6

Reclamation of Water-Logged and Saline Soils for Agricultural Purposes

6.1. Definition of Salinity and Water-logging

An agricultural land is said to be water-logged, when its productivity gets affected by the high watertable. The productivity of land infact, gets affected when the root zone of the plants gets flooded with water, and thus become ill-aerated. Ill aeration reduces crop yield, as explained below :

The life of a plant, infact, depends upon the nutrients like nitrates, and the form in which the nitrates are consumed by the plants is produced by the bacteria, under a process called *nitrification.* These bacteria need oxygen for their survival. The supply of oxygen gets cutoff when the land becomes ill aerated, resulting in the death of these bacteria, and fall in the production of plant's food (*i.e.* nitrates) and consequent reduction in the plant growth, which reduces the crop yield. Apart from ill-aeration of the plants, many other problems are created by water-logging, as discussed below :

(*i*) The normal cultivation operations, such as tilling, ploughing, etc. cannot be easily carried out in wet soils. In extreme cases, the free water may rise above the surface of the land, making the cultivation operations impossible. In ordinary language, such a land is called a swampy land.

(*ii*) Certain water loving plants like grasses, weeds, etc. grow profusely and luxuriantly in water-logged lands, thus affecting and interfering with the growth of the crops.

(*iii*) Water-logging also leads to salinity, as explained below :

If the watertable has risen up, or if the plant roots happen to come within the capillary fringe, water is continuously evaporated by capillarity. Thus, a continuous upward flow of water from the watertable to the land-surface, gets established. With this upward flow, the salts which are present in the water, also rise towards the surface, resulting in the deposition of salts in the root zone of the crops. The concentration of these alkali salts present in the root zone of the crops has a corroding effect on the roots, which reduces the osmotic activity of the plants and checks the plant growth, and the plant ultimately fades away. Such soils are called **saline soils**. From the above discussion, it becomes evident that the water-logging ultimately leads to salinity, the result of which is, the reduced crop yield. For this reason, salinity and water-logging are treated as a twin problem; under the head 'salinity and water-logging'. *Whenever there is water-logging, salinity is a must.*

6.2. Causes of Water-logging

Water-logging is the rise of watertable, which may occur due to the following factors :

(i) **Over and Intensive Irrigation.** When a policy of intensive irrigation is adopted, then, the maximum irrigable area of a small region is irrigated. This leads to, too much of irrigation, in that region, resulting in heavy percolation and subsequent rise of watertable. For this reason, to avoid water-logging, a policy of *extensive irrigation* (*i.e.* irrigation spread over wider regions) should supersede the policy of *intensive* irrigation.

(ii) **Seepage of Water from the Adjoining High Lands.** Water from the adjoining high lands may seep into the sub-soil of the affected land and may raise the watertable.

(iii) **Seepage of Water through the Canals.** Water may seep through the beds and sides of the adjoining canals, reservoirs, etc., situated at a higher level than the affected land; resulting in high watertable. This seepage is excessive, when soil at the site of canals, reservoirs, etc. is very pervious.

(iv) **Impervious Obstruction.** Water seeping below the soil moves horizontally (*i.e.* laterally) but may find an impervious obstruction, causing the rise of watertable on the upstream side of the obstruction. Similarly, an impervious stratum may occur below the top layers of pervious soils. In such cases, water seeping through the pervious soils will not be able to go deep, and hence, quickly resulting in high watertable.

(v) **Inadequate Natural Drainage.** Soils having less permeable sub-stratum (such as clay) below the top layers of pervious soils, will not be able to drain the water deep into the ground, and hence, resulting in high water level in the affected soil.

(vi) **Inadequate Surface Drainage.** Storm water falling over the land and the excess irrigation water should be removed and should not be allowed to percolate below. If proper drainage is not provided, the water will constantly percolate and will raise the level of the underground reservoir.

(vii) **Excessive Rains.** Excessive rainfall may create temporary water-logging, and in the absence of good drainage, it may lead to continued water-logging.

(viii) **Submergence due to Floods.** If a land continuously remains submerged by floods, water loving plants like grasses, weeds, etc. may grow, which obstruct the natural surface drainage of the soil, and thus, increasing the chances of water-logging.

(ix) **Irregular or Flat Topography.** In steep terrain, the water is drained out quickly. On flat or irregular terrain having depressions, etc., the drainage is very poor. All these factors lead to greater detention of water on the land, causing more percolation and raised watertable.

6.3. Water-logging Control

It is evident that water-logging can be controlled only if the quantity of water into the soil below is checked and reduced. To achieve this, the inflow of water into the underground reservoir should be reduced and the outflow from this reservoir should be increased, as to keep the highest position of water-table at least about 3m below the ground surface. The various measures adopted for controlling water- logging are enumerated below:

(1) **Lining of Canals and Water Courses.** Attempts should be made to reduce the seepage of water from the canals and water courses. This can be achieved by lining them. It is a very effective method to control water-logging.

(2) **Reducing the Intensity of Irrigation.** In areas where there is a possibility of water-logging, intensity of irrigation should be reduced. Only a small portion of irrigable land should receive canal water in one particular season. The remaining areas can receive water in the next season, by rotation.

(3) **By Introducing Crop-rotation.** Certain crops require more water and others require less water. If a field is always sown with a crop requiring more water, the chances of water-logging are more. In order to avoid this, a high water requiring crop should be followed by one requiring less water, and then by one requiring almost no water. Rice may be followed by wheat, and wheat may be followed by a dry crop such as cotton.

(4) **By Optimum Use of Water.** It is a known fact that only a certain fixed amount of irrigation water gives best productivity. Less than that and more than that, reduces the yield. But most of our cultivators are unaware of these technicalities, and they feel that by using more water they can increase crop yield. Therefore, they try to use more and more water. This can be checked by educating the cultivators by proper propaganda. Moreover, the revenue should not be charged on the basis of irrigated area but should be charged on the basis of the quantity of water utilised. A strict watch should also be kept at the outlet, in order to stop undue tapping.

(5) **By Providing Intercepting Drains.** Intercepting drains along the canals should be constructed, wherever necessary. These drains can intercept and prevent the seeping canal water from reaching the area likely to be water-logged.

(6) **By Provision of an Efficient Drainage System.** An efficient drainage system should be provided in order to drain away the storm water and the excess irrigation water. A good drainage system consists of surface drains as well as sub-surface drains (described in details a little later).

(7) **By Improving the Natural Drainage of the Area.** To reduce the percolation, the water should not be allowed to stand for a longer period. Some relief in this direction can be obtained by removing the obstructions from the path of natural flow. This can be achieved by removing bushes, jungles, forests, etc. and improving the slopes of the natural drainage lines.

(8) **By Adopting Consumptive Use of Surface and Subsurface Water.** The introduction of lift irrigation to utilize ground water helps in lowering the water-table in a canal irrigated area, where water-table tends to go up. *Hence, the ground water should also be used in conjunction with canal water for irrigation,* as the continuous use of ground water will not allow any appreciable rise in the level of water-table, due to continuous seepage of canal water.

This combined use of subsurface water (ground water) and the surface water (canal water) in a judicious manner, as to derive maximum benefits, called **conjunctive use,** should hence be adopted to control water-logging.

6.4. Reclamation of Saline and Alkaline Lands

Land reclamation is a process by which an unculturable land is made fit for cultivation. Saline and water logged lands give very less crop yields, and are, therefore, almost unfit for cultivation, unless they are reclaimed. Before summarising the remedies for reclaiming such lands, we shall first review the process, whereby, a land becomes, 'saline' or in extreme cases 'alkaline'.

Every agricultural soil contains certain mineral salts in it. Some of these salts are beneficial for plants as they provide the plant foods, while certain others prove injurious to plant growth. These injurious salts are called *alkali salts* and their common examples are Na_2CO_3, Na_2SO_4, and NaCl. **Na_2CO_3 or black alkali* is the most harmful; and NaCl is the least harmful.** These salts are soluble in water. If the watertable rises up, or if the plant's roots happen to come within the capillary fringe, water from the watertable starts flowing upward. The soluble alkali salts also move up with water and get deposited in the soil within the plant roots as well as on the surface of the land. *This phenomenon of salts coming up in solution and forming a thin (5 to 7.5 cm) crust on the surface, after the evaporation of water, is called effeorescence.* Land affected by effeorescence is called *saline soil.* The salty water surrounding the roots of the plants reduces the osmotic activity of the plants, as explained below :

Since the plant roots act as semi-permeable membranes, so we have almost pure water on one side of the membrane (*i.e.* the water already extracted by the roots) and highly concentrated salt solution on the other side. Now, from the knowledge of physical chemistry, we can conclude that pure water from within the roots will start flowing out of the roots by **'osmosis'** towards the salt solution, until the pressure on pure water side becomes equal to the osmotic pressure of the salt solution. The plant will, hence, die due to lack of water, as shown in Fig. 6.1.

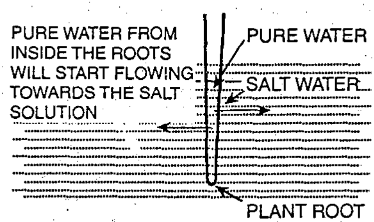

Fig. 6.1

Such a salt affected soil is unproductive and is known as "saline soil". If the salt effeorescence continues for a longer period, a base exchange reaction sets up, particularly if the soil is clayey, thus *sodiumising the clay*, making it impermeable and, therefore, ill-aerated and highly unproductive. Such soils are called *alkaline soils*. The reclamation of alkaline lands is more difficult.

Reclamation of salt affected lands. It is evident from the above discussion that effeorescence can be avoided if the watertable is maintained sufficiently (about 3m) below the roots, so that the capillary water is not able to reach the root zone of the plant. *Hence, all those measures which were suggested for preventing water-logging hold good for preventing salinity of lands also.* An efficient drainage system consisting of surface drains as well as sub-surface drains (explained in the next article) must be provided in order to control and lower the watertable in saline lands. After the high watertable has been lowered by suitable drainage, the soil is freed from the existing salts by a process, called *Leaching.*

6.4.1. Leaching. In this process, the land is flooded with adequate depth of water. The alkali salts present in the soil, get dissolved in this water, which percolate down to join the watertable or drained away by surface and sub-surface drains. The process is repeated till the salts in the top layer of the land are reduced to such as extent that some salt resistant crop can be grown. This process is known as leaching. High salt resistant crops like fodder, berseem, bajra etc., are now grown on this leached land for one or two seasons or till the salinity is reduced to such an extent that an ordinary crop like wheat, cotton, citrus garden crops, etc. can be grown. The land is then said to have been reclaimed.

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* It is known as black alkali because it dissolves some organic constituents of soil, which when in solution with it, appear black. The ground, therefore, gets spotted with patches of black stain.

When sodium carbonate (Na_2CO_3) is present in the saline soil, gypsum ($CaSO_4$) is generally added to the soil before leaching and thoroughly mixed with water. Na_2CO_3 reacts with $CaSO_4$ forming Na_2SO_4, which can be leached out as explained earlier.

6.4.1.1. Leaching requirement (LR) of a soil. In order to maintain status quo on the salinity of a given soil, and to avoid any further increase in its salinity, it is necessary to apply water to the soil in excess of the consumptive use (*i.e.* the requirement to meet evapotranspiration needs). This excess water will flow down beyond the root zone of the crop to the underground drainage system or to the underground reservoir, washing down the excess salts, which otherwise would have been deposited in the soil to further increase the salinity of the soil.

This excess water, which is required to meet the leaching needs, is generally expressed as the percentage of the total irrigation water applied to the soil (field) to meet the consumptive use as well as the leaching needs. This percentage quantity of water required for maintaining equilibrium in the salt content of the soil, has been computed to be expressed by the following equation :

$$LR \text{ (Leaching Requirement)} = \frac{D_d}{D_i}$$

$$= \frac{\text{Depth of water drained out per unit area}}{\text{Depth of irrigation water applied per unit of area}} \quad ...(6.1)$$

where D_i = Total irrigation water depth applied.

$= C_u + D_d$

C_u ↓ Consumptive use + D_d ↓ Drained out water depth

$$\therefore \quad L.R. = \frac{D_d}{D_i} = \frac{D_i - C_u}{D_i} \quad ...(6.2)$$

For salt equilibrium, the ratio $\frac{D_d}{D_i}$ is found to be equal to $\frac{C_i}{C_d}$; where C_i is the salt content of irrigation water, and C_d is the salt content of drainage or leached water. Since the salt content is directly proportional to the Electrical conductivity* (*EC*), $\frac{C_i}{C_d}$ will be equal to $\frac{EC_{(i)}}{EC_{(d)}}$ where $EC_{(i)}$ is the *electrical conductivity of irrigation water*; and $EC_{(d)}$ is the *electrical conductivity of drained water* (leached water or leaching water). Hence, equation (6.1) can be written as :

$$L.R. = \frac{D_d}{D_i} = \frac{EC_{(i)}}{EC_{(d)}} \quad ...(6.3)$$

The *E.C.* of drainage water, or leaching water, *i.e.* $EC_{(d)}$, may be assumed on the basis of permissible salt tolerance limit of the grown crop, but is generally assumed to

* **Electrical conductivity** is a measure of salt content in a given water sample, and is dealt in more details in article 1.7(2).

be twice the E.C. value of the *saturation soil extract** *i.e.*, $E.C._{(e)}$. Hence, eqn. (6.3) can also be written as :

$$L.R. = \frac{D_d}{D_i} = \frac{EC_{(i)}}{EC_{(d)}} = \frac{EC_{(i)}}{2EC_{(e)}} \quad ...(6.4)$$

Example 6.1. *Estimate the leaching requirement when electrical conductivity (EC) value of a saturated extract of soil is 10 m mho/cm at 25% reduction in the yield of a crop. The EC of irrigation water is 1.2 m.mho/cm. What will be the required depth of water to be applied to the field if the consumptive use requirement of the crop is 80 mm? EC value of the leaching water may be suitably assumed.*

Solution. The given values are :

$EC_{(e)}$ = E.C. value of saturated soil extract = 10 milli mho/cm

$EC_{(i)}$ = E.C. value of irrigation water = 1.2 milli mho/cm

C_u = Consumptiveuse = 80 mm

The *Leaching Requirement* (LR) is given by the Eqn. (6.3) as :

$$LR = \frac{D_d}{D_i} = \frac{EC_{(i)}}{EC_{(d)}}$$

where $EC_{(d)}$ is the E.C. value of leaching water, which may be assumed to be equal to $2 \cdot EC_{(e)} = 2 \times 10$ m.mho/cm = 20 milli mho/cm

Substituting the above values, we get

$$L.R. = \frac{EC_{(i)}}{EC_{(d)}} = \frac{1.2 \text{ milli mho/cm}}{20 \text{ milli mho/cm}} = \frac{1.2}{20} \times 100\% = 6\%$$

Hence, the Leaching Requirement is 6%. **Ans.** ...(1)

Now using eqn. (6.2), we have

$$LR = \frac{D_d}{D_i} = \frac{D_i - C_u}{D_i} = \frac{D_i - 80\text{ mm}}{D_i} \times 100\% \quad ...(2)$$

Equating (1) and (2), we have

$$6 = \left(\frac{D_i - 80\text{ mm}}{D_i}\right) \times 100$$

or $6\,D_i = 100\,D_i - 8000$ mm or $94\,D_i = 8000$ mm

or $D_i = \frac{8000}{94}$ mm = **85.1 mm**

Hence, the required water depth for irrigation = **85.1 mm Ans.**

LAND DRAINAGE

Surface irrigation is a blessing only if it is practised with great care. Only optimum amount of water should be supplied to the crop, in accordance with the requirement of that crop, and the properties of the soil must be given full consideration. Excess water, which the root zone of the soil fails to absorb, may percolate and help in raising the

* The water solution extracted from a soil at its saturation percentage.

watertable. Sometimes, this gravity water may encounter an impervious stratum and may not be drained up to the watertable. As explained earlier, this excess water is not only a waste but may be harmful to crop yield also. If such conditions are likely to occur, it becomes necessary that the excess water is removed and drained out from below the soil and discharged back either into a river, a canal, etc. or somewhere else. *Hence, while designing a canal irrigation network, it is sometimes desirable to provide a suitable drainage system, for removing the excess irrigation water.* This may be necessary in areas of high watertable and in river deltas, when irrigation facilities are extended to such areas. Drainage system is also required for draining out the storm water, and thus to prevent its percolation and to ensure easy disposal. Two types of drainage can be provided, *i.e.*,

(1) Surface drainage, (2) Sub-surface drainage, called Tile- drainage or Underground drainage. These are explained below :

6.5. Surface Drainage or Open Drainage

Surface drainage is the removal of excess rain water falling on the fields or the excess irrigation water applied to the fields, by constructing open ditches, field drains, and other related structures. The land is sloped towards these ditches or drains, as to make the excess water flow in to these drains.

When irrigation is extended to arid regions, drainage ditches become necessary to remove water required for leaching undesirable salts from the soil, and to dispose off the excess rainfall.

The open drains, which are constructed to remove the excess irrigation water collected in the depressions on the fields, as well as the storm (rain) water, are broad and shallow, and are called *shallow surface drains.* These drains carry the runoff to the *outlet drains,* which are large enough to carry the flood water of the catchment area from the shallow surface drains, and are of sufficient depths to provide outlets even for the underground tile drains, if provided. These outlet drains may be called *deep surface drains*.

Surface drains constructed for removing excess irrigation water applied to the farms and the storm water, cannot and should not be deep enough, as to interfere with the agricultural operations. They are, therefore, designed as shallow surface drains.

Land grading, which results in a continuous land slope towards the field drains, is an important part of a surface drainage system. Land grading or land leveling is also necessary for surface irrigation.

The **shallow surface drains** are trapezoidal in cross-section. Strictly speaking, they should be designed to carry the normal storm water from the fields, plus the excess irrigation water. Many a times, the excess irrigation water is neglected and these drains are designed only for the runoff resulting from the average storms. It is neither economical nor desirable to design these drains for exceptional storms. Kutter's or Manning's equations may be used to design these drains, keeping the velocity within the limits of the critical velocity, and thereby avoiding silting or scouring. Manning's equation is, however, generally used for the design of shallow as well as deep surface drains.

Deep surface drains or **outlet drains** carry the storm water discharge from the shallow surface drains, and the seepage water coming from the underground tile drains. They are, therefore, designed for the combined discharge of the shallow surface drains as well as that of the tile drains. Generally, a cunnette of about 0.6 m depth is provided in the centre of the drain-bed, so as to carry the seepage water of the underground tile drains. A steeper slope is given to the cunnette and it is lined, so as to withstand higher flow velocities, and thus, to inhibit weed growth. The full section would be operative only during the rainy season, as otherwise, the flow will be confined only within the cunnette.

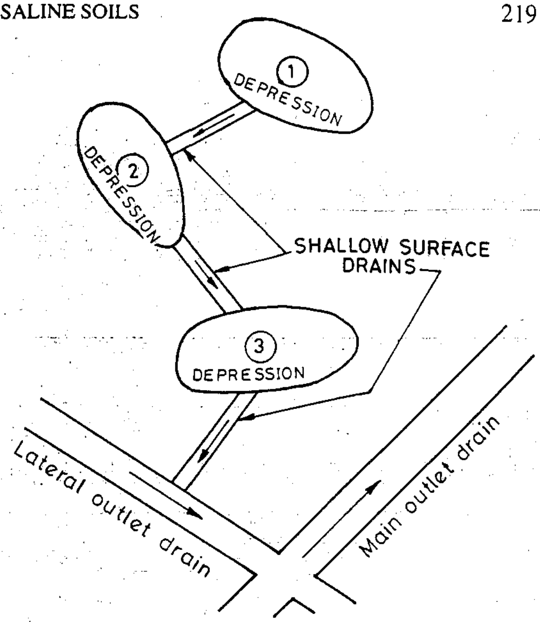


Fig. 6.2. Random field-drain (shallow surface drain) system for surface drainage.

6.5.1. Surface Inlet. The surface water from the pot holes, depressions, road ditches, farm steads, etc. may be removed either by connecting them with the shallow surface drains, sometimes called *random field drains* (shown in Fig. 6.2), or by constructing an intake structure called an *open inlet* or *surface inlet* (Fig. 6.3). A *surface inlet* is a structure constructed to carry the pit water into the sub-surface or tile drain. A cast iron pipe or a manhole constructed of brick or monolithic concrete, is sufficient and satisfactory. Manholes with sediment basins are sometimes used as surface inlets.

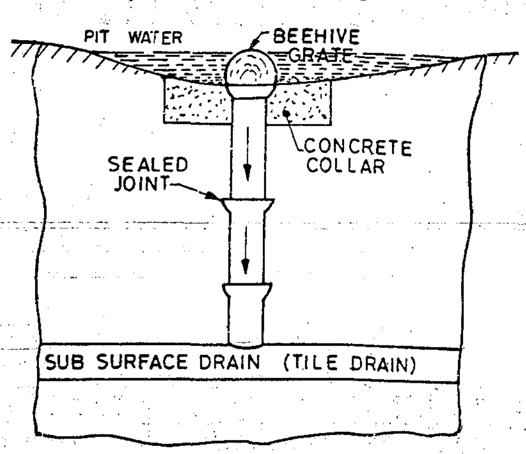


Fig. 6.3. surface inlet draining the surface water into a tile drain.

At the surface of the ground, a concrete collar extending around the intake is constructed on the riser to prevent growth of vegetation and to hold it in place. On the top of the riser, beehive grate or some other suitable grate is provided, so as to prevent trash from entering the tile. When the inlet is constructed in a cultivated field, the area immediately around the intake should be kept in grass.

When the surface inlet is connected to a main tile drain, it is a good practice to offset the surface inlet from the main. Such constructions may eliminate failure of the system, if the surface inlet structure should become damaged.

6.5.2. French Drain. When the quantity of water to be removed from the pits or depressions is small, a *blind inlet* may be installed over the tile drain. The blind inlet is also called *french drain.* These are constructed by back filling the trench of the tile drain with graded materials, such as gravel and coarse sand, or with corn cobs, straw and similar substances, as shown in Fig. 6.4.

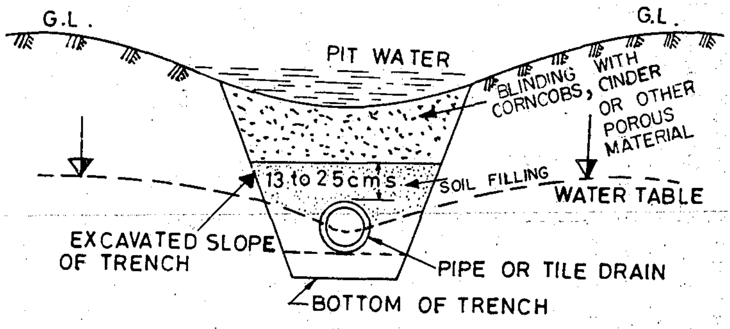


Fig. 6.4. Blind inlet or French drain.

Such inlets are not permanently effective. The voids in the backfill of the blind inlet become filled up with the passage of time, thereby reducing its effectiveness. Even though they are not permanently effective, they are economical to be installed and do not interfere with the farming operations.

6.5.3. Bedding. Bedding is a method of surface drainage which makes use of dead furrows, as shown in Fig. 6.5. The area between the two adjacent furrows is known as

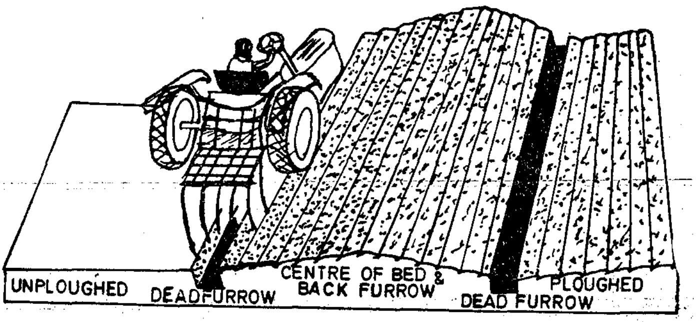


Fig. 6.5. Cross-section of bed showing method of construction.

a bed. The depth of the bed depends on the soil characteristics and tillage practices. In the bedded area, the direction of farming may be parallel or normal to dead furrows. Tillage practices, parallel to the beds, retard water movement to the dead furrows. Ploughing is always parallel to the dead furrows. Bedding is most practicable on flat slopes of less than 15%, where the soils are slowly permeable and the drainage is not economical.

6.6. Sub-surface Drainage or Tile Drainage

Plants need air as well as moisture in their root zones for their survival. Excess irrigation farm water is free to move into the underground tile drains, if provided*. This water, if not removed, retards the plant growth, because it fills the soil voids and restricts proper aeration. *Surface drains are, therefore, needed for removing the excess farm*

* Underground tile drains are not very common in India, where water-tables are generally falling and availability of water is becoming scarce.

water, for most of the cultivated crops on flat or undulating topography. Sub-surface drains, on the other hand, are required for soils with poor internal drainage and a high watertable. If no impervious layer occurs below the farm land and the watertable is low (lower than about 3m from the ground), internal soil drainage may be sufficient and no tile drains needed. For maximum productivity of most of the crops, both surface as well as sub-surface drains may sometimes,however, become, essential, particularly in areas of higher water-tables.

Advantages of Tile Drains. Tile drainage helps in increasing crop yields by draining the water or by lowering the watertable in the following manner :

(*i*) Removes the free gravity water that is not directly available to the plants.

(*ii*) Increases the volume of soil from which roots can obtain food.

(*iii*) Increases air circulation.

(*iv*) Increases bacterial activity in the soil, thus improving soil structure and making the plant food more readily available.

(*v*) Reduces soil erosion. A well drained soil has more capacity to hold rainfall, resulting in less runoff and hence, reduced erosion.

(*vi*) Reduces and removes toxic substances such as sodium and other soluble salts, which when present in large concentrations may retard plant growth.

(*vii*) Lesser time and labour is required for tilling and harvesting the soils, as these drains do not obstruct farming operations. With a crop such as corn, a delay in planting may decrease the yields. Planting in wet soils is also likely to decrease yields. All such troubles are removed in tile drained soils.

(*viii*) Tile drains permit deep roots development by lowering the watertable, especially during spring months, as shown in Fig. 6.6.

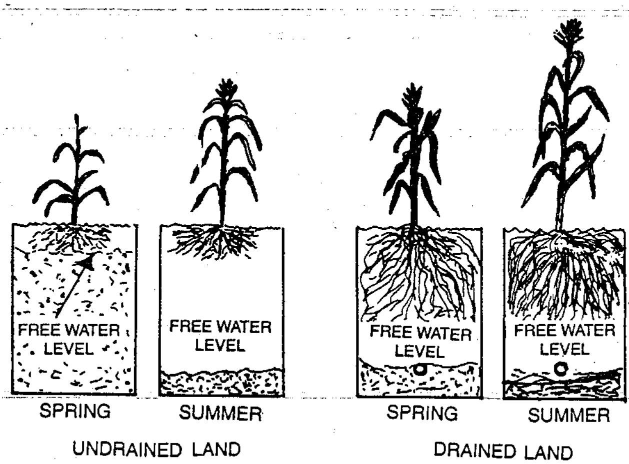


Fig. 6.6. Root development of crops grown on drained and undrained land.

Note : A plant having deep roots can extract water from greater depths and hence, can withstand droughts better than the one having shallow roots. Moreover, a deep rooted plant is larger and, therefore, capable of more transpiration and hence, giving increased yields.

Providing underground tile drains, however, is a costly proposition and may be required only in areas of high water-table, and where the ground soil has a poor internal drainage capacity.

6.6.1. Envelope Filters. Tile drains, are usually, pipe drains made up of porous earthenware and are circular in section. The diameters may vary from 10 to 30 cm or so. These drains are laid below the ground level, butting each other with open joints. The trenches in which they are laid, are back filled with sand and excavated material, as shown in Fig. 6.7. As far as possible, the tile drains should not be placed below less pervious strata. Because in that case, they may remain dry even though the land above the impervious strata may be water-logged, as the water will not be able to reach the drain.

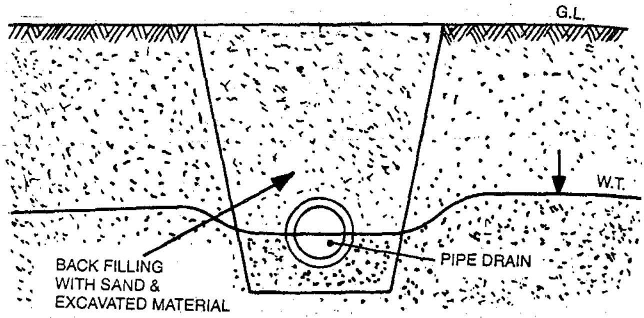


Fig. 6.7. Cross-section of a tile drain in pervious soils (without any filter).

When tile drains are placed in less pervious soils, they are generally surrounded by graded gravel filters, called *envelope filters* (Fig. 6.8). The envelope filter serves two functions : (*i*) it prevents the inflow of the soil into the drain, and (*ii*) it increases the effective tile diameter, and thus increases the inflow rate. The filter consists of different gradations, such as gravel, coarse sand, bajri, etc., The coarsest material is placed immediately over the tile, and the size is gradually reduced towards the surface. The minimum thickness of the filter is about 7.5 cm. The graded filter may sometimes be substituted by a single gradation, depending upon the availability and cost considerations.

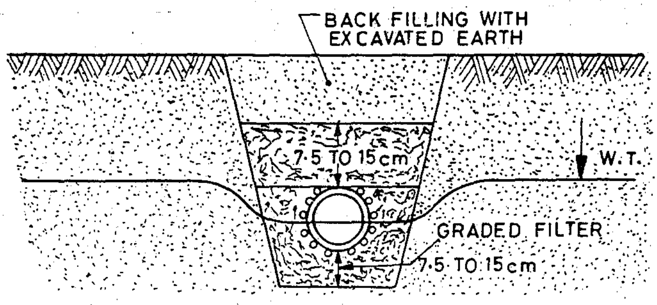


Fig. 6.8. Cross-section of a tile drain in less pervious soils (*with graded filter*).

6.6.2. Outlets for Tile Drains or Closed Drains. The water drained by the tile drains is discharged into some bigger drains, called deep surface drains. The water from a tile drain may be discharged into an outlet drain either by gravity or by pumping, depending upon which, we can have gravity outlet or pump outlet, as described below:

(*a*) **Gravity outlet.** If the bed level and the full supply level (FSL) of the outlet drain is lower than the invert level of the tile drain, then the water can be discharged easily into the outlet drain by the mere action of gravity. Corrugated metal pipe with a flap shutter to prevent entry of rodents and back flow from the outlet drain into the tile drain, is generally provided at the outfall point, as shown in Fig. 6.9.

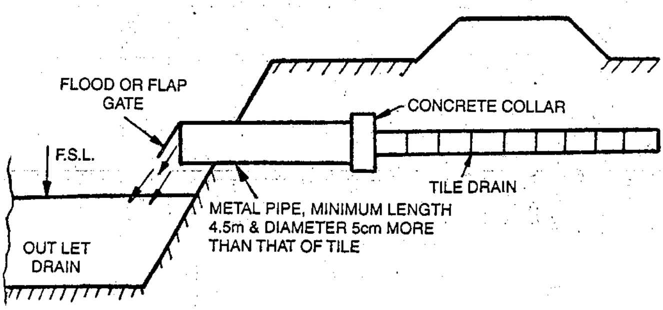


Fig. 6.9. Gravity outlet (outfall) for tile drain.

(*b*) **Pump outlet.** When the bed level of the outlet drain is higher than that of the discharging tile drain; a pump outlet has to be installed, as shown in Fig. 6.10. It consists of an automatic controlled pump with a small sump for storage. Pump outlets are costly and require technicality. Possibility of deepening the outlet drain should, therefore, be investigated. The cost of installing and maintaining a pump outlet should be compared with that of excavating and maintaining a deeper outlet drain, before making a final selection.

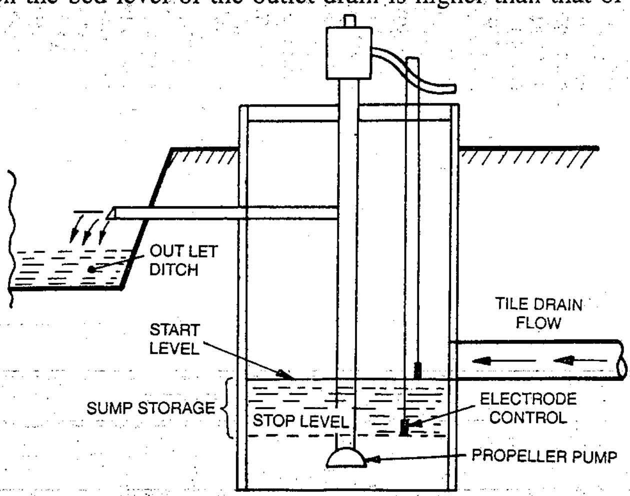


Fig. 6.10. Pump outlet (outfall) for tile drain.

6.6.3. Drawdown Curve or Movement of Water into the Tile Drains. In a fully saturated soil, water flows into the tile drain along the path shown in Fig. 6.11 (*a*). Since the quantity of water moving between any two flow lines is the same, the drawdown will be more near the tile than at the points farther away. After the saturated soil has drained for a day or so, the resulting watertable will be, as shown in Fig. 6.11 (*a*). With series of tile drains, the sub-soil water level directly over the drains, is lower than the level midway between them as shown in Fig. 6.11 (*b*).

When a filter is provided around the tile drains to surround the drains with more pervious soil, then the overall drawdown will be more. The rate of drop of watertable mainly depends upon the soil permeability and spacing of the drains. In this case, the water has to travel more distance horizontally than vertically before it reaches the drain, the horizontal permeability of the soil is more important. The permeabilities of most of the soils decrease with depth. This change in permeability affects the shape of the flow lines and the rate of the fall of watertable.

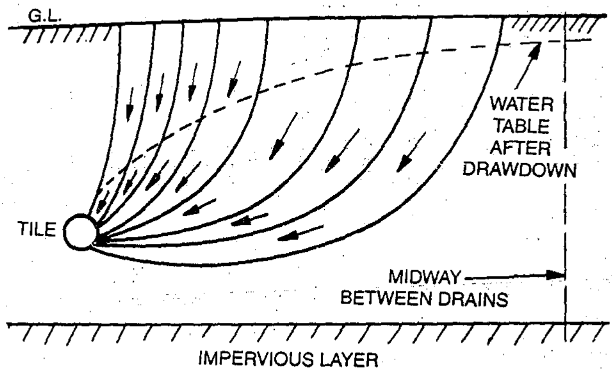


Fig. 6.11. (*a*) Drawdown curve with a single tile drain.

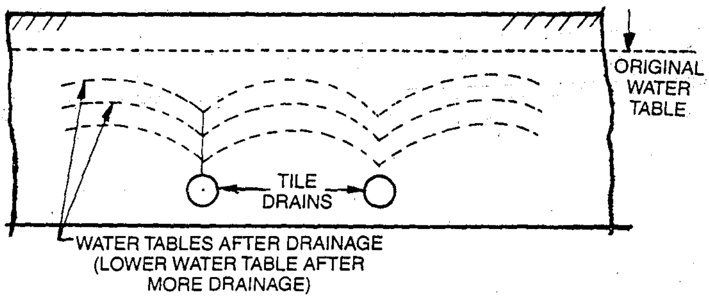


Fig. 6.11. (*b*) Drawdown curve with a series of tile drains.

6.6.4. Depth and Spacing of the Tile Drains. The closed drains are generally spaced at such a distance as to be capable of lowering the watertable sufficiently below the root zone of the plants. For most of the plants, the top point of the watertable must be at least 1.0 to 1.5 metres below the ground level; although this distance may vary from 0.7 to 2.5 m., depending upon the soil and the crop.

The tile drains may be placed at about 0.3 metre below the desired highest level of the watertable. A fair idea of the spacing between the tile drains can be obtained based on the above theory, as follows :

Let S be spacing between the drains, and a be the depth of impervious stratum from the centre of the drains, as shown in Fig. 6.12. Let the maximum height of the drained

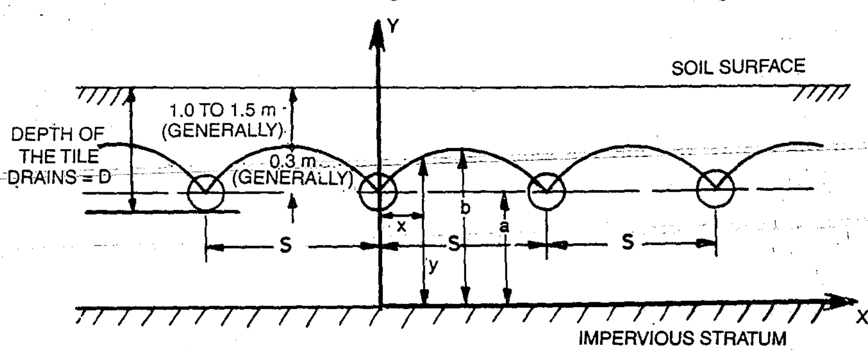


Fig. 6.12. Spacing of tile drains.

watertable above the impervious layer be b. At any distance x from the centre of a drain, let the height of the watertable above the impervious stratum be y. Then, according to Darcy's Law, we have

$$Q = KI \cdot A$$

where K = permeability coefficient in m/sec.

$\therefore$ Discharge per unit length of the drain passing the section at y (q_y) is given as :

$$q_y = K \cdot \frac{dy}{ds} \cdot y$$

Assuming the inclination of the water surface to be small, such that the tangent $\left(i.e. \frac{dy}{dx}\right)$ can be used in place of sine $\left(i.e. \frac{dy}{ds}\right)$ for the hydraulic gradient, we get

$$q_y = K \cdot \frac{dy}{dx} \cdot y \quad \text{...(6.5)}$$

But when $x = \frac{S}{2}$, $\quad q_y = 0.$

and, when $x = 0$, $\quad q_y = \frac{q}{2}$

where q *is the total discharge per unit length carried by the drain*, so that $\frac{1}{2}q$ enters the drain from either side.

Also assuming that q is inversely proportional to the distance from the drain, we can write

$$q_y = \frac{1}{2}q - \frac{1}{2}q\frac{x}{S/2} = \frac{1}{2}q\left(1 - \frac{x}{S/2}\right)$$

or

$$= \frac{q}{2S}\left[S - 2x\right] \quad \text{...(6.6)}$$

Equating Eqs. (6.6) and (6.5), we get

$$\frac{q}{2S}(S - 2x) = K\,y \cdot \frac{dy}{dx}$$

Rearranging and integrating, we get

$$\int \frac{q}{2SK}(S - 2x)\,dx = \int y\,dy.$$

Assuming the soil permeability to be constant, we get

$$\frac{q}{2K.S}\left[Sx - \frac{2x^2}{2}\right] = \frac{y^2}{2} + C \quad \text{...(6.7)}$$

when $x = 0$, $\quad y = a$

$$\therefore \quad \frac{q}{2KS}[0] = \frac{a^2}{2} + C \quad \text{or} \quad C = -\frac{a^2}{2}$$

Substituting $C = -\frac{a^2}{2}$, equation (6.7) becomes

$$\frac{q}{2KS}\left[Sx - x^2\right] = \frac{y^2}{2} - \frac{a^2}{2}$$

or $$\frac{q}{2KS}x(S-x) = \frac{y^2 - a^2}{2}$$

or $$q = \frac{KS(y^2 - a^2)}{(S-x)x} \quad \text{...(6.8)}$$

Also, when $x = \frac{S}{2}$, $y = b$, equation (6.8) then becomes

$$q = \frac{KS \cdot (b^2 - a^2)}{\left(S - \frac{S}{2}\right)\frac{S}{2}} \quad \text{or} \quad q = \frac{KS(b^2 - a^2)}{\frac{S^2}{4}}$$

or $$\boxed{\mathbf{q = \frac{4K}{S}(b^2 - a^2)}} \quad \text{...(6.9)}$$

or $$S = \frac{4K}{q}(b^2 - a^2) \quad \text{...(6.10)}$$

Equation (6.10) can be used to predict the spacing (S) between the drains, if q is known. q will depend on the infiltration discharge into the ground, which should be removed by the drains. Different values have been suggested. Generally, a value equal to 1% of the average annual rainfall of a place is considered to be drained by the tile drains in 24 hours. If the average annual rainfall of the place is $P_{A.A}$ (metres), then

$$q = \left(\frac{0.01 \times P_{A.A}}{24 \times 3600}\right)(S \times 1) \text{ cumecs/m length of drains}$$

$$= \frac{0.01 \times P_{A.A} \cdot S}{24 \times 3600} = \frac{P_{A.A.} \cdot S}{86{,}40{,}000} = \frac{P_{A.A} \cdot S}{8.64 \times 10^6} \quad \text{...(6.11)}$$

Equating with equation (6.9), we get

$$q = \frac{4K \cdot (b^2 - a^2)}{S} = \frac{P_{A.A} \cdot S}{8.64 \times 10^6}$$

or $$S = \sqrt{\frac{(8.64 \times 10^6)\, 4K \cdot (b^2 - a^2)}{P_{A.A}}} \quad \text{...(6.12)}$$

Hence, spacing (S) can be determined easily by using eq. (6.12).

Example 6.2. *In a tile drainage system, the drains are laid with their centres 1.5 m below the ground level. The impervious layer is 9.0 m below the ground level and the average annual rainfall in the area is 80 cm. If 1% of the annual rainfall is to be drained in 24 hours to keep the highest position of the watertable to 1 metre below ground level, determine the spacing of the drain pipes. Coefficient of permeability may be taken as 0.001 cm/sec.*

Solution. Although eqn. (6.12) can be directly used in this question, since that eqn. has been derived for designing the drains to take 1% of the average annual rainfall in 24 hours, which tallies with the given data, yet it would be prudent to use the basic eqn. (6.10) for determining the spacing of tile drains, and separately compute q, as:

$$q = \frac{\frac{1}{100} \times \left(\frac{80}{100}\right) \times (S \times 1)}{(24 \times 60 \times 60)} \text{ m}^3/\text{s}$$

$$= \frac{0.8S}{8.64 \times 10^6} \text{ m}^3/\text{s/m length of tile drain}$$

Using eqn. (6.10), we have

$$S = \frac{4K}{q}(b^2 - a^2)$$

where b = ht. of W.T. above the impervious layer
$= 9 \text{ m} - 1 \text{ m} = 8 \text{ m}$

a = depth of impervious stratum below the centre of the drains $= 9 - 1.5 = 7.5$ m

$K = 0.001 \text{ cm/s} = \frac{0.001}{100} \text{ m/s}$

Substituting values, we get

$$S \cdot q = 4 \times \frac{0.001}{100}(8^2 - 7.5^2)$$

or $$S \times \left(\frac{0.8S}{8.64 \times 10^6}\right) = \frac{4 \times 0.001}{100}(8^2 - 7.5^2)$$

or $$0.8S^2 = \frac{4 \times 0.001}{100} \times (8.64 \times 10^6)(8^2 - 7.5^2) = 2678.4$$

or $$S = \sqrt{\frac{2678.4}{0.8}} = \sqrt{3348} = \mathbf{57.86\ m} \quad \textbf{Ans.}$$

6.6.5. Drainage Coefficient (D.C.). The rate at which the water is removed by a drain is called the *drainage coefficient.* It is expressed as the depth of water in cm or metres, to be removed in 24 hours from the drainage area. The drainage coefficient largely depends upon the rainfall but varies with the type of soil, type of crop, and degree of surface drainage, etc. Its recommended value is 1% of the average annual rainfall to be removed per day.

In irrigated areas, the discharge through the tiles may vary between 10 to 50% of the total water applied. Since the entire area is not irrigated at the same time, the drainage area to be used to calculate tile flow is not the same as the entire tiled area, but is estimated from the area irrigated. A suitable value of drainage coefficient (DC) may be taken for the calculations, depending upon the local recommendations. Values of 1 to 2.5 cm/day for mineral soils and 1.25 to 10 cm/day for organic soils for different crops, have been suggested for humid regions, by U.S. Soil Conservation Service.

Example 6.3. *A tile drainage system draining 12 hectares, flows at a design capacity for two days, following a storm. If the system is designed using a D.C. of 1.25 cm, how many cubic metres of water will be removed during this period ?*

Solution. D.C. of 1.25 cm means that 1.25 cm of water depth from the drainage area shall be removed by the drain in 24 hours.

∴ Volume of water entering the drain per day

$$= \left(\frac{1.25}{100}\text{ m/day}\right) \times (12 \times 10^4 \text{ m}^2) = 1{,}500 \text{ m}^3\text{/day}$$

Volume of water passing the drain within 2 days of flow

$$= 2 \times 1500 = \mathbf{3000\ m^3} \quad \textbf{Ans.}$$

6.6.6. Drainage Area. The area actually drained by the tile drain system is called its *drainage area*. Sometimes, the surface water is also to be removed by the tiles. In that case, the watershed area will be the drainage area, even though it may not be entirely tiled.

6.6.7. Size of the Tile Drains. The tile drains are designed according the Manning's formula to carry a certain discharge decided by D.C. and drainage area. The drains are laid on a certain longitudinal slope varying from 0.05 to 3%. A desirable minimum working grade is 0.2%. Where sufficient slope is not available, the grade may be reduced to 0.1%. Depending upon the available slope of the soil surface and the depth of the outlet, suitable value of longitudinal slope can be given to the tiles. Their sizes can be easily evaluated from Manning's formula. 10 to 15 cm tiles are minimum recommended sizes. The minimum size for perforated tubing or pipes can be reduced, as in that case, the misalignment at joints or cracks is not a problem.

Example 6.4. *Determine the size of a tile at the outlet of a 6 hectare drainage system, if the D.C. is 1 cm and the tile grade is 0.3%. Assume the rugosity coefficient for the tile drain material as 0.011.*

Solution. 1 cm D.C. means that 1 cm of water from an area of 6 hectares is entering the tiles per day.

∴ Volume of water passing the drain in 1 day $= \left(\frac{1}{100} \times 6 \times 10^4\right) = 600 \text{ m}^3\text{/day}$

∴ Volume of water passing the drain in 1 second $= \left(\frac{600}{24 \times 3600}\right) = \frac{1}{144} \text{ m}^3\text{/s}$

∴ $Q = \frac{1}{144} \text{ m}^3\text{/s}$ Now, $Q = \frac{1}{n} \cdot A.R^{2/3} \cdot S^{1/2}$

For a circular drain of diameter D, we have

$$A = \frac{\pi D^2}{4}, P = \pi D, R = \frac{D}{4}$$

or $$\frac{1}{144} = \frac{1}{0.011} \times \left(\frac{\pi D^2}{4}\right) \cdot \left(\frac{D}{4}\right)^{2/3} \cdot \left(\frac{0.3}{100}\right)^{1/2}$$

or $$\frac{1}{144} \times \frac{0.011 \times 4}{\pi} = \frac{D^2 \cdot D^{2/3}}{(4)^{2/3}} \times \frac{1}{\sqrt{333.3}}$$

or $$\frac{0.011 \times 4 \times 2.52 \times 18.26}{144 \times \pi} = D^{8/3}$$

or $D = (0.00447)^{3/8} = 0.132 \text{ metre} = 13.2 \text{ cm}$ **Use 15 cm dia. pipe. Ans.**

Example 6.5. *Sugarcane (root zone depth 1.8 m) is grown in a particular area where the ground water table is 2.0 m below ground. If the size of the soil pores is 0.08 mm in diameter and surface tension = 0.054 N/m, is the field water-logged ? If so, determine the vertical location of closed drains below ground, spaced at 15 m. Take drainage coefficient as 0.116 cumecs/km^2. Coefficient of permeability as 10^{-6} m/s, and the impervious stratum to occur at 7.0 m, below ground.*

Solution. We have stated in article 6.4 that if the water table rises up or if the plant roots happen to come within the capillary fringe, the salinity and water-logging of the land occurs. Here we have to see as to whether the plant roots (extending 1.8 m below the ground level) do come within the water-table or extended water table (due to capillary fringe). The actual water table is 2 m below ground and hence is not directly affecting the roots. But the capillary fringe is to be seen.

The height to which water rises by capillary action in a soil is given by eqn. (6.3) in "Soil Mechanics and Foundation Engineering" by the same author, as

$$H_e = \frac{4T \cdot \cos \alpha}{d \cdot \gamma_w}$$

where $\alpha = 0$ for max. capillary height

d = Dia of pores = 0.08 mm = 0.08×10^{-3} m

γ_w = Unit wt. of water = 9.81×10^3 N/m^3

T = Surface tension = 0.054 N/m

$$\therefore \quad H_e = \frac{4 \times 0.054 \times 1}{0.08 \times 10^{-3} \times (9.81 \times 10^3)} = \frac{4 \times 0.054}{0.08 \times 9.81} = 0.28 \text{ m}$$

The water-table thus effectively stands at 2 – 0.28 = 1.72 m below the ground, thereby causing slight water logging, since the roots extend up to 1.8 m below the ground. **Ans.**

In order to design the tile drains, we represent the given conditions in Fig. 6.13 as follows. Let the tile drains be laid at a height '*a*' above the top of the impervious layer.

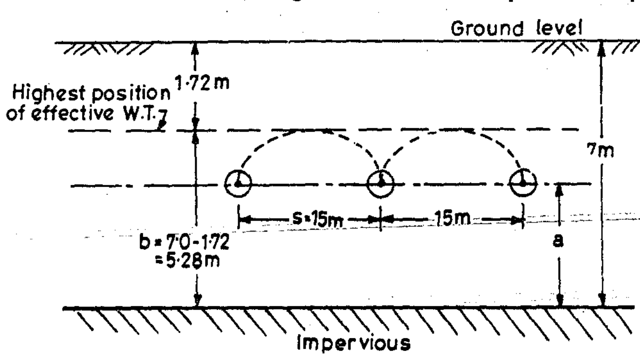


Fig. 6.13.

From eqn. 6.9, we have

$$q = \frac{4K}{S}(b^2 - a^2) \qquad ...(i)$$

where $S = 15$ m (given)
$K = 10^{-6}$ m/s (given)
$b = 7 - 1.72 = 5.28$ m
$a = ?$
q = discharge carried by each tile drain in cumecs/m run

The tiles have a drainage coefficient of 0.116 cumecs /km^2. Each tile carries discharge from 15 m width and 1 m length (considering 1 m length ⊥ to diagram).

∴ The discharge carried by each tile drain of 1 m length, q is given as :

$$q = 0.116 \frac{\text{Cumecs}}{\text{km}^2} \times \text{Area in km}^2$$

$$= 0.116 \times \left(\frac{15}{1000} \times \frac{1}{1000}\right) \text{cumces} = 1.74 \times 10^{-6} \text{ cumces/m run}$$

Substituting values, in (i) we get

$$1.74 \times 10^{-6} = \frac{4 \times 10^{-6}}{15}(5.28^2 - a^2)$$

or $\qquad a = \mathbf{4.62\ m}$

The tile drains should therefore be laid at $7 - 4.62 = \mathbf{2.38\ m}$ below the ground. **Ans.**

6.6.8. Materials of Tile Drains. Pipes used for tile drains are generally made from materials, such as clay or concrete, in short lengths. Sometimes, they may be made of bituminous fibre or steel. Corrugated plastic perforated pipes are gaining popularity, because of its lightness and reduced labour in handling it.

Comparison between clay and concrete pipes. Good quality concrete pipes are very resistant to freezing and thawing, but may deteriorate in alkaline and acidic soils. Clay pipes, on the other hand, are not affected by acid or alkaline soils. When subjected to continuous freezing or thawing conditions, concrete pipes are found to be safer than the clay pipes, although clay pipes are resistant to frost damage. Both the types of pipes should have sufficient strength, so as to withstand static and impact loads transmitted from the soil above.

Good clay or concrete pipes should have the following characteristics:

(*i*) Resistant to weathering and deterioration in the soil.

(*ii*) Low water absorption, *i.e.* high density.

(*iii*) Uniformity in shape and wall thickness, etc.

(*iv*) Freedom from defects, such as cracks, etc.

(*v*) Resistant to freezing, thawing and frost damage.

(*vi*) Sufficient strength to withstand static and impact loads for which designed.

6.6.9. Layout of Tile Drains. The tile drains may be aligned in different fashions, depending upon the topography of the area. Generally, laterals (branch drains) run through most of the drainage area and join the mains, which in turn, outfall into some deep open drain. The depth of the deepest tile drain shall be kept within the range of 3 metres from the surface, since the root zones of crops get affected by water within this depth range. A simple network of the drainage arrangement is shown in Fig. 6.14.

Various possible alternative **layouts for the tile drainage system** are shown in Fig. 6.15, and are discussed below:

(1) **Natural system.** The natural system is generally adopted *in rolling topography, where drainage of isolated areas is required.* The mains and the connected laterals are provided in natural course, as shown in Fig 6.15 (*a*). This system is suitable when the land is not to be completely drained. The system is quite flexible and permits location of drains where they are most needed.

(2) **Grid iron system.** This drainage system, consisting of laterals and mains (or submains), is shown in Fig 6.15 (*b*). In this

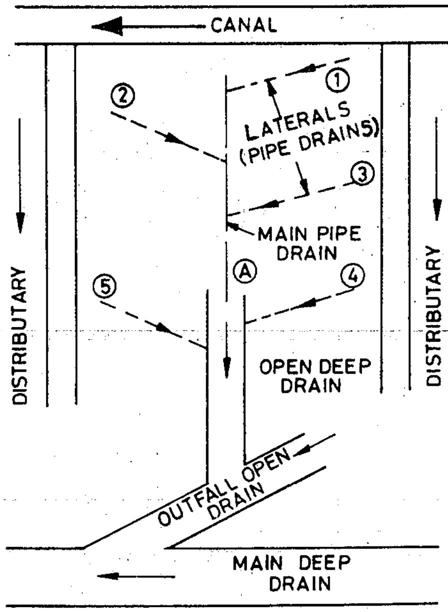
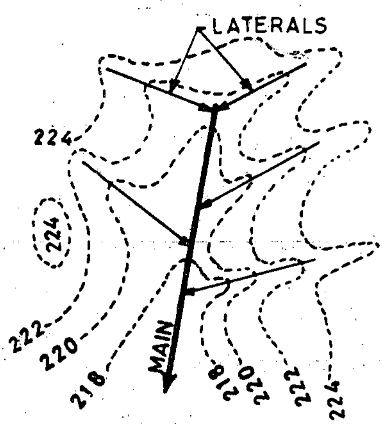
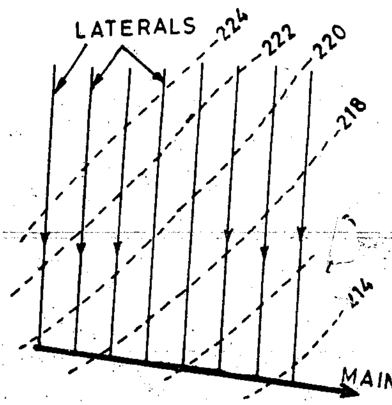


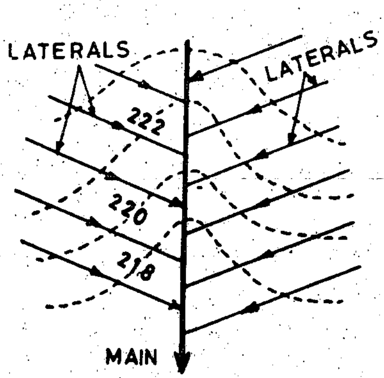
Fig. 6.14. General layout of a tile drain network.



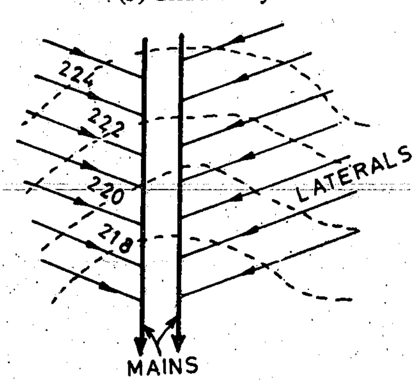
(*a*) Natural System



(*b*) Grid Iron System.

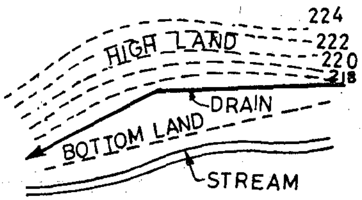


(*c*) Herring Bone System



(*d*) Double Main System.

(Fig. 6.15 continues)



(*e*) Intercepting Tile Drains System.
Fig. 6.15. Different Layouts of Tile Drainage Systems.

system, the laterals are provided only on one side of the main, as shown. *This system is adopted when the land is practically level; or where the land surface slopes away from the sub main on one side, and when the entire area has to be drained.*

(3) **Herring bone system.** In this layout pattern, laterals join the mains (or sub-mains) from each side, alternatively, as shown in Fig 6.15(*c*). This layout is adopted, when the main (or sub-main) is laid in depression. *The land along the main is double drained, but since it exists in depression, it probably requires more drainage than the land on the adjacent slopes.*

(4) **Double main system.** This system has two mains with separate laterals for each main, as shown in Fig 6.15(*d*). *This layout is adopted when the bottom of depression is wide.* This arrangement reduces the length of the laterals and eliminates the break in slope of the lateral at the edge of the depression.

(5) **Intercepting tile drains system.** In this system, there is no lateral drain. A main (or submain) is provided at the toe of the slope, as shown in Fig 6.15(*e*). *This arrangement is preferred when the main source of drainage is from a hilly land.*

In general, all mains and submains should be kept away from trees, as the roots of trees can easily enter the open joints of the tile drains, and thereby blocking them.

PROBLEMS

1. (*a*) What is meant by "water-logging"?

(*b*) What are the principal causes and effects of water-logging in a canal irrigated farm?

(*c*) What precautions and measures will you adopt to prevent water logging of irrigated lands?

2. (*a*) What are the principal causes of water-logging in a canal irrigated tract?

(*b*) What precautions will you observe in constructing a new canal system to avoid water-logging?

[**Hint**. Provide lined canals equipped with under-drainage system]

(*c*) What steps will you take to improve an already water-logged tract?

3. What is meant by water-logging? What are its ill effects? Describe some anti-water-logging measures with suitable sketches.

4. Discuss different types of drainage systems provided in irrigated tracts as precautions against water-logging. Give salient features of an open drain system.

5. (*a*) What is meant by "saline" and "alkaline" soils?

(*b*) What precautions will you adopt to prevent salinity of irrigated land?

(*c*) How will you proceed to reclaim saline land?

6. (*a*) Discuss critically the statement : "intensive irrigation leads to reduced crop yields".

(*b*) What are "tile drains" and how do they help in preventing water logging? How will you decide the depth and spacing of tile drains?

7. (*a*) What is meant by "Land Drainage", and where is it needed?

(*b*) What are the two principal types of drainage systems necessary for draining irrigated tracts to avoid their water-logging?

8. (*a*) What is meant by "open drainage" and "closed drainage" as applied to draining irrigated tracts?

(*b*) A tile drainage system draining 15 hectares, flows at a design capacity for three days, following a storm. If the system is designed using a drainage coefficient of 2.25 cm, how much water will be removed during this period?

[**Hint.** Follow example 6.3] [**Ans.** 10125 m^3]

9. (*a*) What is meant by "Drainage coefficient" and how does it help in determining the sizes of tile drains to be laid for preventing water-logging of irrigated farms?

(*b*) What are the different materials which are commonly used for the drains, and what are their comparative merits and demerits?

(*c*) Determine the size of a circular tile drain, draining 6 hectares of a drainage area, if the drainage coefficient (D.C.) is 1.5 cm and the tile grade is 0.4%. Assume the rugosity coefficient for the tile material as 0.013.

[**Hint.** Follow example 6.4]

10. What is meant by "tile drains" and what are the different methods of aligning them? How will you proceed for fixing their depth, spacing and sizes? What are their advantages?

11. Write notes on any two of the following:

(*i*) Open drainage (*ii*) Tile drainage
(*iii*) Surface inlet (*iv*) Blind inlet or French drain
(*v*) Envelope filters (*vi*) Gravity outlets
(*vii*) Pump outlets (*viii*) Movement of water into tile drains
(*ix*) Random and Herring bone types of tile drainage systems.

12. Fill in the blanks with appropriate words:

(*i*) If the soil is more permeable, the chances of water-logging are .... (less/more)
(*ii*) Intensive irrigation should be .... in areas susceptible to water-logging. (adopted/avoided)
(*iii*) Extensive irrigation should be .... in areas susceptible to water-logging. (adopted/avoided)
(*iv*) .... irrigation helps in checking water-logging. (Flow/Lift)
(*v*) The remedial measures for water-logging are ......
(*vi*) Drainage schemes are implemented for ..... water-logged areas.

Ans. (*i*) more; (*ii*) avoided; (*iii*) adopted (*iv*) lift; (*v*) installing lift irrigation schemes, and implementing drainage schemes; (*iv*) reclaiming.]