20. Head regulator: See article 8 of chapter xii. Silt problem in the design is not considered. Velocity of entry of water through head regulator spans should be practically the same as the mean velocity of water in the channel downstream.

21. Cross regulator: See article 9 of chapter xii.

22. Canal fall: See article 10 of chapter xii.

Water cushion, which is depressed below the downstream G. B. L., may not be necessary in case of ledge and hard rock; in such case, a low wall (parallel to drop wall and slightly away from it) constructed across the downstream canal bed will create a dead pool of water to dissipate the surplus energy of falling water; in case of hard soils, depressed water cushion may be of smaller magnitude. Also, in case of simple vertical fall, if the length of body wall be equal to 75% of the upstream canal bed width, wire-drawing will be avoided.

23. Rapid: It is, in essence, an inclined fall in the bed of an irrigation channel as shown in fig. 99(a). Where there is a considerable and sudden fall in the level of natural
ground along the alignment of a channel and the ground there is sufficiently hard, canal bed levels on the upstream and downstream sides of the point of sudden fall in country are joined by inclined bed known as rapid. The bed and sides of channel along this incline (called a rapid) are pitched with stone; also, the canal bed and sides are pitched for some distance on the upstream and downstream sides of the rapid.

24. **Canal escape:** See article 11 of chapter xii and note the following point:

It is only the canal scouring escape (and not the silt ejector) that is *commonly* used in the head reach of main canal.

25. **Irrigation outlets:** See article 12 of chapter xii and note the following point:

Non-adjustable proportional semi-module will do in non-alluvial area. Silt problem does not affect the design and type of irrigation outlets (to be used) in non-alluvial area.

26. **Gibb's module:** See article 13 of chapter xii.

27. **Venturi meter:** See article 14 of chapter xii. Due to silt problem, Venturi meter is comparatively undesirable in alluvial area than in non-alluvial area.

28. **Flumes:** See article 15 of chapter xii. Silt problem affects *slightly* their design in alluvial area only.

29. **Regulating gates and Gate-hoist:** See article 16 of chapter xii.

30. **Tail reservoir:** It is a small lake at the tail of a big-size irrigation channel in which the surplus irrigation water is stored instead of being wasted out of this channel. The stored water can be used, when required for irrigating land near the tail of channel. Such lake is possible only when the natural contours of ground at the tail of channel are favourable towards the creation of a surface storage. The surplus water that is stored may be due to:

(a) Excessive rainfall on irrigated area.

(b) Less demand for irrigation water by the cultivators.
31. **Tunnel section of irrigation channel**: The construction of tunnel section for an irrigation channel becomes necessary when a high ridge comes in the alignment of irrigation channel and a detour in the channel alignment is costlier and less desirable than the straight alignment through this high ridge. Sometimes when the ridge is not so high, a deep cut (instead of tunnel) is given along the straight alignment to carry the water from one side of ridge to the other. The length of tunnel or deep cut depends on the magnitude of the ridge.

The irrigation water tunnel may be lined or unlined. Lining is given to support the unstable strata round the tunnel and to increase the velocity of flow through the tunnel. When a tunnel does not run full, it is called a free-flow tunnel; this type is usual for carrying irrigation water. When a tunnel runs full of water, it is called a pressure tunnel; this type is constructed under certain conditions. In case of free-flow tunnel, lining is sometimes omitted, as when the surrounding strata are quite stable; lining is however necessary in case of pressure-tunnels and, when the surrounding strata are not so stable and require a support for their stability. Lining is reinforced when, on the tunnel, there is internal pressure or external pressure or both.

![Horse-shoe section of tunnel](image)

**Fig. 99(b)**

The section of the tunnel [see fig. 99(b)] is usually determined by the characteristics of the rocky strata through
which the tunnel passes and by the conditions of tunnel operation i.e. whether the tunnel is free-flow tunnel or a pressure tunnel. The rectangular and horse-shoe sections are used for small-size tunnels and when the tunnel is a free-flow tunnel, arched roof is usually provided in tunnel construction. Circular section is used for high-pressure tunnels. The minimum cross section of tunnel should be such as to provide adequate working space during construction; hence a minimum width of 1.8 m (6') and a minimum height of 2.1 m (7') are usually provided.

In case of a free-flow tunnel having lining, a maximum velocity of flow of 3 m/sec (10 ft./sec) is usually allowed. Free-flow tunnel is also known as gravity tunnel.
CHAPTER XIV

SUBSOIL WATER IRRIGATION

1. Introductory: It has been said in chapter III that a part of rainfall percolates under the ground and when percolation is deep, this water joins the underground water table. Subsoil water table is the upper surface of free water in the subsoil, as shown in fig. 100; thus, the soil below subsoil water table is fully saturated with water; this water, under certain conditions, can flow laterally from one part of subsoil to the other and obeys the laws of hydraulics governing its flow. This subsoil water can be used for irrigation purposes, usually by lifting it above the ground by means of some water-lifting devices; subsoil water irrigation is thus mainly a form of lift irrigation and is therefore more expensive. In India, however, about 33% of the irrigated area is watered annually by the subsoil water and as such, the subsoil water irrigation is doing a good service in India. It has still greater scope of development in future.

2. Forms of subsoil water irrigation: Subsoil water for irrigation purposes is available from the following sources which therefore represent the forms of subsoil water irrigation:

(a) Well.
(b) Karez.
Well irrigation is practised from wells. A well is a hole (of certain diameter) from ground level to a point below the subsoil water table. Wells may mainly be:

(i) *Dug* wells called Open wells or Percolation wells.
(ii) *Bore* wells or Drilled wells.

An open well is of a fairly big diameter (usually 1·2 m to 3·6 m or 4' to 12') and is more common than a bore well. Its *economically* feasible depth is upto 30 m (100 feet) below ground. It may be in alluvial soil or in non-alluvial soil. In alluvial soil, its construction and maintenance are comparatively difficult but the supply of water from it is more and also reliable; coarser the subsoil particles, greater the supply of water from the subsoil. Open well in alluvial soil may be lined with brick from inside or it may not be lined. A well with lining or steining is usual and is shown in fig. 101; it is comparatively permanent, though costlier than a well without lining. The latter well is possible for small depths upto about 6 m (20'), where the alluvial soil is fairly hard to stand vertical face and the water table is only a little below ground. Lining is usually 0·45 m (1½') thick for wells upto 15 m (50') depth and 0·6 m (2') thick for the portion deeper than 15 m below ground. Lining is constructed along with the digging of well. Lining may be pervious or impervious; the latter is more common and in such case, water percolates into the well from only the bottom of well. In case of pervious lining, water gets into well from the sides of well also. Well with pervious
lining is comparatively of small depth as compared to a well with impermeable lining. In alluvial soil, the maximum safe discharge of an average open well with impervious lining is about 4.2 litres/sec (0.15 cusec) and the well is constructed with its bottom about 6 m (20') below water table. In non-alluvial area, if the soil is soft and porous, lining is necessary; when however the soil is rocky and hard, no lining is necessary. An open well in rocky stratum is called a spring well and it gets its supply from water which gets into the well through crevices and fissures in the rocky stratum. In case of hard soil in non-alluvial area, steining can be constructed after the whole well has been dug.

As far as practicable, an open well should be located in the centre of irrigated area and on highest patch of ground on this area. Open well should also be sufficiently away from the neighbouring open well so as not to interfere with the discharge of that well.

Artesian and sub-artesian wells

**Fig. 102**

Bore well may be a tube well or an artesian well. It is essentially of very small diameter, say, from 15 to 75 cm (6" to 30") or so. Artesian wells are possible only in such localities where the special conditions (known as artesian conditions) exist, just as near Pondicherry and Quetta. Artesian well may be fully artesian well or semi-artesian well; the former is also called a flowing well and the latter is called a sub-artesian well. These are shown in fig. 102. In case of a flowing well, water comes up the bore under pressure and is available above
ground; in case of sub-artesian well, water is available, in the bore, below ground level and has to be lifted by pump or some such device before it can be applied on the adjoining land. Ordinarily, artesian well means a flowing well unless mentioned otherwise. Artesian wells are rare, of less discharge and costly and, therefore, are of not much importance for irrigation purposes. They may be constructed for irrigating very costly crops; in such case, the continuous flow of a flowing well is first stored in a tank from where the water is taken for irrigation as and when required. Tube wells are very deep and tap many water bearing strata below ground as is shown in fig. 103; they are more successful in

![Diagram of Tube Well]

alluvial soil and are drilled when more discharge (e.g. discharge greater than 0.15 cusec which is available from an average open well) is required. Tube wells, however, are more costly than open wells; the latter being cheap, are plenty in number and are owned by cultivators. Tube well like an open well is called a water table well. A fully artesian well is not a water table well because, from it, water is available above ground.

Karez (fig. 104) is an underground tunnel along a hillside and is possible in certain localities, as in Baluchistan and North West Frontier Province (West Pakistan). The tunnel has certain bed inclination and taps the underground springs.
It is constructed like a tunnel by the irrigator himself; its cross section is rectangular with arched roof and should be wide enough so that it can be cleaned (by irrigator) of any debris deposited in it. As it is in hard stratum, it is usually not lined. At its downstream end, it meets the ground and from this point onwards, water from karez is taken in an open channel to the storage tank from where it can be used as and when necessary. This is how irrigation water can be had, from subsoil, by tunnelling.

3. **Yield of open well in permeable stratum in alluvial soil:** When an open well is dug in a permeable stratum, water level in well is *practically* the same as that of water table outside and around it; that is why it is called a water table well. When water from inside the well is taken out by some water lifting device, water level inside the well falls below the level of water table and hence, the water from saturated soil (below water table) around the well comes into the well, by percolation, under *percolation head* which is the difference of water levels inside and outside the well. This percolation head $h$ (see fig. 101) is also called the *depression head* or depletion head or infiltration head or draw-down. Greater the percolation head, greater the water percolating into the well and vice versa. Discharge formula for an open well with impervious lining is,

$$Q = A \times v = A.C.h \text{ c.ft/sec}$$

where, $Q$: Amount of water percolating into well, in c.ft/sec. It is usually expressed in c.ft per hour and then it is called *yield* of the well as
this much water, that percolates in the well, can be taken out of the well for irrigation purposes.

\[ A = \text{Area, in sq. ft., of } \text{pucca well at its base through which water percolates into the well.} \]

\[ v = \text{Mean velocity of water percolating into the well, in ft/sec. Its value is very small and hence, it is usually expressed in ft/day. Coarser the soil particles, greater the value of } v. \]

\[ C = \text{Constant for saturated soil which is round the well. Coarser this soil, greater the value of } C \text{ and vice versa. Its value is very very small. This constant is called the } \text{percolation intensity coefficient.} \]

\[ h = \text{Depression head in feet which, if kept constant, will give the above-said discharge by percolation into the well.} \]

From the above it appears as if by increasing the value of \( h \), we can get more and more yield. This is true upto a certain limit beyond which if the value of \( h \) is increased, the velocity of percolation will be so great as to disturb soil particles (at the base of the well) which will therefore come into the well along with the incoming water. This limiting value of \( h \) is called \textit{critical depression head} and the velocity of percolation induced by it is called critical velocity of percolation. Yield of well corresponding to critical depression head is called \textit{critical yield} or \textit{maximum possible yield}. The critical head varies from soil to soil; coarser the soil, greater the value of critical depression head for it and vice versa. In practice, however, no well is worked under critical depression head; the maximum allowable \textit{working} head is usually \( \frac{1}{3} \) of the critical head, thus ensuring a factor of safety of 3. The yield of a well under such maximum safe working head is called the \textit{maximum safe} yield of the well. Unless specified otherwise, yield of an open well means its maximum safe yield.

Following are the fundamental principles regarding the hydraulics of flow into wells:
(i) The yield of a well is approximately directly proportional to the depth of penetration of well in a water-bearing layer of subsoil.

(ii) The yield increases very rapidly with the coarseness of particles of the water-bearing layer.

(iii) The yield increases with the radius of influence. Radius of influence is the horizontal distance between the axis of well and the farthest point (of surrounding water table) at which the draw-down curve (fig. 101) meets the practically horizontal water table line outside the well.

(iv) The yield is approximately proportional to the depression head.

(v) The yield is increased very little by increasing the diameter of well.

(vi) The yield is decreased if there is interference from neighbouring well. The two wells are said to interfere with each other’s yield when their circles of influence intersect.

4. Tests to ascertain the yield of an open well dug in a permeable stratum: Before an open well is actually dug on an area in alluvial soil, idea about the likely yield of well can be had by drilling a bore on the site of the proposed well and performing one of the following tests on the bore during the driest part of the year:

(a) Pumping test or Constant level test.

(b) Recuperation test.

In the pumping test, water level in the bore is depressed below water table by an amount which represents the safe working head for subsoil at the site of well. This water level is kept constant by so regulating the pumping that whatever water percolates into the well under this constant depression head, is taken out by the regulated pumping. The time for which this regulated pumping is done is noted and the amount of water taken out of bore in this time is measured. Then, the water taken out in one hour is calculated and this represents the yield of well per hour per base area of the bore. Knowing the diameter of proposed open well, its probable
yield can be worked out as the base area of bore is known. The test may also be carried out on an existing open well.

In recuperation test, the water level of bore is depressed (by pumping out water) by an amount which is less than the safe working head for the proposed open well. At this instant, the time is noted, pumping is stopped and water level in the bore is allowed to rise or recuperate. When it rises by some amount (and is yet below water table), the then depression head and the time of recuperation upto that level are noted. Thus (see fig. 105), let the initial depression head at the beginning of experiment be \( h_1 \) feet and the final depression head at the end of experiment be \( h_2 \) feet; clearly, \( h_2 \) will be less than \( h_1 \) as the water level has recuperated. Let \( T \) hours be the time taken by water level to recuperate from depression head \( h_1 \) to depression head \( h_2 \). Then, we have,

\[
\frac{K}{A} = \frac{2.303}{T} \log \frac{h_1}{h_2}
\]

where, \( A \) = The area, in sq. ft, of bore through which water percolates into the bore.

\[
\frac{K}{A} = \text{The specific yield or specific capacity of the bore in c.ft per hour per sq. foot of the area through which water percolates under a unit constant depression head.}
\]
Knowing the safe working head \( h \) for the proposed lined open well and its diameter, its yield will be found from the formula,

\[
Q = \left\{ \frac{K}{A} \times \text{base area of the lined well} \times h \right\} \text{c.ft/hour.}
\]

The values of \( \frac{K}{A} \) for some of the soils are given below:

<table>
<thead>
<tr>
<th>Soil</th>
<th>( \frac{K}{A} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay</td>
<td>0.25</td>
</tr>
<tr>
<td>Fine sand</td>
<td>0.50</td>
</tr>
<tr>
<td>Coarse sand</td>
<td>1.0</td>
</tr>
</tbody>
</table>

This test can also be performed on an existing open well.

The above-mentioned two tests can also be performed on the existing spring wells.

5. **Tube well**: Water from a tube well is lifted by some mechanical appliance as the diameter of tube well is small and its depth is very great, usually a few hundreds of feet. Water so lifted is delivered in irrigation channel carrying the water to the field. The average discharge of a tube well is about 1.5 cusecs (42 litres/sec). A tube well, in essence, consists of a deep bore of certain diameter (in inches or cm), passing through many permeable and impermeable strata in which is lowered and fixed a tube well pipe of practically same depth but of diameter slightly less than that of the bore, as is shown in fig. 103. Thus if the diameter of tube well pipe be 25 cm (10″), that of the bore may be about 45 cm (18″). The tube well pipe consists of alternate lengths of plain (i.e. without slots or perforations) pipe and the brass strainer pipe. Plain pipe is put in an impermeable stratum and strainer pipe is put throughout the thickness of a permeable stratum. A permeable stratum is also called a water bearing stratum or an aquifer because water comes from such stratum into strainer pipe and from strainer pipe it comes to the tube well pipe. Strainer pipe is a perforated pipe covered all-round by a metallic net of very minute meshes such that the water from
water-bearing stratum passes through this net and the strainer pipe perforations into the strainer pipe, while the soil particles are kept out by the net which is also called the straining material or sometimes only *strainer*. Cross section of strainer pipe is shown in fig. 106. The lower-most portion of tube well pipe is called blind pipe because it is a piece of plain pipe blind (i.e. plugged) at its bottom. The plugged bottom of this blind pipe should be a little above the bottom of bore otherwise it will give way under the weight of whole pipe length above it. The various pipe lengths are screwed together to make the entire tube well pipe. Tube well pipe may be of uniform diameter as in case of tube well of ordinary depth but, in case of very deep tube well, it may be of *progressively* bigger diameter from its bottom to its top so as to effect some economy. The methods employed for drilling or boring a tube well bore are:

(a) Percussion method or Rope method.
(b) Water jet method.
(c) Core-drill method.

In percussion method, a sludger (fig. 107) is used to form the bore. It is useful in sandy and gravelly soils, as in alluvial areas. The soil is reduced to powder by the cutting edge which is at the bottom of sludger; at the bottom
of sludger and above the cutting edge, is a non-return valve opening only in the upward direction. The loosened soil gets collected inside the sludger and is taken out from the sludger when it becomes full; sludger is then re-used. The diameter of sludger pipe will be practically same as the required diameter of bore and, when in operation, the sludger works in a casing pipe of inside diameter slightly greater than the required bore diameter. Casing pipe is also known as boring pipe and its length has to be increased as the depth of bore goes on increasing during boring operations. When the bore of required depth is obtained, there will be in it the casing pipe upto the bottom of bore. After this instant, the tube well pipe (consisting of blind pipe and, alternate plain and strainer pipes) is lowered in the casing pipe. The annular space between the lowered tube well pipe and the casing pipe is filled with fine sand slowly and gradually; this process is called shrouding. As the shrouding is being done, the casing pipe should be gradually lifted out of bore, till the full depth of annular space is shrouded and the casing pipe is fully taken out. At this instant, in the bore, there will be tube well pipe surrounded by sand shrouding. Next, a circular pump-house of masonry is constructed round the bore at its top, as shown in fig. 108. A centrifugal pump is installed in the pump-house either above or below the water table. The delivery pipe from this pump delivers water in a water course which carries water to the field. The water course should preferably be lined to cut down transit losses. When the pump works, it creates a strong vacuum head under which water from various water bearing strata (pierced by the bore) rushes with a great (i.e. much more than critical) velocity through the strainer pipes into the tube well pipe and travels up this pipe into the delivery pipe. As this velocity of water is above critical velocity for the soil, soil particles get loosened and rush to the strainer pipes along with water. However, as the strainer net is of
very fine meshes, these disturbed particles cannot pass through it into the tube well pipe. It is due to the greater velocity of water which can be induced in case of tube well that its discharge is greater than that of an open well; also, tube well taps more than one aquifer. Usually, the top-most aquifer is left un-tapped as otherwise this will interfere with the discharges of neighbouring open wells which usually tap the first aquifer below the ground. Hence, instead of a strainer pipe, a plain pipe is used in the first aquifer of the bore of a tube well.

Cross section of tube well at its top, showing pump house etc.

Fig. 108

In the water jet method of boring, instead of a sludger, a jet of water with very great velocity is used for loosening the soil, as is shown in fig. 109. This method is useful for hard clay soils. The soil is washed
out of bore by a jet of water. The casing pipe is used in boring operation as usual. After the bore of required depth is made, the lowering of tube well pipe, shrouding, the lifting up of casing pipe, construction of pump-house etc. will be done as usual.

Drilling method is useful in hard rocky soil. In this case, a drilling machine worked by pneumatic pressure is used to drill a bore. The drill of machine brings up (from bore) the cylindrical cores of hard soil, which can be inspected easily and an idea can be formed about their qualities. The subsequent operations, after the drilling of a bore, will be as said before.

A certain establishment in the form of an operator, mistry etc. will have to be engaged to look after the working and maintenance of pump, to note the amount of water supplied to irrigators and to assess the area irrigated by the tube wells. Now-a-days the pumps are usually worked by electric power. Tube well irrigation is feasible where

(a) the supply of water in water-bearing strata (below ground) is ample, as in alluvial soil.

(b) this well water is suitable for irrigation purposes; the $pH$ value of water should be between 7 and 9; $pH$ value is a measure of the degree of alkalinity or acidity of water and hence, its suitability or otherwise for irrigation purposes.

Before any large scale programme for the drilling of tube wells is undertaken, it would be wise to explore the availability of sufficient and suitable ground water; hence, a few exploratory borings are first made on the area on which the tube wells are proposed to be drilled.
6. Advantages and disadvantages of well irrigation:

(a) *Advantages:*

(i) Water is under the sole control of irrigator in case of open wells and *private* tube wells and hence, he can use it as and when required by crops. In case of canal irrigation, such facility is lacking to some extent. Thus, with well water, 2 or 3 crops can be raised in a year; also the yield of crops is more because of the timely waterings.

(ii) Isolated areas, not served by any other irrigation scheme, can be irrigated by wells.

(iii) Well irrigation lowers the water table of adjoining area and hence, there is no fear of water-logging of irrigated land.

(iv) In years of drought, reliance can be put on well water rather than on canal water which may not be available then.

(v) Well water is used economically by the irrigators; hence, the duty of water is more in well irrigation than in canal irrigation; in other words, the delta for a crop when irrigated by well water is less.

(vi) Well irrigation is particularly suitable for the intensive irrigation of valuable crops.

(vii) In many cases, well irrigation can supplement canal irrigation.

(viii) In tube well irrigation, water can be supplied to irrigators on *volumetric* basis; thus, there is more scope for the economic use of water.

(ix) Wells are on or near irrigated area and hence, the transit losses are only those occurring in water courses.

(b) *Disadvantages:*

(i) Well irrigation is after all a kind of lift irrigation i.e. some appliance is used to lift up the water from great depths. It is, therefore, costlier than canal irrigation which is usually a kind of flow irrigation.
(ii) Well water has no fertilising qualities; hence, more manure is applied on agricultural land to raise crops.

(iii) In case of tube well irrigation, the supply of water will be interrupted if the pump goes out of order or the power working the pump gets cut off due to certain reasons. Also, the straining material round the perforated pipe will have to be replaced when it gets choked or rusted or goes out of service due to any other cause.

(iv) Only small area can be irrigated by a well. The area irrigated by a well in one year is called its duty and is expressed in acres. Duty of a well depends on the kind of lifting device, amount of lift and the efforts made by irrigator.

7. Degree of permissible salinity in the water of an irrigation well: Subsoil water contains some dissolved mineral matter in it. This dissolved matter should be in such quantity as not to hinder the growth of crops; nor should it make alkaline the land irrigated by it. The soluble mineral salts of sodium (especially NaCl, Na$_2$SO$_4$ and Na$_2$CO$_3$) are undesirable in any appreciable quantity. Ordinarily, the total soluble salts should not exceed about 300 parts in 100000 parts of irrigation water otherwise the water will prove objectionable for irrigating most of the crops. When Na$_2$CO$_3$ is present in water, the total limit of soluble salts allowable may be less than 300 parts in 100000 parts of water and when Na$_2$CO$_3$ is the predominant salt, still lower limit will be allowed.

Calcium salts, if present in irrigation water, retard the evil effects of sodium salts. A rough formula to know the suitability of irrigation water is as follows:

\[
\text{Salt index} = (\text{total sodium in parts} - 24.5) - 4.85 \quad (\text{total calcium} - \text{calcium in CaCO}_3).
\]

If the value of salt index is negative, the water is suitable for irrigation purposes and vice versa.

Not only should the total soluble salts be within safe limit, but the $pH$ value of water should be between 7 and 9. Water with $pH$ equal to 7 is called neutral water, example being the distilled water; water with $pH$ value from 0 to 7
is called acidic and that with $pH$ value from 7 to 14 is called alkaline. Irrigation water is usually alkaline and it is the too much alkalinity that has adverse effect on crop-growth and is therefore undesirable.

8. Methods of lifting irrigation water: As said in chapter 1, lift irrigation is mainly practised from wells (open and tube). In some cases, lift irrigation is practised from canals and small streams at certain locations along their lengths. The appliances or contrivances for lifting irrigation water consist of:

(a) Rati or Pulley: (fig. 110).
(b) Denkli or Lat or Lever: (fig. 111).
(c) Mote or Churus or Kosh or Leather bag: (fig. 112).
(d) Rahat or Nar or Persian wheel: (fig. 113).
(e) Archimedean screw: (fig. 114).
(f) Doon: (fig. 115).
(g) Pumps; some of them are:
   (i) Chain pump: (fig. 116).
   (ii) Centrifugal pump: (fig. 117).
   (iii) Wind mill (pump): (fig. 118).
   (iv) Air lift pump: (fig. 119).
Rati and Denkli are the devices used for irrigating small garden plots. They are useful for low lifts of say 3 m to 15 m (10' to 50') and hence, they are installed on the top of an un-lined (i.e. katcha) well or one having pervious lining. Rati

![Lever Diagram](image)

**Lever**  
*Fig. 111*

Leather bag or Skin bucket  
*Fig. 112*

consists of a pulley the axle of which is fixed between two brackets overhanging the top of well. Water is taken by means of a rope going over the pulley, a bucket being tied at the lower end of rope. Denkli consists of a lever-rod rocking over the top of a vertical upright post. At that end of the lever rod
which is overhanging the well, is tied a rope with bucket and at the other end of lever-rod is fixed a counter-weight. When the bucket is to be filled with water, irrigator has to pull down the overhanging end of lever rod till the bucket dips in well water. When the bucket is full, he has simply to guide the rope with his hands so that the filled bucket, while coming up under the action of counter-weight, does not strike the sides of well. The irrigator has not to use any force while the bucket comes up because the counter-weight is of such weight that its moment about the top of upright post is greater than the moment of filled bucket about the same point.

Persian wheel
Fig. 113

Mote and Persian wheel are used for irrigating crops on a small area. They are useful for lifts upto 30 m (100'), mote being comparatively more desirable for greater lifts within this limit. They are installed on lined wells. A mote consists of leather bag with one open end large and the other open end small; the smaller open end is called the discharging spout. One end of a rope is tied to the bigger open end of mote; this rope goes round a pulley (or roller) fixed on a bracket near the top of well and its other end is tied to the
yoke of bullocks which are used to pull the mote up. Another rope is taken and its one end is tied to the discharging spout of the mote; this rope, in turn, goes round another pulley fixed on another overhanging bracket near the top of well and its other end is tied to the yoke. There is a ramp with a down-slope from the parapet wall of well; the bullocks move up and down on this ramp. The two ropes are of such a length that when bullocks are near the parapet of well, the mote just dips in well water and becomes full of water. When the mote becomes full, the bullocks move down the ramp i.e. away from the well; as they move down the ramp, mote is pulled up and when bullocks reach the lower end of ramp, the mote just reaches the top of well-parapet, it lengthens out as shown in the sketch and discharges water through its discharging spout into a trough (or chute) kept at the top of well. Water from this trough flows into a water course which carries it to the field. While the mote is being lifted up, both of its open ends are held in vertical position so that the water is retained in mote. This is also shown in the figure.

Persian wheel is quite common in North India. It is much better method of lifting water than the mote. It consists of a framed wooden wheel of big diameter fixed in vertical position above the top of well. At the end of horizontal axle of this wheel is another vertical wooden wheel of smaller diameter. This smaller wheel gears with a horizontal small-diameter wooden wheel at its top. From the centre of this horizontal wheel, starts a vertical wooden spindle the top end of which has bearing in a horizontal beam which is fixed in two masonry pillars at its two ends. To the centre of this spindle is fixed a wooden horizontal bracket of certain length. The animal (i.e. bullock, buffalo or camel) is yoked to the free end of this horizontal bracket. The animal moves round and round in a circle on a horizontal circular platform which is constructed round the small wooden wheels and the spindle. Round the big-diameter vertical wooden wheel is an endless rope (dipping in the well water) to which are tied the vessels (usually earthen). As the animal moves round and round, some vessels come up full of water, they discharge in a trough kept at the centre of big-diameter verti-
cal wheel and go down empty in the well to be filled up again. The water from trough flows into water course or field channel. Some readers must be familiar with a peculiar creaking sound of a persian wheel which can be heard from a distance. In some cases, when lift irrigation is practised from irrigation canal, a circular well-like pit is excavated on the inside berm of the canal, the pit being connected with the canal by an open cut. Thus, the water in the pit will be available at a level at which it is available in the canal. Over this pit, is installed a persian wheel which is called Hurlo in Sind (now in W. Pakistan).

The remaining lifting devices are described in the subsequent articles.

9. **Archimedean screw**: It is used for low lifts upto 1.2 m (4') or so in case of an irrigation channel. It consists of a hollow cylinder, fitted with a helicoid screw inside it. Lower end of the screw ends in a shaft which has bearing in an upright member fixed in the bed of channel. Upper end of the screw ends in a shaft with handle at its end; this upper end has also a bearing in an upright member fixed on the berm of canal. Lower end of the hollow cylinder should
remain immersed below water level in the channel; when handle at the upper end of screw is turned round and round, the water from channel moves inside the hollow cylinder, up the screw, and discharges from the upper end of cylinder into a field channel. This appliance is common in Egypt.

10. **Doon**: This also is used for low lifts upto 1.2 m (4') or so in case of an irrigation channel. It consists of a long wooden semi-circular chute which is blind at one end and open at the other. At its centre, the chute is supported on a horizontal rod on which it rocks. The blind end of chute is connected, by rope, to one end of an overhead lever rocking about a fulcrum; a counter-weight is tied to the other end of rocking lever. A wooden platform is fixed in the channel near its berm such that the top of platform is above the water level in channel. The cultivator stands on this platform and forces down the blind end of trough till it dips in water; he then releases it so that the chute rocks (due to turning moment caused by counter-weight) and discharges the water from its open end into a field channel.

11. **Chain pump**: This is a contrivance for lifting water from shallow wells. It consists of two iron drums,
one at the bottom (being slightly below well water level) and the other at the top of well. The upper drum has teeth, on its surface, which engage loops of an endless chain moving round the two drums. The drums are surrounded by a cylindrical iron casing which is partitioned into two compartments, one being a narrow cylindrical compartment touching the inside of casing. At the top of this narrow cylindrical compartment is a spout from which the lifted water comes out. A number of washers (called floats) are fixed on the endless chain, at certain distance centre to centre; these floats are such that they can just move up through the narrow cylindrical compartment, with a little clearance between them and the inside of this compartment. When the handle fixed to the axle of upper drum is turned round and round, floats move up the small compartment, lifting well-water bodily over them. When this water comes upto the discharging spout, it goes out and flows into field
channel. The floats, while moving up, are in horizontal position so that they can hold and drag water over them; but, while moving down the bigger compartment, they turn about a hinge near the chain and lie in practically vertical position as shown in the figure. The chain pump is worked by hand. It is not a common water lifting device as the leakage of water, past the floats, is appreciable and its mechanical efficiency is therefore low.

12. Centrifugal pump: This pump is quite common in the field of irrigation. It is used to lift water from canals, streams, open wells and tube wells. Mote and Persian wheel are common for open well but a centrifugal pump, worked by a diesel engine or electric motor, is more economical. It is fixed below water level or above it; when it is fixed above water level, it shall have to be primed before it can work or else, it should be a self-priming centrifugal pump. Centrifugal pump can be worked by mechanical power or electric power. It is simple, reliable and economical. For details of this pump, the reader may refer ‘Fundamental Hydraulics Vol. II’ by the author.

13. Wind mill: From canals, water can be pumped up by a wind mill. A wind mill utilizes wind power and essentially consists of a steel trestle fixed on the bank of canal, with a big diameter vane-wheel at its top and a plunger type reciprocating pump at its bottom. The upper end of plunger rod is fixed eccentrically to the vane wheel. To the base of plunger pump, is connected a suction pipe with
its far end dipping below canal water; a delivery pipe rising from top of pump goes to an over-head steel reservoir in which the lifted (i.e. pumped) water is first stored and is then used as and when required. When a strong wind blows, it turns the vane wheel (round and round) which works the pump and the water gets lifted up. When wind is feeble,
Wind mill will not work. Wind mill therefore will work in high velocity wind areas like those in Saurashtra (Gujarat State), Belgaum and Dharwar (Mysore State), Coimbatore district (Madras State), Jodhpur (Rajasthan State), etc. The minimum economical velocity of wind to work a wind mill economically is about 15 miles (24 km) per hour. Wind mill pumping is costlier than most other water lifting methods excepting those where the animal power is utilized to lift water. Wind mill also requires constant attention and necessary repairs when it goes out of order. As its lifting capacity is less, it is economically feasible for irrigating costly garden crops and where the lift is not much.

Wind mill can also be used for providing cheap electric power in rural areas for domestic use and small scale industries. A low-cost wind mill is being evolved by the Wind Power Sub-Committee of the Council of Scientific and Industrial Research, India. Rupees 70 million project for the installation of about 25000 wind mills in wind-swept areas of India was planned under the Second Five Year Plan. Ambitious scheme has been outlined for the Third Five Year Plan also. A pilot project, with about 200 such wind mills, was proposed to be launched throughout the country preparatory to the undertaking of the full-scale programme in the Third Five Year Plan.

14. Air lift pump: This may be used for lifting water from deep open wells and the tube wells upto depth of 90 m (400') or so. Its efficiency is, however, very low and it is therefore not much used. It consists of a delivery pipe (also called education pipe), some appreciable length of which should be submerged below water level in the well; in addition, there is an air pipe with cross section area about 15 to 20 % of that of the water (or delivery) pipe; the lower end of air pipe terminates in a nozzle which just enters the lower end of vertical water pipe. Compressed air from the compressed air machine is allowed to go down this air pipe and issue out, from the nozzle, in the water at the bottom of water pipe. As the compressed air gets incorporated in water inside the water pipe, density of this water gets reduced more and more and hence, the water column in water pipe
rises more and more (above water level outside the water pipe) till water inside the water pipe comes out of a dis-

![Diagram of an air lift pump](image)

Air lift pump

Fig. 119

charging spout at its top. Air lift pump can handle water of any quality say, water having much debris in it.
CHAPTER XV

BANDHARA IRRIGATION

1. Introductory: Bandhara irrigation is, in essence, a diversion irrigation scheme on non-perennial streams. A bandhara or dharan is a masonry diversion weir of small height generally 1·2 to 4·5 m (4' to 15') constructed across a nalla or a small stream and its tributaries for diverting the water of nalla or stream or its tributaries into a small main canal taking off from the upstream side of bandhara. It is the cheapest and most economical type of irrigation and has been in vogue in the districts of Nasik, Khandesh and northern parts of Poona district from the pre-British period. Over one stream, there may be a series of bandharas one below the other. Thus the water from isolated small catchments, which cannot be economically included in large irrigation schemes, is profitably utilized. In Nasik district alone, there are over 300 bandharas. Area irrigated from water diverted by one bandhara in Nasik district ranges from a few acres to as many as 800 acres (325 ha). This type of irrigation is successful in places where there are a number of small size streams that have sufficient flow in monsoon and up to the end of January. There is a primary need, in some area, of securing protection to kharif and rabi crops against failure due to deficiency of rains and this can very well be satisfied by bandhara irrigation. If the flow of stream be perennial, some portion of the irrigated area can be brought under sugarcane or other perennial crops also.

2. Site of bandhara: The success of bandhara irrigation depends mainly on the selection of suitable site for bandhara. The main points to be attended to, in the selection of its site, are:

(a) The site should preferably be below the confluence of tributary and main stream so as to have good supply of water and very few cross drainage works.

(b) If possible, the site should be just on the upstream side of steep bed-slope in the stream.

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(c) It should be within a reasonable distance from the irrigated area.

(d) Hard and sound rock foundation should be available at stream bed level or slightly below the bed, at the site of bandhara.

(e) At site, the natural banks of stream should be high enough to avoid any submergence of marginal land during floods because the flood water overflows natural banks if they are low.

(f) The supply of water at the site should be dependable as regards its quantity and duration.

(g) The cost of construction should be about Rs. 150/- or less per acre of the irrigated area; otherwise, the scheme will not be economically feasible.

3. Form and design of bandhara: (fig. 120): The form or profile of a bandhara is rectangular if it is very

low or, trapezoidal if it is fairly high. The trapezoidal cross section has its upstream face vertical and there is a batter on the downstream face as required from the stability point of view. The crest width may be sufficient from stability point of view and may be wide enough to be used as roadway during fair weather. During floods, the surplus water
flows over its entire length; the discharge formula for a bandhara is as for a broad-crested weir, viz.,

\[ Q = CLH^{3/2} \text{ c.ft/sec, neglecting the velocity of approach} \]

where, \( Q \) = High flood discharge in cusecs.

\( C = \) Weir coefficient; \( C = 3 \) for flat topped broad-crested weir as a bandhara usually is.

\( L = \) Length of bandhara, in feet.

\( H = \) Maximum flood depth, in feet, on weir crest.

This depth should be kept as low as practicable.

*Note:* In Metric system, \( Q = 1.65 LH^{3/2} \) cumeecs.

Weir wall should satisfy the usual conditions of stability, taking uplift into account if it is present.

Just at the end of a bandhara (fig. 121) and near the main canal offtake point, a small sluice to work as weir scouring sluice is provided for keeping the stream bed, just in front of the offtake point, free from silt deposit. At the other end of weir, there is a flank wall keyed into the bank of stream and with its top about 0.3 m (1') above the upstream H.F.L. At the main canal side of bandhara, there is a masonry screening wall (going upstream) at right angles to the bandhara alignment; top of this wall is kept about 0.3 m (1') above the upstream H.F.L. so that the upstream flood water may not out-flank bandhara and enter the main canal. From the upstream end of this screening wall, starts a flood embankment (for some distance further upstream) to confine the flood water in the stream.
From the offtake point, starts the main canal; for some distance downstream of the offtake point, the main canal has a masonry rectangular cross section. The side wall on the right side of this masonry channel is called lining wall and it has its top above the downstream H.F.L. in stream so that the downstream flood water may not enter the canal.

Index plan of bandhara irrigation scheme
Fig. 122

There may be a canal scouring sluice (in form of a small hole) in the lining wall to keep the masonry canal trough free from silt deposit. At the end of this masonry canal trough, is the main canal head regulator which is like a non-modular sluice type irrigation outlet of major irrigation scheme and is controlled by a steel or wooden shutter like the above-said irrigation outlet.
4. **Irrigation channels and canal masonry works:**
The main canal is of small size and is aligned, on falling contour, like the main canal in storage irrigation scheme as is shown in figures 122 and 123; thus, it forms the boundary of irrigated area which will be between it and the stream. The minimum full supply discharge of main canal should be 2 cusecs (57 lit/sec). The cross drainage works are very crude and small road culverts are constructed where a cart track cuts the alignment of main canal. Scouring sluices and surplus escapes are provided at required points along the length of main canal. Water from main canal is taken to the fields by baras (i.e. temporary or katcha outlets) which are provided at suitable places along the length of main canal. In some cases, when the main canal is of fairly big size and the
irrigated area is wide enough, a distributary may be taken from the main canal. In the area of their location, these irrigation channels are doing a very good service during the food shortage periods. The improvement in bandhara irrigation works consists in providing regulators, scouring sluices, cross drainage works etc. of better design. Also, the alignment and the design of channels require some improvement.

5. Phad system of irrigation: The system of irrigation prevalent in areas served by some bandharas is known as phad system of irrigation. According to this system the irrigated area, which is called 'Thal', is divided into 3 or 4 parts called the 'phads'. Hedge lines demarcate the boundaries of these phads. Each phad has a number of agricultural plots in it belonging to different irrigators of the same village; these individual fields are demarcated by boundary stones. In one year, only one kind of crop is raised in all the plots of one phad. Thus, suppose phad No. 1 is decided to be under sugarcane, then all the plots in it will have nothing but sugarcane on them. Similarly, all the plots of phad No. 2 may be under wheat and so on. The various crops grown in the entire thal are raised on each phad, by rotation among all the phads of thal. One or two guards are appointed by villagers to look after the whole thal; also, a water-distribution man known as patkari is appointed to release water from irrigation channels to the individual fields according to a fixed schedule of turns prepared by him in consultation with the villagers. Under the phad system, irrigation assessment is fixed and it consists of both the irrigation water rate and the land tax. Such irrigation assessment is also called the composite assessment or consolidated assessment. This assessment is compulsorily to be paid to the government whether land is actually irrigated by the irrigator or not. Such a step ensures the use of water on entire irrigable area under the command of main canal.

6. Maintenance of irrigation works in bandhara irrigation: When bandhara and its allied works are completed, the responsibility of P.W.D. is over. Irrigators have
to maintain the irrigation works by ordinary repairs etc., when required, to keep the works in proper working order. If any special and major repairs are to be done, the same are executed by P.W.D., on a request by villagers. P.W.D. undertakes such repairs only when the villagers deposit, with P.W.D., one-third of the probable cost of such repairs.

7. Advantages and disadvantages of bandhara irrigation: Such minor irrigation works are doing a very great help, now-a-days, to tide over the present food shortage in India. The irrigated area is compact, irrigation is intense and the transit losses are less, all factors resulting in high duty of water. The water of small catchment, which would otherwise run to waste, is fruitfully utilized. The only major disadvantage is that the irrigated area is fixed; hence, even though (in some year) there may be more water available, it cannot be utilized. Other disadvantage is the uncertainty of supply of water in the case of a bandhara across some small non-perennial nalla.
CHAPTER XVI

INUNDATION IRRIGATION

1. Introductory: This chapter deals with the inundation irrigation which is mainly practised from perennial alluvial rivers in Sind, Punjab and Egypt. It is possible only at certain sites of river which runs on ridge. Flood irrigation is also called basin system of agriculture. In Egypt, it is called flood irrigation. There are no head works across river but the flood water is guided to the fields by means of canal system. It is practised during a certain period (in a year) known as the inundation season which, in Sind and Punjab, starts by about 1st May and ends by about 15th October. During this period, there is much rise in water level above the fair weather water level in river. As there are no head works across river,

![Diagram of Head of inundation main canal](image)

**Fig. 124**

the supply of water in the inundation main canal depends on water level in the river. In the main canal, water will be available only for that period (called inundation season) during which the water level in river is above the bed level of inundation main canal at its offtake point from the river. Kharif crops like rice, bajri, jowar, cotton, etc. are raised on the available water in the canal system. In some cases
(as is usual in Punjab and to some extent in Sind), some fallow land is flooded with water, by the end of inundation season, for raising on it some rabi crops like wheat; as there will be no water in the canal system after the middle of October, subsequent waterings required by rabi crops are given from open wells on the cultivated land. Some lift irrigation is practised from the head reach of main canal and also from other irrigation channels, specially at the beginning and the end of inundation season because then, water is available in irrigation channels at very low level and has to be lifted up. The usual appliance used for lifting this water is called 'Hurlo' which is a type of Persian wheel.

2. Head of the main inundation canal: There is no head regulator at the outtake point of main canal near river bank; only, an open cut is given in the river bank to allow river water to flow into the main canal as shown in fig. 124. The bed level of this cut is much above the deepest river bed at that site, as shown in the figure. The selection of outtake point (or the head) of main canal is very important because on this depends the success or failure of the inundation canal system. The main points to be considered while selecting the site for head of main canal are:

(a) Nearness to the irrigated area.

(b) At the site of head, river course should be straight, river bed and banks should be stable and unerodable and the natural banks should be fairly high. At the site, the river should have normal width, normal velocity of current and the low range of variation of water levels. If the river-reach at the site is not straight, it may have a gentle curve; in such case, the head of main canal should be on the convex side of curve to avoid silt trouble in the head reach of main canal.

(c) The best site for the head of main canal is on a bypass (or creek) of river if one such is available near the irrigated area. The head, in such case, is located just near the point (on creek) where the creek flows back into river. With such location (shown in fig. 125), there will be less silt trouble in the head reach of main canal because the velocity of water in creek will usually be equal to or slightly greater than that
which is to be given to water in the main canal. In short, the choice of site, angle of offtake and the level of intake sill near river bank will have to be carefully planned.

![Diagram](image)

**Head of inundation main canal**

**Fig. 125**

At the end of head-reach of main canal, a regulator called *flood* regulator is usually provided; it is a few miles downstream of the offtake point (i.e. head) of main canal so that it may not be washed away by floods when the river is in spate during inundation season. A canal escape is provided just on the upstream side of this regulator; through this escape surplus flood water, during the closure of flood regulator, will be disposed off into the river via a lead channel. Sometimes, an offtake channel (i.e. branch canal or distributary) also takes off from the upstream side of this flood regulator. The *main* function of this regulator, as its name implies, is to prevent heavy river floods from entering the main canal when river is in spate. The head reach (i.e. the open cut from head of main canal to the flood regulator) of main canal remains submerged during floods. The other
function of this regulator is to regulate the flow of whatever water is available on its upstream side. The regulator (shown in fig. 126) is provided with vertical lift gates in tiers so as to exclude heavy bed silt from entering the main canal as far as practicable. Along the alignment of flood regulator, flood embankments are provided parallel to river course to confine river flood which would otherwise interfere with the working of main canal. After some time, the head reach gets silted up so badly that sufficient water does not flow through it to the flood regulator. In such case, a new head reach is excavated from the regulator to the river, meeting the river at some other offtake point.

3. Irrigation channels: F.S.L. of main canal is fixed at a level which is called fair-irrigating level i.e., that level at which the water in river is more or less steady for a certain maximum number of days (about 40 to 50 days) during inundation season. Canal bed level at the offtake point should be as low as practicable to take advantage of river water for as much more period as practicable. After fixing these two levels, F.S.D. = F.S.L. − C.B.L. Knowing the F.S.Q. of main canal and fixing the suitable bed slope, bed width of canal is calculated. The cross section of canal is kept liberal where rabi crops are also to be watered while kharif crops are yet standing on the irrigated land. The cross section is also to be made rather extravagant because
the time-factor in inundation irrigation is very low and uncertain and the water supply cannot be much relied upon. In designing the cross section of channel, the idea, 'Make hay while the Sun shines', is to some extent kept in view by the designer. Inundation main canal is deeper and narrower (i.e. B/D ratio is small) as compared to a canal of other irrigation schemes where there are head works across river to control water level in the river. Main canal as well as other channels are tortuous and hence, the silting problem is acute along their lengths too. The silt problem, as already said, is serious in the head reach of main canal. Every year, after the end of inundation season, clearance of silt-deposit in irrigation channels is done so that they may be fit for use during the next inundation season. On many occasions, irrigation channels (i.e. branch canals and distributaries) are fed on rotation system as the water supply from river is variable and unreliable. This fact is kept in view while designing these channels.

4. Advantages and disadvantages of inundation irrigation: The main advantage is that as there are no costly head works across river, this type of irrigation is cheap; also, the water has more manurial properties because it carries fine silt in suspension to the fields. The disadvantages are, however, many; some of these are as follows:

(a) The supply of water is variable and unreliable; hence, there is always cry for water and there is dissatisfaction amongst the irrigators (sometimes resulting in fights amongst them) usually at the beginning and at the end of inundation season.

(b) Due to variable and uncertain supply, the cross sections of channels are made liberal and extravagant; also, there is lavish use of water when it is available in plenty in the canals, thus resulting in low duty of water.

(c) Due to constant silt trouble, there is a recurring expense on silt-clearance of the channels.

(d) Due to bad and tortuous alignment of channels, they do not function satisfactorily. There occur silting and scour at curves which are in plenty on these channels.
(e) Due to frequent water rotation on the channels, many irregularities are usually committed by some of the irrigators and the low-paid P.W.D. staff. There is more likelihood of malpractices at the beginning and at the end of inundation season when every irrigator desires to have water which is actually in short supply then. The irregularities are all the more because, due to the variable supply, the irrigation outlets are non-modular in majority of cases.

(f) As there are no head works across river, the river may change its course, thus either leaving the head reach of main canal dry or washing away the head reach and the flood-regulator.

Due to many disadvantages, some of the inundation canals are being converted into the perennial ones by the construction of suitable head works across river at suitable sites near the offtake points of the existing inundation main canals. Also, the inundation canal systems are being remodelled.
CHAPTER XVII

SOIL MOISTURE AND THE MODES OF IRRIGATION

1. Introductory: Every agricultural soil is essentially porous and the voids exist between its constituent particles. In these voids, there may be air, moisture (i.e. water) or both. Porosity of a soil depends on the size and gradation of its constituent particles; this size and gradation is called the texture of soil. Soil texture also refers to the relative amounts of sand, silt and clay present in a soil. The manner in which these particles are arranged in groups (i.e. clusters) is known as the structure of soil. Granular structure is best for plant growth. Soil structure affects plant growth more than any other physical property of the soil does. The good structure (i.e. the good arrangement of soil particles in relation to one another) is called good tilth of soil. This tilth can be maintained by carefully hoeing and loosenning a soil; this is necessary because when soil is in good tilth, evaporation loss from the surface of soil is less, soil becomes properly aerated and hence, the yield of crop is also better.

2. Soil moisture: Following are the kinds of soil moisture present in the voids between soil particles:

   (a) Hygroscopic moisture.
   (b) Capillary moisture.
   (c) Gravitational (or Free) moisture.

If a sample of soil is put in a laboratory-oven, the temperature of the oven raised to 105°C and maintained there for some time, all the moisture of the soil will be driven out due to this protracted heat. The sample is then called an oven-dry sample and it does not contain any moisture whatsoever in it. When this oven-dry sample is taken out of the oven and is exposed to atmosphere, it will at once take up a certain amount of moisture from the atmosphere. This amount of moisture, now present in the soil sample, is known
as *hygroscopic moisture* and it exists in the form of a very thin film of moisture around the particles of soil sample. Even the sunshine at ordinary temperature cannot remove this moisture present in the soil sample. It is only the protracted heat in oven that can relieve the soil particles of this hygroscopic moisture. This moisture has an appreciable effect on the cohesion of soils.

If a little water is added to an *air-dry* soil sample (i.e. that soil sample which has got only hygroscopic moisture in it), it will be held in the voids between soil particles, due to surface tension. This moisture added to the air-dry soil sample is called *capillary* moisture. On adding still more water, *slowly and gradually*, a time will come after which any more addition of water cannot be retained by the soil in its voids and, if added, it will simply flow down freely from the soil sample. At this instant, the soil sample is said to have *maximum capillary moisture* in it. The capillary moisture in a soil can move up, down and sideways (by capillary action) to any region of soil which is comparatively dry. If water in a *sufficient* quantity is added to an air-dry sample, some of this water will be held in soil-voids to the extent of maximum capillary capacity of soil sample; any water over and above this quantity will flow down from the soil sample, obeying the law of gravity. Such water is therefore known as *gravitational* moisture or *free* moisture. In soils, in the crust of earth, this gravitational moisture goes down to the lower layers of subsoil and after saturating them in turn to their maximum capillary capacity, the balance joins the ground water table and raises its level. Gravitational moisture obeys the laws of hydraulics while flowing *laterally* through soil.

It is the capillary moisture that is useful for plant growth. However, all the capillary moisture is not available for plant growth; it has been found that when a *very little* moisture is added to an air-dry sample, it is not available for plant growth as the plant-roots are not able to suck it from soil. This condition obtains till the moisture equivalent to about 50% of the hygroscopic moisture has been added to the air-dry sample. Any moisture, in the soil, over and above that represented by about 1½ times the hygroscopic moisture, can be used by plants. The moisture content in
soil above which water is available for plant growth, is called *wilting coefficient*. All the above-said moistures are shown, in the following table, for some of the soils; the moistures are shown as percentages of the weight of an oven-dry sample.

<table>
<thead>
<tr>
<th>Type of soil</th>
<th>Hygroscopic moisture expressed as %</th>
<th>Wilting coefficient expressed as %</th>
<th>Maximum capillary capacity expressed as %</th>
<th>Available capacity (i.e. when voids are full) expressed as %</th>
<th>Total capacity expressed as %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse sand</td>
<td>1.0</td>
<td>1.5</td>
<td>13.0</td>
<td>11.5</td>
<td>33.0</td>
</tr>
<tr>
<td>Fine sand</td>
<td>2.1</td>
<td>3.3</td>
<td>14.0</td>
<td>10.7</td>
<td>34.0</td>
</tr>
<tr>
<td>Loam</td>
<td>9.1</td>
<td>13.4</td>
<td>18.0</td>
<td>4.6</td>
<td>38.0</td>
</tr>
<tr>
<td>Clay</td>
<td>13.2</td>
<td>16.5</td>
<td>20.0</td>
<td>3.5</td>
<td>42.0</td>
</tr>
</tbody>
</table>

The various moistures are shown on line diagram in fig. 127. The moisture in the *root-zone* of soil should always be above that represented by wilting coefficient of the soil because, when the moisture gets depleted to the wilting coefficient, the plant-roots have no *available* capillary moisture to fall upon and hence, the plants show signs of wilting or withering. The moisture in root zone should also not be above the point of maximum capillary capacity as then it cannot be retained by soil and it will unnecessarily run to
waste to the water table below. It has been found that when about 40 of 60% of the voids of most of soils are full of water and there is air in the balance of void space, plant growth is rapid and healthy. Such moisture content in the root zone of soil is therefore called the ideal or optimum moisture in the soil. The function of irrigation is to give to the agricultural land this optimum water supply and maintain the optimum moisture in the agricultural soil as far as practicable. This moisture forms about 70% of the total capillary moisture. Approximately 90% of crops have their roots in the first foot of the soil below ground level. For most crops, however, the soil may be kept moist to a depth of about 0.6 m (2′), by irrigation.

3. Preparation of raw land for irrigation: Before irrigation water is actually applied on a raw (i.e. that which has not been irrigated before) land, this land has to be properly prepared. This preparation consists of the following operations:

(a) Clearing the jungle, if any, including the grubbing of roots.

(b) Smoothening (i.e. making even) the land by destroying high patches and filling in the depressions as otherwise the application of water on the land will be uneven, resulting in the waste of water also.

(c) Giving necessary slope to the surface of land in the required direction, making the plots of suitable size (by means of small earth banks) and excavating subsidiary water courses or field ditches for proper distribution of water over the entire land. This operation should suit the method of application of water which depends on local conditions, soil and the plants to be raised.

4. Suitability of soils for irrigation: All soils are not suitable for irrigation. Following points are usually considered to know the suitability of soil for irrigation.

(i) Proper conveyance and distribution of water on soil.

(ii) Physical properties of soil.

(iii) Chemical contents of the soil.
The soil should be examined to find out if the water can by conveyed properly and the flow on it can be controlled easily. For this, the topography of soil should be convenient and suitable.

The soil should not contain excessive quantity of sand or clay; it should not be prone to easy water-logging. It should be such as can be easily drained.

The soil should contain sufficient fertilizing chemicals so that the cost of supplying artificial fertilizers is less. The soil should not contain excessive amount of soluble salts or else, it may become alkaline.

5. Methods or Modes of irrigation (or Modes of applying water on land): The three methods of irrigation are:

(a) Sub-surface irrigation.
(b) Surface irrigation.
(c) Sprinkler irrigation.

In sub-surface irrigation, water is supplied directly to the root zone of plants by a system of underground pipes laid (below the land) with their joints open. Water, running through these pipes, comes out through the open joints and keeps the root zone moist. This method entails less loss of water (due to evaporation and absorption) but as it is expensive and gives less yield of crops, it is quite uncommon.

The universal method of irrigation is the surface irrigation and it has the following sub-types; the method to be adopted depends on crop, soil, topography and water supply available:

(I) Flooding method (of irrigation).
(II) Furrow method: (fig. 129).
(III) Corrugation (or Zigzag) method: (fig. 130).
(IV) Basin method: (fig. 131).

Flooding method and furrow method are more common than other methods.

In the flooding method, a certain depth (in inches) of water is put on land. In this method again there may be,
(i) Free flooding method:
(ii) Border method: (fig. 128).

Free flooding method is quite common in India. In this, the land is divided into suitable-size oblong plots, by ridging; each plot is practically level; water is admitted at the higher or upstream end of plot and when water reaches its downstream or lower end of plot, the supply of water is cut off.

**Main water course**

![Main water course diagram]

**Border method of irrigation**

*Fig. 128*

**Main water course**

![Main water course diagram]

**Furrow method of irrigation**

*Fig. 129*

In the border method, land is levelled and divided by 0.3 m (1') high bunds of field ditches into a number of long and narrow strips. Water is allowed at the head or
upper end of each strip and it flows along the strip, in form of a thin 5 to 7.5 cm (2" to 3") sheet of water, to the lower end of the strip as shown in fig. 128.

The furrow method is usually useful for crops which are planted in rows e.g. onions, chillies, etc. In this method, a number of furrows (with their beds practically level) are laid out on the land with a plot between every two furrows, as shown in fig. 129. These furrows (i.e. very small ditches) are filled with water from the subsidiary water courses. The water of two neighbouring furrows percolates from their beds and sides and thus saturates the root zone of plot between the two furrows. The roots of plants raised on this plot take this moisture which has come, by percolation, from the furrows.

![Corrugation method of irrigation](image)

Corrugation method of irrigation

Fig. 130

In the corrugation method (fig. 130), on each oblong plot, are constructed small earth ridges to serve as baffle walls to the water admitted at the upper end of plot. The water takes a circuitous path along the plot and when it reaches the lower end of the plot, the supply is cut off. It is most suitable for practically level plots.

In basin method, a basin is excavated round a plant as shown in fig. 131; this basin is filled with water which percolates gradually to the root zone. This method is often adopted for orchards.

In sprinkler irrigation, the sprinkling device showers water on the agricultural land in the form of fine spray, very
similar to rain. Each crop can be provided with the necessary amount of irrigation water as and when required, through the sprinkler. A sprinkler system usually consists of: (i) a pumping plant to create pressure and velocity in water (ii) pipe lines for carrying irrigation water from the source of supply to the field (iii) sprinkler or sprinkling device for sprinkling water. The sprinkling device has perforations or nozzles through which water is sprayed out at high velocity created by pumping plant. There are a few types of sprinkler devices. The initial cost of installation and the cost of operation and maintenance of sprinkler system are rather high, as compared to the outlay on the usual surface methods of irrigation. Hence the sprinkler irrigation is in use for only nurseries, vegetables and cash crops which fetch high prices. However, this type of irrigation is the only alternative where water is scarce and expensive. In India, it has many points to recommend itself. This type of irrigation can be adapted to both the light soils and heavy soils.

![Diagram of Basin method of irrigation](image)

**Fig. 131**

The advantages of sprinkler irrigation are:

(i) The waste of water on the field can be greatly reduced. Hence the utilization of water by crops can be greatly raised.
(ii) Erosion, salination and water-logging of agricultural soil, which are usually caused by surface methods of irrigation, can be prevented.

(iii) Water on the field can be fruitfully and economically used and this is very important.

(iv) Output of crops can be increased because of intelligent use of water.

It is advisable that the irrigation engineers in India think as seriously about adopting sprinkler irrigation as their counterparts have done in Israel and elsewhere. It has however to be seen that, for economic feasibility, the sprinkler system is operated continuously and this further assumes that the water supply is continuous and not intermittent.
CHAPTER XVIII

OPERATION AND MAINTENANCE OF IRRIGATION WORKS

1. Introductory: In this chapter will be described the items pertaining to the operation and maintenance of irrigation works and also a few miscellaneous items. The items of the first category treated here are:

(a) Administration or Personnel.
(b) Economy of water.
(c) Operation and maintenance of irrigation works including their repairs.
(d) Irrigation water rates (or the methods of irrigation water assessment).

The items treated under the second category are:

(i) Block system of irrigation.
(ii) Irrigation projects.

2. Administration: In India there are 79 million acres \((32 \times 10^6 \text{ ha})\) of land under irrigation of which nearly 50\% land is irrigated by the State-owned irrigation works. The rest is irrigated by minor irrigation works owned privately. The minor works have been built privately by the people in their constant struggle against famine, draught and vagaries of monsoon.

In India, a good personnel is maintained by irrigation department to look after the design, construction, operation and maintenance of irrigation works. Every State in India has got its own irrigation department which is a main part of the Public Works Department (i.e. P.W.D.). The irrigation department of a State is controlled by one or more Chief Engineers who are the administrative heads of the department. Each Chief Engineer (i.e. C.E.) has a few Superintending Engineers (i.e. S.Es.) under him. Superintending Engineer is the administrative head of a portion of the irri-
Irrigation department called Circle. In each Circle, there are a few Divisions. Each division is controlled by an Executive Engineer (i.e. E.E.) or a Divisional Engineer (i.e. D.E.). Each Executive Engineer has few Sub-divisional Officers or Assistant Engineers under him. Each such S.D.O. or A.E. looks after one Sub-division of the Division. Each S.D.O. has a few overseers, sub-overseers, mistries and some lower establishment under him. Each overseer or sub-overseer is in charge of a portion of canal system and the connected irrigation works or, a portion of head works. The jurisdiction of engineering staff of irrigation department is upto the heads of water courses. Below irrigation outlets, the irrigators’ jurisdiction starts.

3. Economy of irrigation water: By now, it is clear that irrigation water is made available from the source, at a very great cost; hence, every cusec of it should be used most economically. In fact, extravagance — whether of water or of money — will threaten the economy of any undertaking. Whatever waste is unavoidable, cannot however be helped; but, whatever waste can be avoided, should deserve the careful consideration of both the supervisory engineering staff of irrigation department and the irrigators. The staff should enforce such methods of regulation and distribution of water as ensure the maximum possible economy of water. Further, the irrigators should be trained and advised to be most economical. Each cusec of irrigation water, that is secured at an appreciable cost, will be a national waste if it is not properly used. Where practicable, the water courses may be lined; also the agricultural land should be divided into small plots for the economical application of irrigation water. The irrigators should use the better and scientific methods of irrigation and cultivation to cut down the criminal waste of water-gold brought with great pains, to the fields, by the irrigation engineer. Let all concerned bear in mind the saying: “Waste not water, want not food.”

4. Operation and maintenance of irrigation works: All irrigation works, after construction, should be maintained in the first class condition by frequent supervision, examination and necessary repairs. Some works, if found
not working satisfactorily, may require remodelling. All the irrigation channels should work efficiency so that,

(a) the lands at their tail get their due share of water; supply by rotation may often become necessary to run the canals at their F.S.Q. as far as practicable;
(b) there is efficient and economical distribution of water;
(c) there is no net scour or silting.

Causes of the defects in works, if any, should be found out and the defects should be rectified at an early date. The cross section of channel should be properly maintained. Weed growth, if any, should be removed periodically. No undesirable vegetal growth should be allowed to grow within canal boundaries. The discharges of government channels should be taken with velocity rods or some other appliance once or twice a week and of water courses at least once or twice in each crop season. The gauge readings and the discharges should be entered regularly in the registers to form a permanent record of the working of these channels. No private traffic should be allowed to use canal paths, except when such traffic is specially authorized by competent authority.

All masonry works should be inspected regularly and the defects, if any, should be immediately remedied. Steel work of these structures should be regularly painted. All the working or moving parts of these structures (e.g. gates etc.) should be kept in good working order and should be kept properly oiled or greased. The protective aprons of the structures should be carefully inspected and maintained in good condition.

It will be of great interest to an irrigation engineer to keep a record of observations about the following:

(i) Rainfall in the catchment of a scheme in his charge.
(ii) Yield of this catchment, and also H.F.Q.
(iii) Any other miscellaneous hydrographic surveys of utility e.g. flood hydrographs, etc.
(iv) Sedimentation of reservoirs in his charge.
(v) Siltling of irrigation channels in his jurisdiction.
(vi) Percolation and seepage through and under the irrigation works in his charge.

(vii) Water levels in open well in his jurisdiction.

(viii) Water-logging and salt efflorescence, if any.

(ix) Area actually irrigated from the available water; also, the condition and the yield of crops irrigated by the available water.

(x) The working (satisfactory or otherwise) of all the irrigation works in his jurisdiction.

These records are of immense use in the proper design and maintenance of the irrigation works.

5. Irrigation assessment: Irrigation water is made available by government to irrigators and hence, the government takes from the irrigators some charge for this facility provided to them. This charge is called irrigation assessment or irrigation revenue. It consists of,

(a) Irrigation water rate and,

(b) Land rate or Land tax.

Land tax is a charge on the extent of irrigated land owned by an owner and is charged from owner of the land because the value and utility of his land has increased after it has been served by the canal system introduced by the government.

Irrigation water rate is a charge for the use of irrigation water only and is taken from irrigator (i.e. cultivator) who may or may not be different from owner of the irrigated land. Irrigation rate takes the following usual forms:

(i) Crop rate.

(ii) Volumetric rate.

(iii) Seasonal rate.

Crop rate is most prevalent in India. The irrigated area is visited by a responsible official of Revenue Department or P.W.D. (according to the practice prevalent in a particular State in India) who assesses the area on which crop actually stands. This area may be the same as that irrigated or may be less than that. It becomes less when, in some cases, due to unavoidable circumstances the crop fails
on a portion of the irrigated area; in such cases, the area assessed is equal to the area irrigated minus the area remitted and the irrigator is said to have been granted remission for the remitted area (i.e. that area on which the crop has failed due to no fault on the part of irrigator). The crop rate is charged on this assessed area at the rate of so many rupees per acre of the successful crop on this area; it thus varies from crop to crop, being more for that crop which requires more water for its growth. Crop rate also varies from State to State and it may even vary from canal system to canal system in the same State according to the relative facilities provided by the canal systems. Crop rate will be less for lift irrigation than for flow irrigation from canals. Crop rate is more for that crop which has greater market value. The disadvantage of crop rate is that it penalises careful husbandry and this results in the water courses not being kept in good condition by irrigators. However, as it is easily understood by the irrigators in India, it is most common in all the States of India.

Volumetric rate is levied according to the actual volume of water supplied to irrigators. It has many advantages, main one being the economical use of water; but, as it is not appreciated by the Indian irrigators, it is not common in India. The water is given by volume through,

(i) Venturi meter.
(ii) Modular outlet.

Venturi meter at the head of water course is however not suitable for the water carrying much silt; it also entails greater loss of head and is costly.

Modular outlets are used for equitable distribution of water; for this use only they are used in India. They can however give water by volume and hence, they can be used when the irrigation rates are charged on volumetric basis; for this purpose, however, they are not used in India.

The only disadvantage of charge on volumetric basis is that irrigators near the head of water course are more benefitted as compared to those at the tail of water course; because there will be transit losses of water in the water
course and the irrigator at tail will get much less than one cusec when this one cusec is released at the head of water course. He will however be charged for the water released at the head of water course like any other irrigator elsewhere along the alignment of this water course.

In some States, on some irrigation schemes, irrigation rate is charged for a particular season and is, hence, known as seasonal rate. It takes into consideration the kinds of crops grown in that season, the value of these crops and the water used by these crops. It is an overall rate for all the crops of a season and is charged as so many rupees per acre of the land under the crops of that season. It is therefore different for different seasons.

In some States, on a few irrigation schemes, irrigation water rate and land rate are not charged separately but a combined charge is levied for both. Such a charge is called consolidated rate or composite rate.

In general, the irrigation water rates should provide for,

(i) Interest on the cost of irrigation works.
(ii) Charges for the maintenance of these works.
(iii) Charge for the actual value of water supplied.

These rates should be reasonable so as to encourage the easy growth of irrigation works.

6. **Dr. M. Visvesvaraya's block system of irrigation:** This irrigation system is the development of phad system of irrigation and is prevalent on major canal systems of Bombay-Dccean and elsewhere in India. According to this system, the irrigators group themselves into blocks of land; each block is guaranteed, on the payment (by irrigators) of a certain through rate per every acre of the block, a fixed volume of water for a certain number of years. The internal distribution of the water supplied to a block is left to the irrigators of that block. If the irrigators want more water over and above their guaranteed quota, the same may be supplied to them if available but at different water rates known as the crop rates. Thus, the economy of water is effected and more land can be brought under cultivation.
Also, to some extent, the advantage of the volumetric distribution of water is achieved indirectly. In each block, the area allowed under sugarcane should be equal to or less than \( \frac{1}{3} \) of the area of block. The fixed supply of water to each block is given through Gibb's module. This system is indeed the best for Indian conditions where irrigators do not appreciate and accept the principle of (direct) volumetric rate.

This system was suggested to the Indian Irrigation Commission by M. Visvesvaraya when he was Executive Engineer in Bombay P.W.D., with head quarters at Poona. The Commission came to Poona on 20th December 1901 and asked about 358 questions from Visvesvaraya on the then existing irrigation practice in Bombay-Deccan and Gujarat; the Commission also invited suggestions from this excellent engineer to improve the then prevalent irrigation practice in Bombay-Deccan and Gujarat. One of the suggestions given by Visvesvaraya was this block system of irrigation. The Commission accepted the proposal of Visvesvaraya in toto and communicated its approval to the Government of India which in turn asked the Bombay Government to introduce this system on the canal systems in Bombay. As such, this system was first introduced by Visvesvaraya himself on Nira Left Bank canal in 1903. It gave very good results as so ably conceived by him. At present, this system is prevalent on many other major canal systems in Bombay-Deccan.

7. Irrigation projects: An irrigation project may be defined as a tough and constant fight of an irrigation engineer with that intractable element called water which is often esteemed as 'Jal-devata' (i.e. Water-god) by some Indians. The truth about this fight is that it does not end with the construction of irrigation works but exists as long as these works exist. An irrigation project may envisage the taming of mightiest of the mighty rivers. It envisages the construction of lofty and gigantic dams and the connected irrigation works. An irrigation engineer has therefore to be extraordinary careful. He should be highly realistic in his every approach to the varied problems that arise while he has to
deal with water. He is a *true and accomplished* irrigation engineer who,

(a) has reality, idealism, humour and sensitiveness in him in *proper proportions*;

(b) is highly learned in his science and *keeps himself uptodate* with the latest developments in his science;

(c) is unremitting in his toil;

(d) is true to the noble traditions of his profession and tries hard to keep them high;

(e) is highly rational and studies each problem carefully and minutely;

(f) comes out with a *definite* solution after taking all the factors (general and local) into consideration and does not entertain any prejudice in arriving at his conclusions;

(g) is healthy, stout-hearted and square-shouldered. And last but not be least,

(h) is just, kind-hearted, free from greed, envy and jealousy; and, *who firmly believes that the service of humanity is the highest service known to mankind*.

Such a personality can *indeed* give excellent irrigation projects that will exist after him for centuries and will benefit humanity at large.

Irrigation works are mostly owned by government as they are costly; there may, as already said, be a few private works which are quite cheap. The government schemes may be either productive or protective. The productive scheme fetches a good revenue to the government; but, the primary object of a protective scheme is to protect the area, served by it, from the recurring famines. Such schemes are also necessary because otherwise the government has to incur a huge expense on relief measures *whenever* a famine occurs anywhere in its jurisdiction. A *realized* irrigation project has the following stages:
(a) Preliminary investigation of the project to know its general feasibility and rough cost.

(b) Detailed investigation and detailed design of the various irrigation works when the scheme has been found to be feasible.

(c) Preparation of detailed plans and estimates to find out the probable cost of the scheme. A report on the scheme is also prepared giving the details and main features etc. of the scheme.

(d) Construction of the irrigation works according to the detailed plans and specifications.

Investigation of a project is the most important stage because on its accuracy depends, to a large measure, the success of the scheme. The two main items to be investigated are:

(i) The water available.

(ii) The land proposed to be irrigated.

Hydrographic surveys are undertaken in connection with the first item. Contour surveys and soil surveys are necessary with regard to the second item.

The reliability of foundations of masonry structures has to be explored. The sources of materials of construction are to be located in the vicinity of works. It is to be found out whether the proposed command area is fit for irrigation, what crops can be profitably raised on it, what amount of water will be required by these crops and what system of regulation and distribution of water will give the best results. The allied problems of flood control, soil erosion, water-logging etc. should be given due consideration. If the scheme is a multi-purpose one, the inland navigation, water power generation, malaria control, fish culture etc. have to be given their proper weight in the whole scheme.

In fact, for a real success in the project connected with such huge quantities of water as in irrigation engineering, a great vision, foresight and correct judgement are the unfailing attributes of an irrigation engineer.
CHAPTER XIX

LAND RECLAMATION

1. Introductory: The words 'land reclamation' form a comprehensive phrase. Land reclamation is a process of making an unculturable land fit for cultivation; such an unculturable land is then said to have been reclaimed. Thus, a waste land under thick jungle, badly eroded land, alkaline (i.e. salt-affected) land and water-logged land can be made culturable by the methods of land reclamation. In this chapter, however, the land reclamation of only alkaline and water-logged agricultural lands, under irrigation, is treated.

2. Necessity of land reclamation: Some agricultural land, after being irrigated for some time, may become unproductive (i.e. infertile or unculturable) by being alkaline or water-logged. This may be due to over-irrigation and it also happens when the subsoil of land has no good drainage properties naturally. For reclaiming such infertile land, artificial drainage of the land has to be introduced in the first instance; then, suitable methods of reclamation are adopted.

3. Salt efflorescence: Every agricultural soil has certain mineral salts in it. Some of these are beneficial salts as they form the food of plants while the other are injurious as they hinder plant growth. Injurious salts are also called alkali salts and their common examples are NaCl, Na₂SO₄ and Na₂CO₃. These salts prove harmful when they are present, in excess, in the root zone of plants. Out of these three salts, Na₂CO₃ is most harmful and NaCl is least harmful; as such, comparatively greater quantity of NaCl can be tolerated by plants without themselves being adversely affected by this salt; similarly, comparatively less quantity of Na₂CO₃ is allowable in agricultural soils in order that it may not have
adverse effect on plants. $\text{Na}_2\text{CO}_3$ is sometimes called *black alkali*.

When these soluble alkali salts are in excess in a soil and further, the ground water table is very near ground (i.e. at a little distance below G.L.), the water from water table rises up by capillary action and brings with it the alkali salts in solution; water evaporates from the surface of land, leaving behind an accumulation of these salts, in patches, on the surface of land. This phenomenon of the salts coming up in solution and forming a thin (5 cm to 7.5 cm or, 2" to 3") crust on the surface after the evaporation of water is called *salt efflorescence*. While coming up, some salts also get deposited in the first 0.9 to 1.2 m (3 to 4 feet) of the soil layer below ground. This concentration of salts, when present in the root zone of any plant, has corroding effect on the roots with the result that the growth of the plant gets checked and the plant ultimately dies. Such a salt-affected soil is also known as *saline soil* and is unproductive i.e. it cannot support any plant life. Thus, saline soil has excessive total soluble alkali salts in it. These excessive salts should be removed early. If, however, the salt efflorescence is allowed to be on land for some time and the soil is clayey, a base exchange reaction may take place, thus *sodiumising* the clay, making it impermeable (and therefore ill-aerated) and highly unproductive. Soil is then known as *alkaline soil* and it is comparatively more difficult to reclaim it than reclaiming a mere saline soil. Alkaline soil is therefore a sodiumised soil and it has an excess of exchangeable sodium either with or without excessive total soluble salts. Reclamation becomes more and more difficult as the alkalinity (i.e. sodiumisation) of the soil increases with time.

In some cases, land may also become saline or alkaline when it is irrigated by alkaline irrigation water for some time.

**4. Reclamation of salt-affected land:** The following measures are adopted to reclaim salt-affected land:

(a) Adequate artificial drainage is provided to lower the ground water table below the limit of capillary action so that water cannot rise above the ground (by capillary
action). This limit, naturally, depends on the kind of soil; thus, in clay soils, ground water table should be lowered to a greater extent than in sandy soils. Both the surface drains and under (i.e. sub-surface) drains are to be provided for the efficiency of reclamation. Usually, the surface drains are open trapczoideal drains and the under drains are pipe drains; sometimes, deep open drains are used for under-drainage. Surface drains, constructed on land, will take away the excess irrigation water or rain water from the land and thus will not allow such water to percolate and raise the water table. Under-drains will lower the existing high water-table to safe limit. These drains will be described, at length, under ‘water-logging’ which is treated in subsequent articles.

(b) Then, the excess salts are leached from the top 0.9 to 1.2 m (3 to 4 feet) of soil to the ground water table, by flooding the land with certain depth of water. This water depth on land dissolves the deposited salts and the salts in solution percolate down and join the water table. Washing out of salts from the upper zone of soil by flooding is known as leaching process. Leaching process is continued for some time till the quantity of salts left in the root zone of soil is such as can be tolerated by some salt-resisting crops.

(c) When the amount of salts has been reduced to such a safe limit that they can be tolerated by suitable salt-resisting crops, such crops are grown on the land. Thus, in summer the coarse rice is grown and in winter the berseem or even gram may be grown. Rice and berseem can tolerate the alkali salts to a greater extent and they also give shade to the land, thus reducing evaporation from the surface of land. They are grown for one or two seasons till the alkalinity of soil is reduced to such an extent that the ordinary (i.e. not salt-resisting) crops like wheat, cotton-etc. can be grown. The land is then said to have been reclaimed i.e. on it, the common crops for which it is suitable can be grown. The time taken to reclaim a land depends on its degree of alkalinity; greater the alkalinity of land, more the time taken and vice versa. It also depends on the nature of alkali and, the texture, structure and permeability of the soil. Thus, NaCl and Na₂SO₄ can be comparatively more easily removed
than Na$_2$CO$_3$. Also coarser the texture of soil, more easily can the land be reclaimed.

(d) When Na$_2$CO$_3$ is present in a salt-affected soil, a chemical treatment is given to the soil before adopting leaching process. Powdered CaSO$_4$ (i.e. gypsum) at the rate of about one ton per acre is mixed intimately with soil in the presence of water. Na$_2$CO$_3$ is turned into Na$_2$SO$_4$ by a chemical reaction. Na$_2$SO$_4$ is then leached out as before; also, the suitable plants are grown as before to complete the land reclamation process.

(e) To reduce evaporation from the surface of land, such operations as manure-mulching, dry-mulching (by surface hoeing) are used sometimes, especially in bad cases where the water table is very near ground and much evaporation is feared. Mulch is a loose covering on the surface of soil. It usually consists of organic residue but it may be of loose soil produced by cultivation.

5. Prevention of lands from becoming salt affected: Prevention is better than cure; hence, preventive methods should invariably be adopted so that the agricultural land does not become salt-affected in the first instance. Such methods are:

(a) Using just the sufficient quantity of irrigation water for raising crops.

(b) Provision of adequate surface drainage on irrigated land.

(c) Allowing lower intensity of irrigation on the land that is likely to be salt-affected.

(d) Resorting to such methods of cultivation as help in retarding surface evaporation.

(e) Not using alkaline water for irrigation purposes.

6. Water-logging: An agricultural land is said to be water-logged when its productivity or fertility is affected by the high (i.e. near the ground) water table. The productivity of land becomes affected when the root zone of plants gets flooded with water and thus becomes ill-aerated. On such
land, ordinary crops cannot grow due to the lack of aeration and warmth in the soil; also, the normal cultivation operations like ploughing and mulching cannot be carried out in such wet soil; such a land can support only some water-loving (or aquatic) plants like grass, weeds etc. In some bad cases of water-logging, free water may be above the surface of land which then, in ordinary language, is said to be swampy land. Some alkaline lands become water-logged after some time if the water table is allowed to rise and no measures are taken to check its upward movement. Water-logging can be detected by the following indications or signs:

(a) When ground water table progressively rises and approaches the root zone, there results a temporary rise in the normal productivity or yield of land.

(b) Observations on the subsoil water level in open wells on irrigated area may be taken every year just at the end of each dry season. If there is a gradual and progressive rise in S.S.W.L. every year, it shows that the water table is gradually and progressively rising and the adjoining land may become water-logged in due course of time.

7. Causes of water-logging: Land becomes water-logged due to high water table which, in itself, is due to:

(a) Over-irrigation on the land, resulting in heavy percolation and the subsequent rise of water table.

(b) Seepage of irrigation water from adjoining high land to the subsoil of land (which becomes water-logged).

(c) Seepage of water through bed and sides of adjoining canals, reservoirs, tanks etc. which are at higher level than the water-logged land. This seepage is serious when soil at the site of canals, reservoirs, etc. is very porous.

(d) Inadequate surface drainage on land, resulting in the percolation of water and the subsequent rise of water table.

(e) Impervious obstruction in the path of laterally flowing subsoil water, causing the rise of water table on the upstream side of obstruction.
(f) Soils having no good natural drainage properties e.g. soils with clay substratum. Such soils therefore become water-logged soon.

8. Reclamation of water-logged land: Water-logged land can be made productive by providing efficient surface drainage and subsurface drainage; by providing this artificial drainage, the water table is lowered below root zone of plants. For most plants to grow, it is necessary that the water table should be lowered to at least 1.5 m (5 feet) below the surface of land. Surface drainage consists in constructing open surface drains of the required trapezoidal cross section to carry away surplus water from the surface of agricultural land. Sub-surface drainage consists in providing,

(a) Pipe (or Tile) drains: (fig. 132).
(b) Deep open trenches or Drainage canals: (fig. 133).

![Diagram of pipe drain]

Cross section of pipe drain

Fig. 132

The pipe drains are laid, below ground, in a permeable and saturated stratum. They are pipes of vitrified clay which are laid on 15 cm (6") sand bed, butting against each other and with open joints. These open joints between pipes are covered over by tarred paper so as not to allow the sand and earth to get into pipes through the open joints. The pipe trenches (in which these pipes are laid at a suitable gradient) are then filled back with the sand and excavated earth so that the cultivation can be done on the land above
them. Pipe drains can be safely used upto about 45 cm (18") diameter or so; there is likelihood of their breaking under the earth load over them if the diameter is bigger than this. Where bigger diameter is required according to calculations, the deep open trench is constructed in preference to a pipe drain; also, the open drains are cheaper. The above-said classification of sub-surface drains (viz. pipe drains and open drains) is according to the shape of drains. The pipe drains are laid, at a level which may be about 0.6 m (2 feet) below that level upto which the water table is to be lowered. The open drain is deep enough to traverse water table, with its bottom a little below that level upto which the water table is to be lowered; its F.S.L. will be below ground level so as to avoid water-logging and salt efflorescence. The subsurface drains when classified according to their function are named as,

(a) Relief drains: \]
(b) Carrier drains: \}
(c) Interception drains: (fig. 135).

Relief drains relieve a saturated soil of its superfluous water which percolates from soil into them. They may be pipe drains (as is usual) or open trenches when the water drained from the soil is much and requires a big diameter pipe drain for its disposal.

Carrier drains receive the water from relief drains and are therefore of bigger size. They may be pipe drains less than 45 cm (18") diameter, or open trenches. Carrier drains pass through impermeable strata. There may be drains performing both the functions of relief and carrier drains.

Interception drain is a drain which is constructed parallel to a canal from which seepage to the adjoining low land is
feared. This seepage is intercepted by an intercepting deep trench, is carried away and thus is not allowed to join the water table of the adjoining low land.

Layout of drains

Fig. 134

Interception drain

Fig. 135

The whole underdrainage system consists of branch drains, main drains and out-fall drains as shown in fig. 134.
The branch drains (usually working as relief drains) will be on the upper extremity of land and will be smallest in size. The main drains (usually working as carrier drains) receive the drained water from branch drains and should be of bigger size. The main drains discharge into an outfall drain which is invariably an open trench. Outfall drain takes the drained water to a neighbouring natural drainage line or nalla. From above it is clear that the branch drains will be at less depth below the surface of land and the main drains will be at a greater depth.

The time taken to reclaim a land depends on the extent by which the water table is to be lowered and on the texture and structure of the soil to be drained.

9. Alignment and location of drains for subsurface drainage: To decide the alignment and location (i.e. position) of drains, it is very important to know surface topography and nature (i.e. texture and structure) of the substrata which are to be drained of their superfluous or free water. For efficient and successful drainage, relief drains should be located in pervious strata. These drains are given suitable longitudinal gradients for their efficient working. Man holes of at least 0.9 m (3') diameter are provided at every 300 m (1000 feet) on straight reaches of pipe drains; they are also provided on pipe drains at every change of gradient, change of diameter, change of direction or change of spot level. The depth and spacing of drains will vary with the types of soils and the crops grown on it.

10. Design of drains for subsurface drainage: Each relief drain has its own underground catchment area which is relieved of its surplus water. Knowing the extent of this catchment area and the drainage characteristics of subsoil which is to be relieved of water, the quantity of water percolating into drain through the open joints can be calculated. Fixing the gradient, the cross section of drain can be worked out. If any drain receives water from other drains, the same should be taken into consideration. Thus, along the alignment of any one drain, its diameter will go on progressively increasing from its head to its tail. Also, if any
under-drain receives rain water in addition to drained water, due provision should be made for carrying it. The cross section actually provided is made liberal, say, about 50% more than that which is required according to calculations.

Open trench is trapezoidal and its cross section is calculated by one of the various formulae for flow in open channels, after first working out the amount of water (drained water plus rain water) to be carried by the drain. Here too, the actual cross section provided is about 50% more than that required by calculations. These open trenches are in fact designed, constructed and maintained like small irrigation channels. Weeds are regularly removed from these trenches.

11. Prevention of water-logging: Following measures should be adopted to prevent the water-logging of agricultural lands:

(a) All measures which effect economy and prevent the waste of irrigation water: e.g. lining of water courses and small distributaries, supply of water by rotation, reducing the intensity of irrigation, use of just the sufficient quantity of irrigation water, etc.

(b) Providing adequate surface drainage, specially where the land is flat.

(c) Providing under-drainage along with the introduction of irrigation, where it is feared that the land will become water-logged soon after irrigation.

(d) Construction of intercepting drains where necessary.

12. Preparation of drainage project for water-logged agricultural land: Drainage project may be prepared along with irrigation project if necessary; otherwise, as soon as the agricultural land shows signs of water-logging after being irrigated for some time, the drainage project should be prepared and the necessary drains should be constructed. If this is not done early, the land may become badly water-logged with the result that it will be very costly and more difficult to reclaim it. In what follows, main points showing the preparation of a drainage project have been given:
(a) Sub-divisional officer (i.e. S.D.O.) will prepare preliminary plan of the affected area, to a scale of 1 cm = 80 m (1" = 660"), showing all the readily available and necessary information about the area, viz.

(1) Rough extent of the affected area.
(2) Rainfall figures for area, collected from the records kept by meteorological department.
(3) Sub-soil water levels, taken from records kept by P.W.D.
(4) Survey numbers, found from records kept by revenue department.
(5) Existing roads on the affected area.
(6) Natural topography, streams, etc.
(7) Soil classification data, obtained from the records kept by revenue department.

He will send this preliminary plan to his Executive Engineer (i.e. E.E.) along with a rough estimate of the survey work that will have to be undertaken in case the project is found feasible. The E.E. will scrutinize the plan and estimate and if he finds it desirable, he will ask the S.D.O. to collect data by doing the actual survey work.

(b) On receipt of orders from his E.E. to commence work on the project, S.D.O. with the assistance of his overseers and soil-classifier will have the entire area surveyed in details. This survey work will be regarding,

(1) Actual soil classification.
(2) Actual extent of damage by water-logging.
(3) Positions of open wells on the area, along with their hot-weather water levels noted on the plan.
(4) Courses of natural drainage lines.
(5) Location of existing irrigation channels.
(6) Location of existing roads, etc.
(7) Location of other topographical features with special reference to the outfall conditions for the proposed under-drainage system.

All the above-said survey work will be put on the plans which will be sent to E.E. along with the S.D.O.’s proposals to do pit work (i.e. boring operations) in order to find by actual boring the nature of substrata and the position of subsoil water.

The E.E. will go carefully through the work submitted by his S.D.O. He may suggest changes or approve of the S.D.O.’s proposals in toto.

![Diagram of Murum isobaths and Hydro isobaths]

Murum isobaths and Hydro isobaths
Fig. 136

(c) After hearing from his E.E., the S.D.O. will get the pit work and the levelling work done along the courses of natural drainage lines on the area. The information so obtained will be shown on the plans which will be sent to E.E. along with S.D.O.’s proposals for the alignment of proposed drains and the boring work along the alignment of these drains.

(d) After approval or modifications by E.E., the proposed pit work shall be done by means of boring tool called boring auger. For each bore hole, the information regarding thickness and nature (specially porosity) of the substrata shall be collected. Also, for each bore hole, the depth of murum layer and water table below the ground shall be
noted. Bore holes showing the same depth of murum below G.L. shall be joined by a free-hand curved line which is known as murum isobath. If the above-said depth of murum layer is 1·8 m (6') below G.L. in case of all the above-mentioned bore holes, the curved line will be called 1·8 m murum isobath. Similarly the bore holes showing same depth of sub-soil water (i.e. water table) below G.L. are joined by a line which is called hydro isobath. If this depth is 0·9 m (3'), the line will be called 0·9 m hydro isobath. From inspection of murum isobaths and hydro isobaths on plan, one can at once judge the positions of murum layer and subsoil water below the ground level. These isobaths are useful in proper laying of the under-drains and they are shown in fig. 136.

While doing pit work, it has been observed that when the bore hole becomes deeper, some free water may be found in it. Also, when a certain depth of bore hole has been drilled by auger, the water suddenly rushes slightly up the bore hole with a peculiar hissing sound. The level of the bottom of bore hole when this occurs is known as the level of First Strong Flow (i.e. F.S.F.). It suggests that the stratum below this level is pervious and saturated with water. Hence, for success in drainage, the invert of pipe relief drains should always be kept below the level of F.S.F.

All the above-mentioned information obtained from bore holes is shown on plans which are sent to E.E. along with the detailed design of drains.

Also, the detailed design of other subsidiary works are submitted by S.D.O. to his E.E. These masonry works consist of manholes along pipe drains and, the ramps, causeways, bridges, standing wave flumes, inverted syphons, aqueducts, etc. on open drains.

(e) On the issue of final orders from E.E. to S.D.O., the latter will complete the final plans and designs of all drainage works and will send these fair and final plans, detailed designs and detailed estimates to his F.E. along with his final and detailed report on the project.

Some of the main final drawings submitted by S.D.O. to his E.E. are as under:
(i) General index plan on the scale of 2" = 1 mile (4 cm = 1 km), showing the general details of area.

(ii) Index plan on the scale of 2" = 1 mile, showing the area actually damaged, likely to be damaged and the area to be reclaimed.

(iii) Index plan (2" = 1 mile) showing the progressive increase of damage, year by year, for the past few years.

(iv) Detailed plan (1" = 660' or, 1 cm = 80 m) showing complete subsoil-survey information e.g. substrata, water table, porosity of substrata, F.S.F., hydro isobaths, murum isobaths, etc.

(v) Longitudinal section etc. of natural drainage lines (horizontal scale 1" = .100' or, 1 cm = 10 m; vertical scale 1" = .10' or, 1 cm = 1 m).

(vi) Longitudinal sections and cross sections of all the drains (pipe and open).

(vii) Plans showing the drawings of all important works along the alignment of drains.

13. Land reclamation in India: About $4.2 \times 10^6$ acres of land were reclaimed during Third Five Year Plan. The target for Fourth Plan is $2.5 \times 10^6$ acres of land.
CHAPTER XX

SOIL CONSERVATION AND FLOOD CONTROL

1. Introductory: Soil conservation and flood control are two allied agricultural cum engineering problems confronting the irrigation engineer and, as such, they are treated together in this chapter. The loose layer on top of earth's crust, with organic matter mixed in it, is called agricultural soil; it is the result of disintegration of rock, carried over a big term of years. This soil has humus, chemicals and crop nutrients in it and hence, it supports all plant life directly; it also supports all animal life indirectly. The thickness of this fertile layer of soil is more at one place and less at another.

When this top fertile layer of soil wears away and the worn part of it is transported from one place to another by certain agency, the phenomenon is called soil erosion. Due to soil erosion, the productivity or fertility of the soil becomes less and when the whole layer of soil is worn away, the land becomes infertile or unproductive for all purposes; only thin grass or low grade forest can thrive on such land. The wearing away and transportation of soil is due to the fast-moving water and/or strong wind. Soil conservation is a process of preserving the fertility of agricultural soil.

2. Causes of soil erosion: The causes of soil erosion are:
   (a) Natural.
   (b) Artificial or Man-made.

Some portion of soil gets eroded and transported naturally by the action of rain water and wind; but, at the same time, the disintegration of rock goes on naturally to form the agricultural soil. Usually, there is a natural balance between the soil eroded naturally and the soil formed naturally from rock. Thus, the fertility of land is not generally affected.

However, man has brought about the artificial erosion by his sheer negligence. Due to his inappropriate actions,
the resulting soil erosion is much more than the soil formed naturally. Thus, there is no balance between the two and this soil erosion, if allowed unchecked, will result in the progressive decrease of soil fertility and the ultimate unproductivity of land. By soil erosion, we always mean this artificial soil erosion brought about by the ill-advised actions of man. Thus, in nut shell, the main cause of soil erosion is *the misuse of agricultural land by man.* The detailed causes of soil erosion are as under:

(a) Man disturbs the balance of nature by destroying unintelligently the natural cover of land; this cover may be in the form of grass, forest, etc. standing on land. T
cis vegetal growth protects land from the direct impact of rainfall and the erosive action of surface flow; also, the roots of this growth bind the soil particles together and thus make the soil stable. The grass cover is destroyed by allowing reckless grazing on the land. To bring more land under cultivation, the forest is destroyed by artificial fire or by ruthless and sudden deforestation. The land, thus made bare and uncovered, is badly attacked and eroded by the erosive agencies like water and wind.

(b) Intensive and faulty methods of cultivation adopted by man weaken the resistance of soil to erosion. *Some* of the faulty methods of cultivation are:

(i) Improper rotation or no rotation of crops: To be most satisfactory, a crop rotation should include a legume. Legumes are plants which belong to the pea family e.g. clover, alfalfa, cow peas, soya bean etc. They add Nitrogen to soil on which they stand.

(ii) Lack of proper bunding and terracing on the land where bunding and terracing are necessary: Terracing is absolutely necessary if the cultivation is done on steep slopes.

(iii) Lack of the use of proper manures.

(c) Intense rainfall and high velocity of surface runoff.

(d) Strong winds.

3. **Kinds of erosion:** There are two main kinds of erosion, viz.,
(a) Water erosion.
(b) Wind erosion.

Water erosion is due to high velocity of flowing water on the surface of land and is more common than wind erosion. Its sub-types are:

(i) Sheet erosion.
(ii) Gully erosion.

When soil from the surface of land is taken away (by water) in the form of a thin sheet of practically uniform thickness, the erosion is known as sheet erosion. This goes on, every year, on the soft and weak soil. This type of erosion goes on unobserved and it can be detected only from the progressively less productivity of land. This type of erosion is more common and more dangerous as it remains undetected for long time.

When sheet erosion is allowed to remain unchecked for some time, it usually results in the land being cut up by trench-like gullies which go on becoming deeper and wider as time passes on. This is known as gully erosion. The land is traversed by numerous gullies and hence, it cannot be cultivated. Gully erosion can also be observed along and across the banks of some rivers, the gullies progressing towards the land side. Gully erosion can be easily detected.

Wind erosion is due to high velocity of wind. Strong wind moves coarse sand particles bodily or blows them and deposits them elsewhere on a good cultivable land. This layer of infertile layer of sand makes the fertile land unfit for cultivation.

4. Results of soil erosion: Following are some of the evils due to soil erosion:

(a) Due to deforestation, there is less absorption and percolation of rain water and hence, more water comes from the bare hilly catchments in the form of sudden and short-lived floods to the plains lower down. Due to the quick and intense floods,
(i) There is much loss of life and property and the resulting economic evils crop up.

(ii) There is dislocation of many inland lines of communication, resulting in hardship to the people of those localities.

(iii) The river, receiving water from such bare catchment, is dry for more period and is in spate for some time of the year. This unequalized flow in river affects the supply in any irrigation reservoir across the river. In monsoon season, much water shall have to be necessarily wasted out of the reservoir and in fair weather season, there will not be sufficient water for storing in the reservoir. This state of affairs will have adverse effect on the crops irrigated from water of such reservoir.

(iv) There is more erosion on the downstream side of such catchments. During floods, the eroded coarse silt gets deposited on plains when the river in spate overflows its banks. Also, there is much silt deposit along the course of river, thus interfering with inland navigation if the river be otherwise navigable. Further, more silt will get deposited in the reservoir across such river. The silt problem in the canals, getting water from such river, will also be of greater magnitude. The silting at the river mouth will block harbour entrance, if any. The silitation along river affects also the works designed to control the quick and short-lived floods. Thus, the soil conservation and flood control problems are inter-dependent and intimately connected with each other.

(b) Soil erosion is a creeping death for all animal life. It results in low standard of living of the people of that region. The cattle of that region is also under-fed and ill-nourished.

(c) There is lower rainfall due to deforestation.

(d) There will be so much less forest-yield due to deforestation.

5. Soil conservation: From what has been said before, it is clear that the agricultural soil is our very life and
hence, its fertility should be maintained at all costs. The two broad general principles of soil conservation are:

(a) Stabilization of soil to make it more stable and non-erodible.

(b) Reduction of the erosive forces, specially the eroding action of water.

Soil can be made strong and stable by:

(i) Afforestation of the bare land.
(ii) Control of deforestation.
(iii) Control of grazing.
(iv) Suitable rotation of crops.
(v) Use of the proper methods of cultivation.

Where the land has been unjudiciously made bare, the same should be covered by growing some vegetation on it. Also, some sort of vegetation like grass may be grown on sandy area so that the sand from it may not be blown away by strong wind.

The reckless deforestation should be checked by some controlling authority like Forest Department or Revenue Department. Thus, the forests may be classed as reserved forests and minor forests. The reserved forests should not be allowed to be destroyed at any cost. The minor forests should be controlled and properly supervised by the controlling authority. The rights of adjoining villagers regarding timber, fuel, cultivation, grass-grazing (by their pastoral flocks) in the minor forests should be regulated by this authority.

On the pastures grazing should be made rotational; or, in some cases, the stall-feeding may be enforced.

It has been found that by the improper rotation of crops, soil does not get proper cover all the year- round; also, soil becomes weak and hence it can be easily eroded.

Suitable methods of cultivation go a long way to make the soil more stable.

As for the reduction of erosive forces, wind-breaks in the form of narrow belts of trees are planted to check the loose soil like sand from being blown (by strong wind) from