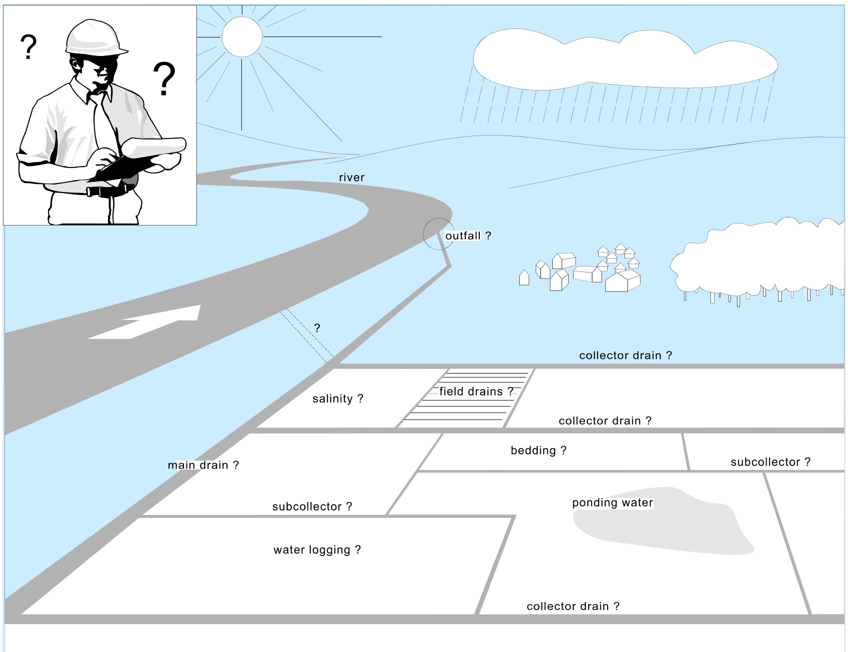
Main Drainage Systems

Technical Report · January 2014

Henk Ritzema
Wageningen University & Research

UNESCO-IHE
MSc Programme Land and Water Development for Food Security

Main Drainage Systems[1]



Dr. ir. Henk Ritzema

Wageningen University
Wageningen, The Netherlands
February 2014

1 These lecture notes were prepared for teaching purposes only. The author does not assume responsibility for the accuracy or the completeness of the information enclosed herein. These notes or any part of thereof may not be reproduced or translated without the written permission of the author.

Summary

Course	Hydraulic Engineering – Land and Water Development
Module	Aspects of Irrigation and Drainage
Subject	Main Drainage Systems
Lecturer	Dr.Ir. Henk Ritzema, Alterra-ILRI, Wageningen University and Research Centre, P.O. Box 47, 6700 AA Wageningen, The Netherlands, Email: henk.ritzema@wur.nl
Study load	Study load: 16 hours Contact hours (Lectures): 8 hours
Lecture notes	This workbook Suggested literature: • ILRI Publication 16 "Drainage Principles and Applications", Chapter 19 • ILRI Publication 60 "Subsurface Drainage Practices: Guidelines for the implementation, operation and maintenance of subsurface pipe drainage systems"
Learning method	• Lectures • Individual assignments and exercises • Self-study
Learning Objectives	*Knowledge* Understand the need for drainage and the components out of which a drainage system is built up. *Skills* Application of the knowledge in design exercises and/or MSc thesis. *Attitude* Awareness that the design of a drainage system needs a systematic approach and should not be done merely from handbooks.
Brief description of subject	The need for drainage will be discussed: (i) in humid regions, drainage is a tool to combat waterlogging and waterponding and; (ii) in arid and semi-arid regions, drainage is a tool to combat waterlogging and salinization. An overview of the systems that are available to drain agricultural lands is presented and the soil and hydrological factors which influence drainage are discussed.
Contents	• The Need for drainage • Drainage systems • Examples of drainage systems in various climatic regions

Contents

1 Introduction

This series of lectures

In this series of lectures "Main Drainage Systems" we shall discuss the procedure to design a main drainage system. After a brief introduction into the need for drainage in agricultural lands (Chapter 2), the components of a drainage system are discussed, with special emphasis on the main drainage system (Chapter 3). Finally in Chapter 4, examples of drainage practices are presented: from the Netherlands (representing the temperate humid region), from Egypt (representing the arid and semi-arid regions) and Malaysia (representing the humid tropics).

Field drainage systems will be further elaborated in the lectures "*Subsurface drainage*" in Module 11 "*Advanced methods and Equipment*" (WSE-HELWD11).

Purpose of this workbook

The purpose of this workbook is to guide you through the relevant theories presented in the following publications:

- ILRI Publication 16 "Drainage Principles and Applications", Chapter 19
- ILRI Publication 60 "Subsurface Drainage Practices: Guidelines for the implementation, operation and maintenance of subsurface pipe drainage systems".

These publications can be downloaded from:
http://www.alterra.wur.nl/NL/publicaties+Alterra/ILRI-publicaties/Downloadable+publications/.

For each subject the relevant sections in these two publications are indicated and, where necessary, specific points are highlighted.

Glossary

For the definitions of the technical terms and expressions used in this workbook, please refer to the glossaries of the two ILRI publications.

Exercises

When appropriate, exercises are included.

Follow-up

You can use the theories discussed in this series of lectures to design a main drainage system for a situation resembling the conditions in your own country.

2 Need for drainage

🕮 Self study ILRI Publication 16 - Chapter 17.3

Context In this chapter, the need for drainage is discussed.

2.1 Drainage for agriculture

Objectives of drainage

The four main objectives of drainage in agricultural land are:

- Drainage to prevent or reduce waterlogging
- Drainage to control salinity, or
- Drainage to make new land available for agriculture
- Drainage to sustain the land and water resources

Water balance

Agriculture depends on the availability of water (Figure 1). In humid regions, the main source of water is rainfall (9), in arid or semi-arid regions supplemented by irrigation. To apply irrigation water to a crop, water has to be diverted from a river or lake (1) or from the groundwater reservoir (2). The amount of water diverted has to be greater that the quantity required by the crops because the diverted water will leave the area not only as evapotranspiration by the irrigated crop (3), but also as evaporation (4), seepage (5) and operational spills (6) from the irrigation canal system, as tailwater runoff from irrigated fields (7), and as deep percolation (8). In the field, irrigation water together with any rainfall (9), will be partly stored on the soil surface (10) and partly infiltrate in the soil (11).

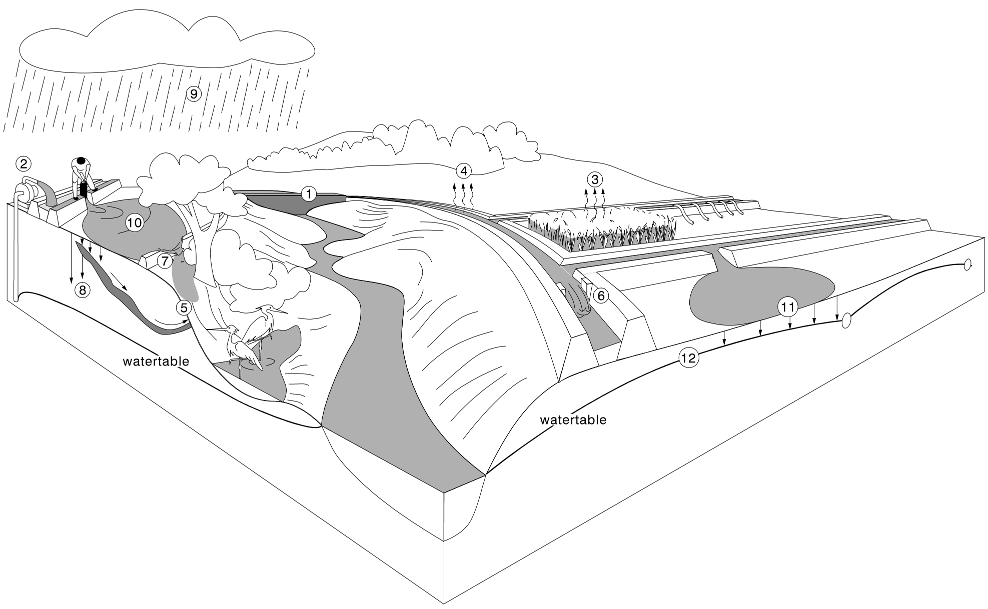


Figure 1 The water balance in an irrigated area

Water ponding

When rain or irrigation continues, pools may form on the soil surface, and this excess water needs to be removed. This standing water on the soil surface is called ponding water.

Ponding is the accumulation of excess water on the soil surface

Water-logging

Part of the water that infiltrates the soil will be stored in the pores and used by the crop (3) and part of the water will be lost as deep percolation (8). When the percolating water reaches that part of the soil which is saturated with water, the watertable will rise (12). If the watertable reaches the root zone, the plants may suffer (Figure 2). The soil has become waterlogged.

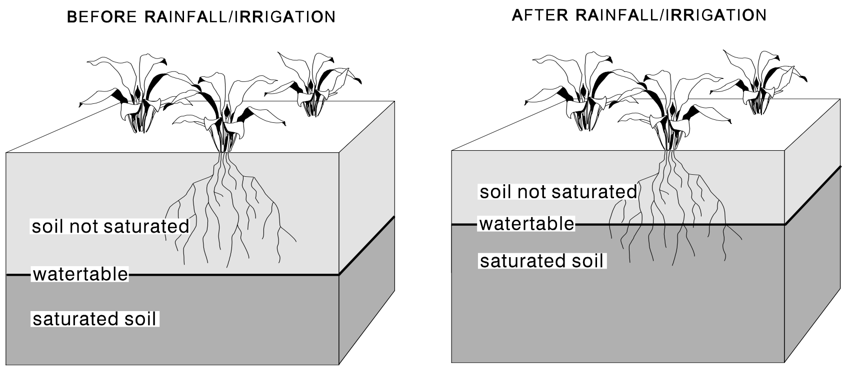


Figure 2 After rainfall or irrigation the watertable may rise and reach the root zone

Waterlogging is the accumulation of excess water in the root zone of the soil.

Salinisation

Drainage is needed to remove the excess water and to control the rise of the watertable. Even in irrigation water of very good quality there are salts, thus bringing irrigation water to a field means also bringing salts to the same field. The irrigation water is used by the crop or evaporates directly from the soil. The salts, however, are left behind (Figure 3). This process is called salinisation.

Salinisation is the accumulation of soluble salts at the surface, or at some point below the surface of the soil profile, to levels at which they have negative effects on plant growth and/or soils.

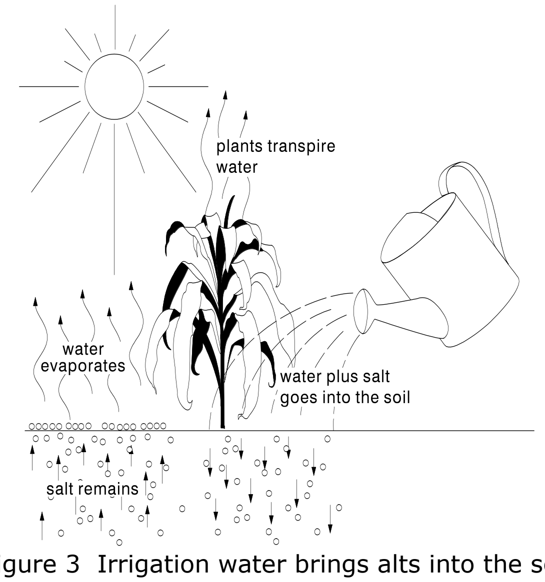


Figure 3 Irrigation water brings alts into the soil

If these salts accumulate in the soil, they will hamper crop production. Some crops are more tolerant to salts than others. The highly tolerant crops can withstand a salt concentration in the root zone up to 10 dS/m, the moderately tolerant crops up to 5 dS/m and the sensitive crops up to 2.5 dS/m (Lecture Notes *Field Irrigation and Drainage - Part 1*). To grow more sensitive crops, drainage is needed to remove these salts.

Thus drainage is used to control ponding at the surface, to control waterlogging in the soil and to avoid salinisation, and may be defined as:

Definition of drainage

Drainage is the removal of excess surface and subsurface water from the land to enhance crop growth, including the removal of dissolved salts from the soil.

Drainage is necessary for successful irrigated agriculture because it controls ponding, waterlogging and/or salinity. Drainage can be either natural or artificial. Most areas have some natural drainage; this means that excess water flows from the farmer's fields to swamps or to lakes and rivers. However, the natural drainage is often inadequate to remove excess rainfall during extreme rainfall conditions or to remove the extra water or salts brought in by irrigation. Under these conditions, an artificial or man-made drainage system is required.

Definition of a drainage system

A **drainage system** is an artificial system of land forming, surface and/or subsurface drains, related structures, and pumps (if any), by which excess water is removed from an area.

2.2 Drainage to control water ponding

Surface drainage

To remove excess (ponding) water from the surface of the land we use surface drainage. This is normally accomplished by shallow open field drains. In order to facilitate the flow of excess water towards these open drains, the field is usually given an artificial slope by means of land shaping or grading (Figure 4).

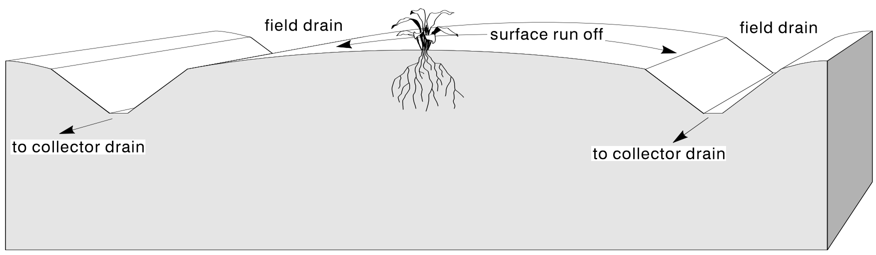


Figure 4 Surface drainage to remove excess water from the land surface

Surface drainage is the diversion or orderly removal of excess water from the surface of the land by means of improved natural or constructed drains, supplemented when necessary by the shaping and grading of land surfaces to such drains.

2.3 Drainage to control waterlogging

Subsurface drainage

To remove excess water from the root zone we use subsurface drainage (Figure 5). By subsurface drainage we control the watertable, and excess water is removed from the underground by gravity through open or pipe drains installed at depths varying from 1 to 3 m.

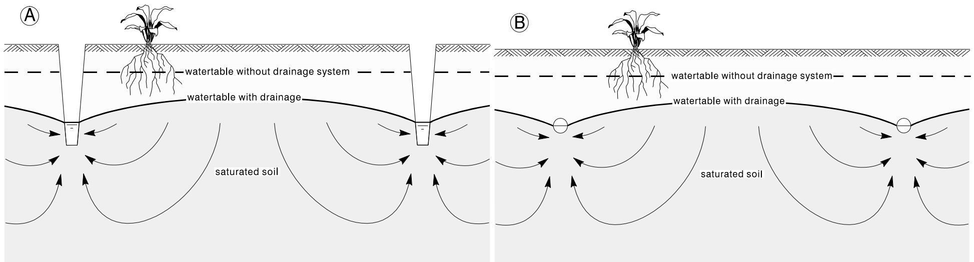


Figure 5 Field drains for subsurface drainage may be open (A) or pipe (B)

Subsurface drainage is the removal of excess water and dissolved salts from soils via groundwater flow to the drains, so that the watertable and root zone salinity are controlled.

Tubewell drainage

Tubewell drainage is a special type of subsurface drainage where excess water is removed by pumping from a series of wells drilled into the ground to a depth of several tens of metres (Figure 6). The pumped water is then discharged into open surface drains.

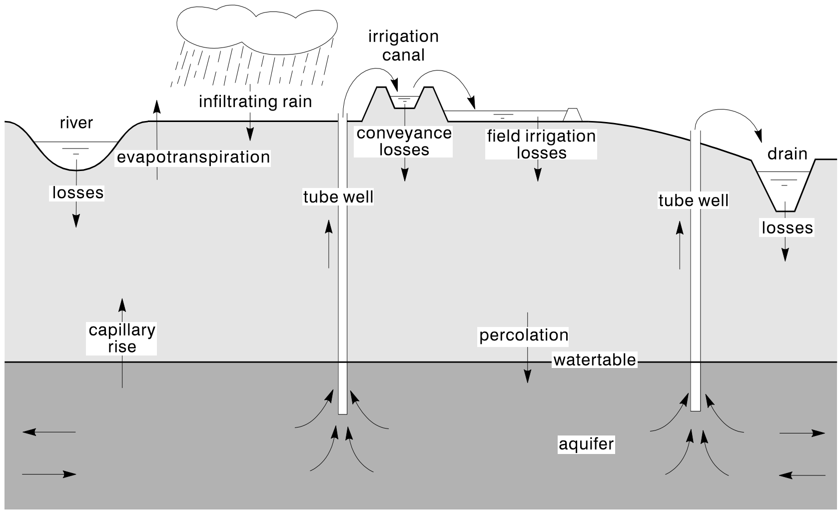


Figure 6 Tubewell drainage is a technique of controlling the watertable by removing the excess water from the (more permeable) underground

Tubewell drainage is the control of an existing or potential high watertable, or of artesian groundwater, through a group of adequately-spaced wells.

2.4 Drainage to control salinisation

Leaching

To remove salts from the soil, water is used as a vehicle: more irrigation water is applied to the field than is required for crop growth. This additional water infiltrates into the soil and percolates through the root zone. During percolation the water takes up part of the salts from the soil and removes these through the subsurface drains (Figure 7). This process, in which the water washes the salts out of the root zone, is called leaching.

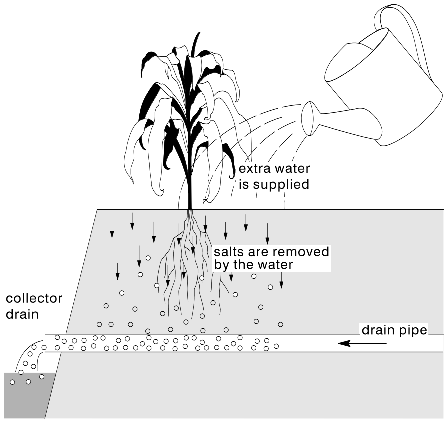


Figure 7 Extra irrigation water is applied to remove salts from the rootzone

Leaching is the removal of soluble salts by the passage of water through soil.

The additional water required for leaching must be removed from the root zone by means of drainage, otherwise the watertable will rise and this will bring the salts back into the root zone. Thus salinity control is achieved by a combination of irrigation and drainage measures.

The different types of drainage systems, which can be used for the control of the watertable and/or the soil salinity, are discussed in Chapter 3.

Example

Example: Drainage to sustain irrigated agriculture in Egypt

Agriculture in the Nile Delta in Egypt depends almost entirely on irrigation from the River Nile. The total amount of irrigation water applied to the crops is about 1200 mm/year. Although this irrigation water is of good quality (0.3 dS/m) it brings a lot of salts into the soils:

Total volume of irrigation water :

V_i = 1200 mm/year = 1200 x 10^{-3} x 10^4 m^3/ha/year = 12 x 10^3 m^3/ha/year

Salinity of irrigation water:

EC_i = 0.3 dS/m = 0.3 x 640 mg/l = 192 mg/l = 1.92 x 10^{-4} ton/m^3

Total salts brought into the soil:

S = V_i x EC_i = 12 x 10^3 m^3/ha/year x 1.92 x 10^{-4} ton/m^3 = 2.3 ton/ha/year

Thus every year about 2.4 tons of salts are added to the soil profile and leaching is required to maintain a favorable salt balance.

Exercise 1 The need for drainage in your own country

Describe a common drainage problem in your own home country. Elaborate whether it is a water ponding, waterlogging and salinity problem or a combination?

Exercise 2 Drainage: from problem to solution.

In exercise no.1 you have described a common drainage problem in your own home country. Briefly discuss how this problem is solved. Mention 3 good points of this approach and three weak points.

3 Drainage systems

🕮 **Self study**

ILRI Publication 16 - Chapter 17.2 and 19.2
ILRI Publication 60 – Chapter I.3

In this chapter, we shall discuss the components of a drainage system.

3.1 Components of a Drainage System

Components of a drainage system

A drainage system can be divided into three components (Figure 8):

- Field drainage system
- Main drainage system and
- Outlet.

A field drainage system is used to avoid ponding water and/or to control the watertable in the field. The main drainage system is used to convey the water away from the farm area. And the outlet is the point of safe disposal of the drainage water. In the following we will briefly discuss these three components.

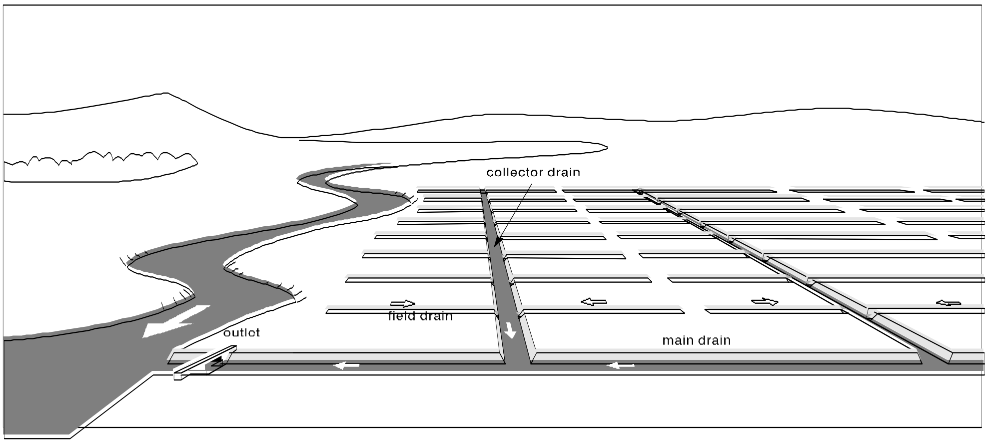


Figure 8 Schematic lay-out of a drainage system

Field drainage system

For farmers, the field drainage system is the most important part of a drainage system. It controls water ponding and/or waterlogging in his field. It can be a surface drainage system (to remove ponding water from the surface of the land), a subsurface drainage system (to control the watertable in the soil) or a combination of these two. Field drainage systems will be discussed in more detail during the lectures "*Subsurface drainage*" in Module 11 "*Advanced methods and Equipment*" (WSE-HELWD11).

The **field drainage system** is a network that gathers the excess water from the land by means of field drains, possibly supplemented by measures to promote the flow of excess water to these drains.

Main drainage system

The main drainage system consists of collector drains and a main drain. A collector drain is a drain that collects water from the field drains and carries it to the main drain for disposal. As field drains, collector drains may be either open or pipe drains. The main drain is the principal drain of an area, it receives water from collector drains, diversion drains, or interceptor drains (= drains intercepting surface or groundwater flow from outside the area), and conveys this water to an outlet for disposal outside the area. The main drain is often a canalized stream which runs through the lowest parts of the agricultural area.

The **main drainage system** is a water conveyance system that receives water from the field drainage systems, surface runoff, and groundwater flow, and transports it to the outlet point.

Outlet

When agricultural lands are located along rivers, lakes, estuaries, or coastal areas, dikes can protect them from being flooded. To enable the drainage of excess water from the protected area, the dikes are provided with outlet structures. These can be sluices with doors, gated culverts, siphons, and/or pumping stations. The water levels of the canals, rivers, lakes, or seas that receive this water may vary, because of tides, for instance. When the outer water levels are high, drainage might be temporarily restricted. This means that the drainage water accumulating inside the protected area has to be stored - in the soil, in ditches, in canals, and/or in ponding areas.

The **outlet** is the terminal point of the entire drainage system, from where it discharges into a river, lake, or sea.

3.2 Outlet

Gravity outlet or pumping station

The outlet can be a gravity outlet structure or a pumping station. A gravity outlet structure is a drainage structure in an area with variable outer water levels, where drainage can take place by gravity when outside water levels are low. In delta areas, drainage by gravity is often restricted to a few hours per day during low tide. In the upstream regions of a river, drainage by gravity can be restricted for several weeks, during periods of high river discharges. A pumping station is needed in areas where the required water levels in the drainage system are lower than the water level of the river, lake or sea.

Outlet

The location of the outlet, where drainage water is discharged into a river, lake, or sea, influences the layout and functioning of the drainage system. To ensure the uninterrupted discharge of water throughout the drainage season, the outlet should not be blocked by a sand bank or vegetated flats, nor should it be at the inner curve of a river, where sedimentation occurs. At the outlet, the main drainage canal usually cuts through the natural river embankment or the dike. To prevent flooding of the agricultural area, the outlet is usually fitted with a sluice, which can be closed when the outside water level is too high. The sluice should be near the lowest part of the area to be drained. Soil conditions at such a location, however, may cause foundation problems, and the sluice may have to be moved to a higher, more suitable, location.

Location

To avoid damage if there is a change in the course of the river or coast line, sluices are built at a certain distance from the river or sea. The entire length of the main canal reach downstream of the sluice and part of the river embankment or coast must be protected against erosion.

Access

To operate and maintain the gates properly, it is essential that the sluice is accessible throughout the year. The cost of constructing and maintaining an all-weather access road may influence the choice of a site for the drainage outlet.

If the hydraulic gradient over the outlet sluice is insufficient to discharge all drainage water within a selected period (3 or 5 days), a pumping station may be added to the outlet. In such a case also the cost of power supply to the pumping station influences its location.

Exercise 3: Outlets

Describe a common outlet used in your own home country. Elaborate the following points:

- Is it a gravity or pumped outlet?
- What are the problems associated with this type of outlet?
- What are the main advantages of using this type of outlet?
- What are the main disadvantages using this type of outlet?
- Recommend three measures to improve the performance of the outlet.

3.3 Main Drainage

Main drainage system

Systems of drainage canals and their related structures collect and convey excess water to prevent damage to crops and/or to allow farm machinery to work the land. Besides these agricultural functions, a drainage canal system may have to supply water for irrigation in the dry season, act as a means of transport for shipping, etc. In this chapter, we shall concentrate on the agricultural functions of the system. A main drainage system is, in principle, a mirror-image of a main irrigation system. The main function of both systems is to convey the water. The difference is that in an irrigation system the source is the inlet point in a river, lake or reservoir from where the water is distribute to all fields in the project area and the sources of the drainage system are all these fields from where the excess water is evacuate back to wards the (same) river, lake or sea. The design principles are the same: either a steady-state approach (e.g. Manning) or an unsteady-state approach (e.g. Duflow) is used to calculate the dimension of the irrigation or drainage canel. A major difference is the design capacity. For irrigation canals, the design capacity is based on the crop water requirements, a flow conditions that regularly occurs (depending on the irrigation efficiencies). For drainage canals, the design capacity is based on the excess rainfall, based on a certain frequency of occurrence, e.g. once every 1, 5 or 10 years. Thus the design flow conditions in drainage canals only sporadically occur (with a frequency of once every 1, 5 or 10 years), most of the time the system operated below the design conditions.

Question

What are the consequences of the sporadic occurrence of the design flow conditions for the O & M of a main drainage system? Compare these O&M requirements with the requirements for the O&M of main irrigation systems.

Broadly speaking, there are two kinds of drainage canal systems:

Sloping lands

- A system to intercept, collect, and carry away water from sloping agricultural lands, both agricultural and nature areas. Most of the water in this system originates from surface runoff. It will be discharged for brief periods only, causing high flow rates and sediment transport;

Flat agricultural plains

- A system to collect and carry away water from a relatively flat agricultural area. Here, the main source of water is precipitation on the area or irrigation. Because of surface detention and groundwater storage, water is discharged over a longer period than above. Furthermore, the flat gradient canals have little or no sediment transport capacity.

3.3.1 Sloping Lands

Sloping lands

If a flat agricultural area is partly surrounded by sloping lands, the surface runoff from these lands should be intercepted and discharged to prevent inundation of the agricultural area. The extent to which drainage problems in the agricultural area are caused by this surface runoff should be determined by making a water balance of the area.

High discharges and erosion

Runoff from sloping lands causes two major problems in the downstream areas; (i) rainfall causes high discharges of short duration, (ii) the surface runoff causes erosion, and the related sediment transport down the steep gradient of the canals causes sedimentation in the flatter canal sections.

Both problems can be eased by a combination of the following measures:

- Planting trees and encouraging the growth of natural vegetation on steep slopes;
- Contour ploughing and terracing intermediate slopes (up to 10%). Terracing is the levelling of the slopes along the contour lines in combination with the planting of crops;
- Encouraging the growth of crops that give a soil cover during the rainy season;
- Constructing retention reservoirs in the streams to temporarily store peak runoff.

These techniques are a form of erosion control; their application greatly eases the downstream drainage problems.

In sloping areas, the main drainage system usually will be limited to the reconstruction of channel reaches and to the construction of energy dissipators.

Routing

Streams originating in sloping areas can be connected to a major river, lake, or sea along two alternative routes; (i) via an interceptor canal, which channels the water around the agricultural area to a suitable outlet, or (ii) via a canalized stream through the agricultural area.

The major advantage of the interceptor canal is that peak discharges and sediments from the sloping lands do not disturb the functioning of the drainage system in the flatter agricultural area.

Limiting discharge rates

It is possible to limit the required discharge capacity of a channel that transports water from sloping lands to a suitable outlet if the channel discharges from one of the following two structures:

- A retention reservoir that is filled by the peak stream flow, which is then released through a bottom outlet. As a result, the discharge peak is lower, but of longer duration;
- A regulating structure that consists of a weir of limited discharge capacity in the stream and a side weir immediately upstream of it. If the stream flow exceeds a predetermined rate, it overtops the crest of the side weir. Most of the additional stream flow then discharges over the side weir into an area where inundation or overland flow causes little damage.

Which of these two lay-outs (or an intermediate lay-out) is the best solution can usually only be decided after a reconnaissance study.

3.3.2 Flat Agricultural Areas

The agricultural areas that require drainage are usually coastal plains, river valleys, or plains where excess rainfall and/or the inefficient use of irrigation water has caused waterlogging. In coastal plains, the drainage problems are exacerbated by several hydrological features, typical of such plains, being:

Problems related to drainage

- Gentle hydraulic gradient of the rivers in the coastal plain, which leads to low flow velocities and the deposition of sediments;
- Tidal levels in river water levels near the sea and of saline water intrusion;
- A complicated network of river branches and ramifications, which can cause natural drains to disappear in coastal swamps giving the river or stream what is known a "bad outlet";
- Rapid changes in channel configuration that can occur after each major flood;
- Low elevation of the coastal lands with respect to the level of rivers and the sea. To prevent the inundation of the coastal plain, dikes along the rivers and the sea shore are essential.

Examples of lay-outs

To illustrate alternative lay-outs for a drainage canal system, let us consider an irrigated coastal plain that lies between sloping lands (hills) and the sea. The plain is intersected by parallel rivers and streams and by an irrigation canal system. Depending on factors such as run-off from the sloping land, construction and maintenance cost of canals, quality of drainage outlets, etc., alternative lay-outs can be considered:

- Combined system: the sloping land and coastal plain are drained by one combined system
- Separate system for sloping lands: the sloping land and coastal plain are drained by three separate systems
- Two drainage systems in a coastal plain: the sloping land and coastal plain are drained by four separate systems.

Combined Drainage System

Combined drainage system

Figure 9 shows a drainage canal layout that combines the drainage system of the sloping land with that in the plain. All run-off from the sloping land is intercepted and carried away by canalized streams. These streams, and the lateral drains along the river dikes, flow into a main drainage canal that runs parallel to the sea dike. One drainage sluice with a well-defined, stable (suitable) outlet has been planned on that drain. The other streams are dammed by the sea dike. Concentrating all the drainage water discharge through one sluice eases sedimentation problems in the outlet canal.

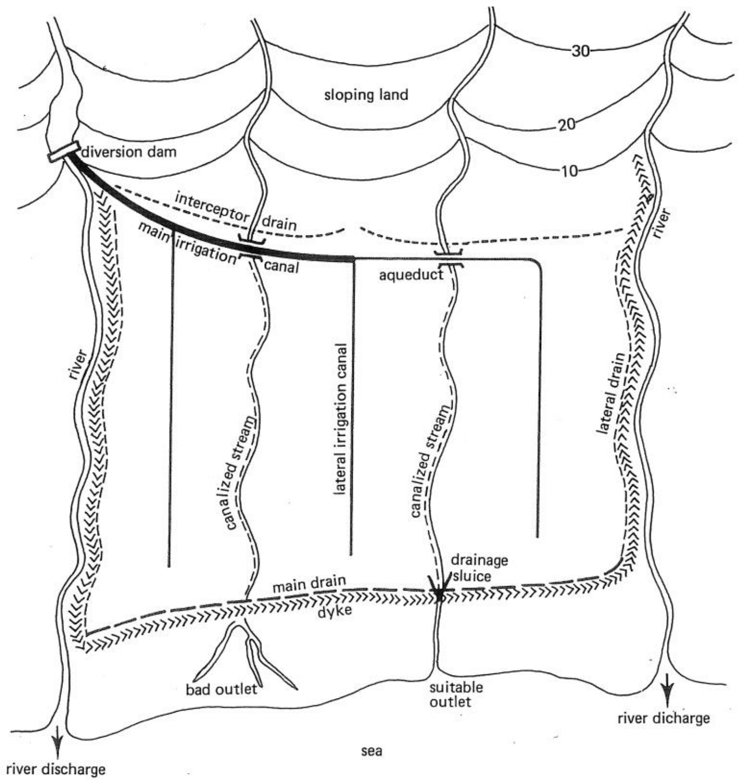


Figure 9 Combined system: the sloping land and coastal plain are drained by one combined system

Separate System for Sloping Land

Separate system for sloping lands

If relatively high discharges come from the sloping lands, or if the plain is wide, intercepting and diverting streams into the nearest river is a sound alternative to the lay-out of the combined system. The streams are dammed and the interceptor drains discharge all water from the sloping lands through two sluices into the rivers (Figure 10). As a result, the coastal plain has a separate drainage system that discharges precipitation, unused irrigation water, and groundwater inflow. Drainage has been decentralized into three independent systems: two for the sloping land and one for the coastal agricultural area.

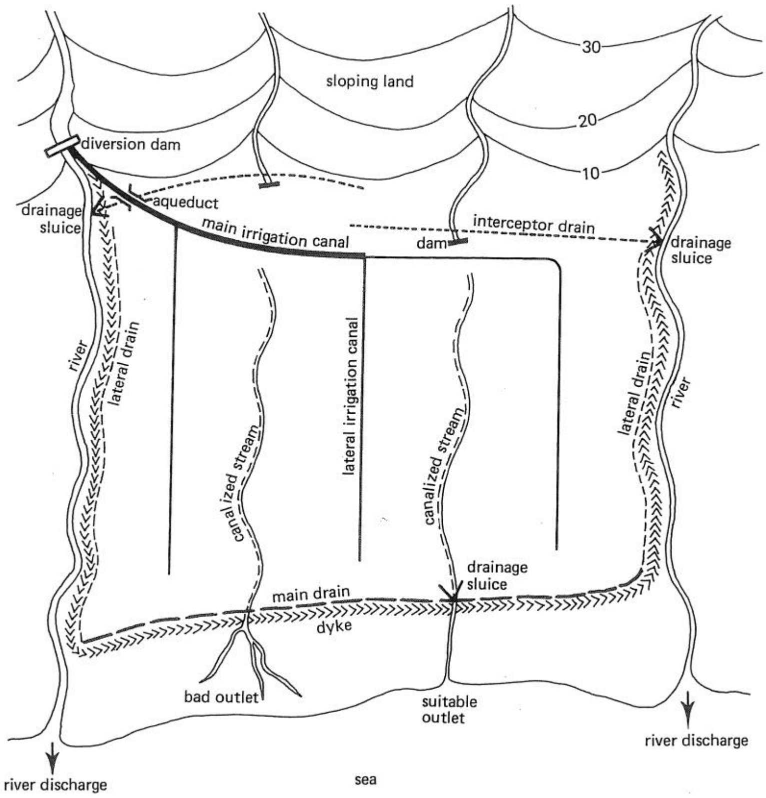


Figure 10 Separate system for sloping lands: the sloping land and coastal plain are drained by three separate systems.

Two Drainage Systems in a Coastal Plain

Two drainage systems in a coastal plain

The transport of mud and sand along a coastline often blocks the outlets of all minor streams into the sea, and dredging may be needed to maintain a sufficient depth at the river mouths. Under such circumstances, none of the stream mouths is suitable as a drainage outlet. Water that is collected by the main drain along the coastal dike is then discharged into the nearest river. Figure 11 shows four separate drainage canal sub-systems: two for the sloping lands and two for the coastal plain.

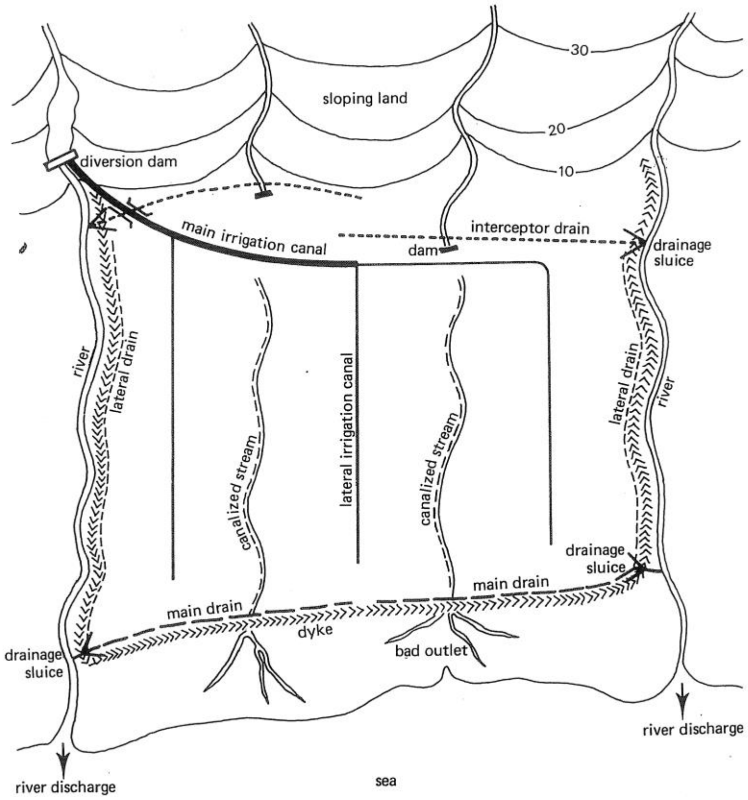


Figure 11 Two drainage systems in a coastal plain: the sloping land and coastal plain are drained by four separate systems

Exercise no. 4 Design options for main drainage systems
In this section three alternative options for the layout of a main drainage system have been discussed. These options depends on, among others, the topography, the climate, the location in the catchment, size of the area, etc. Discuss the advantages and disadvantages of these design options. Similar to the other exercises try to relate the discussion to the conditions in your own country.

3.3.4 Planning the layout of a main drainage system

Location of drainage channels and related structures

To determine the location, hydraulic properties, visual characteristics, and condition of existing channels, planned canals, and related structures, one needs a 1:10 000 scale topographical map with a contour interval of 0.50 m or less, and a 1:10 000 controlled photo mosaic. Maps, especially in flat topography, should be field checked. This step should be done in the earliest planning stage to avoid the need for major revisions later. The following information is needed to plan a canal system (adapted from U.S. Dept. of Agriculture 1977):

1. Layout of the drained area and the junctions of existing streams and all flow control points. Drainage areas should also be delineated for the "land level units";
2. Approximate profiles in existing channels, showing the elevation of the channel bottom, low bank, points of natural low ground away from but subject to drainage into the channel, and elevation and dimensions of all structures in or over the channel. The condition and serviceability of all structures should be recorded. Adequate survey data are needed for all

structures to compute the discharge capacity for each;
3. Representative channel and valley cross sections for each hydraulic or economic reach. Additional cross sections should be taken as needed for a reliable estimate of: quantities of excavation and land clearance, damage evaluation in the plain or valley because of high water levels, and to permit the computation of storage in flood plains, ponds and marshes;
4. Manning's roughness coefficient 'n' for each existing channel. Even if channel elements are very uniform, the n value should be estimated for each 1-km reach;
5. Location and elevation of all soil investigation sites along the proposed canals. To determine the maximum permissible velocities and bank slopes, soil investigations should extend to a depth of at least 3 m below the anticipated future canal bottom (Figure 12). Use the Unified Soil Classification of Section 19.3.4;
6. Landscape character and use patterns along major existing and anticipated drains. Data must include: scenic views, area and density of brush and trees, and isolated but valuable trees;
7. Location and ownership of boundary lines in the vicinity of all probable canals and structures;
8. Other significant features that will be affected such as roads, pipelines, power and telephone lines, buildings, wells, cemeteries, and fences.

Field investigations for canal alignment

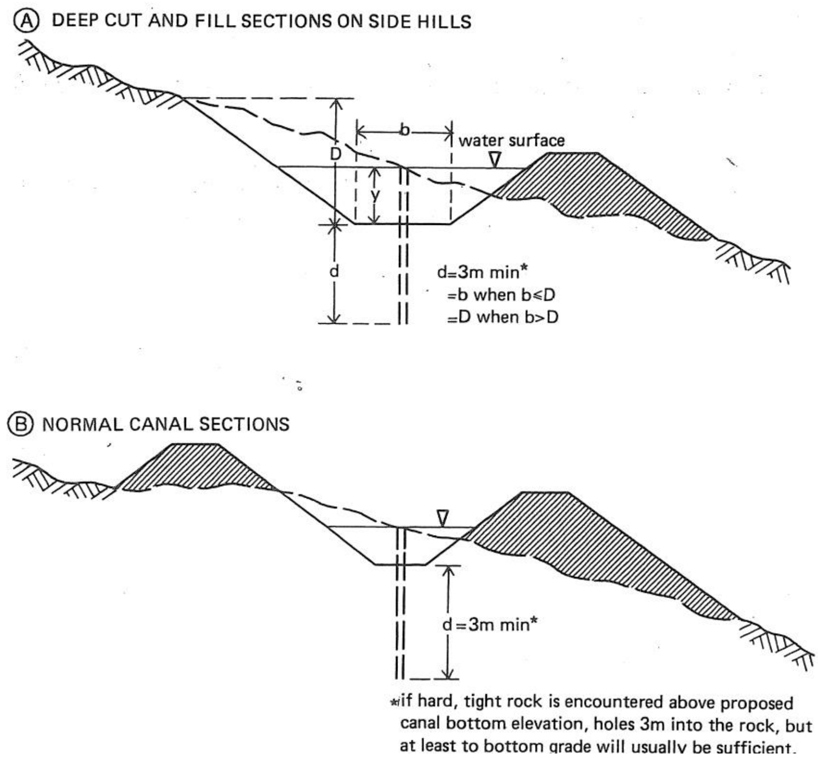


Figure 12 Depth of preliminary exploratory holes for canal alignment (after U.S. Bureau of Reclamation, 1973)

Preparing a preliminary design

Based on the above information, the center line of all the canal system is drawn in pencil on the photo mosaic, showing curves, intersecting angles, and so on. Mark the stationing on these center lines with a short dash at each 100-m point.

After this preliminary design phase at the office, the canal location should be field-checked. For this check, one should walk the full length of the canal's center line, noting the following on the preliminary design drawing:

- Probable realignment of the center line;

- Points of significant breaks in the grade;
- Location of all rock outcrops or critical soil conditions;
- Approximate locations of points where more cross sections could be obtained;
- Location of significant canal junctions and places where side inlets may be needed;
- If not already visible on the aerial photo, note the location of all buildings, utilities and structures that may be affected by the drainage canal works. These include, but are not limited to, facilities that are within 100 m of the alignment and 1 m below the future canal bottom;
- Location of valuable landscapes and large individual trees adjacent to the alignment.

Following the field check, one should accurately establish the revised center line on the photo mosaic. The final alignment should be based on the previous cross sections, and geological and environmental data. Indicate on the photo mosaic where the cross sections and soil surveys were made.

3.3.5 Schematic Map of the Main Drainage System

Schematic map of main drainage system

Maps showing the layout of a drainage canal system must give detailed information on the location of canal reaches and related structures. Normally, this information is given on the same map that shows the irrigation canal system, roads, and the boundaries of irrigation units. To keep such maps legible, standard symbols must be used to indicate the center line of the canals and related structures. The schematic map in Figure 13 uses these symbols. It shows:

- Location of the center lines of drains and irrigation canals, numbered for each reach;
- Radii of the center lines;
- Reserve boundaries of canals and boundaries of any adjacent obstructions, roads, and land level units. The area of land level units must be shown also;
- Boundaries and number of irrigation units (if applicable);
- All structures, numbered and with position dimensioned with respect to center lines or boundaries;
- North point and scale.

Example of a schematic map

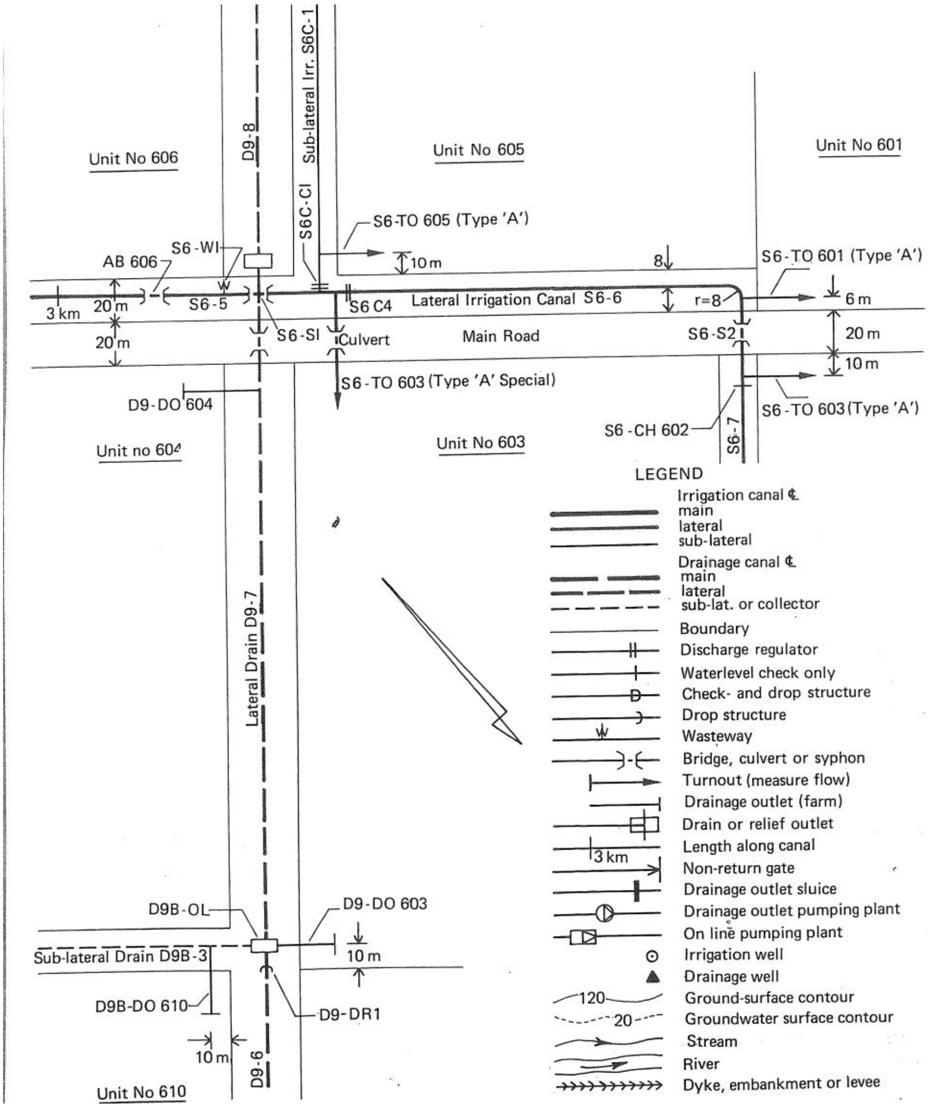


Figure 13 Example of a schematic map

Longitudinal profiles

A schematic map must be supplemented by longitudinal profiles of all main and lateral canals. On both the map and longitudinal profile, a certain notation has been used to identify a canal reach and its related structure. After the system has been constructed, this notation must also appear on the structure. The notation consists of two parts: (i) the number of the canal and (ii) the number of the canal reach or the structure identification number. It is presented in the following table.

Notation for canals and related structures

Notation for canals and related structures

Type of canal or structure	First part of notation (i)	Second part of notation (ii)	
Drainage canal:			
main	MD		
lateral	D9	Number only; assigned	
sub-lateral	D9B }	consecutively from	
Irrigation canal:		upstream end of canal	
main	MS	or drain	
lateral	S6		
sub-lateral	S6C		
Discharge regulator		C	Plus number;
Water-level check		CH	assigned
Drop structure		DR }	consecutively
Check-and-drop structure		CD	from upstream
Wasteway		W	end of canal or
Bridge, culvert, or syphon		S	drain
On-line pumping plant		P	
Turnout (measures flow)		TO	Number of
		DO }	structure;
Drainage outlet (farm)		SW	identical to farm
Irrigation well		DW	block number
Drainage well		AB	or number
Farm access bridge			of irrigation unit served or adjacent
Drain or relief outlet		OL }	No number
Non-return gate		NG	
Drainage outlet sluice			
Drainage outlet pumping station }		Proper name only	
River diversion dam			
Storage dam			

Exercise no. 5 A common main drainage system in your own country

Describe the main features of a common main drainage system in your own country, discussing details as:

- Topography
- Land type: coastal plain or upstream area
- Functions of the main system
- Main constraints
- Options for improvement

4 Examples of drainage systems

Self study

ILRI Publication 16 – Chapter 17.5
ILRI Publication 60 – Part III – Case studies

Role of drainage varies between the different agroclimatic zones

The role of drainage varies between the different agroclimatic zones. In the temperate zone, mainly located in the northern hemisphere, the role of drainage is to prevent waterlogging by removing excess surface and subsurface water resulting from excess rainfall. In the arid and semi-arid zone, the role of drainage is to prevent irrigation-induced waterlogging and salinity, not only by removing excess surface and subsurface water but also by removing soluble salt brought in by the irrigation water. In the humid and semi-humid zone, the role of drainage is to prevent waterlogging and salinization to various degrees. About 64% of the drainage is located in the temperate zone, 24% in the arid and semi-arid zone and 12% in the humid and semi-humid zone.

4.1 Rainfed lands in the temperate regions – example from The Netherlands

Historical developments

Example from the Netherlands

In the Netherlands, 25% of the land is below sea level and about 65% of it would be flooded where it not for the dikes (Figure 14).

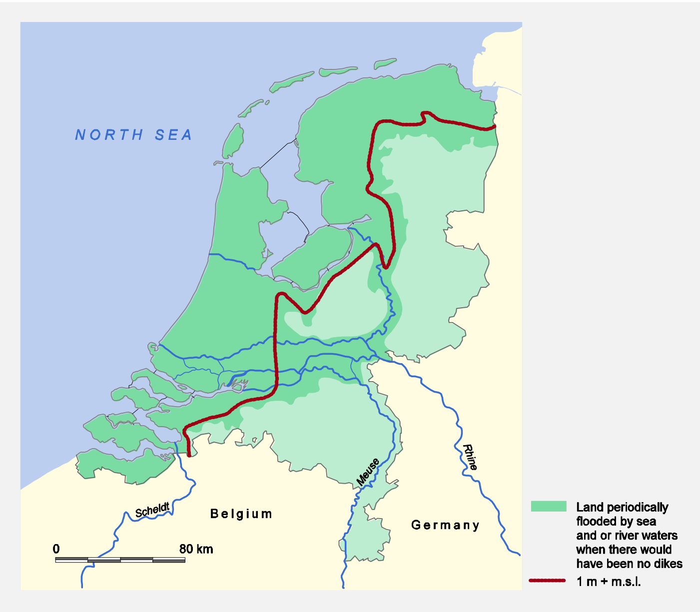


Figure 14 Land periodically flooded by sea and river

Climate

The climate is relatively mild with an average annual rainfall of about 725 mm and an annual evaporation of about 475 mm (Figure 15). The removal of excess rainfall in combination with the low elevation, the lowest area is 6.5 m below mean sea level, requires an intensive drainage system to keep one's feet dry, both man and crops. The expansion of agriculture in the Netherlands started some 1000 years

Agricultural development since 1000 AD

ago with a gradual change from shifting cultivation towards a more permanent development and occupation of the land. Farmers had to learn to organise themselves to mobilise enough labour and capital under evolving authorities: abbeys (1000-1200 AD), feudal rulers (1200-1500), locally organised groups (1300-1500) and water boards (1300-present). Moreover the water management was influenced by private or municipal land reclamation companies and peat mining companies (1500-1700), companies to drain and reclaim lakes (1500-1900), and governmental services to reclaim lakes, swamps and heath lands (1900-2000). Field drainage has always been the responsibility of the land user and the main drainage systems the responsibility of the above-mentioned institutions. Exceptions are the large-scale, government-supported, land reclamation and land consolidation projects in the second half of the 20th century: in these projects, both the field and main drainage systems were implemented by a Government agency.

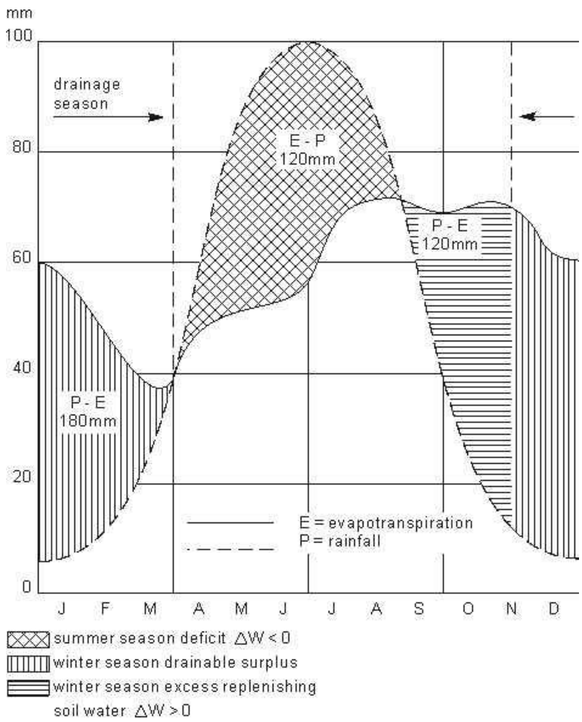


Figure 15 Monthly values of rainfall, evaporation, storage and drainage surplus in The Netherlands

Large-scale reclamations in the 20th century

Large scale reclamations

The generally felt need for better agricultural production conditions in the 20th century resulted in a number of government-financed, long-term programmes in which the construction of subsurface drainage systems was a significant part. Important programmes were the land reclamation programme in the former Zuiderzee area and the rural development programmes on the "*old lands*", the so-called land consolidation projects. The public organisations involved in these programmes were the IJsselmeerpolders Development Authority for the newly reclaimed areas and the Government Service for Land and Water Use for the "*old lands*". Both organisations were multi-purpose organisations whose tasks included drainage installation. The IJsselmeerpolders Development

IJsselmeerpolders Development Authority

Authority carried out most of the works themselves in forced account. The construction of drainage systems in the land consolidation projects was carried out by consultants and contractors under contract with Government Service for Land and Water.

Commonly used subsurface drainage system

Singular pipe field drains, open collector and main drains and a pumped outlet

In the Netherlands, subsurface drainage systems are used in almost all agricultural lands, except in the peat areas, where a high groundwater table is require to reduce subsidence and only shallow open drainage systems are used. The most commonly installed subsurface drainage system is a singular system with piped field drains discharging into open collector drains (Figure 16). The main function of the field drains is to control the watertable level. The corrugated plastic field drains (Ø 60 mm) are installed at a depth of 1.0 to 1.3 m. In fine or reduced (risk of ochre formation) soil layers, voluminous organic (coconut fibres) envelopes were used in the past, but they have been replaced by synthetic pre-wrapped envelopes. Depending on the drain depth and soil texture, installation is done by either trencher or trenchless drainage machines. The discharge from the subsurface field drains and the surface runoff is removed by gravity through a system of open collector drains.

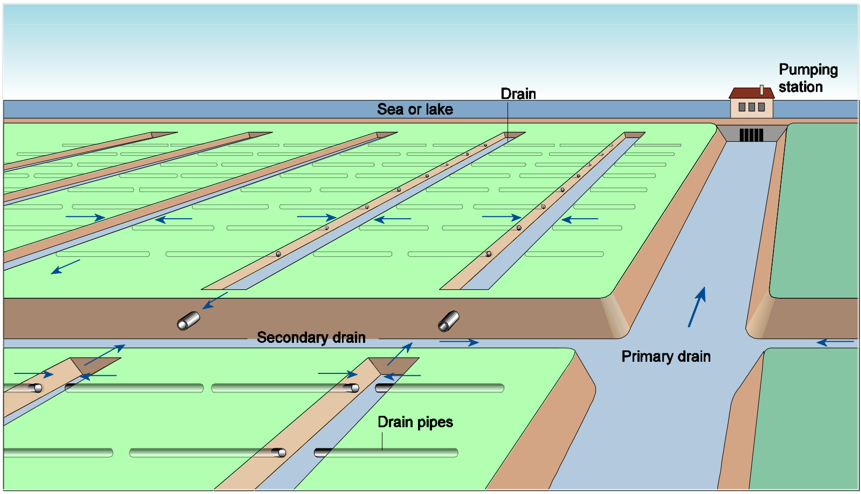


Figure 16 The single subsurface drainage system in the Netherlands consists of pipe field drains, open collector, secondary and primary drains and a pumping station.

Design criteria for the open collectors

The design criteria for the open collector drains are based on two criteria (Figure 17): a high water-level criterion (HW) and a normal water-level criterion (NW). The HW criterion specifies that the water level in the collector may exceed a level of 0.5 m below the soil surface only 1 day a year. The NW criterion specifies that the water level in the collector may exceed the outfall level of the field drains (i.e. 1.0 to 1.1 m below soil surface) no more than 15 days a year. For collectors serving small areas, the second criterion is the most critical and will therefore be adopted for the design, whereas for collectors serving large areas, the first criterion is the appropriate one.

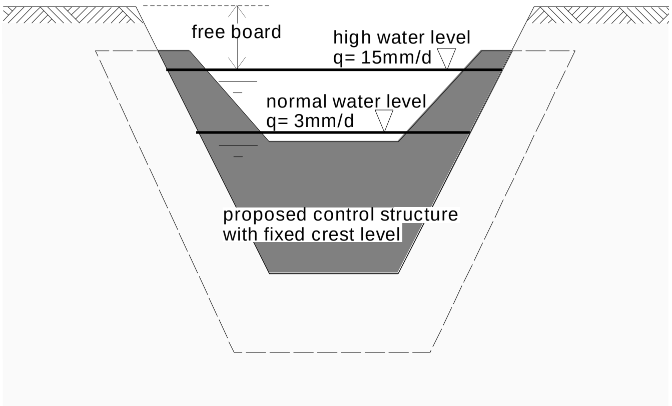


Figure 17 High water-level (HW) and normal water-level (NW) criteria used in the Netherlands for the design of collectors.

4.2 Irrigated lands in arid and semi-arid regions - example from Egypt

Climate

Egypt's Nile Valley and Delta, one of the oldest agricultural areas in the world, has been under continuous cultivation for at least 5000 years. Egypt has an arid climate, characterised by high evaporation rates (1500-2400 mm/year) and little rainfall (5-200 mm/year), thus agriculture depends almost entirely on irrigation from the river Nile (Figure 18). From ancient times onwards, irrigated agriculture in the Nile Valley and Delta depended on the annual floods of the River Nile.

Aswam high dam

The receding floods also drained and leached the cultivated areas. The construction of the Aswan High Dam in 1964 ended the annual flooding but made irrigation water available throughout the year. Since then, two to three crops can be grown each year, resulting in a practical continuous growing season.

These developments had as a secondary effect that the natural annual drainage and leaching ceased to exist.

Need for drainage

The absence of this natural drainage and leaching, in combination with the intensification of agriculture, made it necessary to provide the Nile Valley and Delta with an artificial drainage system to control water logging and salinity. Although the quality of the water from the River Nile is good (EC = 0.3 dS/m), salinity control is needed; otherwise over the years salt will be accumulated in the root zone. Therefore, in the 1960's, the Egyptian Government started an ambitious programme to drain all of Egypt's agricultural land (approximately 2.5 million ha). This programme is expected to be completed around 2012. Since the 1960, organisational reforms, the local production of drainage materials, mechanisation of the installation together with the necessary basic and operational research has resulted in a drainage organisation and drainage industry that has an annual implementation capacity of about 75 000 ha.

Figure 18 Agricultural land in Egypt

Composite field drainage system, open main drainage system a pumped outlet

The drainage systems in Egypt consist of a network of piped field drainage systems and open main drains (Figure 19). The field drainage system consists of subsurface field (lateral) and collector pipes that runs by gravity. The piped collectors discharge into open main drains from where the drainage water is pumped into large open gravity drains which eventually discharge into the River Nile or the sea. Pumping is necessary almost everywhere in the Delta and the Valley, expect in some areas in Upper Egypt, where there is enough gradient to dispose of the effluent freely by gravity.

The main function of the field drains is to control salinity; the corresponding design discharge rate is 1.0 mm/d. The corrugated plastic field drains (Ø 80 mm) are installed at a depth of 1.2 to 1.5 m, a spacing of 40 to 80 m and a length of 200m. The collector drains are also pipes, this is possible because the design discharge rates are small: 4 mm/d for rice areas and 3 mm/d for non-rice areas. These rates are slightly higher than the rate used for the field drains, because it is assumed that the collectors also evacuate some excess irrigation water. Collectors are nowadays also made of plastic pipes (in the past concrete pipes were used), the depth varies between 1.5 and 2.5 m, the spacing is about 400 m (twice the length of the field drains). The diameter increases from the upstream end (Ø 100 mm) to maximum 500 mm near the outlet.

Implementation process

The implementation of drainage systems involves the following steps:

- Construction of open main drains or the remodelling of the existing main drains;
- Construction of drainage pumping stations to keep the water

level in the open main drainage system at 2.5 m below field level so that the piped systems can discharge by gravity in these main drains;
- Construction of piped field drainage systems consisting of field drains (named laterals in Egypt) and piped collector drains.

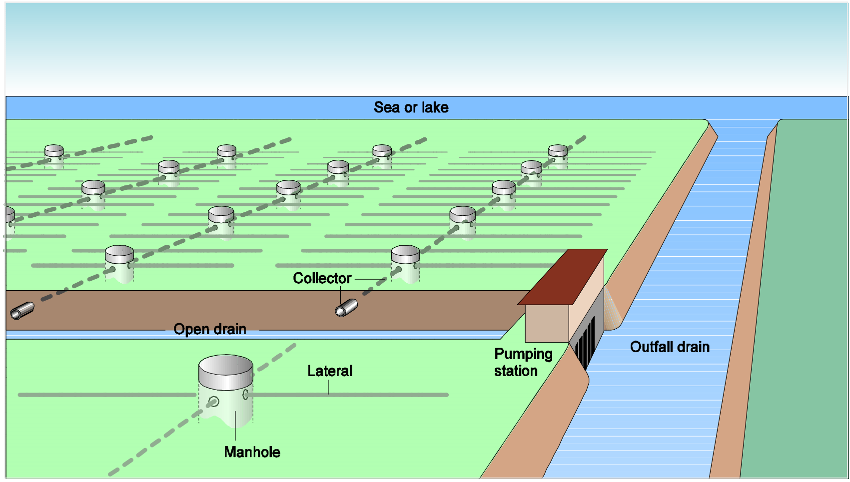


Figure 19 Schematic representation of the drainage system used in Egypt

4.3 Drained lands in the humid tropics - example from Malaysia

Climate

The climate in Malaysia is characterised by its uniform temperature, high humidity, and high rainfall intensity. It is influenced by two monsoon winds, namely the Northeast Monsoon from November to February and the Southwest Monsoon from April to September. The mean monthly temperature is stable, varying between 24°C and 27°C. The rainfall is higher than the annual evaporation (Figure 20). The evaporation is fairly constant. The rainfall, however, is much more irregular, both in time and space. There are significant, and often consistent, differences between the different regions; for example the rainfall in Pontian in the south western part of Peninsular Malaysia is around 2500 mm/yr compared to 3600 mm/yr in Mukah, in Central Sarawak. These differences are linked closely to the average rainfall intensity and not so much to the number of days of rainfall.

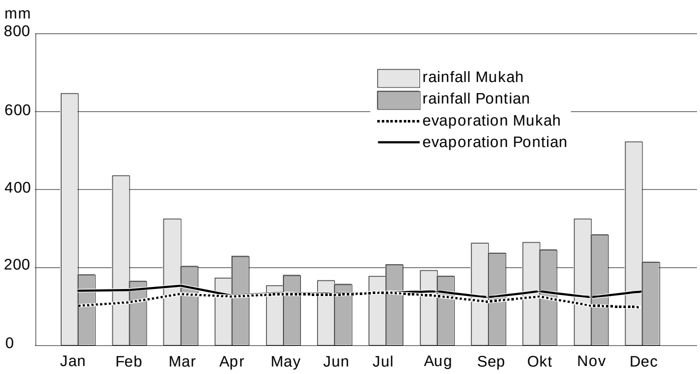


Figure 20 Long-term average monthly rainfall (P) and evaporation (ET) in Pontian (Western Johore) and Mukah (Sarawak)

Open drains

Two seasons can be distinguished: the rainy or monsoon season and the dry season. As rainfall exceeds evaporation in the monsoon (or rainy) season drainage is needed to remove excess rainfall and to control the water levels in the field. In the dry season, when evaporation is more or less equal to the rainfall, control structures are used to reduce drainage in order to avoid water stress in the root zone (Figure 21).

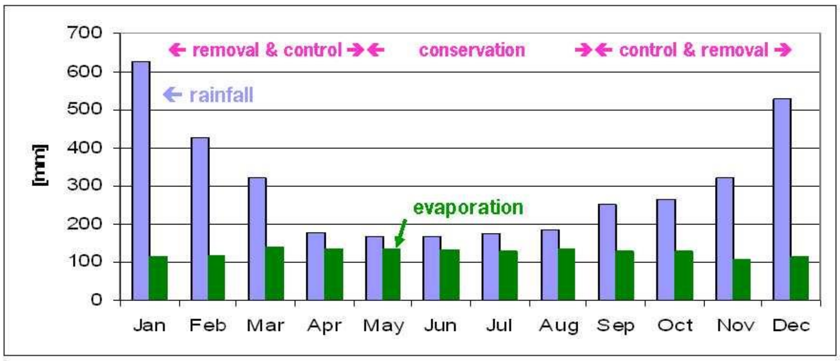


Figure 21 In the rainy (or monsoon) season drainage is needed to remove excess rainfall, in the dry season control structures are needed to conserve the water.

Because of the high rate of excess rainfall, drainage systems consist of open field and main drains. The design criteria are based on an extreme rainfall with a return period of 1 x 5 years. To minimize costs, the design for the secondary drains follows the steepest possible gradient, i.e. perpendicular to the contour lines. As an example the main characteristics of the drainage system for the Western Johor Integrated Agricultural Development Project, located in the south western part of Peninsular Malaysia (Figure 22), are:

	Secondary drains	Tertiary Drains
Spacing (m)	800	200
Design depth (m)	1.6	0.9
Design discharge (mm/d)	52 - 86	52
Design discharge (l/s/ha)	6.0 - 10.0	6.0
Duration of flooding (hours):		
- coconut, rubber, oil palm, orchards		72
- banana, cocoa, coffee, papaya		48
- maize, sorghum, and pineapple		24
- tobacco, vegetables		0

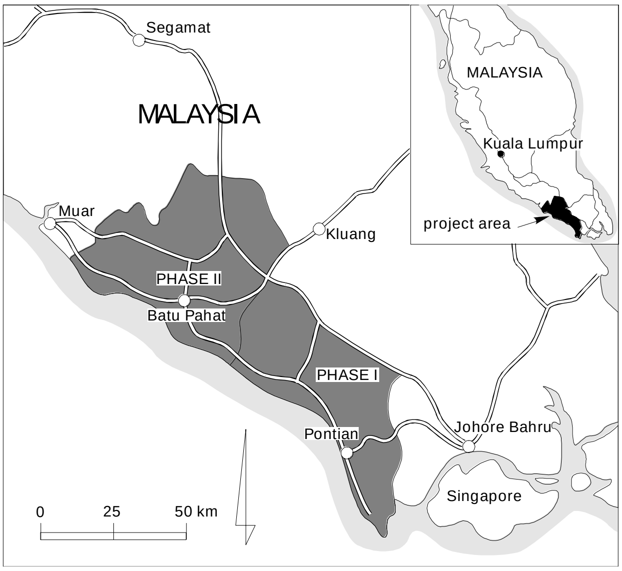


Figure 22 Location of the Western Johor Integrated Agricultural Development Project

Exercise 6: Comparison design criteria between the 3 regions

In the examples, drainage practices in three climatic regions were discussed, i.e. The Netherlands as an example from a country in the temperate zone, Egypt, an example from a (semi-)arid region and Malaysia in the humid tropics.

Discuss the differences between the drainage systems in these three regions.

Bibliography

(Ref: ILRI Publication 60)

DRAINAGE OF CLAY SOILS

1995 Rycroft, D.W. and M.H. Amer. *Prospects for the Drainage of Clay Soils.* Irrigation and Drainage Paper No. 51. FAO, Rome. 52 pp.

This bulletin discusses the drainage of clay soils. The book starts with a discussion of the physical and chemical properties of clay soils, the movement of water and salts in these soils and then reviews the techniques to drain and reclaim heavy clay soils. Case studies of drainage of heavy clay soils in Yugoslavia, Portugal, Spain and Egypt are included.

DRAINAGE DESIGN

1984 Framji, K.K., B.C. Garg, and S.P. Kaushish. Design Practices of Open Drainage Channels in an Agricultural Land Drainage System : A Worldwide Survey. ICID, New Delhi. 343 pp.

This volume on open drainage channels consists of two parts: Part I is devoted to a general review of the design aspects of open drainage channels: system lay-out, design capacity, channel shape, roughness coefficient, permissible channel velocity, longitudinal channel slope, side slope; Part II contains the country reports of Australia, Bangladesh, Canada, Colombia, Czechoslovakia, Egypt, France, Federal Republic of Germany, German Democratic Republic, Great Britain, Greece, India, Iraq, Ireland, Japan, Malaysia, Morocco, Portugal, Saudi Arabia, Sudan, and the U.S.A.

1980 Food and Agriculture Organisation of the United Nations. *Drainage Design Factors*. Irrigation and Drainage Paper No. 38. 1980. FAO, Rome. 52 pp.

This manual, which is based on an expert consultation, gives 28 questions and answers regarding drainage design factors.

1980 U.S. Department of the Interior, Bureau of Reclamation. Drainage Manual – A guide to integrated plant, soil, and water relationships for drainage of irrigated lands. U.S. Government Printing Office, Washington, 286 p.

The manual contains the engineering tools and concepts that have proven useful in planning, constructing, and maintaining drainage systems for successful long-term irrigation projects. Although the manual is not a textbook, it provides drainage engineering with a ready reference and guide for making accurate estimates of drainage requirements. All the methods and techniques covered in the manual have proven to be very satisfactory through observed field conditions on irrigated lands in the USA but also in other parts of the world.

DRAINAGE GUIDELINES

1992 Ochs, Walter J. and Bishay G. Bishay. *Drainage Guidelines.* 1992. World Bank Technical Paper Number 1995, The World Bank, Washington. 186 pp.

This paper provides research results for and experiences with agricultural drainage and related subjects. It has been developed to guide Bank staff, consultants, and borrowing-country technicians as they work through the project cycle, seeking to assist planners and designers, as well as those responsible for implementation and follow-up, when projects involve drainage measure.

1990 Schultz, B. *Guidelines on the Construction of Horizontal Subsurface Drainage*

Systems. International Commission on Irrigation and Drainage, New Delhi. 236 pp.

These guidelines give general criteria and recommendations for the construction of horizontal subsurface drainage systems. The book starts with an inventory of subsurface drainage systems and then briefly reviews design aspects. It gives attention to drainage materials and to equipment to install the drains. It then recommends construction methods, and describes operation and maintenance. Finally, it treats the cost-benefit analysis of projects. Includes a glossary.

1983 Food and Agriculture Organisation of the United Nations. *Guidelines for the Preparation of Irrigation and Drainage Projects*. Revised Edition. FAO, Rome. 31 pp.

Gives guidelines for the main text of a feasibility study, which provides the answers to questions that might be raised in the course of project appraisal.

DRAINAGE MATERIALS

2001 Vlotman, W.F., L.S. Willardson, and W. Dierickx. 2001. *Envelope Design for Subsurface Drains*. ILRI Publication 56, ILRI, Wageningen, 358 p.

The book is a compilation of the most recent information on how to design and select envelope materials for agricultural drains. It is especially valuable for drainage engineers, contractors, drainage-equipment manufacturers, students, teachers, and researchers who need to understand soil-hydraulic conditions and how to prevent soil particles from moving into drains so that they can design successful subsurface drainage systems. The publication consists of two parts. In part one, guidelines for the design of envelopes for subsurface drains are presented, it includes the following subjects: the needs for a drain envelope, material selection, design, cost, implementation, maintenance and evaluation. Part two, the "resources" section, presents the back-ground of drain envelope design, the theory and testing of existing design criteria and experiences.

2000 Stuyt, L.C.P.M., W. Dierickx and J. M. Beltrán. *Materials for subsurface land drainage systems.* Irrigation and Drainage Paper No. 60. FAO, Rome, 183 p.

This paper provides practical information to drainage engineers and contractors for the selection, installation and maintenance of drainage materials as well as specifications and standards for such materials. In addition, the manual also contains practical guidelines for the implementation of laboratory and field investigations to evaluate the performance of drainage materials.

1970 Food and Agriculture Organisation of the United Nations. *Drainage Materials*. Irrigation and Drainage Paper No. 9. FAO, Rome. 122 pp.

This manual gives an overview of the materials used in the construction of pipe drainage systems.

DRAINAGE PLANNING, DESIGN AND MANAGEMENT

2004 Smedema, L.K., W.F. Vlotman and D.W. Rycroft. Modern Land Drainage: Planning, Design and Management of Agricultural Drainage systems. 450pp.

New edition of the publication Land Drainage (published in 1983). The book is based on traditional drainage methods for rainfed agriculture in the humid temperate zone. Significant parts are devoted to drainage for salinity control of irrigated lands in (semi-)arid zones, and to drainage of rice land in the humid tropics. Institutional, management and maintenance aspects are covered, as well as the mitigation of adverse impacts of drainage interventions on the environment. Moreover, various applications for drainage design and management are treated. The book is intended for use both as a university level textbook and as a professional handbook.

1983 Smedema, L.K., and D. Rycroft. *Land Drainage: Planning and Design of Agricultural Drainage Systems*. Batsford Academic and Educational Ltd., London, United Kingdom. 376 pp.

The text discusses the diagnosis of agricultural drainage problems and their solutions, based on an understanding of the physical principles involved. Land drainage is treated as being a field of applied soil physics and applied hydrology. All major drainage problems are covered, each in its particular environment and field of application: Groundwater Drainage; Watertable Control; Surface Drainage of Sloping and Flat Lands; Shallow Drainage of Heavy Land; Drainage for Salinity Control in Irrigated Land; Drainage and Reclamation of Polders; Drainage for Seepage Control; Main Drainage: Design Discharges, Canal Design, Outlets. The book stresses the universal relationships between the main design variables and soil, climatology, and other relevant environmental conditions.

DRAINAGE PRINCIPLES AND APPLICATIONS

2007 Ritzema, H.P. (Editor-in-Chief). *Drainage Principles and Applications, Third Edition*. ILRI Publication 16, ILRI, Wageningen, 1125p.

This completely revised second edition on drainage principles and applications is based on lectures delivered at the International Course on Land Drainage, which is held annually by the International Institute for Land Reclamation and Improvement, Wageningen, The Netherlands. The book presents the basic principles of land drainage with applications. The book provides a coverage of all the various topics useful to those engaged in drainage engineering. Includes a glossary. Also available is a Spanish version published in 1977, entitled: Principios y Aplicaciones del Drenaje (en cuatro volúmenes).

DRAINAGE SYSTEMS

1999 Skaggs, R.W., J. van Schilfgaarde (Ed.). *Agricultural Drainage.* Number 38 in the series Agronomy, American Society of Agronomy, Madison, USA, 1328 p.

This monograph summarises the information developed during the past two decades and deals with the many aspects of contemporary agricultural irrigation and drainage systems, placing these systems into the perspective of comprehensive water management. It can serve as the scientific basis for decision-makers in developing management strategies to improve the soil conditions of the field and protect water quality from contamination by cropping practices. The 42 chapters which contributions from 71 scientists and professions are presented in 12 sections: I) Introduction; II) Overview of drainage and crop production; III) Soil water movement in drained lands; IV) Movement and fate of solutes in drained lands; V) Modelling in the performance of drainage systems; VI) Drainage for salinity control and reclamation; VII) Water table control; VIII) Hydrology and water quality impacts of drainage; IX) Planning and design of drainage systems; X) Drainage methods and materials; XII) Special drainage problems; XII) Determination of soil properties for drainage design, and; XII) Socio-economic impacts of agricultural water management systems.

DRAINAGE TESTING

1976 Food and Agriculture Organisation of the United Nations. *Drainage Testing*. Irrigation and Drainage Paper No. 28. FAO, Rome. 172 pp.

This publication gives guidelines on how to test the functioning and adequacy of single drains and drainage systems.

DRAINAGE TRAINING MANUALS

1996 Ritzema, H.P., R.A.L. Kselik and F. Chanduvi. *Drainage of Irrigated Lands.* Irrigation

Water Management Training Manual No. 9. Food and Agricultural Organisation of the United Nations, Rome, 74 p.

Drainage of Irrigated Lands is the ninth in a series of training manuals on irrigation. The manual is intended for use by field assistants in agricultural extension services and irrigation & drainage technicians at the village and district levels who want to increase their ability to deal with farm-level irrigation and drainage issues. It discusses the needs for drainage in irrigated areas, focusing on drainage at farm level. It reviews the systems that are available to drain irrigated lands and explains which factors of soil and hydrology influence drainage. It touches briefly upon the design, construction, operation and management of field drainage systems.

CASE STUDIES

Egypt

2003 Advisory Panel Project on Water Management. *Precious Water: a celebration of 27 years of Egyptian- Dutch Cooperation.* APP Central Office, Cairo, Egypt, 84 p.

The booklet published through the Secretariat of the Egyptian-Dutch Advisory Panel on Water Management, on the occasion of the Third World Water Forum, March 2003, presents an overview of an unique 27-year cooperation between the Governments of Egypt and the Netherlands in the Egyptian-Dutch Advisory Panel on Water Management. This bilateral cooperation on water started, in 1975, on drainage, with a main focus on design and implementation of large-scale drainage systems. Throughout the years of the bilateral co-operation, the Advisory Panel successfully widened its scope from drainage specific issues to water management topics and gradually changed from technical support to policy advice. The main objective of the Panel in its present set-up is to assist the Ministry of Water Resources and Irrigation in carrying out its responsibilities towards managing the quality and quantity of Egypt's freshwater resources more efficiently and effectively. This task is accomplished with an Annual Panel Meeting, Workshops, consultant missions (local and international), Working Group Meetings, Task Forces, etc., coordinated by a Secretariat, based in Cairo, Egypt, and Wageningen, The Netherlands. In the booklet the "nuts and bolts" of the Panel as well as many of the achievements of the last 27 years are described in 13 interviews with Panel members, Officials of the Netherlands Embassy in Cairo, and the Panel's Secretariat.

2003 El Guindy, S., M. Salah El Deen, A. Bazaraa & W. Wolters. *"Seminar on Water Management Development in Egypt, Results of Long-term Egyptian-Dutch Cooperation"*. Proceedings seminar on water management development, 12-14 December 2002, in Hurghada, Egypt. Advisory Panel Project on Water Management, Cairo, Egypt.

The proceedings highlight the results of the long-term, 27 years from 1975-2002, Egyptian-Dutch cooperation on water management. The objectives of the Seminar were threefold:

- To highlight the achievements of more than 25 years of Egyptian-Dutch cooperation
- To reflect on the evolution of the cooperation programme from technology transfer in land drainage towards integrated water management and planning, institutional reform, capacity building and environmental management.
- To exchange experiences, lessons learned, vision for the future of Egypt's water sector and coordination issues of donor cooperation.

The proceedings include the critical success factors for such a bilateral cooperation programme as well as the Main Findings and Recommendations of the Seminar. A CD with all papers and presentations completes the Proceedings.

2001 Drainage Research Project I & II. 2001. *Drainage Research Project I & II, Final Report, Dec 1994 – June 2001.* Drainage Research Institute, Kanater, Cairo, Egypt, 172 p.

The report presents the results of the long-term co-operation of drainage research in Egypt between the Drainage Research Institute (DRI), Egypt and the International Institute for Land Reclamation and Improvement (ILRI), the Netherlands. After a brief sketch of agriculture and agricultural research in Egypt, with emphasis on the activities by DRI, the achievements in the field of design criteria are described in 6 sections: I) Project details; II) Research on design criteria; III) Monitoring and evaluation; IV) Research on drainage technology; V) Crop production and water management; VI) Research Management. The report concludes with a list of publications by the project.

2000 H.J. Nijland (Ed.) *Drainage along the River Nile.* RIZA Nota nr. 2000.052, Ministry of Public Works and Water Resources, Egypt, Ministry of Transport, Public Works and Water Management, Directorate-General of Public Works and Water Management, The Netherlands, 323 p.

This publication presents the achievements of 15 years of co-operation on institutional and technical aspects of Agricultural Land Drainage in Egypt between the Egyptian Public Authority of Drainage Projects (EPADP) and the Netherlands Directorate General of Public Works and Water Management (RWS). It presents various aspects of large-scale implementation of drainage, covering subjects that are technical, economic, and organisational, or that concern operation research, and institutional and human resources development. The contributions of 40 authors are presented in 5 parts: I) Drainage in Egypt and The Netherlands; II) Training: III) Planning and Organisation; IV) Information Technology, and; V) Drainage Technology.

1989 Amer, M.H. and N.A. de Ridder (Eds.) *Land Drainage in Egypt.* Drainage Research Institute, Cairo, Egypt and the International Institute for Land Reclamation and Improvement (ILRI), The Netherlands, 377 p.

The project presents the achievements of 14 years of technical co-operation between Egypt and The Netherlands on agricultural land drainage. The book summarises the knowledge gained in research studies that were conducted to combat waterlogging and salinity in the Nile Delta and Valley with the aim to provide some 2.1 million hectares with subsurface drainage systems. The results are presented in seven: 1) Drainage survey and design practices; 2) Drainage technology; 3) Operation and maintenance of drainage systems; 4) Vertical drainage feasibility in the Nile Valley; 5) Re-use of drainage water for irrigation; 6) Economic evaluation of drainage projects, and 7) Institutional and management aspects of drainage projects. The book provides in depth guidance to practising engineers in planning and designing drainage systems.

India

2003 Indo-Dutch Network Project on Drainage and Water Management for Salinity Control in Canal Commands in India. *Research on the control of waterlogging and salinization in irrigated agricultural lands*. Central Soil salinity Research Institute, Karnal, India and Alterra-International Institute for Land Reclamation and Improvement, Wageningen, The Netherlands, 4 Volumes, 380p.

This report presents the findings of the Indo-Dutch Network Project on research on the control of waterlogging and salinization in irrigated agricultural lands in India. The project, covering the period 1995 – 2002, was a collaboration between the Central Soil Salinity Research Institute, Karnal , the four State Agricultural Universities of Andhra Pradesh, Gujarat, Karnataka and Rajasthan and Alterra-ILRI. The four volumes of the report cover the following issues:

- A methodology for identification of waterlogging and soil salinity conditions using remote sensing: Based on eight studies covering areas ranging from 5 000 to 350 000 ha in the Indo-Gangetic plains (3), heavy clay or black soils (3) and sandy soils (2), two methodology, one based on visual and another for digital interpretation are recommended.
- Recommendations on Waterlogging and Salinity Control based on pilot area drainage research: presenting the research findings of 7 drainage pilot areas (ranging in size from 20 to 188 ha), covering 5 agro-ecological sub-regions in India with soils ranging from sandy loam to heavy clay. For each sub-region specifications for subsurface drainage systems, both open and pipe drains, are presented.
- Computer modelling in irrigation and drainage: four computer simulation models, SWAP, UNSATCHEM, SALTMOD and SURDEV, were tested to assess the short and long-term impacts of water management options on the land and water productivity and the environment.

- Human resource development and the establishment of a training centre: the report discusses the adopted approach in technology transfer, capacity building and institution strengthening of the four network centres.

1995 Rajasthan Agricultural Drainage Research Project. 1995. *Analysis of Subsurface Drainage Design Criteria*. Chambal Command Area Development Authority, Rajasthan, India, 260 p.

The report presents an intensive review of the present state of scientific knowledge and technology in the subsurface drainage research activities undertaken by the Rajasthan Agricultural Drainage Research Project (RAJAD) during1991-1994. These activities have resulted in the development of criteria and guidelines for subsurface drainage installation to assist with the formulation of large-scale subsurface drainage procedures for the installation of subsurface drainage in about 25 000 ha in the Chambal Command Area, Kota, Rajasthan, India. The information is presented in 10 chapters: 1) Project description; 2) Background information on Chambal Command Area; 3) Salinity and waterlogging; 4) Description of the experimental drainage test sites; 5) subsurface drainage design criteria development; 6) Multidisciplinary aspects of subsurface drainage; 7) Hydraulics of subsurface drainage systems; 8) Subsurface drain envelope requirements; 9) Subsurface drainage installation costing procedures; 10) Design guidelines for subsurface drainage.

The Netherlands

1993 Ven, G.P.van de (Editor). Man-made lowlands: history of water management and land reclamation in the Netherlands. Matrijs, Utrecht, 293 p.

Man-made lowlands presents a comprehensive and richly illustrated picture of the way the Dutch have made and kept their lowlands habitable. A indispensable standard work for anyone interested in the Dutch history of water management and land reclamation. The publication covers subjects: 1) The Netherlands, the country and its inhabitants; 2) Water management from about 800 to about 1250; 3) Water management from about 1250 to about 1600; 4) Water management from 1600 to about 1800; 5) The Netherlands, its inhabitants and water management administration from 1800 till present; 6) Water management in 'Laag-Nederland' from about 1800 till present; 7) Water management in 'Hoog-Nederland' from about 1800 till present; 8) Improvement of the large rivers; 9) The Zuiderzee and the Delta projects; 10) Epilogue and the prospects of water management in the Netherlands.

Pakistan

2001 Alterra-ILRI. Netherlands Research Assistance Project: a bilateral cooperation in drainage between IWASRI and ILRI – Final Report 1988-2000. Alterra-ILRI Rapport 354, Wageningen, 90 p.

This is the final report of the Netherlands Research Assistance Project, a joint undertaking by the International Waterlogging and Salinity Research Institute (IWASRI), Lahore, Pakistan and the International Institute for Land Reclamation and Improvement (ILRI), Wageningen, The Netherlands. The project, with covered the period 1988-2000, had two main activities: work on technical aspects of drainage and the development of a participatory approach to drainage. The report discussed three main issues:

- Technical lessons learned, in particular: (i) envelope materials; (ii) drainage design with computer simulations; (iii) drainage design criteria; (iv) salinity measurements by magnetic induction; (v) interceptor drainage; (vi) groundwater approach to drainage design; (vii) operation and maintenance of drainage systems (viii) benefits of shallow drainage, and (ix) the use of poor quality water for crop production and reclamation.
- Participatory drainage development: lessons learned on development and implementation, and
- Institutional development, including capacity building through training and the execution and dissemination of research.

1984 MARDAN SCARP. 1984. *MARDAN SCARP Subsurface Drainage Design Analysis*.Water and Power Development Authority, Pakistan, 224 p.

This reports presents the subsurface drainage design analysis for the Mardan Salinity Control and Reclamation Project (SCARP) carried out by the Pakistan Water and Power Development Authority (WAPDA) and consulting engineering companies Engineering with assistance by the Canadian International Development Agency (CIDA). The Mardan SCARP project encompasses 123 600 acres of the Culturable Command Area of the Lower Swat irrigation canal in the Northwest Frontier Province of Pakistan. The achievements are presented in 8 chapters: 1) Background information; 2) Design drainage rates, drain depths and spacings; 3) Subsurface drainage pipework; 4) drain envelopes; 5) Cost estimates; 6) Economic analysis; 7) Subsurface drainage plans, and; 8) Evaluating the performance of subsurface drainage.

USA

1987 Pavelis, G.A. (Ed.). *Farm Drainage in the United States: History, Status and Prospects.* Miscellaneous Publication No. 1455, United States Department of Agriculture, Economic Research Service, Washington DC, 170 p.

This publication covers the historical, technological, economic, and environmental aspects of agricultural drainage in the USA. The main purpose is to review the evolution of modern farm drainage and to identify farm drainage objectives for agricultural extension specialists and agents, environmental specialists, drainage consultants, installation contractors, and educators. Farm production, water management, and other benefits and costs associated with the drainage of wet soils on farms are described within the context of existing USDA programs and other Federal policies for protecting wetlands. The publication, which draws from the combined knowledge of academic and USDA professionals, covers subjects: 1) A framework for future farm drainage policy: the environmental and economic setting; 2) A history of drainage and drainage methods; 3) Advances in drainage technology: 1955-85; 4) Purposed and benefits of drainage; 5) Preserving environmental values; 6) Principles of drainage; 7) Drainage system elements; 8) Planning farm and project drainage; 9) Drainage for irrigation: managing soil salinity and drain-water quality; 10) Drainage institutions; 11) Economic survey of farm drainage; 12) Drainage potential and information needs, and: 13) Drainage challenges and opportunities.

Glossary (Ref: ILRI Publication 16)

Agricultural drainage: See Land drainage.

Alluvial plain: A plain bordering a river, formed by the deposition of alluvium eroded from areas of higher elevation.

Aquifer: A water-bearing soil layer.

Base flow: Water flow appearing in a river or stream as a result of groundwater discharge, with a characteristic delayed reaction to recharge. Most clearly visible after direct runoff has stopped.

Basin irrigation: A system of surface irrigation in which water is ponded on level land parcels surrounded by earthen bunds or banks.

Bedding: A surface drainage method accomplished by ploughing land to form a series of low narrow ridges, separated by parallel furrows. Water from the furrows discharges into a perpendicular field drain at the lower end of the field.

Catchment: See Drainage basin.

Collector drain: A drain that collects water from the field drainage system and carries it to the main drain for disposal. It may be either an open ditch or a pipe drain.

Composite drainage system: A drainage system in which both field drains and collectors are buried.

Culvert: A square, oval, or round closed conduit used to transport water horizontally under a highway, railway, canal, or embankment.

Design discharge: A specific value of the flow rate which, after the frequency and the duration of exceedance have been considered, is selected for designing the dimensions of a structure or a system, or a part thereof.

Direct runoff: That portion of excess rainfall that turns into overland flow.

Discharge hydrograph: A graph or a table showing the flow rate as a function of time at a given location in a stream.

Diversion channel: A channel constructed across a slope to intercept surface runoff and conduct it to a safe outlet.

Diversion drain: See Interceptor drain.

Drain spacing: The horizontal distance between the centre lines of adjacent parallel drains.

Drainable surplus: 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 groundwater or surface water.

Drainage base: The water level at the outlet of a drained area.

Drainage basin: The entire area drained by a stream in such a way that all stream flow originating in the area is discharged through a single outlet.

Drainage coefficient: The discharge of a drainage system, expressed as a depth of water that must be removed within a certain time.

Drainage criterion: A specified numerical value of one or more drainage parameters that allow a design to be calculated with drainage equations.

Drainage effluent: The water flowing out of a drainage system which must be disposed of either by gravity flow or by pumping.

Drainage gate: A gravity outlet fitted with a vertically-moving gate or with a horizontally-hinged door or plate (flap gate).

Drainage intensity: (1) An agricultural drainage criterion based on the ratio between the design discharge and the depth of the watertable. (2) The number of drainage provisions (e.g. natural or artificial open drains, pipe drains, or tubewells) per unit area.

Drainage sluice: A gravity outlet fitted with vertically-hinged doors, opening if the inner water level is higher than the outer water level, and vice versa, so that drainage takes place during low tides.

Drainage survey: An inventory of conditions that affect the drainage of an area, made at various levels, ranging from reconnaissance to design level.

Drainage system: (1) A natural system of streams and/or water bodies by which an area is drained. (2) An artificial system of land forming, surface and subsurface conduits, related structures, and pumps (if any), by which excess water is removed from an area.

Drainage techniques: The various physical methods that have been devised to improve the drainage of an area.

Energy dissipator: A hydraulic structure in which the total hydraulic head of water in a canal is safely reduced by providing a protected approach section, a drop, a stilling basin, and a protected outlet transition.

Envelope: Material placed around pipe drains to serve one or a combination of the following functions: (i) to prevent the movement of soil particles into the drain; (ii) to lower entrance resistances in the immediate vicinity of the drain openings by providing material that is more permeable than the surrounding soil; (iii) to provide suitable bedding for the drain; (iv) to stabilize the soil material on which the drain is being laid.

Estuary: The mouth of a river, subject to tidal effects, where fresh water and sea water mix.

Evaporation: (1) The physical process by which a liquid (or solid) is transformed into the gaseous state. (2) The quantity of water per unit area that is lost as water vapour from a water body, a wet crop, or the soil.

Evapotranspiration: The quantity of water used for transpiration by vegetation and lost by evaporation from the soil.

Excess rainfall: That part of the rain of a given storm which falls at intensities exceeding the soil's infiltration capacity and is thus available for direct runoff.

Field drain: (1) In surface drainage, a shallow graded channel, usually with relatively flat side slopes, which collects water within a field. (2) In subsurface drainage, a field ditch, a mole drain, or a pipe drain that collects groundwater within a field.

Field drainage system: A network that gathers the excess water from the land by means of field drains, possibly supplemented by measures to promote the flow of excess water to these drains.

Field lateral: See Field drain.

Filter: A layer or combination of layers of pervious materials, designed and installed so as to provide drainage, yet prevent the movement of soil particles in the flowing water.

Gravity outlet structure: A drainage structure in an area with variable outer water levels, so that drainage can take place by gravity when outside water levels are low.

Groundwater: Water in land beneath the soil surface, under conditions where the pressure in the water is equal to, or greater than, atmospheric pressure, and where all the voids are filled with water.

Horizontal drainage: A method of groundwater drainage in which low watertables are maintained by pipe drains or open ditches.

Hydrograph: A graph showing, for a given point, the stage, discharge, velocity, or other properties of water flow as a function of time.

Ideal drain: A drain without entrance resistance.

Interception: (1) The capture and subsequent evaporation of part of the rainfall by a crop canopy or other structure, so that it does not reach the ground. (2) The capture and removal of surface runoff, so that it does not reach the protected area. (3) The capture and subsequent removal of upward groundwater seepage, so that it does not reach the rootzone of crops.

Interceptor drain: A channel located across the flow of groundwater and installed to collect subsurface flow before it re-surfaces, normally used on long slopes and on shallow permeable surface soils overlying relatively impermeable subsoils.

Irrigation: Controlled applications of water to agricultural land to allow the cultivation of crops, where otherwise, owing to a deficiency of rainfall, agriculture would be impossible.

Land drainage: The removal of excess surface and subsurface water from the land to enhance crop growth, including the removal of soluble salts from the soil.

Land forming: Changing the micro-topography of the land to meet the requirements of surface drainage or irrigation. In land forming for surface drainage, two processes are recognized: land grading and land planing.

Land grading: Forming the surface of land to predetermined grades so that each row or surface slopes to a drain.

Land planing: Smoothing the land surface with a land plane to eliminate minor depressions and irregularities without changing the general topography.

Land reclamation: Making land capable of more intensive use by changing its general character: by draining excessively wet land, by recovering submerged land from seas, lakes, and rivers; or by changing its saline, sodic, or acid character.

Leaching: Removing soluble salts by the passage of water through soil.

Leaching requirement: The fraction of irrigation water entering the soil that must flow effectively through and beyond the rootzone to prevent a build-up of salinity resulting from the addition of solutes in the water.

Longitudinal profile: An annotated design drawing of a canal along its centre line, showing original ground levels, canal bank levels, design water levels, bed levels, and other relevant engineering information.

Main drain: The principal drain of an area, receiving water from collectors, diversion drains, or interceptor drains, and conveying this water to an outlet for disposal outside the area.

Main drainage system: A water conveyance system that receives water from the field drainage systems, surface runoff, interflow, and groundwater flow, and transports it to the outlet point.

Mole drain: An unlined underground drainage channel, formed by pulling a solid object, usually a solid cylinder with a wedge-shaped point at one end, through the soil at the proper slope and depth, without a trench having to be dug.

Open drain: A channel with an exposed water surface that conveys drainage water.

Outlet: The terminal point of the entire drainage system, where it discharges into a major element of the natural open water system of the region (e.g. river, lake, or sea).

Outlet drain: A drain that conveys collected water away from the drained area or project, either in the form of a natural channel or as a constructed drain.

Overland flow: Water flowing over the soil surface towards rills, rivulets, channels, and rivers. It is the main source of direct runoff.

Peak runoff: The maximum rate of runoff at a given point or from a given area during a specified period, in reaction to rainfall.

Pipe drain: A buried pipe - regardless of material, size, or shape - which conveys drainage water from a piece of land to a collector or to a main drain.

Polder: A tract of low land, reclaimed from the sea or another body of water, by endiking it. In a polder, runoff is controlled by sluicing or pumping, and the watertable is independent of the watertable in the adjacent areas.

Precipitation: The total amount of water received from the sky (rain, drizzle, snow, hail, fog, condensation, hoar frost, and rime).

Rip-rap: Broken stone or boulders placed compactly or irregularly on dams, levees, dikes, or similar embankments, and at the downstream end of structures, to protect earth surfaces from the action of waves, currents, and flowing water.

Roughness coefficient: A dimensionless parameter appearing in Manning's Equation for uniform steady flow in open canals, related to surface irregularity, vegetal drag, and material retardance of the wetted perimeter.

Salinity: The content of totally dissolved solids in irrigation water or the soil solution, expressed either as a concentration or as a corresponding electrical conductivity.

Salinization: The accumulation of soluble salts at the surface or at some point below the surface of the soil profile.

Singular drainage system: A drainage system in which the field drains are buried and discharge into open collectors.

Subsurface drainage: The removal of excess water and salts from soils via groundwater flow to the drains, so that the watertable and rootzone salinity are controlled.

Subsurface drainage system: A man-made system that induces excess water and salts to flow via the soil to wells, mole drains, pipe drains, and/or open drains, and be evacuated.

Surface drainage: The diversion or orderly removal of excess water from the surface of the land by means of improved natural or constructed channels, supplemented when necessary by the shaping and grading of land surfaces to such channels.

Surface drainage system: A system of drainage measures such as channels and land forming, meant to divert excess surface water away from an agricultural area in order to prevent waterlogging.

Surface irrigation: Irrigation whereby the water flows over the soil surface, thereby partially wetting the soil through infiltration, as in basin, border, and furrow irrigation.

Surface runoff: Water that reaches a stream, be it large or very small, by travelling over the surface of the soil.

Tidal drainage: The removal of excess water from an area, by gravity, to outer water which has periodic low water levels owing to tides.

Tidal river: A river whose water level is influenced by tidal water level fluctuations over a considerable distance.

Tide: The periodic fluctuations of the sea-water level that results from the gravitational attraction of the moon and the sun acting upon the rotating earth.

Tile drain: See Pipe drain

Tubewell: A circular well, which may be used to dispose of surface water, to control groundwater levels, or to relieve hydraulic pressures, where local physical conditions are appropriate for their use.

Tubewell drainage: The control of an existing or potential high watertable or artesian groundwater through a group of adequately spaced wells.

Tubewell drainage system: A network of tubewells to lower the watertable, including provisions for running the pumps, and drains to dispose of the excess water.

Vegetated waterway: An earthen channel to dispose of excess water safely, and therefore lined with vegetation to stabilize the channel and prevent erosion.

Vertical drainage: See Tubewell drainage.

Water balance: Equating all inputs and outputs of water, for a volume of soil or for a hydrological area, to the change in storage, over a given period of time.

Waterlogging: The accumulation of excessive water on the soil surface or in the rootzone of the soil.

Water management: The planning, monitoring, and administration of water resources for various purposes.

Watershed: See Drainage basin.

Watertable: The locus of points at which the pressure in the groundwater is equal to atmospheric pressure. The watertable is the upper boundary of groundwater.

Well field: See Tubewell drainage system.

Wetlands: Land where the saturation with water is the dominant factor determining the nature of soil development and the types of plant