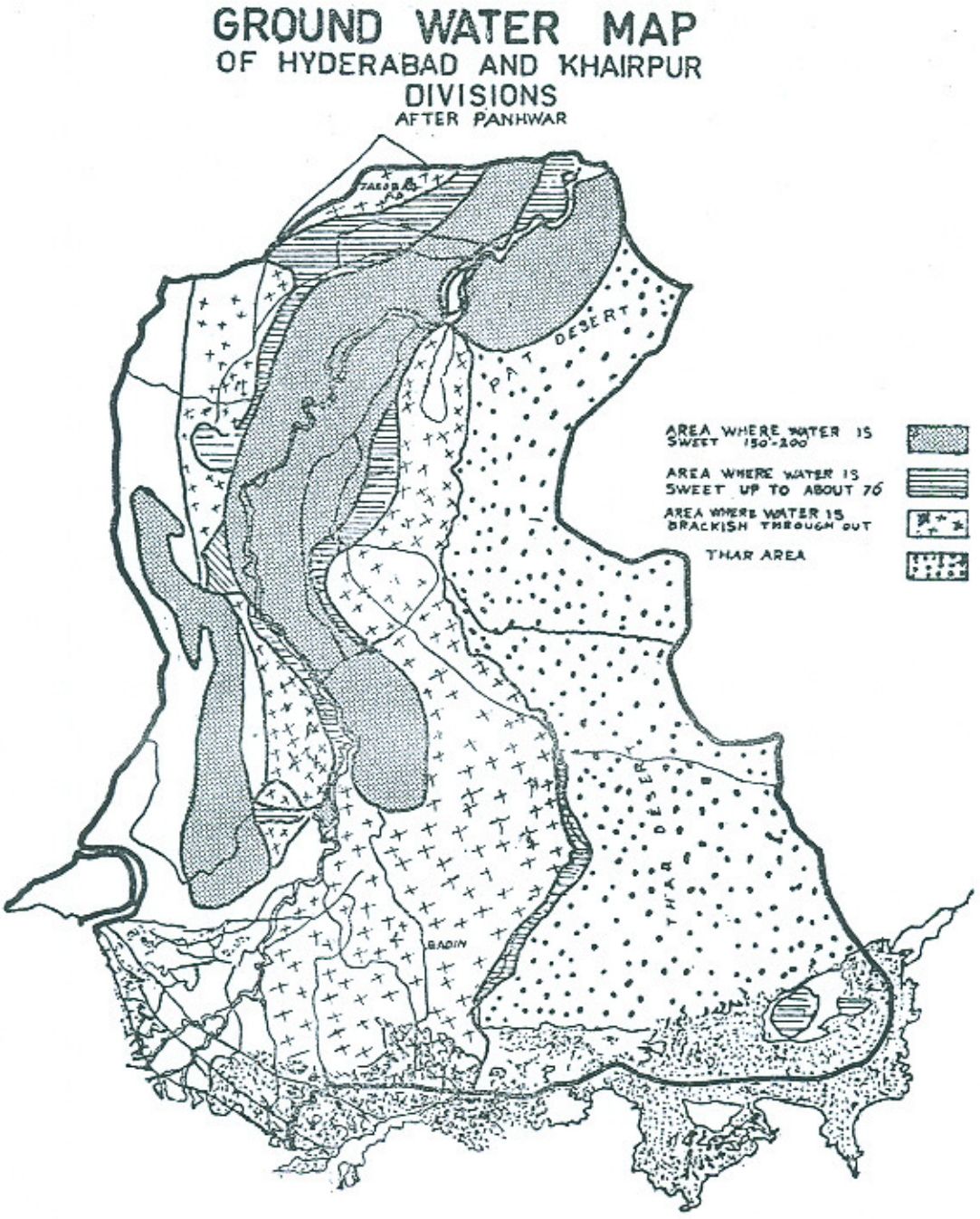

GROUND WATER MAP
OF HYDERABAD AND KHAIRPUR
DIVISIONS
AFTER PANHWAR
PAT DESERT
THAR DESERT
BADIN
AREA WHERE WATER IS SWEET 150-200
AREA WHERE WATER IS SWEET UP TO ABOUT 76
AREA WHERE WATER IS BRACKISH THROUGH OUT
THAR AREA

Fig. 13

Another similar information about the depth of good quality ground water in Sind has been furnished by Panhwar (19) who has carried out several bore for installing tubewells. In his book on ground water he has located the depth of good quality ground water in each district of Sind. Fig. 13 is after Panhwar. It shows the extent and location of deep and shallow fresh ground water at various sites. He has not marked the pockets of fresh ground water lying within the area marked as saline and unfit for use, although Panhwar himself has installed several tubewells in the area of south and south-east of Sukkur Barrage Command at Ghulam Ali and Tando Allahyar etc., withdrawing fresh ground water. Thus even in Sind in large irrigated areas, top shallow depth of fresh ground water is in existence.

Fresh water seepage from Saline Ground water Zones being wasted

We have stated in the Punjab about one quarter of the total irrigated areas possessing saline ground water receives fresh water recharge.

In Sind except for a small area in Khairpur, Rohri North and South where utilization of fresh water has either started or is being planned, the majority of the 17 maf. of percolation is going waste. About 14 maf. of water constituting about 80 per cent of the percolation is being wasted in Sind and about 8 or 9 maf. in the Punjab and Bahawalpur.

How to exploit Shallow good quality ground water Potential

There are three types of formations under which shallow ground water has been found out.

(*i*) There are sites where relatively impervious clay layer exists in the formation generally within a depth of 100 feet. The granular formations above a clay deposit has often been found to possess good quality water followed by saline ground water below the clay formation. (Fig. 14).

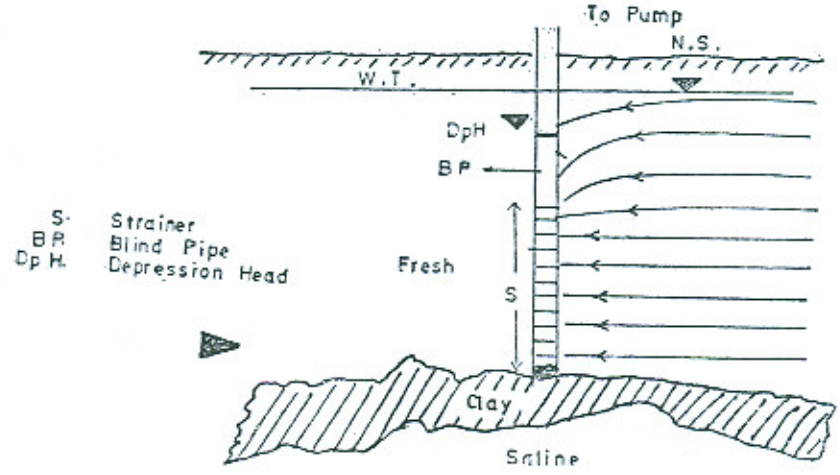


Fig. 14. Strainer Fully Penetrating in Fresh Water

(*ii*) Sites with deep clay formations and with top fresh water followed by water of changing quality. Below a thin layer of fresh water, lies water of intermediate quality increasing in salinity with depth.

(*iii*) Sites where highly saline water appears suddenly below very thin top fresh water. The transition zone is practically non-existing. Sites of type (*i*) with clay deposits at least 2 feet thick and occurring at a depth of say 60 to 100 feet, are ideal for installing skimming tubewells. Here the strainer can be installed reaching the clay bed and the full fresh water zone can be exploited; such examples are of Gaga area see Fig 14 where tubewells Nos. 4, 5 and 14, 15 and 16 have worked successfully for several years, withdrawing fresh water. In case, the yield of one strainer is low, more than one strainers can be coupled to the same pumping set as was done for the tubewells installed in the Gaga area.

The ground water of second and the third case is difficult to be exploited by tubewell strainers located in the fresh water zone. The creation of low pressure in the well, causes the establishment of the flow lines as depicted in Fig. 15a. Some of the flow lines, from the saline water zone, also enter the

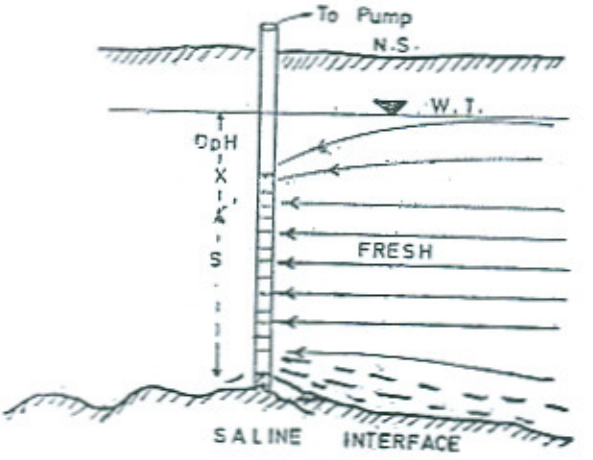


Fig. 15*a*. Strainer up to Saline water Interface

strainer causing deterioration of water quality. The suction of some quantity of the saline ground water can be reduced by cutting short the length of the strainer (Fig 15b) so that with non-penetrating strainers, the withdrawal of saline ground water is reduced.

This is further helped by the difference in the horizontal and vertical permeabilities of the formation. The vertical permeability is often hundred to a thousand times lower than the horizontal permeability. Actual data in support are put forth in Table 19a for Sind and in Table 19b for the Punjab. This also partly helps to reduce the mixing of saline water with the top fresh water.

The higher density of the saline ground water is also helpful to a small extent to reduce the inflow of saline water into the fresh water.

Under all these conditions, where good quality ground water exists at shallow depths, it is not possible to use a turbine pump unless the fresh water aquifer is very extensive and saline water is deep. A centrifugal pumping set can only be employed in these cases. With a centrifugal pumping set it is possible to instal any number of shallow strainers and thus to increase the yield. This is not possible with a turbine pump. The workability of such suggestions has been fully proved by tubewells installed in Gaga area of G.M. Barrage, at Niazbeg and at s me sites in the border area of Lahore.

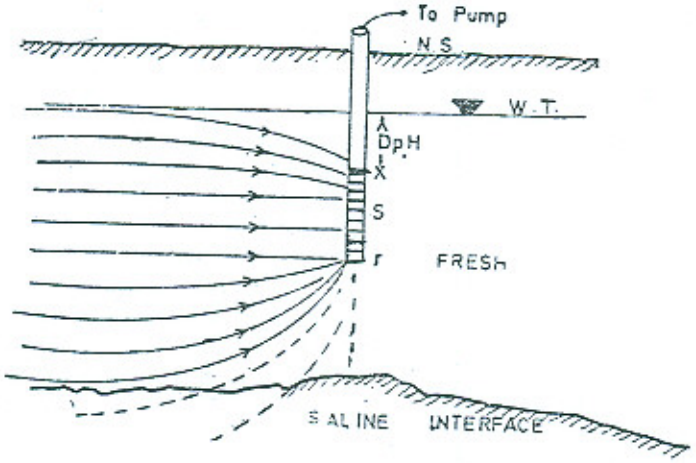


Fig. 15*b*. Strainer in Fresh water, Partial penetration

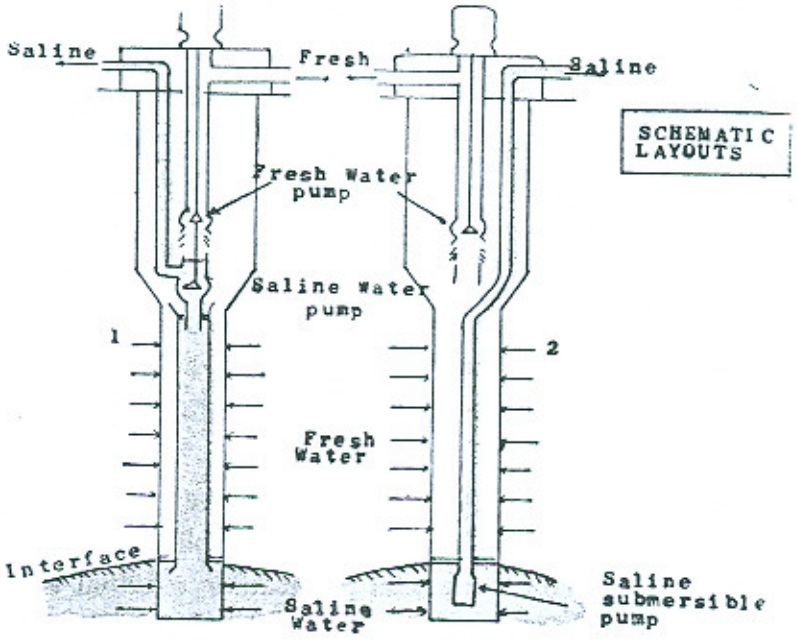


Fig. 16. Compound Tubewell

This type of tubewells were possible where the clay layer existed cutting off the fresh and saline ground water.

Recently a very useful idea has been put forth by Hunting to instal a compound tubewell. This suggestion is explained in Fig. 16. Two pumping bowels are proposed, withdrawing fresh and saline ground water separately. This type of tubewell can, however, be installed only at those sites where the formation thickness is sufficient to yield an economical discharge with a turbine pump; which can also create higher suction as compared to the centrifugal pump.

TABLE No. 19a—*Rohri North area. Lateral and vertical permeabilities, specific yields and specific capacities.*

Test Well No.	Lateral Permeability $x10^{-3}$ (ft./sec.)	Vertical Permeability $x10^{-3}$ (ft./sec.)	Specific yield of formation	Specific capacity of T/wells (cusecs/ft.)
T. W. 1*	1.52	0.080	0.12	...
T. W. 3*	1.74	0.150	0.12	0.200
T. W. 4	1.48	0.350	0.20	..
T. W. 5	2.04	..	0.09	..
T. W. 30*	1.17	0.002	..	0.111
R. N. 3	1.04	0.020	0.25	0.110
R. N. 4	1.32	0.020	0.25	0.195
R. N. 5	1.20	0.040	..	0.108
R. N. 6	1.19	0.021	...	0.194
R. N. 7	2.02	0.002	0.05	0.112
R. N. 8	1.83	0.050	0.25	0.184
R. N. 9	1.61	0.112	..	0.136
R. N. 10	1.46	0.060	0.35	0.142
R. N. 11*	1.50	0.240	...	0.143
R. N. 14	1.50	0.035	0.12	0.252
R. N. 15	1.61	0.026	0.03	0.149
R. N. 21*	1.38	..	0.03	0.124

TABLE No. 19a—contd.—*Aquifer characteristics, Rohri South area.*

Test Well No.	Screen Length (feet)	Lateral Permeability $x10^{-3}$ (ft./sec.)	Vertical Permeability $x10^{-3}$ (ft./sec.)	Storage coefficient of formation	Specific Capacity (cusecs/ft.)
RN 15	130	1.61	0.002	0.03	0.149
RN 18	70	1.72	0.060	0.17	0.102
RN 20	100	1.15	0.140	0.29	0.115
RN 21	105	1.38	..	0.03	0.124
RN 22	125	1.52	..	0.03	0.131
RN 23	132	1.08	0.022	0.12	0.128
RN 24	135	1.03	0.017	0.18	0.114
RN 30	155	0.84	0.001	..	0.079
RN 35	76	0.96	0.001	0.01	0.052
RN 35	76	0.96	0.001	0.01	0.052
RN 36	125	1.12	0.020	0.025	0.118

TABLE No. 19a—contd.—*Aquifer characteristics, Rohri South area.*

Test Well No.	Screen length (ft).	Lateral Permeability $x10^{-3}$ (ft./sec.)	Vertical Permeability $x10^{-3}$ (ft./sec.)	Storage coefficient of formation	Specific Capacity (cusecs/ft.)
TW 37	165	1.96	0.006	0.07	0.267
TW 38	160	2.59	0.025	0.18	0.267
TW 39	165	2.55	0.180	0.33	0.253
TW 40	105	1.53	0.150	0.39	0.120
TW 41	95	1.64	0.020	..	0.128
TW 42	95	1.76	0.009	0.10	0.131
TW 41	150	1.32	0.050	0.20	0.15

TABLE No. 19b.—*Vertical permeability determined for the Punjab Area.*

Test No.	Site	Vertical permeability determined by Jacob's Bessel Function Analysis, Cusecs/ft. $X10^{-3}$	Transmissibility determined in Jacob's Bessel Function Analysis, Cusecs ft.	Lithology of interval between water table and top of screen.
R-32	Chak Jhumra	0.02	0.45	2′ clay; 24′ fine sand; 16′ medium sand.
R-35	Muradwala R. H.	0.06	1.17	154′ sand with numerous clays streaks.
R-46	Nandipur	0.05	0.38	17′ clay; 137′ sand
R-55	Toba Tek Singh	0.04	0.40	43′ fine sand and silt
R-57	Kamrana R. H.	0.04	0.53	10′ clay, 60′ sand.
B-58	R. D. Vanike Disty	0.03	0.41	5′ clay; 60′ sand.
R-9	R. D. 1000 Khadir Branch	0.08	0.48	2′ clay, 16′ fine sand, 24′ coarse sand.
C-20	Kot Khan	0.01	0.23	5′ clay; 16′ fine sand.
C-29	Chak Saidu Phalia	0.12	0.47	70′ fine sand and silt.
C-40	R. D. 170 Shahpur	0.03	0.20	3′ clay; 68′ sand.
B-5	Renala Khurd	..	..	2′ clay; 93′ sand.
B-2	Pakpattan	..	..	2′ clay; 93′ sand.
B-9	Near Harrapa	..	..	14′ clay 46′ sand.
B-10	Arifwala	0.07	0.15	11′ clay; 55′ sand.

In order to reduce the mixing of saline and fresh water, pumping with a smaller depression is very helpful. A centrifugal pumping set has low suction and it is possible to use multiple strainers to exploit even a very thin aquifer. An idea of such a compound centrifugal fitted tubewell is shown in Fig. 17. It is possible to use two separate pumping sets working close by with strainer of one lying in the saline water and that of the other in the fresh water. Only one set with two separate pumps mounted on the same shaft of the electric motor can also serve the same purpose (Fig. 18).

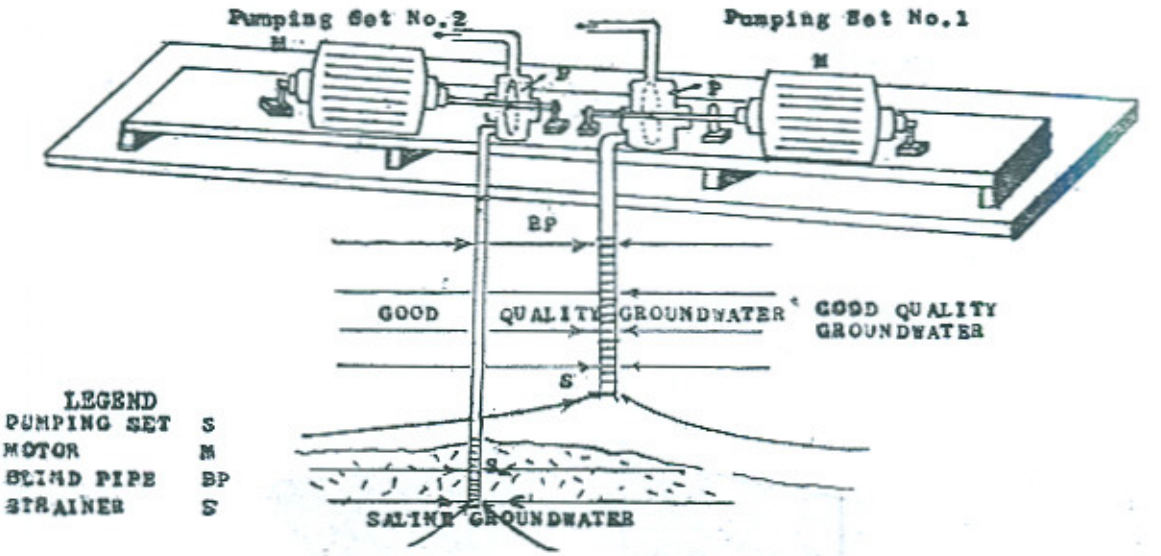


Fig. 17. Two Separate Pumping Sets
No. 1. Pumping good quality ground water
No. 2. Pumping saline water

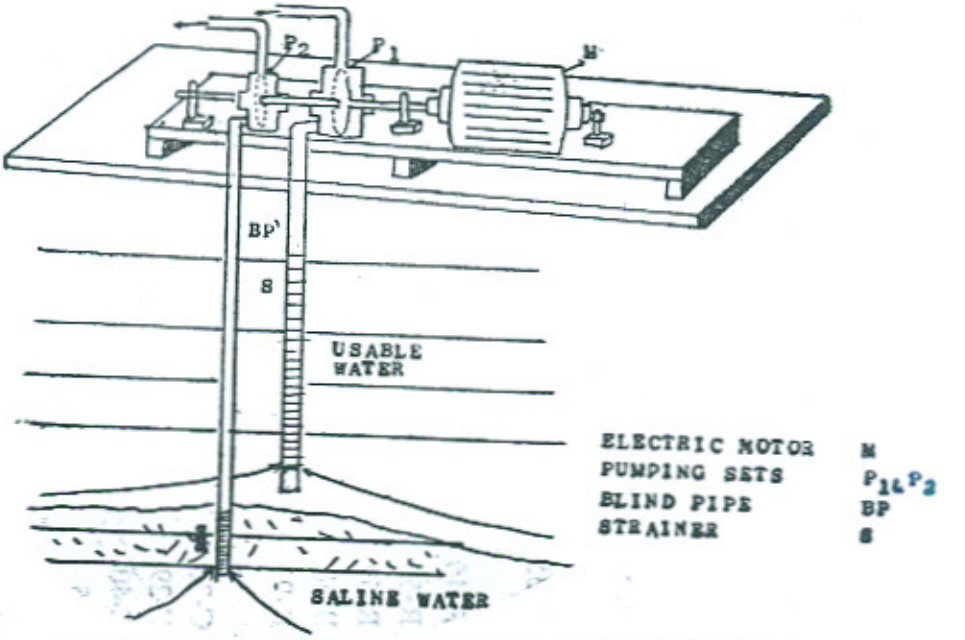


Fig. 18. Two pumps mounted on the same shaft of the Motor

If the formation of fresh water is very thin, multiple strainers, operated by the same pumping set or separately, can e installed as shown in Fig. 19. In this type of pumping, it should be the aim to withdraw as little of saline water as possible. Actually the strainer in saline zone is to be subjected to a greater suction than the tubewells working in the fresh water. This will avoid the intermixing of the two waters. This is possible by having a very short length of the strainer in the saline water zone. (See Fig. 20).

Such tubewells can be installed with great advantage by having full information about the quality of saline ground water. It can be made possible to pump as little of ground water from the intermediate saline water zone as to permit the mixing of the two waters and still keep the quality within usable range.

So far no such tubewell has been installed in the Indus Plains. The main purposes of this paper is to interest the irrigation engineers to install these types of compound tubewells. An experiment can be started on tubewells of Scarp area which are closed due to pumping of unfit water. Based upon the knowledge of the location of saline ground water, their strainer can be plu ged up to the depth of fresh ground water and a separate tubewell can be installed with blind pipe in fresh water zone and a short strainer in saline ground water. This measure will save the expenditure already incurred on these tubewells. Besides affecting drainage and eliminating the possibility of pumping saline water as suggested in the Scarp proposals of the Punjab and Sind, the possibility of replacement of saline water zone with fresh water also exists.

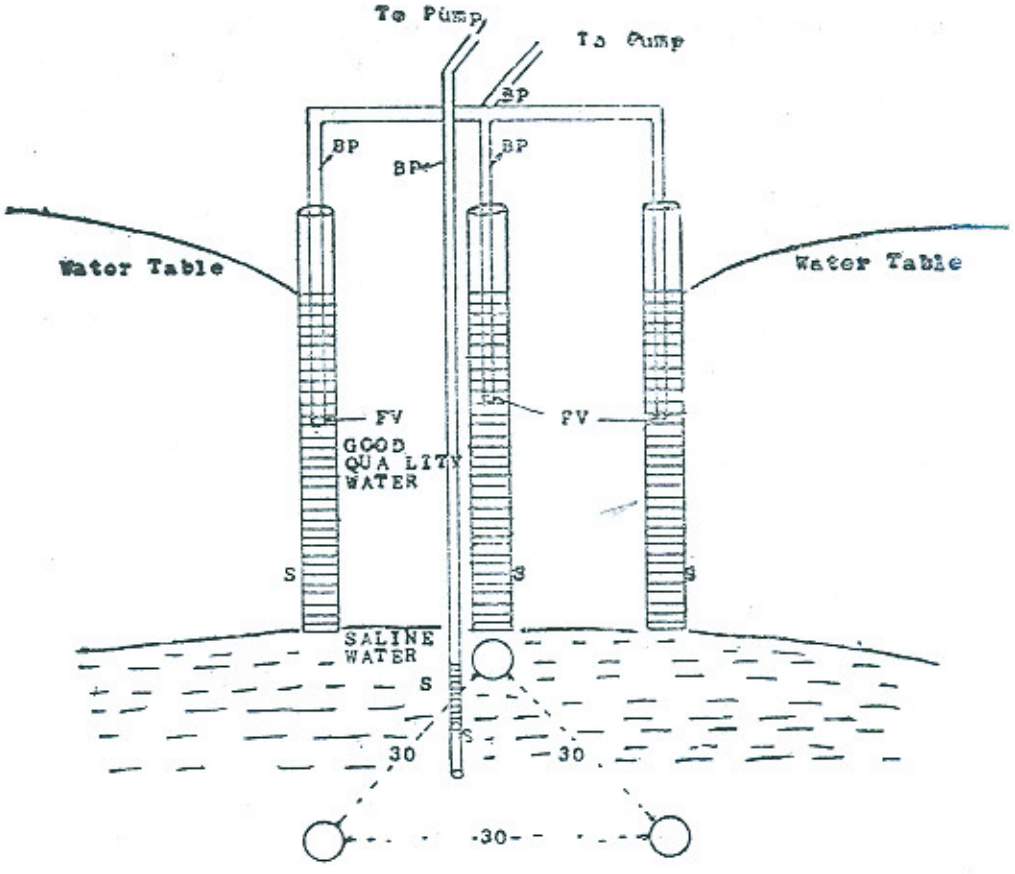
By this measure it will be possible to cheaply exploit the ground water recharge potential of about 22 maf. a large proportion of which is going waste at present.

Conserving Flood Run-off

In the beginning of this paper we have discussed the volume of water which runs off every year to the sea. The excess surface water is available during the two summer months and which cannot be utilized nor conserved in the existing storages, and hence flows out into the sea. There are no immediate possibilities to build storage to conserve this water. The construction of a surface storage is also very costly and takes a long time to complete. In West Pakistan, possibilities of conserving a part of this water in the sub-surface formation exists. These methods are described in this paper.

Some characteristics of the formation under the Indus Plains

(*i*) The formation under Indus Plains is high water yielding. Some thousand tubewells installed in the area have proved that with a bore depth



S - STRAINER
BP-BLIND PIPE
FV-FOOT VALVE

Fig. 19. A three strainer Tubewell with a Single well pumping Saline Water

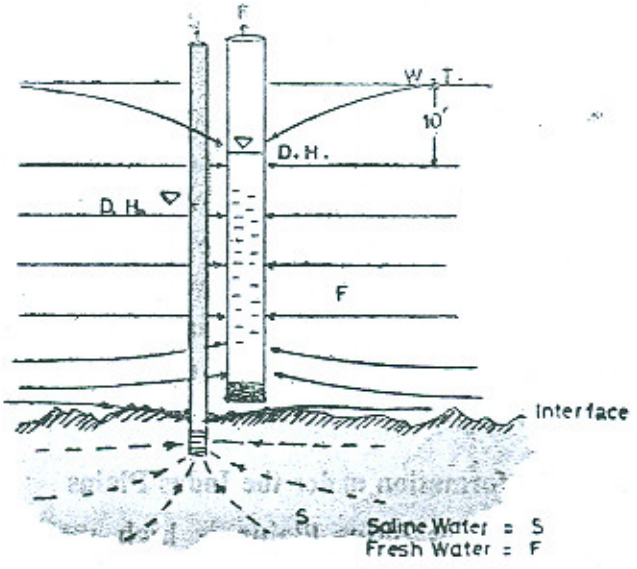


Fig. 20. Flow Lines in a Compound Tubewell

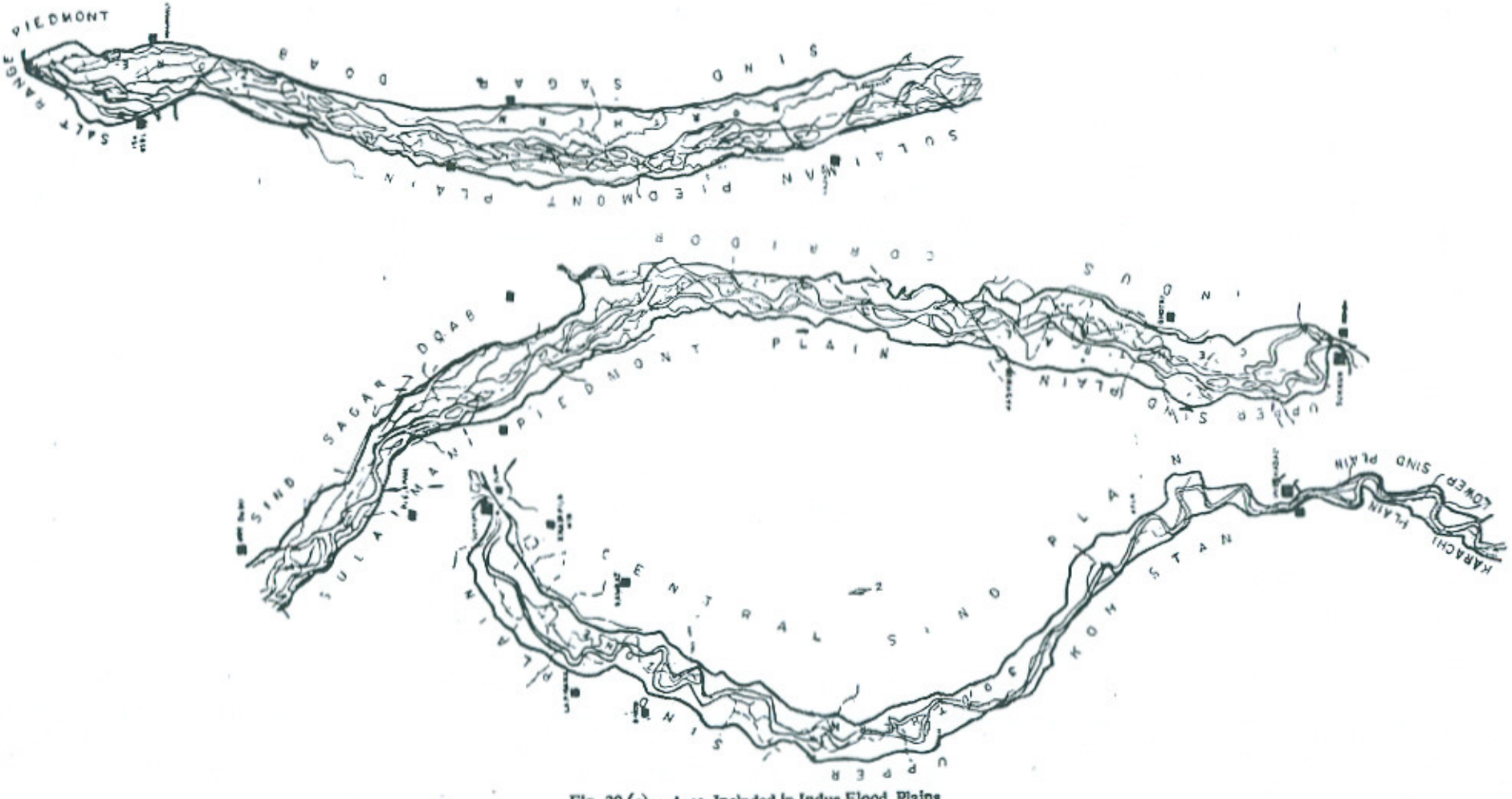


Fig. 20 (*a*). Area Included in Indus Flood Plains

of 200 to 300 feet, 18 to 22 inches in diameter and with a strainer length of 150 feet to 180 feet, it is possible to pump 4 to 5 cusecs with a depression of 5 to 8 feet per cusec.

(*ii*) The aquifer is one continuous connected formation so that pumping at a site results in drawing of water from extensive areas.

(*iii*) Many of the sites have perennial sources of surface water with sandy pervious beds, so that the ground water levels of those sites are influenced by the water levels in the surface sources. Replacement of pumped ground water is very quick. Such areas lie generally within the flood plains of the Indus.

In Scarp I, after intensive pumping for about nine years, the lowering of water table in the scheme areas of Beranwala, Chuharkana, Hafizabad, Pindi Bhattian is hardly 3 to 5 feet.

Similarly in Scarp 2 after five years of pumping the fall in ground water level is 2 to 4 feet. Khairpur area has also shown a lowering of 2 feet only after pumping for two years. These are sites where over-pumping with large number of tubewells is possible. Here the replenishipment of ground water is also very quick. There are many sites in the irrigated doabs where the top soil crust is thin and pervious with perennial canals existing on this type of soil. The main line canals particularly below falls or link canals in deep digging, are the sources of high percolation replenishing the aquifer.

There are some such areas even close to the perennial rivers. The triangular areas, enclosed by the two arms of the rivers, such as the Lower Thal in Muzaffargarh district, in Jhang near Trimmu and Multan close to Ravi and Chenab, receive persistent recharge from the rivers.

These sites have always high ground water level and are under the direct influences of the water level in the rivers. Lands within the active flood plains of the rivers are included in this category. The ground water levels in these areas often 5 to 20 miles wide are directly under the influence of the water level in the rivers.

The Indus active flood plains shown in Fig 20a is another example of this type of area directly influenced by seepage of the Indus. Actually in Sind (See Fig 12a,b) about 500 miles long area enclosed between bunds has many suitable sites for intensive pumping and getting fresh recharge every year during Monsoon months.

According to Hunting the total area enclosed between bunds is 1.9 m. acres of which the main river channel occupies 0.3 m. acres. The detail of the area between different reaches from Gudu to sea is as follows :

TABLE 20.—*Land use in Riverain Area* 1000 *acres.*

River reach	Abandoned Land	Non-Productive Lands excluding abandoned land	Mian River channel	Arable Lands	Forest Lands	Total areas between bunds
Gudu to Sukkur	13.7	198.36	71.0	188.34	94.56	565.86
Sukkur to G.M.	78.22	393.88	146.88	176.3	217.24	1012.52
G.M to the sea	27.24	121.96	81.22	32.53	75.18	338.12
Total ..	119.16	714.2	299.1	397.17	186.88	1916.5

It means that excluding the area of main river channel, the rest of the areas in between bunds constitute about 400, 1300 & 700 square miles between G.M. Barrage to the sea, Sukkur to G.M. Barrage and Gudu to Sukkur Barrage respectively.

Thus there is considerable area which can be dewatered in winter and recharged during summer flood season. The points, against storage in this area, are the withdrawal of river water by tubewells pumping and the adverse effect on the regeneration. The direct withdrawal from the river can be reduced by siting the tubewell away from the river edge. Hunting has worked out that siting a four cusecs tubewell, 8,000 feet from water edge, 120 days of pumping will draw only 2.7 per cent of tubewell discharge from the river. The proportion of river discharge drawn by a four cusecs tubewell by siting it 4000 and 8000 feet from water edge was as follows.

TABLE 21.—*Proportion of water taken from the river.*

	Proportion of well discharge from river			
Time from start of Pumping, days	Well at 400 ft. dis. from river	% of 4 cusecs dis.	Well at 8000 ft. dis. from river	% of 4 cusecs dis.
30	0.26	6.5	0.01	0.2
45	0.36	9.0	0.06	0.6
60	0.43	10.75	0.10	2.2
80	0.51	12.75	0.19	4.75
120	0.57	14.25	0.26	6.5
Average	0.37	9.25	0.11	2.7

Thus siting a tubewell at 8,000 feet away will not draw significant water from the river. The second serious point is with regard to the regeneration. The order of regeneration is high in the beginning when the river starts falling and with time, it continues to decrease. Hunting has estimated 0.6 maf. to be the regeneration between Sukkur to G.M. Barrage. No doubt pumping will affect the regeneration but the volume of tubewell water will be considerable and will include ground water which originally was wasted non-beneficially. The 300 square miles of area below G.M. Barrage will have no such problem. This area can also be used to conserve ground water if there is no problem of intrusion of sea water.

Similarly 1300 square miles of land between Sukkur & G.M. can conserve flood water in the underground formation. There are several sites in the Indus flood plains where ground water can be conserved. It may also be noted that this measure will have some other problems connected with the proper design of tubewells, their protection during floods etc., the details of which shall have to be examined.

How to store the surface water during periods of excess flows into the formation

Select a site prone to the recharge influences of the surface sources. Instal a number of tubewells concentrated close together. Operate them during low flow winter months from October to March or April. These wells will not operate during summer high flow months. In winter high withdrawals causing a sort of over-pumping will be carried out. The dewatered formation will be replenished during summer. Generally, tubewells working one mile apart have very small interference, but if these are big capacity wells pumping about 10 cusecs from one square mile, these can dewater a considerable extent of the formation. It is suggested to select a pervious stretch of lands, say about 10 miles long and 2 to 4 miles wide and instal submercible or turbine pump of about 3 cusecs capacity. Suppose these are one mile apart so that in an area of 20 sq. miles 30 tubewells will be in operation yielding say about 60 to 75 cusecs. This arrangement will dewater a zone of 20 sq. miles up to a depth of 15 to 20 feet. If the storage is taken as 25 per cent and with 10 feet of dewatering, one sq. mile of area will have an unsaturation of 62.5 m. cubic feet (about 1435 a. ft.) and from an area of 20 sq. miles a water storage equal to 1240 m. cubic feet (about 2870 a. ft.) will be available. This corresponds to at least 40 cusecs of water. If one million acre feet of water is to be stored, thirty-five such sites will be needed. Actually about 700 square miles dewatered to ten feet depth is needed. The increase in the size of pumping area and increase in the depth of dewatering can reduce the number of sites.

As to the cost of such a measure, installation of 30 turbine fitted tubewells of 3 cusecs capacity will cost about Rs. 15,00,000 and operating 35 such sites

will need a capital cost of Rs. 52.5 million. If the operation cost is taken as Rs. 5000 per cusec, their withdrawing of one maf. of ground water will cost Rs. 7.0 m. per year. This is a much cheaper way to conserve 1 maf. of surface water. Construction of a surface storage of this capacity will cost about Rs. 600.0 million.

The cost of installation can still be reduced by providing centrifugal pumping set and installing shallow multiple bore tubewells, for quick dewatering. This design will reduce the cost to one half of the tubewell having turbine pumps.

Effects on Regeneration of Rivers

The first objection against this suggestion will be the possibility of reduction in regeneration into the rivers particularly at Trimmu and at G.M. Barrage. The regeneration estimated by Hunting from Gudu to G.M. Barrage is about 0.25 maf. per 100 miles of the river. Between Gudu to Sukkur it is 2.0 maf. and from Sukkur to G.M. Barrage about 0.6 maf. Installation of pumping system in the flood plains of the Indus, can yield much more than this amount. The area in Sind, enclosed between bunds, is about 2500 square miles. The total surface area, required to conserve one maf. of water with 10 feet of dewatering, is 700 square miles. This is a much smaller area as compared to the large active flood plains, and other areas with possibilities of quick recharge. In fact Sind is in a much better position to adopt this system of water conservation. If we use only the flood plains of the Indus, we can develop large areas to conserve the flood run-off.

Some examples of deep dewatering operation in West Pakistan

Several deep dewatering operations have been carried out in the Indus Plains during the construction of hydroelectric stations. At Chichoki Mallian Hydel station, ground water in the waterlogged areas was lowered by 38 feet with the operation of ten tubewells with submercible pump and having short length of strainer up to a boring depth of 100 feet, beyond which existed 2 to 5 feet thick clay layer. The area dewatered was 250×150 square feet. The tubewells constantly pumped 16 to 18 cusecs of water during operation of Upper Chenab Canal 600 feet away from the site of construction, below Joyandwala fall, and having pervious bed. When the canal was closed, the quantity of water pumped in to maintain the dewatering level was reduced by four cusecs. Similar dewatering was done at Gujranwala, Shadiwal, Ravi Syphon and at many other sites in the Indus Plains. Thus by concentrated pumping, dewatering to any depth is possible even in waterlogged area and with pervious sources of seepage close by.

Dewatering and recharge of the formation takes nearly equal time

It is a common observation that a quick fall of watertable occurs in the initial few hours of operation of a tubewell. The fall continues to decrease with time. The cone of depression close to the well stabilizes in a short time and its influence continuously extends with time. Working a well for several days nearly stabilizes the cone of depression.

It has also been noticed that stoppage of pumping gives nearly the same type of recoup curve, quick rise in the first few hours of stoppage and slow rise subsequently. An example of such a case of development of cone of depression and its recharge after closure is shown in Fig. 23. This happens under similar

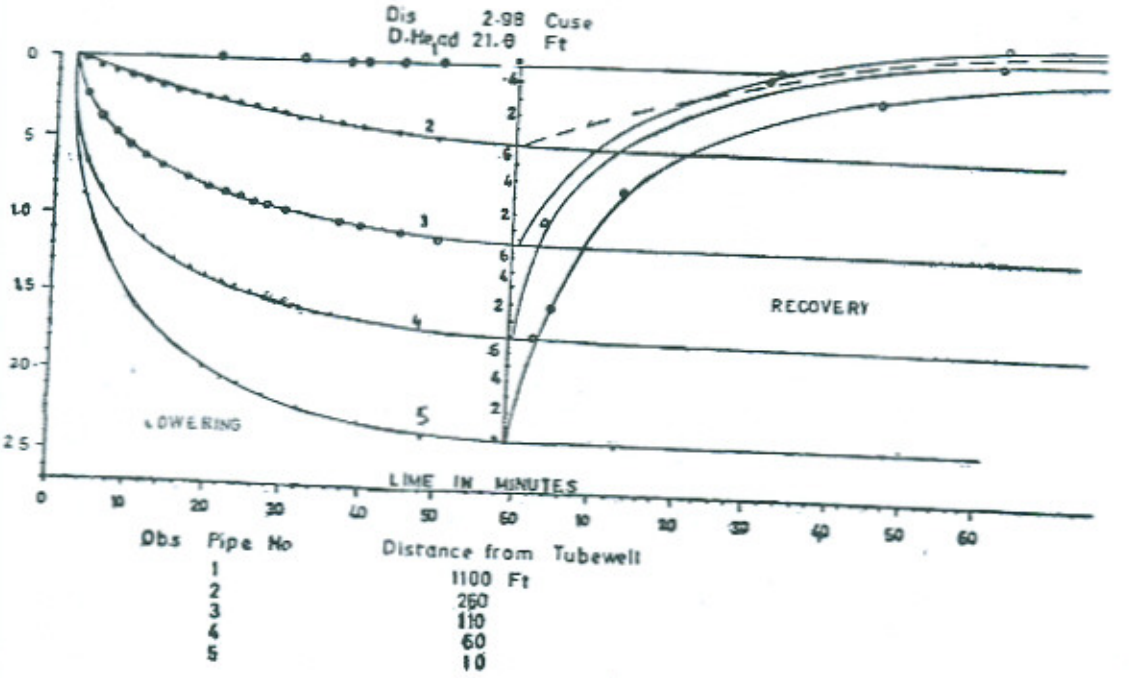


Fig. 23. Behaviour of Pipes to the West of Tubewells No. 8, Chuharkana Reclamation scheme 1st Hour of Running and Stopping for the same time.

condition during operation and during recharge but in summer the conditions are not the same as during winter. The recharge will take a much less time due to increase in the levels of the source of seepage and other causes of spreading of water, due to floods and monsoon rains.

Conserving flood water in unsaturated formations

In West Pakistan there are several sites, where watertable is still deep, formation is unsaturated, dry, and can hold large volume of water. Greater Thal is one big unsaturated region for which Tipton and Kalambach, Consultants to W.P. WAPDA, have already suggested a surface storage with the help of dikes

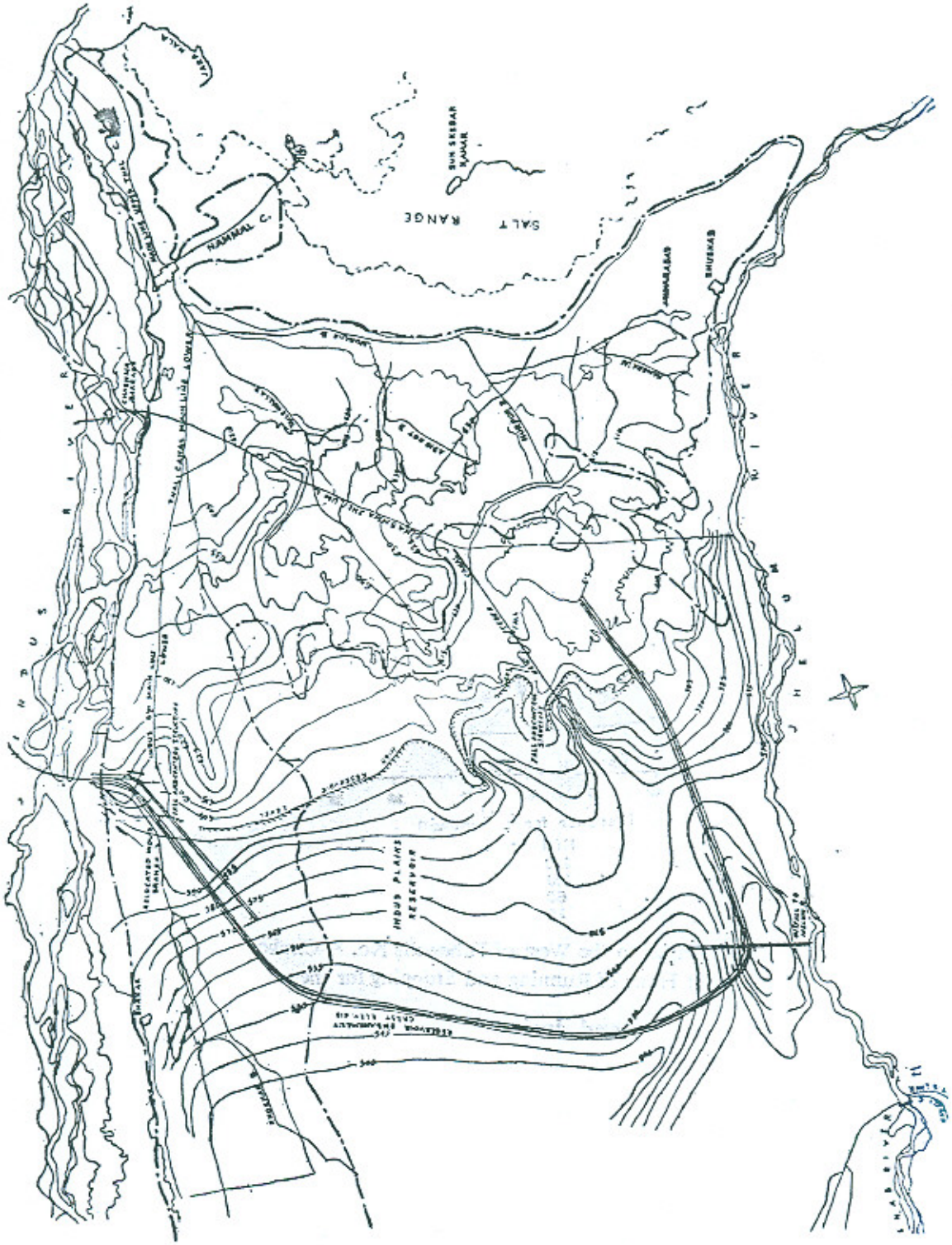


Fig. 21. Location of Indus Plains Reservoir Dykes inlet and outlet are shown



Fig. 22. Scarp 6, Disposal System for Pumped Saline Ground Water

and embankment. A storage potential of 10 maf. has been worked out. The site for location of the storage is shown in Fig. 21. It is suggested that instead of making it a surface storage, it can be made to conserve ground water. Actually ground water has already started to be accumulated in the Thal Doab.

In case of Scarp No. 6, for Panjned Abbasi Canal areas, it is proposed to pump 500 cusecs of saline water from the scarp area and discharge it into artificially constructed tanks in the adjacent waste lands (Fig. 22). The disposal of water is expected by evaporation. It is suggested that these very sites can be a source of flood water diversion and storage in surface as well as in the underground. The drainage of the area with saline ground water can, however, be effected by compound tubewells. Such unsaturated formation also exists in Cholistan next to the canal irrigated areas in Bahawalpur region. Suitable sites can be selected where at present the ground water is deeper than 50 feet.

Conserving flood water in depressions

There are many sites in the flood plains of the Ravi and Sutlej which used to receive water from flood spills. These sites needs to be marked out to store rainfall and flood spill. Some sites will be available in the old bed of the Beas. These can be converted to store rainfall run-off or flood water.

The possibility of ponds above Islam Headworks and even Suleimanki needs to be studied to store water. The dry beds of the Ravi and Sutlej also need to be investigated for possible recharging of the formation, which will dry out after complete diversion of these rivers by India.

Recharge Technique

So far irrigated areas of West Pakistan had an excess of ground water, resulting in waterlogging of some lands. Now with intensive utilization of ground water we shall soon be faced with falling watertable and it will become necessary to recharge the aquifer. Lahore city is one example of quick falling ground water. If we have to save the huge investment of the farmers who have installed thousands of centrifugal pumping sets, we shall have to start taking measures to recharge the aquifer.

The most common recharging device is an open type of well provided with filter at bottom, so as to check the inflow of clay and fine material. Recharging can also be carried out by the strainer which can be a feeding source to the aquifer. Some sandy beds with deep clay stratification can also be selected. The main problem will be choking of filter bed as it happens in case of water supply filtration tanks. Actually several experiments shall have to be carried out to develop a suitable technique to recharge the aquifer. The recharging technique is a big subject. It has not been dealt with in this paper.

The summary of the main inferences

1. The Indus Plains of West Pakistan constitute an area of about 50 m. acres. This extensive flat land is one of the wonderful gifts of nature.

The area of the Indus Basin lying within the boundaries of West Pakistan constitute 139 m. acres, the rest 61 m. acres forms a separate hydrological division of Kharan desert and Makran coast in Baluchistan.

2. Within the 71 million culturable acres of the Indus Basin, about 32 m. acres are canal irrigated and 7.6 m. acres depend upon rainfall.

3. The surface water resources of the area are out of the three western rivers, the Indus, Jhelum and Chenab, with a total annual flow of about 140 maf of which 82.3 maf constituting 58 per cent of the total flows during the three summer months of July, August and September.

This flow is much more than the present diversion capacity of the canals which is limited to 248,650 cusecs. The result is that about 40 maf of water, about 224,000 cusecs during each of 90 summer days, runs off to sea every year.

During the Monsoon months, 50 per cent of the annual rainfall occurs. This also is a cause of the flood flow of the rivers.

4. Ground water is another very important natural gift. Very few countries of the world possess such vast, soft, granular formation, filled to brim, with good quality ground water which has been built up during several centuries.

5. The development of irrigation system causing seepage and percolation further augmented the ground water resources. Harza, a consulting firm, has estimated that with 92.1 maf of canal diversions, 46.2 maf seeps into the formation, 32.6 maf in the northern and 13.6 maf in the southern regions, where presently the canal diversion has increased to 39 maf, raising the seepage correspondingly to 17 maf. The consultants of the World Bank have also estimated the annual recharge into the Indus formation equal to about 49.0 maf, up to 1975.

6. This volume of water, seeps on areas both possessing deep, fresh ground water and shallow saline ground water. The proportion of the seepage on the two areas according to the World Bank consultants is 34 maf and 15 maf respectively. In the Punjab, the saline ground water lies under about 25 per cent of the total irrigated areas whereas in Sind such areas constitute about 80 per cent of the total irrigated lands. Thus about 8 to 9 maf of fresh water is seeping on the saline ground water area in the Punjab and Bahawalpur and about 14 maf in Sind.

7. So far there is very little exploitation of this 22 maf, of water which is being added to the area possessing shallow good quality ground water followed by saline ground water. At present much of this is being wasted.

8. In this paper suggestions about the use of compound tubewells with single or multiple strainers and worked by centrifugal pump are put forth to recover a major portion of this fresh water seepage. Suggestions about the design to be adopted at different sites are given.

9. As to the conservation of a portion of 40 maf of annual run-off, it is suggested to mark all the various sites in the Indus plains which are under the direct influence of percolating canals and rivers. In those areas installation of battery of tubewells is proposed to dewater the formation to a depth of 10 feet during the winter months. An area of about 700 square miles dewatered to a depth of 10 feet will be able to store about 1 maf of water which will be recouped during the summer high flow months. The amount of conservation of water in the formation depends upon the selection of the various sites.

10. An estimate of cost shows that conservation of 1 maf of water in the formation and its utilization is cheaper and quicker than to construct a surface reservoir to store this amount of water.

11. It is also suggested that there are several sites in Thal, Cholistan and Bahawalpur, where the ground water is still deep and flooding of the areas with fresh river water will result in recharging the empty aquifer and thus conserve some water out of the annual run-off. There may be several sites where surface water could be stored in depressions, in abandoned headworks or in the old beds of the rivers. Such sites need investigations.

12. In this country, no work has yet been done on development of suitable design of a recharge well. It is time that research type studies are undertaken to select areas where various designs of recharge wells need be investigated to feed the aquifer.

13. The main purpose in submitting this paper was to draw the attention of the irrigation engineers to effect a change in their age-old concepts of irrigation system and now start introducing new ideas and methods to recover as much of the 28 maf of seepage and 40 maf of annual run-off to sea as possible. The paper is to point out new horizons in the utilization of water resources of the country.

ACKNOWLEDGEMENTS

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