Review of Reclamation Activities and Methods and Suggested Measures for Waterlogging and Salinity Control

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Introduction

Irrigated agriculture all over the world exhibits similar problems of water-logging or salinity or water-logging and salinity together. Excess soluble salts and alkali cause sterility and barrenness in the soils of semi arid and arid regions. Reclamation of saline and alkali soils and prevention of deterioration of irrigated fertile lands are of paramount importance in arid regions. The history of the arid and semi-arid irrigated areas shows that irrigated agriculture cannot be regarded as permanent unless the plant and soil water requirements are fully satisfied and drainage of land is properly taken care of.

The irrigation system in the Indo-Pak sub-continent is quite old but the extension of irrigation to the arid and semi-arid zones now forming the West Pakistan was taken up only 60 to 70 years ago. To start with, the water supply factor on the basis of one cusec for 352 acres with crop intensity of 25% in Kharif and 50% during Rabi appeared adequate under those conditions when pressure on land was not high.

However, the water supply has not been increased since that time, and, with the increase of population, the same quantity of water is applied on more acres with the result that there is a decrease in delta of about 40%. The total water applied per unit area is too inadequate to keep the trend of salt movement downward. This is one of the major causes of spread of the salinity over the areas where the water-table is still very deep, say, beyond 25 feet from the ground surface. Since the drainage was not properly taken care of, the rise in the water-table was in the order of one foot a year and in vast areas it has now come within the capillary zone which has further aggravated the condition of salinity-affected areas under the low delta irrigation applications. High water-table areas are more severely damaged by salinity. Water-logging and salinity is a twin problem and so is the irrigation and drainage. With this end

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in view the history of reclamation activities and methods and suggested measures for waterlogging and salinity control are reviewed and discussed hereunder :

Irrigated Agriculture and Allied Problems in Countries of the World

In the arid and semi-arid zones, covering about one-third of the land surface of the earth, irrigation is a predominant factor for the successful crop production and sound economic development. The natural resources are tapped for supplementing the scanty rainfall. but a few years after irrigation has been introduced, it has often been observed that salines begin to appear in places where none was present before. In other places the previously existing salinized areas are found to expand, obviously not following the scientific irrigation methods and agricultural practices. In many parts of the world, large areas of formerly productive soil have become unproductive since irrigation was introduced.

In the western United States, several hundred thousand acres in California alone have been thus affected. It has been estimated that in one-fourth of the 29 million acres of irrigated area of U.S.A. the productivity has been lowered due to salinity. In the older irrigated countries the spread of salinity has assumed alarming proportions.

In Egypt, as long as the ancient system of spreading the flood waters of Nile was practised, alkali was not a serious problem in the Nile delta, except in the low-lying areas near the Mediterranean. After the completion in 1895 of the dam across the Nile, perennial irrigation replaced the system of one annual flooding and soon thereafter salinity began to appear here and there in the Nile delta. Subsequently the construction of the great dam at Aswan in southern Egypt served to extend irrigation to large areas and enabled intensive irrigation, but it led to considerable intensification of the alkali probelm.

In Iran, about 20 years ago water supply was provided to the Shabankareh Plains from the Shapour river. Shortly after the introduction of large scale irrigation, the ground water level began to rise, the salt content of the soil increased, and the land deteriorated. A soil survey revealed that 95% of the area had been infested with salts and only the 5% light textured well-drained soil near the river was free of salts. Several other large irrigation projects in Iran are confronted with the problems of waterlogging and salinity. The total loss of crop including date palm due to waterlogging and salinity is approximately half a million dollars annually.

One of the earliest civilization was developed in the valley formed by the Euphrates and Tigris in ancient Mesopotamia. To-day, Baghdad, in the heart of these once productive plains, is located in almost barren and desolate waste. All this economic ruin to these areas was as a result of the appearance of salinity.

In India during the famine of 1837-38, the demand for water suddenly increased and special embankments were constructed on both sides of the Western Jumna Canal to increase supplies. The area under cultivation and income to the Government were greatly enhanced but it was not long before the defects of alignment and the absence of drainage works became apparent. Salinity made its appearance on large areas and some areas were totally waterlogged. Some 8% of central canal tract was permanently under water. During the period 1870 to 1875 a remodelling scheme of Jumna Canals at a cost of Rs. 11 million was undertaken which included the opening up of the natural drainage system of the country and the provision of an extensive system of surface drains. These measures resulted in lowering the water-table to the extent of 5 to 15 feet.

In 1876, the Reh Commission was set-up by the Government of India to investigate the causes of deterioration of lands in the Aligarh district which lies south-east of Delhi, between the Ganges and Jumna rivers. The Commission found that the introduction of canal irrigation was the principal cause of Reh (Salinity) extension. There were over 2 million acres of salinized land in the whole of India in 1903, occurring more conspicuously throughout Indus Valley, in valleys and basins in Western India and Pakistan; the Ganges Valley West of about 80°E long; on the uplands of the Deccan plateau, especially between the Tapti, Godavari and Bhima rivers; the saline marshes of the sea coast, and of the river deltas of the Ganges, Indus, Cauvery and Mahanadi; the coastal salt flats along the Rann of Cutch.

The major part of the Indus Basin now in West Pakistan lies in arid and semi-arid zones with annual rainfall ranging between 5 to 25 inches which is not sufficient for raising successful crops. The agricultural production even at a bare subsistence level is almost entirely dependent upon the availability of irrigation water. The first stage of irrigation development on individual basis was sinking of shallow wells and lifting water by various devices suiting the local conditions. The next stage was development of inundation canals dug and maintained either by the state or on a co-operative basis by the public. Later on the construction of weir-controlled canals started. The Sirhind canal was the first project (now in India) which included a permanent masonry work across the river at the canal head and was a forerunner of the present magnificent barrage-controlled irrigation systems. As the very first irrigation project gave rise to the appearance of salts and waterlogging, Highem predicting similar consequences of the future weir controlled irrigation projects started a series of well observations in irrigated tracts of the West Punjab with regular rainfall observations in the year 1882. In the Rechna Doab, however, systematic measurements of ground water levels in the observation wells was not started until 1905.

After the Sirhind Canal, the Lower Chenab Canal with a discharge of 11,742 cusecs started irrigation in 1892, followed by Lower Jhelum Canal in 1901 with a discharge of 5,280 cusecs. The seepage from these canals combined with the effect of extra heavy rains of 1908, resulted in serious complaints of water-logging and salinity, more particularly in the Rechna Doab. By the year 1915, the triple canal project consisting of Upper Jhelum, Upper Chenab and Lower Bari Doab Canals carried 27,000 cusecs of water supply from the rivers into the interiors of Chaj and Rechna Doabs. In the 90 miles length, the Upper Jhelum Canal had to cross some 70 natural drainages (with discharge ranging from 1,000 to 150,000 cusecs) and had to be constructed alternately in heavy cutting and deep filling. The Upper Chenab crosses numerous important drainage ways such as Deg as well as railway lines and roads. The Rayya Branch which runs across the slope of the Doab, crosses some 17 natural drainage ways, some of which have a discharge of 4,000 cusecs. The obstruction to major natural drainages and flow of enormous discharges at a high level or in deeply cut beds with little soil crust left over sand layers contributed considerably to the rise of water-table. In the Assessment Report of Gujranwala district for the year 1924-25 the rise of water-table over a span of 11 years in some of the villages was reported of the order of 1.67 feet per year. The average rate of rise, however, works out to 1.4 feet annually when the water-table was below 20-25 feet from natural surface.

After the lull of 1918-26 due to financial stringency caused by World War I, the construction of new canals again started. Sutlej Valley Project canals were commissioned in 1933, Haveli Project in 1939 and Thal Project in 1948. Taunsa Barrage, Ghulam Mohammad Barrage, Guddu Barrage and Kurram Garhi and Warsak Dam Projects have been completed after independence. There are now 18 head works across the principal rivers. The main canals and distributaries system have a length of about 30,000 miles delivering 256,000 cusecs with the total cultivated commanded area of 33 million acres. According to the estimates about 53% of the cultivated area of the existing canal projects is affected by salinity under various stages of deterioration.

The experiments on lining of channels had started in 1911 and a number of materials had been tried. In light of the experience gained up to that time the main channel of Haveli System, completed in 1939, was lined with burnt bricks and the main line of Thal Canal completed in 1947, with cement concrete. In Thal tract the rate of rise of water table increased from 0.07 feet before opening of the canal to 0.706 feet per year after the opening of the canal.

Origin and Nature of Saline, Alkali and Waterlogged Soils

Saline soils are soils having excess soluble salts that make the soil solution sufficiently concentrated to injure plants and impair soil productivity. The term alkali soil is applied to soils which have an excess of Exchangeable Sodium either with or without excessive total soluble salts.

The word alkali as applied to soil is of Arabic origin and means wood ashes. The resemblance of salt incrustration to the wood ashes led to this nomenclature. In the West Pakistan several different terms are used such as Reh, Thur, Kallar and Ussar, and if the soil is specially difficult to deal with agriculturally it is called Rakkar, Bara or Bari. In Russia the words 'solonchak', 'Solonetz' and 'solod' are applied, all of which contain the root sol meaning salt. Solonetz means soils with little salt (alkaline) solonchak denotes having much salts (saline) while solod refers to a particular kind of alkali soils which has been subjected to prolonged leaching following the accumulation of soluble sodium salts.

The term white alkali in the United States refers to neutral salts chiefly chlorides, sulphates and nitrates while black alkali denotes chemically alkaline salts such as soluble carbonates. Alkaline solutions of sodium salts being solvents for soil organic matter leave a dark colour residue upon evaporation commonly in the form of a thin crust or rings round small depressions. Hence the name black alkali. Although sodium salts usually predominate, $CaCl_2$, $MgCl_2$ and $MgSO_4$ are also present in certain localities. In the Indus Basin covered by the former Punjab and Bahawalpur areas, the predominating salt in white Kallar is Na_2SO_4 whereas in the lower part of Basin in Sind the predominating salt is NaCl. Sodium carbonate which forms balck Kallar is not common in Sind soils.

Mineral soils are derived largely from the weathering of rocks. In humid climates natural precipitation is usually sufficient to leach out the soluble salts approximately as fast as they are formed but in dry regions it is not possible. As regards the origin of the soils of Indo-Gangetic plain the geologists believe that geotectonic forces involved in the erection of Himalayas produced a concomitant depression in the northern part fo the peninsular foreland at the foot of these mountains. This was occupied by a Sea which extended to Attock in the West and Nainital in the East. The over-thrust mountains are of recent origin and their rivers are active in eroding their beds, which in course of time filled up the sea by sediments thereby resulting in the formation of a vast plain of alluvial deposits.

Soil profile studies reveal that before the commencement of irrigation, salt is distributed throughout the depth of soil crust or with some concentration of salt at a certain depth depending upon the rainfall. Under irrigated conditions if the water applications are not enough to take care of the consumptive use of water by crops and the leaching requirements of soil a zone of accumulation of salts is formed at some depth below the surface. The upper limit of this zone of accumulation is well marked and its position in the soil crust depends on the intensity of irrigation and the agricultural practices. If the agriculture is of such a type that the amount of water used for irrigation is sufficient to counterbalance that lost by transpiration and evaporation, the zone of accumulation will tend to remain stationary or to move to a greater depth. If, however, the quantity of irrigation water used is insufficient to balance the losses due to transpiration and evaporation, the tendency will be for the zone of accumulation to move upwards and ultimately it starts appearing at the soil surface in patches. If the reclamation of the soil is taken up at this stage of deterioration, it takes 3 years with a total surface application of about 180" to leach down the salts. With the advanced stage of soil deterioration, sodium soils are formed, which are difficult and sometime uneconomical to reclaim.

Probable Causes of Waterlogging

The causes of rise of sub-soil water had been under active investigation for a number of years in the former Punjab area. The sources from which additions of water supply have been possibly made to the water-table are:

1. Rainfall.
2. Canal Irrigation System.
3. Seepage losses from field under existing cropping pattern.
4. Flooding by river.
5. Obstruction in the sub-soil flow of water.
6. Presence of a subterranian ridge, and impermeable zone below soil surface.

Re. 1. Rainfall

Statistical examination of records made by Taylor, Malhotra and Mehta in 1933 in the Upper Chenab Canal area showed that there was a significant correlation between the rise of water-table and the monsoon rainfall. The data available for pre-irrigation period is as under:

Year	Rise of water-table	Rainfall in inches
1907—08	—0.85	14.07
1908—09	+2.10	33.10
1909—10	+0.29	23.57
1910—11	+1.25	27.26
1911—12	—0.80	10.71
1912—13	+0.75	15.62

The figures show that within a period of six years there was a rise of 2.74 feet (.46 average per year) in the sub-soil water level.

The figures of rise of water-table in Thal Canal area for pre-irrigation and post irrigation periods are compared below:

Year	Rise of water-table before opening of canal		Year	Rise of water-table after the start of canal	
	Average rise in feet June to June	Average rain-fall in inches June to June		Average rise in feet June to June	Average rain-fall in inches June to June
1935—36	—0.190	9.05	1945—46	0.145	5.86
1936—37	0.361	5.54	1946—47	0.27	3.66
1937—38	—0.030	4.93	1947—48	0.23	6.58
1938—39	—0.030	9.50	1948—49	0.24	7.20
1939—40	0.430	6.87	1949—50	0.61	8.24
1940—41	—0.180	7.27	1950—51	0.44	11.28
1941—42	0.010	9.62	1951—52	0.38	4.97
1942—43	—0.090	7.17	1952—53	0.68	7.9
1943—44	0.100	8.99	1953—54	1.52	12.1
1944—45	0.250	11.99	1954—55	1.99	9.20
Mean rise in feet per year.	0.07			0.706	

From the perusal of the above it is seen that during the pre-project conditions, and first 6 years of the post-project period, the influence of the rain is practically the same, and the marked effect of rainfall is noticed thereafter. This may be due to the depth of pellicular zone which is reduced considerably under irrigated agriculture and the influence of rain is more marked. In his analysis Khanger also reported the rainfall a major contributive factor for the rise of water-table. Although there is a paucity of regular scientific data on this point, but if the information given above is relied upon, a significant relationship is evident.

Re. 2. Seepage from canal irrigation system

Defective distribution of irrigation supply was the major cause of seepage losses. In the original design of Upper Bari Doab there were no distributing channels. Irrigation was carried out by a system of cuts in the main canal.

There was less area to be irrigated and plenty of water was available for everybody, but this system contributed largely to the waterlogging of the commanded area. According to the estimate of Blench and Kennedy seepage losses work out to 47% of the head supplies.

Re. 3. Seepage losses from fields under existing cropping pattern

Khanger on the basis of evapo-transpiration work done in other countries and at Lyallpur Agricultural College concluded that some portion of irrigation and rainfall applied to rice must go to the sub-soil water, while no irrigation water will find it way to the water-table from irrigated fields bearing crops of Cotton, Wheat, Maize, Bajra, Jawar and gram with present irrigation intensities and methods. He further argued that in the Chaj and Rechna Doabs the area under rice is very small as compared to the total area under other crops and water added by the small percentage of the area under rice can be neglected.

Lysimeter experiments in the Land Reclamation Directorate indicated that Cotton, Wheat, Gram and Maize were exhaustive with respect to soil moisture, while sugarcane, berseem and rice caused accretion to the water-table. Under controlled irrigation and improved agricultural practices the wasteful use of the water can be eliminated to a greater extent.

Re. 4. Flooding by Rivers

The spills from torrents, rivers and rains are responsible for huge additions to the water-table. In the Rechna Doab Nullahs like Aik, Deg and Bhed Overspill almost every year or whenever a heavy downpour is experienced in its catchment area. Jhelum is known to flood a large part of the country and enormous quantity of waters are added to the sub-soil water in Chaj Doab. Heay floods from Ravi and Chenab also cover a large part of the Doabs, whenever these occur. In 1950, the floods spread water on 4.8 million acres while those of 1956 affected 18.6 million acres. During this period the entire soil profile is saturated to field capacity and absorption losses form a direct addition to the watertable.

Re. 5. Obstruction in the sub-soil flow of water

As already stated irrigation and drainage are inseparable. In the past due consideration was not given to the drainage of surface and sub-surface water. The obstruction in the sub-soil flow aggravated the conditions in many parts.

Re. 6. Presence of a sub-terranean ridge and impervious cones below the sub-surface

In 1927-28 a gravitational survey was carried out by Wilsdon and Bose, to attempt to determine the depth of alluvium overlying a suspected rock ridge thought to exist under the Chaj Doab. Carlston pointed out that in calculation of depth of bed rocks the errors range from 42% to 82% and that the results are most anomalous. From the distribution of the out-crop of Archean rocks it is possible to deduce a sub-surface range of high peaks under the Indus Valley alluvium. Between the peaks are deep valleys. There is no continuous rock ridge as envisioned by certain workers. There is also no evidence that the alluvium above the Archean "Highs" is any more compact than elsewhere in the Punjab. It is true that elsewhere in the world there is geological evidence of compaction of sedimentary formations over ridges and hills of resistent bed rocks. Such compaction, however, requires many millions of years. The Indus Valley alluvium overlying the Archean hills in the Rechna Doab has been deposited in the latter part of the Pleistocene and in recent times. There has not been sufficient time for any appreciable degree of differential compaction over the buried hills as contrasted with elsewhere in the valley. Thus there is no known geological reason why the buried rock under the Rechna Doab should significantly influence the surface of the water table under the Doab.

Summing up, it can be said, that no one source of recharge is the sole cause of the rise of water-table and that one source in the presence of the others makes the contribution to the sub-soil water reservoir. It is the cumulative effect of sources enumerated 1 to 5 which cause waterlogging.

Effect of Salinization and Waterlogging on Soils and Crops

The presence of large quantities of certain soluble salts change the physical and chemical conditions of the soil which effect the fertility, while the primary effect of soil salinity on crops is one of retarding growth by limiting the uptake of water. Certain salts are specifically toxic to some crops. Boron for example when present in the soil solution in concentration of more than 1 ppm is toxic to many crops. Alkali soils remain flocculated and their properties are usually similar to those of saline soils as long as considerable amounts of soluble salts are present. As the concentration of salts in the soil solution is lowered by leaching, the adsorbed sodium present causes undesirable characteristics to develop. The particles may disperse and the soil may become unfavourable for the entry and movement of water and air for tillage. Adsorbed sodium also may be toxic and cause various nutritional disturbances in plants. It was, therefore, considered essential to find a corelation between the salt content, alkalinity, and yield of crops. Puri as a result of certain experiments on Punjab soil established relations between the yield of wheat and exchangeable sodium and Mehta related the yields of rice to the salt content and alkalinity of soil. Puri had shown that provided the salt content is low the yield of wheat is not affected until pH value rises above 8.5. Mehta found that a soil with high pH value and a relatively high sa ltcontent appears to give a higher yield than a soil with high pH value and low salt content, and attributes the difference to the effect of salt, on the physical condition of the soil.

Based on these observations, the following standards were laid down for reclamation projects:

Soil Type	Salt content.	pH value	Characteristics
1.	Lower than 0.2%	Not exceeding 8.5	Good land. Normal crop and yield.
2.	Lower than 0.2%	0.5 to 9.0	Slightly below normal yields.
3.	Up to 0.5%	9.0 to 9.5	Mild Rakkar land. Suitable for limited type of cropping.
4.	Above 0.2%	Not exceeding 9.0	Easily reclaimable deteriorated soils.
5.	High	Higher than 9.5	Difficult and expensive to reclaim.

The waterlogged soils are generally poorly drained. The early season coldness of poorly drained soils is one of the limiting factors in their use for crop production. The high moisture content of these soils also delays the fitting of the soil for planting and thus necessitates their use for late planted crops or for the seeding of early crops in poorly prepared soil.

The roots of the most commonly grown crops require a supply of oxygen for the process of respiration and as poorly drained soils contain an abnormally low proportion of air the roots get suffocated. With an inadequate oxygen supply, decomposition of organic matter must be largely of an anaerobic nature with the production compounds some of which are toxic to plants in a reduced chemical state. The disagreeable odours from stagnate pools during warm weather bear witness to the production of unoxidised compounds in waterlogged soil. Under such conditions oxidised mineral compounds may also be reduced to poisonous combinations such as sulphides from sulphates, nitrites from nitrates and ferrous iron from ferric iron. Plants may also suffer because the normal decay of organic matter with the accompanying liberation of variable nutrients is hampered in waterlogged soils. Furthermore, it is doubtful that the plant roots can efficiently carry on the process by which nutrients are liberated from the surfaces of the soil particles, and are absorbed.

Measures Adopted in the Past for Combating the Problem

In West Pakistan the problem of salinity and waterlogging came to the notice of Government in 1908 but the gravity of the situation was not realized at that stage because there was little pressure on the land. Plenty of land was available for cultivation in the new colonies. The first organized attempt at assessing the problem was made in 1917 when Drainage Board was set up. In 1918 Mr. Bates, Superintending Engineer Lower Chenab, recommended the following anti-waterlogging measures :

(*a*) Lining of selected reaches of main lines of both Upper and Lower Chenab Canals;

(*b*) Elevation of supply in these main lines be as far as possible reduced;

(*c*) During the winter complete closures be observed; and

(*d*) Seepage drains be constructed in severely affected localities.

During the year 1918, about 8 lakhs of rupees had been spent on lining of a total length of about 12 miles scattered over different channels. A total length of 80 miles of drain were dug at a cost of rupees 4 lakhs. By the end of 1922 the total cost of lining which had been carried out on the Lower Chenab Canal and its branches amounted to 27 lakhs of rupees.

The Waterlogging Enquiry Committee appointed in 1925 initiated the invaluable statistical investigations and experimental work in connection with both waterlogging and salinity. In 1928, the committee was reconstituted and named as Waterlogging Board consisting of Financial Commissioner, Finance Secretary, Directors of Agriculture and Public Health and the Chief Engineers. This Board remained in vogue up to the partition in 1947.

Experiments on the Reclamation of Saline and Waterlogged Soils

At the initiation of the Waterlogging Committee it was decided in 1926 to start field experiments at Chakanwali through installation of different types of drains in an area of 3,645 acres severely saline and waterlogged, situated on right bank of Lower Chenab Canal at R. D. 105,000. In this reach of the Canal the waterlogging was noticed in 1904, immediately after the opening of the Lower Chenab Canal. The water-table being 1-4 feet deep the area had been abandoned from cultivation and the owners had been given land in exchange in the Lyallpur district.

It was believed at that time that waterlogging brought about radical changes in the soil texture and soil constituents, making the land unfit for cultivation for ever. Investigations therefore, started into the causes of infertility of waterlogged lands, permanet changes in chemical and mechanical composition of soil and the methods by which these lands could be restored to normal fertility. Experiments based on the use of title drains mole drains, porous gallery and open field drains were carried out. It was found that the use of open field drains with free outfall was more beneficial and economical as compared to other types of drains. The methods of reclaiming saline, alkaline and waterlogged lands were standardised which were applied for general reclamation of proprietary areas taken up at a later stage.

As a result of reclamation and de-watering, the waste land previously affected by the twin problem of salinity and waterlogging, is now giving an annual profit to the tune of Rs. 1,80,000 (1958-59). Apart from raising normal food and cash crops, even a fruit orchard constituting mangoes, falsa, guava and banana has been successfully established.

The cost of the construction of field drains under the present rates works out to Rs. 17/- per acre and that of collector drains comes to Rs. 20/- per acre. The maintenance charges are Rs. 10/- per acre per year.

The said Waterlogging Enquiry Committee also initiated the systematic study of the available well data. The first study was made by Wilsdon and Sarathe for the Chaj and Rechna Doabs in 1927. From the weighted data of rainfall and well observations regression curves were prepared to indicate variations of the additions to the water-table. The authors concluded that both irrigation and rainfall contributed to the rise in water-table, but the monsoon rainfall was the major cause of the rise. They recommended canal closures in order to reduce the seepage component of the irrigation load. This measure was tried, but it resulted in dislocation of the agricultural system and had to be abandoned as an anti-waterlogging measure. During the period 1926-33, numerous other measures such as provision of seepage drains along the Main Line lowering the full supply of the Main Line, tubewell pumping, restriction of water supply for irrigation, provision of hydrautomats and pumping from Gujranwala and Sheikhupura town ponds were adopted in the Upper Chenab Canal area. The seepage drains along the Main Line had subsequently to be replaced by drains constructed at some distance as they increased seepage from the canal. Lowering of the water surface level of the Main Line had only a local effect extending not more than half a mile from the canal. Tubewells being too small in number, also had a purely local effect which did not last after the pumping was stopped. Restriction of water supply for irrigation had very little effect on the water-table. Pumping from ponds proved useful for the control of water-table near the large towns.

The well observations, rainfall and canal discharge data of the Upper Chenab Canal area were again examined statistically by Taylor, Malhotra and Mehta in 1933. They concluded that there was no correlation between the rise of water-table and irrigation water applied but there was a hig correlation between rise of water-table and monsoon rainfall. As a result of their work and due to adverse effect of heavy rains of 1933 and 1935 on the water table, construction of a large number of drains to deal with the storm water of the monsoon period was undertaken.

The experiments on lining of channels as already stated had started in 1911 and a number of materials had been tried. In light of the experience gained up to that time the main channels of Haveli system completed in 1939 were lined with burnt bricks. The main line of Thal Canal completed in 1947 was lined with cement concrete. The lining of old channels being too expensive and impracticable, this method could be of limited application only for the new canals to be constructed in future.

Salinity Control: Up to 1939 canal irrigation had been extended to over 14 million acres in the former Punjab area. In this area, the salts previously spread in the whole soil profile started upward movement. forming zones of concentration and appearing on the soil surface over large areas. By the year 1940 the malady of salinity had assumed alarming position and salts were visible on the surface of about 5 lakh acres of land. At that time the Land Reclamation Board was set up to advise on reclamation operations based on the research conducted up to that time. Preliminary work on diagnosis and reclamation of saline and waterlogged areas was carried out by the Land Reclamation Section of the Irrigation Research Institute during the period 1925 to 1940. With a view to expand and intensify the anti-salinity measures a separate directorate known as the Directorate of Land Reclamation was opened in 1945 under the control of the Irrigation Department. The Director of Land Reclamation was to co-ordinate the reclamation operations in various canal circles and provide scientific guidance based on Laboratory and field experiments.

Reclamation of Deteriorated Land in Canal Circles

The measures adopted and the methods tried to reclaim the saline alkali soils have been :

1. Removal of surface deposit.
2. Lowering the toxic concentration of salts in surface soil.
3. Cultivation of salt resistant and tolerant plants.
4. Use of chemical amendments.
5. Addition of organic matter (green manure).
6. Flushing of the soil and drainage.
7. Combination of some of the above methods.

Re. 1. Removal of surface deposit

The soil scrapings usually consist of a mixture of sodium chloride and sodium sulphate. This method could be useful if the salts existed only within the top soil, but this is not the case and the incrustation of the surface if once removed, is reformed very soon because of the upward movement of salts from the entire soil profile, as on an average about 100 tons of salts per acre are present in a 10 feet depth of soil crust.

Re. 2. Lowering the toxic concentration of salts in surface soil

The method of mixing of good soil, silt or sand to lower the toxic concentration of salts in the soil is very temporary relief and is unpracticable on large scale in addition to being very expensive.

Re. 3. Growing of salt or alkali resistant plants

This is very appealing to a casual observer but there is no economically sound and useful crop which can withstand high salt concentrations. Under Punjab conditions trial of some plants like Acacia Arabica (kikar), Tamarix Articulata (Frash), Suaeda Fruiticose (Lana), Bicinus Communie (Castor) etc. was carried out. Cultivation of such plants is, however, no solution of the problem.

Re. 4. Use of Chemical amendments

The saline soils are reclaimed by getting rid of excessive salts through leaching and providing artificial drains if the water-table is high, but the removal of excess of soluble salts is not enough to restore alkali soils to productivity. Most of the adsorbed sodium must be replaced with calcium. When alkali soils do not naturally contain gypsum, chemical amendments are needed for the replacement of adsorbed sodium. The suitability of the various types of amendments is governed primarily by their solubility and the lime content and pH reading of the soil. Any amendments may be used on alkali soils containing lime, but the addition of limestone will be of no value. Acid and acid-forming amendments react with the lime in the soil to form gypsum. The addition of acid or acid-forming amendments to soils without lime tends to make them acid, and the choice of amendments is limited to soluble calcium salts, unless limestone also is applied.

The selection of an amendment is influenced generally by cost considerations and the time required for its reaction in the soil. The cheaper amendments are slower to react. Because of its high solubility in water, calcium chloride is probably the most readily available source of soluble calcium but is seldom used because of its high cost. Similarly iron and aluminium sulphates are too costly to be used. Sulphuric acid, gypsum or sulphur are most commonly used in foreign countries because of their relatively low cost.

The use of sulphur in West Pakistan has been found suitable for alkali soils where high salt concentrations are not present. The cost of treatment per acre will be about Rs. 70/-. The improvement observed was not encouraging in view of the cost involved. If some extra water supply is available, Sesbanis Aculeata green manuring has proved to be quite a simple and good alternative for Punjab soils.

It may be stated that a chemical process to absolve toxic effect of sodium salts by rendering these insoluble for lowering the ionization value is yet to be discovered.

Re. 5. Alkali soils can be improved by green manure of various types but this step is not sufficient and can be only a helper in reclamation of such soils by some complete process.

Re. 6. The only measure which has been successful in removing salts from the soils is the use of excessive quantity of water to dissolve the salts and remove the salt solution through the sub-soil to the water reservoir or through a drainage system to a natural outfall. This has been adopted in various countries as a general method of reclamation of saline or saline alkali soils with some modification to suit the local conditions. In West Pakistan the special feature of reclamation of saline or saline alkali soils is the growing of a salt resistent crop requiring high delta of water like rice or sesbania aculeata (Jantar) during the summer season. This is followed by a leguminous crop during the winter to compensate the loss of nitrogen caused by excessive leaching.

In case of alkali soils, green manuring should precede rice cultivation, etc., to help in the replacement of exchangeable sodium. This method is very successful as there is enough $CaCO_3$ in the soils of Indus Basin. With only summer supplies for reclamation the cropping suggested for soils of different characteristics in various stages of deterioration are given below :

Cropping Arrangements for Reclaiming Uncultivated Waste Land

Year	Harvests	Uncultivated Waste Land	
		Alkaline stiff clay with low salt content (Rakkar) ESP > 15	Alkaline stiff clay with high salt content ESP > 15
1st	Summer	Jantar	Jantar
,,	Winter		
2nd	Summer	*J. G.M. Rice	Rice
,,	Winter	Berseem	Berseem
3rd	Summer	Rice	Rice
,,	Winter	Berseem	Berseem
4th	Summer	Rice	Rice
,,	Winter	Berseem	Berseem
5th	Summer	Rice	Rice
,,	Winter	Berseem	Berseem
6th	Summer	Rice	J. G. M. Rice
,,	Winter	Gram	Senji.
7th	Summer	Sugarcane	Sugarcane
,,	Winter	Sugarcane	Sugarcane
8th	Summer	Sugarcane (R)†	Cotton
,,	Winter	Methra	Senji

* J. G. M.=Jantar Green Manure. † (R.)=Ratoon.

Cropping arrangement for Reclaiming Cultivated Saline Soils.

Year	Harvest	Loamy soil with low pH	Saline stiff clay	Saline Clay loam	Saline light loam and sand
1st	Summer	Rice	Rice	Rice	Rice
,,	Winter	Berseem	Berseem	Gram	Berseem
2nd	Summer	Rice	Rice	Rice	Rice
,,	Winter	Gram	Berseem	Gram	Gram
3rd	Summer	Rice	Rice	J.G.M. Rice	Guara*
,,	Winter	Gram	Gram	Fodderpeas	Wheat
4th	Summer	Rice	J.G.M. Rice	Sugarcane	Jawar Mash
,,	Winter	Senji	Barley	Sugarcane	Gram.
5th	Summer	Sugarcane	Jawar Mash	Sugarcane(R)	Guara
,,	Winter	Sugarcane	Wheat	Mathra	Wheat
6th	Summer	Sugarcane(R)	Guara G.M.†	Jawar Mash	Jawar Bajra
,,	Winter	Methra	Wheat	Wheat	Berseem
7th	Summer	Cotton	Jawar	Guara G.M.	Maize
,,	Winter	Senji	Berseem	Wheat	Senji
8th	Summer	Jawar Mash	Cotton	Cotton	Bajra Moth
,,	Winter	Senji	Senji	Gram	

* Guara (Vetch). † G.M.=Green Manure.

For the reclamation of farmer's lands, additional canal water is provided during the summer season at the rate of one cusec for 45 acres on perennial channels and 60 acres on non-perennial channels. This is four to six times the normal allowance of water for cultivated land. The cultivator is required to level the fields, construct levees for holding water in quarter-acre plots, and to apply water after every 7 days to start downward movement of salts and lower the surface concentration to enable the rice seedlings to establish. Rice or sesbania aculeata is sown during the summer and irrigated Egyptian Clover or any other leguminous fodder in winter and grams or lentils under un-irrigated conditions. Green manuring is carried out in the beginning, in cases where exchangeable sodium is high.

By this mehod even the hard sodium soils of the Montgomery and Multan districts (called Bara or Rakkar locally) have been successfully reclaimed. There were some 40,000 acres of such crown waste area on Lower Bari Doab Canal which had defied all attempts of colonization. As soon as a successful technique of its reclamation was finalized in 1946, the land was leased out by the Government on half resumeable or similar terms to reclamation lessees.

The progress of general reclamation in cultivated proprietory areas of the former Punjab area is given in the table given below :

Progress of Land Reclamation Operations in Ex-Punjab Area

Year	Reclamation supply utilized (cusecs)	Area tackled (Under rice)	Area reclaimed during the year	Area reclaimed upto date
1940-41	60	2550	..	..
1941-42	213	8520	..	..
1942-43	1130	5000	2021	2021
1943-44	2036	78088	16000	18021
1944-45	2657	98354	25000	43921
1945-46	2558	85421	23086	66107
1946-47	2616	88644	28913	95020
1947-48	2498	73310	29336	124356
1948-49	2254	60520	24026	148382
1949-50	2354	67840	19437	167819
1950-51	2108	58745	22195	190014
1951-52	2161	62949	16644	206658
1952-53	2624	77427	14798	221456
1953-54	4143	124214	26827	248283
1954-55	4005	115655	27841	276124
1955-56	3499	107712	34383	310507
1956-57	3156	96924	23918	334425
1957-58	3040	95877	27843	362268
1958-59	3090	103134	37067	399335
1959-60	2548	80131	27151	426586
1960-61	2408	38067	28508	465093
1961-62	2107	79577	N.A.	N.A.
1962-63	2019	75862	N.A.	N.A.

It will be seen that in addition to the increased production of food grains to the tune of 13 lakh maunds, an area of about 30,000 acres is restored to fertility every year. Since the start of operations an area of 460,000 acres has been reclaimed. The present rate of reclamation is lagging far behind the annual rate of deterioration which is 100,000 acres for West Pakistan. In order to pace the rate of deterioration, effective steps are being taken now to extend the reclamation activities in the non-projected areas of other than former Punjab regions of West Pakistan. The flood supplies are distributed in accordance with the provisions under the "Rules for the remodelling of channels and outlets required for the distribution of reclamation supplies". For this the basic data on the salinity affected area is collected. The category-wise figures for salinity (Thur) in various regions of West Pakistan are given in table as follows :

Table showing Salinity Affected (Thur) Areas in various regions of West Pakistan (1961-62)

S. No.	Name of Region	Total area surveyed	Never cultivated Thur	Thur abandoned	Thur under cultivation (partially afffected)	Total
1.	Ex-Punjab	17008158	704141	557314	1746691	3008146
2.	Former N.W.F.P.	891509	15612	8721	8841	33174
3.	Ex-Bahawalpur.	4081205	128823	66490	146529	341842
4.	Former Sind.	12711864	899500	381866	603636	1885002
	Total:	36492736	1748076	1014391	2505697	5268164

Name of Scheme	Year of operation	Water-table	Fall in water-table	Increase in intensity of cropping	Increase in value of crop	Area gone out of cultivation at start of scheme	Area brought back to cultivation
		Feet	Feet	%age	(Rupees)	(Acres)	(Acres)
Chuharkana	1954	1954-55= 5.5 1961-62= 7.51	2.0	1955-56= 78 1961-62=113	1952-53 680000 1961-62= 1350000	3869	3200
Pindi-Bhattian	1958-59	9/1960=16.54 9/1962=20.75	4.21	*B. 57-58= 69 1961-62= 89.31	1958-59= 1237608 1961-62= 1392721	5567	4709
Jaranwala Khand	1957 1960	3/1960 = 8.11 6/1962 =11.98	3.87	1957-58= 90 1961-62=118.5	..	14200	8220
Chichoke-Mallian.	1960	1959-60= 6.0 1961-62= 7.54	1.54	B. start = 64 1961-62= 68	1959-60= 222038 1961-62= 849000	3329	1761
Khanqah Dogran	1960	3/1961= 7.45 9/1962= 9.50	2.05	B. 60-61= 70 1961-62= 86	1960-61=12613479 1961-62=14880022	24477	2566
Herse Sheikh.	1961	10/1961=12.00 9/1962=16.10	4.10	B. 60-61= 92.56 1961-62= 98.55	1960-61= 4194561 1961-62= 4533337	2977	587
Beranwala	1961	10/1961= 9.74 9/1962=13.41	3.67	B. 60-61= 87.20 1961-62= 98.56	1960-61=12184573 1961-62=12948577	18004	2413
Shadman	1960-61	1960-61= 7.50 1961-62= 7.54	0.04	B. 60-61= 79 1961-62= 85	1959-60= 5279000 1961-62= 6546000	24934	2500
Shahkot	1961-62	1/1962= 8.66 9/1962= 9.70	1.04	Before 1960-61	= 4793234	22309	1990
Hafizabad	1961	9/1961= 7.58 12/1962=10.60	3.02	B. 60-61= 61.72 1961-62= 67.80	1960-61=19494010 1961-62=22989010	42601	4583
Sangla Hill	1961	9/1961= 7.61 9/1962 = 10.50	2.89	6	= 326465	21677	3524
Zafarwal	1962	(Operations have just started)				29462	1500
					Total: ..	213406	37553

*B Denotes before

At the present rate of deterioration it is anticipated that the majority of irrigated lands will go out of cultivation within the next 20 years or so. For the present, until the permanent arrangements are made to increase the general water allowance from 350 acres per cusec to at least 150 acres per cusec from either ground water or surface water supplies which will take some decades it is advisable to make effective use of the additional surplus supplies available during the flood season.

Soil Reclamation Board

Under the general reclamation scheme operated by the Irrigation Department, areas are only tackled if they are in a state of active deterioration. If immediate preventive and reclamation measures are not undertaken in these areas, they would go out of cultivation in a short time. The resources available to the Irrigation Department, as well as the authority vested in it by existing laws, were both inadequate to carry on reclamation operations on a permanent basis. In order to remove this shortcoming and to make provision for an organization equipped with proper means and authority to effectively deal with the situation, the Punjab Soil Reclamation Act was passed in 1952 and Soil Reclamation Board was constituted there-under with the Chief Engineer, Irrigation, as its Chairman; the Director, Land Reclamation, as its member and Technical Advisor; and the Superintending Engineer, Drainage, as its member. The Board was charged with the planning and implementation of reclamation projects by providing adequate additional water supply through installation of tubewells in compact areas. The tubewell supply with canal water is provided at the rate of one cusec for 150 acres. The tubewells also help in lowering the water-table. Efficient open drainage systems were to be provided for the disposal of surplus surface run-off and seepage of surplus moisture from the sub-soil.

By the end of 1962, the Board was operating on an area of approximately 1.2 million acres divided into 12 schemes having 2154 tubewells; 1800 of these tubewells have been constructed by WAPDA. These schemes were started in different years. Scheme-wise progress in respect of depletion in water-table, increase in the cropping intensity and value of crops and the unculturable land brought back under cropping is given in table below :

So far 37553 acres have been brought back under cultivation, and there has been appreciable effect on the sub-soil water level which has been lowered by 4.21 feet. (Pindi Bhattian).

Recent Steps Taken to Counteract the Rising Water Table

As already mentioned under causes of waterlogging, the expreiments and observations of several workers had emphasized the necessity of open drains to take away the rain run-off, flood spills and excess of sub-soil water to keep the water-table at reasonable depth. The Irrigation Department has more or less continuously maintained a separate drainage circle to plan and execute a network of drains. Now there are about 4600 miles of drain for disposal of surface runoff and sub-soil water of waterlogged areas. There are over 1000 miles of river bunds to protect the cultivated area from spreading of flood water which makes huge contributions to the sub-soil water.

As already mentioned, 2154 tubewells in SCARP I in Rechna Doab have exerted an appreciable effect in lowering the water-table.

Systematic measurement of ground water levels in the observation wells in Rechna Doab was started in 1905 by the Irrigation Department, but the first attempts to record the Thur-affected area were made in 1927 by the Waterlogging Enquiry Committee. Thur Girdawari (Salinity Surveys) were conducted by the field staff of the Civil Department. During the period 1927 to 1939, surveys were carried out only in areas where the water-table was within five feet from the normal ground surface and were confined to selected estates of certain districts. These surveys, therefore, do not give a complete idea of the problem of Thur in the province as a whole or even in any Doab.

From the Figures of Civil Thur Girdawari, Mehta in 1940 estimated that approximately 5 lakh acres had gone out of cultivation due to salinity, and the rate of deterioration was of the order of 25,000 acres per annum.

It was decided in 1943 that Thur Girdawari (Salinity Surveys) should be carried out by the Irrigation Department, to determine the salinity-affected and waterlogged areas in the entire canal-irrigated tracts in various stages of deterioration and their occurrence by outlets, distributaries and canal systems. Such fields were to be recorded as Thur if more than 20% of the surface shows signs of the presence of salts.

Of a total area of West Pakistan of 198 million acres, 34.69 million acres is the total culturable area, if existing canal projects out of which 23 million acres are put under irrigated crops. According to the survey under the Colombo Plan, out of the area under cultivation the area severely damaged by salinity is 7 million acres (20% of CCA) while the area which is only partially affected is 12 million acres (33% of CCA). In the former Punjab area the culturable area of the existing canal projects is 15 million acres out of which 14 million acres are under irrigated crops. Area partially damaged by salinity is 5 million acres while 1.3 million acres have completely gone out of cultivation. The rate of annual increase in deteriorated area (average over 10 years) is estimated to be 70,000 acres for the Ex-Punjab area and 100,000 acres for the West Pakistan.

According to the statistics collected by the Directorate of Land Reclamation (Irrigation Department) for the year 1961-62 out of the total area of 34.69

million acres surveyed the salinity-affected area is 5.2 million acres. This is 15.1% of the gross area surveyed.

In the Ex-Punjab area, before the introduction of the Canal Irrigation, the water-table was at the deepest position being 90 to 100 feet near Lyallpur, 40 feet near Sialkot and Sheikhupura, 30 feet near Daska and Pasrur, while in the rest of the Rechna Doab water table ranged at a depth from 20 to 40 feet. According to the recent estimates (Thur and Sem Girdawari for 1961-62) the total area which has actually gone out of cultivation due to waterlogging is 40,000 acres in West Pakistan out of which 22,000 acres are in Ex-Punjab area. Some sort of cultivation goes on until water actually comes within one foot or on surface of the soil. The water-table is stabilised at some depth between 4 to 10 feet from the natural ground surface, depending upon the land elevation, intensity of irrigation seepage from canals and climatic factors. The areas where the water table is within 5 feet remedial measures must be adopted.

The statistics regarding areas in various water-table depth zones is given for different regions of West Pakistan in the table given below :

Table showing areas of Water-table depth zones in various regions for all of West Pakistan (June 1959).

		0°—5′	5′—10′	10′—15′	Beyond 15 feet.
Peshawar Region	..	20787	182067	106496	17313690
Chaj Doab	..	432200	1926400	442000	423400
Rechna	..	483400	2982800	1886400	1563400
Thal & Derajat	..	250000	1650000	950000	9936173
Bari Doab	..	16783	1365903	1780838	3390076
Bahawalpur	..	240000	990000	1210000	8227187
Sind	..	572621	3346152	1286349	30720958
Quetta & Kalat	..	..	..	..	..
Part Pindi & D. G. Khan Region	..	..	..	..	..
Karachi	..	..	..	..	..
Total	..	2015791	12643322	7664283	71579884