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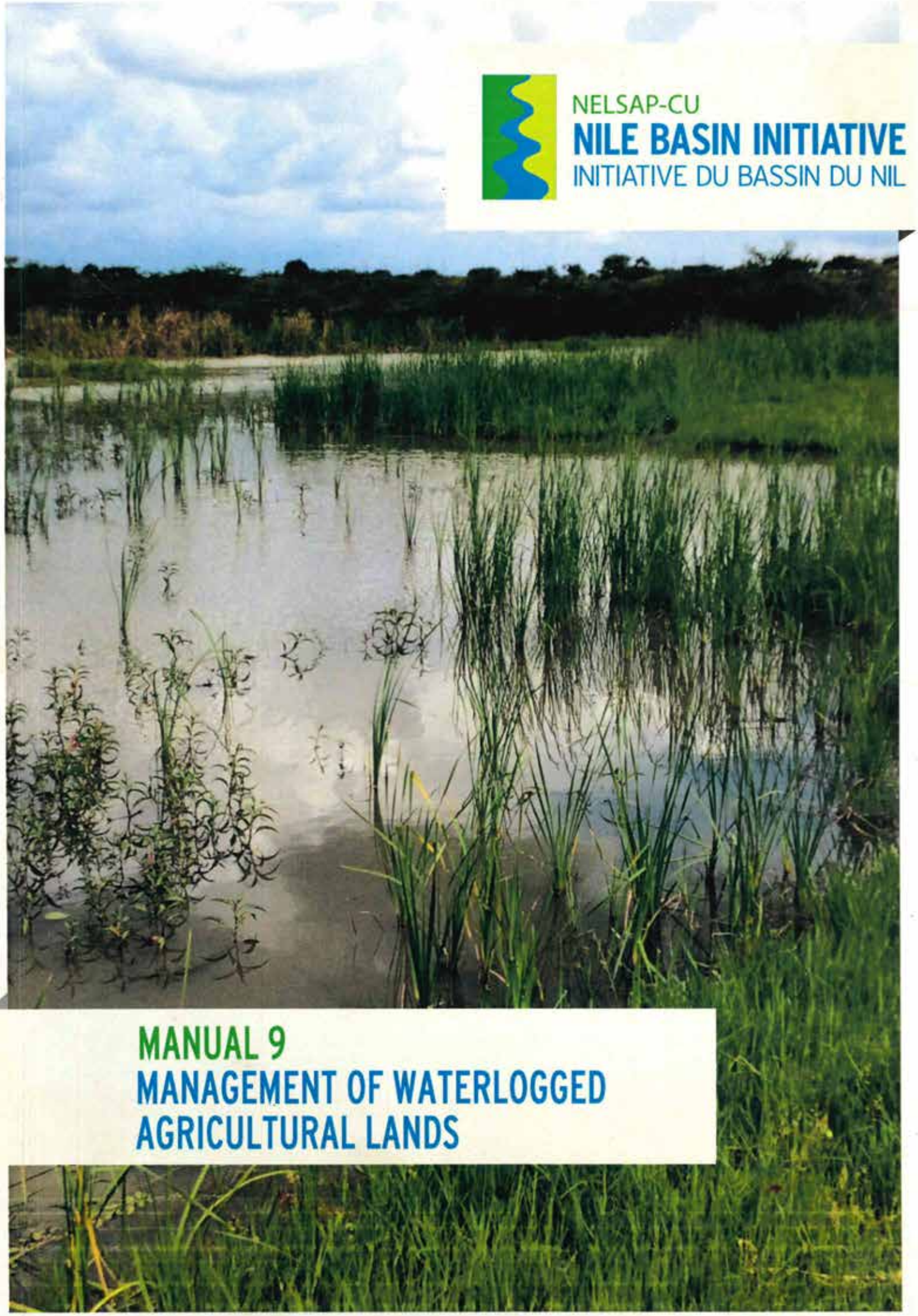

MANUAL 9
MANAGEMENT OF WATERLOGGED AGRICULTURAL LANDS

NELSAP-CU
NILE BASIN INITIATIVE
INITIATIVE DU BASSIN DU NIL

NELSAP
REGIONAL AGRICULTURE & TRADE PROJECT (RATP)

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The Nile Basin Initiative (NBI) is an Intergovernmental partnership of ten Nile Riparian countries that is seeking to manage and develop the common Nile Water resources in acooperative manner and promote regional peace and security.

The Nile Equatorial Lakes Subsidiary Action Program (NELSAP) is one of the investment arm of the NBI and is mandated to facilitate identification, preparation, and resource mobilization and implementation supervision of "Cooperative and Consultative Nile Projects" and builds subregional capacity for country implementation of transboundary investment projects in the Nile Equatorial Lakes (NEL) region.

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About this Training Manual

The Nile Basin Initiative (NBI) is a partnership of the riparian states (Burundi, Democratic Republic of Congo, Egypt, Ethiopia, Kenya, Rwanda, Sudan, Tanzania and Uganda, Eritrea is participating actively in the NBI as an observer) that seeks to develop the river in a cooperative manner, share substantial socioeconomic benefits, and promote regional peace and security through its shared vision of "sustainable socioeconomic development through the equitable utilization of, and benefit from, the common Nile Basin water resources". NBI's *Strategic Action Program* is made up of the *Shared Vision Program (SVP) and Subsidiary Action Programs (SAPs).* The SAPs are mandated to initiate concrete investments and action on the ground in the *Eastern Nile (ENSAP) and Nile Equatorial Lakes' sub-basins (NELSAP).*

NELSAP through its sub basin programs implements pre-investment programs in the areas of power, trade and development and natural resources management. As part of its pre-investment framework, the Regional Agricultural Trade and productivity Project (RATP), in concert with the NELSAP, intends to promote and disseminate best practices on water harvesting and small scale irrigation development as a contribution towards agricultural development in the NEL Countries. NELSAP has previously implemented a project called Efficient Water Use for Agriculture Project (EWUAP). One of the recommendations of EWUAP was the need to develop Training/Dissemination materials on "*adoption of low cost technologies for water storage, conveyance, distribution, treatment and use for agriculture that can be adapted by communities and households of the rural and peri-urban poor*". This Training Manual is the initiative of NELSAP, for that purpose.

This Training Manual summarizes the major problems associated with waterlogging in agricultural lands, and their resolution through drainage and utilization of the same lands. It covers the major types and components of Drainage systems, their design, development, operation and management as well as the salient factors considered. The Manual is meant to improve the skills of engineers, technicians, extension workers, managers and practitioners of agricultural water management, where excessive water in the soil is a problem. More specifically, the manual equips the reader with knowledge on how to (i) identify the appropriate drainage system for a given area or circumstances, and (ii) plan and design of drainage systems. It is meant to inform, educate, enhance knowledge and practice targeting smallholder irrigation in the NEL region. The information contained here may not be exhaustive and thus, readers are encouraged to seek further information from references cited in this publication and elsewhere.

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Glossary of Key Terms

Term	Definition/Brief description
Actual crop evapotranspiration (ETca)	The sum total of actual evaporation and transpiration from a crop grown under prevailing conditions. Under optimal growth conditions, ETca equals potential evapotranspiration (ETc).
Agricultural water management (AWM)	The holistic management of water for agriculture (crops, trees, and livestock) in the continuum from rainfed systems to irrigated agriculture. It includes irrigation and drainage, soil and water conservation, rainwater harvesting, agronomy, in-field water management, integrated watershed management and all relevant aspects of the management of water and land.
Crop coefficient	The crop coefficient, denoted as Kc, is the ratio between crop evapotranspiration and reference crop evapotranspiration.
Crop evapotranspiration (ETc)	The evapotranspiration from disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions.
Desertification	Land degradation in arid, semi-arid and dry sub-humid areas resulting in deserts or desert-like conditions.
Drainage	The process of managing and/or removing excess surface water and controlling water logging from shallow water tables.
Ecosystem	A system formed by the interaction of a community of organisms with their physical environment
Environment	A combination of the various physical, geographic, biological, cultural and political elements that affect the life of an individual or organism.
Evaporation (E)	The annual net water loss from a free water surface (mm)
Evapotranspiration (ET)	The sum of water lost from an area through the combined effects of evaporation from the ground surface and transpiration from the vegetation.

Term	Definition/Brief description
Groundwater	Water that exists beneath the earth's surface in underground streams and aquifers.
Integrated Water Resource Management (IWRM)	A process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems
Irrigation	Any process, other than by natural precipitation, which supplies water to crops or any other cultivated plants.
Land degradation	The reduction in the capability of the land to provide goods and services, and/or benefits from a particular land use under a specific form of land management.
Land reclamation	The restoration into economic value and use, wastelands and lands which have been rendered degraded or have severe reduction in productivity.
Leaching	The process of flooding the land surface with abundant irrigation water to remove and flush out unwanted soluble salts.
Marginal-quality water	This term includes urban wastewater, agricultural drainage water, and saline/sodic surface water and groundwater
pH	A measure of acidity or alkalinity of a liquid or medium. A pH of 7.0 is neutral; a pH less than 7.0 is acidic; a pH greater than 7.0 is alkaline.
Rain-fed agriculture	In rain-fed agriculture, local rainfall, which falls directly on a given field is the predominant source of water for growing crops, trees or pasture on that field.
Recycled water	Water that has already been diverted and used at least once. Recycling takes place, for example, by reusing drainage water or urban waste water.
Salinity	Soils having high concentration of soluble salts. Salinity may be

Term	Definition/Brief description
	caused by the presence of salts in the soil or from irrigation water.
Salinization	The increased accumulation of excessive salts in land and water at sufficient levels to impact on human and natural assets (plants, animals, aquatic ecosystems, water supplies or agriculture).
Soil degradation	The sum of geological, climatic, biological and human factors which lead to the degradation of the physical, chemical and biological potential of soil productivity.
Stream flow	Flow or discharge of water that moves along a river or channel (m3/s).
Sub-surface irrigation (Sub-irrigation)	Applying irrigation water below the ground surface either by raising the water table within or near the root zone or by using a buried perforated or porous pipe system that discharges directly into the root zone.
Supplementary irrigation	Providing additional water to stabilize or increase yields where rainfall is insufficient for crop growth
Waste water	The water which is of no further immediate value to the purpose for which it was used or in the pursuit of which it was produced because of its quality, quantity or time of occurrence.
Waste water treatment	Process to render waste water fit to meet applicable environmental standards or other quality norms for recycling or reuse and irrigation.
Water control	The physical control of water by measures such as conservation practices on the land, channel improvements, and installation of structures for reducing water velocity and trapping sediments.
Water harvesting	Activities where water from rainfall and/or surface runoff is collected, diverted, stored and utilized.
Water logging	State of land in which the water table is located at or near the surface resulting in poorly drained soils, adversely affecting crops production. Drainage can be used to solve the problem

Term	Definition/Brief description
Water resources	Is water that is available in rivers and aquifers, and having good quality to be used for human purposes.
Water resources management	The decision-making, manipulative, and non-manipulative processes by which water is protected, allocated, and/or developed.
Water storage capacity	Maximum capacity of soil to hold water against the pull of gravity, also called field capacity.
Water table	Upper limit of the ground water
Wetland	Areas of marsh, fen, peat land or water, natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine waters, the depth of which at low tide may not exceed six meters.

1. WATERLOGGING IN AGRICULTURAL LANDS

1.1 What is waterlogging?

Waterlogging is a condition of land in which the soil profile is saturated with water either temporarily or permanently (Figure 1.1). In waterlogged lands, the water table rises to an extent that the soil pores in the crop root zone are saturated resulting in restriction of the normal circulation of air. This causes a decline in the level of oxygen and increase in the level of carbon dioxide. Generally, the water table is located at or near the surface resulting in poorly drained soils, adversely affecting crop production. Areas with water table within 2 m below the ground surface are considered as prone to waterlogging and those with water table within 2-3 m are considered to be at risk. Waterlogging can reduce the agricultural and economic value of land causing yield reductions or at times, total crop failures. Waterlogging is a drainage problem.

Figure 1.1 (a) Temporary waterlogging after a heavy rainstorm (photos by B. Mati) (b) Permanent waterlogging resulting from ground water contribution (wetland)

1.2 Categories of waterlogging

Waterlogging in agricultural lands can be of various types categorized according to:

a) Causes:

(i) Natural, e.g. natural swamps and valley bottoms
(ii) Human-induced waterlogging, e.g. through agricultural and other activities.

b) Permanence

(i) Temporary – whereby waterlogging lasts a few days to several months
(ii) Permanent waterlogging – which occurs throughout the year.

c) Source of water

(i) Rain fed - mostly source of excess water is direct rainfall
(ii) Irrigated agriculture – waterlogging caused by water supplied for irrigation

d) Located on

(i) Agricultural lands – including cultivated lands
(ii) Other utility lands e.g. built up areas, urban areas.

1.3 Causes of waterlogging

Waterlogging is a drainage problem that results of high water inflow caused by rain, runoff, interflow, rise in groundwater, over irrigation or flooding. Drainage problems can be caused by low water outflow due to low infiltration rate, low hydraulic conductivity, flat terrain, lack of outlet or restricted outlet in the soil. In irrigated agriculture, drainage should be part of the overall design and implementation to avoid problems of waterlogging. Waterlogging can be caused by natural conditions or human induced activities, as follows:

1.3.1 Natural causes

a) Physiography of a watershed

Physiography i.e. the topography, its slope, shape and drainage pattern has an important bearing on the drainage of a watershed. Areas that lie in valley bottoms, depressions and other flat lowlands tend to become waterlogged naturally as surface flows concentrate in these lowlands, causing natural swamps.

b) Geology

Some areas have an impervious stratum below the top soil which obstructs the infiltration of rainfall. This creates a false water table or perched water table. Also, Areas with shallow soils, high water tables or a hard pan close to the ground surface are likely get waterlogged, particularly if subjected to high rainfall events.

c) The weather

Areas that receive heavy rainfall for prolonged duration can get waterlogged temporarily or permanently (Figure 1.2-a).

d) Soil type

Heavy clay soils such as black cotton soils are prone to waterlogging, as they hold moisture for long periods. In addition, soils prone to surface sealing cause temporary waterlogging (see Section 1.5).

e) Seepage inflows

Seepage and interflow from other water bodies e.g. lakes, rivers and shallow aquifers can cause waterlogging of adjacent lands. Also, subsoil flows from upper regions to lower areas may result in water logging (Figure 1.2-b).

Figure 1.2 (a) Waterlogging after heavy rains on shallow water table (photos by B. Mati) *(b) Waterlogging due to seepage inflows from river valley*

1.3.2 Human-induced causes of waterlogging

Human induced causes of waterlogging in agricultural lands are usually associated with bad water management whether under irrigated or rain fed agriculture. For instance:

a) Irrigation

Irrigation, if not well planned, can cause drainage problems for the irrigated lands and adjacent ones. This is because irrigation adds extra water to the soil profile, over and above the naturally occurring rainfall. There are several ways in which irrigation can increase waterlogging. They include:

(i) ***Over irrigation:*** over irrigation and intensive irrigation result in waterlogging. The excess water from irrigation and without proper drainage contributes to rise in the water table.

(ii) ***Seepage from canals:*** Excessive seepage from unlined canal system and

water courses result in the rise of water table leading into waterlogging

(iii) ***Inadequate drainage:*** in irrigated areas, water losses from canal system and water courses continuously contribute to water table (Figure 1.3-a).

(iv) ***Poor irrigation management*** **:** poor irrigation and cropping management by the cultivator

(v) ***Obstruction of natural drainage:*** interception of natural drainage by the construction of canals, roads, railways, water courses, etc.

(vi) ***Land locked parches having no outlets*****:** Waterlogging develops due to absence of outlet to drain excess irrigation or rain water (Figure 1.3-b).

Figure 1.3 (a) Waterlogged paddy due to poor drainage (photos by B. Mati) *(b) Waterlogging due to poor land levelling*

b) Rain fed systems

(i) ***Excessive rainfall:*** Rain, apart from irrigation, is the major cause of water logging when it is in excess and in the absence of adequate drainage (Figure 1.4-a).

(ii) ***Flat topography:*** Flat terrain with depressions lead to waterlogging as disposal of excess water is delayed resulting in increased percolation into the soil.

(iii) ***Occasional spills by floods:*** Occasional flooding of the countryside and storm floods water not quickly drained off gives rise to water table.

(iv) **Closed/contour** water conservation structures – Construction of soil and water conservation structures on the contour can impound too much water

causing waterlogging.

Figure 1.4 (a) Waterlogging from excessive rainfall and diversion of runoff (photos by B. Mati) *(b) Waterlogging on wheat field after heavy rainfall due to flat terrain*

1.4 Undesirable effects of waterlogging

Waterlogging can have both beneficial and negative effects. Beneficial effects include being a habitat for certain plants and animals e.g. mudfish. Also, the wetlands regulate the hydrogeology, resulting in more sustainable river flow. However, for agricultural purposes, waterlogging can have negative impacts on the soil, crops and farm operations.

1.4.1 Effects of waterlogging on soils

(i) ***Lack of aeration:*** Waterlogging expels air from the soil pores resulting in a saturated condition. Without air, plant roots degenerate and crops can die. Certain microorganisms cannot survive resulting in reduced microbiological activity necessary for formation of plant food. Waterlogging also increases acidity buildup which is harmful to most food crops.

(ii) ***Reduced soil temperature:*** waterlogged soil is slow to warm up. Lower soil temperature restricts root development, depresses biotic activity in the soil resulting in lowered rate of production of available nitrogen hampering seed germination and seedling growth. Reduction of soil temperatures; results in stunted growth and reduced production of nitrogen.

(iii) ***Salinization:*** *Salinity build up is increased* when water from lower soil layers which may contain salts is brought up to the soil surface by capillary action (Figure 1.5). Thus, high salinization and deposits of sodium salts in the soil at or near the ground surface are created which may be toxic or lead to the formation of alkaline conditions.

(iv) ***Inhibiting activity of soil bacteria:*** when soil structure is affected and tillage and cultivation of wet soil takes place, bacteria tend to reduce normal biotic activity and this affects root development.

(v) ***Denitrification:*** occurs because of the competition for nitrogen by the soil micro-organisms that thrive in saturated soil and reduction in numbers of nitrifying organisms due to lack of aeration. There is reduction of nitrogen in the soil which in affects plant nutrients uptake.

(vi) ***Retards cultivation:*** Difficulty in carrying out normal cultivation in waterlogged soil.

Figure 1.5 (a) A poorly drained paddy field with salinity build up (photos by B. Mati) *(b) Salt crusts visible on the surface after the paddy field dry up.*

1.4.2 Effects of waterlogging on crops

(i) ***Delayed cultivation operations:*** normal cultivation operations of tillage and ploughing are adversely affected due to presence of excess water in the soil (Figure 1.6).

Figure1.6 Excessive seepage from canals causes *(b) Cultivation and rudimentary tools renders*

waterlogging in fields (photos by B. Mati) *in-field water control difficult*

(ii) ***Aquatic weeds.*** Water-loving wild plants grow profusely and have competition with the crops, thereby affecting the growth of useful crops weed removal also entails extra investments and in extreme waterlogged conditions, only wild grow is there.

(iii) ***Diseased crops:*** Waterlogged conditions cause physiological disease to crops. Decay of roots, external symptoms on the foliage and fruits are common.

(iv) ***Loss of cash crops:*** Cash crops desired to be grown cannot be cultivated and the land is restricted to few crops like paddy rice.

(v) ***Low yields:*** Maturity period of crops is reduced resulting in low yields. The yield of crops is adversely affected if the water table is within 90 cm (sugarcane), 60 cm (rice), 90 cm (gram and barley), 90-125 (wheat), 120 cm (fodder), 125 cm (maize and cotton), and 210-240 cm (lucerne).

(vi) ***Oxygen depletion:*** In saturated soil, plant roots are denied normal circulation of air; the level of oxygen declines and that of carbon dioxide increase resulting in wilting and ultimately death of plants. The rotting of the plant roots under conditions of reduced supply of oxygen causes yellow color to leaves. The lack of air in the soil causes precipitation of Manganese that is toxic to plants.

1.4.3 Effects on the environment

Waterlogging results in stagnant water which can host disease vectors such as malaria, snails and slugs. It impairs sanitary conditions and can bring on diseases like malaria and bilharzias, resulting in unhealthy environment for human population, animals and plants in an area.

1.5. Soil properties relevant to land drainage

A healthy soil consists of mineral and organic particles, water, air and certain micro-organisms. Plants need all these constituents as a medium for growth. A waterlogged soil is one which is saturated and all the voids (pores) in are filled with water. A soil is unsaturated when part of it is filled with water and part with air. Water in the soil is also called soil moisture. Permeability is the capacity of a soil to transport water; it depends upon the porosity, the pore size distribution, and the soil texture and soil structure. Generally, soils with a drainage problem have low permeability.

1.5.1 Bottom-lands

Most irrigation schemes are located in areas where the terrain is relatively flat, mostly to enable gravity flow of water, and ease of field operations. These areas often have one of more soil types known as bottom-land soils. Bottom-lands are areas of varying shape and size with nearly level and often concave topography and usually have slopes of less than 1%. Included in the category of bottom lands are *"salt flats"*, *"valley bottoms"*, *"depressions"* and volcanic *"sink holes"*. They have no outlet and as a result, ground water and surface water accumulate. This leads to subsequent accumulation of fine sediments, or clay particles, making the soils poorly draining. Because of the lack of proper outlets, the external and internal drainage condition is poor, and this can lead to salt accumulation. Bottom-lands are quite often prone to waterlogging.

Soil conditions in bottom lands vary greatly depending on the source and type of parent material, the prevailing drainage condition and the stage of development of the soil. The following soil types are commonly encountered in bottom areas considered for irrigation and drainage: (a) Vertisols (b) Planosols, (c) Saline soils, (d) Sodic/ Alkaline soils, and (e) Alluvial soils.

1.5.2 Vertisols

Vertisols are mainly dark, *montomorillonitic clays* which display characteristic swelling and shrinking or "vertic" properties. They are sometimes called cracking clays or *"black cotton soils"*. Spread over large areas in the semi-arid Tropics, the soils develop large cracks, usually more than 1 cm wide and 50 cm depth during the dry season. When it rains, the soils absorb water and swell, closing the cracks. As the cracks close, water intake by the soils become negligible thus the soil becomes impervious. Due to their low hydraulic conductivity when wet, vertisols are usually poorly drained. They are thus prone to flooding and seasonal waterlogging during the rainy season. Moreover, vertisols are very hard when dry and very sticky when wet. This affects both land preparation and crop growth conditions. As a result, vertisols require mechanical tillage and can be worked on even during the dry season. Crops sensitive to waterlogging may be planted on ridges, but with water management techniques such as bedding or ridging. The soils are suited for paddy rice production which favors flooding. These soils, however, require a drying out period before flooding in order to maintain their bearing capacity and to absorb air.

1.5.3 Planosols

These soils, also called *"Vlei soils"* are found in plains and plateaus, but have a tendency to develop hard pans. They are, therefore poorly drained. The top soil is characterized by a relatively light in texture and permeability, shallow depth up to

about 30 cm but is abruptly underlain by a slowly impermeable horizon (hard pan). Root development is largely confined to the top soil layer where fertility is low and has problem in maintaining favorable soil moisture for crops. Production may occur on slightly elevated or sloping areas, where drainage to surrounding lower area is possible. These soils are less suitable for surface irrigation, but if top soils are over 60 cm deep, overhead irrigation could provide a favorable moisture regime. Internal drainage of these soils can be improved through sub-soiling, albeit loosening the subsoil has, in many countries, not resulted in notable improvements in productivity.

1.5.4. Saline soils

Saline soils contain high levels of soluble salts, measured as the extractable solution of the soil when it has an electrical conductivity exceeding 4 mmhos/cm, which is beyond the tolerable limits of most crops. Purely saline soils may be non-sodic, meaning the extractable solution could have exchangeable sodium percentage of less than 15, and a pH of less than 8.5. Otherwise, it is common for soils in arid areas to be both saline and sodic. Saline soils are generally light coloured, with low organic matter and poor structure. Crop yields on saline soils are reduced due to the presence of toxic concentration of salts in the root zone.

Visual characteristics of a saline soil

Saline soils are commonly found in poorly draining areas in arid and semi-arid zones. This is because due to high evaporation rates, the salts dissolved in the soil water are pulled to the surface through capillary action. They accumulate and salt efflorescence and crusts form. Visual characteristics of saline soils include:

(i) White salt crystals (which can be seen precipitated on the sides of the profile pit or along cracks).

(ii) Clay is flocculated and gives a loose granular or blocky structure;

(iii) A white salt crust covering the ground or a very loose surface caused by the growth of long needle-like crystals of sodium Sulphate. If the land is not reclaimed early, it deteriorates to alkalinity.

Problem with salinity build up: From an engineering point of view, excessive contents of soluble salts in the soil cause structural problems. Water dissolves the salts, resulting in collapse of irrigation and drainage ditches. The presence of such soluble salt in the soil moisture creates a high osmotic pressure which subsequently reduces the availability of water to plants. Also, some ions may be present in the soil solution at toxic levels for plant growth.

Remedial measures: Soluble salts can be leached out. This requires good permeability of the soil, good quality irrigation water, and good drainage conditions.

Temporary salinity control can be achieved by improving the permeability of the soil, e.g. through deep tillage or incorporation of organic residues.

1.5.5 Sodic/Alkaline soils

Sodic soils contain excessive exchangeable sodium, and are by nature, alkaline. These soils, also called "solonetz" that may contain little soluble salt. A sodic soil has an exchangeable sodium percentage of more than 15, an electrical conductivity of extractable solution measuring less than 4 mmhos/cm and a pH exceeding 8.5. A saline-sodic soil has both salinity and sodicity problems as shown in the Table 1.1:

Table 1.1 Salinity and alkalinity levels in soils

Type of soil	Electrical conductivity (micromhos/cm)	Exchangeable Sodium Percentage (ESP)	pH
Saline	>4000	<15	<8.5
Saline-Alkali	>4000	>15	8.5
Alkali	<4000	>15	8.5-10.0

A high level of exchangeable sodium causes the clay to disperse. The dispersed clay subsequently moves from the top soil into the subsoil and usually a characteristic columnar structure develops. Upon wetting, this horizon becomes virtually impermeable, causing waterlogging. Salts easily accumulate in such a soil.

Visual characteristics of a sodic soil

A sodic soil has a thin, coarse-textured A-horizon from which clay has been alleviated. The A-horizon overlies a compact, heavily textured B-horizon (nitric B-horizon) as a result of clay illuviation from the top. The sol exhibits a columnar structure with rounded tops. It has low permeability due to nitric B-horizon and a dark colors or "black alkali" soils.

Problems: High sodium contents in the soil result in poor soil structure, poor aeration and low permeability. With the sodium present and the salt concentration low, the soil structure collapses on addition of water. Internal drainage becomes almost impossible. Sodic hard pans are also common. High sodium level also preclude uptake of other necessary ions and is toxic to crops.

Remedies: Solonetz soils are generally impossible to reclaim in an economic way. The leaching of sodium is almost impossible as permeability is poor due to the high sodium levels. It is best to avoid irrigating or draining sodic soils.

1.5.6 Acid soils

Acid soils are those with a low pH levels due to accumulation of acidic ions. Examples include the acid Sulphate soils in rich tropical coastal wetlands. They are also found in high rainfall mountain areas having very deep soils. When soil drainage is deep, subsoil layers are exposed to air and become oxidized. This leads to the formation of sulphuric acid from the pyrites, increasing soil acidity, which is harmful to many crops. However, some crops such as coffee and tea, thrive on soils with low pH.

Problems: The pH levels in the water draining from these areas can drop below 3, seriously harming plant and animal life, including mangroves and fish. Iron and aluminium can also be mobilized from soils when then the pH levels drop, causing aluminium toxicity which has implications for human health if the downstream water is used for drinking purposes.

Remedies: Maintaining a high water table to prevent the pyrites from oxidizing, can control soil acidity problem. In some places, lime and organic mulch are applied to neutralize the acidity. Also, minimizing the displacement of acidic ground water to the river by laser levelling, planting in mounds, reducing the length of the drainage ditches to reduce the acid sourced from the drain banks and liming drainage banks. The process of control and leaching is different from salinity, but the effect on water requirements is similar.

1.5.7 Alluvial soils

Alluvial soils are usually found in valley bottoms, and are formed from alluvial deposits originating from upper areas of the watershed. They are young soils that do not have horizon differentiation due to time being too short for soil forming processes, but they show strong stratification due to sedimentary deposition. Coarse soil layers of sand may alternate with fine layers of clay. Alluvial soils have an organic matter content that decreases irregularly with depth and they receive fresh sedimentary materials at regular intervals if flooded. Because they are located in poorly drained valleys, alluvial soils are prone to waterlogging.

Problems: The layers with contrasting texture affect water movement through the soil. Water tends to stagnate in these layers resulting in drainage and aeration problems. The layers may also offer mechanical impedance to root development.

Remedies: Since they are generally fertile, most alluvial soils are well suited to agriculture. Some may require mechanical mixing to homogenize the profiles when stratification is prominent, which is economically feasible. Drainage of alluvial soils may work well if an outlet can be found for the drainage water.

1.6. Flood control

A flood is any relatively high flow that overtops the natural or artificial banks in any reach of a stream, canal or other water conduit, sometimes resulting into damage of property and/or loss of life. Floods are quite often caused by excessive rainfall. One of the most important rainfall characteristics is its intensity. Rainfall events bearing high intensities are referred to as storms. During such storms, large amounts of water that is too much for infiltration to cope with, are received in a short time thus causing runoff and at times devastating floods. The water surplus in the form of a flood or water beyond the soil storage capacity and is lost as runoff.

However, temporary floods may be short lived and can be put to good use. Otherwise, the flood water is soon lost and water deficit sets in. More often than not, the water deficit in dry areas may be as a result of low infiltration of rainwater where it falls, resulting into higher runoff losses which may cause flooding in another area. In dealing with excess water, consideration should therefore be given to the following:

(i) ***Storage in situ***- the same water could be required at the same place in the future.

(ii) ***Diversion*** - the same water could be required at another place now.

(iii) ***Storage ex-situ*** - the same water could be required at another place in the future.

All these interventions, while they may be implemented for water storage, and flood control or to remove excess storm water, also help to drain the land and reduce waterlogging.

1.7 Benefits of removing excess water from fields

Land drainage, or control of waterlogging on agricultural lands, has many benefits which include:

(i) Increasing the productivity of a land – improved crop yields

(ii) A wider range of crops can be grown when there is water control

(iii) Improving tillage operations

(iv) Land preparation of farms becomes easier, thus reducing costs

(v) Improving availability of nutrients to plants

(vi) Improvement of soil aeration

(vii) Increase in nitrogen availability due to bacteriological activities

(viii) Excess salts are removed from the soil, improving plant water uptake

(ix) Drained fields are in hygienic condition, reducing disease vectors

(x) Farms have fewer weeds, making weed control manageable.

2. PREVENTATIVE MEASURES AGAINST WATERLOGGING

Agricultural lands become poorly drained mostly as a result of poor water management; either under rain fed or irrigated agriculture. By simply adopting various designs and proper land husbandry, waterlogging can be reduced or even eliminated. These measures are presented here categorized as either rain fed or irrigated systems.

2.1 Preventing waterlogging in irrigated agriculture

Irrigation without proper drainage sometimes increases the total water held in a soil profile to an extent of causing poor drainage. This can be controlled through reduction of excessive water inflow into the subsoil as follows:

2.1.1 Control of canal seepage:

Canal seepage is a major source of water losses, and waterlogging in irrigated areas. It can be controlled by:

(i) Lining of canals with impervious material e.g. concrete, clay, polythene, so as to control excessive seepage from unlined canals is a very important preventive measure.

(ii) Lowering of designed full supply level to the canal, with a view to cut down the seepage losses.

(iii) Increasing the gradient of the canal t enable faster flows hence less ponding

(iv) Interception drains along the canals 15 to 30 meters away from the canal banks are effective to arrest seepage from the canals.

(v) If possible, convert water conveyance system from canals to piped systems.

(vi) Regulating canal discharge: seepage losses can be minimized if canal discharge is regulated during non-irrigational period. Overuse of canal water is curbed if canal supply is regulated together with pumping of ground water.

2.1.2 In-field water management

This is perhaps the most important aspect of avoiding the percolation of unnecessary water in irrigated lands. It entails:

(i) Applying only the requisite amount of irrigation water (not to exceed the field capacity), so that all the water applied is used by plants

(ii) Adopting more efficient irrigation methods e.g. drip irrigation

(iii) Where feasible, convert from surface irrigation methods to sprinkler or drip irrigation.

(iv) Restrict irrigation in areas with high water table to receive supplemental irrigation during dry season, or only a fraction of total command area

(v) Economical use of water like levelling the fields and refraining from applying more water than the soil can hold.

2.1.3 Control of inflow from other water bodies

Flood water can overrun irrigated fields from overflowing rivers, flood plains and channel obstruction. Such flooding should be stopped from reaching the low-lying fields: This can be achieved through"

(i) Construction of dykes to train the river movement,

(ii) On- stream dams, which act like regulating dams

(iii) Off-stream dams

(iv) To conserve the catchment with run off collection and disposal systems.

2.1.4 Control of ground-water inflows.

Interflow water is mainly from sloping ground rivers, high infiltration rate and a can cause increased waterlogging. These are controlled by:

(i) Construction of an interceptor,

(ii) Growing trees e.g. eucalyptus or crops) that have high water consumption rates (e.g. sugarcane, arrow roots).

(iii) Construction of spring protection works

2.1.5 Control of water from higher ground into lower fields:

Excessive water inflows from higher ground can sometimes inundate irrigated lowlands through ground water recharge. The solution would be to:

(i) Obtain the water for irrigation from somewhere else,

(ii) Proper irrigation water management, and

(iii) Incorporate fish or duck farming.

2.2 Preventative measures in rain fed agriculture

Rain fed agriculture usually suffers from temporary waterlogging associated with excessive rainfall, flat topography or poor land and water management. Poor drainage can be controlled using preventative measures such as:

a) Reducing unnecessary percolation of rainfall

This involves efficient disposal of storm water in excess of crop water requirement. The excess water collects because of high seasonal rainfall (termed in-situ rainfall), concentrated over a short period, in an extensive flat land, or downstream channel obstruction, or soils of shallow impermeable barrier (planosols) or low infiltration rates (vertisols). The solution would be to have

(i) Cambered beds,

(ii) Levelling of flat areas to reduce depressions,

(iii) Sub-soiling to break the hard pans and improve infiltrations.

(iv) Excavation of farm ponds to store water for later and use/ supplementary irrigation,

(v) Grow water loving plants e.g. sugarcane, and

(vi) Improving terrace outlets before the rains. A functional outlet is the most important part of the drainage system.

b) Controlling surface runoff

Surface runoff from large catchments or paved areas such as homesteads, urban areas and roads can be excessive to the point of causing waterlogging of receiving lowlands. The excess water can be due to high intensity storms on sloping ground, high ratio of catchment to receiving areas or poor land use and management practices in the catchment. The solution would be to:

(i) Construct diversion ditches/cut off drains to intercept the runoff

(ii) Conservation in the catchment areas to reduce runoff accumulation,

(iii) Water harvesting and storage in tanks, pans and other structures,

(iv) Developing a functional runoff collection and disposal system.

c) Tree planting

Tree planting, particularly of species that take up a lot of water, e.g. eucalyptus tree species, can be helpful in lowering water table. The trees further ameliorate the environment and can be used for commercial purposes. Deep rooted eucalyptus trees

have roots extending up to 3 m and have the ability to transpire water at a high rate and thus work as a biological pump. This they can take care of unwanted drainage water in irrigation schemes and temporary water logging in rain fed systems. But the bio-drainage is only effective if there is adequate aeration in the root zone and the roots extend up to ground water reservoir and draw water from capillary zone.

2.3 Other preventative measures

(i) **Land grading:** land grading is useful for improving surface drainage in waterlogged soils, especially in irrigated lands.

(ii) **Cropping patterns:** vegetation and crops which have high rate of evapotranspiration may be patronized to serve as natural drainage system.

(iii) **Optimum water use:** conjunctive use of surface and ground water be encouraged by digging wells and sinking shallow tube wells.

(iv) **Better irrigation methods:** Improvements in water applications by giving only the optimum depth of irrigation water. Sprinkler and drip irrigation methods be introduced to reduce percolation losses.

(v) **Punching underground barriers:** Geological formation such as buried ridges as may be interfering with the subsoil flow leading to waterlogging conditions may be punctured to lower the water table.

(vi) **Efficient drainage system:** an efficient drainage system is essential for the quick disposal of the storm water and excess irrigation water.

(vii) **Removing obstruction in natural drainage:** improved by removing debris from the water ways and providing adequate waterway under the road bridges and drainage crossings.

3. COMPONENTS OF A DRAINAGE SYSTEM

3.1 What is drainage?

Drainage is the process of managing excess surface water and controlling water logging from shallow water tables. It involves activities that supplement natural surface and sub-surface removal of excess water. The purpose of drainage includes the reclamation of land for agriculture, forestry, recreation, construction, livestock and wildlife habitat, improvement of soil workability to enable early and timely field operations e.g. tillage, and to improve productivity of crops and pasture. Drainage also enables a farmer to change the farming system to allow production of crops that cannot withstand waterlogging, and it can be used to remove of excess salts from the soil (Figure 3.1).

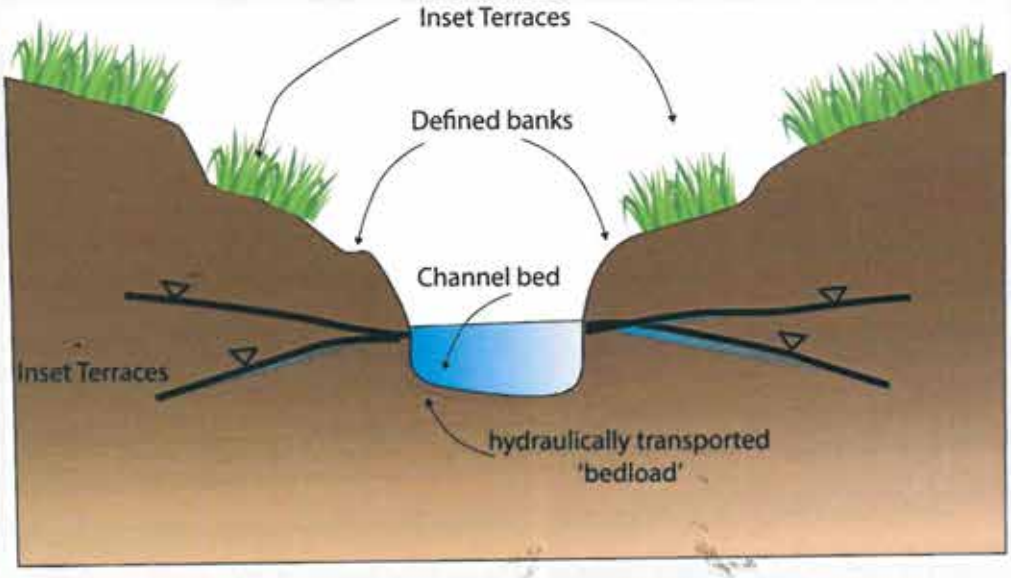

Figure 3.1: Channel bed drainage system for control of water logging

3.2 Advantages and disadvantages of drainage

3.2.1 Advantages of drainage

Well drained land has many benefits for crop production due to an increase in yields and shift from low value to high value crops. Animal production benefits from reduced incidences of animal diseases like foot rot and liver flukes, increased length of grazing period, increase quality and quantity of forage and reduced pasture and soil damage by animals. There are also advantages to farm operations because of increase number of working hours and improved machinery efficiency.

Drainage helps maintain the water table at a reasonable depth so that water cannot rise above the natural ground by capillary action. Above the ground water table, in the unsaturated zone, water is retained in the pores by capillary forces: the water is under negative pressure; smaller pores retain water more easily than larger pores; actually some water can flow upwards from the saturated zone into the unsaturated zone; this is called capillary rise.

Socio-economic benefits of drainage include creation of land for settlements, increased food and cash supply, improved accessibility, provision of employments opportunities and reduction in disease incidences.

3.2.2 Agronomic impacts of drainage

Technically, drainage is beneficial to agricultural production due to the following reasons:

(i) Improvement of the soil structure and increase in productivity of the soil

(ii) Facilitates ease of tillage operations due to improved soil tilth

(iii) Lengthening of crop growing season

(iv) Facilitating early ploughing and sowing of the crops. Crop period is thus increased resulting in higher crop yields

(v) Maintains proper aeration of upper soil layers

(vi) Maintains higher soil temperatures which is good for faster crop growth

(vii) Harmful salts are leached off

(viii) Improvement in sanitary conditions of the area

(ix) Weed control

(x) Control of water borne diseases vectors e.g. malaria

3.2.3 Negative impacts of drainage

Drainage systems are designed to alter the field hydrology (water balance) by removing excess water from waterlogged soils. But there are concerns about the downstream hydrological effects caused by draining the excess water. Hydrological changes in a landscape sometimes occur when it is converted from native vegetation to agricultural production. Subsurface drainage has potential negative impacts on the hydrology of watersheds. It affects the water quality of receiving water bodies, as well as the amount and quality of wetlands. Subsurface drainage can cause imbalances in stream flow, increasing high floods in the receiving areas, while reducing base flows from the drained areas. It may reduce peak flows in some situations.

3.3 Classification of drains

There are different categories of classifying drainage systems, either according to construction or function (Figure 3.2).

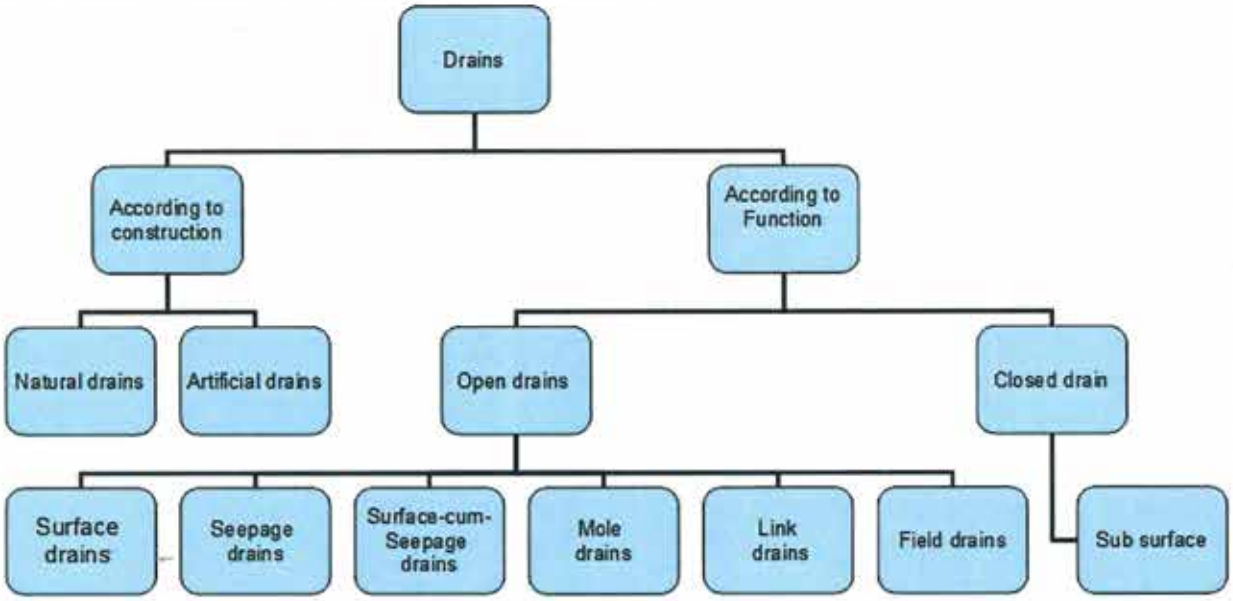

Figure 3.2: Classification of drains

3.3.1 Classification according to construction

a) Natural drains

These are naturally occurring drains which are identified and utilized. They are normally found at the lowest valley line between two ridges. Small streams and dry valleys can also be used as natural drains.

b) Artificial drains

These are the constructed drains generally aligned along drainage line sometimes taken across the valley to reduce length of the drain or the drain or to have proper outfall conditions. They can be on the surface (surface drainage) on in the subsoil (subsurface drainage) – which are described in Chapters 4 and 5 of this manual.

3.3.2 Drain classification according to function

a) Open drains

Open drains are sometimes referred to as surface drains. They are used for the removal of excess surface irrigation water or the disposal of storm water. Diversion ditches (cut off drains) are in this category. Open drains are designed to remove water before it causes damage (Figure 3.3). Whether constructed for the purpose or not, deep surface drains with bed level below water table also cater for seepage water removal. The depth of surface drains ranges about 1 – 1.5 m.

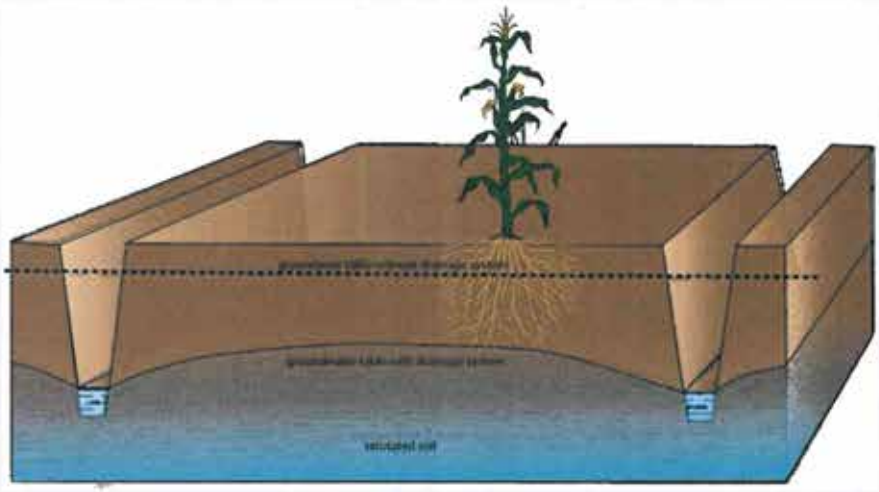

Figure 3.3 A typical open drainage ditch

A drainage ditch is a particular type of open channel waterway designed to provide overall drainage for a watershed area. The emphasis is that these ditches are not primarily peak flow rates, but on removing water rapidly enough to prevent serious crop damage. Empirical formulas for the design capacity of drainage ditches have been developed.

Drainage ditches are good for carrying large volumes of water. They suit gentle slopes and are made in places where roots can block the drain pipes. They are less costly and easy to maintain. However, the main disadvantages of open drains include:

(i) wastage of land, i.e., the land brought under the drain cross-section,

(ii) They dissect the land and thus require bridges while passing drain under road, railway line, canal etc.,

(iii) require frequent cleaning, (harbor and spread obnoxious weeds.

b) Closed drains

Closed drains are sometimes called sub-surface drains since they are mostly installed within the sub-soil profile. They remove water which has entered the soil. They are usually laid 1 to 1.5 m below the ground surface and at a suitable spacing and grade to lower water table to greater depths. The most common types are pipe/tile drains.

3.4. Essentials requirements for drains

The drainage system of an area is just the reverse of the irrigation system: the field drains collect water from the waterlogged area directing it into lateral drains and outfall into major drains and ultimately into a river, lake or the sea. Drains cater for storm water and seepage water. The seepage water collected in the drain can be reused for irrigation in downstream reaches.

In irrigated areas, there are three types of drainage systems:

a) **Type I.** Area with water table between 0 to 1.5 m. Drain is required 2.5 to 3.0 m deep. Natural drainage may be deepened so that 0.5 to 0.6 m depth of drain is in pervious strata.

b) **Type II.** Area with water table between 1.5 to 3.0 m and is likely to rise. Drain is required along the canal to the limit of 1.25 to 1.75 m or up to the pervious strata whichever is less.

c) **Type III.** Water table is below 3 m - Artificial drains are not required. The natural drainage may be trained to the depth of 1.5 to 1.75 m or up to the pervious strata.

In nearly all cases, the essential requirements for a proper drainage system should:

(i) Admit all the flood discharge from the catchment,

(ii) Quick and unobstructed flow towards the drain from the catchment

(iii) Capacity to carry away the received water to the outlet (outfall)

(iv) Ideal outfall conditions and locality in relation to drained field

(v) Stable section with non-silting tendency and capacity of avoiding sloughing of side slopes.

(vi) Seepage and or low discharge does not spread thin over the entire section.

(vii) Low maintenance costs,

(viii) Be low initial cost or simply cost-effective.

3.5 Layout of drainage system in the field

The arrangement of drains in the field depends on the sources of excess water, the topography, and the location of the outlet. Some of the common layouts include:

3.5.1 Random field ditches

These are best suited to the drainage of scattered depressions or pot holes. These are usually parabolic or triangular in shape, and may be grassed to maintain channel stability, or may be cultivated in some instances depending on the nature of the crop. When farming operations cross the channel, the side slopes should be in excess of 8:1 (side slope is here defined as the ratio of the horizontal distance to the vertical distance). The side slopes may be reduced to a minimum of 4:1 in cases where it is possible to farm parallel to the ditch. The outlet for a system of random drains may be a natural water course, a constructed drainage ditch or a protected slope.

3.5.2 Bedding systems

Bedding is a method of surface drainage which consists of narrow width plough lands with equally spaced dead furrows running parallel to the prevailing land slope (Figure 3.4). The area between two adjacent furrows is known as a bed onto which the crops are grown. The beds may be of different shapes. Each bed is cultivated separately either parallel or normal to the dead furrows. The depth of the bed depends on the soil characteristics and tillage practices. In the bedded area, the direction of farming may be parallel or normal to the dead furrows. Tillage practices, parallel to the beds, retard water movement to the dead furrows. Ploughing is always parallel to the dead furrows. Bedding is most practicable on flat slopes of less than 15%, where the soils are slowly permeable and tile drainage is not economical. A collection ditch must be provided to collect the water from the dead furrows and channel it to some outlet ditch.

Figure 3.4 (a) Bedding system on alluvial soils in river valley (photo by B. Mati)

(b) Wider beds on compact clay soils (photo by O. Rafalimanana)

3.5.3 Parallel ditch systems

These are similar to bedding systems but with the channels spaced further apart and with a greater capacity (Figure 3.5). The ditches are usually trapezoidal in shape. The systems may be further subdivided based on their side slopes and their depths. The minimum side slopes are of the order of 1:1 in sandy soils and 1.5:1 in other mineral soils. The walls may be vertical in histosols.

Figure 3.5(a) Newly excavated parallel ditch system (photo by O. Rafalimanana)

(b) Parallel drainage ditch system in paddy field (photo by B. Mati)

3.5.4 Cross-slope ditch systems

These are mainly used for the drainage of sloping lands. The drains run across the slope and intercept water flowing from upslope (Figure 3.6).

Figure 3.6(a) Newly excavated cross-slope ditch system (photo by O. Rafalimanana) *(b) Cross-slope ditch system with raised beds (photo by B. Mati)*

3.6 Preparation of a farm drainage plan

The design and installation of a good drainage system requires information on soils, crops, climate and topographical field data. Once the system has been installed, the plan needs to be updated to show the system as built. The drainage plan should be passed on to subsequent landowners.

3.6.1 Reasons for a drainage plan

A drainage plan provides step by step information on how to construct and install a complete land drainage system. The plan includes information on:

(i) Best possible outlet location (without a topographical survey the best outlet location is not always obvious).

(ii) Location, size, depth, spacing and slope of all open ditches and subsurface drains.

(iii) Location of all pertinent obstructions – buildings, trees, fences, gas, oil, water, telephone and transmission lines.

(iv) Upland and surface runoff considerations.

(v) Backfilling, blinding and outlet requirements.

(vi) Unusual construction problems.

A project plan enables the drainage contractor and designer to lay out the drainage system in the most cost effective way. The plan also allows for evaluation of materials required and anticipated projects costs. The plan provides a record for future reference and is useful for other development work such as planning crop rotation, land levelling and irrigation.

3.6.2 Essential features of a plan

a) Soil survey

A soil survey is required to determine the drainage requirements. It should take account of the type of drainage system (whether surface or sub-surface drainage). In the case of sub-surface drainage, full profile assessment should be done. A soil base map should be prepared showing land boundaries, roads, creeks and other landscape features. Soil boundaries and profile pits should also be shown.

b) Topographic survey

A topographic survey, showing important elevations and key physical features of the property, used in conjunction with soils and groundwater information enables the designer to layout the drainage plan. Before beginning the survey, it is necessary to locate existing and potential outlets, boundaries, all problem areas and any other important topographical features that should be included. On steep slopes, 1.0 – 2.0 m contours may suffice while 0.25 m contours may be required on level fields. Good vertical accuracy is required because of the low grades on agricultural land. The topographical survey should include fence lines, ditch bottoms and water levels at regular intervals, culvert inverts and diameters, farm roads and gates, farm buildings, rock outcroppings, trees and any other pertinent obstacles.

c) Drainage plan and design

A drainage plan is essential for the installation of a drainage system and equally important for future maintenance purposes. In producing a drainage plan, it should show adequate level of detail. It should show bench marks and give their descriptions and locations. The location of drains, culverts, miscellaneous structures and appropriate landmarks should also be indicated.

4. SURFACE DRAINAGE SYSTEMS

4.1 What is surface drainage?

Surface drainage is the removal of excess water from the surface of the land. This is normally accomplished by excavation of shallow ditches, also called open drains. The shallow ditches discharge into larger and deeper collector drains. In order to facilitate the flow of excess water toward the drains, the field is given an artificial slope by means of land grading and levelling. Meanwhile, agricultural drainage is the use of surface ditches, subsurface permeable pipes, or both, to remove standing or excess water from poorly drained lands. This is because excess surface water standing on the field for longer than half a day, can cause prolonged absence of air in the soil and subsequent damage to the crops. Surface drainage ditches are normally used on the land surface to remove of excess water from waterlogged soils, irrigated fields or storm water from excessive rainfall.

4.2 Types of surface drainage ditch systems

The type of surface ditch depends on the source of runoff, quantities being removed, land topography and its function. The commonly used types of surface drainage systems include:

4.2.1 Field drains

- Are the ditches directly connected to the field to be drained, and they remove excess irrigation water applied to the farms and the storm water (Figure 4.1). They should not be too deep as to interfere with agricultural operations. They are, therefore, designed as shallow surface drains. Land grading, which result in a continuous land slope towards the field drains, is an important part of a surface drainage system. Land grading, or land levelling is also necessary for surface irrigation. The shallow surface drains are trapezoidal in cross-section. Strictly speaking, they should be designed to carry normal storm water, plus, the excess irrigation water. It is neither economical nor desirable to design these drains for exceptional storms

Figure 4.1 (a) Field drains in basin irrigation system (photos by B. Mati) *(b) Field drains in temporary waterlogged rain fed system*

4.2.2 Shallow surface drains

These are broad and shallow open ditches constructed to remove excess water either from field drains in irrigated agriculture or excess rainfall in rain fed agriculture. They act like the laterals in an irrigation system. These drains are large enough to carry flood water and of sufficient depth to take the water to the outlet ditches. They carry runoff to the point of entrance to outlet ditches. When used in rain fed agriculture, they are variously called cut off drains or diversion ditches.

4.2.3 Deep open drains

Deep open drains are actually sub-surface drains but made very deep so as to remove water in the subsoil. The excess water from the root zone flows into the open drains and is taken out to an outlet (Figure 4.2).The main limitation with this type of subsurface drainage is that it makes the use of machinery to excavate and is difficult.

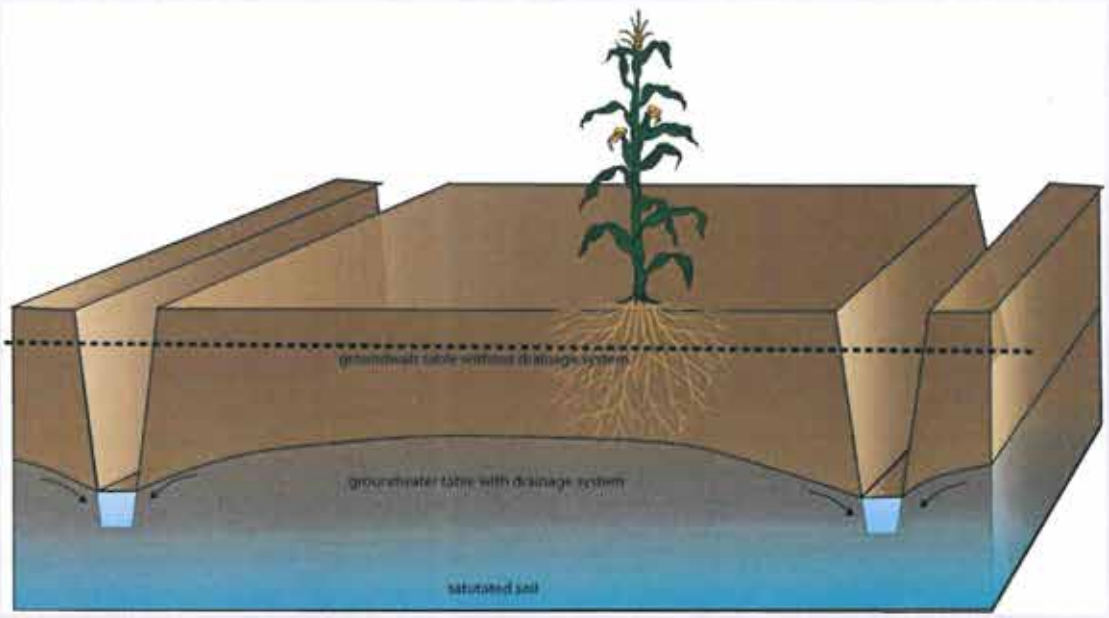

Figure 4.2: Control of the groundwater table by means of deep open drains

4.2.4 Seepage drains

Seepage drains cater for the subsoil water. They are made deep enough to allow water table to drop in the drain and seepage water is taken away (Figure 4.3). They are of smaller section compared to surface drains. They help maintain aeration of the root zone depth. Usually these are construction along the canal bank to drain directly into a natural outfall or into a carrier drain.

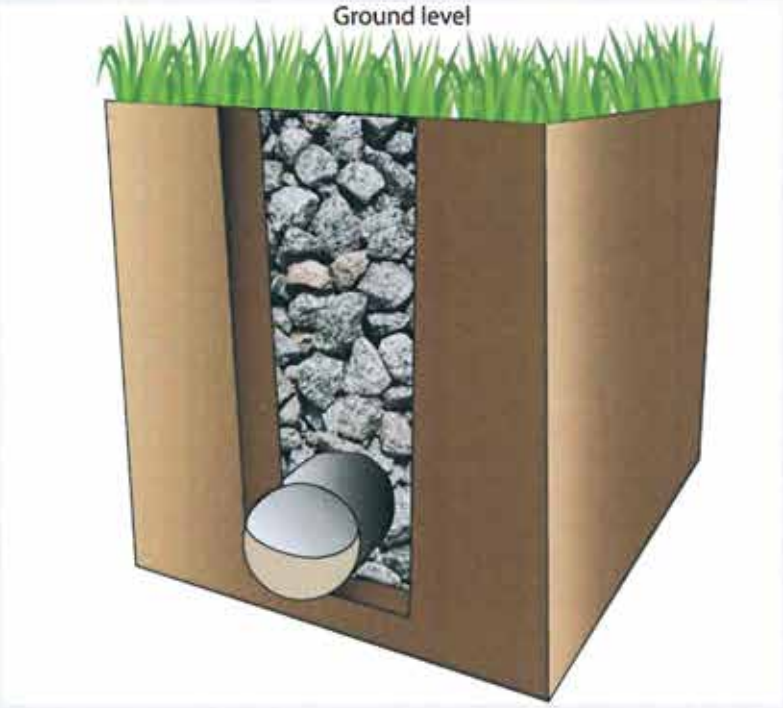

Figure 4.3: Control of groundwater by use of French seepage drain

4.2.5 Surface-cum-seepage drains

They serve the dual purpose of seepage and storm water drain. During rainy season they carry storm and seepage water. They have bed level below the water table. A cunnette is usually provided to cater for the small seepage water.

4.2.6 Link and field drains

Link drains are branch drains draining sub-catchment in to the outfall drain (Figure 4.4). These are aligned along subsidiary valley lines. Field drains are small drains draining individually or a group of fields into the link drains.

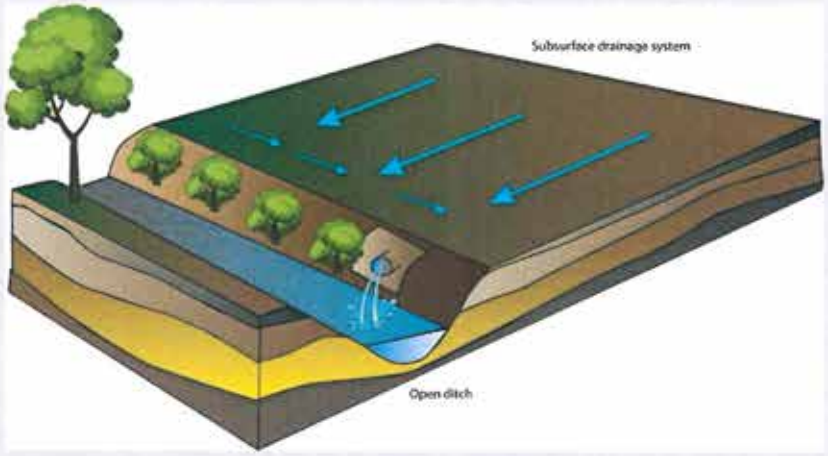

Figure 4.4: Link and field drains system for control of sub-surface water

4.2.7 Outlet ditches

Outlet ditches or deep surface drains carry the seepage water coming from a sub-surface drain, other surface drains or storm water (Figure 4.5). They are, therefore, designed for the combined discharge. Generally, a cunette is provided in the center of the drain-bed, so as to carry the seepage water. A steeper slope is given to the cunette, and it is lined so as to withstand higher flow velocities and thus to inhibit weed growth.

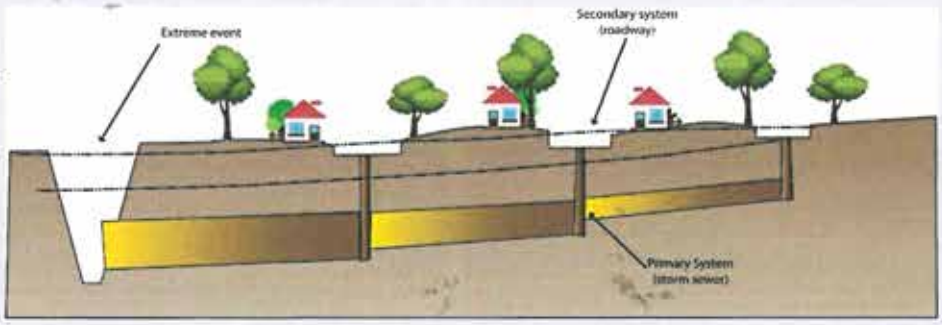

Figure 4.5: Management of storm waters by means of outlet ditches

4.3 Design of surface drains

Surface drains are designed to cater for storm and seepage water removal. They are suitable when

(i) large volume of either surface or subsoil water from the land are to be catered for,

(ii) slope is too slight to permit installation of the tile drains,

(iii) plant roots are likely to clog the tile drains,

(iv) there is satisfactory outfall for tile drain, and

(v) low cost works are desired. Generally, surface drains are usually 1 to 1.5 m deep. The design considerations include the following:

(i) Design rainfall

The rainfall intensity, frequency and duration affect the design discharge of a drain. Usually the maximum of 3 days duration is considered on economic consideration. For drain section, rainfall corresponding to 5 year return, and 10 or 15 years for higher degree of protection is considered. If masonry structures are to be constructed, then rainfall corresponding to 50-year return is used.

(ii) Depth and duration of submergence

The flow discharge to be removed by the surface drain depends on the permissible depth and duration of submergence which in turn varies from crop to crop. The period of disposal is limited to 7-10 days for paddy, 3 days for maize and cotton, 7 days for sugarcane and 1 day for vegetables.

(iii) Economic considerations

Economic considerations include the costs of excavated drain section. It should be designed with most efficient cross-sectional area.

(iv) Environmental impacts

Both positive and negative impacts of drainage on the environment must be considered. Remedial measures should be included in the drainage design. On-site impacts on drained land include soil erosion and other degradation of soil and water; off-site impacts include downstream pollution or deposits of eroded soil. The distinction is important because on-site impacts are borne by the party that benefit from drainage, while off-site impacts are borne by others, sometimes including downstream beneficiaries of the drainage. Farmers would weigh the cost of on-site impacts against the benefits of drainage, and decide how much on-site damage to accept. However, framers may adopt a short time horizon and may not possess full knowledge about these impacts, so their decision may not be optimal.

On-site impacts, on the other hand, exemplify negative environmental externalities. Inexpensive pollutant disposal is beneficial to the creator of pollution, but harmful to the downstream recipient. Unless the polluter pays the recipient for the costs they face- or, under some circumstances, the recipients pay the polluter to reduce pollution- the optimal level of pollution will be exceeded. Strategic solutions to off-site impacts often involve getting the affected groups to agree on how to share the

benefits and costs of the new project, and to mediate the disputes that will inevitably arise as the re-mediated drainage system is constructed, operated and maintained.

(v) Drain capacity

In determining the drain section, peak rate of run-off, total volume of run-off as also distribution of run-off throughout the year is considered. The standard recommended runoff coefficient for different soils in plains is 0.7 for plateaus lightly covered, 0.55 for clayey soils, stiff and bare clayey soils lightly covered, 0.4 for loam, lightly cultivated or covered, 0.30 for loam, largely cultivated and suburbs with gardens, lawns and roads, 0.20 for sandy soils, lightly growth and 0.05-0.20 for parks, lawns, meadows, garden, cultivated areas.

(vi) Alignment

Where it is necessary to change the direction of an open channel, the change should be gradual, with the degree of curvature dependent on the velocity of flow and the erodibility of the side slopes. The alignment of the drain is required to be such that it traverses through the lowest contours, i.e., along the drainage line. The length of the drain should be the minimum that is consistent with the requirement to drain off the lowest spots by either directly or through subsidiary drains. It should not cross the irrigation canal or pass through village habitations but be as far as possible. Drains aligned down the slope are usually much more effective than those excavated normal to the direction of the slope of the ground. The reduced distances, RDs, are marked along the drain, the zero RD being at the outfall end and increasing upstream, i.e., just the reverse of canal wherein RDs increase toward downstream.

(vii) Water surface slope

Water surface slope in the drain is governed by the general slope of the ground and outfall condition. Non-weeding velocity which is considered higher than non-silting velocity is provided. The slope is either kept constant or gradually decreasing towards the outfall in keeping with the increased discharge downstream. Slope is generally determined from Lacey's formula

$$S=0.003f^{5/3}/Q^{1/6}$$

The channel slope is determined by topography and the depth of the waterway. In flat areas, the channel slope should be as steep as possible, as long as the limiting depth or the limiting velocity criteria are not violated. The channel should be deep enough

to collect all the drainage water from the area. In some cases, the depth is constrained by the depth of subsurface drains that empty into the waterway.

(viii) Permissible velocity

Drainage ditches should flow with a velocity that allows water to move without causing erosion damage. The design of permissible velocities assumes the same methods and equations as for other open channels, and can adopt Manning's formula as follows:

$$Q=1/n\ AR^{2/3}S^{1/2}.$$

Where:

Q = Flow rate in m3/s

S = slope gradient

R = Hydraulic radius (equivalent to the ration of cross-sectional Area to wetted perimeter)

N = roughness coefficient (estimated as 0.025 for earthen channel).

Generally adopted permissible velocities for open drains are as follows:

Soil type	Permissible velocity (m/s)
Firm loam and clay loam	0.5-1.0
Alluvial soil	0.6-1.25
Ordinary gravelly soil	1.0-1.25
Coarse gravel, shingle	1.25-1.50

(ix) Channel side slopes

The channel side slopes for surface drains are designed according to the type of soil they lie upon and the surface condition. Thus, recommended side slopes for various soil types are as follows:

Soil type	Recommended Side slopes
Loose rock and hard soil	0.5:1
Alluvial soil	1:1
Sandy soil and deep black cotton soil	2:1
Very sandy soil	3:1

(x) Bed width and depth

An open drain should have a bed width and depth corresponding to Manning's formula discussed above. The discharge is divided into suitable reaches considering that the flow increases towards the downstream, without taking into account transmission loses applicable to canals. The full supply line is generally kept below the natural ground level, say by 0.6 m, so that there is no flooding outside and the drain caters for the drainage effectively but not higher than 0.3 m above average ground level at the starting point of the drain.

It is a good practice to dig a cunnette (a small narrow depression) at the center of the drain to cater for low flow and seepage. Cunnette section also helps in preventing weed growth because low flow is not made to spread thin over the entire section but is contained within the cunnette section. It also reduces maintenance which for most periods is required for the cunnette portion only.

Drains are excavated for ordinary flood discharge only at the lowest average level of the adjoining wet fields while the maximum flood discharge section will have its maximum level at 0.3 m above ordinary flood level with a very wide berm.

(xi) Bank width

The drains in general, are not banked on both sides. The top embankment is usually

kept 1 m higher than design full supply level and 1 m minimum berm width. Bank is essentially required on one side and side contributing flow may be left un-banked. Where heavy spilling may take place on both sides, continuous embankments on both sides are provided. Regulated inlets are provided, where necessary, to allow the outside water to enter into the drain. In diversion drains continuous banks on both sides of the drain are essentially provided.

Minimum bank width is 2.0 m; general practice being 3 m width on non-patrol bank and 6 m on patrol bank side. In large capacity drains a boundary road 5 m wide is provided. Consult the environmental regulations and water resources management authorities on wetlands to work within the permissible buffer zones.

4.4. Operation and maintenance of surface drains

Surface drains, are open to the elements and thus likely to suffer damage e.g. from farm operations, excessive flooding or blockage. Proper operation means that they are opened wherever necessary to drain out the excess water. The ditches require regular maintenance to keep them functional. This may entail desilting, reshaping and re-aligning. Also proper care is needed to avoid stagnation of water in the drains which can lead to salinity buildup. One of useful way to maintain drains could be to utilize the tail water for productive purposes (see Chapter 7).

5. SUBSURFACE DRAINAGE SYSTEMS

5.1 What is subsurface drainage?

Subsurface drainage is the removal of water from the crop root zone. It can also be described as the removal or control of ground water and removal or control of salts by means of water. Subsurface drainage is accomplished by deep open drains, digging underground tunnels (moling) or with buried pipe/tile drains. Subsurface drainage promotes better root growth and plant health when soils have poor internal drainage (Figure 5.1).

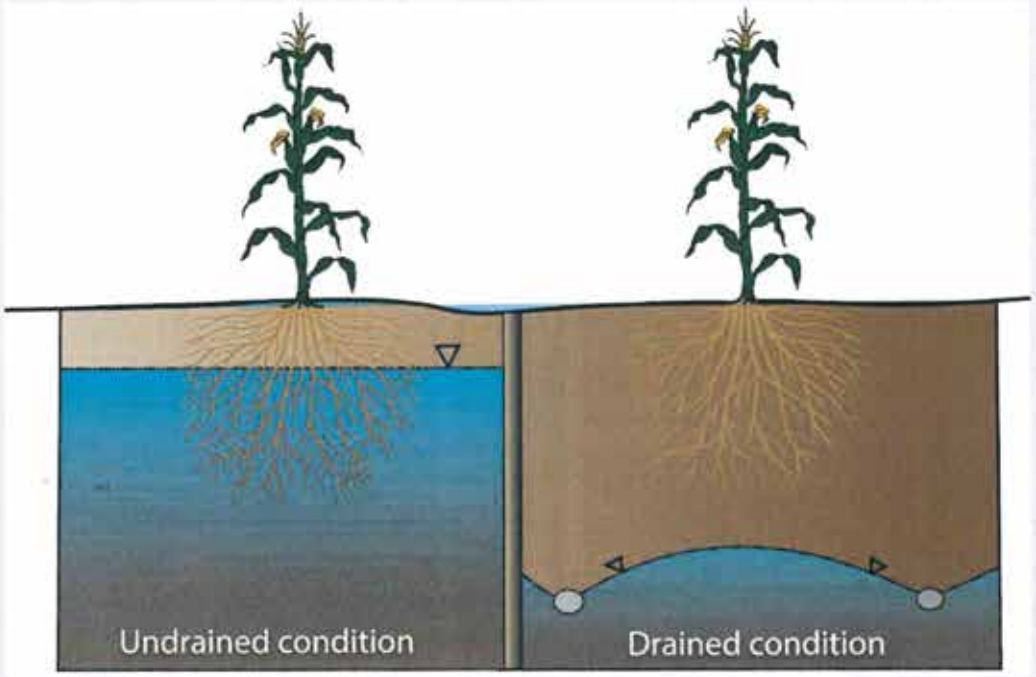

Figure 5.1: Sketch illustrating subsurface drainage

Open ditches, although applicable for subsurface irrigation if made quite deep, but they utilize land that otherwise could be used for crops. They restrict the use of machines and may require a number of bridges and culverts for road crossings and access to the fields. Open drains require frequent maintenance e.g. weed control and repairs. In contrast, buried pipes cause no loss of cultivable land and maintenance requirements are limited. The installation costs, however, of pipe drains may be higher due to the materials, the equipment and the skilled manpower involved.

Sub-surface drains are required for soils with poor internal drainage or where an impervious layer occurs below the farmland and water-table is high, thus inhibiting the internal drainage of the soil. Surface drains, on the other hand, are needed for removing the excess farm water, for most of the cultivated crops on flat or undulating

topography. For optimum productivity of most crops, both surface as well as sub-surface drains are essential.

5.1.1 What is a closed drainage system?

Closed drains are underground or sub-surface drains laid deep in the ground and then covered. They are particularly useful for permanent drainage of lands subjected to deep waterlogging. They help lower the full saturation line adequately below the ground surface. Closed drains are placed in permeable stratum, at a suitable depth and grade below the ground surface depending on the topography, existing water table and the extent of depression of water table required. In low permeable stratum, the drain is shrouded with filter materials of high permeability to ensure effective drainage. Most closed drainage systems are used for subsurface drainage.

5.1.2 Advantages and limitations of closed drains

Closed drains are below ground and hence do not interfere with farming operations. They do not occupy external physical space on the land surface; hence no area is put out of production. Since they draw water from deeper layers, they give crop root zone greater depth and also lower the water table to greater depth. They offer a permanent method of reclamation of waterlogged, saline and saline-alkali soils.

The main limitations with closed drains include high initial cost as they can be more expensive to install that open ditch systems. In addition, they can only handle smaller flows hence have limited drainage capacity. Closed drains require steeper slope, which is difficult to attain underground. Since they are underground, closed drains are difficult to inspect thus it is not easy to know when they have failed. Also, repairs may be costly and inconvenient.

5.1.3 Types of subsurface drainage systems

There are many types of subsurface drainage systems depending on construction material, layout and functions. The most commonly used systems on agricultural lands are:

a) Pipe drains (also called tile drains)

b) Mole drain

c) French drain,

d) Other subsurface drainage systems e.g.

(i) Vertical drainage, and

(ii) Controlled drainage.

5.2. Tile (pipe) drainage system

5.2.1 What is tile drainage?

A tile or pipe drainage system consists of buried pipes (or clay tiles) with openings through which the soil water can enter. The drainage pipes convey the water to a collector drain (Figure 5.2). The drain pipes are made of clay, concrete or plastic. They are usually placed in trenches by machines. In clay and concrete pipes (usually 30 cm long and 5-10 cm in diameter) drainage water enters the pipes through the joints. Flexible plastic drains are much longer (up to 200 m) and the water enters through perforations distributed over the entire length of the pipe. In the field, tile drains comprise a main drain, its branches and subsidiary drains, with the system so devised as to cater for all wet areas that could eventually be drained into one main drain.

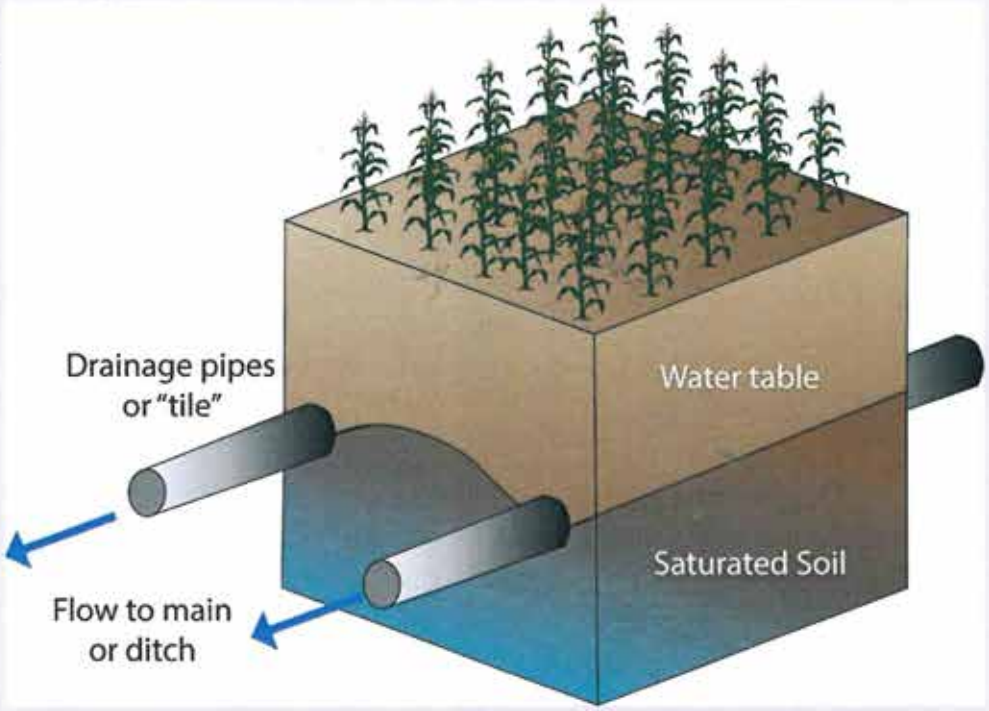

Figure 5.2: Sketch showing control tile (pipe) drainage system

(Source: Busman and Sands, 2001)

Tile drains permit deep root development by lowering the water-table, especially during the rainy season. A plant having deep roots can extract water from greater depths, and hence, can withstand droughts better than one having shallow roots. Moreover, a deep rooted plant is larger, and, therefore, capable of more transpiration and hence, increased yields.

5.2.2 Design of tile drains

Tile drains are the most efficient and permanent type of sub-surface drainage for the irrigated areas where the water table has permanently risen close to the ground service. Free water enters through the open joints of the tiles. The water drained by the tile drain is disposed of by gravity into deep surface drain or pumped out depending on outfall conditions. In the system, laterals remove water from the soil; sub-drains collect water from a laterals and empty into mains for disposal into outfall.

a) Tile spacing and depth

The drain depth is reckoned from the ground surface to the bottom of the tile. They are located at a suitable depth, usually 1 to 1.5 m, below the ground surface and at a suitable spacing and grade depending on the soil, climate and topography of the area. The center of the tile drain is usually 0.3 to 0.6 m below the level up to which the water table is desired to be lowered below the root zone of the plants. The deeper the drain the more is the drainage area per drain line and farther is the spacing of drains. The drains are closely spaced in clay soils and far apart in sandy soils. Recommended drains placed about 1.25 m deep have the spacing shown in the table below using Hooghoudt formula.

$$S^2 = \frac{4K(H^2 - h^2 + d - 2hd)}{}$$

Where

S= spacing between tile drains,

V= rate of discharge or rainfall per unit area of land surface.

d= depth of bottom of drain above impervious layer,

h= depth of water in tile drain,

H= maximum height of water table above drain bottom,

k= coefficient of permeability.

For practical purposes,

$$S^2 = \frac{4K(2d + H)}{V}$$

Considering drain is empty and h=0.

The spacing depends on soil type and its hydraulic conductivity as follows:

Soil type	Hydraulic Conductivity	Spacing (m)
Clay and Clay Loam	Very slow(<1.3 mm/h)	9 to 21.5
Silt and Silty Clay Loam	Slow to moderately slow(1.3-2.0 mm/h)	18.5 to 30.5
Sandy Loam	Moderate to rapid (20- 250 mm/h)	30.5 to 91.5

b) Capacity of the tile drain

The capacity of the tile drain flowing full is determined from **Manning's velocity formula** taking roughness coefficient, n=0.018. The diameter of the drain is computed by equating the capacity of the tile drain to the design runoff for the area. The tile diameter is given by the formula:

$$D = 0.1635 D_c^{0.375} * S^{-0.1875} * A^{0.375}$$

Where,

d= internal diameter of tile (cm),

D_c= drainage coefficient (cm per day),

A= drainage area (m^2),

S=drain slope.

The minimum size of tile is about 10 to 15 cm diameter. The allowable velocities through a tile depend on soil types as follows:

Soil type	Allowable velocity (m/s)
Sand and sandy loam	1.1
Silt and silt loam	1.5
Silty clay loam	1.8
Clay and clay loam	2.1
Coarse sand or gravel	2.2

c) Tile gradient

Tiles are laid on a slight grade so as to let the water flow. If the gradient is too small, they tend to fill up quickly while those with steep grade cause high velocities of flow. The desirable range of working grade along the tile drain is 0.1 to 0.2%. The grade for

10 cm tile is 0.10%, for 13 cm tile is 0.07% and for 15 cm tile is 0.05%. The drainage coefficient with no surface water admitted directly into the drain is 5 to 10 mm/day, with a recommended recurrence interval of 5 years.

The laying of tiles begins at the lower end of the line and progresses up the grade. The tiles are laid true to the line of the trench and firmly bedded in the bottom of the trench and on grade. Joints between the tiles are kept open, shrouded with filter, to admit drainage water into the line. A gap of 3 mm in the case of silt, loam and clay soils and 6 to 10 mm for peat and muck is usually allowed.

It is assumed that the hydraulic gradient at a distance x from the drain is dy/dx, when y is the height of water table above the impervious layer. Flow lines are parallel and cross sectional area of flow at a distance x is y*1= y, and discharge q towards the drain is inversely proportional to the distance from the drain, and Q is the total discharge per unit length carried by the drain so that half (0.5) Q enters the drain from either side.

According to **Darcy's law,** Q= KIA, or q= Ky * dy/dx,

Where,

q is the discharge per unit of drain passing through-y.

K is the coefficient of permeability of the soil.

Now, q= 0.5Q, when x=0 and q=0 when x=S/2.

Where

S = spacing of the tile drain (m),

Integrating, then use Dupuit formula as follows:

$S=2\sqrt{k/v}\,(b^2-a^2)$,

Where

a= depth of impervious layer from the center of the drain,

b=maximum height of the drained water table above the impervious layer.

$Q = 4k\,(b^2-a^2)/S$, and depends on infiltration into the ground and is usually assumed as 1% of the average annual rainfall in 24 hours.

5.2.3 Inlets for tile drains

a) Surface inlets

A surface inlet is a structure constructed to carry the pit water into the sub-surface drain. A galvanized iron pipe or a manhole, constructed of brick or monolithic concrete, is sufficient and satisfactory. Manholes with sediment basins are sometimes used as surface inlets. The surface water from a waterlogged field, depressions, road ditches, or homesteads is connected to the tile drain through an intake structure called an *open inlet* or *a surface inlet*.

At the surface of the ground, a concrete collar extending around the intake is constructed on the riser to prevent growth of vegetation and to hold it in place. On top of riser, a beehive grate or some suitable grating is provided so as to prevent trash from entering the tile. When the inlet is constructed in a cultivated field, the area immediately around the intake should be kept in grass. When the surface inlet is connected to a to a main tile drain, it is a good practice to offset the surface inlet from the main. Such constructions may eliminate failure of the system, if the surface inlet structure should become damaged.

b) Surface inlet alternatives

Alternatives to the traditional "open inlet" are used. One design involves digging a trench, placing drainage pipe at its bottom, and filling the trench with small rock. These "rock" or "blind" inlets slow the flow of water (compared to open inlets) and may reduce the amount of sediment reaching the drainage system. Another design involves the installation of subsurface drainage pipes in a very tight pattern in a small area in the middle of a wet spot. Another, more traditional, technique involves replacing open inlets with perforated risers. All these designs have the potential to do a better job of protecting water quality than open inlets, while still providing adequate drainage so crops don't "drown."

5.2.4 Envelope filters.

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

When the tile drains are placed in less pervious soils, they are generally surrounded by graded gravel filters, called *envelope filters*. The envelope filter serves two functions:

(i) It prevents the inflow of the soil into the drain.

(ii) It increases the effective tile diameter, and thus increases the inflow rate.

The filter consists of different gradations such as gravel or coarse sand. The coarsest material is placed immediately over the tile, and the size is gradually reduced towards the surface. The minimum thickness of filter is about 7.5cm. The graded filter may sometimes be substituted by a single gradation depending upon the availability and cost considerations.

5.2.5 Outlets for tile drains

The water drained by the tile drains is discharged into some bigger ditches, called deep surface drains. The water from the tile drains may be discharged into these outlets drains either by gravity or by pumping, depending upon which, they can be gravity outlets or pumped outlets, such as:

a) Gravity outlets

If the bed level and full supply level of the outlet ditch is lower than the invert level of the tile drain, water can be discharged easily by the mere action of gravity. Corrugated metal pipe with a flap shutter to prevent entry of rodents is generally provided at the outlet point. If there is a danger of food water backing up into the drain, a flood gate may be provided.

b) Pumped outlets

When the bed level of the outlet ditch is higher than the discharging tile drain, a pump outlet has to be installed. It consists of an automatic controlled pump with a small sump for storage. Pump outlets are costly and require technical support during operation. Possibility of deepening the outlet ditch should, therefore, be investigated so as to sue gravity flow. The cost of installing and maintaining a pump outlet should be compared with that of excavating and maintaining a deeper ditch, before making a final selection.

5.2.6 Layout of tile drainage systems

There are various ways to arrange the tile drainage system across a farm. The most common ones include:

a) Random system

In this system, the drains are laid more or less at random targeted at the wet areas. The main drain is located at the natural drainage line and individual wet spots are connected through sub-mains and laterals. Where wet spots are large the arrangement of the sub-mains and laterals for each wet place may utilize one or more of the parallel systems to provide the required drainage. It is used in areas with uneven topography that have scattered wet areas which may be isolated from each other.

b) Natural system:

This consists of a system of drains, in which the main drains are located along the natural depressions or low spots to conform to the topography. Natural system is generally installed in areas of rolling or broken topography where drainage of isolated track is required and can cover quite some large areas.

c) Parallel system

Parallel system consists of a system of drains with long parallel laterals emptying into a single main drain. It is used in poorly drained soils having uniform texture and little slope.

d) Herringbone system

This system consists of a main or sub-main along the depression with parallel lines of field drains sloping towards the main drain and joining it at staggered intervals. It is used for lands lying on both sides of a narrow depression and laterals must enter from both sides. It is less economical on account of double drainage occurring where the laterals and main join.

e) Grid Iron system

In this system, the field drains are constructed in parallel lines along the direction of the slope and join the main drain at its bottom. It is used for flat land with a uniform slope.

f) Double main system

This system is similar to herringbone system except that there are two main drains in this system on each side of the depression. It is used when then the bottom of the depression is wide.

g) Grouping system

It is similar to the Natural system except that a few laterals are provided in the wet areas or ponds along the system. It envisages collection of water from a number of smaller systems and discharging to the ditch through one outlet. It is used where the topography and wetness on the field vary and pattern of drainage must be changed to fit the different conditions.

h) Intercepting system

Tiles are place along the hillside to intercept the seepage water that follows the upper surface of an impervious sub-soil to prevent it from reaching the bottom land. It is used for draining seepage along hillsides.

i) Composite system

A *composite system* is a combination of systems of tile drain arrangement such as the herringbone and grid iron systems.

j) Sink hole drainage system

A sink hole drainage system is a system of drainage used to intercept seepage water, but has addition wells dug at regular intervals to let the water come up from a lower stratum and enter the drain.

k) Zigzag System

In this system field drains as well as mains are constructed zigzag to reduce high velocities.

5.3 Mole drainage

5.3.1 What is a mole drain?

A mole drain is an unlined circular earthen channel 5 to 10 cm diameter, formed in the subsoil by pulling a mole plough to create the tunnel. The moling plough is pulled along the sloping ground with the mole shoe at a depth of 60 cm. they are spaced 3.5 to 5 m apart. A round channel is formed in the soil with cracks along the mole. The drainage water enters the mole through these racks and is carried along the slope in subsurface or open drains. Mole drains function much like pipe drains and constitute valuable supplement to open drainage where they can be used. They are useful in equalizing water level between ditches for both drainage and for sub-irrigation. They are suitable in

The success of a mole drainage system is dependent upon satisfactory water entry into the mole channel and the mole channel itself remaining stable and opens for an acceptable period. Currently, mole drainage systems are most commonly used for surface water control in perched water table situations. Mole drains are also used in some groundwater problem areas and in paddy fields. They are also used as a temporary subsurface drainage system for the reclamation of saline and saline sodic soils.

Compared to pipe drains, the main advantages of mole drains are that they are low cost, and hence can be installed economically at very close spacings. The main limitation includes the fact that mole drains offer temporary solution to the problem of drainage, and thus must be re-created every year.

5.3.2 Creating mole drains

Mole drains are formed with a mole plough, which comprises a cylindrical foot attached to a narrow leg, followed by a slightly larger diameter cylindrical expander (Figure 5.3). The foot and expander form the drainage channel and the leg generates a slot with associated soil fissures which extend from the surface down into the channel. The leg fissures are vertical and are formed at an angle of approximately 45° to the direction of travel.

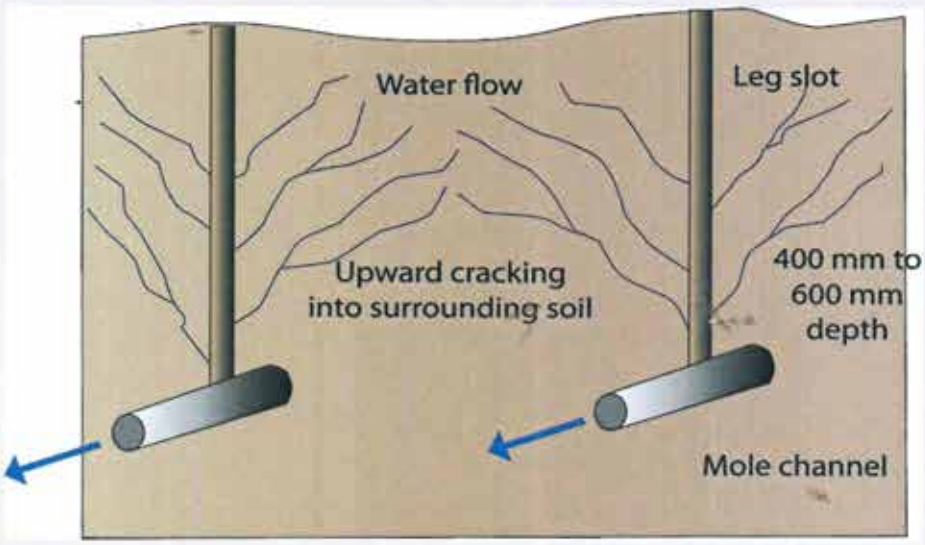

Figure 5.3: Illustration of foot and expander in a mole channel

The number and size of the leg fissures produced with a given mole plough depends on the soil condition. A smaller number of wide fissures tend to form under drier conditions, but as the soil-water conditions become increasingly plastic, the fissures become narrower and more numerous. These changes continue until fissure development ceases under very plastic conditions.

Figure 5.4: Newly installed mole drain, viewed from the tail drain, showing fine fissures (Source: Bennett et al, 2004)

Figure 5.4: A stable mole drain two years after installation (Source: Bennett et al, 2004)

Mole channel walls become smoother as soil-water contents increases, the following expander increasing the smoothing effect (Figure 5.5). At high water contents in low density soils, the expander tends to seal off the connection between the leg slot and the mole channel. The success of a mole drainage system is dependent upon satisfying two requirements: achieving the desired water flow path for the particular drainage situation, and installing stable mole channels. The installation technique adopted must meet these requirements.

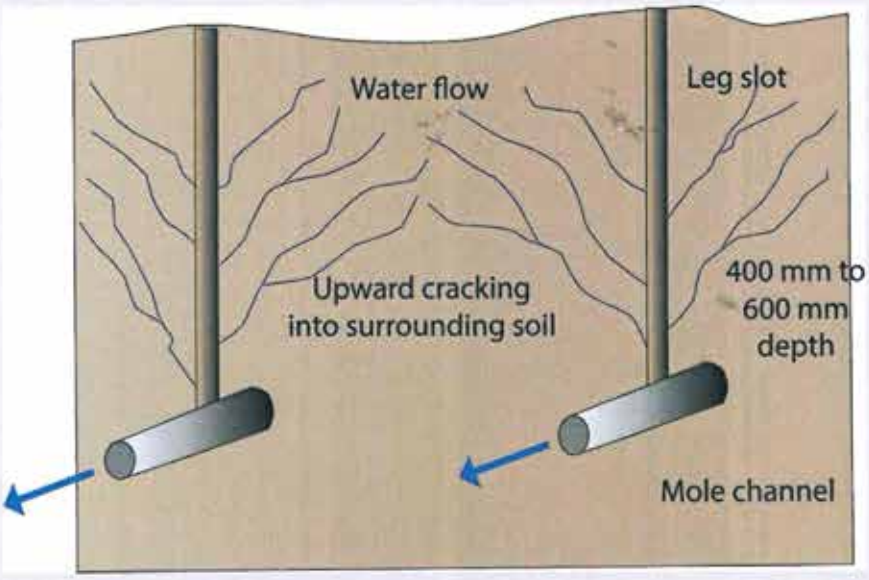

Figure 5.5 mole channel

5.3.3 Factors considered in designing mole drainage

Mole drainage requires the construction of a series of stable, unlined soil 'pipes' or moles of even and low grade. Creating the mole channel results in the formation of a series of fine fissures or cracks in the soil which provide the major flow paths for soil-water to move into the mole channels and then out into the drainage system.

Several factors influence the success of a mole drainage system and the longevity of the mole channels. Correct management of these factors is critical to the success of mole drainage. When installed correctly, a mole drain may last up to five years before remoling is required.

(i) Soil type

Good moling soils must have a high clay content (30 per cent or more) at 200-700 mm depth. These soils texture as clays, silty clay loams or clay loams. Some of the best moling soils have clay contents in excess of 45%, whereas soils with less than 30% clay are rarely good molers. Uniform soils are most satisfactory. Mole channels in soils containing sand or silt pockets are more prone to collapse.

However, high clay content is not the only soil factor affecting mole stability. Soil chemical factors such as salinity, sodicity and clay type are also important in determining soil stability. Soils with high levels of salinity and sodicity (an excess of sodium ions relative to chlorine ions) are unstable when mole drained and moles are likely to fail due to dispersion and slaking. This happens when fresh water (from rainfall or irrigation) comes into contact with highly saline or sodic soil in the mole channel. Because salinity and sodicity generally increase with soil depth, it is often best to keep the mole drainage system as shallow as possible on saline soils.

(ii) Soil structural stability on wetting

Soil structural stability on wetting is a crucial factor influencing channel life. The more resistant the soil structural units are to collapse on wetting; the more stable the mole channels are likely to be. Weakly structured and dispersive soils are unsuitable for moling, unless the electrolyte or salt concentration of the drainage water entering the mole channel can be increased to improve stability. This can be achieved in saline soils by preventing the direct access of surface water of low electrolyte concentration through the leg fissures and leg slot. The introduction of soil-amending materials such as gypsum into the neighborhood of the channel also assists an increasing electrolyte concentration. In addition, mole channels in soils with a high bulk density tend to be more stable than those in low density ones, because of slower swelling rates.

(iii) Soil moisture and timing

Sufficient soil moisture is critical for mole drainage. Moling should be done when the soil, at mole depth, is as close to its upper plastic limit as possible. That is, it is easy to shape or mould by hand but it is not so wet that it loses its shape easily. There is often a trade-off between soil surface moisture and traction and soil moisture at depth. Ideally, the soil needs to be moist at moling depth and quite dry and friable near the surface. This is also important for the development of the soil cracks and fissures above the mole channel.

Soil at moling depth needs to be in a state of plastic consistency to enable the formation of the most stable, firm, smooth-walled mole channel. The smooth wall is preferably fissured at intervals along its length, the fissures acting as focal points for water entry. After installation, the moles should be left for as long as possible (at least 2 weeks) to settle and 'cure' before they receive large flows of either rainfall or irrigation water. Moling should never be done when the soil is waterlogged.

(iv) Collector drains

Under common situations, a mole drain should not exceed 50-60 m length before it has an outfall. Longer mole lengths may cause instability and poor drainage because of irregular gradients, poor soils and presence of sand or silt. Collector drains installed across the field at close intervals provide an effective network to collect and discharge mole drain water.

(v) Moling depth

Mole channels are commonly installed at depths between 0.4 and 0.7 m, although there is no restriction to deeper installation. Wherever possible, installation should always be in the most suitable and structurally stable soil layer. Moles should be installed deeper in situations where deep soil drying and cracking are likely to occur; this reduces the risks of cyclical swell/shrink failures. The herringbone pattern of leg fissures along the mole run is usually very obvious at the soil surface when the moles are being installed correctly, below the critical minimum depth. Reducing the diameters of the mole plough foot and expander brings the critical minimum moling depth closer to the surface, hence allowing shallower moling.

(vi) Mole drain spacing

Mole drains are usually spaced closer together due to the semi-permanent nature of mole drains and the risks of collapse. This ensures that drainage performance is not seriously impaired if some of the mole drains collapse. These closer spacings have

minimal implications on cost, because mole drains are very cheap to install. Common mole drain spacings range between 2.0 and 3.5 m.

(vii) Mole channel grade

Mole gradient causes water ponding if too level, or erosion if too steep. Extended water ponding within the channel, particularly to depths greater than half the channel diameter, can result in collapse of the mole. Reverse gradients, are a major cause of ponding and should therefore be avoided. Thus, suitable channel gradients range about 0.02 to 0.03. Lower gradients are satisfactory, so long as local reverse grades can be avoided. In certain situations, it may be advantageous to grade the mole channel positively, to a gradient different from that of the general soil surface. Under certain conditions, with relatively large channel gradients and higher flow velocities, a local channel blockage can disrupt water flow, causing water to 'blow-out' to the surface, creating a wet area. This problem can be minimized by reducing channel gradients.

(viii) Mole channel outlets

Outlets for mole drains (called outfall) should be stable and fully draining. Outfalls into open ditches must be stabilized with short lengths of pipe (0.8 to 1.0 m long) at the outlet. Sometimes, a longer length of stabilizing pipe is inserted into the channel to protect and support the most vulnerable section near the open ditch. Gravel, crushed stone, or strong clinker are commonly used as the permeable backfill material for mole outlets. The permeable backfill should extend to a minimum height of 50 mm above the top of the mole drain.

Mole drains themselves can be used as collector outfalls and these are frequently known as major moles or moled mains. The moled mains should be installed first, in pairs about 1 to 2 m apart, in the required outfall position. The field moles are then drawn above and across the moled mains, with the field mole channel invert within approximately 50 mm of the top of the moled main. In some field situations (wet, soft, or poorly structured soil conditions), it is advisable to make a positive connection between the two channels, to ensure water discharge from the field mole into the main. This can be achieved by forcing a spear, 5 to 10 mm in diameter, between the two channels.

5.3.4 Gravel mole drains

In situations where mole channels collapse quickly, through causes other than complete soil structural instability, their life can be increased considerably by in-filling them with stone or gravel. The installation equipment comprises a hollow leg approximately 75 mm wide, with a gravel hopper above. The gravel is inserted into

the channel through the hollow leg, and the thickness of the gravel zone in the channel is controlled by an adjustable gate at the rear of the leg. The size range of gravel used is between 5 and 15 mm diameter, to ensure free flow without bridging during installation. The large side area of the leg produces leg fissures similar to conventional mole plough leg fissures. These fissures provide direct access for water from the surface layers into the gravel filled channel.

5.4 Vertical drainage

Vertical drainage involves pumping out the excess water from subsoil to lower water table. The method used may include use of shallow tube wells, deep tube wells, seepage-cum-pumping stations and open wells. The pumped water can be used for irrigation as it is or by mixing with canal water. Its advantage over horizontal drainage is that it is quite flexible and effective depending on extent, disposition and characteristic of aquifer. However, vertical drainage can be quite expensive in terms of the energy costs. Also, the disposal of drainage water may pose a problem.

5.5 French drain

A French drain (or blind drain, rubble drain, rock drain, drain tile, perimeter drain or land drain) is a trench covered with gravel or rock that redirects surface and groundwater away from an area (Figure 5.6). A French drain can have perforated hollow pipes along the bottom to quickly vent water that seeps down through the upper gravel or rock. French drains are common drainage systems, primarily used to prevent ground and surface water from penetrating or damaging building foundations. Alternatively, the French drain technique may be used to distribute water, such as a septic drain field at the outlet of a typical septic tank sewage treatment system. French drains are also used behind retaining walls to relieve ground water pressure.

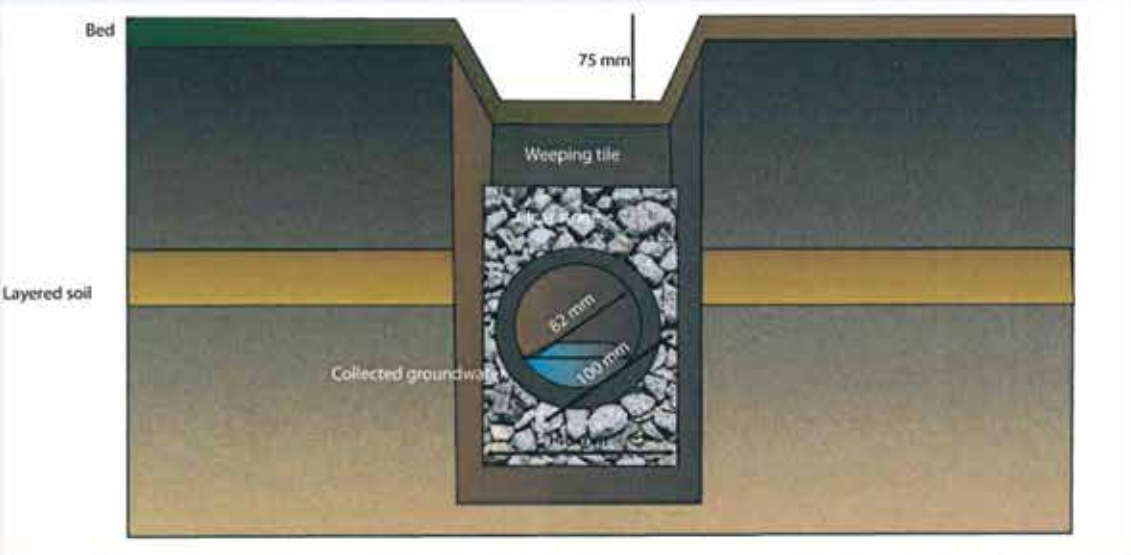

Figure 5.6: Illustration of a French drain

In preparing a French drain, the ditches may be dug by hand or with a trencher. An inclination of 1 in 100 to 1 in 200 is typical. Lining the bottom of the ditch with clay or plastic pipe increases the volume of water that can flow through the drain. Modern French drain systems can be made with perforated pipe (weeping tile) surrounded by sand or gravel and geotextile or landscaping textile. Landscaping textiles are used to prevent migration of the drainage material as well as preventing dirt and roots from entering and clogging the drainage pipe. The perforated pipe provides a minor underground storage volume but the prime purpose is for the perforations to drain the area along the full length of the pipe and to discharge any surplus water at its end. The direction of percolation will depend on the relative conditions inside and outside the pipe.

5.6 Controlled drainage

Controlled drainage involves placing simple water control structures at various locations in the system to raise the water elevation. Water control structures at the final point of drainage outlet can be used to regulate water depth in the ditch, field-water table depth and water outflow. This elevated water causes the water table in the soil to rise, which, in effect, decreases the drained depth of the field. This helps to decrease nitrate losses which is a common problem in conventional drainage systems. If managed properly, controlled drainage can improve crop yields by making more water available to plants.

The concept of controlled subsurface drainage can be applied as a means to reduce the quantity of drainage effluent. In design, a control structure at the drainage outlet or a weir placed in the open collector drain allows the water table to be artificially set at any level between the ground surface and the pipe drainage level, so promoting

root water extraction (Figure 5.7). The size of the areas where the water table is controlled by one structure depends on the topography. During system operation, it is important that the water table be maintained at a relatively uniform depth.

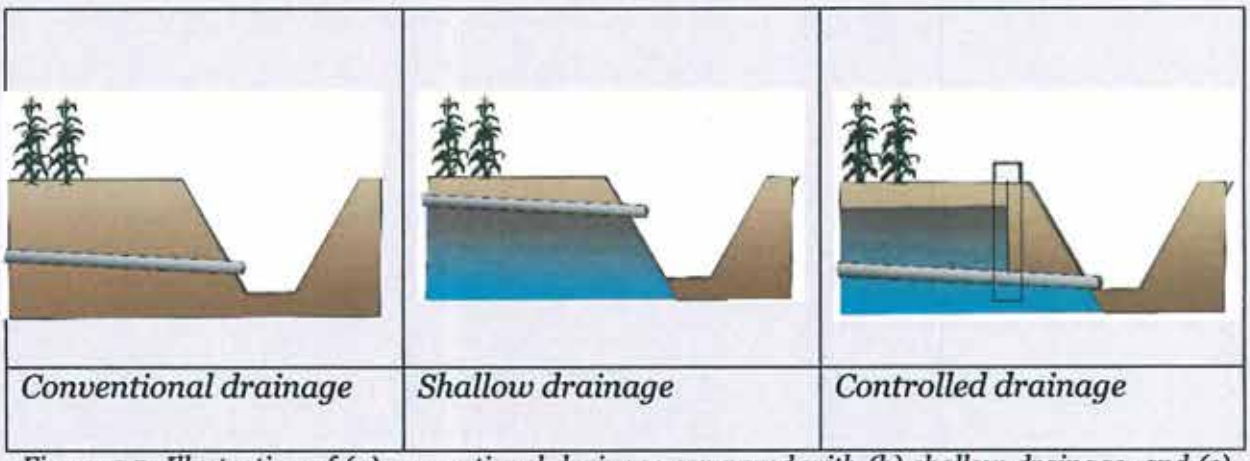

Figure 5.7: Illustration of (a) conventional drainage compared with (b) shallow drainage, and (c) controlled drainage

The application of controlled drainage techniques is limited, however, by topography. The process is economically unfeasible on land slopes greater than about one percent because more water control structures are needed as slopes increase. In addition, controlled drainage adds new management requirements to systems (also increasing with slope) that can be a disadvantage.

6. LAND RECLAMATION

6.1 What is land degradation?

There are areas which can be considered useless for agricultural production, and whose potential has deteriorated due to various reasons, whether natural or through human induced activities. Such areas are known as ***degraded lands*** and their problems vary depending on the causative factors. The process of lowering the productivity of land is known as land degradation.

a) Land degradation

Land Degradation is the process that lowers the current and/or potential capability of land to produce goods (crops, support livestock, timber) or provide services (such as unpolluted water). There are six types of land degradation;

(i) water erosion,

(ii) wind erosion,

(iii) biological degradation (loss of biodiversity),

(iv) physical degradation,

(v) chemical degradation (pollution by pesticides, industrial effluents), and

(vi) salinity build up (salinization). The problem of soil erosion was dealt with in Training Manuals 4 and 5 of these series, while salinization has been discussed in Chapter 1 of this Manual. Land degradation can lead to, or be caused by soil degradation.

b) Soil degradation

Soil degradation, is the sum of geological, climatic, biological and human factors which lead to the degradation of the physical, chemical and biological potential of soil, and endanger biodiversity and survival of human communities. Soil degradation is a global process, but sub-Saharan Africa is affected most, with arid and semi-arid zones being particularly affected. Depletion of nutrients and soil organic matter and erosion are the principal forms of soil degradation. Overgrazing and cultivation practices that are not adapted to local environments are the principal causes of soil degradation. Overgrazing is often the result of the loss of pastures to agriculture. Producing crops without compensating the nutrient losses by removing plants also leads to soil degradation.

c) Desertification

In tropical countries, the problems of land degradation, soil degradation or waterlogging can lead to desertification. Now, desertification is defined as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities". Combating desertification includes activities which are part of the integrated development of land in arid, semi-arid and dry sub-humid areas for sustainable development which are aimed at prevention and/or reduction of land degradation, rehabilitation of partly degraded land and reclamation of desertified land.

d) Chemical deterioration

Chemical deterioration involves loss of nutrients or organic matter, salinisation, acidification, soil pollution, and fertility decline. The removal of nutrients reduces the capacity of soils to support plant growth and crop production and causes acidification. In arid and semi-arid areas problems due to accumulation of salts can arise, which impedes the entry of water in plant roots. Soil toxicity can be brought about in a number of ways, but typical examples are from municipal or industrial wastes, oil spills, the excessive use of fertilizer, herbicides and insecticides, or the release of radioactive materials and acidification by airborne pollutants. While soil toxicity may be a relatively minor problem at present in Africa, it is likely to become of increasing importance in future years.

e) Physical deterioration

Physical deterioration involves soil crusting, sealing and compaction and can be caused by several factors like compaction through heavy machines or animals. It occurs in all continents, under nearly all climates and soil physical conditions. Soil crusting and compaction tend to increase runoff, decrease the infiltration of water into the soil, prevent or inhibit plant growth and leave the surface bare and subject to other forms of degradation. Severe crusting of the soil surface because of breakdown of soil aggregates can inhibit water entry into the soil and prevent seedling emergence.

Regardless of whether the problem of land degradation is caused by waterlogging, soil erosion, denudation or desertification, degraded lands can be reclaimed and their productivity increased.

6.2 What is land reclamation?

Land reclamation is the process of restoring to economic value and use, lands which have been rendered degraded or have suffered severe reduction in productivity. Several factors are considered in identifying the methods to apply for land reclamation. This is based on the main degradation problem, such as: Soil characteristics, salt distribution and total soluble salt content in the soil, pH value, irrigation water quality, and present land-use and objective of reclamation.

6.3 Effects of reclamation of waterlogged soils

The land reclamation process, especially in waterlogged fields, involves land drainage (discussed elsewhere in this Manual). The effects include:

(i) ***Reduction in salt content***: - This is achieved by the leaching and rice cultivation. Sufficient depth of water in rice cultivated lands tends to maintain the salt at a safe depth below the surface from crop growth point of view. It is the first step of reclamation.

(ii) ***Reduction in soil alkalinity***: - Achieved through proper drainage. Carbon dioxide generated by crop roots on soil replaces the sodium which brings about improvement in soil.

(iii) ***Restoration of nitrogen***: nitrogen essential for plant food, and it is reduced in waterlogged soils due to absence of air and excess water content of the soil. A leguminous crop is grown in between rice cropping to restore the soils' nitrogen.

6.4. Reclamation of salt affected soils

Principal methods of reclamation of salt affected soils includes:

6.4.1 Land levelling:

Land levelling is usually necessary before implementing reclamation measures in irrigated fields. The land is essentially levelled to ensure uniform application of water and prevention of accumulation of water in fields. Land levelling is a reclamation activity as it make it affects drainage and farming operations.

6.4.2 Leaching

Leaching is the process of flooding the land surface with abundant irrigation water to a depth of at least 15-25 cm. the dissolved salts are drained off through deep seepage

drains. The leaching operation may be repeated periodically, if salt deposits re-appear. Leaching is a prerequisite for reclamation of saline or sodic soils.

Leaching requirement, is the amount of water required to control soil salinity. It depends on soil salinity, the salinity of irrigation/cleansing water, crop tolerance, type of soil and the acceptable yield reduction. It is sometimes expressed as a quantity (mm/d) and sometimes as the fraction of irrigation water to be used for the leaching of salts.

$$LR = {}^{D_d}/D_i = {}^{EC_i}/EC_d$$

Where

LR= Leaching requirement expressed as ratio or %,

D_d= Equivalent depth of drainage water,

D_i = Depth of irrigation water

EC_i= Electrical conductivity of irrigation water (mmhos/cm), and

EC_d= Electrical conductivity of drainage water (mmhos/cm).

The depth of irrigation Di, is related to the consumptive use Dc and the equivalent depth of drainage water Dd by the equation:

$$D_i = D_c + D_d$$

By eliminating $D_d$from the above equation, the leaching requirement can be easily calculated as:

$$D_i = {}^{D_c}/(1-LR)$$

The depth of water to be added (or irrigation water needed for leaching excess salts) can be calculated using electrical conductivities (which are easier to measure) as follows:

$$D_i = [EC_d/(EC_d - EC_i)]D_c$$

The leaching requirement is determined by the following equation:

6.4.3 Crop rotation

Normally, leaching is followed by a combination of crop rotation. The most effective crop rotation for reclamation of an alkali soil is manuring with a combination of mulching with leguminous plant materials such as *Sesbania* or *Tephrosia*. For paddy rice, rotations should include grams between successive cropping seasons. Sugarcane might also stand an alkalinity of pH 9.5. In areas susceptible to waterlogging, light irrigation crops should be introduced (see Figure 6.1).

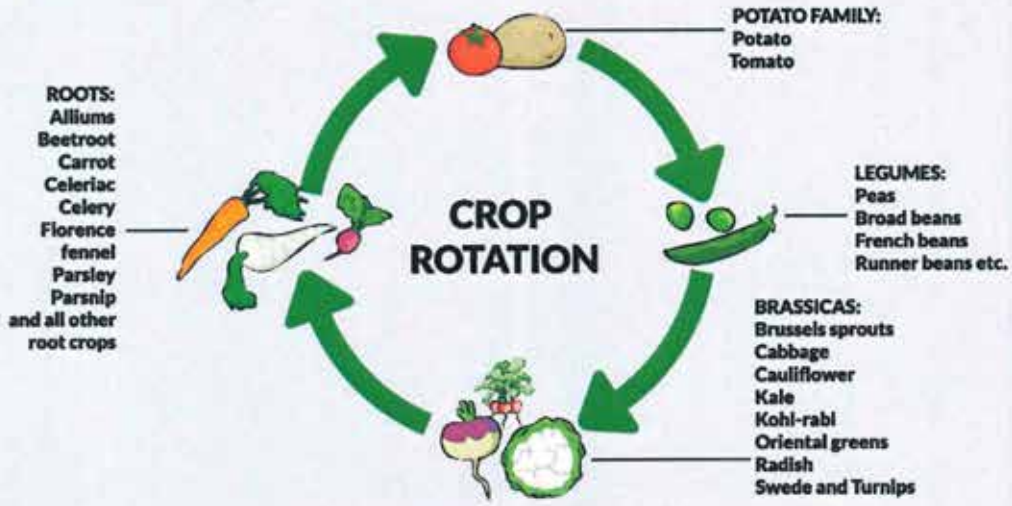

Figure 6.1: Model crop rotation system

6.4.4 Addition of amendments:

Addition of amendments containing soluble calcium salts such as gypsum, acid or acid forming fertilizers is very useful for the improvement of alkali soils. For saline-sodic soil, use of gypsum results in not only in higher yield of crops but also in improving the soil. Unlike fertilizers, gypsum application is not to be repeated every year.

6.4.5 Surface drainage

Drainage washes out salts from the soil surface and also removes them from within the soil. Reduction in salt content by drains is very slow but they help in reclamation of saline soils.

6.4.6 Subsurface drainage

Provision of subsurface drains is a very effective reclamation measure for areas with high salt content throughout the profile or saline underground water.

6.4.7 Dug-out ponds

For permanent reclamation of waterlogged and saline-alkali soils, the excess runoff is collected in dug out ponds of sufficient capacity in low lying areas. Either runoff from the first rain of the season is not ponded or such water with high sodium carbonate content could be used for irrigation with addition of gypsum.

6.4.8 Breaking impervious pan

This involved deep chiseling or deep tillage with sub-soiler plough to break the hard impervious subsoil pan. This improves internal drainage of the soil reducing accumulation of salts.

6.4.9 Skimming drainage

The brackish water overlies saline water in areas of rising water table. The upper water of better quality can be removed by skimming drainage, i.e. installing partially penetrating wells just to pump out top and better quality water.

6.4.10 Soil conservation

Soil erosion, borne either by wind during dry season or water itself is relatively common, leading to nutrient loss as well as depleting the topsoil. Less top soil may not be a problem initially, but can eventually make rooting difficult for plants and make them more susceptible to being uprooted by wind or water. Wind-borne erosion is less common in drainage schemes but can be quite severe if the soil structure has been degraded by other factors like salinization. Therefore is the need for wind breaks or other appropriate methods for soil conservation.

6.5 Reclamation of polluted soils

6.5.1 Chemical soil and water amendments

The aim of applying chemical amendments to soil or water is to improve poor infiltration caused by either a low salinity or by excessive sodium. The problem is most severe at low electrolyte concentration and high sodium absorption ratios (*SAR*). Improvements can be expected if the soluble calcium content is increased or a significant increase in salinity is achieved. Most soil and water amendments supply

calcium directly or indirectly through acid that reacts with soil calcium carbonates. Acid is not effective where calcium carbonate is not present in the soil profile. However, calcium carbonate is often present in arid soils.

6.5.2 Maintaining favorable soil structure

The sodium hazards of waterlogged area are related to the ability of excessive sodium or extremely low salinity concentrations to destabilize soil structure. The primary processes responsible for soil degradation are swelling and clay dispersion. Provided that the salt concentration in the soil water is below a critical flocculation concentration, clays will disperse spontaneously at high exchangeable sodium percentage (*ESP*) values, whereas at low *ESP* levels inputs of energy are required for dispersion. The salt concentration in the soil water is crucial to determining soil physical behavior because of its effects in promoting clay flocculation. However, the boundary (*ESP* /salt concentration of the soil water) between stable and unstable conditions varies from one soil to the next and changes with the clay mineralogy, *pH*, soil texture, and clay, organic matter and oxide content.

6.5.3 Maintaining favorable levels of ions and trace elements

High concentrations of trace elements in soil, ground and drainage water can occur in association with high salinity and can be affected by the same processes. However, in some places they may also occur independently of salinity. In examining ways to control levels of ions and trace elements in the root zone, it is necessary to understand the processes that affect their mobility. The two processes that largely control the mobility of trace elements in the soil water are:

i) adsorption and desorption reactions; and

ii) solid-phase precipitation and dissolution processes.

These processes are influenced by changes in pH, redox state and reactions, chemical composition and solid-phase structural changes at the atomic level.

6.5.4 Cultural practices

Cultivation is usually done for weed control or soil aeration purposes rather than to improve infiltration. However, where infiltration problems are severe, cultivation or tillage are helpful as they roughen the soil surface, which slows down the flow of water, so increasing the time during which the water can infiltrate. Cultivation is only a temporary solution. After one or two irrigations, another cultivation may be needed. Moreover, the construction of (broad) beds may help mitigate the ill effects of standing water as it prevents direct contact of the plants with the water.

7. OTHER UTILITIES OF WATERLOGGED LANDS

7.1 Crop production in waterlogged valley bottoms

In many parts of sub-Saharan Africa, waterlogged soils have been utilized for agriculture as they are without an attempt to drain them. The techniques usually involve growing crops that withstand waterlogging or rearing certain fish species e.g. mud fish. In the semi-arid areas, utilization of residual moisture in sand rivers, high water tables and seepage from streams has been used to grow crops as a traditional practice throughout Africa. Generally, "women's crops" such as arrow roots, sweet potatoes, fruits and vegetables were grown in the valley bottoms ensuring better nutrition for the family. Sugarcane and rice have also traditionally been grown in river valleys. Valley bottoms are very important for providing food during the long dry season, especially as a drought mitigation measure.

7.2 Planting pits within waterlogged soils

Various types of pits are used by farmers to utilize residual moisture on streambeds and other waterlogged areas. As the dry season progresses, water levels recede and there is need for the crop to reach water. An innovative farmer in Mwingi, Kenya, devised method of planting sugarcane in pits (Figure 7.1). The design, used on sand riverbeds, involves digging holes that are about 1 x 1 m square, with depths that range from 0.6 to 0.75 m. The holes are spaced about 0.6 m apart within rows (edge to edge) and 0.6 m between rows. The depth of each pit varies with distance from the stream bank, making holes deeper the further from the river. Normally, four sugarcane cuttings are planted in each corner of every pit, and manure applied. During the rainy season, the holes get flooded, replenishing not only water but also the nutrients. The result is that the sugarcane grows faster, survives the drought better, yields much larger and healthier cane, thereby fetching prices more than triple those on conventional flat areas.

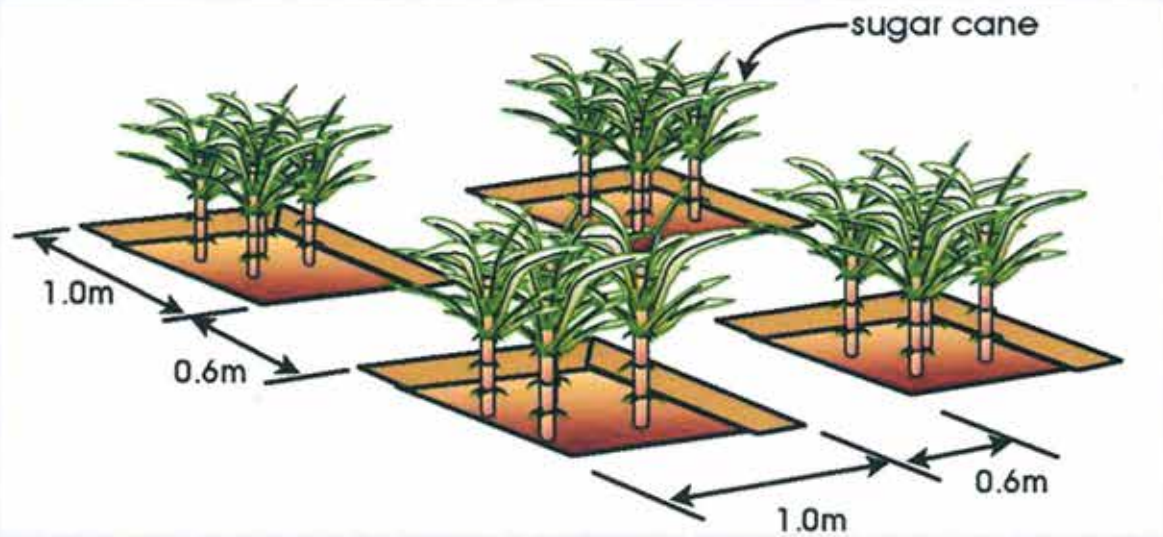

Figure 7.1: Utilizing high water table on riverbeds for sugarcane production.

7.3 Soil mounds

Sweet potatoes are traditionally grown in waterlogged valley bottoms in many parts of East Africa. The practice involves creating mounds of earth or sand in the wet areas, as normal part of earthing up for tuber production, as well as to drain excess water (Figure 7.2). The potatoes are planted on top of the earth mounds where they produce tubers within 3 months. This method is particularly popular in dry areas as part of utilization of residual moisture in valley bottoms,

Figure 7.2 (a) A farmer makes planting mounds on a sand river bed(photos by B. Mati) (b) Sweet potatoes planted on raised soil mounds

7.4 Ridging waterlogged soils

Ridging is sometimes done in waterlogged areas, without any effort to drain away the excess water (Figure 7.3). The idea is to lift the soil high enough during the wet season to permit crop production. During the dry season, the crop roots have established well enough to reach residual moisture as moisture levels recede. Crops such as sweet potatoes, sugarcane, vegetables and even field crops like maize are grown.

Figure 7.3 (a) Freshly excavated ridges utilizing valley bottom (photos by B. Mati) *(b) Sweet potatoes grown on raised beds without external outlet to waterlogged valley*

7.5 Constructed wetlands

Constructed wetlands are artificially created wet zones, mostly for the treatment of waste water. They utilize specially selected flora and fauna, to facilitate biological degradation of organic wastes. However, constructed wetlands can also be used to treat water from drainage systems before it is released into nearby rivers or lakes (Figure 7.4). Biological activity in wetlands can be effective at removing nitrate by converting it to nitrogen gas through a denitrification process that's similar to what occurs in soils. Constructed wetlands can remove from 20 to 80% of the annual nitrate in subsurface drainage water depending on the ratio between the areas of drained land and wetland. The process of treating drainage water presents some challenges. Site topography may pose difficulties in getting subsurface drainage waters to the surface and into wetlands. Land requirements and the cost of construction are also important economic factors. Constructed wetlands are more effective in warmer climates where biological activity is enhanced.

Figure 7.4 (a) Layout of a constructed wetland

(b) Foundation for a constructed wetland-under construction (photo by B. Mati)

7.6 Drainage water reuse

In areas where irrigation water is scarce, the recycling of drainage water is an important strategy for supplementing water resources. Furthermore, reuse may help alleviate drainage disposal problems by reducing the volume of drainage water involved. The reuse of drainage water for irrigation can reduce the overall problems of water pollution. The water recycled after drainage can be used for:

(i) Conventional agriculture, including supplemental irrigation;

(ii) To grow salt tolerant crops;

(iii) For integrated flood management systems;

(iv) To support forestry, rangelands and wildlife habitats

(v) To replenish water in natural wetlands

(vi) To recharge shallow wells and ground water tables

Only those drainage water reuse measures relating to agricultural production are discussed here.

7.6.1 Quality of drainage tail waters

Water leaving a drainage system is normally of inferior quality compared to the original inflow or irrigation water. Thus, adequate attention needs to be paid to management measures to minimize long-term and short term harmful effects on crop production, soil productivity and water quality at field or watershed scales. The drainage water quality determines which crops can be irrigated. Highly saline drainage water cannot be used to irrigate salt sensitive crops, but it can be used on salt tolerant crops, trees, bushes and fodder crops. A major concern in reuse measures is that reused drainage water is often highly concentrated, requiring careful management.

Subsurface drainage water generally shows increased concentrations of salts and sometimes certain trace elements and soluble nutrients. Salts and trace elements play a major role in the reuse of drainage water. Above a certain threshold value, high total concentrations of salts are harmful to crop growth, while individual salts can disturb nutrient uptake or be toxic to plants.

A high sodium to calcium plus magnesium concentration ratio may cause unstable soil structure. Soils with unstable structure are subject to crusting and compaction, degrading soil conditions for optimal crop growth. Toxic trace elements such as boron can interfere with optimal crop growth and others such as selenium and arsenic can enter the food chain when crops are irrigated with water containing high concentrations of these trace elements. This is of major concern for human and animal health.

7.6.2 Pollution of drainage tail waters

Pollutants from surface runoff, i.e. sediments, pesticides and nutrients, play a minor role in reuse for crop production. However, for sustainable agricultural practices and to prevent environmental degradation, nutrients supplied with reused drainage water should be deducted from the fertilizer requirements in order to prevent imbalanced and excessive fertilizer application.

Bacteriological and organic and inorganic compounds seriously pollute main drains, posing an environmental hazard to both human and wildlife and restricting reuse from main drains. The biochemical oxygen demand (*BOD*) is defined as the amount of oxygen consumed by microbes in decomposing carbonaceous organic matter. The chemical oxygen demand (*COD*) is the amount of oxygen required to oxidize the organic matter and other reduced compounds. The high chemical versus biological oxygen demand (*COD/BOD*) ratios implies significant industrial pollution. Total coliform is the most probable number of fecal coliform in 100 ml and a high value indicates severe pollution from municipal sewage water.

7.6.3 Conjunctive use – blending

Where drainage water salinity exceeds the threshold values for optimal crop production, it can be mixed with other water resources to create a mixture of acceptable quality for the prevailing cropping patterns. Where reuse takes place by mixing drainage water from main drains with surface water in main irrigation canals, the most salt sensitive crop determines the final water quality. Where mixing takes place at the farm level, the salinity of the blended water can be adjusted towards the salt tolerance of individual crops.

7.6.4 Conjunctive use – cyclic use

Cyclic use, also known as sequential application or rotational mode, is a technique that facilitates the conjunctive use of freshwater and saline drainage effluent. In this mode, saline drainage water replaces canal water in a predetermined sequence or cycle. Cyclic use is an option for where the salinity of the drainage water exceeds the salinity threshold value of the desired crop. A condition for cyclic use is that two different water sources can be applied to the field separately.

8. OPERATION AND MAINTENANCE OF DRAINS

Drainage canals and conduits are designed and constructed on land that already has a basic water management problem. Thus, their proper operation can be hampered by natural situations as well as human activities. Therefore, regular maintenance is required to keep them functional as designed. There are various factors on which the frequency and degree of maintenance depends, such as the amount of rainfall, climate (affects evaporation), ground water conditions and type of crop enterprise.

8.1 Operation and maintenance problems in drainage

The main problems affecting drainage ditches and conduits include:

(i) Drains carry variable flow, unlike irrigation channels; which can reach a maximum during heavy rains and then very small discharge during the dry season. As such, they are susceptible to erosion and silting up and may not maintain the design cross-sectional area/volume for long.

(ii) They are easily infested with weeds since the water runs at low velocities for most of the time. The weeds can choke the drainage way causing water stagnation.

(iii) Repairs and maintenance are difficult because of drains are normally located at the end of an irrigation scheme or other infrastructure. In addition, closed drains are below ground and difficult to unclog

(iv) Drains are rarely inspected since they are situated away from irrigation channels and generally not provided with inspection funds.

(v) Roads, railway lines and canals often cause obstruction to drainage as they cause an influx in water level and create congestion.

(vi) Cross bunds are often put up across the drain to divert or pump out water for irrigation and not entirely removed afterwards, impairing the normal functioning of the drains.

It is therefore imperative that, in general, a drain has a cunnette to cater for seepage water and the widened width to carry surface water so that the problem of weed growth which is the main maintenance problem is minimal and that too is in the cunnette section only.

8.1.1 Common problems with surface drains

The general drainage problems in open drains are

(i) Erosion of bed and banks

(ii) Settlements

(iii) Sloughing

(iv)Silting, vegetation and seepage

8.1.2 Common problems with pipe drains

The buried (pipe) drains have maintenance problems like

(i) Physical blockages

(ii) Organic or biological blockages

(iii) Chemical or mineral sealing and outlet restrictions

8.2 Maintenance of drains

The maintenance of drainage systems can be low input, such as with unblocking of outlets. In general, open drains require maintenance after a heavy storm. High level input could mean evacuation of all excess water, improving drainage networks and expensive drainage design and implementation.

The maintenance of drains includes the following activities:

(i) Regular monitoring of the condition of the drains

(ii) Cleaning of various drain section and banks

(iii) Root removal and cleaning and repair of outlet grills.

The drains with very small gradients require maximum maintenance, as they are more likely to clog up. Drains with gradients that result in velocities of 0.3 m/s or less require frequent cleaning. The properly designed and installed sub-surface drains generally require comparatively lesser amount of maintenance work for satisfactory operation. In the early period of operation, these drains however, need proper inspection to ensure that they are operational and effective.

8.3. Institutional and socio-economic considerations

The institutional issues bearing impact on drainage planning and management include both the rules (laws, regulations and customs) and the organizations (support agencies, WUAs, cooperatives, or farmer groups) that put those rules into practice through operations and maintenance activities (O&M). Whereas many WUAs have experience with irrigation management, drainage tends to get little attention. The institutional and socio-economic support of drainage O & M can be improved through the following actions:

(i) Developing clear responsibilities which are enshrined in by-laws of the organization or group that is implementing drainage. In particular, the regulation and operation of the drainage schemes should be separate from the oversight, so that one agency is not responsible for both operating a drainage scheme and enforcing the laws governing the allocation of the inflow (e.g. irrigation, urban, storm) water and the discharge of drainage waters.

(ii) To minimize the potential for conflicts when water resources are scarce, the rights to water user groups should be clearly established. Whether to be established in law, by-laws or left to the local custom is a decision that will depend on circumstances, but rights have to be widely understood and accepted.

(iii) Laws and rules governing irrigation and drainage schemes need to be enforced with impartiality, so that no influential land owners take surface and ground water beyond their allocations and discharge contaminated drainage water to receiving bodies of water or downstream users.

(iv) There should be effort to initiate drainage where it is necessary but does not exist. Under-investment in drainage contributes to loss of productivity and this can have negative effects on large areas.

(v) Organizations that control a drainage system's operation and maintenance should be formed at the local level. Other stakeholders, such as downstream communities dependent on the water bodies receiving the drainage water, should be involved in the important decisions about drainage infrastructure; there can be conflicts because of the off-site impacts of drainage. The management of water and the environment conditions in the project area are a concern of many more people than the direct beneficiaries, and all need to be involved if such projects are to have long-term success and stability. Generally, the planning of the drainage system should be carried out as part of the integrated water resources management (IWRM).

(vi) Where routine maintenance and occasional rehabilitation are not fulfilling the purpose for which the scheme was originally designed, modernization should be considered. Modernization is" A process of technical and managerial upgrading (as opposed to mere rehabilitation) of irrigation or drainage schemes, combined with institutional reform, with the objective to improve resource mobilization (labor, water, economic, environmental) and water delivery (or disposal) service to farmers or beneficiaries.

(vii) Training and extension services to beneficiary communities engaged in agricultural drainage is necessary as in many cases, drainage is a new technology to agrarian communities in sub-Saharan Africa.

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Appendix 1: Supplementary sources of information

Internet		
agra-alliance.org	ofbf.org	www.extension.umn.edu
agspsrv34.agric.wa.gov.au	Pakistan	www.fao.org
Amherst	plant-trees.org	www.getebook.in
archivia.unict.it	plumbot.com	www.infonet-biovision.org
banglajol.info	postconflict.unep.ch	www.ircwash.org
Conservation Engineering Seventh Edition,	Practices of Irrigation & On-farm Water	www.iwmi.cgiar.org
cssri.nic.in	project2.zalf.de	www.oieau.fr
datagears.org	res2.agr.gc.ca	www.p2pays.org
documents.mx	restechkenya.org	www.plantstress.com
edepot.wur.nl	soils.org	www.scribd.com
en.wikipedia.org	www.abe.msstate.edu	www.sera17.ext.vt.edu
Encyclopedia of Earth Sciences Series, 2008.	www.agedi.ae	www.stewardshipcentrebc.ca
eprints.soton.ac.uk	www.agf.gov.bc.ca	www.tankonyvtar.hu
fr.scribd.com	www.agric.wa.gov.au	www.teagasc.ie
Global Issues in Water Policy, 2014.	www.aussiedrain.com.au	www.ukessays.com
globalinitiative-escr.org	www.brimag-systems.co.il	www.uni-kiel.de
gov.mb.ca	www.coursehero.com	www.wamis.org
imawesa.info	www.crcc.es	www.wg-drg.icidonline.org
	www.environment.go.ke	www.worldagroforestry.org

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