USDA Natural Resources Conservation Service

Irrigation Toolbox: Chapter 1

Lesson Plan 4

Drainage Primer

Introduction

Water management involves practices which may control the quantity, quality and use of water within a watershed. Land drainage is an important part of water management and may influence storm runoff, ponding, and the quality and quantity of water discharged into a stream. Drainage increases the farmers' opportunities to reduce the unit cost of production.

It is often said that the aim of drainage is to control the water table and field wetness, to optimize soil conditions for cultivation and plant growth, and within certain limits, to improve a particular land use. In practice, however, land drainage is actually employed to establish a compromise between restoration of the soil aeration and the removal of as little water as is necessary to obtain the needed soil air content.

Soil

Soil is the medium in which crops grow. It provides water and nutrients for growth. "Soil" includes the topsoil, subsoil, and substratum. Topsoil usually contains the highest amount of organic matter which gives it a darker color. The subsoil is usually, but not always, more dense and compact than the topsoil. The substratum is generally the parent material from which the above layers were derived. The soil consists of three major components: soil particles, and void spaces consisting of water and air.

Soil structure refers to the physical arrangement and organization of particles in the soil. Soil structures differ in class, shape, size and orientation. The soil structure porosity strongly influences water movement in the soil profile as well as water retention, aeration, root penetration, microbiological activity and erodibility. Soil structure can be influenced and changed by soil management practices. Soil structure is formed by physical and chemical forces. Figure1 shows the common types of soil structure and their effect on water movement.

Soil compaction is a reduction in the total air space in a volume of soil. Compaction also reduces the number and size of the large beneficial air pores in the soil. The solid particles and the water in a soil are not compressible. Therefore, a completely saturated soil cannot be compacted. The soil may be damaged structurally due to smearing and puddling if disturbed in a wet state. The cutting edge of a drainage plow, tillage plow, disc, or tine causes the soil to compress and smear on the underside, often restricting water movement. Compaction of the surface layers can often be corrected by frost action over one winter but deep compaction resulting from heavy equipment on wet soil will take many years to correct and will impede the vertical flow of water.

Plant growth in a compacted soil is restricted due to the high resistance to root penetration and the smaller water storage capacity.

Soil Porosity and Aeration

Soil porosity is the percentage or fraction of the soil volume filled by air and water. The "aeration porosity" or "non-capillary" porosity is the volume of air which enters the soil after freely drained water has been removed. The "capillary porosity" is the volume of all the small pores that retain water after the larger pores have drained. Plant and soil organisms need a steady supply of oxygen from the atmosphere for respiration. The carbon dioxide produced by them must be removed. Plants also need a plentiful supply of soil moisture. When the volumes of aeration and capillary pores are about equal, the exchange of gases between soil air and the atmosphere is optimum. The concentration of carbon dioxide in the soil does not reach toxic levels nor does the oxygen become limiting. Some plant roots, like potatoes, die in about 5 days when their roots are deprived of oxygen. Ample practical evidence exists that poor soil aeration results in reduced crop yields. Pore size distribution and continuity of pores rather than total pore space is more important in drainage and the water holding properties of a soil. Good drainage and organic matter tend to increase the number of non-capillary pore spaces whereas compaction crushes and reduces them.

Soil Water

Soil water infiltrates into the soil and adds to the groundwater already present. It renews the soil profile moisture depleted by evaporation and crops. The sources of soil water are often rainfall, snowmelt, groundwater flow and surface runoff.

The upper surface of the groundwater is called the water table. It is at atmospheric pressure and approximates the water level which might be found in an open post hole after one day. (see Figures **2** and **3).** The water table will be highest in the late fall and early spring and lowest during the summer when evaporation and transpiration are high.

The soil above a water table is unsaturated, except for the capillary fringe. The amount of capillary soil water present depends on the depth to the water table and will change with each rainfall. Due to capillarity, moisture will rise from the water table. The height of this rise depends on the texture of the soil and the continuity of connected pores. Table 2 provides representative amounts of capillary rise that might be experienced in different soils.

Soil water is often described as being made of three components:

a. gravitational water
b. capillary water
c. hygroscopic water

Gravitational water fills the non-capillary pores or large open voids in the soil. The purpose of soil drainage is to remove this gravitational water as quickly and economically as possible after a rainfall so air will replace this water in the large soil pores. Figure 5 depicts the difference between gravitational and capillary water.

Capillary water, or available water, forms a film of varying thickness around each particle and is bound by cohesion to the hygroscopic moisture. The capillary water fills the small capillary pores of the soil. This moisture will not drain away as the capillary force holds it against the force of gravity. Capillary water is what is used by plants. It is replaced by rainfall, or by capillary rise from the groundwater.

Hygroscopic moisture, or absorbed water, is a thin film of water absorbed on soil particles with so much energy that it is unavailable to plants and cannot be drained. Plants only use moisture within a certain range. The hygroscopic moisture is held in the small pores of the soil with so much energy that plant roots cannot extract it. If this is the only moisture available, plants will wilt.

Soil permeability, more properly called hydraulic conductivity, is the rate at which water will move through a soil. Movement of water through soil is affected by soil texture and the continuity of soil pores. Soil permeability is estimated by NRCS soil scientists when they prepare a **SOILS5** information page on each soil.

Why is Drainage Required?

During late autumn, winter and early spring there is usually an excess of rainfall over and above the storage capacity of soils. The ability of the soil to dispose of surplus water quickly is an important requirement for many agricultural crops. Timeliness in working the soil and in planting improves crop yields and aids the farm workload. Soils that have some natural drainage may be tile drained to gain the advantage of managing the timing of crop operations.

All soils that are not naturally well-drained require some improvement to be used for agricultural purposes, or to optimize crop production. Indications of poor drainage are:

a. Farmer's experience of difficulties in working a field or in obtaining satisfactory yields.
b. Surface indications of:
    - i. ponded water
    - ii. boggy conditions
    - iii. water emerging on the surface
    - iv. high water level in ditches
    - v. damage to fields from livestock and machinery rutting
    - vi. areas of crop damage, with partial or total loss
    - vii. cloddy field surface
c. Presence of water-loving vegetation such as reeds, willows, sedges, horsetail, rushes, and coarse grasses
d. Subsurface indications are a high water table, mottled colored soil profile and shallow crop roots

Benefits of Drainage

A drained soil has enough empty pore space to store water for plant use. Water infiltrates into the soil instead of running off over the surface. Table 1 shows the average yield of crops in Ontario with the percent increase from drained land. Figure 4 shows the effect of drainage on plant root growth.

Alfalfa is sensitive to impaired drainage and has a low tolerance to flooding. On a well-drained soil alfalfa remains in a mixture much longer before timothy grasses take over. In planting small grains, experience has shown that the seeding date can be advanced about **2** weeks on drained land compared with land that only has surface drainage. The surface of waterlogged soil tends to heave when frozen; plants are lifted and their roots are broken. All cash crops will have increased yields and improved quality when grown on well-drained land.

Good drainage is also needed when the crop is harvested. Crops such as potatoes have a high oxygen demand and will rot after being waterlogged for 24 hours. Many fruit crops react similarly. Crop roots which use nodules to obtain their nitrogen supply are susceptible to temporary water logging. Tap-rooted crops are less able to contend with poor drainage than crops with lateral root systems.

Drainage Systems

In the earlier days of subsurface drainage, tile systems were installed largely to remove the water from "wet spots" in pastures and cropped fields. The tile system would connect a series of "wet spots" to a drainage outlet in what is known as a random system. See Figure **7.** Much of the modem tile that is installed is in a pattern of some form, and therefore called pattern tiling. This encourages tiling entire fields to optimize crop production, not just remove water from "wet spots".

The top portion of Figure 6 shows the configuration that is sought by farmers seeking to optimize crop production on their fields. If the drainage tiles are too far apart as shown in the lower portion of the figure, an area of poor crops results over the subsoil that is inadequately drained. If a tile has become partially or fully blocked by sediment, the effective width of drainage is reduced. When the tile was first installed, the field would have good crops as shown in the upper part of Figure 8, but as the tile fills with sediment, the field becomes more like that shown in the lower portion of the sketch, with an ever widening band of poor crops between the sections that produce well.

Drainage tile was originally made of clay, often reddish in color, and hence the name tile evolved. When concrete became popular as a building material, it was also formed into drainage tile. Older systems are often lengths of clay or concrete tile, laid such that the sections have a small gap between them which allows water to enter the tile line and leave the field. In recent years, drainage tile made of corrugated plastic has become quite popular, for its ease in installation, and hence, low cost. It has slits cut in the sides which allow water to enter the tile. The corrugated plastic drainage tile comes in long coils for smaller diameter sizes. When the diameter reaches about 12", the tile is too rigid to coil so it is shipped in 20 foot lengths.

Factors Affecting the Rate of Flow into Drains

The movement of water into drains is influenced by many variables:

1. ***Soil permeability.*** The horizontal and vertical permeability of the soil horizon(s).

2. ***Depth of drain.*** The depth of the drain below the surface and the drain location with respect to the various soil horizons.

3. ***Drain openings***. The size and distribution of openings into the drain; for example, cracks between tile, perforations in the tile, gravel envelopes, or unlined channels.

4. ***Distribution of potential at the flow boundaries.*** The configuration and location of the free water surface, and the presence and magnitude of artesian pressure or of back pressure in the drain.

5. ***Drain spacing***. The horizontal distance between individual drains.

6. ***Drain diameter.*** The diameter of drain tubes.

Tidbits

A. If the outlet is undersized, plugged, or inadequate, the system will not function as desired.

B. Regular maintenance is needed on a tile capacity.

C. Tile size is increased to allow the water from a larger watershed to be conveyed. A larger tile size normally means a fairly small increase in the amount of water drawn from the soil to the tile.

D. Drainage capacity can be limited by 1) the rate at which the soil conveys water to the tile, or by 2) the size of the tile outlet and its ability to convey water away from the field.

E. As a tile system deteriorates, the field becomes wetter and wetter. This can be seen in a series of aerial photos taken at regular intervals.

F. A blowout occurs when something plugs a tile and the pressure of the water trying to Ieave exceeds the resistance of the soil and tile.

G. The economic benefit of tile is realized over a period of years with higher crop yields and quality, timeliness of field operations, and efficiency of operations.

H. H. A tile system with surface inlets to convey surface water to the outlet needs to be larger than does a system where only subsurface water is conveyed.

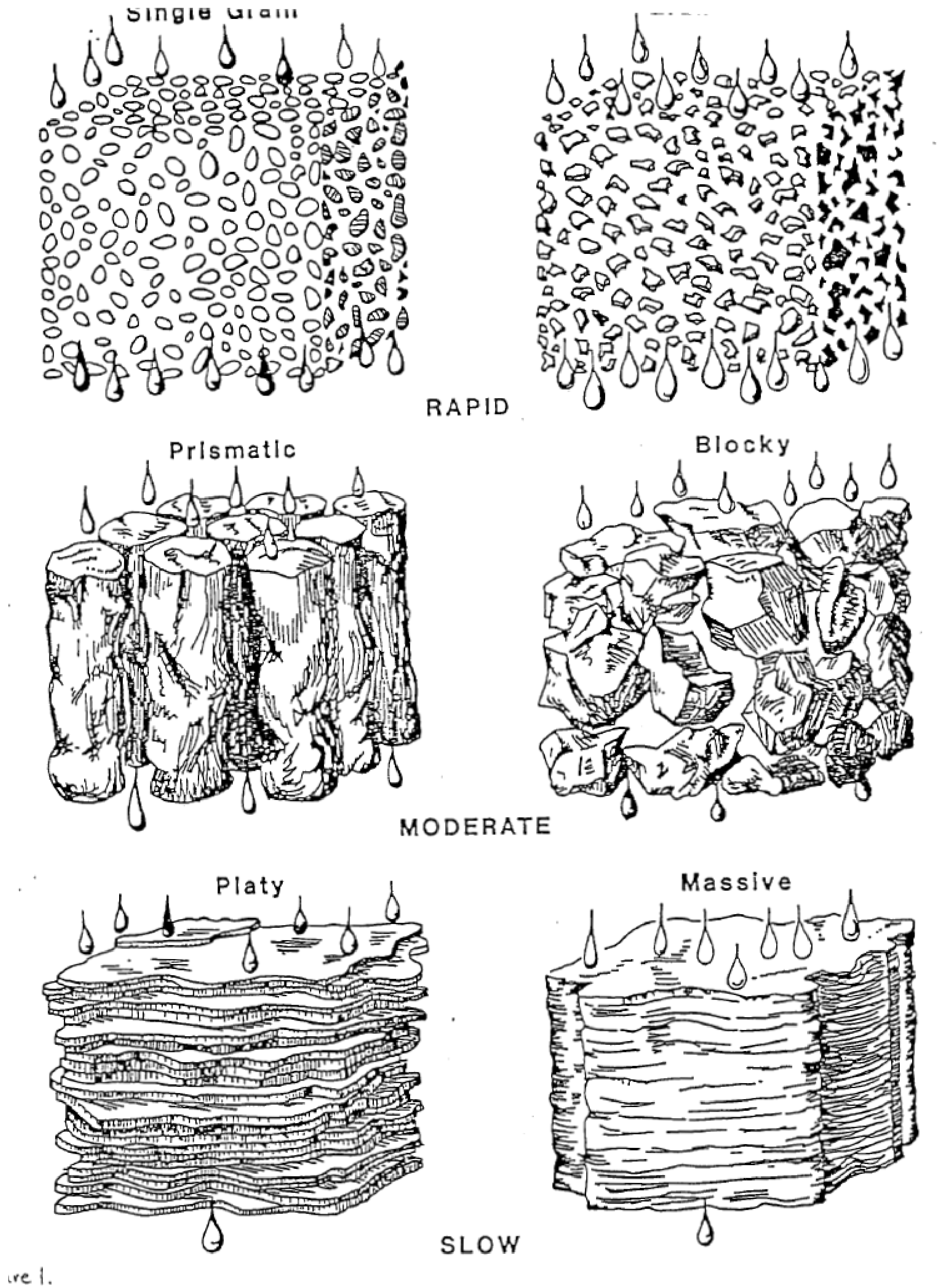

Figure 1: Types of soil structure and their effect on downward movement of water

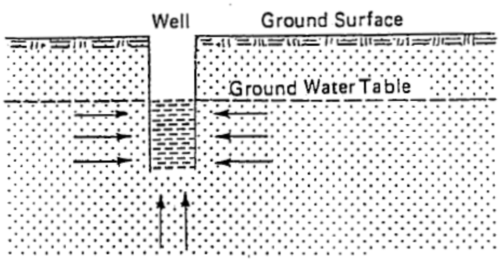

Figure 2: Groundwater table in a posthole

Average Yield of Field Crops, 1978-1986

Crop	Yield - bu/acres (t/ha) Tiled Land		Untiled Land		Increase (%)
Winter Wheat	61	(4.02)	44	(2.93)	37
Spring Grain	58	(2.85)	36	(1.80)	58
Corn	101	(6.64)	75	(4.93)	35
Soybeans	37	(2.44)	30	(1.96)	25

Table 1: Average Yield of Field Crops

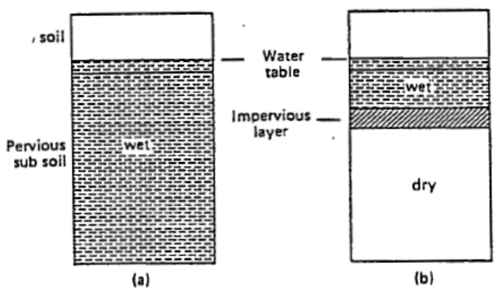

Figure 3: Deep and perched water tables

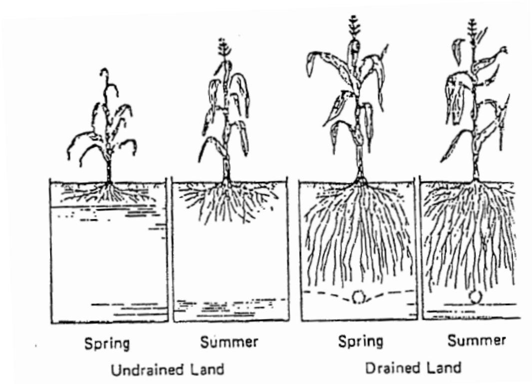

Figure 4: Effect of drainage on plant root growth

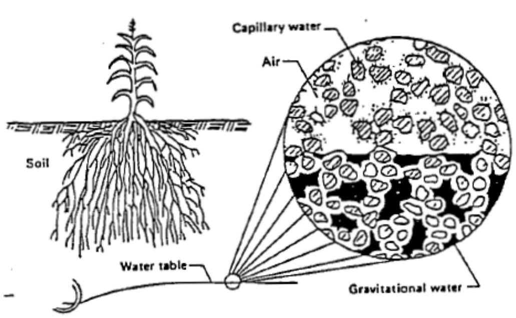

Figure 5: Forms of soil water

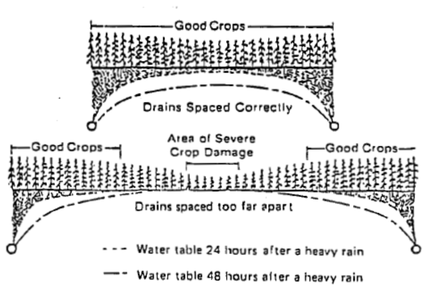

Figure 6; Effect of wide drain spacing on plant growth

Estimates of Capillary Fringe

(from: Mausbach, M.J. 1992. Soil survey interpretations for wet soils. p. 172-178. In Eighth International Soil Correlation Meeting.)

Soil Texture	Capillary Fringe (cm)	Capillary Fringe (in)
Coarse sand	1 - 7	0.4 - 2.8
Sand	1 - 9	0.4 - 3.5
Fine sand	3 - 10	1.2 - 3.9
Very fine sand	4 - 12	1.6 - 4.7
Loamy coarse sand	5 - 14	2.0 - 5.5
Loamy sand	6 - 14	2.4 - 5.5
Loamy fine sand	8 - 18	3.1 - 7.1
Coarse sandy loam	8 - 18	3.1 - 7.1
Loamy very fine sand	10 - 20	3.9 - 7.9
Sandy Loam	10 - 20	3.9 - 7.9
Fine sandy loam	14 - 24	5.5 - 9.4
Very fine sandy loam	16 - 26	6.3 - 10.2
Loam	20 - 30	7.9 - 11.8
Sandy clay loam	20 - 30	7.9 - 11.8
Sandy clay	20 - 30	7.9 - 11.8
Clay loam	25 - 35	9.8 - 13.8
Silt loam	25 - 40	9.8 - 15.7
Clay	25 - 40	9.8 - 15.7
Silt	35 - 50	13.8 - 19.7
Silty clay loam	35 - 55	13.8 - 21.7
Silty clay	40 - 60	15.7 - 23.6

Table 2: Estimates of Capillary Fringe

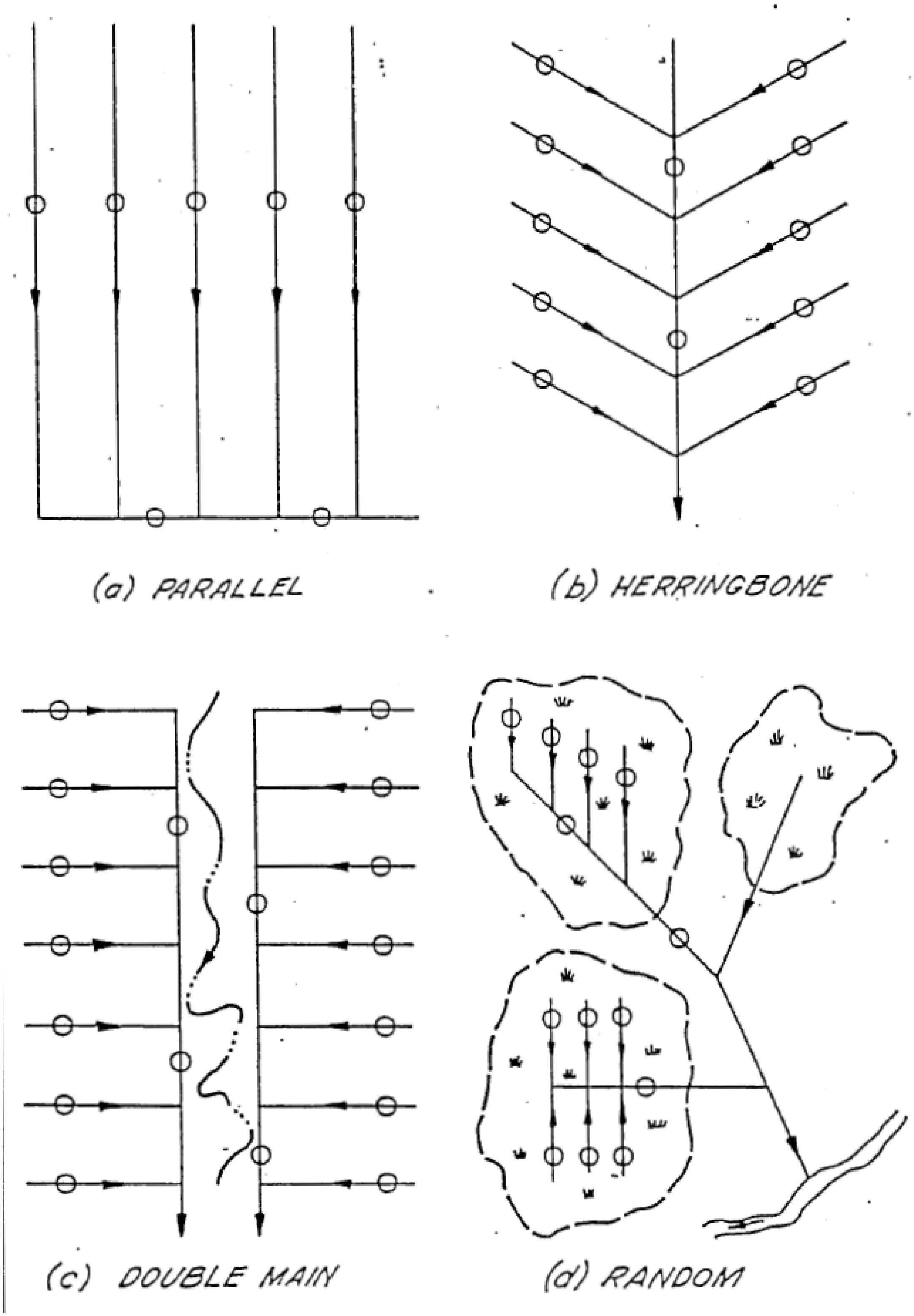

Figure 7: Types of drainage collection systems

Document originally released by National Employee Development Center, October 1, 1996.