Paper No. 312

Drainage of Irrigated Soils in Arid Regions

A review on the drainage measures adopted by various countries and a discussion of the information available in the Punjab

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Introduction.

Drainage of a country improves agricultural land and increases crop yields. In case of irrigated soils, it facilitates early and efficient ploughing, improves soil aeriation, ensures easy penetration and development of root system and better percolation with consequent control over upward movement of salines in arid and semi arid regions. In humid zone excess moisture is added by nature in the form of rainfall and in arid and semi—arid zones, human efforts in irrigation practice, add more moisture to the land which must be removed quickly and which otherwise reduces soil air, suffocates the plants, reduces activity of bacteria which help in production of plants food and consequently reduces the extent of volume of soil on which the plants feed itself. Excess moisture also lowers the soil temperature as water with high specific heat, needs large amount of heat, to raise its temperature and consequently the plant growth is affected adversely.

All the semi-arid countries are not lucky to have natural sources of water but those which are fortunate to possess it, have developed irrigation as far as possible and have exploited their water resources to full extent. Practically in all these countries problems of waterlogging, high concentration of salts in the root zone and formation of alkaline soil due to base exchanges under temperate and moist condition, are seriously facing the population. Arid zone countries which have sources of natural water supplies, are, Pakistan, Egypt, Iraq, America, South Africa, Australia, India and to some extent Morocco. All these countries have problems of waterlogging,

salinity and alkalinity of lands Severity of such problems is more where rainfall is neither well-distributed nor is reasonably ensured during a year.

Other countries having arid or semi-arid climate are, Turkey, Syria, and its adjoining regions, Libya, Sudan, Tunisia, Spain, Mexico etc. These have either no good sources of water supplies or are plateaus or have natural sub-surface drainage and thus have no serious problem of waterlogging.

In order to have information about the methods adopted by each country to solve its problem of waterlogging and salinity, a questionnaire was issued at the close of the year, 1952, to the participants in the arid-zone (1)
Ankara Symposium and to those who had contributed to the reviews of (2)
Research in arid-zones. They were requested to supply information on the use of :—

(i) Open drains,

(ii) Tile drains and

(iii) Drainage by tube well as practised in their country.

Workers in every country who are facing these problems replied to the questioner willingly and sent detailed information, drawings, designs, published papers and reports which have been used in preparing this note.

Countries and persons who answered the questioner.

The largest information was received from Australia, followed by Union of South Africa, Egypt, America, Turkey, Morocco and Holland. The names of the persons to whom the questionnaires were sent and the organisation which replied to them are given in the form of a table (Table 1). The countries having no serious problem of waterlogging or having no good drainage system such as India and Iraq were not contacted. The replies received are also given in tabular forms. Table 11 contains the reply of Australia of which seven different organizations took part. The information was printed and circulated to persons interested in this line of investigations. In Table 111 are summarised the replies received from South Africa, Egypt, Morocco, America and Holland.

Open Drains

The following main inferences are drawn from the literature given in tables II and III. The important provinces in Australia where Irrigation is practised are Victoria, New South Wales, Queens-Land, South Australia and West Australia. Waters from river Murray and its tributaries, particularly that of Murrumbridge, is used for irrigation. In this country open drains are constructed in waterlogging land which is either sand or sandy loam having a permeability coefficient equal to 33×10^{-6} to 3.3×10^{-6} ft. per second. The watertable usually lies at 3 to 10 feet, and the field drains vary in depth from $1\frac{1}{2}$ ft. to 4 feet, the maximum depth never exceeds six feet. The distance apart two drains varies from 300 to 990 feet. The side slopes of field drains are generally 1 : 1 but vary upto $1\frac{1}{2}$: 1.

All the big drains are either pumped to rivers or discharged into swamps or ocean. The side slopes of big drains are increased to 3 : 1 for

sandy soil and 2 : 1 for clay soils. Drains are not free from the trouble of falling banks or weed growth for which clearance is carried out regularly. The slope of a drain is generally one foot per mile and wide berms upto ten feet are provided.

Egypt is semi-arid with rainfall upto 4.0", has very fertile soil, particularly in the delta area where basin irrigation is practised from the times of Pharoas but now irrigation is done by perennial canals taken out from the Nile. In this country problems of salinity, alkalinity and water-logging have appeared in irrigated soils. Watertable now lies at 2 to 4 feet below surface. There are extensive shallow field drains, 2 to 3 feet deep, dug in heavy clay as well as clay loams, with distance apart varying from 55 to 120 feet, and side slopes equal to 1 : 1. There is little trouble of falling banks although weed menace is common in big carrier drains of which clearance is carried out by labour.

Union of South Africa has all type of climates ; arid, semi arid and humid. Kala Hari Desert and sand dunes exist between Latitude 28°S to 33°S. Temperature variation is of the order of 27°F to 103° F. All types of soil exist in this country and problems of waterlogging and high accumulations of harmful salts are not uncommon. In irrigated land, mainly on River Orange and Limpono, the watertable has risen within to 2 to 3 feet below surface and field drains (minor) are installed 3 to 4 feet in depth, suitably spaced, depending upon topography, permeability and other soil conditions. For shallow drains, steep slopes, even vertical, are kept but for deep drains or those in sandy areas, side slopes to a maximum of 3:1 are practised. The usual side slopes are $1\frac{1}{2}$ to 1. This country distinguishes herself in two things which no other country has done. The section of big drains are parabolic, based upon formula of the type $X = A\sqrt{Y}$ and all the big seepage and storm water drains are concrete lined and are consequently free from the menace of weeds and falling banks

United States of America has the largest drainage system and has produced the greatest volume of literature on the subject. In the area where serious problem of alkaline soil exists, the range of temperature is similar to that in the Punjab. Irrigation is extensively practised and as a consequence water table has risen within ten feet below land surface. The depth to drain lies between 6 to 12 ft, below natural surface, and distance between them varies from half a mile to one mile. The side slopes of field drains are usually 1. 5 to 1, and even flatter. Chemical weeds killer for soil sterilization are used but dredging and weed clearance is most common.

Morocco has no big irrigation system. In areas of Sidi Umar where irrigation is practised water table lies between one to 15 feet below surface and drainage has become essential. This country has not yet adopted any definite rule of design about depth and distance of field drains. With the variation of the nature of soils there is much variation in the depth and distance apart of the drains.

Netherlands is a country of humid region. This example is put in to show that drains are also as essential in humid countries as in arid lands. In this country tile drains are most common, probably due to the high cost

of land. Where ever open drains have been dug, these are 24 inches deep, located in sandy loam, with side slope of 1 : 1 and distance between them varying from 25 to 100 ft. The weed growth is eliminated by hands and there is very little trouble of falling banks. It may be noted that humid zone soils are quite different from arid zone soils and thus have quite different types of drainage problems.

Tile Drains.

Tile drains have been used only in some parts of Australia and are usually of baked clay, shrouded alround upto a depth of 3 to 6 inches. These are placed at a depth of 4 to 8 feet below natural surface, having slopes of 20 to 23 ft. per mile and are 44 to 132 feet apart depending upon salinity and type of soil.

These are not very common in Egypt. Tile drains used there, are made of cement concrete, placed so as to keep their joints wrapped by jute and covered by 4 inches thick shrouding made of broken red brick or gravel. Depth at which these are laid below surface is 3 to 4 ft. These are placed at 150 ft or more apart, with a slope of 5 ft. per mile for 4. 0″ diameter pipes, which is reduced from 3 to 2 ft. per mile for tiles of 8 to 10 inches in diameter.

In South Africa, un-reinforced precast concrete pipe, 6·0 ft. long and 12 to 15 inches in diameter are laid with open joints encased with clean unweathered stone up to 3·0″ size. The gravels are placed in the form of a filter.

Glazed earthen pipes 4 to 6 inches in diameter, 2 feet long are used for small field drains. The shrouding is done on the full pipe length including joints and its thickness varies from 6 to 9 inches. The drains are laid below watertable or below the normal zone of root penetration, with distance 20 to 40 feet apart and with slope as steep as possible to avoid troubles of silting up.

Tile drains are practised in America to a very large extent. After the invention of Dipper Dredger in 1885, drainage by this method has ever been on the increase. The available information with the authors was upto 1930 and by this time, this country, had constructed 58,000 miles of tile

(15)

drains in an area of 84 million acres, The field drains were only 7000 miles, while ditches had a length of 140,000 miles. This was accomplished with a capital investment of 2700 million rupees. Tiles have been used to drain humid, arid, semi arid and in fact all types of areas. These are made of rich cement concrete, baked clay, glazed pipe and other available materials. Their diameters vary from 3 to 10 inches but length is not more than 2 to 3 feet ; with ends butting against each other and the full pipe length is shrouded by gravel. The thickness of shrouding varies from 3 inches to 12 inches. Tiles are laid 3 to 5 feet deep, depending upon the position of watertable, and with distance between them varying from 50 to 150 feet, de pending upon the nature of soil. The slope of these drains is kept very high, often 10 feet per mile or even steeper if topography permits.

Tiles drains are installed extensively in Holland, although several regions of England and France have also been drained and made fit for agricultural purposes. Holland is the only European country which has used them extensively. Tiles are usually made of baked clay or concrete, 2 to 3 inches in diameter, with thin shrouding all round the length of pipes with joints covered by fibrous peat. The depth of these drains varies from 2 to 3 feet, with spacings varying from 25 feet to 100 feet. The slopes of tile drains usually vary upwards from 10 feet per mile.

Tube Well Drainage

The drainage wells used in Australia are usually shallow, their depth varying from 30 to 90 feet. The discharge is 0.3 to 1.3 cusecs and is pumped generally into rivers due to high salt content. The well screens are made of 8 to 28 gauge bronze, with rectangular slots backed by bronze frame. The strainers are of 7 inch diameter with shrouding up to 10 inches.

Egypt, South Africa and Morocco have not yet made use of this method of drainage. None of the humid zone need to adopt it and in Holland, these are not practicable due to land being lower than the sea level. America is the only country which has extensively used this method of drainage. Very little information, however, could be gathered from the replies to the questioner but American practice gathered from other publications is discussed later.

PROBLEM OF WATERLOGGING AND SALINITY IN THE PUNJAB.

Early Investigation

During recent years innumerable notes and reports have been written on the conditions of land of the Punjab. Every writer has traced the history of the irrigation in this country and its effect on the rise of watertable, water-logging and deterioration of lands due to accumulation of salts within the root zone of crops.

Early studies in waterlogging, seepage from the canal and rise of watertable go to the credit of Wildson[25a], Bose[25b], Taylor[7] and Malhotra and Metha[10 A, B, C & D] and to a certain extent to Metha[8].

In 1937 Bawa Natha Singh[5] presented a paper on waterlogging on the Upper Chenab Canal and discussed its causes and suggested some remedies.

In 1940 Blench[6], as Officer on special duty for waterlogging investigation, collected information on the seepage losees from Lower Chenab Canal and Upper Chenab Canal and possibilities of lining them.

In 1947 another informative paper was presented to the Punjab Engineering Congress by Khungar[4] who considered the various factors which contri-

buted to the rise of watertable and worked out the amount of seepage from various canal in the two main Doabs of the Punjab, Rechna and Chej. The factors like addition from rainfall as well as irrigation practices, were also taken into consideration by him. Fundamental investigations on the movement of moisture through soil were carried out by Asghar. (9)

In the year 1950 when F. A. O., and T. C. A., came forward with a programme to help the backward countries of the East, Hamid, as Officer on special duty, collected the existing information for the convenience of foreign experts on the problems of waterlogging and salinity in this country. (3)

A recent note of this nature is by Carlston, ground water geologist, sent by F.A.O., who collected information from this country, in a short period of three months and put forth his own conclusions. The inferences of various investigators will be referred to in this note at proper places. (11)

Nature of the Land of the Punjab

The lands lying between the rivers Jhelum, Chenab and Ravi consist of alluvium, deposited by these rivers. The topography of the country is practically flat, with surface slope on the average a foot per mile, increasing to five feet per mile near the foot hills. Chej Doab is mainly irrigated by lower Jhelum Canal (L.J.C) opened in 1905 and Rechna Doab by lower Chenab Canal (L.C.C) opened in 1887. Both these canal systems follow the slope of the land and are high level channels. A feeder canal crosses each of the Doabs, Upper Jhelum canal (U.J.C.) in the Chej and Upper Chenab Canal (U.C.C.) in the Rechna. These carrier Canals were opened in 1916, do very little irrigation and usually run across the country, deep in the natural surface.

Before the introduction of irrigation, the ground watertable had attained a stable level under the influences of various agencies of infiltration and extraction. At places the watertable was as deep as 90 ft. (Lyallpur) and as close to surface as 20 ft. or even closer near the rivers.

With the introduction of L. C. C., and L. J. C., the balance was upset, and several new factors, such as constant flow of water in irrigation channels in the heart of the Doabs, spread of irrigation water, changes in natural surface and sub-soil drainage etc , started to affect the watertable, which as a natural consequence started to rise. The earliest reliable records of ground watertable are those from the year 1905, although some information has been collected for periods upto 1882. After the irrigation canals had been in operation for one decade and feeder canals were put in command, the approach of water close to the surface and even appearance of surface water in low lying areas, alarmed the Government which started to take measures to check the rise of watertable and deterioration of the lands.

Present extent of waterlogging and salinity

In table IV is given a statement of the areas of the two doabs in which watertable lies between 0 to 5 feet, 5 to 10 ft, 10 to 15 ft., and beyond 15 ft.

below the natural surface. This data is given at intervals of five years beginning from the earliest recorded year of 1892.

A study of the table reveals that only 7% of the areas of the two doabs is such in which water-table lies within a depth of 0 to 5 ft., and this area has attained a stable order since 1935. The areas with watertable between 5 to 10 ft., is still increasing and upto 1950, constituted about 30% in Rechna and 50% in Chej Doab. About 27% areas of the two doabs has watertable between 10 to 15 ft., Both the areas with watertable between 10 to 15 ft., and below 15 ft., are slowly being reduced.

Out of 9.5 million acres of irrigated lands by canals, about 4.6 million acres are effected by salts. About 21.4% of the total area has gone out of cultivation and the spread of salt is increasing at the ate of 2.1% per annum, covering 40,000 acres per year. (12)

Physics of Soil Moisture

The whole science of irrigation, drainage and reclamation is based upon soil moisture and its movement. This is a very vast subject and at the same time most complicated. In a note like this, it is not possible to do justice to this subject but because the drainage measures are mainly based upon moisture movement, a short account is given on the various types of moisture. For a detailed understanding, works of Asghar, Baver, Richardson, Hauk (9) (13) (14) (15) (16) Pickle, Isrealson etc., can be consulted.

Gravitational Moisture

This type of moisture is most important from drainage point of view. It moves under the force of gravity and is free from capillary or cohesive forces of soil particles. If a porous tensiometer is kept in this zone, no change in pressure manometer will be visible. (9) Moisture deficiency or tension in soil does not exist with this moisture content.

The Punjab sands have an average pores space of 40 percent so that on complete saturation, one cubic foot of sand has 0.4 cubic feet of water. Particles of sand are very big as compared to soil, so that all empty spaces are easily filled by water and thus complete saturation is possible. On the other hand, clay soil has innumerable small capillaries and the space in between two particles is so small that if an air bubble is entraped in soil, it will need tremendous effort to drive it out and replace it with water. This structural difference is responsible for easy and quick saturation of sand and not of soil by ordinary means. Consequently whenever a sample of soil is taken out from under water, its moisture content is seldom upto 35 percent. (see tables V) although according to pores space it should be above 40% (17). Just as the fineness of pores does not allow complete saturation simi-

larly it obstructs drainage, as the water between soil particles is held by strong capillary forces, and under the influence of gravity very little moisture can be drained out as compared to sand. A sand may yield 30% of its total moisture content, retaining about 10% or less but a clay soil will easily (13 & 15)
retain 22—28 % moisture releasing only 5 to 10%.

The incomplete saturation of soil pores is advantageous because sensitive plants on temporary submergence and weeds on prolonged submergence can survive without suffocation. The entraped air can sustain them. It has also been observed that if a borehole is dug in such a soil free water surface will appear in the hole which will represent the position of water level usually defined as watertable on hydraulic considerations.

Gravitational moisture is the only one which can be drained by all types of drains, open, tiles or tube well, and in this note we have to mainly deal with this stage of moisture.

Capillary moisture

This is the second important type of soil moisture. When a dry soil, dry sand, blotting paper, or a thin bore glass tube is kept in contact with free surface of water, a rise of water is noticed in these materials. The rise is dependent upon the size of the bore of the tube or the pores. This rise is due to molecular attraction of sand water particles and is called surface tension, which is defined as force (dynes per centimeter) per unit length. (18 VI),
According to capillary tube Hypothesis, the height to which water will rise in a capillary tube is given by

$$H = \frac{2T}{pg} \cdot \frac{1}{r} - \frac{r}{3}$$

Where T is the surface tension force equal to 74 dynes/cm at 20°C, r the radius of the tube, ρ is the density of liquid and g is the gravity. Working on this formula the height to which water will rise in fine clay, comes (19a)
to about 150 feet.

Many investigators have tried to determine experimentally the height (19b)
with various grade of particles. So long the medium is granular such as sand, the height of rise of water is reasonable, but with clay or soil the results are far from the theoretical value.

(19b)
In fact Keen, the greatest exponent of capillary theory has stated that in soil the capillary height is seldom more than 3 to 4 feet. (20)
Wisler and Brater have stated that height in a silty material is as high as 8 (21)
feet but in soils it is much less. According to Asghar, this moisture may

rise to greater heights than ordinarily observed by visual inspection but the rise is never equal to that worked out by capillary tube hypothesis.

Capillary zone is a moisture deficiency zone as compared to gravitational moisture zone. If a tensiometer is kept in this zone it will show negative pressure or potential equivalent to the moisture deficiency. If a bore hole is dug in the capillary zone, no free water will be found in this region, as the moisture is all held up by capillary forces.

In fact water held by soil pores has a surface in contact with air. With evaporation when the free water from surface disappears, meniscii are formed between the soil particles and water and with increase of evaporation these come under a tension which is manifested in the form of change in concavity of the meniscii. This results in a fall of level in the monometer installed in soil to record the forces of tension. The greater the development of tension the greater is the fall in monometer level and greater becomes the concavity of the water meniscii, although there is practically no change in the moisture content of the soil.

As soon as the tension is reduced by decreasing the concavity of menciisi by addition of small amount of moisture at the top, the monometer (22 abc)
rises showing disappearance of the tension. If however, the meniscii at surface break down and the upper portions now attain moisture lower than capillary zone (field capacity) and water in monometer falls to a level much below the capillary height, then the addition of small moisture at top does not build up the capillary meniscii and the rise in water level is equiva- (10E)
lent to what has been added to pores to saturate them.

This statement is explained by the following results of experiments which were conducted in plastic tubes in which sand was packed under water. A glass monometer was fixed to the tube. With water level in monometer below the capillary range of sand, small increment of moisture addition at top, only raised the water level by a small amount till the water level was within the capillary zone. Under this condition a small addition of moisture raised the water level quite disproportionally. These results are shown in Fig. 1 (*a*) where the lower straight line is for the case when water table was below capillary range and the upper line is for the case when the water table was within capillary range.

The experiment was repeated by keeping water table below capillary range and adding moisture at bottom. A straight line relation similar to Fig. 1 (*a*) was observed. This is shown in Fig. 1 (*b*).

This is what happens in a field when the water table is within capillary range ; with a slight rain fall water table rises sometime more than 4 feet. In fact the moisture added had been sufficient to satisfy the moisture deficiency in the capillary zone, which was hardly a few percent of the total volume and hence the watertable rose by several feet.

It may not be out of place to mention that rise of temperature decreases the surface tension and thus the capillary height increases. So is the

case with the presence of various types of salts in water or in soil. The effect of salts on rise of capillary moisture was studied by Asghar and (10Ab)
Dhawan and height of capillarity observed in different salts was heighest with sodium nitrate followed by sodium chloride, sodium bicarbonate, sodium carbonate, sodium sulphate in decending order.

Field Capacity Moisture.

This is a third important type of soil moisture above capillary zone in which the soil is unsaturated, possessing a moisture content less than that of the capillary zone. Its moisture content is characteristics of the nature of the soil. If it receives more moisture from top, it faithfully passes it down so that watertable comes up and if it receives less it may try to extend its position downward depressing the water-table.

Pellicular Zone.

This is the zone in which the moistures is under the direct influence of evaporating agencies. It may be a few inches or may extend to several (7)
feet. For Punjab soils, a maximum limit of six feet was suggested by Taylor, (21)
although quite recent experiments of Asghar have shown the evaporation effects beyond a depth of 10 feet.

Percolation or Permeability.

Whenever soil or sand is kept in contact with free water it passes through these media raising their moisture content at the same time. The bigger the pores, the quicker is the motion and greater is the out flow. (23)
Coarse types of Punjab sands have been found to transmit as much as 6.0×10^{-4} cu. ft. of water per second under a unit head (ft) through a unit cross section (sq. ft). Similarly, medium and fine sands, may transmit 3.3×10^{-4} and 1.2×10^{-4} cu ft. per second respectively, but in case of soil, with the increase of clay content the pores become smaller, resistance to motion increases so that the quantity of water flowing out under the above stated conditions may fall from 1.0×10^{-6} to 1.0×10^{-8} cu.ft. per second.

In a dry soil the moisture may have been slowly filling the pores, removing the rigidly held air and some times at a place water may move quicker and at another place it may be held up. The type of motion through unsaturated medium, is not regular and is not governed by definite laws of (24a/b)
nature so far known, although during recent years several useful papers have been produced explaining the motion of water through unsaturated medium. On the other hand through saturated medium from which the air-locks have been completely removed, the motion is regular and the quantity of water being transmitted under a certain head through a certain

medium can be exactly estimated, which is mathematically expressed by Darcy's Law.

The water transmitting quality of various materials depends on their nature. In case of soil, particularly if it is compacted, the passage of water is slowed to such an extent that some times it becomes quite impervious. Six inches to a foot of compacted soil may be quite imprevious to 20 ft. water head, but if the same soil is disturbed by ploughing, it allows quick transmission of water. Soil under this condition may also become impervious if fine colloids, accumulate and form an impervious jell under water.

Mechanism of water-logging.

The canal bed material varies considerably so that in certain reaches it consists of pure sand, in others it may be well compacted clay soil. In a running canal a constant head of water, 15 to 20 feet in depth and 250 to 300 feet wide, kept on all types of soil has slowly worked through the bed material replacing the air of the pores, changing unsaturation to saturated conditions and has finally established the existing high water table conditions. Wherever the clay bed was comparatively impervious, it took several years to establish such a state, while sand gave way within months. Capillaries were effective in all directions and the saturation of sand and soil continued horizontally as well. If the driving head was sufficient to counteract the resisting forces, the motion continued, otherwise it stopped. The extent of spread of saturation was proportional to the driving water head. Slope of free watertable under the soil also aided in the downward motion of moisture. During the last thirty to forty years, watertable has been slowly rising due (25.8)
to seepage from canal, percolation from rainfall, spill of nallahs and increased irrigation intensity, till it came so close to the soil surface as to be (10 B,C,D.)
controlled by forces of evapro-transpiration.

It is stated that an under-ground rock ridge which crosses the doabs at right angle to the flow of rivers, have been instrumental in obstructing the sub-soil flow of water particularly on the upper region. The region below the ridge is still being filled up. This reasoning was advanced by (27)
Glennie, but it has not been verified as yet by actual measurements. The sub-soil water table contours fail to show any abrupt change while crossing over the ridge and are quite regular both up-stream and down stream although local variation do exist. Observations carried out at R. D. 110 (18, iii)
Sheikhupura Drain showed a slope of $\frac{1}{2}$ to $\frac{3}{4}$ ft. per mile and at Chu- (18 iv)
harkana it was found to be 4 feet per mile. Heavy additions in the upper region of the doabs may be due to the feeder canals which run through deep cuttings and have no resisting soil under the bed.

Just as soil resists percolation so does it resist movement of water through it, even when the source of head is at the bottom. The soil crust

in the Punjab may be taken 10 feet on the average. It resisted the movements of moisture through it even when the water had completely saturated the aquifer sand and was still under pressure but it could not pierce through the resistant clay crust. Wherever the thickness of soil crust was small, or its dry bulk density was low or soil was sandy or wherever surface application of water was made in excess, such as through high delta crops of rice or sugarcane, the air locks from unsaturated zone were replaced quicker by water and the area become waterlogged. This particularly happened at places close to canal where the upward head was considerable and water could get through the soil.

Existing Drainage Systems in the Punjab.

Construction of Drains in our country was actively started after the (25)
data collected by Wildson and Sarthy illustrated that rain fall was also a major factor in raising the ground water table. Drains were constructed to carry away the rainfall run-off from the land within a period not detrimental to crops. A Drainage Circle functioned for several years and constructed several storm water drains. Their design, capacity etc., was based upon the consideration to carry away the rain water within a specified period. Capacity determination was based upon several formulae correlating run off, catchment area, intensities of rainfall etc. The aligment of the drains followed the natural drainage of the country and no special consideration was given to their design. The criterian of their design is discussed by Alim-ud-Din : (12 a)

The main drainage systems in the Punjab are :—

1. Chaj Doab.

1. Budhi Nallah System.
2. Fadinian Sillanwali drainage system.
3. Lower Raniwal drainage system.
4. Mona drainage system.
5. Alla Drainage system.

2. Rechna Doab.

1. Niki Deg system.
2. Chicho-ki-Mallian Drainage system.
3. Rechna Outfall drainage system.
4. Ahmadpur Kot Nikka Drainage system.

5. Ahmadpur Wagh drainage system.
6. Aik Nallah drainage system.
7. Jaranwala main drainage system.
8. Chiniot drainage system.
9. Modduana drainage system.

3. Bari Doab.

1. Sukhawal drainage system.

The total mileage of drains on various canal systems is given below :—

TABLE No. VI

S. No.	Name of Canal	Length of drain					
		Seepage		Storm cum-seepag		Storm water	
		Miles	Feet	Miles	Feet	Miles	Feet
1.	Lower Chenab East	22	—	490	—	3	—
2.	Lower Jhelum.	278	2650	—	—	391	4000
3.	Upper Jhelum.	107	—	141	—	114	—
4.	Upper Chenab. (including LHR Div)	519	2196	38	600	202	3649
5.	Central Bari Doab.	331	750	—	—	—	—
6.	Nili Bar Canal.	—	—	—	—	—	—
7.	Haveli Canals.	1	993	1	840	—	—
8.	Lower Chenab West.	115	305	184	3321	17	214
9.	Derajat.	3	2000	29	1000	—	—
10.	Lower Bari Doab.	—	—	12	1000	382	4100

		Miles	*Feet.*
1.	Seepage Drains.....	1080	1894
2.	Storm Çum-seepage drains	896	1761
3.	Storm water drains.	1111	1963
	Total	3088	5618

The drainage capacity of the drain in the two doabs is 13832 and 2901 (12a)
cusecs, respectively, and these flow to capacity for hardly ten days a year and carry either no water or very little discharge at other times of the year. These are not meant to function as seepage drains and have little effect on improvement of soil under excessive moisture conditions. In fact very soon with such large variation in flow, silt deposits in their bed, falling banks decreases the depth and weeds impair their capacity.

In the history of Punjab Irrigation only one attempt was made to dig seepage drains on both sides of the Upper Chenab Canal and Lower Chenab Canal. It was presumed that these will help in removing the additions of seepage water from canals into the subsoil. As there was no scientific background for such an assumption and the drains could not be maintained properly, this experiment failed.

Depth of field drains.

In arid zone soils, the plants develop their root systems to a greater depth than under humid conditions. The soil root zone for common crops in arid regions varies from 2 to 6 ft. and may be more in special cases. For producing healthy crops, a suitable depth of water table is six feet. Crops can take moisture by sub irrigation under such conditions. But, if the sub soil water is saline, rate of upward migration of salts is high, there are greater chances of salinisation of soil within the root zone of the crops. This, however, can be checked by either growing high delta crops and draining out the water from the sub soil or increasing the water requirement of crops to an extent that some drainage is provided through the soil profile. It has been observed that without actually lowering the water table normal crops can be grown provided sub surface water is kept moving, through open drains.

A reference to tables II & III and the literature cited in the biblo- 29 – 36
graphy would show that every country has shallow field drains, usually 3 to 4 feet deep. This is the depth even in very heavy soils. The reason for their effectiveness is that the top one to two feet of soil is disturbed by ploughing and with inter cultures and surface irrigation this zone gets saturated with moisture. Some of the water passes out quickly into the field drains, taking with it the soluble salts.

At Chakanwali Reclamation farm in the Punjab where watertable lies between 1 to 4 feet, shallow Drains 3 to 3.5 ft. have proved very helpful to

produce normal crops. This farm comprises an area of 3645 acres out of which 2479 acres is under crops. An area of 1765 acres has been completely reclaimed while the rest is under operations. The average yield of various crops is given below :—

Crops Yields (Maunds)

Year	*Wheat*	*Gram*	*Peddy*	*Cotton*	*Sugarcane (Stripped).*
1951	5.54	—	14.5	5.9	142.9
1952	3.3	4.9	14.6	2.8	90.0 ,,
1953	5.49	5.89	31.0	2.26	123.2 ,,

High yields of 10, 33, 15 and 600 maunds have been obtained for cotton, peddy, wheat and sugar cane, respectively.

Apart from the above mentioned arable use of the land, fruit trees have been successfully tried and Mulberry, grapes, guava, Banana and Phalsa are giving normal yields.

Spacing and working of Drains.

Usually the division of land is on acre basis with one side width equal to nearly 220 feet. According to practice in foreign countries the distance between open field drains for very heavy soil may be upto 300 feet and for light soil it can be increased to a maximum of 1000 ft. The Punjab soil of old canal colonies generally is heavy loam to sandy loam and for such a soil the distance between the field drain may be half acre to two acres *i. e.* 110 to 440 ft. In heavy type of soil, as for instance the clay loam of Chakanwali Reclamation Farm, distance should not be more than 110 ft. Provision as well as the maintenance of the field drains is to be done by cultivators. Further work is needed to cover all the textural variations of the Punjab soils.

The field drains discharge into carrier or collector drains, which are also constructed by the farmers. These are four feet or even deeper, with side slopes varying between 1/2 to 1 and 1½ : 1, and sufficient to carry the discharge of field drains. The general maintenance and weeds or silt clearance can be carried out by the farmers without the help of any skilled labour.

The carrier drains discharge into seepage cum-flood water drains maintained by the Government and are designed to carry all the see page brought down by the field as well as carrier drains and also the flood water. To ensure quick relief to the area an efficient outfall, natural into a river or artificial by pumping is provided.

Suggestion for a stable design seepage drain.

Seepage cum-flood water drains suffer from a few very serious defects.

The first is the weed growth. There is no easy solution to this menace.

Countries like America and Australia have tried to use chemical soil sterlisers but weed clearance by hand and by cutters are the only commonly adopted means.

The second trouble is that of falling banks. If a seepage cum-flood water drain is to work as seepage collecting ditch also, water must ooz into the drain from the banks. This moves the soil particles from the sides, particularly in noncohesive soils and makes it to flow into the drain thus raising its bed and reducing the capacity, the water level in the drain rises and its effectiveness is reduced. The sides of the drains are the discharge faces for the water coming from the soil. The water table in soil is like a free surface in earth dam. The discharge point or seepage face must be above the water surface level in the drain. This point, for a side slope upto 45°, is usually 1/3 the total head above the water level in drain. If the existance of free surface is assumed then the open drains are not free from this defect due to hydraulic property of water flow and this defect reduces the effectiveness of seepage drain continuously with rising of bed and subsequent rise of water level which will further raise the point of emergence of seepage. (40)

It is proposed that a drain may be designed with wide berms, at least 10 feet, on either side, and a quinnet be provided in the centre of the bed, with capacity to pass the normal seepage discharge of the drain. It is assumed that with adoptation of this proposal, the trouble of falling banks and in-effectiveness of drain due to free surface will be reduced considerably.

Another important point for consideration in the design of open seepage cum-rain water drain is to keep such slopes which should give scouring velocity so as to scour all deposit in the quinnet during full capacity flow. In addition all the joining points of carrier drain and seepage drain should be such as not to reduce the velocity of flow. They may join preferably at an angle of 30° or less. Lining of quinnet with dry brick is another suggestion, if cost is no consideration.

Open field drains have certain advantages and some defects at the same time. An open field and carrier drain can be dug easily by farm labour and is cheap to maintain and a quick removal of weeds obstructing the flow of water can also be done. No doubt about 10% of the land is wasted but this the cultivator can afford in preference to skilled labour which would be required for constructing any other type of drainage system. It is difficult to dig deep open drain unless these are fairly wide, their sides slopes and their maintenance also becomes a problem. If it is intended to keep water table deeper than three feet, it may not be effectively possible by open drain, as neither these can be deep enough to over come their inefficiency due to hydraulic properties, nor can these be maintained at the designed level. (37-39)

The open drains interfere with the movements of farm workers, and machinery and therefore cultivator in mechanically advanced countries has disapproved such a system.

To over come the disadvantages of open drains, tile drains are often recommended.(41) Eaton has advocated their use for Punjab, giving detailed suggestions as to their installation, cost etc. According to him Tile drains of 3 to 6 inch diameter and two feet long can easily be constructed by using local soil and getting them burnt. The difficulty is about shrouding, shingle is too costly. If brick bats can work this will solve problem of a costly material. Egypt has used brick bats. It might be worth while to give a trial to make a brick filter. Laying of tiles is done with the help of machines and is a difficult job particularly in high water table. For obvious reasons the tile laying job has to be done by the Government, while field drains are never the concern of Government. Preferable depth of field tile drains should be below the soil crust or at least ten feet below surface which has constructional as well as financial difficulties.

Another important factor which should be considered necessary for efficient working of tile drains is to keep a proper slope for self silt cleaning. The usual slope adopted in Australia, Africa and America is 10 to 20 feet per mile, so that in a length of 500 feet the slope should be one to two feet. These slopes for short lengths are satisfactory but for longer length of tiles one end will be too close to surface on the upstream side and the other will be too low on the downstream side.

Those who have experience of installation of tile drains have fixed 50 feet apart as the distance for very heavy soil and 150 to 300 feet for sandy soil. Tile drains are usually laid closer than open drains.

It is highly important that before deciding upon installation of tile drains, a through scientific study of soil should be made for its various soil profile characteristics viz., permeability, bulk density, depth of soil crust, existance of sand layer or hard pan, and the maximum rate of water discharge through the tiles.

Field drains are connected to carrier drains which are also made of tiles. These are usually 1000 ft. apart and 10 to 12 feet deep. Carrier drains discharge either in a seepage cum-flood water drain, or must have suitable outfall. In our country it might be difficult to discharge them into seepage drains. Lifting of drained water shall have to be adopted at several places. If water table in area exists under artesian pressure the effectiveness of tile drain is seriously impaired(42) and other methods of drainage should be resorted to.

The selection of a suitable drainage system for a particular area should always be made after consideration of the requirements and nature of the area. Perhaps, there is no place where only one type of system is the ideal one.

DRAINAGE BY TUBEWELL.

Aquifer of Rechna and Chaj Doabs :—

During the installation of wells of Rasul Tube Well Scheme, Karoal Project, and other innumerable wells installed in the two doabs, it has been

observed that usual form of sub-terranian formation consists of sand upto a depth of 300 to 350 feet, which was deposited by river action. The formation consists of either coarse sand of mean diameter 0.35 mm. to 0.4 mm, medium sand of mean diameter about 0 25 mm. or fine sand of mean diameter 0.2 mm. During a boring of 300 to 350 feet one may come across one, two or even three clay layers of varying thickness. In exceptional cases clay layer has thickness more than 50 ft. Generally it is within 10 to 20 feet thick with no extensive spread. Its maximum extent may be about a mile. Within this depth practically in all cases examined so far there is 100 to 150 ft. of good coarse type of sand. Only in exceptional cases a bore of 300—350 feet depth is without a zone of suitable coarse sand. Similarly no case is known to the authors in which the full depth of 300 to 350 feet consisted of either clay or fine sand. At several sites coarse sand appeared just at 30 to 50 feet below the natural surface and extended to 100 and 150 feet in depth. The aquifer in Punjab is such that great variation may be noticed within a distance of 100 feet. The Punjab aquifer sand although of medium size has a high transmission constant due to high uniformity, high pores space and absence of high percentage of fines.

(23)

After analysis of extensive field and laboratory data, it was determined that the permeability coefficient, for Punjab sands is 6.0×10^{-4}, 3.3×10^{-4} and 1.2×10^{-4} feet per second for what we call as coarse, medium and fine sands respectively. The uniformity is also fairly high and its value lies between 1.5 to 3.0. In exceptional cases it has gone upto 4. The pore space of the aquifer lies between 37 to 42% with average value at 40%. From every foot of saturated sand, about 0.25 to 0.3 feet of water can be made available.

The fine nature of Punjab sand when compared to gravel formation of
(43)
America lead Sir Roger to believe that our tube well projectes are bound to fail. These doubts could be expressed only when one has no experience of the permeabilities of Punjab sands. The good qualities of sand have often resulted in yielding quite a good discharge from the wells in the two doabs. Out of a small bore of 15 inch casing, 7½ inch strainer. and length upto 150 feet, it has been possible to pump 6.0 to 7.0 cusecs with 20 to 30 feet
(18ii)
depression head and 2 to 3 cusecs with 10 to 15 feet depression head. Such high yields are only possible from exceptionally good formations which we posseses in the two doabs.

Quality of ground water.

The water of wells installed along canals has been tested and odserved to be of good quality in 95% cases. Agricultural department has tested
(41)
waters of wells located at places away from canals and the results show that 50% wells are of bad quality water. There are doubts about the quality of sub soil water particularly if the well lies away from the canal.

In the absence of a systematic analysis of ground water, it can be assumed that top fifty feet of water is usually saline and those areas which are far from the influence of canal infiltrations, may also have unfit water. At greater depths, say below 200 feet, the water is usually fit and is of the same quality as that pumped from areas close to canal. Typical water analysis for 24 wells of Chuharkana Project in is shown in Table VIII. However, one should wait till scientific examination is completed for more wells in the new project of Ground Water Development Organization.

Evaporation from water-table.

Evaporation is the major factor which stablizes water table. Under the present conditions of stable water table in the upper portion of Rechna and Chaj Doab evaporation is a major factor maintaining its position and if the present position of water table is lowered the evaporation will decrease and in case lowering is attained by pumping we shall be saving a portion of the water which is lost by evaporation.

(21)

Asghar Zaidi and Qayum have stated that 18.6 inches of water was lost in a year, from an uncropped 20′ × 20′ lysimeter when water-table was kept at 11.0 ft. It was also observed that in iron lysimeters of 34 inch diameter, the annual evaporation was 22.17" and all with a water table kept at 13.5 ft. Thus it is concluded that if evaporation is eliminated, a large quantity of water can be made available which otherwise is lost.

Increase of seepage from canal when watertable is lowered.

When watertable was deep but rising, percolation was taking place through unsaturated soil which was slowly being saturated by replacement of air locks which usually resists flow. The rate of percolation was certainly slow at that time but now under the present conditions when the whole of the zone is saturated, the water flow is through saturated soil and follows Darcy's law which states that percolation varies directly as the head. At present, the difference between the full supply level, in canal and the sub soil water table is not much but in case water table is lowered the percola-

(44)

fion from canal will obviously increase.

To create similar conditions as existed before saturation, the existing water table should be lowered to two or three times the capillary height.

(10E)

This was actually demonstrated in the laboratory experiments in 1951. An important observation was that there is a sort of hysterysis and once a saturated connection is established, it is not possible to attain unsaturated conditions even by Lowering the water table beyond the capillary height.

By pumping, the aquifer is drained, removing the water which has waterlogged the soil formation- If the condition at site is such that no free source of supply is directly connected to sub soil such as a canal, a river or

a pond in the area, the drainage of the aquifer. effects the top water-table and quick lowering is possible. In a test carried out at well No. $18R_1$. (8-iii)
Sheikhpura Drain, R.D. 110, a lowering of water-table upto six feet, close to well and 3.0" at a distance of 5000 ft. was observed after 22 days of working of the well, pumping 4 cusecs with 35 feet depression head. (Fig 2a) When two wells, 2100 feet apart, were worked at 10·5 and 40 0 feet depression heads respectively the whole area in between the wells was dewatered to an average depth of 3·0 feet (Fig. 2b). In another test conducted at R D. 112, (18 v)
Upper Gugera canal, with a single well, pumping 2·0 cusecs and located 60 feet from canal, the water-table receded 4 feet close to the well and 3·0 inch at 3000 feet on both sides of the canal. Ths Upper Gugera Canal at this site is 10 to 12 feet deep. 250 feet wide, and has a 7 to 8 feet thick soil crust at the bed. The effect of lowering was even felt under the bed of the Canal. (Fig. 3) Earlier tast, at the same site, with 9 wells, in three groups, working for about 3 to 4 months, produced lowering of water-table which varied (18 vii)
10 to 3 feet in the observational area of 10,000 by 5000 feet. In figures 4 a, b, c, are illustrated original sub soil water level and that attained after pumping.

In case the canal has no soil crust under the bed, either no lowering is expected or that which is attained is temporary. This was observed in two cases investigated at a site close to Chuharkana Rest House. In one case a single well No. 23A. located at R. D. 133, was worked for seven days. The lowering of water table close to well was no doubt four feet, but there was no effect on the opposite side of canal and not farther than 1000 feet (18 iv)
from the canal. The effect was also very short lived. In Fig. 5 is illustrated the observed lowering together with that at well No. 29B. This compares the lowering of water table at two sites, one having sand under the canal bed and the second having thick clay.

(18-i)
At Chuharkana Reclamation Project twentyfour tube wells worked and pumped 1700 acres feet per month in the year 1953 but no lowering took place during the pumping period. Fig. 6, shows the water table contours observed in August and November, 1953.

During 1954 there has been no rain. 9329A-feet of sub soil water has been pumped during June, July and August and the results are illustrated in Fig. 7, which shows ineffective lowering of water table. It is thus suggestive that before installation of tube wells for drainage purposes in the vicinity of canals carrying high discharges, investigation should be carried out to locate sites of high leakage from the beds and suitably treated to reduce the recharge to the sub soil.

From a study of all these instances cited, it may be inferred that Tube wells are most efficient as quick means of lowering the water table. Their effect is also extensive, provided, no free source of recharge is near by.

There are two methods to stop percolation of canal from such sites. We can line these portions by any of the methods known to engineers. But a more simpler method might be to have two or three lines of wells along the canal. The first line will be taking its discharge mainly from the canal or the aquifer maintained by canal. This line of well, infact shields the supplies going to the sub-soil. Another line of wells installed 300 feet away from the first line of wells and located such as to be in line with the first row of well, not staggard, will cater for the sub soil water.

No doubt the first row of wells shielding canal supplies going into sub soil will be pumping water from the canal back into it but this can form an interim arrangement till more money can be spent on expensive lining. There are, however, many constructional difficulties for lining the existing canals which cannot be closed for works requiring long periods.

COMPARISION OF DRAINAGE AND WATER SUPPLY TUBEWELLS.

How to design drainage wells and what depth to lower the water table.

Tubewell may be designed for water supply or for drainage of land. So far the tubewells installed in the Punjab are mainly for water supply. These are of small diameter with long strainers. The discharge is pumped out from great length of formation. These wells when pumped with depression head of 20 to 40 feet lower the water table close to well hardly by 4 to 6 feet. There are several reasons for this small lowering as discussed by Nazir and Isrealson. With such small diametor wells, it is never possible to lower the water table more than this. For greater effectiveness either the diameter should be increased or the number of strainers may be increased.

A large diameter well is costly. Recently attempts have been made to bore down wells 5 ft. in diameter. How these wells will behave in lowering the watertable, has not been investigated so far. This type of wide and deep well have not been commonly adopted in other countries.

The effectiveness of such a well system has recently been illustrated by Isrealson. Nazir also studied interference of multiple wells located along circumference of circles or in line. He determined the discharge of four or eight wells located along circumference of circles of different diameters or two, four and ten wells located in a line and at different distance apart. These wells are more efficient with shorter length of strainer. The reason for the greater efficiency of shorter strainer is obvious. Tube well strainers are non-penetrating and when pumped, flow lines from extensive areas below the bottom of the strainers are attracted which

(10-A)

work as if the length of the strainer has increased. In case two or more short strainers are installed with the total length equal to a single strainer, the attraction of flow lines at the bottom will be from larger area.

(10-A)

This is observed from the efficiency curves plotted in Fig. 8 and has also been confirmed in the field, Well No. 33-A on Upper Gugera Canal has two bores, each with 110 feet long strainer, only 25 feet apart. When pumped with 13 to 15 feet depression head, it gave 3.5 cusecs compared to well No. 29-A with single 200 feet long strainer which was pumped with 17 to 19 ft. depression and gave 2·2. cusecs. Installation of short length strainers has not yet been tried in the field but experience of dewatering by well point method is too well known. It is hoped that if this principle is adopted to dewater areas which are low lying and where the water table is either at surface or at shallow depth dewatering will be very quick, efficient and of low cost.

It is suggested that dewatering of such areas may be carried out by wells only 100 feet deep, with 40 feet of blind pipe and 50 – 60 feet of strainer made by using coir string. The diameter may not be more than 4 to 5 inches and four such strainers may be installed in a line, joined to one pump in the middle. Coir is suggested due to its cheapness and shorter length of strainer will be easy to replace when chocked.

Summary of the main conclusions.

1. Drainage practice of several arid zone countries such as Australia, South Africa, Egypt, America, Morocco, and one humid zone country of Holland, has been studied.

2. All these countries with the exception of Holland, have Irrigation system which has resulted in waterlogging and problems of alkaline and saline soils.

3, These countries have system of drains constructed along the slope of the land to drain the irrigated fields. The depth of field drain varies usually from 2 to 4 ft. and their distance apart varies from 300 to 1000 ft. depending upon the nature of soil. Egypt has very heavy soil and inspite of that, field drains upto a depth of three feet heavy proved quite effective. In fact, depth of drain and their distance apart are interrelated, as one affects the other.

4. Field drain in heavy soil can have side slopes almost vertical or 1 : 1 ; side slopes in sandy soil are never greater than 1½ to 1,

5. Field drains are also free from trouble of falling banks and weeds growth as these are always properly maintained by land owners.

6. Seepage drains to which discharge the field drains are wider apart, have flatter side slope, varying from 1½ to 1, and 3 to 1. Depth of these drains is 6 to 12 ft. and distance apart upto 1000 ft.

7. Seepage drains are not immune to trouble of falling banks and weeds growth. These need dregging and weeds clearance which is often done by special type of cutters. Chemical sterlizers have not proved successful. Suitable slopes are kept to attain high scouring velocities to reduce chances of clogging by silt and weeds.

8. South Africa is the only country which has adopted parabolic side slopes and has lined its seepage drains. This is a good suggestion and need be considered in the Punjab. As seepage drains are to carry only seepage water or rain water, lining them will eliminate their clogging by silt, falling banks and weeds growth.

9. Tile drains have been adopted by those countries which have quite a steep slope of the lands and efficient outfalls. These are extensively used in America, Holland and sparingly in Australia, South Africa and Egypt.

10. The tile drains for field has diameter equal to 3·0″ or more, length of pipe is usually two feet, are made of baked clay, some times glazed and some time of rich cement concrete. The ends of the two pieces are put together, sometime wrapped by gunny bags and have shrouding alround their length varying in depth from 3.0″ to one foot. Egypt has used brick bats as shrouding and South Africa has used a thick shrouding in the from of a filter.

11. The usual distance apart of field tile drains varies from 50 ft. to 150 ft. depending upon the nature of soil. These are in fact kept closer compared to open drains.

12. Slope of tile drains are very steep, never less than 10 ft. per mile. Australia has used double this value so as to keep self cleaning velocity.

13. Drainage of land by tube well is not very common in various countries Australia is the only country other than America which has used drainage by well. In fact these are being extensively used in America which not only drains the land but also uses the water pumped out, for irrigation.

14. A short discussion on the views of various authorities which have studied the problem of waterlogging and salinity in this country is put forth together with a review of movement of soil moisture and its bearing on water logging.

Upto 1950, only 7 percent of land of Rechna and Chaj Doabs had watertable between 0 to 5 feet and 30 to 50 per cent had watertable between 5 to 10 feet below surface.

As successful crop can be grown in arid zone with watertable at 6 0 feet below surface, it is suggested that more importance should be given to crop production and watertable need not be lowered to any disadvantageous depth because greater lowering will eliminate the advantages of irrigation.

15. Tubewell is an efficient and quick means of lowering of water-table in extensive area provided no free sources of reacharge are close by.

16. Deep wells are good for irrigation supplies, and may not be as efficient as shallow wells. A consideration may be give to shallow tube wells which according to laboratory experiments pump more discharge, and may lower the watertable quicker and can be replaced quickly when chocked.

17. If drainage by tubewell is to be made a success, some treatment shall have to be done to pervious reaches of canals which feed the aquifer.

18. For a vast country like Pakistan only one means of drainage may not be suitable under all conditions.

In certain areas particularly close to canal, there is a possibility of existance of artesian pressure under soil crust, and due to non existance of outfall, tile drains may not be as suitable as open drains or drainage by tubewell.

19. Tiles shall have to be installed by Government agencies with machines, whereas open field drain can be dug by farm labour and inspite of consuming about 10 per cent of land may still be cheaper for the farmer.

20. Seepage drains to which both tile or open drains have to discharge, have serious problem of falling banks and weed growth which can be eliminated by designing a drain with 10 feet wide berms on either side, flat side slope equal 2 : 1, and small central quinnet, lined if necessary, and by keeping scouring velocities in the drain.

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TABLE No. I

PERSONAL TO WHOM THE QUESTIONER WERE SENT AND THE ORGANIZATION WHICH SENT THE REPLIES

S. No.	Name of Country	Person to whom the questioner was addressed.	Replies sent by the organization.	Remarks.
1.	Australia ...	Prof. E. Sherbon Hill Un. Prof. in Geology Melbourne, Australia.	Common-wealth Scientific and Industrial Research organization, Victoria.	This organization collected information from seven different institutions located in Victoria, Queens Land, South Australia, West Australia and New South Wales and a summary was edited by Mr. E.A. Jennings, printed for circulation to all those interested in such problems in Australia and abroad.
2.	South Africa ...	Dr. H.F. Frommurze, Assistant Director, Geological Survey, Pretoria, Transval, Union of South Africa.	Mr. R. K. Goose, Director of Irrigation Pretoria and H. Klintroor, Chief of Division of Chemical Service, Dept of Agriculture, Pretoria.	
3.	Egypt. ...	Dr. Y.M. Samika, Inspector General, Nile Control, Cairo, Egypt.	Dr. Y.M. Samika.	
4.	Morocco ...	Dr. M.A. Rabaux, Chief du Centre des Etudes Hydro-geologiques, Director de la Production Indistrielle RABAT, MOROCCO.	Dr. M. A. Rabaux.	

5.	America ...	Prof. R. K. Linsley, Stanford University, Stanford, California and Mr. David S. Stoner, Regional Foreign Activities Co-ordinator, Bureau of Reclamation, Sacrinrents, California U. S. A.	Prof. R. K. Linsley.
6.	Holland ...	Dr. Th. Thisjee, Sec. I.A.H.R. Delft, Netherland.	Dr. Ir. S. Smeding, Director, North Eastern Polder Authority, Netherland.
	Syria ...	S. Mazloom, Director Irrigation and Power, Damascus, Syria.	S. Mazloom, Syria.
8.	Turkey ...	Prof. Berker, Secretary, U. N. E. S. C. O. Centre Tech. University, Istanbul, Turkey.	Director of Irrigation Ankara, Turkey.
9.	Spain, Maxico, Iraq and India	No body was approached as no drainage system is adopted in these Countries.	

TABLE

QUESTIONNAIRE TOGETHER WITH REPLIES FROM

S. No.	Question.	S. R. W. S (Vic)	C. S. I. R. O. Merbein (Vic).
1	2	3	4
1	Region Arid/Semi-Arid/Humid.	Arid, Semi-arid.	Semi-arid
2	Type of soil to be drained.	Sandy, light, heavy, saline.	Ranges from sand to clay Saline, saline alkaline, and alkaline conditions.
3	Mechanical Analysis of a typical DRAINED AREA.	Varies widely from 20%-90% sand.	See CSIRO bulletin Nos :— 123 (Merbein) 42 (Block E Renmark) (Ral Ral Chaffey)
4	Are there Salinity or Alkalinity Problems?	Yes, mainly salinity.	Both
5	What is the General Depth of watertable below natural surface.	3 feet, or considerably more.	In river deposited soils 4 ft. – 8 ft. In Mallee soils 3 ft. – 6 ft. while present.

No. II

AUSTRALIA ON DRAINAGE ETC.

I & W. S C. (QLD) 5	E.W.S.D.(S.A.) 6	P.W.D. (W. A.) 7	C. S. I. R. O. Griffith (NSW) 8	W. C. I. C. (NSW) 9
Humid in most potential irrigation areas.	Semi-arid	...	Semi-arid	Semi-aird
All types from sandy to heavy clay. Both saline and alkaline.	(i) Reclaimed Swamp areas heavy, saline. (ii) Highland areas sandy saline.	Generally heavy.	Sandy loam surface-clay sub-soil.	Generally heavy and moderately saline.
...	...	...	*Very variable.* Surface Sub-*Soil Soil* Clay 20% 50% Silt 10% 10% Sand 70% 40%	Variable both in vertical & horizontal planes.
Yes	Yes salinity	No	...	Yes.
Variable— can be expected to rise to some degree when irrigated intensively.	The natural watertable is deep, but seepage follows after years of irrigation & the waterable may rise to natural surface in places.	...	Perched water table varies greatly, commonly about 6 ft.	(*a*) 4 – 10 ft. where there is general waterlogging and tubewell drainage is being developed. (*b*) Great variation in space & time where localised.

Table II

1	2	3	4
6	What is the usual order of permeability co-efficient.	..	*Values of K cm/sec.* (i) *Distributed sample.* $100 - 1000 \times 10^{-6}$cm/sec. for clay loam to sandy loam. 1000×10^{-6}cm/sec. for river sands. (ii) *In situ.* $5 - 15 \times 10^{-6}$ ft/sec. for river sands.

OPEN

1	2	3	4
1	How deep are field drains.	Generally surface w.th cuts to 6 feet.	..
2	What is their distance apart.	Dependant on topography; surface drains generally follow natural drain lines.	..
3	What is the side slope.	1½ to 1.	..
4	Are the field drains privately owned.	Yes-if internal & draining private property.	..

—*Continued,*

5	6	7	8	9
Unknown at present time.	...	...	...	No concise information.

DRAINS

5	6	7	8
12 – 18″ for farm drain which leads to the community drain.	2 ft. is the minimum.	1 – 4 feet.	Vary from surface level to 6 feet or more.
Varies with type of irrigation. With furrow or border ditch irrigation the spacing may usually be 5 – 8 chains. With heavier soil types this may be 10 chains. 1 chain = 66 ft.	330 to 900 ft.	Variable.	
...	1 to 1	1 to 1.	1 to 1 if mechanically constructed.
Yes.	No.	Yes	Government owned

Table II

1	2	3	4
5	Is there any legislation compelling the owner to dig field drains.	No.	No.
6	Is the discharging drain Government owned.	Yes.	Owned by local irrigating authority.
7	What is the order of salinity or pH. of drained water.	Surface drains generally fresh—subsurface may be salt.	...
8	How is the drained water disposed of.	Generally to rivers.	To river.
9	What means are adopted to avoid weed growth and fungus.	Mechanical cleaning & chemical sprays.	Natural salinity is sufficient in parts.
10	Are the big drains free from trouble of falling banks.	Yes-suitable side slopes are used.	No.
11	Is constant dredging and cleaning of weeds necessary.	Yes.	Yes, annual or biennial.