20  Surface Drainage Systems
R.J. Sevenhuijsen

20.1  Introduction

Surface drainage, the oldest drainage practice, was defined in Chapter 1 as:

‘The diversion or orderly removal of excess water from the surface of land by means of improved natural or constructed channels, supplemented when necessary by shaping and grading of the land surface to such channels.’ (ICID 1982).

Surface drainage has long been regarded as a farmer’s practice. With the introduction of subsurface drainage and farm mechanization – and their related high investment costs – surface drainage became the subject of scientific and engineering research.

Surface drainage is applied primarily on flat lands where slow infiltration, low permeability, or restricting layers in the profile prevent the ready absorption of high-intensity rainfall. The drainage system is therefore intended to eliminate ponding and prevent prolonged saturation by accelerating flow to an outlet without causing siltation or soil erosion.

Developments in surface drainage bear a strong relation to developments in irrigation and erosion control because these activities deal in many ways with the same boundary conditions, be it to attain different goals.

Criteria for the design of a surface drainage system should be based on agricultural constraints (e.g. the sensitivity of crops to ponded water and saturated soils; Chapter 17) as well as engineering considerations of flow through channels and structures (Chapter 19). As surface drainage is aimed at the orderly removal of excess water from the land surface, it has by its nature an effect on the environment of the area (Chapter 25).

This chapter will discuss methods of surface drainage and their application, treating surface drainage components such as land forming and field drainage systems (Section 20.2), both for flat lands (Section 20.3) and for sloping areas (Section 20.6). It will also give attention to the design, construction, and maintenance of surface drainage systems.

20.2  Surface Drainage Systems and Components

The negative effects of poor surface drainage on agricultural productivity can be summarized as:

- Inundation of crops, resulting in deficient growth;
- Lack of oxygen in the rootzone, hampering germination and the uptake of nutrients;
- Insufficient accessibility of the land for mechanized farming operations;
- Low soil temperatures in spring time (temperate regions).

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To improve the growing conditions of crops at field level by ensuring the timely and orderly removal of excess water, the land surface should be smooth and should have a continuous slope to allow the overland flow of water to a collector point. From this collector point, water should flow to the area’s natural or constructed main drainage system of field and collector drains. The design of a surface drainage system therefore has two components:
- The shaping of the surface by land forming, which ICID (1982) defines as changing the micro-topography of the land to meet the requirements of surface drainage or irrigation;
- The construction of open drains to the main outlet.

20.2.1 Bedding, the Traditional Land-Forming System

The bedding system is one of the oldest surface drainage practices. Under this system, the soil is formed into beds by manual labour, animal traction, or farm tractors. The beds are separated by parallel dead furrows oriented in the direction of the greatest land slope. The water drains from the beds into the dead furrows, which discharge into a field drain constructed at the lower end of the field and perpendicular to the dead furrows (Figure 20.1).

In modern farming, bedding is not considered an acceptable drainage practice for row crops, because rows adjacent to the dead furrows will not drain satisfactorily.

Figure 20.1 The bedding system
It is acceptable for grassland in some areas, although there will be some crop loss in and adjacent to the dead furrows.

The typical drainage characteristics of a well-developed bed are shown in Figure 20.2. Because of the construction and land preparation, the top soil of the bed has better hydraulic properties than the underlying ‘impermeable’ soil. A large part of the excess rainfall will therefore flow over the ‘impermeable’ layer by interflow and overland flow towards the dead furrow.

In many areas where high groundwater levels occur (e.g. in rice-growing areas), the bedding system is applied to grow vegetables, tree crops, and staple crops like maize and cassava. Most of these beds are made manually.

Design and Construction
The development of a bedding system is illustrated in Figure 20.3. It often takes several years of ploughing to obtain an adequate bedding system.

During the first ploughing, care should be taken to make beds of uniform width throughout the field and to have the dead furrows running in the direction of the greatest slope. One of the major problems of the bedding system is adequate drainage of the dead furrows into a field drain, but with the excess rainfall concentrated in the furrows, the available head difference should start a flow towards the field drain. Any obstructions or low points in the dead furrows should be eliminated because they will cause standing water and loss of crops. The field drain should be laid out in the direction of the lesser field slope, but should be properly graded towards the field lateral.
To ensure good drainage in a bedding system, the bed width should not be more than 10 m. Further, the width of the beds is governed by the following:
- Kind of crops to be grown: Permanent pasture or hay crops do not require beds as narrow as field crops do. It is usually unprofitable to grow row crops in dead furrows. The bed width should therefore be adjusted to the row spacing;
- Farming operations on beds: Ploughing, planting, and cultivating should fit the width of a bed. Bed width should be a multiple of the effective width of farm equipment.
- Soil characteristics: Soils with low infiltration and low permeability require narrower beds than soils with better characteristics.

Some disadvantages of the traditional bedding system are:
- The top soil is moved from the sides of the bed to the middle, which may cause a reduction of yields at the sides;
- The system restricts mechanized farming;
- The slope of the dead furrows is often insufficient, resulting in ponded areas;
- The dead furrows require regular maintenance to prevent weed growth.

**Land Crowning, an Improved Bedding System**

Land crowning is basically an improved bedding system in which earthmoving machinery is used to make wider beds of 20 to 30 m. These are often referred to as cambered beds.

Crowning is the process of forming the surface of land into a series of broad low beds separated by parallel field laterals. Crowning requires more maintenance than most of the other systems, except for the traditional bedding. The large number of field laterals takes land out of production, and they are a source of sedimentation and erosion, as well as weed and grass infestation. Crowning with crossable field drains provides excellent drainage for pasture crops (ICID 1982). With the wider spacing of the dead furrows, some of the disadvantages of the traditional bedding system are overcome.

**Contemporary Bedding Activities**

Some examples of bedding in different countries are the following:
- The Netherlands: Eastern Flevoland. In the recently reclaimed Flevo Polder (flat topography, typical fluvaquent soils), permanent pasture land for cattle suffered from compaction of the top layer. To overcome standing water, which resulted in sod deterioration and the occurrence of weeds, a bedding system was applied. The beds are 12 m wide with a side slope of 2% (Zelhorst 1969);
- India: International Crop Research Institute for Semi-Arid Tropics/ICRISAT. A bed-and-furrow system was developed on deep vertisols for the drainage of row crops. The system consists of a flat bed 0.9 m wide and a small furrow 0.6 m wide. It resembles a furrow irrigation system, but with shallower furrows. Row crops are planted on the shoulder of the beds;
- Mediterranean area: Morocco, Algeria, etc. For the cultivation of cereals on vertisols (rainfall excess of 180 mm per day), an improved bedding system (crowning), with beds 30 m wide, 200 m long, and a slope of 3%, proved satisfactory;
- Indonesia: Java, Kalimantan. In the tidal lowlands in some parts of Indonesia, rice
is grown in combination with upland crops (vegetables) and tree crops in a raised bedding system known as Sorjan. The width of the rice plots is about the same as that of the raised beds (3 to 5 m), which have an elevation of 0.2 to 0.35 m above the rice plots (Sahat Matondang et al. 1986). Sorjan is illustrated in Figure 20.4.

20.2.2 Land Grading and Land Planing

To overcome the disadvantages of the bedding system, two other methods of land forming have been developed: land grading and land planing (ICID 1982).

Land grading is the process of forming the surface of land to predetermined grades, so that each row or surface slopes to a (field) drain. Land grading for surface drainage consists of forming the landscape by cutting, filling, and smoothing it to planned continuous surfaces. It is a one-time operation, involving the transport of earth according to specified cuts and fills based on the predetermined grades. Land grading for surface drainage differs from land levelling for irrigation in that, for drainage, no uniform grade is required. The grades can be varied as much as is necessary to provide drainage with the least amount of earthmoving. Scarification may be required after land grading to break up the soil which has become compacted by the construction machinery.

Land grading was first applied at the beginning of the fifties to enable the irrigation of row crops in the southern part of the U.S.A., but also proved highly beneficial for surface drainage in humid areas. Land grading promotes the orderly movement of water over the surface and the efficient use of machinery. It eliminates field drains, thus reducing the need for weed control and maintenance, and enables better land utilization.

Land planing is the process of smoothing the land surface with a land plane to eliminate minor depressions and irregularities without changing the general topography. It is frequently applied in conjunction with land grading. The effect of land grading and planing is illustrated in Figure 20.5. In Field A, these activities have eliminated the micro-topography present in the surrounding fields. Irregular micro-topography in a flat landscape in combination with heavy soils can cause substantial crop losses.

Land forming on a scale such as shown in Figure 20.5 can only be realized with heavy earthmoving machinery. As in land levelling for irrigation, specialized contractors are usually employed to do the work.
Design
In the design of land grading for surface drainage, it is not required to realize a uniform slope as for irrigation. A continuous slope is adequate.

The design should further take into consideration the type of crops that will be grown. Three main situations can be distinguished:
a) Crops will be planted in rows and the field surface is shaped into small furrows (for corn, potatoes, sugarcane, etc.);
b) Crops will be planted by broadcast sowing or in rows, but on an even surface (for small grains, hay crops, etc.);
c) Crops will be planted in basins designed for controlled inundation (for wet-land rice, basin irrigation).

Re a): For row crops, the length and slopes of the field to be graded should be selected in such a way that erosion and overtopping of the small furrows is avoided. Table 20.1 lists recommended row lengths and slopes for some soil types.

To prevent erosion, flow velocities in furrows should not exceed 0.5 m/s. In highly erodible soils, the row length should be limited to about 150 m. Slightly erodible soils allow longer rows, up to 300 m. In these long furrows, adequate head should be available to ensure that the water flows towards the field drains. Figure 20.6 gives
Table 20.1  Row grades and row lengths for land grading (after Coote and Zwerman 1970)

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Grade (%)</th>
<th>Row length (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse-textured soil (sandy)</td>
<td>0.1 - 0.3</td>
<td>300</td>
</tr>
<tr>
<td>Fine-textured soil (clayey)</td>
<td>0.05 - 0.25</td>
<td>200</td>
</tr>
<tr>
<td>Fine-textured soil (clayey) with high organic-matter content</td>
<td>0.1 - 0.5</td>
<td>200 (flat)</td>
</tr>
<tr>
<td>Fine-textured soil (clayey) with high organic-matter content</td>
<td>0.1 - 0.5</td>
<td>400 (gently sloping)</td>
</tr>
<tr>
<td>Medium-textured soil (loamy)</td>
<td>0.05 - 0.25</td>
<td>300</td>
</tr>
<tr>
<td>Medium-textured soil (silty loam) with impervious hard-pan at depth</td>
<td>0.5</td>
<td>150</td>
</tr>
<tr>
<td>Medium-textured soil (silty loam) with shallow impervious clay B horizon</td>
<td>≥ 0.2</td>
<td>60</td>
</tr>
<tr>
<td>Moderately coarse-textured soils (sandy loam) with structured clay B horizon at depth</td>
<td>≥ 0.15</td>
<td>200</td>
</tr>
</tbody>
</table>

An indication of acceptable row lengths and grades in relation to erodibility.

The direction of rows (and related small furrows) is not necessarily perpendicular to the slope, but can be selected in a way that meets the above recommendations.

Figure 20.6  Recommended row length in relation to slope and erodibility of soils (after Smedema and Rycroft 1983)
Re b): Where crops are planted on an even land surface (no furrows), the surface drainage takes place by sheet flow. The sheet flow is always in the direction of maximum slope. In this situation, flow resistance is much higher than in small furrows and the flow velocity with the same land slope is less. However, even after careful land grading and smoothing, sheet flow always has a tendency to concentrate in shallow depressions, and gullies are easily formed. An indication of velocities and slopes for sheet flow under different soil covers is given in Figure 20.7.

From the point of view of transport duration for low flow velocities, it is recommended to limit the field length in the flow direction to 200 m or less.

The amount of water that drains from graded fields as described under a) and b) can be calculated with the Curve Number method (Chapter 4).

Re c): In basins for irrigation or for water conservation, the surface is levelled by earthmoving machinery (large basins) or with simple farm implements (small basins in traditional rice farming). Levelled fields are surrounded by field bunds. Any excess water from basins is usually drained through an overflow in the field bunds that spills the water directly into a field drain. In large rice fields (in Surinam up to 6 ha), under fully mechanized farming, the overflow is replaced by a gated culvert with a diameter of up to 0.6 m. In this situation, bunds are made by earthmoving machinery and are often used as farm roads.

Considerations on the dimensioning of overflow systems for basins are presented in Chapter 19.

Figure 20.7 Relation between slope and flow velocity (after SCS 1971)
Construction and Maintenance
In general, land grading is done with a combination of conventional earthmoving equipment and specially designed machinery (Haynes 1966). Normal farm equipment, even if mechanized, can only handle small-scale grading operations or the maintenance of already established grades.

Grading operations involve a number of steps:
- Site preparation: On cleared land, this can be done with regular farm equipment. It mainly involves removing or destroying vegetative matter and other obstacles. Ridges or rows are levelled. The surface should be dry, firm, and well-pulverized to enable the earthmoving equipment to operate efficiently. The field is surveyed after preparation;
- Rough grading: This can be done with several types of equipment. The choice will be dictated by a number of factors (e.g. soil conditions, hauling distances, amount of earthwork, available time and equipment, size of the fields to be graded as one unit, and the experience of the operator). Dozers and motor graders are adapted to move earth over short distances. Scrapers, which come in many types and sizes, are used for hauling soil over long distances. The exact limit as to distance is not definable;
- Finished grading: This is most efficiently done with a land plane (a bottomless scraper) pulled by a farm tractor. Several passes are usually made at angles to one another. The plane should be as long as is feasible under the existing circumstances. Drags, harrows, and floats can be used on smaller fields and for final smoothing. These implements can be pulled by a farm tractor or animal traction.

When extensive grading is done with heavy equipment, it is likely to cause soil compaction. This compaction should be relieved in order to eliminate differences in soil productivity. Various subtiltage tools can be used for this purpose (e.g. subsoilers, chisels, scarifiers, and rippers).

The benefits derived from land grading will often depend on good maintenance in the subsequent years. The land should be smoothed each time a field has been ploughed. This will ensure settlement in fill areas and will erase dead furrows and back furrows. A small leveller or plane powered by a farm tractor can be used for this purpose.

20.3 Land Grading and Levelling Calculations
A land-grading design comprises estimating, from a topographic and soil survey, the best slope of the field, taking into account plans for the irrigation and drainage systems and the field roads. The area should be cleared of vegetation and the surface prepared for the operation.

Land grading is an intensive practice and much expense can be saved if the area is carefully divided into sub-areas that have about the same slope and soil conditions. This will require a topographic survey, preferably a grid survey because it permits staking the field according to the grid and marking the cuts and fills on the stakes. The size of the grids is not critical, but for drainage 9 grid points/ha are usual and for irrigation 16 grid points/ha. Calculations will be simpler if the first line of grid
points in each direction is started at half the grid spacing from the boundary. The origin of the grid system is thus situated half a grid spacing outside two boundaries of the area, and each grid point becomes the centre of a square.

Of the several methods of calculating the cuts and fills, the plane method and the profile method will be discussed here. Specialized land-grading companies often use their own computer programs based on these methods and related to their own means of executing the earthmoving work.

20.3.1 The Plane Method

The plane method is so called because the resulting land surface has a uniform downfield slope and a uniform cross slope. The plane method, also called the 'method of least squares', makes it possible to calculate, for regular as well as for irregular fields, a balanced cut-and-fill.

The procedure is as follows:
- Complete the design and construction survey;
- Determine the initial elevation at each grid point \( E_i \);
- Subdivide the area into sub-areas, each of which can be levelled to a plane surface;
- Locate the centroid of the sub-area \( (x_c, y_c) \).

To give equal cut and fill, the plane must pass through the centroid. The centroid of a rectangular field is located at the intersection of its diagonals. The centroid of a triangular field is located at the intersection of lines drawn from its corners to the midpoints of the opposite sides.

The centroid coordinates of an irregular field are given by the following equations

\[
x_c = \frac{\sum m_x x}{n} \quad \text{and} \quad y_c = \frac{\sum m_y y}{n}
\]  

(20.1)

where

\( x_c, y_c = \) coordinates of the centroid of the sub-area (m)
\( x, y = \) coordinates of the grid lines (m)
\( m_x = \) number of grid points on grid line in x direction (–)
\( m_y = \) number of grid points on grid line in y direction (–)
\( n = \) total number of grid points \( (\Sigma m_x = \Sigma m_y = n) \) (–)

Calculate the average elevation of the sub-area at the centroid

\[
E_c = \frac{\Sigma E_i}{n}
\]

(20.2)

where

\( E_c = \) average elevation of the sub-area at the centroid (m)
\( E_i = \) initial elevation of grid point (m)
\( n = \) total number of grid points (–)
With the desired $s_x$ and $s_y$ slopes, in $x$ and $y$ direction respectively, and the average elevation $E_c$ ($E_c$ usually has to be lowered 1 or 2 cm to satisfy the desired cut/fill ratio), the new elevations of the grid points can now be calculated. The new plane passes through the centroid and therefore the elevation of the origin, $E_o$, will be

$$ E_o = E_c - s_x x_c - s_y y_c $$  \hspace{1cm} (20.3)

The new elevations of the grid points will be

$$ E_n = E_o + s_x x + s_y y $$  \hspace{1cm} (20.4)

After being graded, soil will settle in the filled areas and expand, after being ploughed, in the cut areas. To take this into account, calculations for cuts and fills must be adjusted prior to grading (SCS 1983). Table 20.2 shows some recommended cut/fill ratios.

Using the plane method, we avoid unnecessary earthmoving and find the best-fitting plane for any area. If it is obvious from the topography that the best-fitting slope is outside the limits (e.g. imposed by erosion hazards; see Section 20.2.2), we omit the next calculation and apply the acceptable limit. For non-rectangular fields, the best-fitting slopes $s_x$ and $s_y$ can be found from

$$ s_x \left( \sum x^2 - n x_c^2 \right) + s_y \left[ \sum xy - n x_c y_c \right] = \sum x E_i - n x_c E_c $$  \hspace{1cm} (20.5)

$$ s_y \left( \sum y^2 - n y_c^2 \right) + s_x \left[ \sum xy - n x_c y_c \right] = \sum y E_i - n y_c E_c $$  \hspace{1cm} (20.5)

where

- $\sum x^2$ = sum of the square abscissa of each grid point (m$^2$)
- $\sum y^2$ = sum of the square ordinate of each grid point (m$^2$)
- $\sum xy$ = sum of the products of the coordinates of each grid point (m$^2$)
- $\sum x E_i$ = sum of the products of abscissa and elevation of each grid point (m$^2$)
- $\sum y E_i$ = sum of the products of ordinate and elevation of each grid point (m$^2$)
- $n$ = total number of grid points (-)

For rectangular areas, the term $\sum xy - nx_c y_c$ becomes zero.

Calculate the earth-work volume.
Knowing the initial and new elevation, we can determine the cut and fill in each grid square and can calculate the total volume of soil to be moved.

$$ V = \Sigma C \times A $$  \hspace{1cm} (20.7)

Table 20.2: Cut/fill ratios for various soils (after Coote and Zwerman 1970)

<table>
<thead>
<tr>
<th>Soils</th>
<th>Cut/Fill ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse-textured soils (sandy)</td>
<td>1.1:1 to 1.2:1 or 110 to 120%</td>
</tr>
<tr>
<td>Medium-textured soils (clay-loam)</td>
<td>1.2:1 to 1.3:1 or 120 to 130%</td>
</tr>
<tr>
<td>Fine-textured soils (clayey)</td>
<td>1.3:1 to 1.4:1 or 130 to 140%</td>
</tr>
<tr>
<td>Organic soils</td>
<td>1.7:1 to 2.0:1 or 170 to 200%</td>
</tr>
</tbody>
</table>
where

\[ V = \text{volume of soil to be moved (m}^3) \]
\[ \Sigma C = \text{sum of all cuts (m)} \quad (C = E_i - E_n > 0) \]
\[ A = \text{area of grid square (m}^2) \]

**Example 20.1 Plane Method** (after Coote and Zwerman 1970)

An irregular-shaped field has to be levelled. A topographic survey was made with the use of a 25 m grid, the grid lines being set out in the direction of the rows (direction of y-axis in Figure 20.8). In this figure, the elevations are indicated above at the left of the grid points.

The average row length is 225 m. We are dealing with a fine-textured (clayey) soil, so the row grade can vary between 0.05 and 0.25% (Table 20.1). The required cut/fill ratio is 1.40. The plane method is used to calculate the required cuts and fills. The calculations are as follows (see also Figure 20.8)

**Equation 20.1:**  \[ x_c = 88.68 \text{ m equal } y_c = 123.11 \text{ m} \]

**Equation 20.2:**  \[ E_c = \Sigma E_i/n = 159.44/53 = 3.01 \text{ m} \]
By definition, the plane of best fit has equal cuts and fills:

<table>
<thead>
<tr>
<th>Row No.</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>Σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cuts</td>
<td>0.12</td>
<td>0.19</td>
<td>0.18</td>
<td>0.18</td>
<td>0.25</td>
<td>0.09</td>
<td>1.01</td>
</tr>
<tr>
<td>Fills</td>
<td>0.17</td>
<td>0.19</td>
<td>0.17</td>
<td>0.13</td>
<td>0.13</td>
<td>0.22</td>
<td>1.02</td>
</tr>
</tbody>
</table>

To satisfy the required cut/fill ratio (1.40), the plane of best fit is lowered 0.01 m. The cut/fill ratio now becomes:

<table>
<thead>
<tr>
<th>Row No.</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>Σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cuts</td>
<td>0.20</td>
<td>0.22</td>
<td>0.22</td>
<td>0.22</td>
<td>0.29</td>
<td>0.12</td>
<td>1.28</td>
</tr>
<tr>
<td>Fills</td>
<td>0.09</td>
<td>0.16</td>
<td>0.13</td>
<td>0.10</td>
<td>0.10</td>
<td>0.18</td>
<td>0.76</td>
</tr>
</tbody>
</table>

Cut/fill ratio = 1.28/0.76 = 1.68

This cut/fill ratio is higher than the required one. If this is not acceptable, the calculation can be repeated with a lowering of 0.005 m. In our case, we assume that the accuracy of levelling is around 0.01 m and we thus accept the cut/fill ratio of 1.68. This results in a total earth-work volume of

Equation 20.7: \[ V = \sum C \times A = 1.28 \times 25^2 = 800 \text{ m}^3 \]

For each grid point in Figure 20.8, the final cut or fill is indicated below on the right of the grid point.

20.3.2 The Profile Method

The profile method is particularly appropriate for land grading on comparatively flat lands. It is not as accurate as the plane method, but for surface drainage it should be adequate. The new grade of the field will not be uniform, but will be continuous to the field drains. With this method, ground profiles are plotted and a grade is
established that will provide an approximate balance between cuts and fills and will restrict haul distances to reasonable limits.

The procedure is as follows:
- Complete the design and construction survey;
- Plot the elevations of the grid points on each grid line in the direction of the greatest slope or the direction in which row drainage is desired;
- Draw a profile of the existing land surface along the grid line;
- Draw a new profile for each grid line by trial and error, knowing the allowable slope limits and the desired cut/fill ratio;
- Plot the cross profiles to check whether they exceed the limits. (These limits need not be the same as those chosen for the row grade.);
- Calculate the earth-work volume.

**Example 20.2 Profile Method** (after Coote and Zwerman 1970 and SCS 1983)

To illustrate the profile method, we shall take the same field as in Example 20.1 (Figure 20.9A). We use the grid points to plot the profiles in row-direction (Figure 20.9B). On the basis of the maximum (0.3%) and minimum (0.05%) grades and by trial-and-error, we establish the required grades (the dotted lines in Figure 20.9B). The difference...
between the existing and established grades gives the cut or fill for each grid point (Figure 20.9A). We can now calculate the cut/fill ratio and the total earth-work volume.

Profile method

<table>
<thead>
<tr>
<th>Row No.</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>Σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cuts</td>
<td>0.07</td>
<td>0.14</td>
<td>0.14</td>
<td>0.10</td>
<td>0.10</td>
<td>0.06</td>
<td>0.61</td>
</tr>
<tr>
<td>Fills</td>
<td>0.11</td>
<td>0.11</td>
<td>0.08</td>
<td>0.04</td>
<td>0.06</td>
<td>0.03</td>
<td>0.43</td>
</tr>
</tbody>
</table>

Cut/fill ratio = 0.61/0.43 = 1.42

Earthwork volume \( V = \Sigma C \times A = 0.61 \times 25^2 = 381 \text{ m}^3 \)
On the basis of these earthmoving calculations, haul distances, and the location at which the operation of land grading and levelling is to take place, a contractor is able to prepare a cost estimate. For more detailed information, see Anderson et al. 1980.

20.4 Field Drains and Field Laterals

To prevent ponding in low spots, surface runoff from fields needs to be collected and transported through field drains and field laterals towards the drainage outlet of the area.

A field surface drain is a shallow graded channel, usually with a relatively flat slope, which collects water within a field (ICID 1982).

A field lateral is the principal ditch for field or farm areas adjacent to it. Field laterals receive water from row drains, field drains and, in some areas, from field surfaces (ICID 1982).

20.4.1 Field Drains

Field drains for a surface drainage system have a different shape from field drains for subsurface drainage. Those for surface drainage have to allow farm equipment to cross them and are easy to maintain with ordinary mowers. Surface runoff reaches the field drains by flow through row furrows or by sheet flow. In the transition zone between drain and field, flow velocities should not induce erosion.

Field drains are thus shallow and have flat side slopes. They can often be constructed with land planes as used in land forming. Simple field drains are V-shaped. The dimensions of V-shaped field drains are determined by the construction equipment, maintenance needs, and crossability for farm equipment. Side slopes should not be steeper than 6 to 1. Nevertheless, long field drains in conditions of high rainfall intensities, especially where field runoff from two sides accumulates in the drain, may require a higher transport capacity than provided by a simple V-shaped channel.

Without increasing the drain depth too much, the capacity can be enlarged by constructing a bottom width, creating a shallow trapezoidal shape. Recommended dimensions of V-shaped and trapezoidal drains are given in Figure 20.10. A variation is the so-called W-shaped field drain, which is applicable where a farm road is required between the drains (Figure 20.10C). These ditches are generally farmed through and their upper slopes may well be planted. They should be cleaned before the drainage season (e.g. with a shovel or a V-drag). A small furrow drain is often installed in the centre to ensure that the ditch is dry in sufficient time for tractors to pass through.

The dimensions for V-shaped drains also apply for the W-shaped drain. Care should be taken that the spoil from field drains does not block the inflow of runoff but is deposited on the correct side of the ditch or is spread evenly over the adjacent fields.

All field drains should be graded towards the lateral drain with grades between 0.1 and 0.3%.
Field laterals collect water from field drains and transport it to the main drainage system. In contrast to the field drain, the cross-section of field laterals should be designed to meet the required discharge capacity (Chapter 19). Besides the discharge capacity, the design should take into consideration that in some cases surface runoff from adjacent fields also collects directly in the lateral, requiring a more gentle side slope.

Field laterals are usually constructed by different machinery than field drains (i.e. excavators instead of land planes). The recommended dimensions for field laterals are given in Table 20.3.

Field laterals less than 1 m deep are usually constructed with motor graders or dozers. The soil is placed near either side of the lateral. Scrapers are needed when the excavated soil is to be transported some distance away. Under wet conditions, excavators are used. Maintenance requirements should be considered during design; for example, if the field laterals are to be maintained by mowing, side slopes should not be steeper than 3 to 1.

Special attention should be given to the transition between field drains and laterals, because differences in depth might cause erosion at those places. For discharges below

Table 20.3 Recommended dimensions for field laterals (after ASAE 1980)

<table>
<thead>
<tr>
<th>Type of drain</th>
<th>Depth (m)</th>
<th>Recommended side slope (horz:vert)</th>
<th>Maximum side slope (horz:vert)</th>
</tr>
</thead>
<tbody>
<tr>
<td>V-shaped</td>
<td>0.3-0.6</td>
<td>6 : 1</td>
<td>3 : 1</td>
</tr>
<tr>
<td>V-shaped</td>
<td>&gt; 0.6</td>
<td>4 : 1</td>
<td>3 : 1</td>
</tr>
<tr>
<td>Trapezoidal</td>
<td>0.3-1.0</td>
<td>4 : 1</td>
<td>2 : 1</td>
</tr>
<tr>
<td>Trapezoidal</td>
<td>&gt; 1.0</td>
<td>1.5 : 1</td>
<td>1 : 1</td>
</tr>
</tbody>
</table>
0.03 m³/s, pipes are a suitable means of protecting those places. For higher discharges, open drop structures are recommended.

20.4.3 Lay-out of Field Drains and Laterals

Apart from the ‘dead furrows’ in the bedding system (Section 20.2.1), two typical systems of lay-out are applied in distinct situations:
- The random field drainage system;
- The parallel field drainage system.

**Random Field Drainage System**

This drainage system is applied where a number of depressions are distributed at random over a field. Often these depressions are large but shallow, and a complete land-forming operation is not (yet) considered economically feasible. The random field drainage system connects the depressions by means of a field drain and evacuates the stagnant water into a field lateral (Figure 20.11). To allow mechanized farming operations, the drains are shaped as described in the previous sub-sections.

The system is often applied in situations where farm operations are limited (e.g. on pasture land) or where mechanization is realized by means of small equipment.

It is important that the spoil from the field drains does not hamper the surface flow from the areas between the connected depressions. The spoil can be used to fill up low areas further away from the field drain.

In conditions where the permeability of the soil allows subsurface drainage, the random field drainage system can also be useful in improving the rootzone condition in low pockets that would otherwise require additional measures.

In general, a random field drainage system is not expensive and suits extensive land use. If intensive farming develops, however, the system needs to be replaced by a parallel field drainage system.

**Parallel Field Drainage System**

The parallel field drainage system, in combination with proper land forming, is the....