In Chapter 2, it was shown that when irrigation is introduced into an area, the natural conditions are changed and may need a drainage system. To predict the effects of these changes, the soil and hydrological factors under which the drainage system will have to function need to be known. Some of the most important factors are briefly discussed.

**DRAINAGE REQUIREMENT**

For the design of a drainage system, the drainage requirement or the drainable surplus has to be known. This is the amount of water that must be removed from an area within a certain period so as to avoid an unacceptable rise in the levels of the groundwater or surface water. Removing the drainable surplus has two advantages:

- It prevents waterlogging by artificially keeping the water table sufficiently deep.
- It removes enough water from the root zone so that any salts brought in by irrigation cannot reach a concentration that would be harmful to crops.

The **drainage requirement** is the amount of water that must be removed from an area within a certain period so as to avoid an unacceptable rise in the levels of the groundwater or surface water.

Calculating the drainage requirement is a major problem in many irrigated areas. The natural conditions in these areas are diverse, and different water resources may be involved in the calculations. Therefore field work has to be carried out to find out what the general features of the groundwater regime are, and the water and salt regimes and their balances have to be studied. A proper understanding of these regimes allows the drainage engineer to predict how they will be affected by drainage.

To calculate the drainage requirement, an analysis has to be made of the overall water balance of the study area (Figure 22). Water balances are often assessed for an average year. Waterlogging and salinity problems, however, are not of the same duration or frequency every year. Therefore there is often a need to assess water balances, not only for an average year, but also for specific years (e.g. a very dry year or a year with extreme rainfall), or even for specific periods (e.g. the growing season or the irrigation season).
FIGURE 22
Components of the water balance in an irrigated area

FIGURE 23
The water table, the saturated zone below the water table, and the unsaturated zone above the water table
THE WATER TABLE

The water table is the upper boundary of the groundwater. It is defined as the locus of points at which the pressure in the groundwater is equal to atmospheric pressure.

The water table is the locus of points at which the pressure in the groundwater is equal to atmospheric pressure.

Below the water table, all the soil pores are filled with water. This is known as the saturated zone (Figure 23). Most of the flow of groundwater towards the drains takes place in the saturated zone. Above the water table, there is a zone where the soil pores are filled partly with water and partly with air. This is the unsaturated zone. Water in the unsaturated zone originates from rain or irrigation water that has infiltrated into the soil, and from the capillary rise of groundwater. The unsaturated zone is very important for plant growth. This is the zone where roots take up water.

The water table fluctuates with time. After irrigation or rainfall, there is a sudden rise of the water table, followed by a gradual fall due to the flow of water towards the drainage system (Figure 24).

DEPTH TO THE WATER TABLE

The depth to the water table is measured in observation wells (Figure 25). An observation well is a small-diameter plastic pipe (> 12 mm), placed in the soil. The pipe is perforated over a length that the water table is expected to fluctuate. Sometimes a gravel filter is placed around the pipe to ease the flow of water and to prevent the perforations from becoming clogged by fine particles like clay and silt. In stable soils (e.g. heavy clay soils), simply an auger hole can be made in the ground and no pipe is needed (Figure 25A).

Water levels can be measured in various ways (Figure 26):

- The wetted tape method (Figure 26A): A steel tape (calibrated in millimetres), with a weight attached to it, is lowered into the pipe or auger hole to below the water level. The lowered length of tape from the reference point (e.g. the top of the pipe) is noted. The tape is then pulled up and the length of its wetted part is measured. (This is easier to see if the lower part of the tape is chalked.) The depth to the water level from the reference point is obtained by subtracting the wetted length from the total lowered length.

- With a mechanical sounder (Figure 26B): This consists of a small steel or copper tube (10 to 20 mm in diameter and 50 to 70 mm long), which is closed at its upper end, open at its bottom end, and connected to a calibrated steel tape. When lowered into the pipe, it produces a characteristic plopping sound upon hitting the water. The depth to the water level can be read directly from the steel tape.

- With an electric water-level indicator (Figure 26C): This consists of a double electric wire with electrodes at their lower ends. The upper ends of the wire are connected to a battery and an indicator device (lamp, amp meter, sounder). When the wire is lowered
Factors related to drainage

Into the pipe and the electrodes touch the water, the electrical circuit closes, which is shown by the indicator. If the wire is attached to a calibrated steel tape, the depth to the water level can be read directly.

- With a floating level indicator or recorder (Figure 26D): This consists of a float (60 to 150 mm in diameter) and a counterweight attached to an indicator or recorder. Recorders can generally be set for different lengths of observation period. They require relatively large pipes. The water levels are either drawn on a rotating drum or punched into a paper tape.

- With a pressure logger or electronic water-level logger (Figure 26E): This measures and records the water pressure at one-hour intervals over a year. The pressure recordings are controlled by a microcomputer and stored in an internal, removable memory block. At the end of the observation period or when the memory block has reached capacity, it is removed and replaced. The recorded data are read by a personal computer. Depending
Drainage of irrigated lands

on the additional software chosen, the results can be presented raw or in a calculated form. Pressure loggers have a small diameter (20 to 30 mm) and are thus well suited for measurements in small-diameter pipes.

The water levels of open water surfaces are usually read from a staff gauge (Figure 27) or a water-level indicator installed at the edge of the water surface. A pressure logger is most convenient for this purpose, because no special structures are required; the cylinder only needs to be anchored in the river bed.

The water table reacts to the various recharge and discharge components that form a groundwater system, and is therefore constantly changing. Important in any drainage investigation are the (mean) highest and the (mean) lowest water table positions, as well as the mean water table depth in a hydrological year. For this reason, water-level measurements have to be taken at frequent intervals for at least a year. The interval between readings should not exceed one month, but a fortnight may be better. All measurements in the project area should, as far as possible, be made over the shortest time span possible so that a complete picture of the water table in that time span can be obtained.
FIGURE 26
Various ways of measuring depth to water levels in observation wells

FIGURE 27
Staff gauge to measure the water level in an open drain
Each time a water-level measurement is made, the data should be recorded in a notebook. Pre-printed forms are very handy for this purpose. An example is shown in Figure 28. Even better is to enter the data in a computerized database system. Recorded for each observation are: date of observation, observed depth of the water level below the reference point, calculated depth below ground surface, and calculated water-level elevation (with respect to a general datum plane, e.g. mean sea level). Other particulars should also be noted (e.g. the number of the well, its location, depth, surface elevation, reference point elevation).

If a study of the effect that a rainstorm or an irrigation application has on the water table is needed, daily or even continuous readings may be required. To do this, a pressure logger or an automatic recorder is installed in a representative large-diameter well.

**DISSOLVED SALTS IN THE GROUNDWATER**

All groundwater contains salts in solution. The type of salts depends on the geological environment, the source of the groundwater, and its movement. Irrigation is also a source of the salts in the groundwater. It not only adds salts to the soil, but also dissolves salts in the root zone. Water that has passed through the root zone of irrigated land usually contains salt concentrations several times higher than that of the originally applied irrigation water. Evapotranspiration tends to concentrate the salts at the surface of the land (Figure 29), but when they are dissolved, they increase the salinity of the groundwater. Therefore highly saline groundwater is often found in arid regions with poor natural drainage.

**MEASURING GROUNDWATER SALINITY**

The choice of a method to measure groundwater salinity depends on the reason for making the measurements, the size of the area (and hence the number of samples to be taken and measured), and the time and the budget available for doing the work.

Once the network of observation wells and boreholes has been set out, a representative number of water samples is taken. Sampling can often best be combined with other drainage investigations, such as measuring hydraulic conductivity in open boreholes.

The salinity of groundwater can be rapidly determined by measuring its electrical conductivity (EC).

**Electrical conductivity (EC)** is a measure of the concentration of salts, defined as the conductance of a cubic centimetre of water at a standard temperature of 25°C.
FIGURE 28
Example of a pre-printed form for recording water table levels

GENERAL DATA
MAP NO........................... COORDINATES: X=.................................. Y=..................................
MUNICIPALITY ........................................ PROVINCE........................................
OWNER........................................ INSTALLATION DATE.................. TYPE\(^1\)..................
DEPTH.......................... SCREENED PART.......................... AQUIFER TYPE\(^2\)..................
WELL LOG: FILE NO.......................... WATER SAMPLES: FILE NO....................... 
SURFACE ELEVATION....................... REFERENCE POINT ELEVATION......................

OBSERVATIONS

<table>
<thead>
<tr>
<th>DATE</th>
<th>READING(^3)</th>
<th>ELEVATION(^4)</th>
<th>DEPTH(^5)</th>
<th>REMARKS(^6)</th>
</tr>
</thead>
</table>

1 e.g. village well, open bore hole, piezometer
2 e.g. unconfined aquifer, semi-confined aquifer, semi-pervious covering layer
3 with respect to reference point
4 with respect to general datum, for example mean sea level
5 below ground surface (for phreatic levels only)
6 data on water sample, irrigation, water at the surface, flow from wells, water withdrawal (pumping), etc.
Electrical conductivity is expressed in deciSiemens per metre (dS/m), formerly in millimhos per centimetre (mmhos/cm). Expressing the results in terms of specific electrical conductivity makes the determination independent of the size of the water sample. Conductivity cannot simply be related to the total dissolved solids because groundwater contains a variety of ionic and undissociated species. An approximate relationship for most groundwater with an EC-value in the range of 0.1 to 5 dS/m is: $1 \text{ dS/m} \approx 640 \text{ mg/1}$.

The EC expresses the total concentration of soluble salts in the groundwater, but gives no information on the types of salts. These may be calcium, magnesium, sodium, potassium, carbonate, bicarbonate, chloride, sulphate, and nitrate, and need to be determined in the laboratory. Since these chemical analyses are costly, not all the observation points need be sampled for detailed analysis. A selection of sites should be made, based on the results of the EC-measurements.

**HYDRAULIC CONDUCTIVITY**

The hydraulic conductivity (also known as the K-value) is a measure of the water-transmitting capacity of soils. There are big differences between the K-values of soil types, mainly depending on their texture (Table 2).

**Hydraulic conductivity** is a measure of the water-transmitting capacity of a soil.
There are various ways of measuring hydraulic conductivity. It can be correlated with the soil texture or the pore size distribution, and it can be measured in the laboratory or in the field. The best known field method is the auger-hole method (Figure 30), which works as follows:

Using an auger, a hole is bored into the soil to a certain depth below the water table. When the water in the hole reaches equilibrium with the ground-water, some of the water is bailed out. The groundwater then begins to seep into the hole, and the rate at which it rises is measured. Then the hydraulic conductivity of the soil is calculated with an equation describing the relationship between the rate of rise, the groundwater conditions, and the geometry of the hole.

The auger-hole method measures the K-value around the hole. It gives no information about vertical K-values or about K-values in deeper soil layers. The method is therefore more useful in shallow aquifers than in deep ones.

**TABLE 2**

### Hydraulic conductivity of some soil types

<table>
<thead>
<tr>
<th>Soil type (texture)</th>
<th>Hydraulic conductivity (m/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dense clay (no cracks, pores)</td>
<td>&lt; 0.002</td>
</tr>
<tr>
<td>Clay loam, clay (poorly structured)</td>
<td>0.002 - 0.2</td>
</tr>
<tr>
<td>Loam, clay loam, clay (well-structured)</td>
<td>0.5 - 2.0</td>
</tr>
<tr>
<td>Sandy loam, fine sand</td>
<td>1 - 3</td>
</tr>
<tr>
<td>Medium sand</td>
<td>1 - 5</td>
</tr>
<tr>
<td>Coarse sand</td>
<td>10 -50</td>
</tr>
<tr>
<td>Gravel</td>
<td>100 - 1000</td>
</tr>
</tbody>
</table>

**FIGURE 30**

Equipment used to measure the hydraulic conductivity with the auger-hole method
TOPOGRAPHY

Information on the topography of an area with a drainage problem is essential, because the excess water has to be removed by gravity flow. The topographic map should show all physical features – both natural and man-made – which will influence the design of the drainage system (Figure 31). Minor differences in the elevation of the land surface are important. How to conduct topographic surveys at farm level was discussed in Training Manual No. 2 *Topographic Surveying*.

![Topographic map of an irrigated area](image-url)
Good judgment is needed to decide the extent of the topographic data needed for the design. The flatter the topography, the smaller the contour interval will be. If there are isolated critical points within the field, the map should include spot elevations of these points. The map should also show the location of open drains, bunds, farm roads and farm boundaries.

**IMPERMEABLE LAYERS**

Soils are hardly ever uniform or homogeneous in the vertical direction. At some depth below the soil surface, there will always be an impermeable layer. If this impermeable layer is deep and the groundwater only partly fills the permeable top layer, the water table is free to rise and fall. The groundwater in such a layer is said to be unconfined, or to be under phreatic or water table conditions (Figure 32A).

An impermeable layer is a soil layer through which no flow occurs or, in a practical sense, a layer through which the flow is so small that it can be neglected.

Where groundwater completely fills a permeable layer that is overlain and underlain by impermeable layers, the upper surface of the saturated zone is not free, but is fixed. Groundwater in such a layer is said to be confined, or to be under confined or artesian conditions (Figure 32B). The water level in a well or borehole that penetrates into the permeable layer stands above the top of that layer or, if the artesian pressure is high, even above the land surface. Truly impermeable layers are not common in nature; most fine-textured layers possess a certain, though low, permeability.

Where groundwater completely fills a permeable layer that is overlain by a poorly permeable layer and underlain by an impermeable layer, the groundwater in the permeable layer is said to be semi-confined (Figure 32C). In the overlying, poorly permeable layer, the groundwater is under unconfined conditions because it is free to rise and fall.
Chapter 5

Design considerations

DRAINAGE AS PART OF AN AGRICULTURAL DEVELOPMENT PROJECT

Land drainage usually forms part of an agricultural development project. In such a project, land drainage is just one of the activities. The design of a drainage system is always a multidisciplinary effort, involving agronomists, extension specialists, agricultural, irrigation and drainage engineers and, of course, the beneficiaries (Figure 33). In this manual, emphasis is on drainage systems at field level, so some of the major aspects of their design and construction will be discussed.

LAYOUT OF FIELD DRAINAGE SYSTEMS

The length of the field drains is determined either by fixed (farm) boundaries or by a fixed length for the drain. It is often decided to place the field drains at right angles to the collectors (Figure 34). If so, it may happen that the field drains do not run parallel to the minor infrastructure (e.g. irrigation canals or farm roads). In such a case, it is better to install the field drains at such an angle to the collector that the number of crossings with the minor infrastructure is minimized.

The spacing of the collectors is often determined by the length of the field drains. The collector alignments are further fixed by the field boundaries. The length of a collector is restricted either by a field boundary or by the available slope. The available slope is fixed by the shallowest permissible drain depth, the maximum water level in the main drain, and the slope of the land surface.

The field drainage system is generally designed on a model basis for a sample area. This can be a single farm of less than one hectare or an area of more than hundreds of hectares. In such a sample area, the design variables (i.e. the soil and hydrological conditions and agricultural inputs) are considered to be uniform. This means that the design is only a guideline, which can be adjusted for each single farm to incorporate specific circumstances.
Design considerations

(e.g. a slightly heavier soil or a different cropping pattern, or a specific layout for the irrigation canals).

**Surface and Subsurface Drainage Systems**

Depending on the kind of drainage problem faced, a choice has to be taken on the type of drainage system that will help to overcome the problem (Figure 35). This may be a surface drainage system, a subsurface drainage system, or a combination of the two.

In some areas, drainage problems can be caused by a perched water table. The true water table may be relatively deep, but a hard pan or other impeding layer in the soil profile creates a local water table above that layer or hardpan. If the impeding layer is at shallow depth (0.2 - 0.4 m), the drainage problem can probably be solved by deep ploughing or scarifying.
FIGURE 35
The type of drainage system depends on the kind of drainage problem which is faced.
If the impeding layer is at greater depth (0.4 - 0.8 m), mole drainage can be applied. Mole drainage is a special type of subsurface drainage that uses unlined underground drainage channels. These channels are formed by pulling a solid cylinder with a wedge-shaped point at one end through the soil, without having to dig a trench (Figure 36). Mole drainage can reduce saturation of the top soil by enhancing shallow subsurface drainage flow to field drains.

OUTLET OF A FIELD DRAINAGE SYSTEM

Irrespective of the type of drainage system that will be installed on the farm, a good outlet is a prerequisite for success. If there is no way to evacuate the water away from the field, the drainage system will not work.

The water level at the outlet defines the drainage base. It determines the hydraulic head available for drainage flow. The drainage base is different for different points in a drainage area. For the field drainage system, the drainage base is the water level in the collector drains, whether they be pipes or open drains (Figure 37). For the collector drainage system, the drainage base is the water level in the main drain. And for the main drainage system, it is the water level below the gravity outlet structure during critical periods for crop growth, or the minimum water level at the pumping station.

Care should be taken to ensure that the water level in the recipient drain, whether it is a collector or the main drain, is below the required water level in the field, especially in the period when drainage is most important (e.g. in the rainy season).
DESIGN DISCHARGE

The dimensions of drains, whether they be open drains or pipe drains, are based on the required design discharge. This design discharge is influenced by the storage capacity of the drainage system. By reducing ponding or waterlogging, a drainage system creates a buffer capacity in the soil, ensuring that the discharge is steadier and smaller than the recharge.

If the soil has a large buffer capacity, a longer period of critical duration can be adopted and average recharge and discharge rates over this longer period can be used. In contrast, if the soil has only a small buffer capacity, the infrequent, extreme, recharge and discharge rates have to be assessed and shorter periods of critical duration have to be adopted.

Subsurface drainage systems create a medium storage capacity. In regions with low rainfall intensities (say less than 100 mm/month) and in irrigated lands in arid or semi-arid regions, the design discharge for the month or season with the highest net recharge has to be calculated.

In regions that have seasons with high rainfall (say more than 100 mm per month), it is likely that the problem is one of surface drainage rather than of subsurface drainage. Here, a subsurface system would not be appropriate, or it could be combined with a surface system. In a combined system, the design discharge of the subsurface system has to be calculated from a water balance after the discharge from the surface system has been deducted.

A surface field drainage system, consisting of beds in flat lands or mildly graded field slopes in undulating lands, creates only small capacities for storage. The design discharge must then be based on the water balance over a short period (say 2 to 5 days).

SLOPES OF FIELD DRAINS

The maximum slope of field drains is dictated by the maximum permissible flow velocity. If the topography should call for steep slopes, drop structures should be built into the drains. For pipe drains, these are normally incorporated in manholes.

Special caution is needed if a steep slope changes to a flatter slope: high pressures may develop at the transition point unless the flow velocity on the upstream side is properly controlled and the downstream (flatter) reach has a sufficient capacity.