Water Conservation Studies for West Pakistan

By
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West Pakistan surface water resources are limited to 140 *maf. Out of this* 83.5 *maf. are being diverted to irrigation canals for crops production. The present estimate is that* 36.4 *maf. of this diversion seeps underground and* 13.4 *maf. are evaporated or wasted. This loss is about* 60 *percent of the total diversion. Only* 40 *percent of the water let into the canals is being used for the production of crops.*

In this paper it is shown that at present there is no evidence about the deep percolation of 50,000 *cusecs of seeping water. On the other hand there are strong reasons to believe that this loss is being disposed of as evaporation from free water surface, evaporation from soil and excess evapo-transpiration by plants.*

It is also shown that reducing free water surface evaporation and taking down the watertable to 15-20 *ft. below surface, are measures by which a large component of loss by seepage and evaporation can be conserved and utilized. Although soil sealants, which can reduce percolation of earthen canals, are now giving promising results both with regard to reduction of seepage and cost, yet with the development of cheap tubewells, perhaps the reduction of seepage and consequent reduction of recharge of the aquifer may not now be permissible.*

INTRODUCTION

Although water occupies 3/4 of the total surface area of the world yet shortage of fresh water is being felt all over the world and every developing country is faced with the need for conservation of its water resources for their proper utilization. This is very true for West Pakistan which has 71 million acres of culturable land in the Indus Plains and only 138-140 maf. of water. So far about 20 million acres are kept under irrigated crops at a time out of the total of about 32 million acres for which irrigation facilities exist. For a proper sustained irrigation, the total flow is just sufficient to keep the existing irrigated land under crops. With the growing population, irrigation facilities have to be spread to other culturable lands but under the present circumstances even the existing lands are not being properly irrigated. A large quantity of

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surface water is wasted and lost. The purpose of this paper is to conduct a brief survey of the quantity of water being lost and to suggest means and measures to conserve the wastage.

ESTIMATES OF SURFACE WATER RESOURCES OF THE COUNTRY

The total annual surface flow of the three rivers, left to the share of West Pakistan after 1970, will be about 138.50 maf. It will constitute the flow of the Indus, Jhelum and Chenab. The discharge of each individual river being as under:—

Discharge in maf.

River		Max.	Min.	Average
Indus	..	115	69	29.25
Jhelum	..	29	15	22.00
Chenab	..	29	19	24.25
Total	..	173	103	138.50

At present (1960) the irrigated lands of West Pakistan are also receiving a considerable part of the annual flow of the three eastern rivers, the Ravi, Beas and Sutlej, which will after 1970 be completely diverted by India. Their individual discharges are:—

Discharge in maf.

River		Max.	Min.	Average
Ravi	..	9.30	4.25	6.73
Beas	..	20.20	6.25	13.23
Sutlej	..	17.40	10.25	13.83
Total	..	46.9	20.75	33.79

The flow of all the rivers of the Indus system is such that about 80% of the total discharge runs off during the six summer months. The 2½ months of monsoon carry the major flow. The proportion of the discharges of the summer and the winter six months of the three rivers is as under:—

River		Total maf.	Summer six months flow and % of total, maf.		Winter six months, flow and % of total, maf.	
Indus	..	90.3	76.4	83.4	13.9	17.6
Jhelum	..	22.7	18.1	79.4	4.6	20.6
Chenab	..	25.0	20.2	81.0	4.8	19.0
Total	..	138.0	114.7	81.0	23.3	19.0

The present diversion of water from all the six rivers for the lands of West Pakistan is 83.50 maf. The rest goes waste. A major component, constituting 61 maf. runs off to sea mainly during the monsoon months. About 4.0 maf. percolates and about 16 maf. is wasted. These are the latest (1965) estimated values by Harza Engineering Company (1)* and are based upon the existing data of the country. The detail is given in table I.

The barrages in the Northern Region, mainly in the Punjab and Bahawalpur can divert 114 maf. The three barrages in Sind can further divert 87 maf. The water diversion capacity in each doab in the area is as under:—

Punjab	Capacity in cusecs
Thal canal	6000
Taunsa canals	25058
Chaj	14231
Rechna	57742
Bari	28573
S. V. C. in Bahawalpur	24834
Total	156438
Sind	
Guddu	36529
Sukkur	41665
G. M. Barrage	41272
Total	119466

ESTIMATION OF LOSS OF WATER

The earliest estimate about the loss of water from the irrigation canals was put forth by Kennedy. It was re-estimated by different approaches by Benton, Blench and Khungar etc. Their estimate expressed in percentage of flow showed that about 45 percent of the water let into a canal system was wasted during the delivery:

Canal system	Kennedy	Benton	Blench	Khungar
Main canals ..	5	16.4	5	15.5
Branches ..	15		15	
Distributaries ..	6	6.1	7	5.4
Water courses ..	21	20.2	20	6.5
Total ..	47.0	42.7	47.0	37.4
Farm losses ..	25	19.1		

*Numerals in parentheses refer to items in the list of references at the end.

The farm losses at the field were estimated separately and these amounted to 20-25 percent so that hardly 35 percent of the water diverted at head of a canal was usefully consumed by crops.

Harza has now estimated the total loss of water. It is separated into seepage and evaporation. The detail is given in table I. Out of total diversion of 83.5 maf. in the whole of West Pakistan, the percolation occuring during conveyance constitute about 30 percent, *i.e.*, 23 maf. and evaporation about 10 percent, *i.e.*, 8 maf. The total loss of 40 percent is very near to the estimate of Benton. The estimate of field losses is taken at 25 percent *i.e.* 13.6 maf. out of total diversion, only 54.5 maf. are spread on the fields. This estimate nearly corresponds to the value determined by Kennedy.

According to Harza, 36.4 maf. of water is seeping into the ground. The main seepage is from the canals which is 23 maf. constituting about 64 percent of the total seepage. The rainfall contribution is only 1.2 maf. and that from rivers is 4 maf. The evaporation and other surface losses including those from fields are 13.4 maf.

The estimate of Revelle Panel of Scientists about the seepage loss from canals was slightly different from that of Harza. For the Punjab and Bahawalpur canals the Panel of Scientists estimated it as 13.9 maf. For Sind region it was estimated equal to 11.5 maf. The total seepage according to Panel was thus equal to 25.4 maf. Their estimate of loss by evaporation was 6.8 maf. for the Punjab and Bahawalpur area and 5.7 maf. for Sind. Panel assumed the loss by evaporation equal to 15 percent whereas Harza consider it equal to 10 percent. Except for a minor adjustment of figures and inclusion of the field losses, the two estimates equal to 60 percent loss out of that diverted at the head of barrages. This loss of 50 maf. out of a total 83.5 maf. is a huge component. Of this about 49,600 cu. ft. of water per second are seeping under ground and about 18,600 cu. ft. are being lost by evaporation every second.

DISPOSAL OF 68220 CUSECS OF WATER

There can be only two means for the disposal of this water, either by deep sub-soil flow or by evaporation and evapo-transpiration.

(*a*) Deep percolation and sub-soil flow

As yet there is no information about the direction and magnitude of sub-soil flow. There are, however, evidences which show that the sub-soil flow is not as pronounced as to account for a flow of 50,000 cusecs.

A study of groundwater levels and its salinity characteristics show that sub-soil flow has been causing the accumulation of water in deeper depressions within the country rather than to flow to the sea. Rivers had always remained

a feeding source to the groundwater and the central regions of wide doabs, far away from the rivers, had been the areas to get the recharge from them. The sub-soil gradient was steep towards the centre of doabs as compared to the surface which was towards the slope of the land. Confirmation of this statement is had from the quality characteristics of the groundwater. Regions through which fresh water flowed were washed off the salts and where it accumulated caused concentration of salts. When it will be possible to use Radio Isotopic technique to determine the life of water at different depths it is sure there will be confirmation of this conception. The groundwater quality of West Pakistan is shown in figure I. It supports the conception of the accumulation of seeping water in the centre of the doabs. This argument is put forth to show that fresh water seepage had not flown towards the sea rather it had been accumulating within the country. It is true that in the northern regions, in the Punjab, there was more spreading of surface water, there was more rainfall, and more flood spills from Nullahs. These sources of fresh water washed 77 per cent of the land in the Punjab and accumulated the salts in the rest 23 percent of the area. The table below gives the fresh water and saline water areas.

TABLE

Region-Doabs	Total area	Saline area, salts above 1000 ppm.	Good water quality area, salts less than 1000 ppm.
	Areas in million acres		
Rechna ..	4.70	0.70	4.00
Chaj ..	2.00	0.42	1.58
Thal ..	5.30	1.48	3.82
Bari ..	4.40	1.76	2.64
Total ..	16.40	4.36	12.04

The groundwater on the Eastern side towards the Rajputana desert is both deep and saline. Fresh water has not flown towards that side which in prehistoric periods was the region where many of the present rivers of Indo-Pakistan flowed.

(*b*) Uniformity of rise of groundwater after Irrigation started

Another point which supports the conception of the accumulation of sub-soil flow in the depressions is the rise of groundwater levels after the

introduction of canals in the irrigated regions of the Indus Plains.

It was noted as shown in table below that the rise of groundwater level ranged between 1 to 2 ft. in all the regions. The rise in water level in the Northern as well as in the Southern areas remained the same so long the groundwater was deeper than 20 ft., beyond the influences of evaporation and evapotranspiration.

	Thal	Chaj	Rechna	Bari	Sukkur
Rise per year from deeper Groundwater.	1.75	1.7—2.0	1.8	1.0	1.0

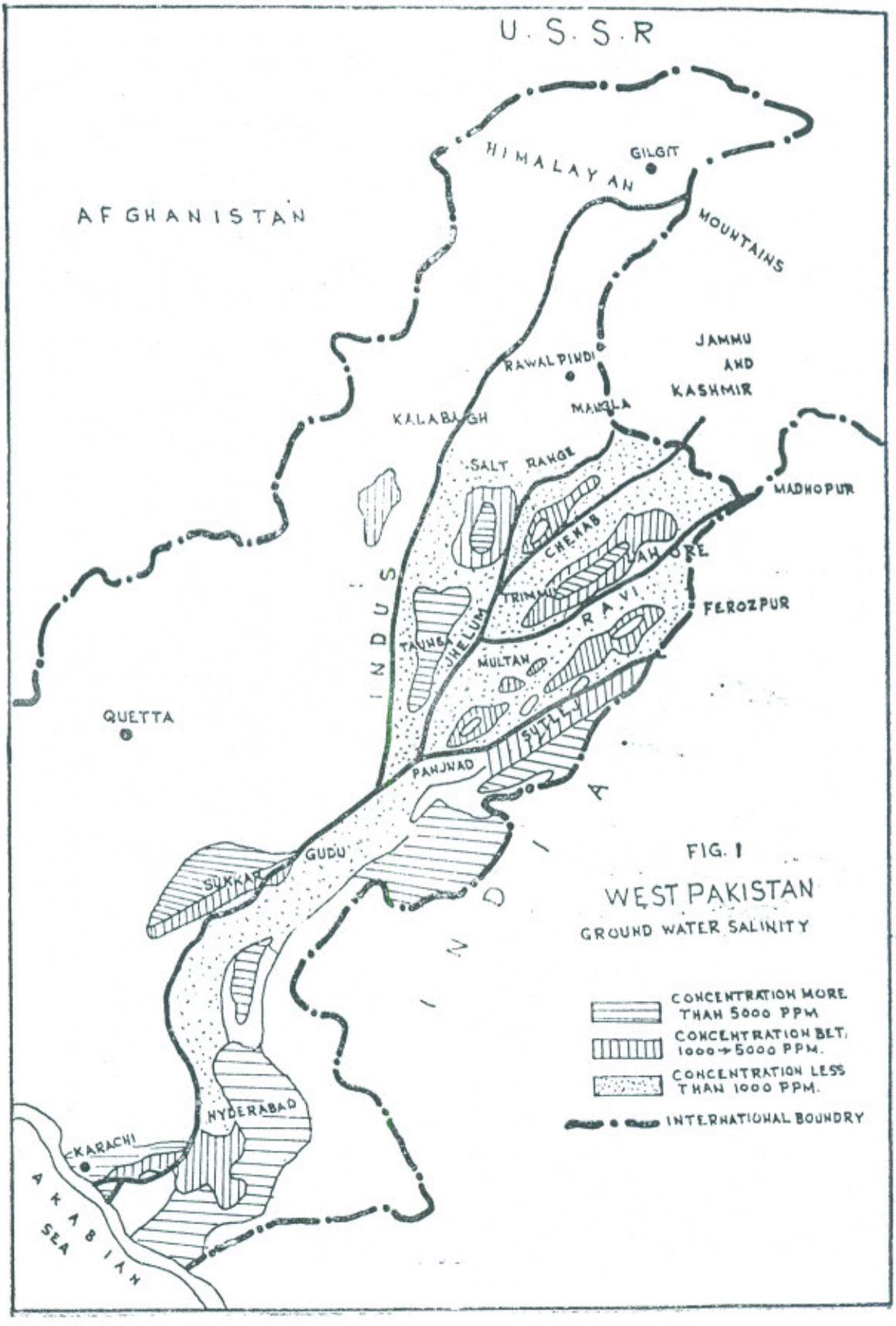
(*c*) Characteristics of the subterranean formation

The third argument in favour of the limited sub-soil flow is based upon the nature of the underground formation. In the Northern regions the hard bed rocks lie at very great depths, except in some areas where their peaks have appeared. Above the rocks, in a depth of 1000 to more than 5000 ft. exists the alluvium brought down by the rivers.

In Sind no extensive boring has yet been carried out but there are evidences that lime stone formations exist close to surface near Sukkur and Kotri. Thus in West Pakistan there appear to be three obstructions to very deep flow. The first is the extension of Aravelli mountains with out crops at Shahkot, Sangla, Chiniot, Kirana etc. Except at the out crops, the general depth of rocks is more than 1000 ft. The second and third obstruction exist near Sukkur and Kotri. Little water can percolate through the rocks. Sub-soil flow must take place through the top alluvium.

These deposits contain sand, silt and clayey layers. Shingles and stones are generally not in existence. Sand is also not coarse but of fine and medium grades. Clay deposits of small thicknesses exist without any order of location. They exist at all depths even close to the bed rock and in the rest of the depth appearing in the form of small lenses. So far no interrelation of the existence of clay lenses has been made with the groundwater quality but it appears that wherever these have existed in larger numbers, the quality of groundwater had remained unsatisfactory. Even close to foot-hill and in the flat plains there are pockets of saline groundwater, enclosed between good quality water. The existence of the clay obstructions reduces the possibility of sub-soil flow.

All these arguments are put forth to prove less possibility for the 50,000 cusecs to flow away to lower regions, to the sea or to other unknown areas. A persistent sub-soil flow of about 20,000 cusecs in the Sind area should have improved its groundwater quality to some extent. But 5 to 6 million acres of the Lower Sind have saline groundwater existing very close to the surface. Even in the irrigated areas under the influence of Sukkur Barrage canals


U.S.S.R
HIMALAYAN
GILGIT
MOUNTAINS
AFGHANISTAN
JAMMU
AND
KASHMIR
RAWALPINDI
MANGLA
KALABAGH
SALT RANGE
MADHOPUR
CHENAB
LAHORE
TRIMMU
RAVI
FEROZPUR
INDUS
JHELUM
TAUNSA
MULTAN
SUTLEJ
QUETTA
PAHJNAD
GUDU
SUKKAR
INDIA
HYDERABAD
KARACHI
ARABIAN SEA
FIG. 1
WEST PAKISTAN
GROUND WATER SALINITY
CONCENTRATION MORE THAN 5000 PPM
CONCENTRATION BET. 1000→5000 PPM.
CONCENTRATION LESS THAN 1000 PPM.
INTERNATIONAL BOUNDRY

during the last 30 years, improvement in ground water of only the top 40 to 60 ft. has taken place.

In the northern regions, 30,000 cusecs are constantly seeping. The direction of sub-soil flow and their magnitude which has not yet been determined will confirm the conclusions. The disposal of 50,000 cusecs is not mainly by sub-soil flow or deep percolation but as will be shown further, is due to evaporation and evapo-transpiration. The evidences collected recently points to this type of possibility. If this were so then counter-measures to reduce evaporation, evapo-transpiration and even seepage losses will yield large volumes of water for utilization on the land.

AMOUNT OF WATER LOST BY EVAPORATION FROM FREE WATER SURFACE

The loss of water by evaporation can either be from free water surface or from soil surface. Recently an analysis of the available data on evaporations from free water surface was carried out. It was based upon actual observations taken at sites spread all over West Pakistan. These were supplemented by observations conducted at Niazbeg. By a correlation of the Niazbeg observations with the actual observations, it was found possible to prepare an estimate of free surface evaporation at all important sites in West Pakistan (2).

The annual loss of water from important canals and dam sites in West Pakistan was worked out on this basis (2). The free water surface evaporation ranges between 3.7 to 8 cusecs per square mile. The sites of Dams, like Tarbela, Bolan, Darawat, and Hub have a large order of evaporation. Some of the important projects which impound water for diversion into the canals are located in areas which lose about 5 cusecs from a square mile of the surface. In this estimate it is shown that Kalari Lake, Mangla and Tarbela Dam, are or will be losing: 397.80, 587.12 and 642.19 cusecs of water respectively. Even small storages like Baran Dam are a source of loss of about 15 cusecs of water. Every cusec saved will be a gain of about 5000 rupees to the department and for irrigation of about 150 acres of land. The present estimates of loss of water by evaporation as per table I is 18,000 cusecs. This is expected to increase to 18 million acres ft. about 25,000 cusecs from its present estimate of 13.4 million acres ft. (18,000 cusecs) by 1975. Some of the water being lost or that will be lost from storage, ponds above barrages and from lakes can be saved. Saving from Kalari lake alone will give 350 cusecs worth Rs. 17,50,000 per year. Saving [15 cusecs from Baran Dam and about 10-12 cusecs from Rawal Dam can be worth Rs. 75,000 and Rs. 60,000 per year.

REDUCING FREE WATER SURFACE EVAPORATION

Many countries of the world are experimenting to develop oil or fatty substances which can be spread on the surface of water to reduce the evaporation losses. The general trend is to use fatty materials in the form of Alcohols, molecule of which have got a property to combine with the water molecules and form a film on the water surface as thin as a single molecule. The common material being used are cetyl alcohol (c_{14}), ethyl alcohol, stearyl alcohol (c_{18}), ceramol, siponol and aldol etc.

The Irrigation Research Institute has started experiments with various materials for reducing evaporation. It has been determined that a 5 percent solution of paraffin wax in turpentine oil spread on the water surface at the rate of five gallons per acre at a cost of Rs. 15.0 reduces the evaporation by 60 to 80% (see table below). The next promising materials appear to be cotton-seed oil, ground-nut oil, which reduce the evaporation by 60 and 40% respectively. The use of cetyl alcohol, however, reduces evaporation loss by 25%. These are yet laboratory scale experiments and may prove effective in the field. Their present costs are also high but experiments are yet in the preliminary stages.

TABLE

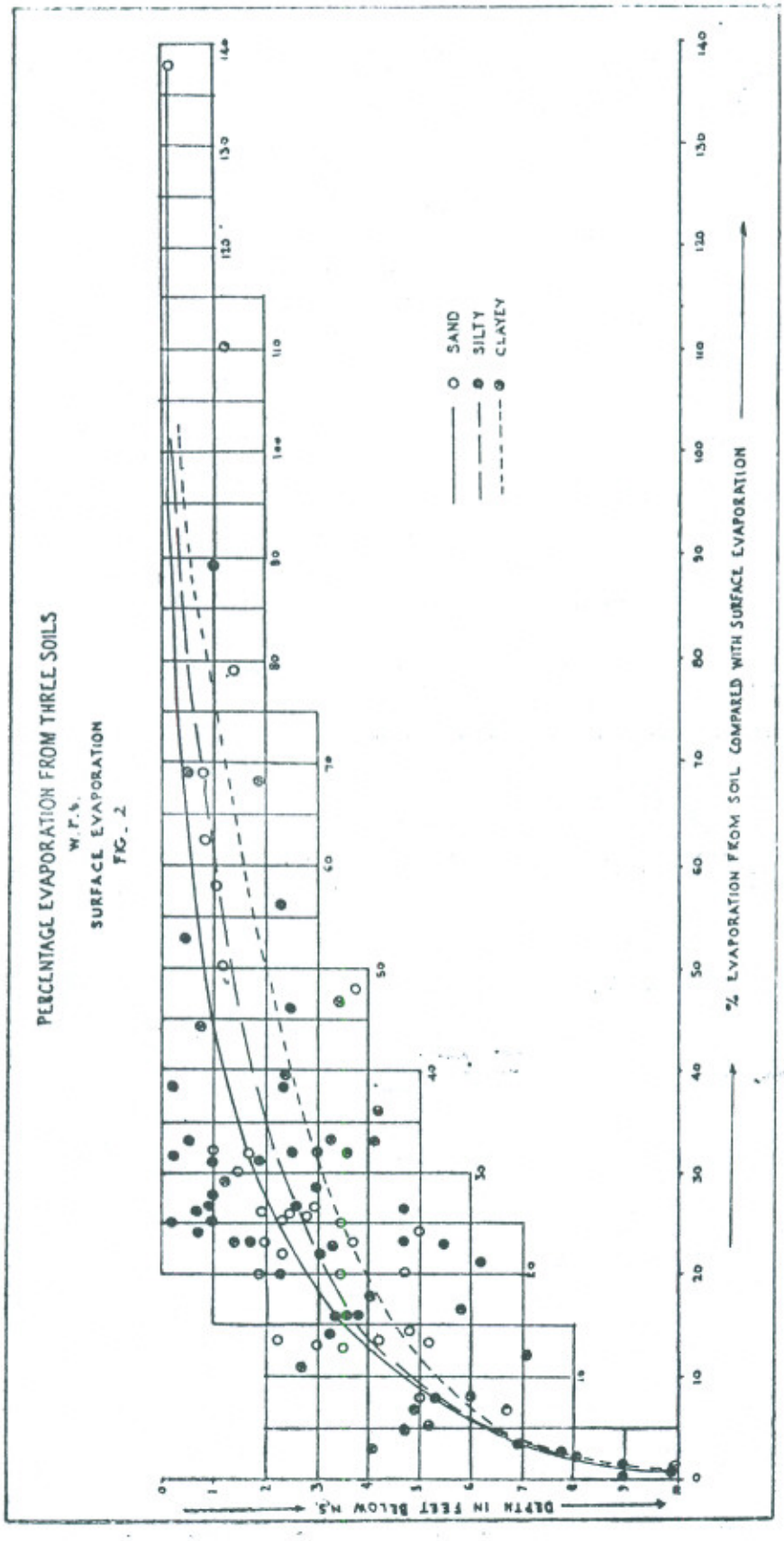
Retardent	% Reduction in Evaporation	Rate of use per acre. gallons	Cost per acre. Rs.
Paraffin wax in turpentine oil ..	75	5	15.0
Ground-nut oil 5% solution ..	43	6	25.0
Cetyl alcohol 3% solution ..	29	7	23.0
Cotton-seed oil ..	58	7	20.0

It may be noted that in this country research on these lines has only recently been started and its future seems to be very hopeful.

LOSS OF WATER FROM BARE SOIL OR LAND KEPT FALLOW

This is the second source of loss of water next to free water surface. As will be explained shortly, a large amount of water is being lost due to the present high watertable.

After the introduction of Irrigation canals, the ground watertable started to rise and by 1959, the depth of groundwater in the whole of West Pakistan existed as shown in table 2. The groundwater level within a depth of 5 ft. existed in about 1 million acres ft. of Rechna and Chej Doabs. Bahawalpur and Derajat Circles have also large areas with this level of groundwater. In about 2 million acres of the land, ground-watertable existed, in 1959, withi


PERCENTAGE EVAPORATION FROM THREE SOILS
W.P.S.
SURFACE EVAPORATION
FIG. 2
SAND
SILTY
CLAYEY
% EVAPORATION FROM SOIL COMPARED WITH SURFACE EVAPORATION
DEPTH IN FEET BELOW M.S.

5 ft. and in about 12 million acres within 10 ft. In another 7.7 million acres it existed within 15 ft. In all about 22 million acres of the Indus Plains had ground water levels within 15 ft.

Loss of water takes place by evaporation from a soil surface. It is more if the surface is bare and is reduced, if it has a cover of some crops. With water-table between 0 to 5 ft. or with watertable at an average depth of about 2.5 ft., the loss of water by evaporation is about 50% of that which takes place from the free water surface. In case of watertable between 5 to 10 ft. the loss by evaporation is about 15 to 20 percent of the free water surface evaporation. With watertable between 10 to 15 ft. the loss is reduced to only 5 percent of the free water surface. These results are based upon experiments conducted in the Irrigation Research Institute on an estimate (3) of evaporation from bare soil surface with watertable maintained at various depths. The results of studies are reproduced in Figure 2 which gives the order of loss by evaporation from soil surface with changes in depth of watertable. If we assume that the soil is bare which is generally not the case, then the amount of water lost per year from about 22 m.a. of land works out to be 19 maf. as explained in table below:

Area m.a.	Watertable ft.	Loss by evaporation in maf.	Evaporation in cusecs	Evaporation in ft per sq. ft. per year
2	2.5	5.0	6,850	2.5
12	7.5	12.0	16,440	1.0
7.7	12.5	1.92	2,630	0.25
Total 22	..	19.0	26,030	..

This high order of loss has been obtained assuming that the soil surface was kept bare and exposed to sunshine. A soil with cover or under shade gives less evaporation. This has not yet been determined but even a loss of water, 50% of the above figure still remains significant.

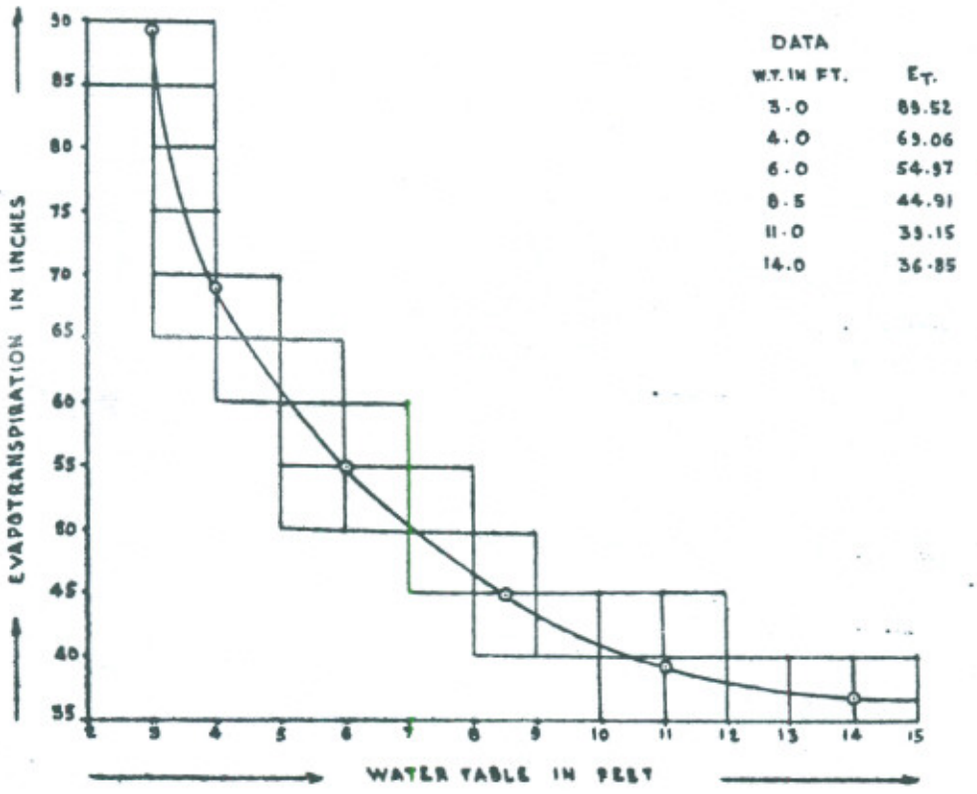
LOSSES BY EVAPOTRANSPIRATION

The third source of loss of water is due to evapotranspiration taking place from crops, by trees and by weeds growing in waterlogged soils. In this section, the loss of water as caused by excessive evapotranspiration by crops is given. Every crop needs a certain order of water for its maturity. The requirement of a crop is known from experience in the country and can be worked out by some empirical relations based on the elevation, percentage sunshine hours and mean average temperature and a certain factor depending upon the nature of the crop. One such relation is due to Blaney-Criddle and

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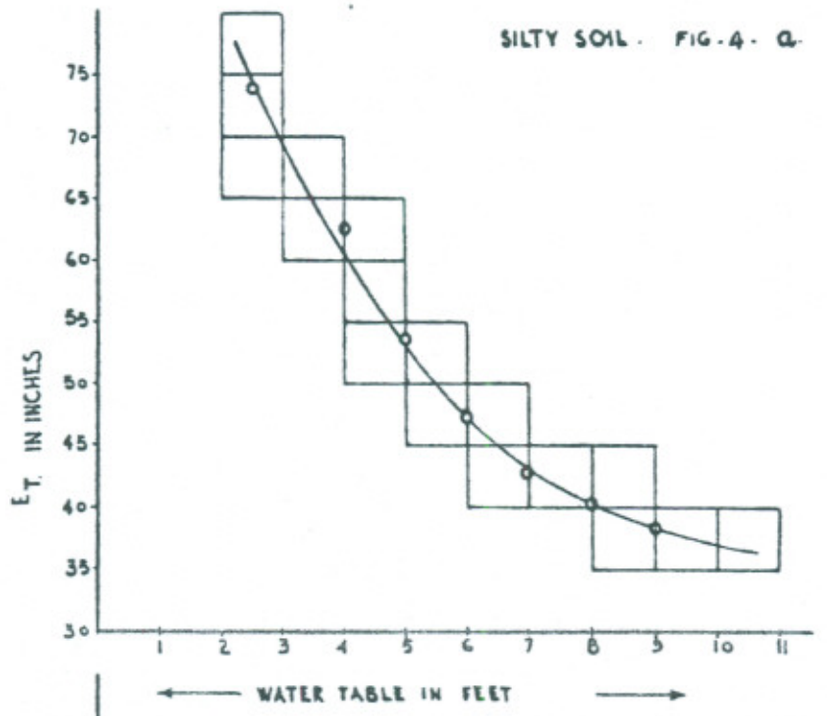
EVAPOTRANSPIRATION BY SUGARCANE
AT DIFFERENT DEPTHS

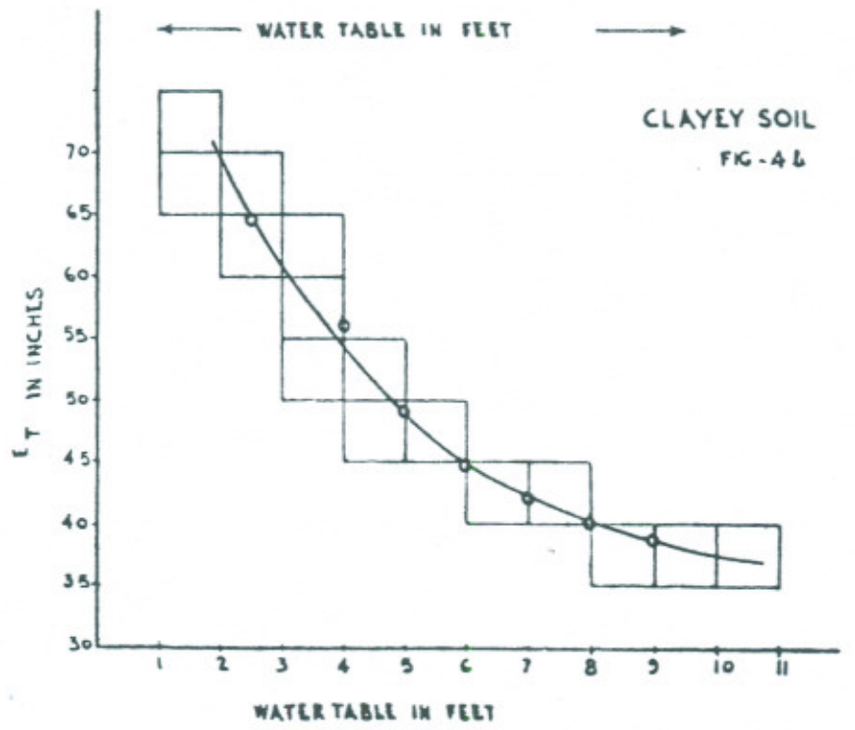
FIG. 5



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15 12 65

EVAPOTRANSPIRATION BY COTTON L.S.S
AT DIFFERENT DEPTH





is expressed as $U = K\Sigma Pt = KF$. In this country water requirements of some crops for the Punjab conditions have been worked out by actual experience. For some important crops, these are as under:

Name of Crop	Consumptive Use in inches
Sugar Cane	52.0
Cotton	33.0
Wheat	18.0
Maize	21.0
Barley	11.7
Chari	26.2

In these estimates, no consideration has been given to the nature of soil formation and on the position of water table. Both these items have important influence on the water utilization by crops. Investigations have shown that the position of groundwater affects the amount of water transpired. With high watertable, the crops evapotranspire large volumes of water till the plants get drowned and are killed. During the last three years investigations have been conducted on Sugar Cane, Cotton Crop and Wheat with changes in level of the groundwater. It was noted that the crops transpired large volumes of water with the rise of water table. In Fig. 3 is plotted the consumption of water by Sugar Cane Crops. When water table is kept at 3.0 ft. the excess water transpired by Sugar Cane amounted to 140 percent when compared to that consumed with watertable at 14 ft. The excess consumption with watertable at 7.5 ft. and 12.5 ft. amounted to 30 & 6 percent respectively. Similar studies were conducted with cotton crop. The water consumed by the crop under different positions of watertable is shown in Figs. 4 a & b. both for clay and silty soils. The percentage of excess water consumed with respect to that with watertable at 9.0 ft. amounted to as under:—

Type of soil	% excess water transpired with watertable	
	2.5 ft.	7.5 ft.
Clay soil	102	27
Silty soil	131	30

A silty soil has high capillarity and evaporates more water. With deep watertable percentage loss both for clay and silty soils become equal. The excessive evapotranspiration over their actual requirement, due to the high watertable is confirmed by all crops. Figures No. 5 and 6 are reproduced from the work of Thampson (4) and Blaney (5). These also confirm the results noted above. There is thus no doubt in the statement that under high watertable waste of water by evapotranspiration increases.

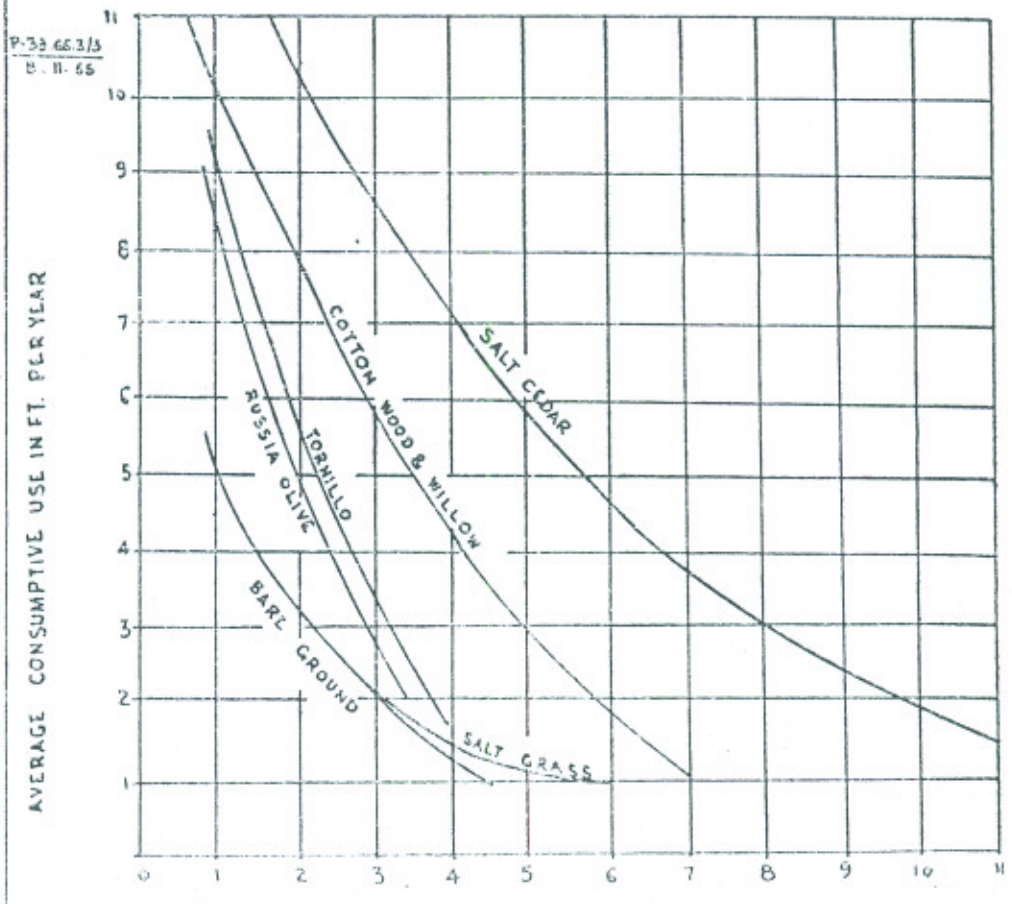

P-33 66.3/3
E. 11. 65
AVERAGE CONSUMPTIVE USE IN FT. PER YEAR
SALT CEDAR
COTTON WOOD & WILLOW
RUSSIA OLIVE
TORHILLO
BARE GROUND
SALT GRASS
DEPTH TO G. WATER IN FEET.

FIG. 5

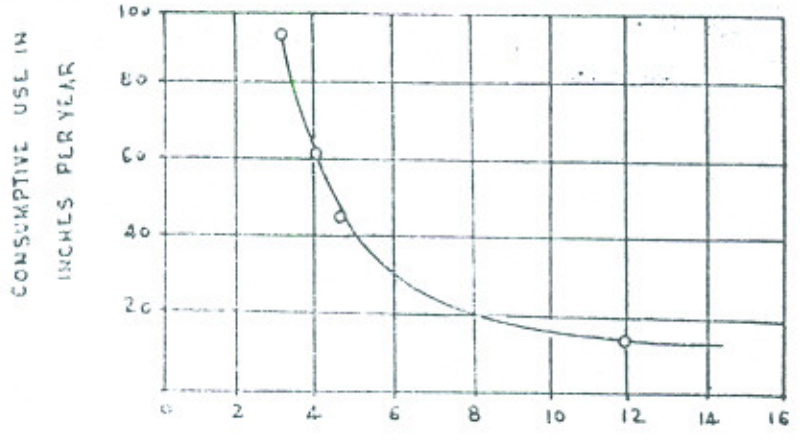

CONSUMPTIVE USE IN INCHES PER YEAR
DISTANCE OF WATER TABLE BELOW GROUND SURFACE IN FEET

FIG. 6

ESTIMATE OF ACTUAL WATER LOSS

Below is an example of water loss worked out for Sheikhupura and Gujranwala Districts. The acres under sugar cane and cotton crop in Gujranwala and Sheikhupura Districts were as noted below. Both these crops waste about 30% excess water when watertable is kept at 7.5 ft. Assuming actual consumption of sugar cane at 52 inches and of cotton at 33 inches, the excess consumption is 15.6 inches for sugar cane and 9.9 inches for cotton. The wastage works out 95,000 a. ft. for sugar cane and 52500 a. ft. by cotton crop for the two districts:

Districts	Cotton crop acres	Sugar cane acres	Excess water in term of a. ft. consumed with W.T. at 7.5 ft.	
	1	2	by cotton	by sugar-cane
Gujranwala ..	18000	24000	15000	30000
Sheikhupura ..	45000	52000	37500	65000
Total ..	63000	76000	52500	95000

Similar is the case with other crops. Only two crops for two Districts which are not sugar cane or cotton producing area, waste about 0.15 maf. of water.

The total culturable area of each of these districts is about 1.5 mac. If 30% of this land is kept fallow with 1.0 ft. per year of water lost from bare surface, the loss is 0.45 maf. With covered surface it will be, say, 1/3 of this value.

WEEDS AND TREES ADD TO THE LOSS OF WATER

In addition to evapotranspiration by crops, water is lost by weeds and trees growing in excess moisture area. The Irrigation canals are sources of percolation and the flow takes place through the embankments. The canal berms in particular have a high level free water surface. In sandy reaches the percolation is still high and strips of land several feet wide, on both sides of a previous canal contain free water full of weeds. The width of this free water zone depends upon the capacity of the canal, its order of percolation and other topographic considerations. Very often in quite a sizeable width of the land, ground watertable is also high, at a depth of 2 to 3 ft. stretches of land between two canals in particular such as M. R. Link and U.C.C. have high watertable. Another instance is that of several miles stretch of land near Khairpur along

the Rohri canals which is full of weeds. Although the exact estimate of the water lost by weeds is not yet fully known but on the basis of the studies conducted by Blaney and Thampson, it is known that these plants transpire large volumes of water. In Fig. 6 given by Blaney, with rise of watertable from 12 ft. to 3 ft., the increase of water consumption is 85%. Similar is the conclusion from Fig. 5 giving increase of loss of water by weeds with rise of water-table.

In this country no systematic study on the consumption of water by trees has been conducted, but experiments were conducted for one year to estimate the water consumption by Poplar and Sheesham. It was observed that these two types of trees transpired 120 & 82 inches of water which was 74 & 36% more than water lost from a free water surface and 115 to 77% more if the loss had taken place from a bare surface with watertable at 8 ft. depth.

Type of Trees	Total of one year	Water drawn from Sub-Surface	Excess as compared to F.W.S.	Excess as compared to soil evap. from surface with watertable at 8 ft.
Poplar ..	120	67	74	115
Sheesham ..	82	82	11.5	77

All figures are in inches.

Evidently trees grown in areas with excess of moisture along the berms in particular cause considerable loss by evapotranspiration. In majority of cases excess evapotranspiration is of no advantage to the plant. These are some of the mediums which are disposing of about 50,000 cusecs of water, seeping into the region. The losses by each of the four factors are significant.

HOW TO SAVE THIS WATER

We have already pointed out that with watertable taken down beyond 10 ft. the soil surface evaporation is considerably reduced. Similar is the case with crops. In many cases high watertable deteriorates the yield; some cases like sugar cane are however exceptions. The yield of cotton, for instance, falls miserably with watertable brought up to 3.0 ft. particularly if the soil is light. The same position of watertable is not beneficial for all sorts of crops. Keeping the watertable at an average level of 15 to 20 ft. appears to be suitable for all the crops except for crops like sugar cane.

CONSERVING THE SEEPAGE LOSS FROM CANALS

Irrigation canals are the major source of loss of water. The loss by evaporation constitutes about 10-15%. The main loss is due to percolation. Lining of canals has always been advocated to save this loss of water, but the difficulties of constructing lining, their cost, their maintenance, etc. have been unsurmountable problems, with the result that about 98% of the canals in this country are unlined. Lining of an operating canal is an impossible problem. There are so many difficulties. But fortunately the research is now fairly advanced to find emulsions which can be added to earthen canals and which will then reduce their percolation even under conditions of flowing water. These soil sealants have been found to be effective under water and reduce the percolation by 30 to 60%. Latest specimen has been found to penetrate 3 to 6 inches into the sandy beds. As regards the cost of treatment, it is much cheaper as compared to the conventional brick or concrete lining. It appears that in the next few years soil sealants will be perfected and will find their uses in the canal for their lining.

CHEAP TUBEWELL versus CANAL LINING

The development of cheap tubewells during the recent years has opened out a controversial point whether to line a canal or allow it to percolate and then use this water by the cheap type of tubewells. It is important to conduct a survey on the relative cost of these two measures. At present the tubewells by private sources are being installed without any consideration of the availability of water. Actually the farmers' tubewells are of low capacity and are operated occasionally when water is needed by them. The withdrawal has not yet balanced the recharge but time is fast approaching when the water level will start falling and to keep these private tubewells in action recharge of the aquifer will become necessary. Thus the point of lining even by cheap sealant, need careful consideration. Under the present circumstances of development of cheap tubewells, whether the lining is at all necessary is a question to be studied.

CONCLUSIONS

1. At present (1966), 83.5 maf. of water is diverted into the irrigation canals of the country.

2. The transit losses which include seepage as well as evaporation and wastage both from canal system and fields as estimated by Kennedy, Benton, Revelle, Panel of Scientists and Harza, are shown in the form of a table.

According to Harza's latest estimate, 49.8 maf. of water being 58.5% of that let into the canals is lost both as seepage and evaporation plus wastage.

Sources of loss	Kennedy		Benton		Harza		Revelle	
	%	Maf.	%	maf.	%	maf.	%	maf.
Canal system ..	47	39.2	42.7	35.6	..	..	..	..
Field ..	25	20.8	19.1	15.9	..	..	..	..
Seepage from C. system ..	..	..	..	..	42.6	36.4	29.7	25.4
Evaporation & wastage ..	..	..	..	..	15.6	13.4	14.65	12.5
Total ..	76	63.4	61.6	52.4	58.5	49.8	44.5	37.9

3. Out of 49.8 maf. or about 68400 cusecs of losses, seepage is about 50,000 cusecs and the rest is evaporation and wastage.

4. There is yet little information about the disposal of 50,000 cusecs of seepage. The consideration of rise of groundwater levels, its salinity accumulation, existence of underground bed rocks and subterracan ridges in the Punjab, Sukkur and Kotri and the nature of the alluvium formation, all point to the fact that the disposal is not by deep underground flow but is due to other causes.

These are:

(*i*) the evaporation loss from free water surface.
(*ii*) evaporation loss from soil due to high watertable.
(*iii*) Evapo-transpiration loss by crops, weeds and trees.

5. It is shown by actual figures that the above three items are the means for the disposal of not only a major component of the seepage but of evaporation component as well.

6. It is shown that:—

(*a*) the use of evaporation reducing materials can save a certain portion of the water being lost from free water surface.

(*b*) lowering the ground watertable to 15-20 ft. below surface will reduce the evaporation and evapotranspiration loss from the soil and by plants etc.

7. Development of soil sealant is promising and will be a useful and cheap means to reduce percolation but it is yet a question whether in the face of development of cheap type of tubewells, it will at all be feasible to line the earthen canals and thus reduce recharge to the aquifer.

TABLE I
Comparison of Water Balances for Indus Plains

Item		Harzint Master Plan (Initial Phase, Jan. 64)	
		Present	1975
		Units millions of acre ft. per year	
River Balances			
Total Surface Water Supply	..	164.5	140.0
Net Percolation to Ground Water	..	−4.0	−3.1
Other Losses	..	−16.1	−11.9
Drainage Return to Rivers	..	..	5.0
Flow to Arabian Sea	..	−60.9	−39.9
Total Surface Water Diversion	..	83.5	92.1
Canal Balance (incl. water-courses)			
Total Surface Water Diversion	..	83.5	92.1
Pumped from Ground Water	..	2.0	26.9
Evaporation Losses	..	−8.0	−10.2
Percolation to Ground Water	..	−23.0	−28.6
Total Delivery to Farms	..	54.5	80.2
Farm Irrigation Balance			
Total Delivery to Farms	..	54.5	80.2
Surface Loss	..	−5.4	−8.0
Percolation to Ground Water	..	−8.2	−12.0
Net Crop Use	..	40.9	60.2
Ground Water Balance			
Percolation from rivers	..	4.0	3.1
Percolation from canals	..	23.0	28.6
Percolation from farms	..	8.2	12.0
Percolation from rainfall	..	1.2	2.5
Total Inflow to Ground Water	..	36.4	46.2
Pumped to Irrigation use	..	2.0	26.9
Pumped for drainage (N. Zone)	..	..	5.0
Average 'Mining'	..	..	..
Evaporation, transpiration, storage, drainage to sea and mining (net)	..	34.4	14.3

TABLE 2

Table showing areas in acres of watertable depth in various regions of West Pakistan (June 1959).

Regions	Total area	0-5′	%	5′-10′	%	10′-15′	%	Beyond 15′	%
Peshawar region ..	17,623,040	20,787	0.118	182,067	1.03	106,496	0.607	17,313,690	98.24
Chaj Doab ..	3,229,000	432,200	13.3	1,926,400	58.42	442,000	13.68	428,400	13.26
Rechna Doab ..	6,916,000	483,400	6.9	2,982,800	43.12	1,886,400	27.27	1,563,400	22.59
Thal and Derajat ..	12,786,173	250,000	0.019	1,650,000	12.90	950,000	7.42	9,936,173	77.71
Bari Doab ..	6,553,600	16,783	0.25	1,365,903	20.84	1,780,838	27.17	3,390,076	51.72
Bahawalpur ..	10,667,187	240,000	2.24	990,000	9.28	1,210,000	11.34	8,227,187	77.12
Sind ..	35,926,080	572,621	1.59	3,346,152	9.33	1,286,349	3.58	30,720,958	85.51
Total ..	93,701,080	2,015,791	2.14	12,443,322	9.89	7,662,083	8.16	71,579,884	76.22

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