NATIONAL ENGINEERING HANDBOOK

SECTION 16

DRAINAGE OF AGRICULTURAL LAND

CHAPTER 4. SUBSURFACE DRAINAGE

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SECTION 16

DRAINAGE OF AGRICULTURAL LAND

CHAPTER 4. SUBSURFACE DRAINAGE

Introduction

This chapter covers subsurface drainage in both humid and arid areas of the United States. The division between the subhumid and the semiarid areas is approximately the 100th meridian. The boundary separating the subhumid from the dry lands receives close to 18 inches of precipitation in the north and about 25 inches in Texas (1). The coastal areas of the Pacific Northwest, the Gulf Coast, and small scattered areas within the intermountain region are humid areas with average rainfall over 20 inches. Irrigated areas in the United States are largely in the arid and semiarid portions of the country.

Chapter 2, Drainage Investigations, of this National Engineering Handbook discusses investigations and surveys commonly used in agricultural drainage operations. Reference will be made to Chapter 2 for information in regard to general methods and techniques for conducting these investigations. This chapter supplements the information in Chapter 2 with more detailed information on certain phases of drainage investigations. Subsurface-drainage conditions, drainage benefits, planning, design, materials, installation, and maintenance will be discussed in this chapter.

In most humid areas, many years of experience with subsurface drainage installation have provided the main basis for determining drainage requirements for various soil types and problem areas. Special investigations are necessary for drainage of soils where experience is lacking.

There are some differences in the cause, effect, and solutions of drainage problems in the arid and semiarid regions, but in general the investigational methods, design, construction, and maintenance are similar. In areas where there have been many years of drainage experience, investigations may be standardized and routine. Where experience has been limited or special problems exist, more extensive investigations are necessary. High water tables, seepage, soil salinity and/or alkalinity are problems that usually require special investigation and consideration.

General

Definition and purpose of subsurface drainage

Subsurface drainage is defined as the removal of excess ground water below the ground surface. In many wet areas both surface and subsurface drainage are required. Surface ditches are necessary to remove excess runoff from precipitation and to dispose of surface flow from irrigation. These surface ditches should be planned to complement the subsurface drainage system. Surface drainage reduces the amount of water to be removed by the subsurface system and permits better control of the water table. Subsurface drainage lowers the high water tables which are caused by precipitation, irrigation water, leaching water, seepage from higher lands or irrigation canals and ditches and ground water under artesian pressure.

A high water table damages most crops to varying degrees. Soil bacterial action is retarded when pore spaces are filled with water because the bacteria must have access to oxygen from the air. Properly drained soils will warm up more quickly in the spring than saturated soils. Good drainage permits earlier planting and better germination. Where drainage lowers a high water table, this increases the active root-zone depth and allows plants to develop their natural root pattern. Where excessive soluble salts are present in the soil profile, good subsurface drainage re-establishes downward percolation of water in the soil profile and permits leaching of these salts.

The optimum depth of the water table is not a constant for all areas, but varies with soil texture, depth of soil and subsoil layers, crops grown, and salinity. In fine-textured soils and subsoils the height of the capillary fringe above the water table may be a controlling factor. This is especially true where harmful soluble salts are present and are pumped to the soil surface through capillarity. In coarse-textured soils or soils underlain by coarse-textured sands or gravels, capillarity may be slight, and the capillary fringe may extend very little above the water table. Under usual conditions where salts are present, a water table within less than 6 feet from the ground surface may be damaging to plant growth. In studying the critical depth of the water table, the position of the capillary fringe must always be considered.

For a permanent irrigation agriculture, salt must be removed from the soil at the same rate as it is introduced by the irrigation water, otherwise a steadily increasing salt concentration in the soil water will cause progressive reductions in crop yield. When salt removed equals salt input, a project is said to be in "salt balance." Salt balance in irrigated areas is maintained by applying excess water in addition to crop needs to leach soluble salts. Subsurface drainage must be adequate to permit the necessary leaching and to hold the water table to a sufficient depth to prevent the upward movement of salty capillary water from reaching the crop root zone.

Sources of excess water

In humid areas the major portion of excess water comes from precipitation which percolates into the soil to become ground water. Where there is poor surface drainage on flat land, temporary flooding occurs and a large percentage of the rainfall infiltrates into the soil.

In northern areas, snow cover frequently protects the soil from freezing, and infiltration of water into the soil is increased. The rate of snow melt and condition of the soil influences the amount of water absorbed by the soil.

In arid and semiarid areas a minor portion of excess water comes from precipitation. The major sources of excess water in irrigated areas are percolation losses from the irrigation and leaching water applied. Losses occur from irrigation canals or ditches within or traversing the area.

In humid, arid, and semiarid areas the source of excess water may be ground water moving through shallow aquifers and emerging as seeps or springs, or ground water under artesian pressure.

When the total quantity of water introduced into the soil from the various sources exceeds the total quantity disposed of through natural drainage processes, the water table will rise. It is then necessary to install artificial drains to remove the surplus water to maintain the water table at some predetermined level which is not damaging to the crops.

Diagnosis and Improvement of Saline and Alkali Soils

General

The diagnosis and improvement of saline and alkali soils involves problems in soil chemistry. These problems are frequently associated with areas needing drainage, especially in arid and semiarid regions, and it is necessary for the drainage engineer to become familiar with them. A publication of the United States Salinity Laboratory, "Diagnosis and Improvement of Saline and Alkali Soils," USDA Agricultural Handbook 60 (2), contains an excellent discussion of the subject including practical methods of treatment. Subsequent publications of the U. S. Salinity Laboratory staff supplement the information contained in Agricultural Handbook 60.

Saline and alkali soils defined

To facilitate a discussion of saline and alkali soils, they have been separated into three groups: saline, saline-alkali, and nonsaline-alkali soils. These three groups are defined in Agricultural Handbook 60 as follows:

> "Saline soils. - Saline is used in connection with soils for which the conductivity of the saturation extract is more than 4 mmhos/cm. at 25° C. and the exchangeable-sodium-percentage is less than 15. Ordinarily, the pH is less than 8.5. These soils correspond to Hilgard's (1906) "white alkali" soils and to the "Solonchaks" of the Russian soil scientists. When adequate drainage is established, the excessive soluble salts may be removed by leaching and they again become normal soils.
>
> "Saline soils are often recognized by the presence of white crusts of salts on the surface. Soil salinity may occur in soils having distinctly developed profile characteristics or in undifferentiated soil material such as alluvium.
>
> "The chemical characteristics of soils classed as saline are mainly determined by the kinds and amounts of salts present. The amount of soluble salts present controls the osmotic pressure of the soil solution. Sodium seldom comprises more than half of the soluble cations and hence is not adsorbed to any significant extent. The relative amounts of calcium and magnesium present in the soil solution and on the exchange complex may vary considerably. Soluble and exchangeable potassium are ordinarily minor constituents, but occasionally they may be major constituents. The chief anions are chloride, sulfate, and sometimes nitrate. Small amounts of bicarbonate may occur, but soluble carbonates are almost invariably absent. In addition to the readily soluble salts, saline soils may contain salts of low solubility, such as calcium sulfate (gypsum) and calcium and magnesium carbonates (lime).
>
> "Owing to the presence of excess salts and the absence of significant amounts of exchangeable sodium, saline soils generally are flocculated; and, as a consequence, the permeability is equal to or higher than that of similar nonsaline soils.
>
> "Saline-alkali soils. - Saline-alkali is applied to soils for which the conductivity of the saturation extract is greater than 4 mmhos/cm. at 25° C. and the exchangeable-sodium-percentage is greater than 15. These soils form as a result of the combined processes of salinization and alkalization. As long as excess salts are present, the appearance and

properties of these soils are generally similar to those of saline soils. Under conditions of excess salts, the pH readings are seldom higher than 8.5 and the particles remain flocculated. If the excess soluble salts are leached downward, the properties of these soils may change markedly and become similar to those of nonsaline-alkali soils. As the concentration of the salts in the soil solution is lowered, some of the exchangeable sodium hydrolyzes and forms sodium hydroxide. This may change to sodium carbonate upon reaction with carbon dioxide absorbed from the atmosphere. In any event, upon leaching, the soil may become strongly alkaline (pH readings above 8.5), the particles disperse, and the soil becomes unfavorable for the entry and movement of water and for tillage. Although the return of the soluble salts may lower the pH reading and restore the particles to a flocculated condition, the management of saline-alkali soils continues to be a problem until the excess salts and exchangeable sodium are removed from the root zone and a favorable physical condition of the soil is reestablished.

"Saline-alkali soils sometimes contain gypsum. When such soils are leached, calcium dissolves and the replacement of exchangeable sodium by calcium takes place concurrently with the removal of excess salts.

"Nonsaline-alkali soils. - Nonsaline-alkali is applied to soils for which the exchangeable-sodium-percentage is greater than 15 and the conductivity of the saturation extract is less than 4 mmhos/cm. at 25° C. The pH readings usually range between 8.5 and 10. These soils correspond to Hilgard's "black alkali" soils and in some cases to "Solonetz", as the latter term is used by the Russians. They frequently occur in semiarid and arid regions in small irregular areas, which are often referred to as "slick spots." Except when gypsum is present in the soil or the irrigation water, the drainage and leaching of saline-alkali soils leads to the formation of nonsaline-alkali soils. As mentioned in the discussion of saline-alkali soils, the removal of excess salts in such soils tends to increase the rate of hydrolysis of the exchangeable sodium and often causes a rise of the pH reading of the soil. Dispersed and dissolved organic matter present in the soil solution of highly alkaline soils may be deposited on the soil surface by evaporation, thus causing darkening and giving rise to the term "black alkali".

"If allowed sufficient time, nonsaline-alkali soils develop characteristic morphological features. Because partially sodium-saturated clay is highly dispersed, it may be transported downward through the soil and accumulate at lower levels. As a result, a few inches of the surface soil may be relatively coarse in texture and friable; but below, where the clay accumulates, the soil may develop a dense layer of low permeability that may have a columnar or prismatic structure. Commonly, however, alkali conditions develop in such soils as a result of irrigation. In such cases, sufficient time usually has not elapsed for the development of the typical columnar structure, but the soil has low permeability and is difficult to till.

"The exchangeable sodium present in nonsaline-alkali soil may have a marked influence on the physical and chemical properties. As the proportion of exchangeable sodium increases, the soil tends to become more dispersed. The pH reading may increase, sometimes becoming as high as 10. The soil solution of nonsaline-alkali soils, although relatively low in soluble salts, has a composition that differs considerably from that of normal and saline soils. While the anions present consist mostly of

chloride, sulfate, and bicarbonate, small amounts of carbonate often occur. At high pH readings and in the presence of carbonate ions, calcium and magnesium are precipitated; hence, the soil solutions of nonsaline-alkali soils usually contain only small amounts of these cations, sodium being the predominant one. Large quantities of exchangeable and soluble potassium may occur in some of these soils. The effect of excessive exchangeable potassium on soil properties has not been sufficiently studied.

"Nonsaline-alkali soils in some areas of western United States have exchangeable-sodium-percentages considerably above 15, and yet the pH reading, especially in the surface soil, may be as low as 6. These soils have been referred to by De Sigmond (1938) as degraded alkali soils. They occur only in the absence of lime, and the low pH reading is the result of exchangeable hydrogen. The physical properties, however, are dominated by the exchangeable sodium and are typically those of a nonsaline-alkali soil."

Effect of salts on crops

To understand the effect of salt concentration on vegetation requires an understanding of the process of osmosis. This is the process whereby plants obtain their moisture from the soil. If two solutions of different strength are separated by a semipermeable membrane, the weaker solution will move through the membrane to the stronger solution. This movement will be in proportion to the difference in pressure between the two solutions which is in direct proportion to the difference in the number of solvent particles. This difference in pressure is termed the "osmotic pressure" and flow through the membrane continues until equilibrium between the two pressures is established. Plant roots have a semipermeable membrane or "skin" that separates the fluid within the plant roots from the soil moisture. Under normal soil conditions (nonsaline) the solution or fluid within the plant roots is a stronger solution than the soil moisture, and a pressure differential (osmotic pressure) is always present. The net difference in pressure is affected also by the soil-moisture tension. When this exists, the plant roots receive an inflow of water or soil moisture sufficient for growth. When soils become salty or saline, the concentration of salt in the soil moisture increases and approaches the concentration in the plant fluid, thereby reducing the inflow of water to the plants. If the soil-moisture solution becomes too strong, osmosis slows down to the point where the plant will wilt. This explains the condition where plants are wilting even though virtually submerged in water.

From the foregoing it is obvious that salinity control is vital to agriculture. It is usually associated with irrigation in western areas, and the irrigation engineer must recognize this and make adequate provisions for maintaining salt balance in the design and operation of irrigation projects. The drainage engineer must understand the principles involved in the drainage of irrigated land in the arid or semiarid areas. There are some cases where it is not economically feasible to reclaim saline or alkali lands by providing adequate subsurface drainage, leaching water, and chemical amendments as required. In these situations the best use of the land may be to plant crops with high salt tolerance, or if the salt condition is severe, to adapted forage crops. Figures 4-1a, 1b, and 1c, Salt tolerance of field, vegetable, and forage crops (3), and Table 4-1, Relative salt tolerance of fruit crops (4), are included as guides to selecting crops suitable to these situations. In Figures 4-1a, 1b, and 1c the indicated salt tolerances apply to the period of rapid plant growth and maturation, from the late seedling stage onward. Crops in each category are ranked in order of decreasing salt tolerance. Width of the bar next to each crop indicates the effect of increasing salinity on yield.

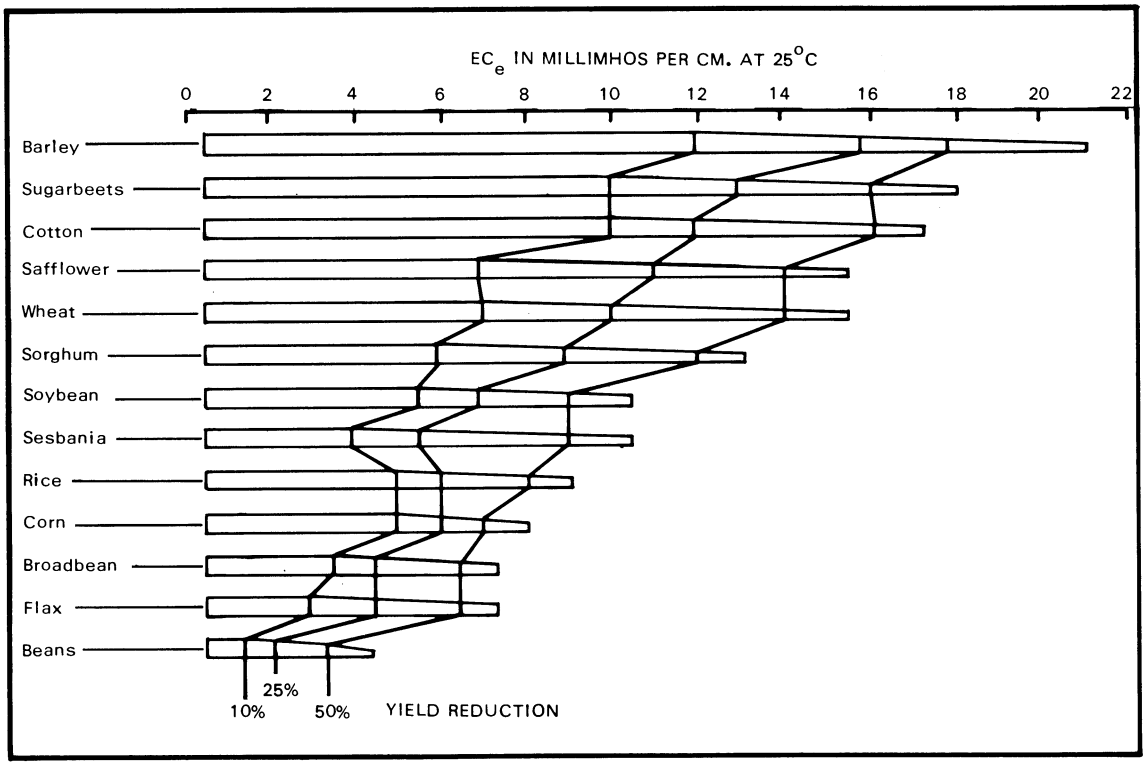


Figure 4-1a, Salt tolerance of field crops

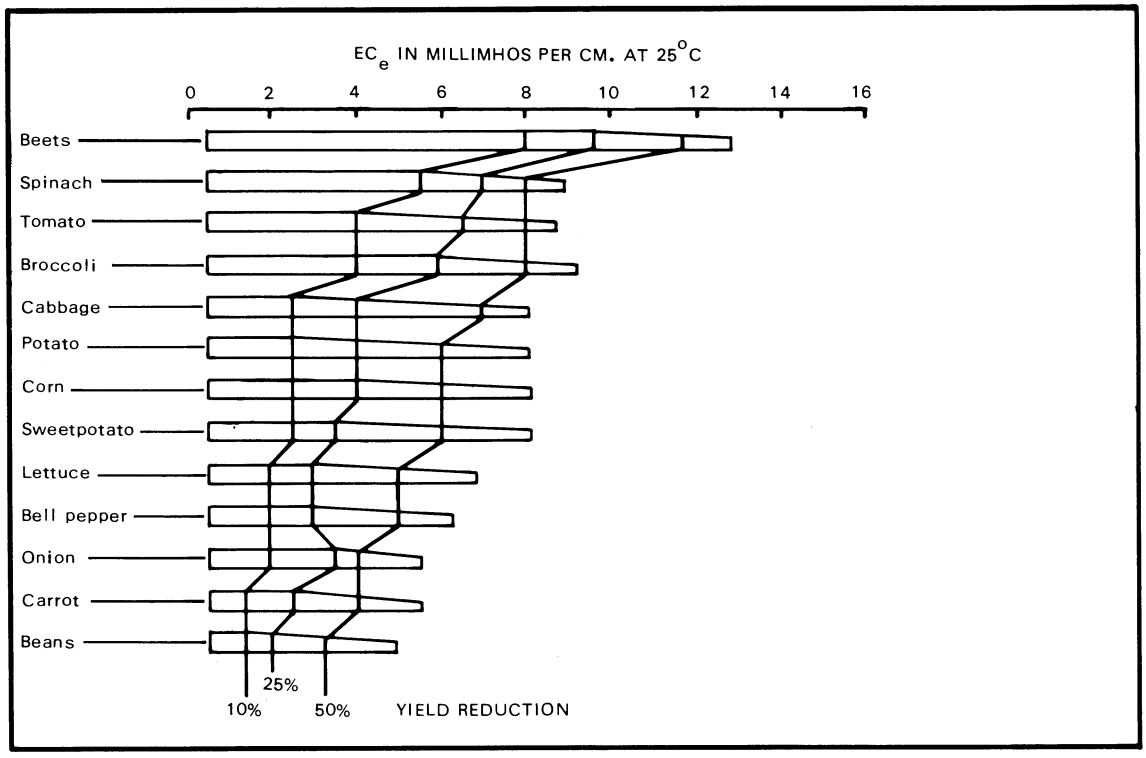


Figure 4-1b, Salt tolerance of vegetable crops

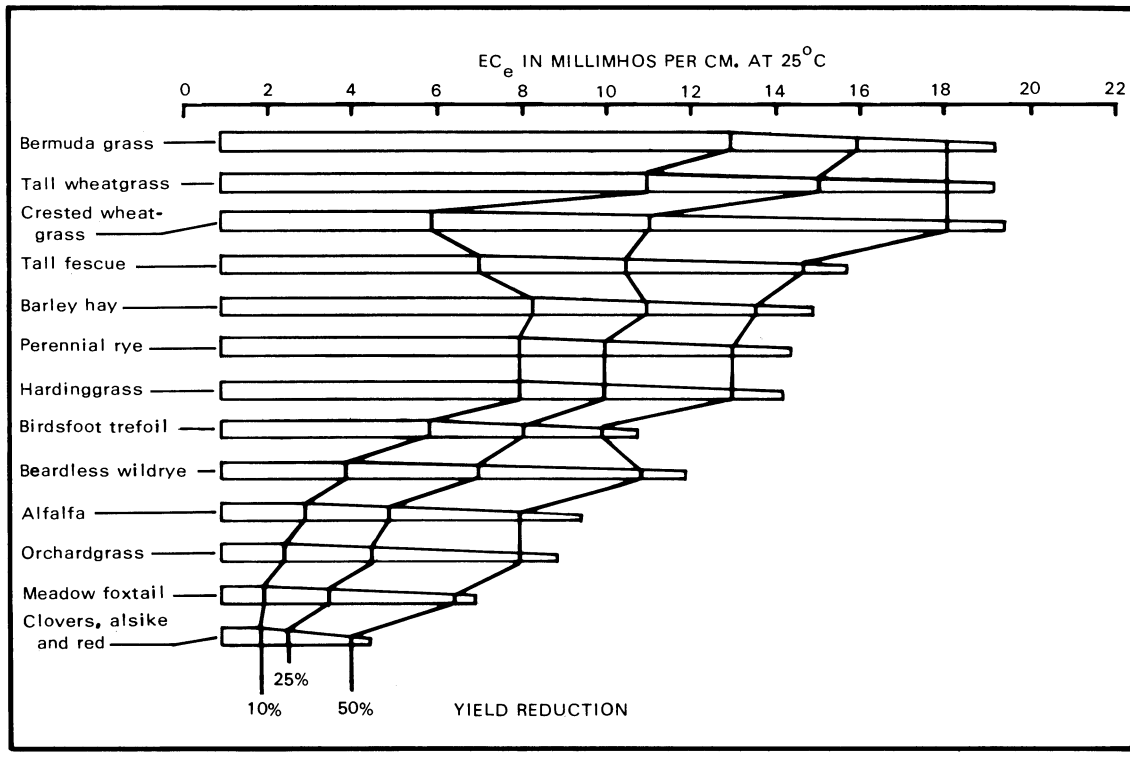


Figure 4-1c, Salt Tolerance of forage crops

Table 4-1, Relative salt tolerance of fruit crops

Crop	Electrical conductivity of saturation extracts (EC_e) at which yields decrease by about 10 percent [1]
	Millimhos per centimeter at 25°C.
Date palm	8
Pomegranate	[2] 4-6
Fig	
Olive	
Grape	4
Muskmelon	3.5
Orange, grapefruit, lemon [3]	3-2.5
Apple, pear	2.5
Plum, prune, peach, apricot, almond	2.5
Boysenberry, blackberry, raspberry[3]	2.5-1.5
Avocado	2
Strawberry	1.5

[1] In gypsiferous soils, EC readings for given soil salinities are about 2 millimhos per centimeter higher than for nongypsiferous soils. Date palm would be affected at 10 millimhos per centimeter, grapes at 6 millimhos per centimeter, etc., on gypsiferous soils.

[2] Estimate.

[3] Lemon is more sensitive than orange and grapefruit; raspberry is more sensitive than boysenberry and blackberry.

Crosslines are placed at 10-, 25-, and 50-percent yield reductions. The relative growth and production of the various crops on saline and alkali soils will give an indication of the soil salinity.

Reclamation of saline and alkali soils

In most of the humid areas of the United States salinity is not a problem, as natural precipitation has leached most of the soluble salts from the soil. In the arid and semiarid regions, where precipitation is low, salinity and alkalinity are common problems. Saline soils, soils with a high percentage of soluble salt, can be reclaimed by leaching and drainage. Alkali soils, soils with a relatively high percentage of sodium salt, are not readily reclaimed by leaching and may require additional treatment with selected chemical amendments in connection with the leaching. Saline-alkali soils are a composite group having a high percentage of both soluble and insoluble salts and the reclamation of these soils may require chemical treatment or leaching with salty water prior to the usual leaching and drainage treatment.

Most of the irrigated areas in the arid and semiarid region have some soils that are saline, alkali, or both. This condition is common in the low-rainfall regions where the average annual precipitation is less than 20 inches. The drainage of saline and alkali soils generally requires drains that are deeper than are needed in areas of neutral or acid soils. The reason for this is that in saline and alkali areas harmful salts move upward by capillarity into the root zone, thereby limiting its useful depth. The required depth for drains in salty areas is to some degree related to the capillary rise in the particular soils and subsoils in the area. Assuming a free water-table level at the same depth, drains in soils with a high capillary rise will need to be deeper than in soils with a low capillary rise. This is illustrated in Figures 4-2a and 4-2b. As a general rule, subsurface drains in saline and alkali areas should range in depth from 6 to 10 feet.

Saline conditions are identified on some soil maps and these should be noted during the reconnaissance investigation. Alkalinity is not usually mapped as a part of regular soil surveys, unless by special request, as this requires special field or laboratory analyses. If during the reconnaissance, alkaline conditions are suspected, it is advisable to consult a soil scientist before proceeding further with extensive surveys and investigations. This is important at this stage of planning as the treatment of alkali soils, in addition to establishing subsurface drains, may increase the cost of the project to the extent that it may not be feasible.

Reclamation of saline soils

Saline soils can usually be improved through leaching, as the soluble salts present will go into solution and be removed with the drain water. Leaching in areas of high precipitation is a natural process after subsurface drainage is established. In arid and semiarid regions it is usually necessary to supply irrigation water to accomplish this leaching. Thus, the reclamation of saline soils can usually be accomplished through some type of leaching without the addition of chemical amendments. Adequate subsurface drainage is a prerequisite.

Reclamation of nonsaline-alkali soils

The treatment of nonsaline-alkali soils is different from that for saline soils as it may be impossible to leach the soil until after certain chemical amendments are added. Through alkalization soil undergoes certain textural changes. These changes tend to destroy the original soil texture and leave the soil as a deflocculated mass. Alkali soils have the consistency of tar or heavy grease,

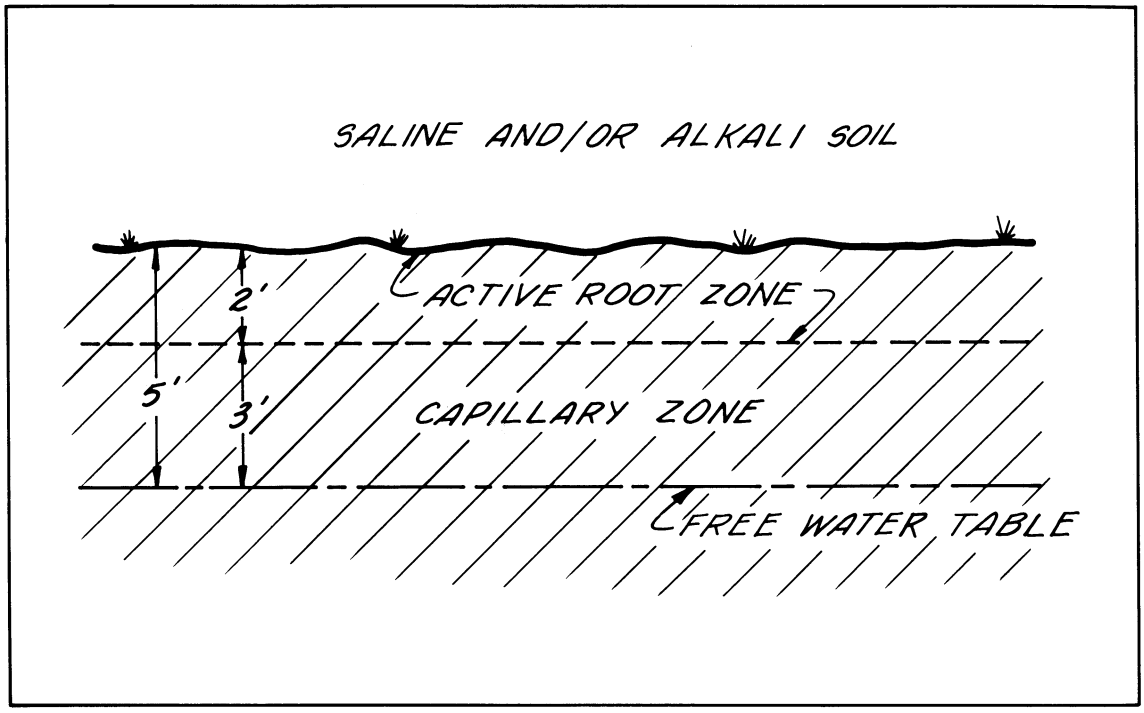


Figure 4-2a, Soil profile showing high capillarity

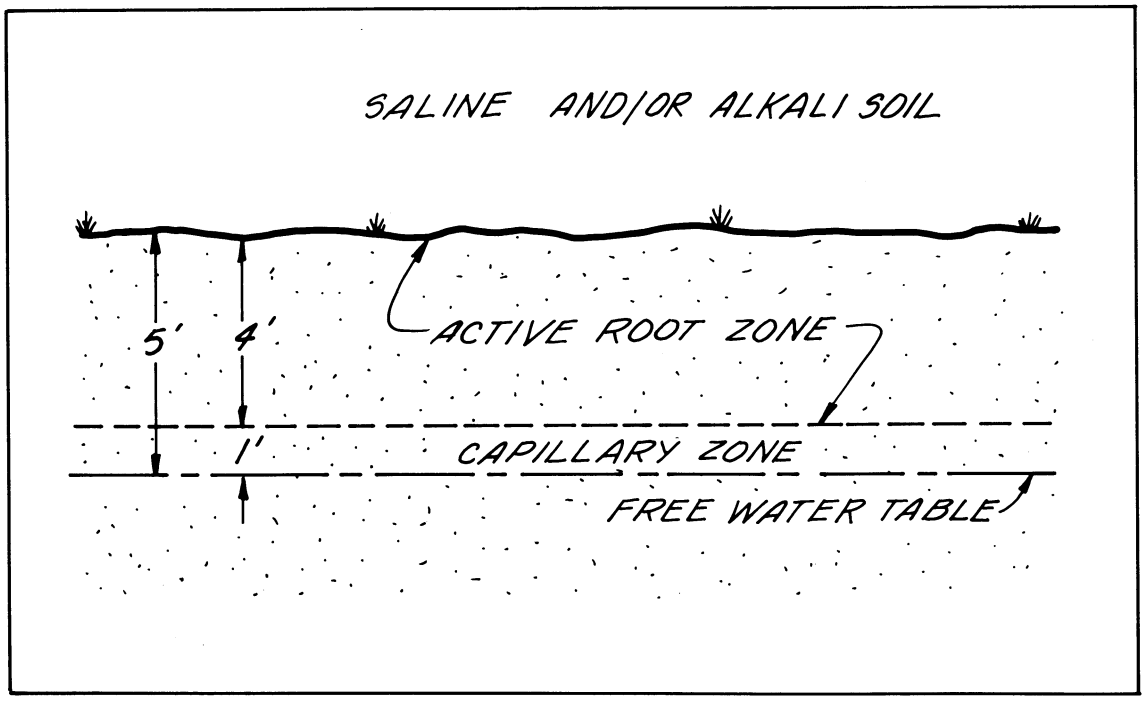


Figure 4-2b, Soil profile showing low capillarity

which is smooth and without texture. Spots of alkali soil in fields are often and appropriately referred to as "slick spots" meaning that they are void of vegetation and textureless. As alkalization progresses, the soil becomes less and less permeable. Strongly alkaline soils become virtually impermeable and impracticable to drain under most conditions.

It is highly important that nonsaline-alkali soils be recognized as such before attempting to establish subsurface drainage. These soils have lost some of their internal drainage characteristics and may not drain properly regardless of the type of drainage system installed. Where it is economically feasible to reclaim these soils, chemical treatment may be necessary to flocculate the soil particles and restore soil permeability before leaching and drainage. Some of the chemical amendments commonly used are calcium chloride, gypsum (calcium sulfate), sulphur, and sulphuric acid. The kind and amount of amendment applied must be based on recommendations from a laboratory following an analysis of representative soil samples.

Reclamation of saline-alkali soils

The treatment of saline-alkali soils is much the same as for nonsaline-alkali soils. Certain chemical amendments may be required, based on laboratory analyses of soil samples. Field identification of saline-alkali soils is difficult as they may exhibit characteristics of both saline and nonsaline-alkali soils. As pointed out in the definition of saline-alkali soils, they may be flocculated due to the presence of excess salts and may have a permeability equal to or higher than nonsaline soils. This is often misleading and may give the impression that soils can be reclaimed through simple leaching. Actually this may not be the case because leaching will remove the soluble salts, thereby causing the soils to become strongly alkaline and the permeability greatly reduced.

Boron

Boron toxicity is a problem in parts of the arid and semiarid regions of southwestern United States. Boron has been found to be present in scattered areas of desert soils that have been reclaimed for irrigation. It is usually associated with saline and alkali soils; however, this is probably accidental as most soils in this general area are salty soils. Boron is essential to the normal growth of all plants but the concentration required is very small, less than 1.0 ppm, and if exceeded may cause plant injury. Certain plant species vary both in boron requirement and in boron tolerance. The concentrations necessary for the growth of plants having a high boron requirement may also be toxic to plants sensitive to boron. This makes it very difficult, if not impossible, to generalize on boron limitations for certain areas without considering the crops and their respective tolerance to boron.

In areas where excess boron occurs, in the soil or in the irrigation water used, boron-tolerant crops should be grown. Table 4-2 indicates the relative boron tolerance of a number of crops grown in areas known to have excess boron.

Symptoms of boron injury may include characteristic chlorosis and necrosis although some boron-sensitive species do not show visible symptoms. Citrus, avocados, persimmons, and many other species develop a tipburn or marginal burn of mature leaves. Boron injury to walnut leaves is characterized by marginal burn and brown-necrotic areas between the veins. Stone-fruit trees, apples, and pears are sensitive to boron, but do not develop typical leaf symptoms. Cotton, grapes, potatoes, beans, peas, and several other plants show marginal burning and a cupping of the leaf that results from a restriction of the growth of the marginal area.

Table 4-2, Boron tolerance of crops (2).

Sensitive	Semitolerant	Tolerant
Pecan	Potato	Asparagus
Walnut	Cotton	Date Palm
Artichoke	Tomato	Sugar Beet
Navy Bean	Radish	Garden Beet
Plum	Peas	Alfalfa
Pear	Olive	Broadbean
Apple	Barley	Onion
Grape	Wheat	Turnip
Fig	Corn	Cabbage
Persimmon	Milo	Lettuce
Cherry	Oat	Carrot
Peach	Pumpkin	
Apricot	Pepper	
Blackberry	Sweet Potato	
Orange	Lima Bean	
Avocado		
Grapefruit		
Lemon		

Current information on boron tolerance does not permit the establishment of definite permissible limits for the three classifications shown in this table. It is thought that the approximate range from sensitive to tolerant is 0.7 ppm to 2.0 ppm of boron.

High levels of boron in soils can usually be reduced through leaching; however, this varies with soil types. Leaching of boron is a slow process and usually requires three to four times as much leaching water as is required for saline and alkali soils. The most economical treatment of boron-affected soils may be to switch to boron-tolerant crops and to apply excess irrigation water (leaching requirement) for a period of several years. This will not deprive the operator of crop income during the leaching process. Good subsurface drainage is always a prerequisite for proper leaching.

Planning Subsurface Drainage

One of the most important phases of planning subsurface drainage is to compile and analyze the field data collected through various surveys, investigations, and studies. Investigations for subsurface drainage are difficult because subsoil and ground-water conditions are not evident through visual inspection of wet areas. Various methods and techniques have been developed whereby these conditions can be determined and made evident through a graphical or statistical presentation. The following is a discussion of some of the methods and procedures commonly used.

Observation well hydrographs

Water-table elevation should be plotted against time on profile paper, cross-section paper, or preferably, printed hydrograph sheets. The time scale which is usually on the abscissa (horizontal) is graduated in days, by months, for a 1-year period. The elevation scale is usually on the ordinate (vertical) and is graduated in feet and tenths to cover the anticipated fluctuation range of the water table. Observation well hydrographs are used where a series of water-table readings are taken at a single-well location for at least a 1-year period or over a cropping or seasonal weather cycle. By plotting these

on a hydrograph sheet it is possible, at a glance, to visualize the water-table behavior at that well. Figure 4-3 illustrates a hydrograph showing two plots; one for a well in an irrigated area and one for a well in a non-irrigated or dryland area.

Observation well hydrographs are often helpful in determining the source of ground water. In the humid area the ground water is usually highest in the late spring at the base of slopes joining uplands and in narrow valleys where deep seeps and artesian water are often present. In irrigated areas ground-water levels tend to build up through the irrigation season reaching a peak at the end of the irrigation period. The illustration shown is for a single-crop area where the highest ground water usually occurs in September or October. In areas where multiple cropping is practiced this will vary with the periods of irrigation. In nonirrigated or dryland areas where accretions to ground water are from precipitation, ground-water levels tend to peak in the spring or early summer months, or after the rainy season. From this it is obvious that well hydrographs may indicate the source of water causing the high water-table condition, i.e., from precipitation or irrigation water.

Figure 4-4 is a hydrograph for a specific observation well in an irrigated area, which also shows a log of the subsurface materials. This type of hydrograph is often very helpful in relating fluctuations of the water table to specific underground strata. It is also an aid to determining the proper drain depth to take advantage of the most permeable strata. This combination hydrograph-log-type representation is preferred by some engineers.

Profile flow patterns

Profile flow patterns may be shown by plotting the surface of the ground, information on subsoil materials, and hydraulic-head values at points where measurements have been made with piezometers. Lines should be drawn to connect points of equal hydraulic head. Convenient hydraulic-head intervals may be selected extending over the range of measured values for hydraulic head. Usually an interval is selected that allows a number of equal hydraulic-head lines to be sketched on the same profile. The component of flow in the plane of the profile is normal to lines of equal hydraulic head if the profile section is plotted on a one to one scale. Using this scale, flow lines can be sketched in at right angles to the equal hydraulic-head lines, with arrows to show the direction of flow. If the vertical scale is exaggerated, the relation between stream lines and equal hydraulic-head lines on the plotted profile is no longer rectangular. Where the vertical and horizontal scales are not equal, the hydraulic-head distribution may be plotted, but flow lines should not be drawn.

A vertical component of flow is indicated where the hydraulic head changes. This component may be either up or down. An equal hydraulic-head line may intercept the water table at any angle, depending on the direction of flow. The water table is not necessarily a flow line as is often assumed, although it may be. A component of upward flow that exists below the water table may continue upward through the soil above the water table to the soil surface by capillarity. Likewise, downward flow may occur in the unsaturated soil above the water table. This is discussed in more detail in Chapter 1, and is illustrated by Figures 1-1 and 1-2 in Chapter 1.

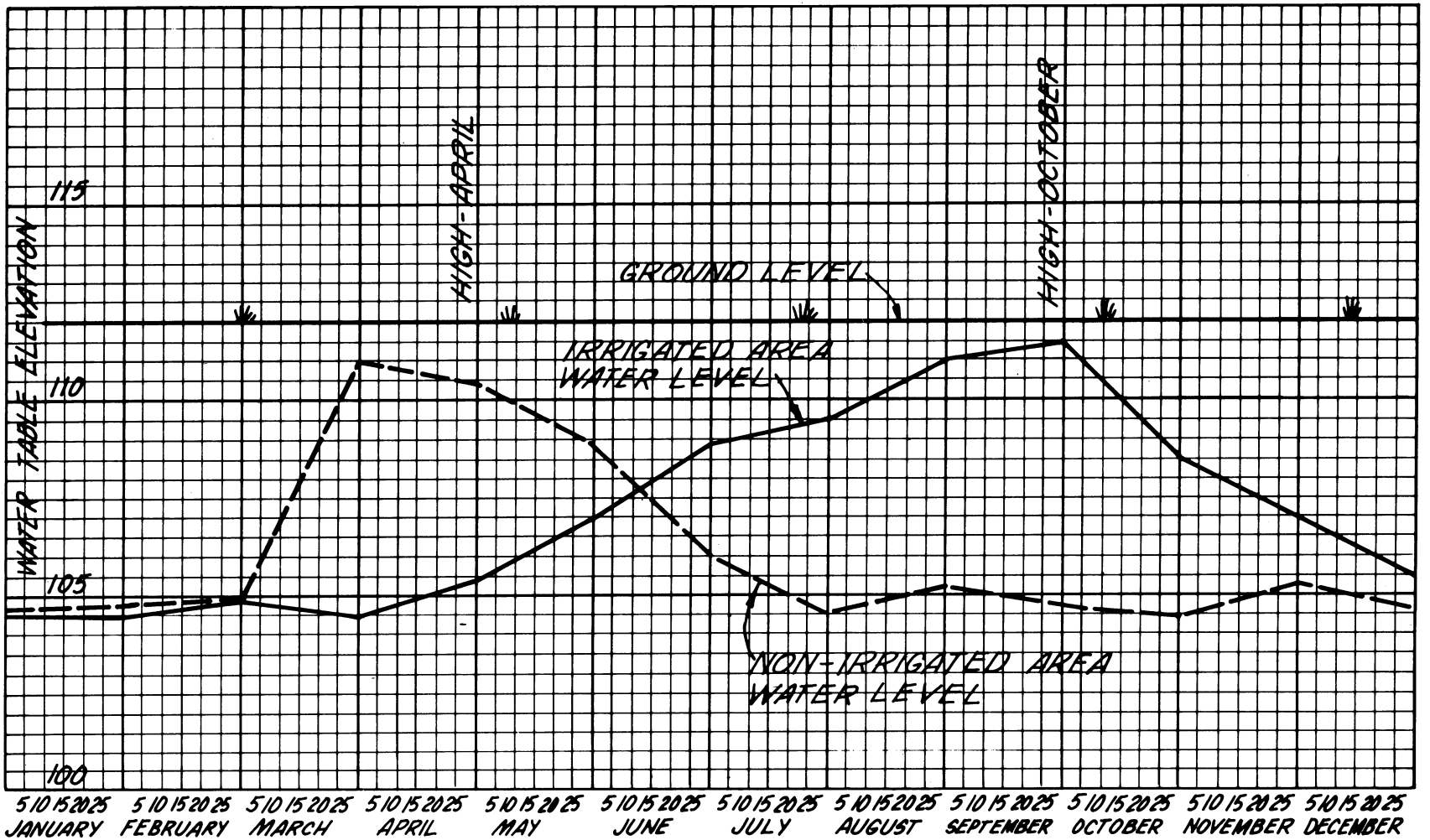


Figure 4-3, Observation well hydrograph

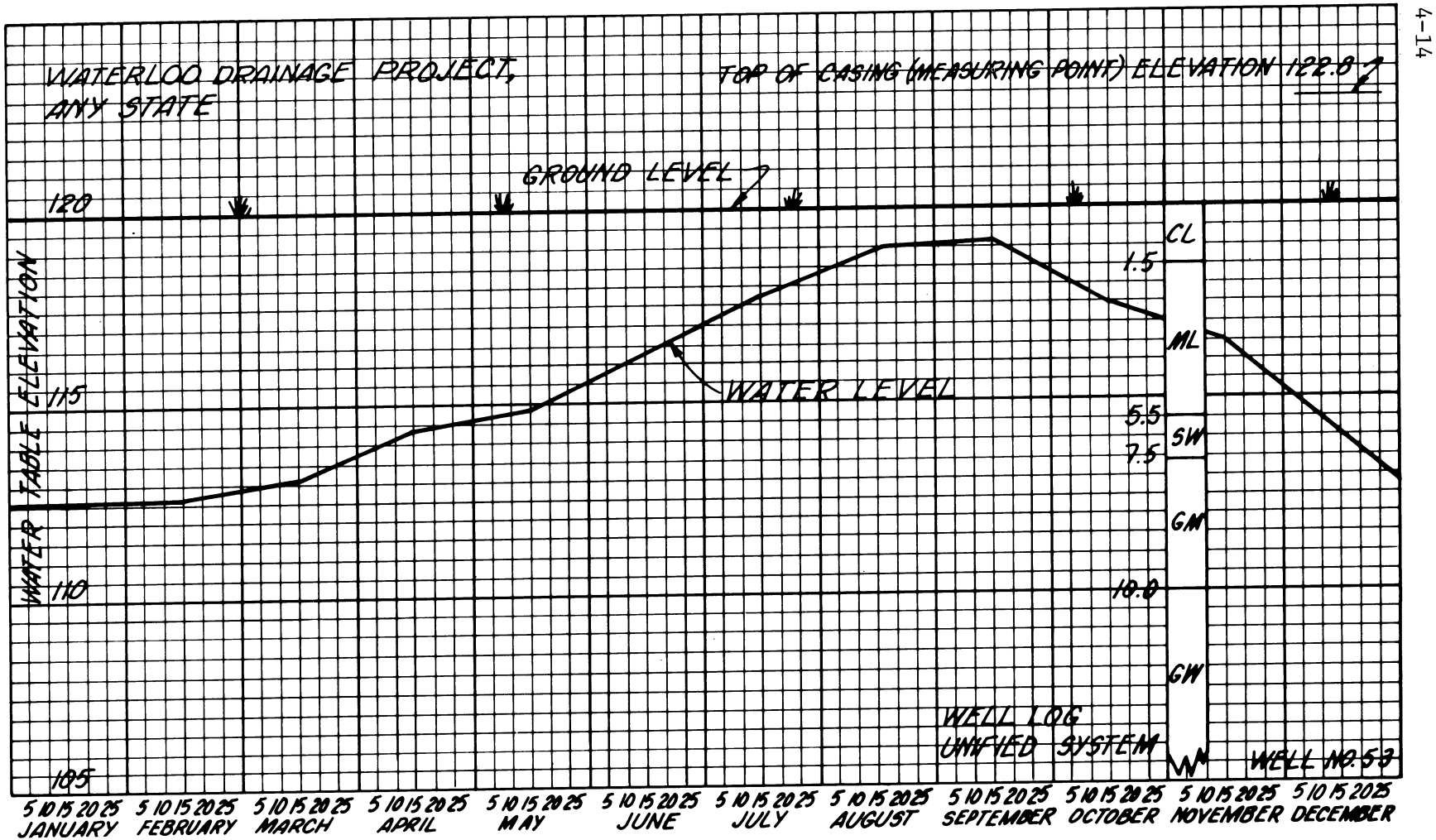


Figure 4-4, Observation well hydrograph

Ground-water contour maps

The elevation of the water table at a particular time at selected points may be plotted on the base map of the project area. These are usually plotted on a rectangular grid pattern on which ground elevations are noted, or on a contour map. By interpolation, lines of equal water-table elevation may be drawn on the map. These lines are referred to as ground-water contours and the completed map is referred to as a ground-water contour map. Such a map shows the configuration of the surface of the water table on a particular date in the area under consideration.

Figure 4-5 is an illustration of a ground-water contour map. Water-table elevations are shown on a rectangular grid pattern of 660 feet or at the corners of each 10-acre tract. By interpolation ground-water contours have been drawn on a 5-foot-vertical interval. From visual inspection the direction of ground-water flow is evident as indicated by the arrows shown. The hydraulic gradient or slope of the water-table surface varies from about 1 to 2 feet per 100 feet and can be determined for any specific area by dividing the contour interval by the scaled distance between contour lines. From visual inspection it is obvious that there is a high mound of ground water extending from the northwest corner toward the southeast corner diagonally across the field. This suggests a source of excess ground water in the northwest portion of the field or possibly in adjacent fields to the northwest.

To be of most use as a tool in planning subsurface drainage, ground-water contour maps should be superimposed on topographic maps to give the relationship between surface configuration and water-table configuration. This is illustrated in Figure 4-6 where ground-surface contours are shown as solid lines and ground-water contours are shown as dashed lines. At any specific point on the map, the depth to water table is the difference in elevation between the surface contour and the ground-water contour.

Figure 4-6 is an example of a ground-water contour map showing a high water table caused by canal seepage. This map shows an irrigated tract containing 960 acres, 100 acres of which are subject to a high water table. All land, both above and below the canal (Scott Canal), is irrigated. The wetland is located in one tract immediately below and adjacent to the canal. The "depth to water" information was developed by obtaining the difference between the elevations of surface contours and ground-water contours. The arrows on the map indicate the direction of ground-water flow which is perpendicular to the ground-water contours. From the map it appears obvious that the problem involves canal seepage. This is substantiated by the fact that there is very little wetland above the canal; that the wet area is in a fan-shaped tract adjacent to and below the canal, and that the direction of ground-water flow is outward from the area of highest water table adjacent to the canal. Having determined that canal seepage causes the wet condition, the section or sections of the canal that are seeping and will require lining or other treatment are then determined. In this example a rough location can be made by projecting the arrows showing the direction of flow to the point or points where they intersect the irrigation canal. To simplify this presentation, this example was selected to show a situation where the canal was leaking at only one point. In most cases, canals will be found to be leaking at several points, and it may be more difficult to "pinpoint" the leaky reaches; however, the general method of investigation would be the same. An examination of the materials in the canal bed would be necessary in planning remedial measures.

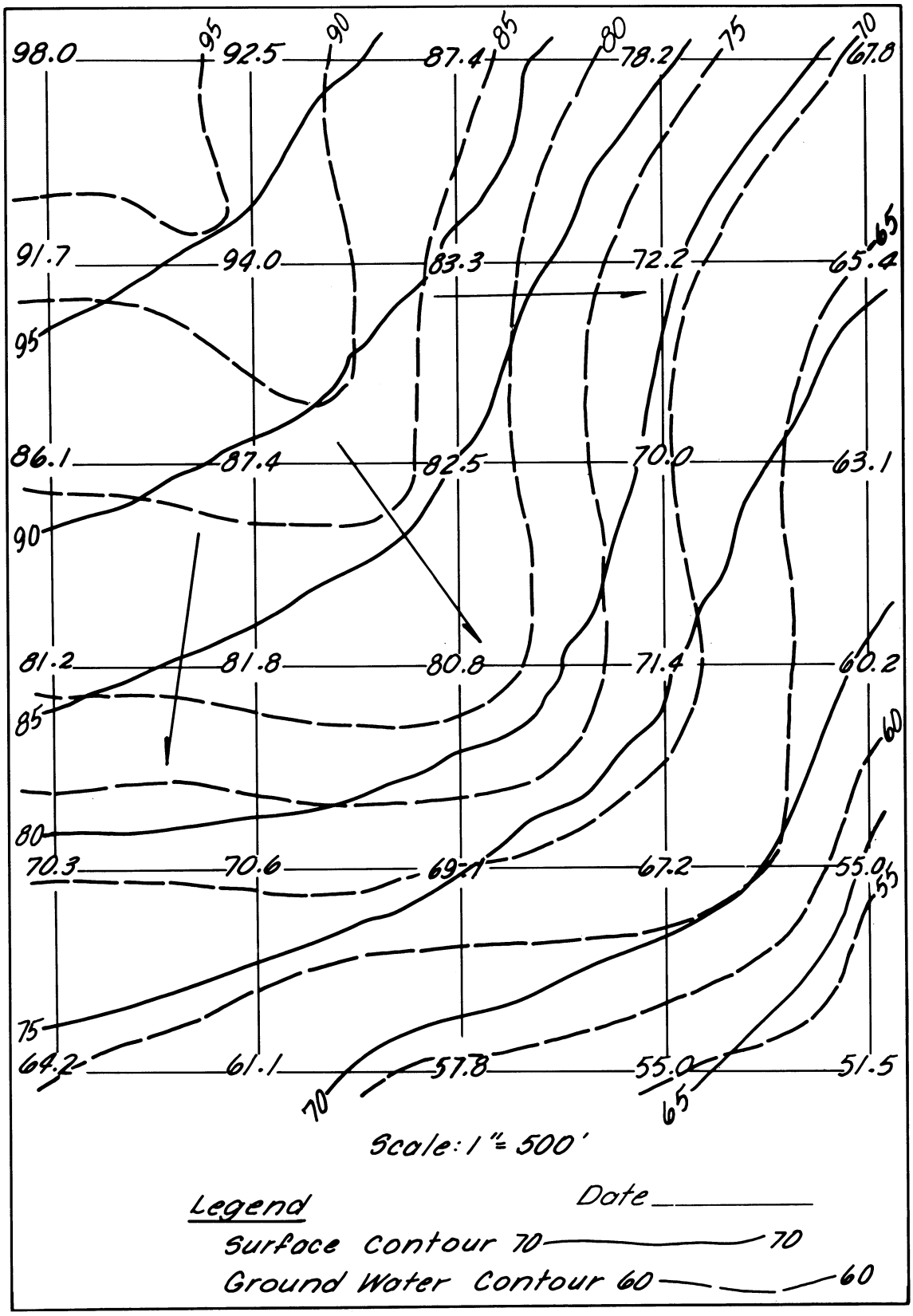


Figure 4-5, Typical ground-water contour map

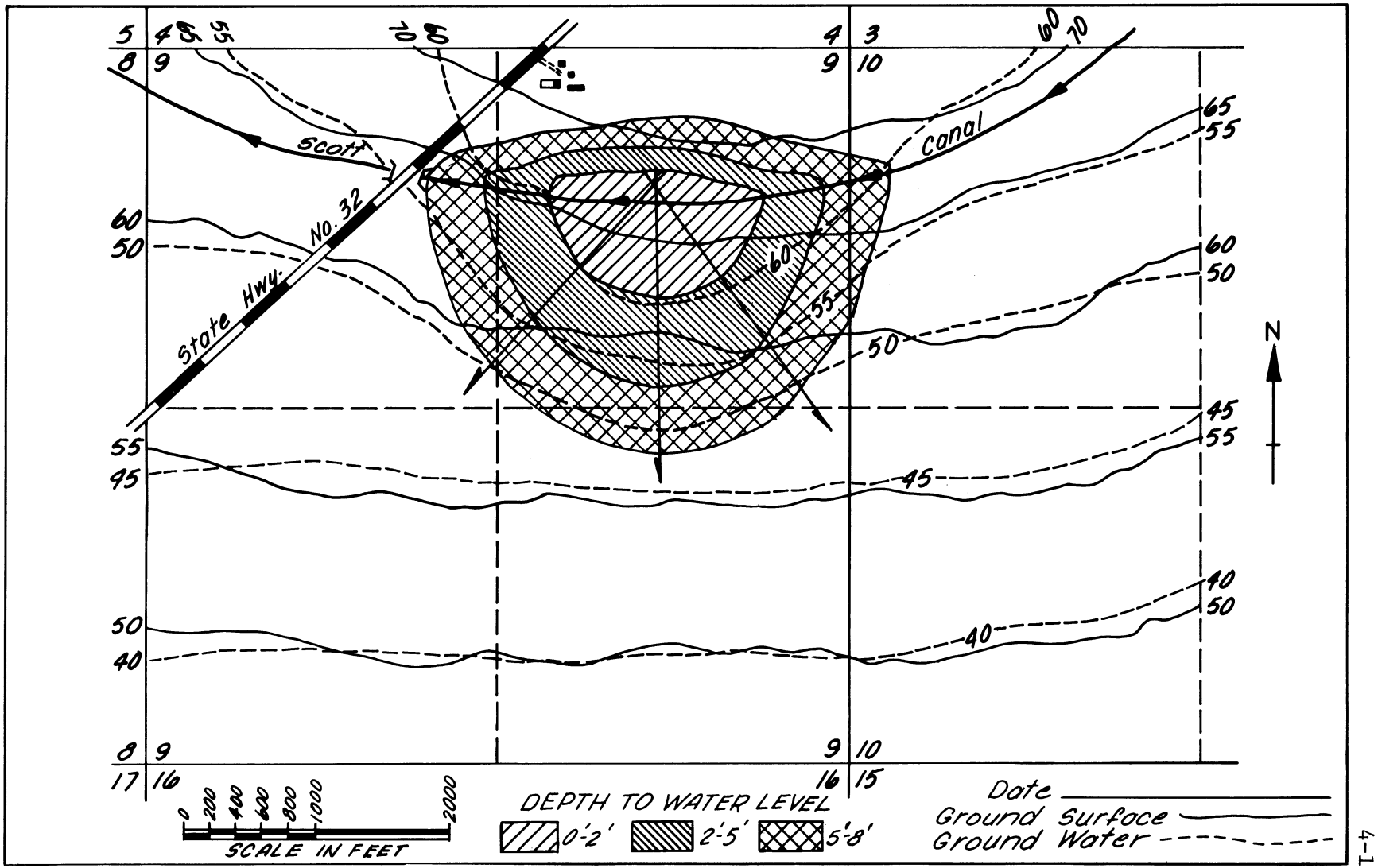


Figure 4-6, Working drawing (canal seepage)

The map shown as Figure 4-7 illustrates the use of ground-water contours in detecting and locating an underground barrier or impermeable material causing a high water table. These situations are common in alluvial flood-plain areas adjacent to major streams. When detected, these situations usually are easily corrected by installing relief drains through the impermeable barrier or immediately upslope and parallel to the barrier. Figure 4-7 shows an irrigated tract located on the flood plain of a major stream. A strip of land about 1,500 feet wide and paralleling the stream is subject to a high water table and is too wet for good production. Surface contours are shown on a 5-foot-vertical interval and ground-water contours (dashed lines) above the barrier are shown on a 1-foot interval. The direction of ground-water flow is directly to the stream. An examination of this map shows that the ground-water contours are closely spaced above the 20-foot contour. This indicates a steep water-table gradient in this area. Above or north of the 33-foot-ground-water contour the spacing of contours is wide indicating a flat gradient. This sharp break in the slope of the water-table gradient indicates the presence of less permeable material or a barrier to ground-water flow in the region of the slope break.

Figure 4-8, Section A-A, shows a cross-sectional profile of the flood-plain area as shown in Figure 4-7. It is sometimes easier to visualize these features from a profile than from a topographic map; however, the extent of the problem or problem area can be shown only on a horizontal projection.

Through the construction of this contour map and profile the position of the barrier or less permeable material has been located within broad limits. At this stage, additional borings will probably be needed in the vicinity of the barrier to make a more detailed investigation of the nature of materials present and the extent of the barrier.

The preceding examples illustrate two of the many uses of ground-water contour maps in solving difficult subsurface drainage problems. Cross-sectional profiles showing surface and water-table elevations, similar to Figure 4-8, often are helpful with investigations of localized problems. There are no exact rules governing the methods to be used in each situation. The drainage engineer must analyze each problem individually and set up a schedule for obtaining the information and data needed to develop the profile and contour maps required to analyze the problem.

Depth to water-table map

The depth to water, i.e., difference in elevation between the ground surface and the water table, should be plotted at selected points on a suitable base map. The lines of equal depth to water table are drawn. The completed map, sometimes referred to as an "isobath map," will show areal delineation of depth to water, which is usually the criteria for determining the need and extent of the wet area needing drainage. Figures 4-6 and 4-7 both illustrate this type of map. Areas with fixed ranges of depth to water table may be delineated and crosshatched or colored to show a graphic picture. A map of this kind is a valuable aid in discussing the project with landowners and is sometimes used as a basis for determining assessments for construction by the local sponsoring groups.

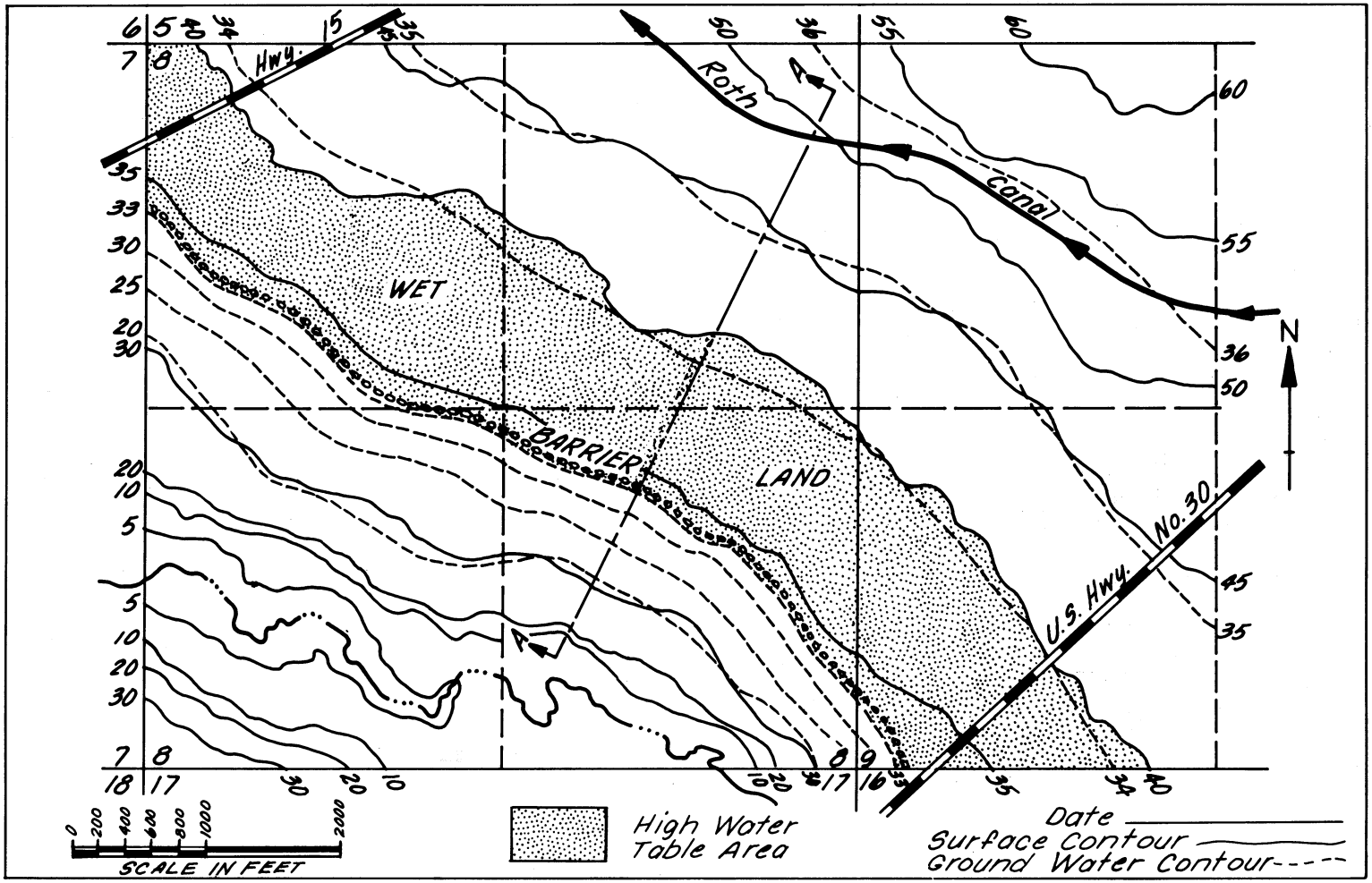


Figure 4-7, Surface contour above ground-water contour

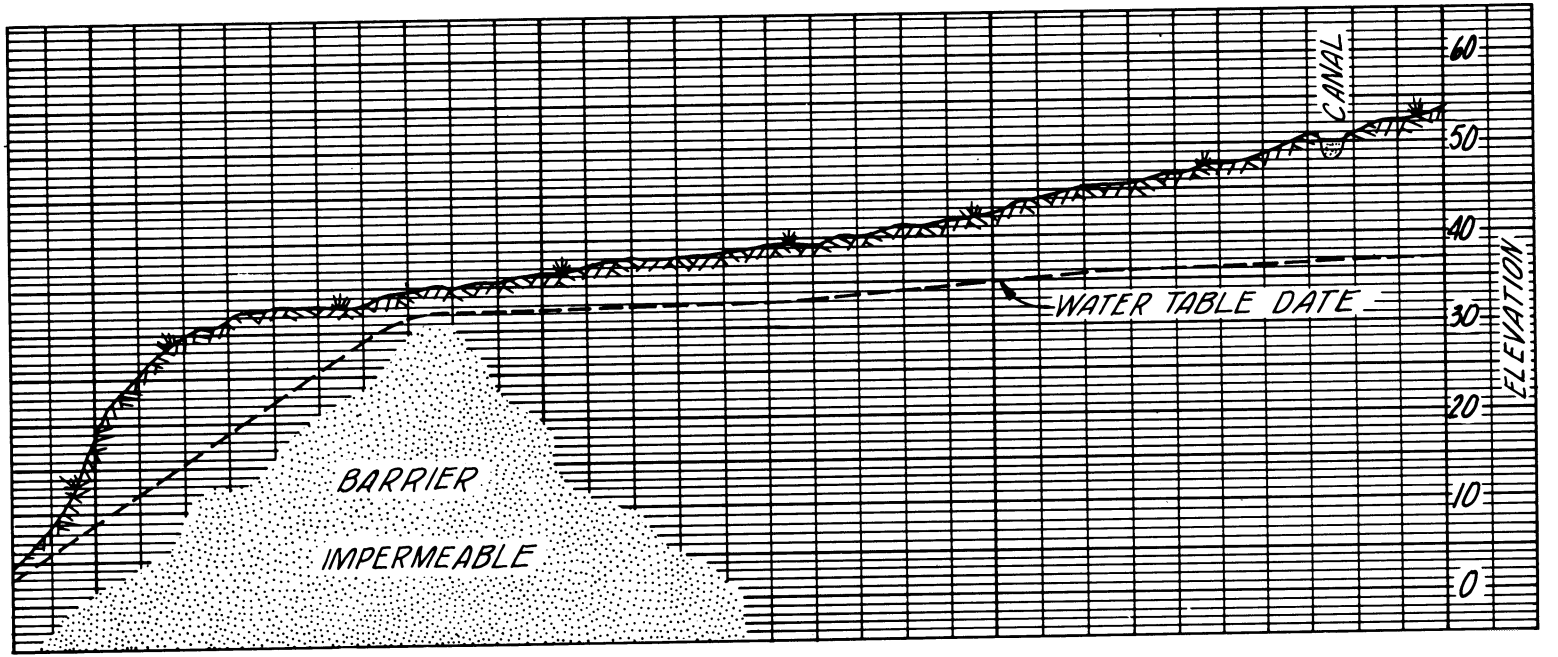


Figure 4-8, Profile section A-A, Figure 4-7

Classification of subsurface drainage

General

From a functional point of view, subsurface drainage falls into two classes: relief and interception drainage. Relief drainage is used to lower a high water table which is generally flat or of very low gradient. Interception drainage is to intercept, reduce the flow, and lower the flowline of the water in the problem area. In planning a subsurface drainage system, the designer must evaluate the various site conditions and decide whether to use relief or interception drainage.

Relief drainage

Open ditches. - Ditches used for subsurface drainage may carry both surface and subsurface water. Because of their required depth they have the capacity for a wide range of flow conditions. Ditches are best adapted to large flat fields where lack of grade, soil characteristics, or economic conditions do not favor buried drains. The advantages in using ditches include the following:

1. They usually have lower initial cost than drains.

2. Inspection of ditches is easier than inspection of drains.

3. They are applicable in some organic soils where drains are not suitable due to subsidence.

4. Ditches may be used on a very flat gradient where the permissible depth of the outlet is not adequate to permit the installation of drains having the minimum required grade.

The disadvantages in using ditches are as follows:

1. Ditches require considerable rights-of-way which reduce the area of land available for cropping. This is particularly applicable in unstable soils where flat side slopes are required.

2. Ditches usually require more frequent and costly maintenance than drains.

Buried drains. - Drains refer to any type buried conduit with open joints or perforations which collect and/or convey drainage water. Drains may be fabricated from clay, concrete, bituminized fiber, metal, plastic, or other materials of suitable quality. Drains, if properly installed, require little maintenance. They are usually preferred by landowners as they are buried and no land is removed from cultivation and maintenance is considerably less than for ditches.

The topography of the land to be drained and the position, level, and annual fluctuation of the water table are all factors to be considered in determining the proper type of drainage system for a given site. Relief drainage systems are classified into four general types: parallel, herringbone, double main, and random. (Refer to Figure 4-9).

Parallel system. - - The parallel system consists of parallel lateral drains located perpendicular to the main drain. The laterals in the system may be spaced at any interval consistent with site conditions. This system is used on flat, regularly shaped fields and on soils of uniform permeability. Variations of the parallel system are often used with other patterns. (Figure 4-9a).

Herringbone system. - - The herringbone system consists of parallel lateral drains that enter the main drain at an angle from either or both sides. This system usually is used where the main or submain drain lies in a depression. It also may be used where the main drain is located in the direction of the major slope and the desired grade of the lateral drains is obtained by varying the angle of confluence with the main. This pattern is used with other patterns in laying out a composite pattern on small or irregular areas. (Figure 4-9b).

Double-main system. - - The double-main system is a modification of the herringbone system and is applicable where a depression, which is frequently a natural watercourse, divides the field to be drained. Occasionally the depressional area may be wet because of seepage coming from the higher ground. Placing a main drain on each side of the depression serves a dual purpose; it intercepts the ground water moving to the natural watercourse and provides an outlet for the lateral drains. (Figure 4-9c).

Random system. - - A random system of drains is used where the topography is undulating or rolling and contains scattered isolated wet areas. The main drain, for efficiency, is usually placed in the swales rather than in deep cuts through ridges. If the individual wet areas are large, the arrangement of submain and lateral drains for each area may utilize the parallel or herringbone pattern to provide the required drainage. (Figure 4-9d).

Pumping system (ground-water removal). - This type of removal applies to deep well drainage where the drawdown is extensive and does not include shallow water-table control such as obtained by pumping muck or tidewater areas. The objective of all subsurface drainage work is to lower and maintain the water table at some level suitable for proper crop growth. This is usually accomplished by the installation of relatively deep subsurface drains. Water-table levels also may be controlled by pumping from the ground-water reservoir to lower and maintain the desired water-table level. In some irrigated areas where irrigation water is obtained from wells, the practices of irrigation and drainage both may be effected by the pumping of wells. This combination practice is limited to those areas with low salinity where it is possible to maintain a proper salt balance. In salty areas where pumping is used to effect drainage and where the quality of the drain water is poor, the drain water usually is discharged into a drainage outlet and not directly reused for irrigation. In some cases it is possible to mix the drain effluent with water of high quality and thereby obtain water suitable for irrigation.

The investigations necessary for planning a drainage facility, using pumps to lower the water-table level, can be quite complex. Detailed information on the geologic conditions and the permeability of soil and subsoil materials are very important. Design involves anticipating what the shape and configuration of the cone of depression will be after pumping. This, in turn, involves spacing of wells to position properly their areas of influence and obtain the desired drawdown over the area to be drained. Usually it is desirable to install test wells to determine the drawdown and spacing of wells. Consultation with a geologist is desirable.

Past experience with this type of drainage installation indicates that, in general, pumping from wells is costly and it is difficult to obtain a satisfactory benefit-cost ratio. Consideration for this type of facility should be limited to high-producing lands with a high-return value per acre.

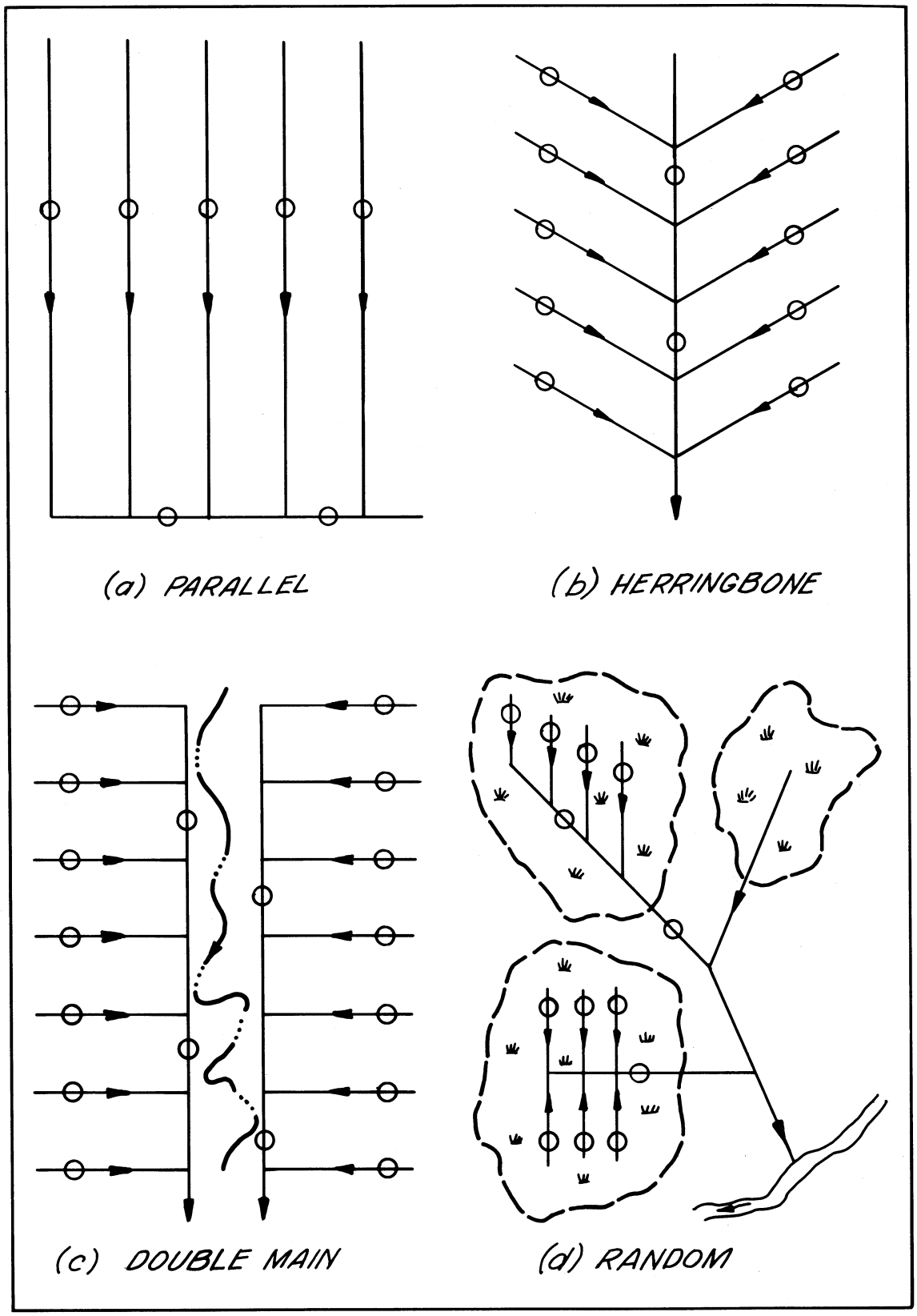


Figure 4-9, Types of drainage collection systems

Combination system. - Combination systems or dual-purpose systems are names that have been given drainage systems that provide both surface and subsurface drainage. In this type of system any combination of open ditches and buried drains may be used. In areas with soils of low permeability which require close spacing of buried drains, it is common practice to use drainage field ditches for surface collectors, drains for subsurface collectors, and ditch-type drainage mains and laterals for disposal. In soils of high permeability such as Indiana and Michigan sands and some coastal plain soils, a field-border ditch for surface water collection is all that may be needed. Drop structures are required where surface collectors discharge into deep open ditches. Buried drains are seldom used to collect or dispose of surface water. The reasons for this are (a) surface waters usually carry debris which may lodge in the drain and cause a plug to form, and (b) surface flows are subject to large variations which dictate a large and expensive drain.

Mole drains. - Mole drains are unlined, approximately egg-shaped earthen channels, formed in highly cohesive or fibrous soil by a moling plow. The moling plow has a long blade-like coulter to which is attached a cylindrical bullet-nosed plug, known as the mole. As the plow is drawn through the soil, the mole forms the cavity, at a set depth, parallel to the ground surface over which the plow is drawn. Heaving and fracturing of mineral soil by the coulter and mole leave fissures and cracks which open up toward the mole and coulter slit. These provide escape routes through the soil profile and into the mole cavity for water trapped at the surface or water that has percolated into the soil.

Mole drains, when properly installed in locations with soils suitable for them, provide drainage for 3 to 5 years and may, with diminishing effectiveness, provide drainage for as much as 5 years longer.

Cultivation of moled lands with heavy equipment reduces the effective life of such drains.

Vertical drains. - Vertical drains or drainage wells, as they are frequently called, have been used as outlets for both surface and subsurface drains. They have been used where gravity outlets were not available or where the cost of obtaining gravity outlets was prohibitive.

Vertical drains must penetrate a suitable aquifer which is capable of absorbing the drainage flow. Investigations for vertical drains must be in sufficient detail to determine that such an aquifer is present and that it is capable of absorbing the expected drainage discharge for an indefinite period of time. This requires a geologic determination made in conjunction with a geologist. It is usually necessary to make a test boring or borings to determine the magnitude, thickness, depth, and extent of the aquifer in question. Laboratory work may be required to determine the physical and chemical properties of the aquifer material.

Vertical drains are wells in which the direction of flow is reversed. Most of the design principles and criteria applicable to water wells are applicable to vertical drains. The major difference is that relatively clean ground water is pumped from water wells; whereas, drainage water discharged into vertical drains may contain significant quantities of salt, sediment, and debris. Unless these pollutants are removed from the drainage effluent before it enters the vertical drain, they tend to plug and seal the drain. Service experience with vertical drains has been disappointing because of the large

percent of vertical drains that seal-up and become ineffective in a relatively short period of time.

Drainage water that is discharged into underground aquifers usually contains pollutants in solution, in addition to the sediment and debris mentioned above. These pollutants may percolate into other aquifers or areas where wells are used for a domestic water supply. For this reason there is danger of contaminating water supplies and most states working with the Public Health Service have enacted laws controlling this practice. Some states forbid the use of drainage wells and others require that a permit be obtained.

Interception drains

General. - Interception drains may be either open ditches or buried drains. Proper location of either type is very important. The location and depth required usually are determined through extensive borings and ground-water studies.

Open ditches. - The ditch type interceptor may serve to collect both surface and ground-water flow. It must have sufficient depth to intercept the ground-water flow. Such ditches usually have excess capacity at the required depth. The interception ditch frequently is used to intercept the surface and ground-water flow at the base of a slope.

Buried drains. - Peculiar or unusual subsurface formations or ground-water conditions may be responsible for a high water table in certain local areas. Likewise, abrupt changes in topographic features may cause certain areas to be subject to a high water table. These situations are difficult to describe. Figures 4-10 through 4-12 are diagrammatic sketches of a few combinations of subsurface materials, topography, and ground-water conditions which may cause a high water table.

Figure 4-10 is a sketch of a cross section of one-half of a valley area. This illustrates an interception drain located at the base of hill land or at the base of a higher terrace or bench. This is a common situation in large stream valleys where the valley lands are subject to seepage from uplands. Often high benches or terraces are subject to seepage from higher land. Many investigations of these situations have shown that wet or high water-table areas usually occur near the base of the terrace and extend for some distance toward the river or stream. Ground-water investigations generally disclose that the water-table surface is close to a straight line or flat curve extending from the water surface in the stream to some distant point beneath the terrace or bench. The wet area exists because of an abrupt change in topography at this point which brings the land surface near to, or in contact with, the water-table surface. The corrective measure, as indicated, is to lower the water table in this area by an interception drain. Some open interception ditches are susceptible to damage from flood flows, causing erosion or channel changes, and use of drains instead of open ditches may avoid such hazards.

Figure 4-11 is a sketch to illustrate an interception drain located upslope above a barrier of impermeable material. Under natural conditions this barrier causes a reduction in the depth or thickness of the aquifer, and in turn, causes the hydraulic grade line or water-table surface to "daylight," or rise to or near the ground surface. This causes a wet or seep area near the barrier. This situation is often found in alluvial flood plains where ancient channel changes have built up barriers of fine-grained sediments, sometimes referred to as slack-water deposits. This condition is difficult

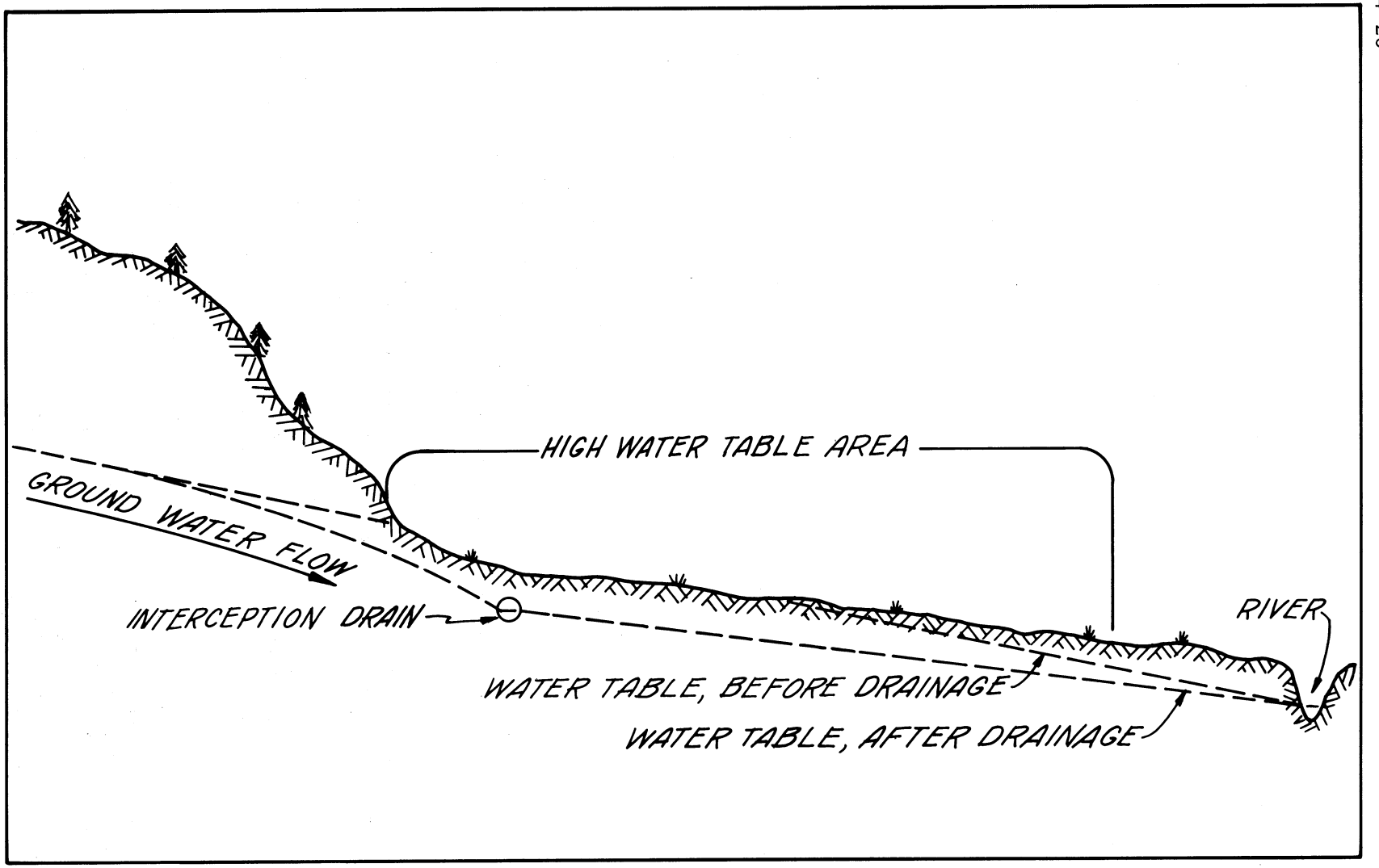


Figure 4-10, Interception drain in a valley area

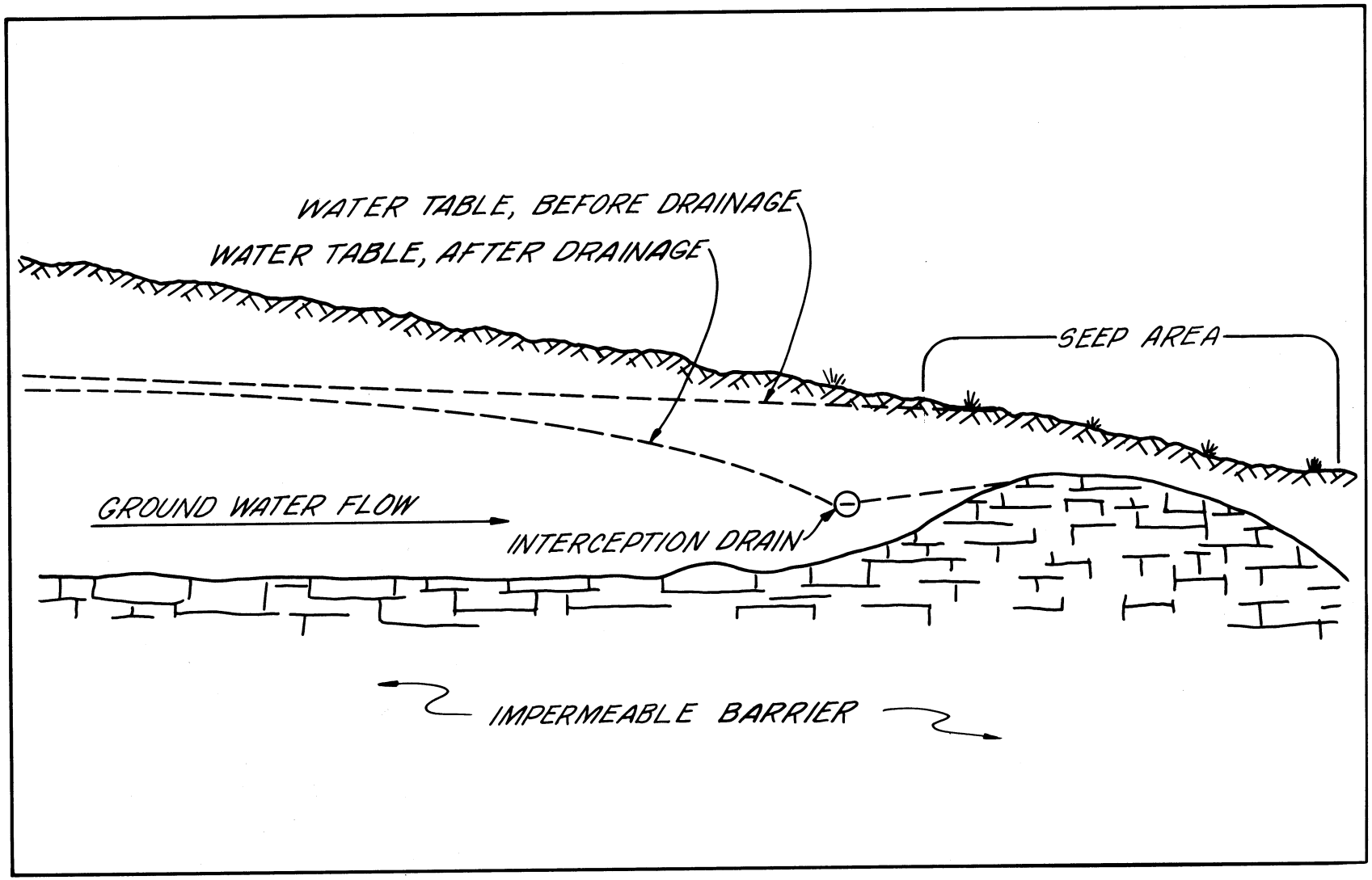


Figure 4-11, Interception drain for barrier condition

to detect and usually requires extensive subsoil explorations. The presence of unexplainable wet areas surrounded by dry areas suggests such a non-conformity in subsoil material. The corrective measure may be a drain just upslope from the barrier and paralleling it as suggested in the sketch.

Figure 4-12 illustrates an interception drain located at the base of a permeable layer, sandwiched between layers of less permeable material. The permeable layer outcrops, causing a seep that may affect a considerable area below the outcrop. This is common in formations that are highly stratified and have an exposed outcrop. Under natural conditions, the permeable layer may be carrying considerable ground water with a hydraulic grade line that intercepts the ground surface at some point in the outcrop area causing a natural seep. An interception drain should be located as indicated, at the base of the permeable material, to collect the flow from the aquifer, and prevent seepage at the ground surface.

Many other situations could be cited which would illustrate variations in drainage problems. It is obvious that there can be no fixed rules or procedures for dealing with these problems. The drainage engineer must make a thorough investigation of the subsurface and ground-water conditions and then make an analysis of these factors based on sound hydraulic principles as they are pertinent to drainage.

Outlets for subsurface drainage

An outlet for the drainage system must be available for gravity flow or by pumping. The outlet must be adequate for the quantity and quality of the effluent to be disposed of without causing damage to other areas and with minimum deterioration of the water quality in the outlet.

An open-ditch outlet for gravity flow from a buried drain should permit discharge from the drain above the elevation of normal low flow in the outlet. Interruption of flow from the drain due to storm runoff in the outlet should not occur so often and with such duration that the rate of ground-water drawdown by the buried drain would fail to meet the design requirements. When this condition exists, pumping the flow from the buried drain should be considered.

Special situations

Use of relief wells. - A high water table may be caused by seepage under hydrostatic pressure in a pervious strata located below a less pervious strata. The presence of hydrostatic pressure in seepage spots can be detected by boring holes in the seepy area. Water may rise in the hole nearly to the ground surface and may even overflow as from a flowing well.

A relief drain employing a relief well to lower a high water table is illustrated in Figure 4-13. This sketch illustrates a condition where very slowly permeable subsoil and substratum materials, which extend below feasible drain depth, are underlain by permeable material under sufficient hydrostatic pressure to maintain the water-table level at or near the ground surface. By installing the relief wells into the permeable material, it is possible to lower the water-table level by the amount of the effective head created. The effective head is the difference in elevation between the water-table level before drainage and the water surface in the drain. The operating head is the effective head less friction loss, entrance losses, etc. in the relief wells. The effective head should be about 5 feet or more before attempting this type of installation. The spacing of relief wells must be on a trial basis for any individual case. Relief wells should be added to the line until

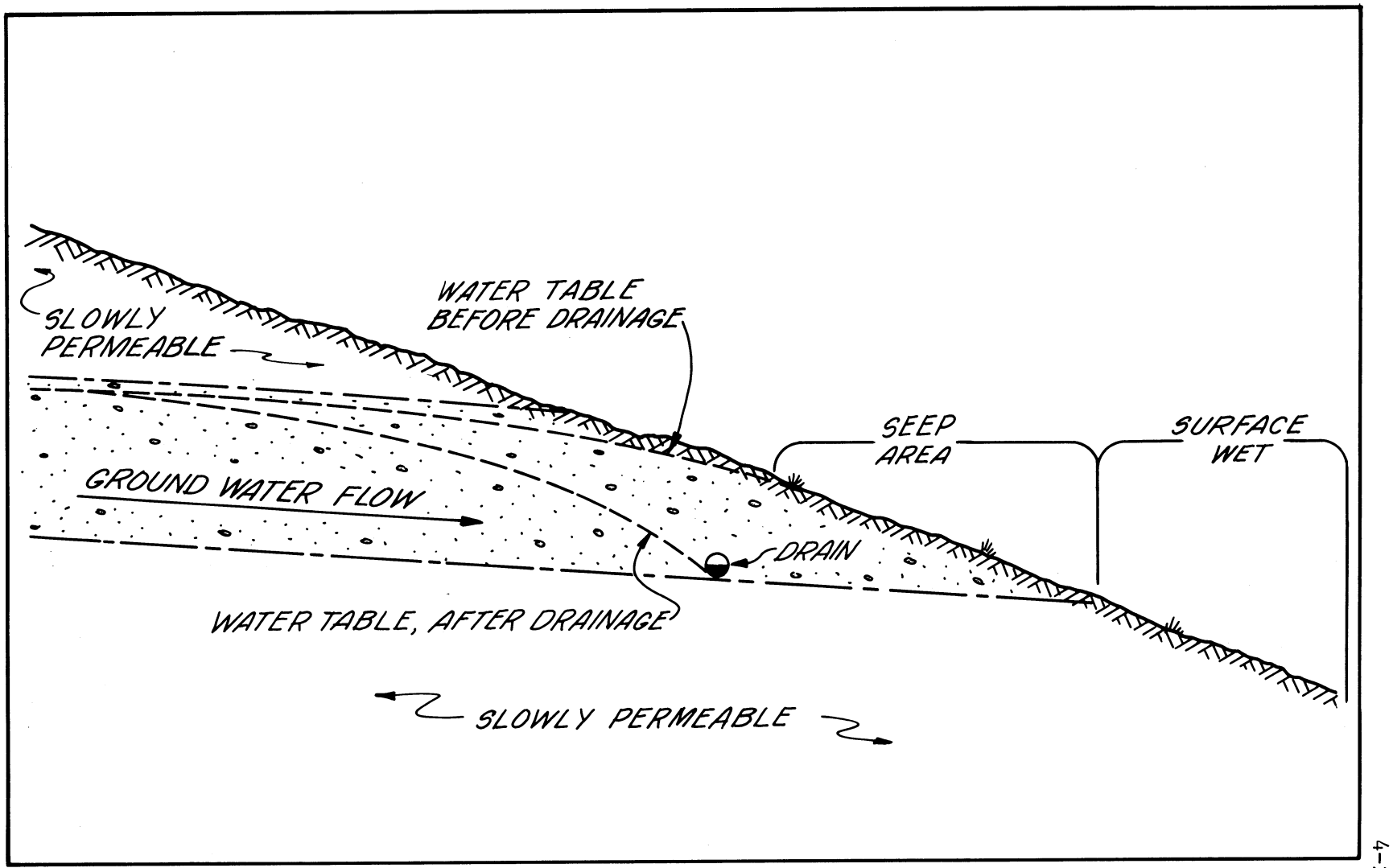


Figure 4-12, Interception drain at outcrop of aquifer

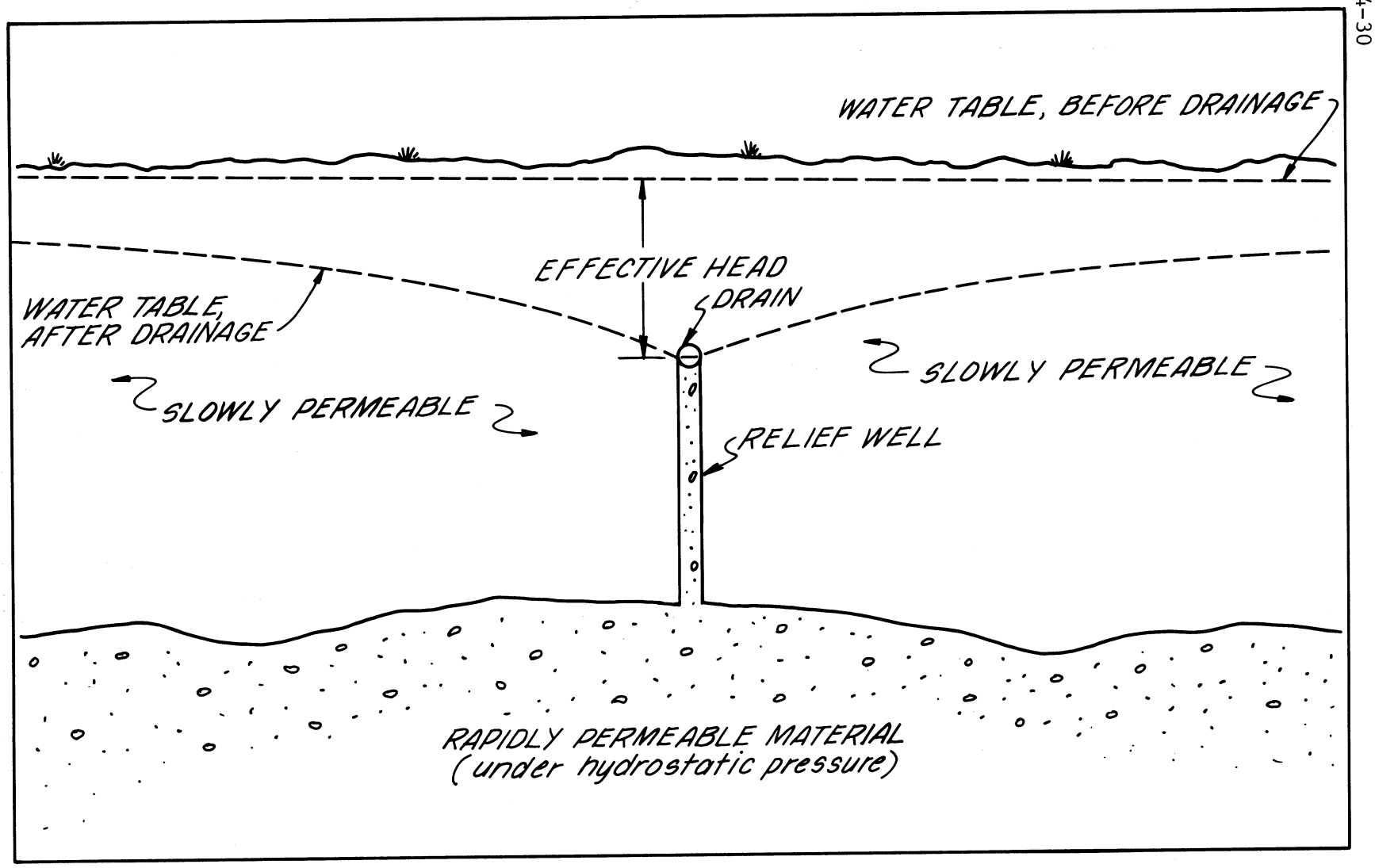


Figure 4-13, Relief well installation

hydrostatic pressures are reduced to near zero at the water surface in the drain. Investigations leading up to an installation of this kind must be thorough. The use of relief wells is restricted to special cases where complete information is available on subsurface materials and ground-water conditions.

The sketch shown as Figure 4-14 illustrates a condition where a constricted aquifer forces the water table to the ground surface. The subsurface materials present are a slowly permeable sediment containing a lens or stratification of very permeable materials serving as an aquifer for ground-water flow. Due to the constriction or "pinching-off" of the aquifer formation, its capacity is reduced and sufficient hydrostatic pressure develops to cause the water table to rise to or near the surface or "daylight" as shown. Situations of this type are difficult to detect and require careful subsurface exploration. Upon examination, the wet area usually appears as a seep area below a definite line of seepage which can be traced through the field.

Salt-water intrusion in coastal areas. - When planning drainage in areas in close proximity to sea coasts, certain precautions must be considered in regard to salt-water intrusion. Beneath coastal areas, the normal movement of fresh ground water toward the sea usually prevents landward intrusion of the denser sea water; however, pumped well drains or pumped surface and subsurface drainage can reverse this situation. If this happens, the consequences can be serious because land once subjected to salt-water intrusion is difficult to reclaim.

Guidelines for prevention. - - In coastal areas salt water is present in underground strata at a depth equal to about forty times the height of fresh water above sea level (5). This is given by the Ghyben-Herzberg relation (refer to Figure 4-15), which expressed mathematically, is as follows:

$$z = \frac{P_f}{P_s - P_f} (h) \qquad \text{(Eq. 4-1)}$$

where:

z = The distance from mean sea level (MSL) to the fresh water-salt water interface.

P_f = The density of fresh water.

P_s = The density of sea water.

h = The head of fresh water above MSL. (See Figure 4-15)

assuming:

$$P_f = 1.000 \text{ g/cm}^3$$

$$P_s = 1.025 \text{ g/cm}^3$$

$$z = \frac{1.000}{1.025 - 1.000} (h)$$

$$z = 40h$$

This relationship is only approximate as the density of sea water varies with temperature and the salts present; however, the ratio of 40.0 to 1.0 is adequate, as a general rule, for the purposes discussed here.

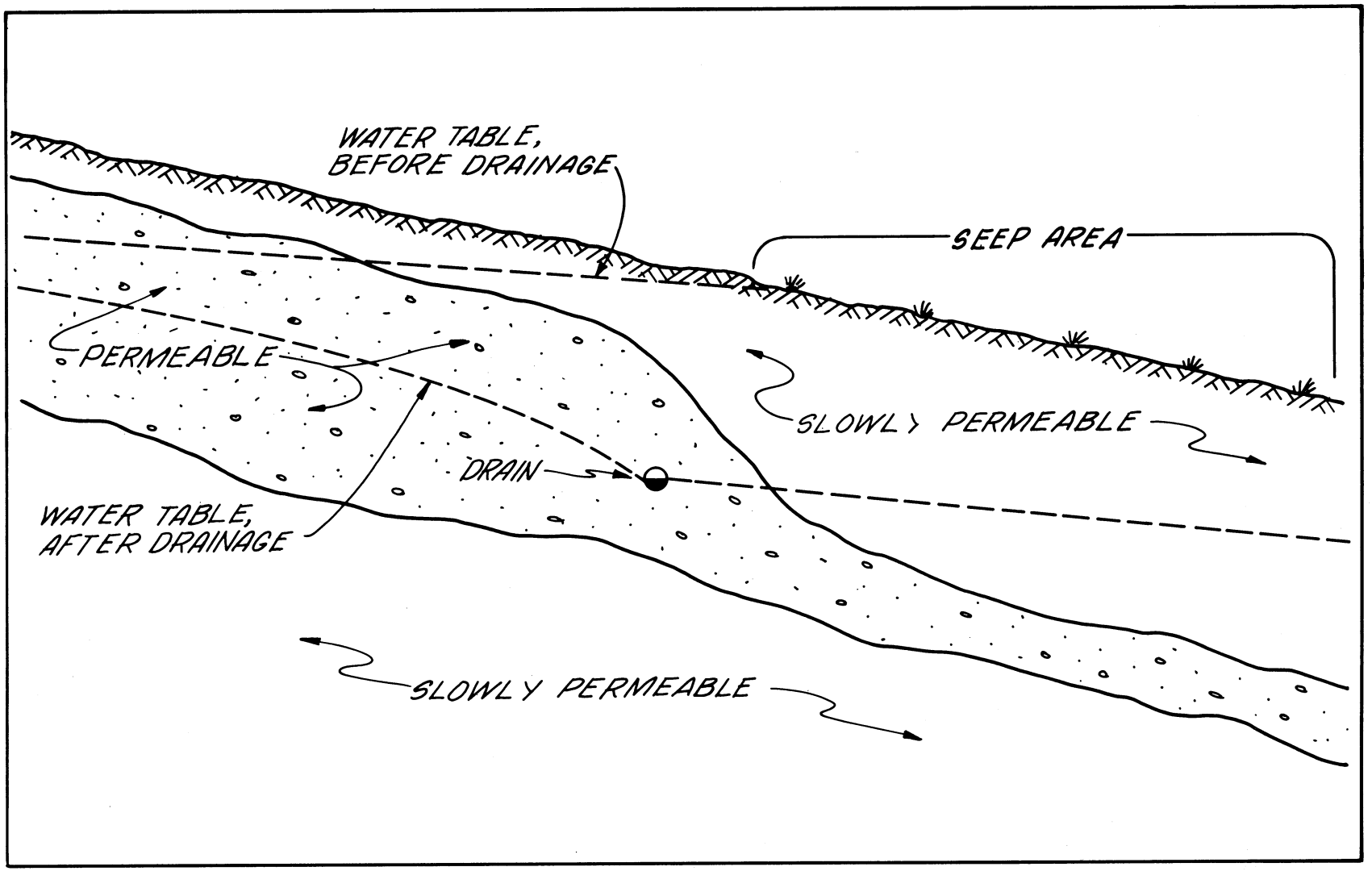


Figure 4-14, Interception drain in a constricted aquifer

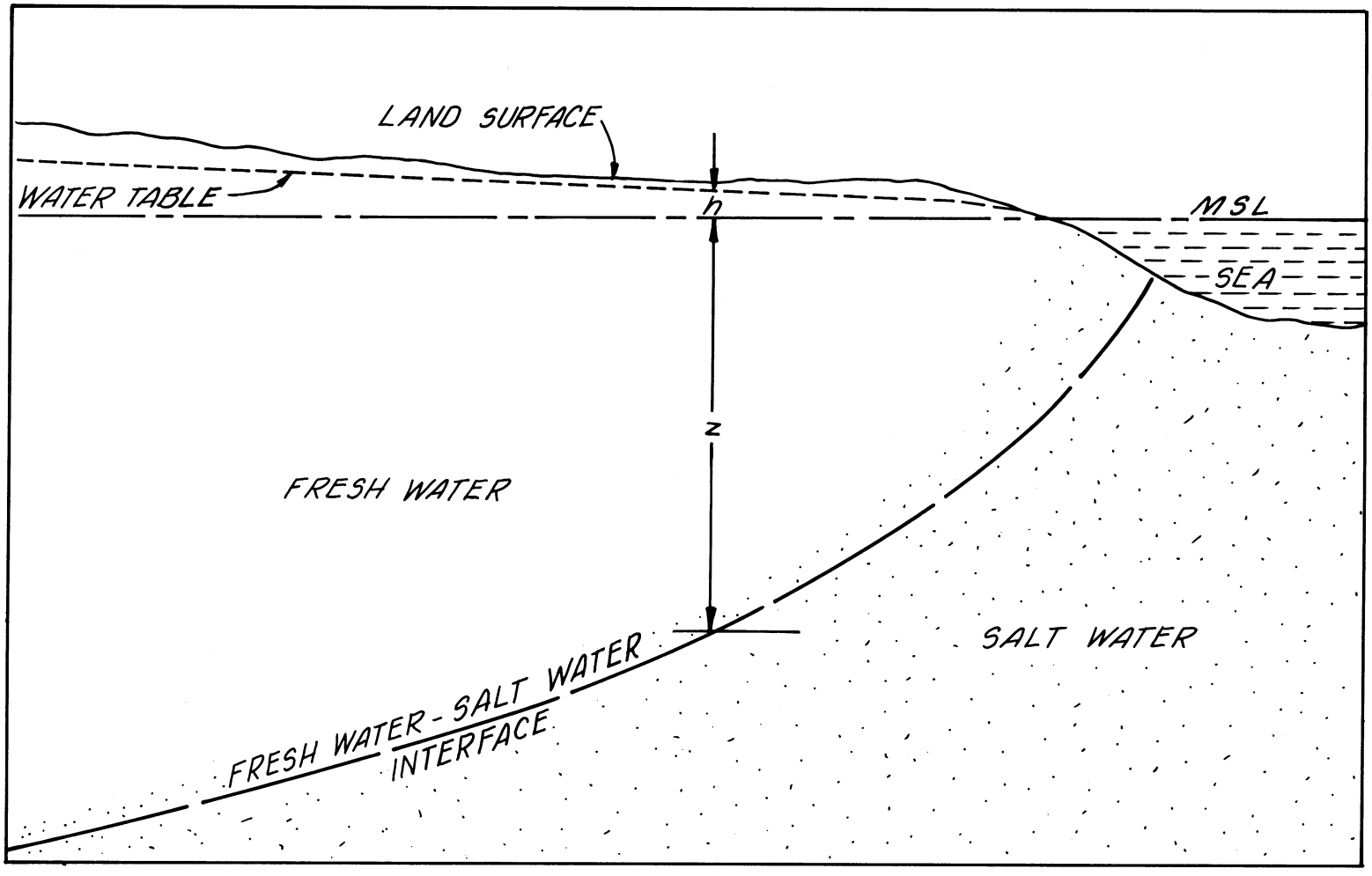


Figure 4-15, Fresh water-salt water conditions

From the prior discussion it is apparent that in coastal areas, lowering of the water table 1 foot will cause a 40-foot rise in the fresh water-salt water interface. Lowering of the water table to mean sea level will bring the interface up to mean sea level which will in most cases render the land salty and unfit for agricultural use.

As a general guide for use in planning pumped well drains near the coast, wells should not pump from below mean sea level. Interior basin wells should bottom above the expected fresh water-salt water interface with the anticipated drawdown. Wells should be designed and developed for minimum drawdown and be located so that drawdown is distributed as widely as possible.

Planning a subsurface drainage system (example)

The following example is an illustration of the use of a topographic map, water-table contour map, and a depth to water-table map in planning a drainage system for a drainage problem area. There are several ways a solution to a similar problem might be worked out. One way is to prepare a working map of the affected area showing topographic and ground-water conditions. Soil and subsoil conditions also may be shown on the map, but it is usually better to indicate these on a separate map or tabulation to avoid too much detail on one map. Transparent overlays, each showing separate features, are helpful working tools. A base map showing cultural and topographic features can be prepared on drawing paper and overlays on transparent sheets added to show soil, subsoil, substratum, and ground-water conditions. Through this procedure working maps are compiled which show the pertinent physical conditions necessary for the analysis of drainage problems. The following is a discussion on the above method showing how such a working map might be developed and used. Although the example is that of an irrigated farm the same procedure is used on nonirrigated farmland.

Figure 4-16 shows a topographic map of an irrigated farm containing about 480 acres. Part of this farm is wet and subject to a high water table and needs subsurface drainage. This map shows the usual features that would be shown on any topographic map of an irrigated area. It will be noted that the main irrigation canal and a few irrigation field ditches are shown. Surface contours are drawn on a 5-foot-vertical interval. This topographic map will serve as a base for the working map to be developed.

Table 4-3 is a tabulation of ground-water information from 23 observation wells on the 480-acre farm. The first three columns on the left show well number, ground-surface elevation at the well, and top of casing or "measuring point" elevation for each well. These are data that can be compiled after establishing wells and completing level surveys. This part of the table should be set up before making measurements of depth to water table in the wells. The depth to the water table (distance from the ground surface to the water-table level) and the water-table elevation reduced to a standard datum are shown for each well for the period of record, May through September. The period of record, or the period over which well measurements are made, varies from project to project. However, May through September was adequate to select a general high water-table condition in this particular example. In reviewing the table it will be noted that the highest water-table reading for each well, regardless of the month in which it occurred, has been marked by parentheses. The number in parentheses at the bottom of the table indicates the number of wells which showed their highest reading in each month during the period of record. It is noted that August, during which 10 of the 23 observation wells showed the highest water-table level, is the critical month

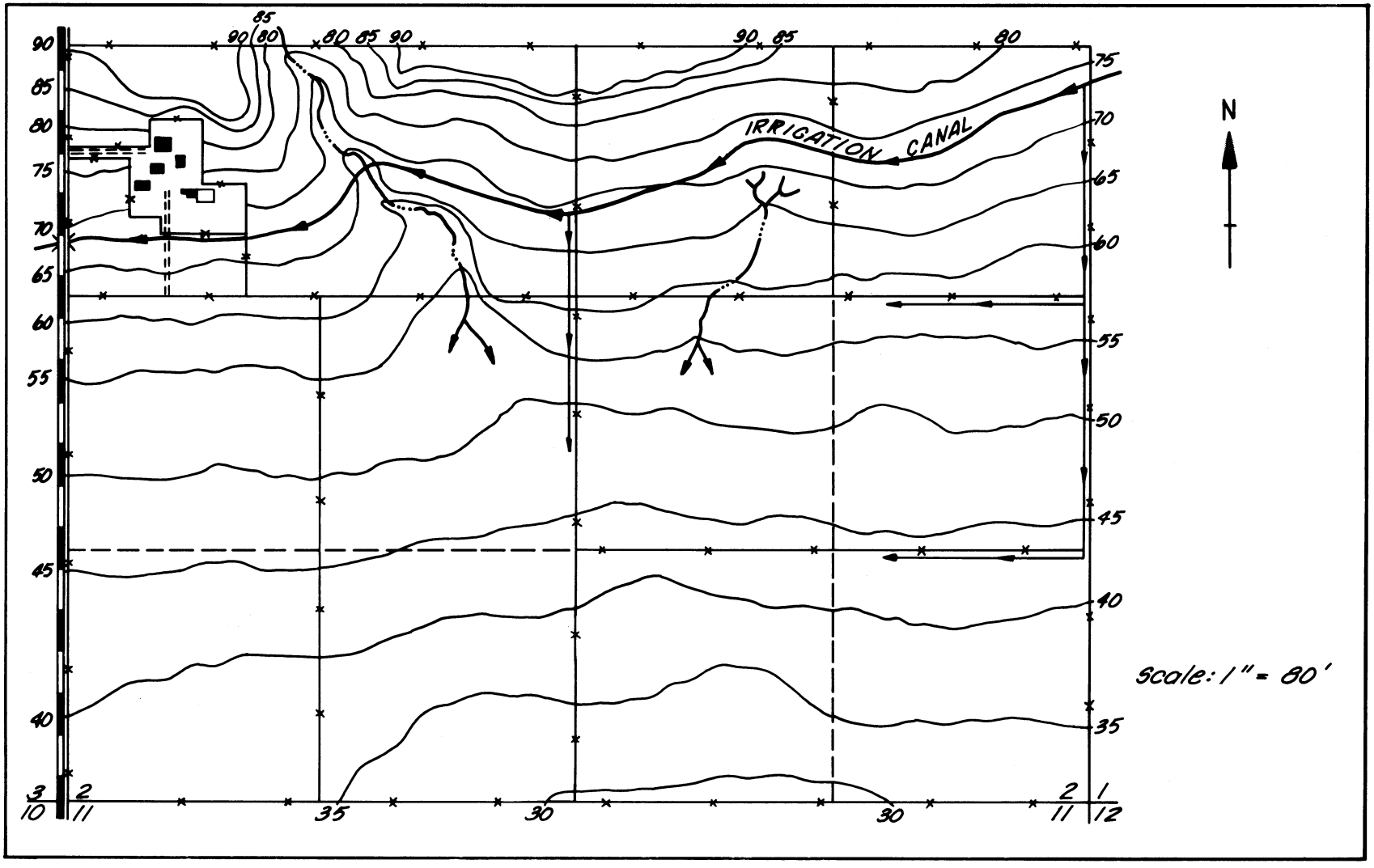


Figure 4-16, Working map--topography

Table 4-3, Observation well data

Elevation			May		June		July		August		September	
Well (No.) (1)	Ground surface (2)	Top of casing (3)	Depth to water table (4)	Water table elevation (5)	Depth to water table (6)	Water table elevation (7)	Depth to water table (8)	Water table elevation (9)	Depth to water table (10)	Water table elevation (11)	Depth to water table (12)	Water table elevation (13)
	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet	Feet
1	94.3	96.8					(18.0)	(76.3)	19.1	75.2	20.1	74.2
2	78.2	81.1	(3.4)	(74.8)	11.2	67.0	8.4	69.8	10.2	68.0	10.8	67.4
3	93.7	95.7	(15.1)	(78.6)	15.8	77.9	19.1	74.6	18.0	75.7	20.0	73.7
4	84.0	87.1	16.0	68.0	16.1	67.9	(9.6)	(74.4)	12.6	71.4	15.1	68.9
5	76.8	78.6	12.8	64.0	(11.0)	(65.8)	11.6	65.2	11.9	64.9	11.6	65.2
6	62.7	64.7	13.6	49.1	(10.0)	(52.7)	11.0	51.7	10.8	51.9	10.1	52.6
7	62.0	64.6	14.8	47.2	12.1	49.9	9.5	52.5	(9.0)	(53.0)	12.2	49.8
8	61.3	63.8	7.2	54.1	3.9	57.4	3.1	58.2	(2.0)	(59.3)	4.1	57.2
9	58.4	60.1	8.0	50.4	6.0	52.4	5.0	53.4	(4.1)	(54.3)	6.3	52.1
10	57.6	58.2	13.1	44.5	11.9	45.7	(9.1)	(48.5)	(9.1)	(48.5)	11.4	46.2
11	46.5	48.4	11.8	34.7	10.2	36.3	9.8	36.7	9.3	37.2	(9.1)	(37.4)
12	46.0	48.6	6.3	39.7	5.1	40.9	4.2	41.8	(3.0)	(43.0)	4.5	41.5
13	43.9	45.8	5.1	38.8	4.2	39.7	3.8	40.1	(3.4)	(40.5)	3.8	40.1
14	44.2	46.6	8.6	35.6	8.1	36.1	(6.1)	(38.1)	7.3	36.9	7.0	37.2
15	44.1	46.2	12.4	31.7	10.8	33.3	(9.3)	(34.8)	9.6	34.5	10.6	33.5
16	37.8	39.6	11.7	26.1	10.1	27.7	11.2	26.6	10.0	27.8	(9.1)	(28.7)
17	35.6	37.0	10.8	24.8	9.8	25.8	9.3	26.3	9.2	26.4	(9.0)	(26.6)
18	29.8	32.1	11.9	17.9	10.6	19.2	10.1	19.7	9.5	20.3	(8.6)	(21.2)
19	29.1	31.6	11.8	17.3	10.8	18.3	11.8	17.3	11.0	18.1	(10.2)	(18.9)
20	33.0	35.4	18.6	14.4	17.2	15.8	13.6	19.4	(12.5)	(20.5)	14.1	18.9
21	49.0	51.4	6.0	43.0	6.1	42.9	3.8	45.2	(0.0)	(49.0)	4.0	45.0
22	52.5	55.0	6.1	46.4	5.6	46.9	2.3	50.2	(1.5)	(51.0)	4.0	48.5
23	50.5	52.6	7.4	43.1	7.8	42.7	5.8	44.7	(5.5)	(45.0)	6.1	44.4
			(2)		(2)		(5)		(10)		(5)	

or the month in which water-table levels are generally high in this area. The data shown for August will be used in this example as it represents the most severe high water-table condition that occurred during the crop season.

Figure 4-17 is the same base map as shown in Figure 4-16 with some ground-water information added. The locations of the 23 observation wells are shown by small circles with the well numbers indicated by the figures within the circles. The elevation of the water table in each well for August (Column 11, Table 4-3) has been shown by the figures adjacent to each well.(Figure 4-17). Using these data and interpolating between wells, the ground-water contours have been drawn. These are the dashed lines shown, and have been drawn on a 5-foot-vertical interval to correspond in interval with the surface contours.

The ground-water contours show the configuration of the water-table surface in the same way that surface contours show the configuration of the land surface.

The direction of ground-water flow can be determined from ground-water contour maps as it is in the direction of maximum slope or hydraulic gradient of the water table. From inspection of the map, Figure 4-17, it is obvious that the ground-water flow is generally to the south with minor variations in localized areas. The arrows on the map indicate this directional flow. From this map it is also possible to determine the slope of the ground-water surface or the hydraulic gradient. In this example the average distance between 5-foot contours is about 500 feet. Therefore, the hydraulic gradient is about 1 percent.

Figure 4-18 uses the same base map as Figures 4-16 and 4-17 and shows information on the depth to ground water. The elevation of the water table at each well has been deleted and in its place the minimum depth to the water table (in parentheses in Table 4-3) has been plotted at the location of each well. With this information plotted on the map, it is possible to delineate areas having a similar depth to water table. For this example areas having water-table levels within the range 0 to 2 feet, 2 to 5 feet, and 5 to 8 feet have been delineated as shown by the dot and dash lines on Figure 4-18. In this example it was assumed that a water-table level 8 feet or deeper was not significant in drainage. It will be noted that the areas having the water table 8 feet or deeper are marked "8+ feet."

The data used in developing the "depth to water" feature on the working map include observation well readings for several months covering the entire period of record. The data used in developing the ground-water contours were taken from one set of observation well readings for August. For this reason the depth to water as shown gives a picture of the most severe water-table condition at each well during the entire period of record. Ground-water contours must always be drawn from water-table measurements of the same date.

Figure 4-19 is the completed working map showing all of the features developed progressively by the previous maps. A "depth to water" legend has been added to delineate areas with different water-table levels. The information given on a working map such as this, plus data from subsurface borings, is generally adequate for planning a subsurface drainage system. In this particular example, the working map developed shows the following:

1. The direction of ground-water flow is generally from north to south with some minor variations.

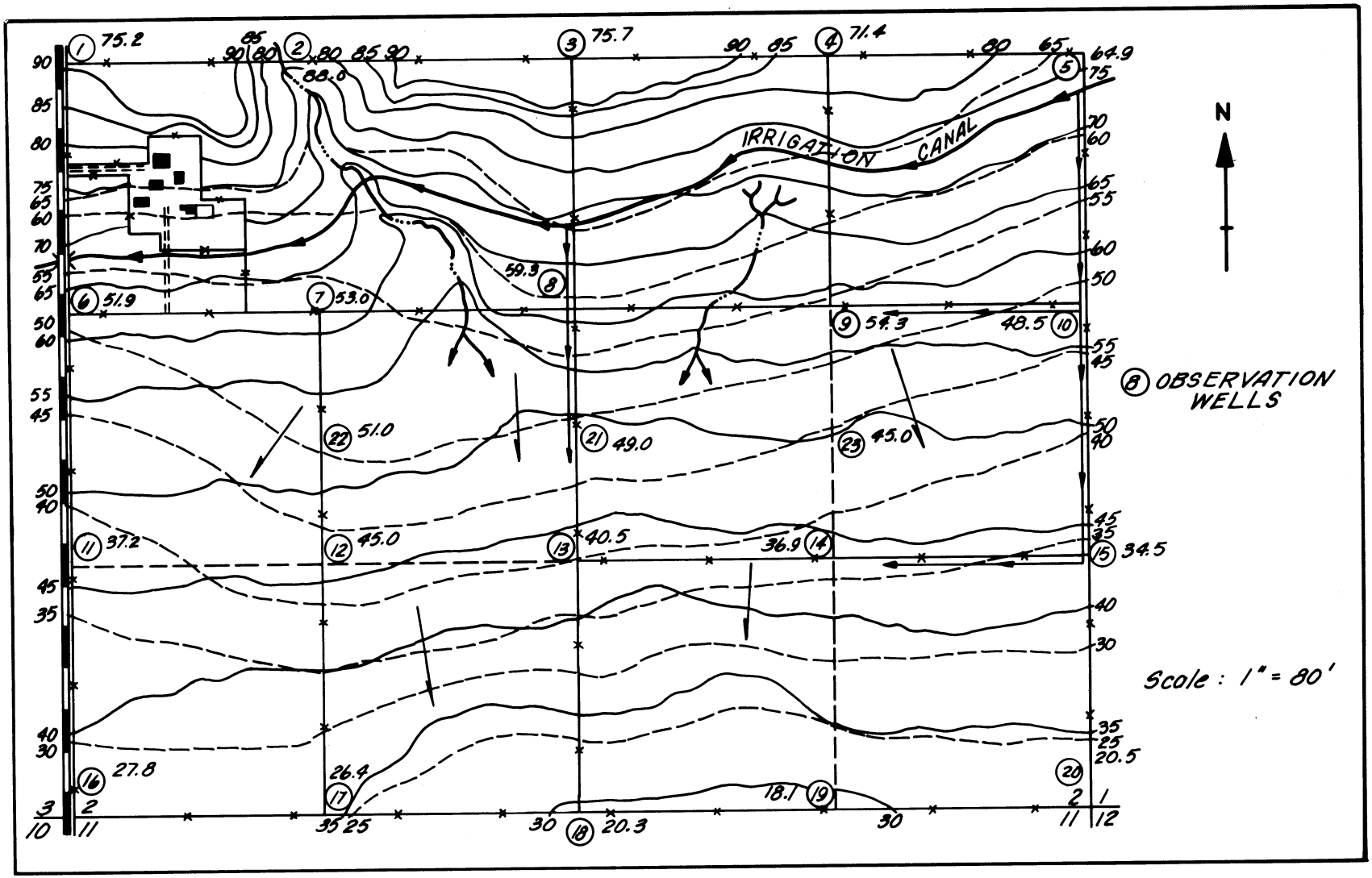


Figure 4-17, Working map--ground-water contours

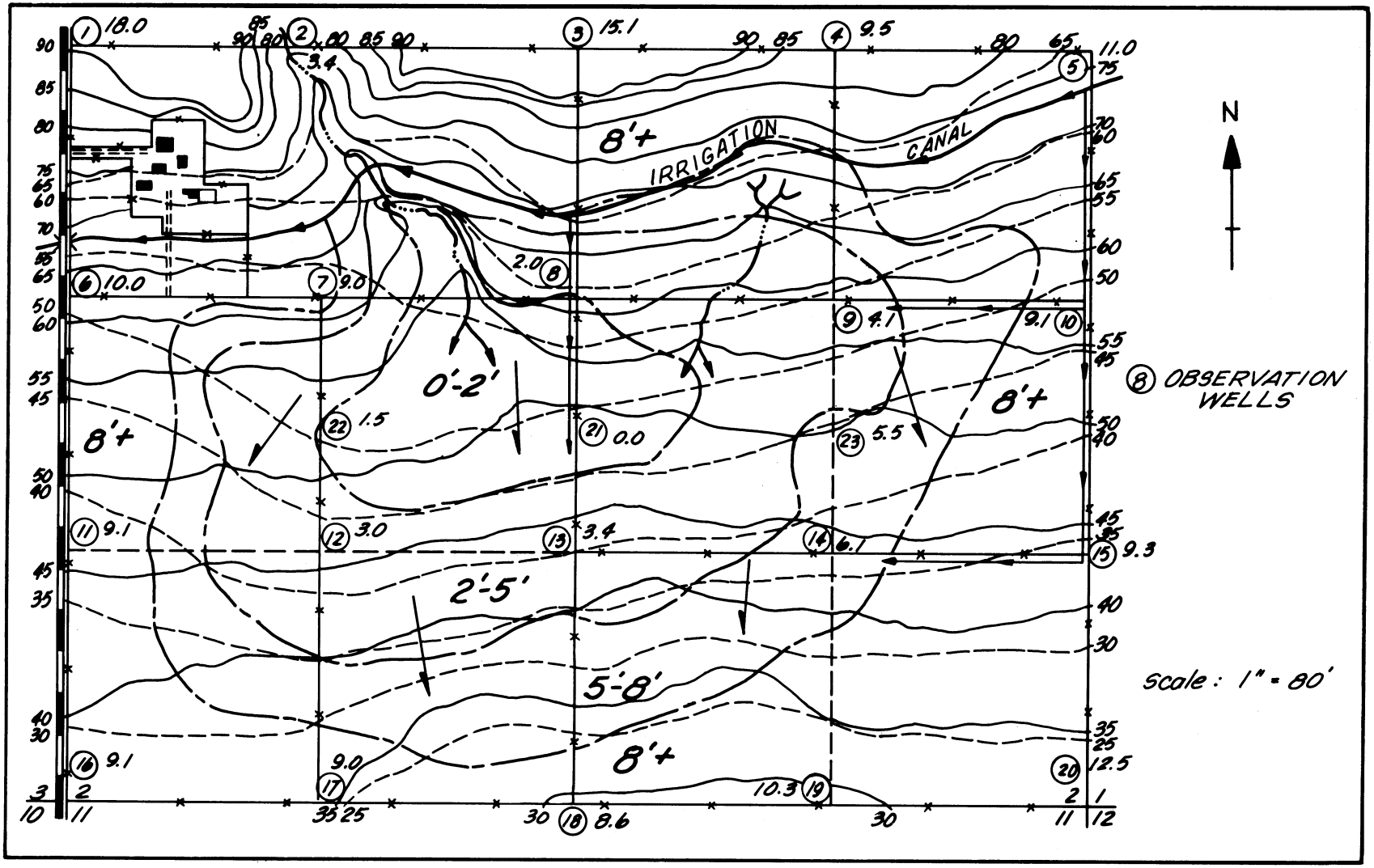


Figure 4-18, Working map--depth to ground water

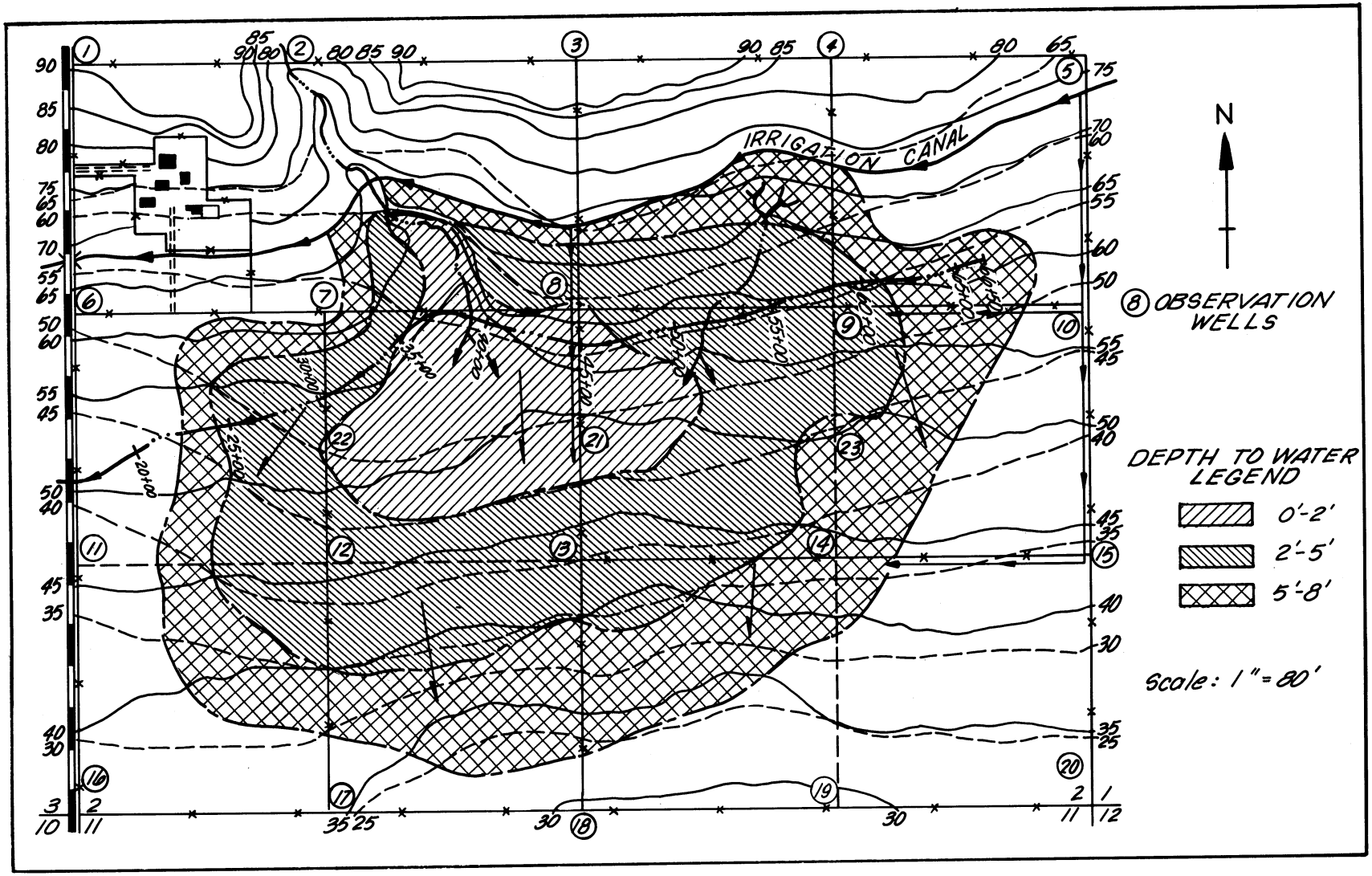


Figure 4-19, Working map--completed

2. The average slope of the water table or hydraulic gradient is about 1 percent, which is rather steep, indicating strong ground-water flow, the quantity depending on the permeability of the soil strata and hydraulic gradient.

3. The location and extent of the high water-table area.

4. The relative degree of wetness within the wet areas as shown by the legend.

5. The configuration of the water-table surface within the wet area and immediately adjacent area.

The completed working map in Figure 4-19 shows some of the more commonly used graphic representations of information necessary for planning a drainage system except for information on subsoil and substratum material. Usually it is not necessary to show this information on the working map; however, it can be shown if it is needed. When logs of subsurface borings are prepared, it is easy to make reference to conditions at the location of each boring. At this stage of development of the working map the general type of drain or drains to be installed can be determined and the locations fixed within approximate limits. Referring to Figure 4-19, it is obvious from the location of the wet area and the direction of ground-water flow that the source of excess ground water is either from canal seepage or from irrigation losses. For this example, it will be assumed that canal seepage has been investigated and found to be a factor in contributing to the high water table, but not sufficient in itself to have caused this wet condition. The source of water is a combination of canal seepage and general losses from irrigation. Under this set of conditions and with a water-table gradient of about 1 percent, an interception-type drain would be recommended. The drain should be located about perpendicular to the direction of ground-water flow and in a position near the upper edge of the wet area. In many locations the interception drain will intercept the water causing a high water table below it and will have a drawdown effect above it sufficient to lower the water table and relieve that area. The combination of relatively high permeability and steep gradient indicates that a large ground-water flow is involved. The proper location for a drain is shown in Figure 4-19. For this example, it is assumed that subsoil and substratum permeabilities are satisfactory for a drain at this location and that an adequate outlet is available for the drain.

Figure 4-20 shows a cross-sectional profile (north and south) from well no. 3 through well no. 18. This illustrates the points discussed before. It is often desirable to examine certain conditions by drawing cross-sectional profiles such as the one in Figure 4-20 which shows the relative position of the ground surface and the water-table level. When subsoil materials are stratified or when there is a definite aquifer present, the location of the top and bottom horizon should be plotted on the profile. This enables a better location of the drain to be made relative to the position of the stratified layer. Often it is necessary to shift the drain location upslope or downslope to get the best position relative to subsurface materials.

This example illustrates conditions where an interception-type drain would be employed. A similar method of compiling and anlyzing data would apply under conditions where a relief drainage system would be used. In either case the drainage system recommended might include open ditches or buried drains. The purpose of this example is to illustrate a method for assembling the data obtained from various surveys, studies, and investigations. This method, or

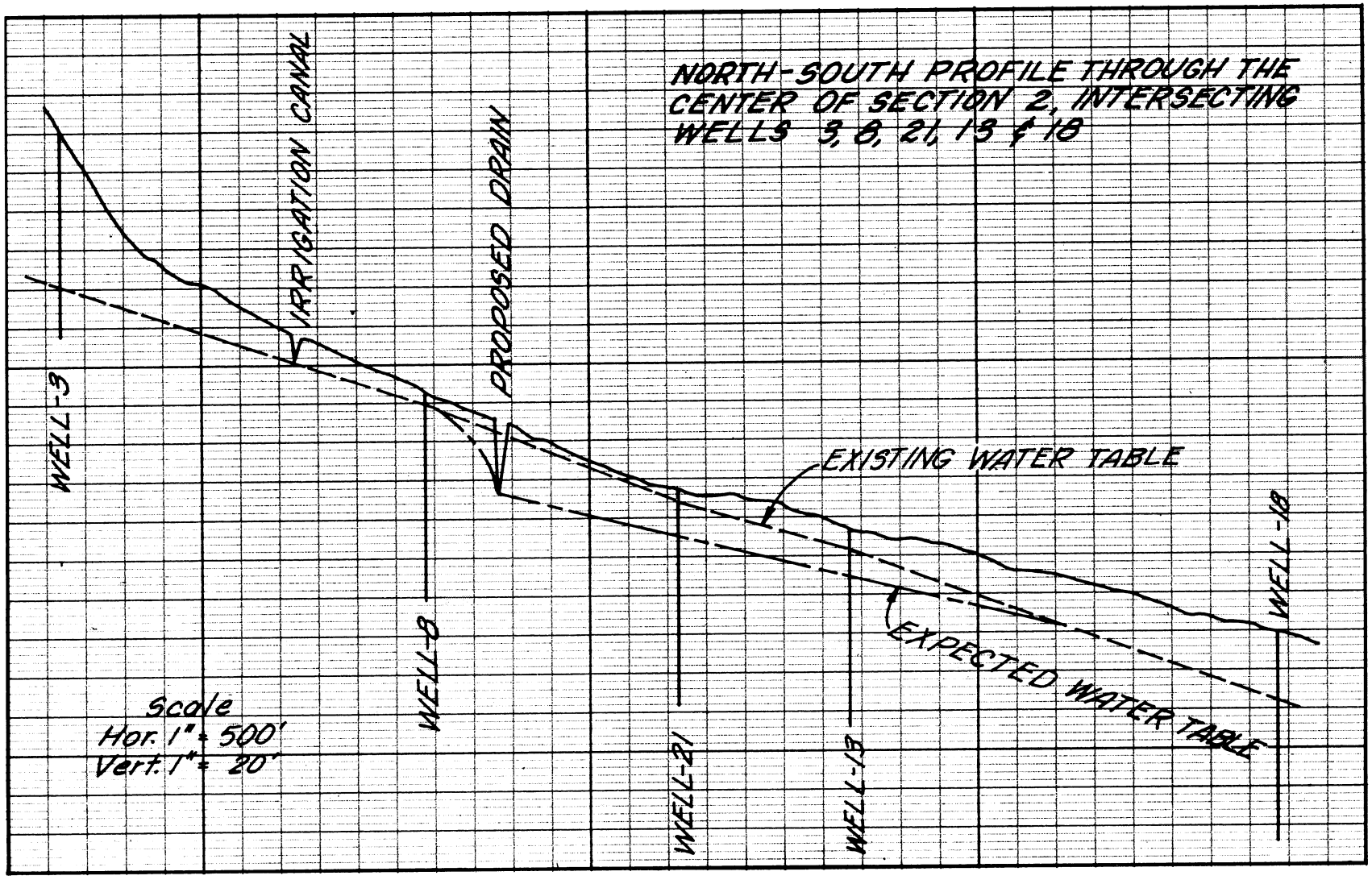


Figure 4-20, Profile--Figure 4-19

some similar method of analyzing available data, is necessary before actual design work on the individual drainage system and appurtenant structures can be started.

Design of Subsurface Drains

Drainage coefficients

The drainage coefficient is that rate of water removal, used in drainage design, to obtain the desired protection of crops from excess surface and subsurface water. The drainage coefficient can be expressed in a number of units, including depth of water in inches to be removed in a specific time, flow rate per unit of area, and in terms of flow rate per unit of area, which rate varies with the size of the area. The last is used most frequently for surface drainage design and the first most frequently for subsurface design.

Humid areas

In the humid areas it is common practice to express the drainage coefficient for subsurface drainage in units of inches depth removal in 24 hours. This coefficient is closely related to the climate, and infiltration characteristics of the soils; therefore, within areas of similar climatic and soils characteristics there is similarity in drainage coefficients. For this reason it is possible to establish ranges of drainage coefficients that are applicable to large areas. The general guides given in the following table are based on many years of drainage experience and list ranges of coefficients applicable in humid areas.

1. When the land to be drained has a separate surface drainage system, drainage coefficients given in Table 4-4 have been used in the northern humid area. Data on soil permeability and climate should be considered in developing coefficients for a specific area.

Table 4-4, Drainage coefficients without surface-water inlets

Soil	Inches to be removed in 24 hours	
	Field Crops	Truck Crops
	Inches	Inches
Mineral	3/8 - 1/2	1/2 - 3/4
Organic	1/2 - 3/4	3/4 - 1-1/2

2. Where it is necessary to admit surface water to drains through surface inlets, an adjustment in the required capacity of the drain must be made. Runoff from an area served by a surface-water inlet takes place soon after precipitation and enters the drain ahead of the ground water. In short lines or small drainage systems where only one or two inlets are installed the size of the drain may not need to be increased. As drainage systems become larger or the inlets more numerous, an adjustment to the drainage coefficient should be made. The timing of the surface-water flow in relation to the entrance of ground water into the drain should be the basis of increasing the coefficient over those shown in Table 4-4.

3. A higher coefficient than those given in Table 4-4 may be necessary to hold crop damage to a minimum. The great variation in drainage requirements indicates the necessity for careful observations and analyses in establishing coefficients.

Arid areas

In arid areas, drainage coefficients applicable to local irrigated areas are highly variable and depend on the amount of irrigation water applied, the method of irrigation, the leaching requirement, and the characteristics of the soil and subsurface materials. It is necessary to develop drainage coefficients for specific areas based on evaluation of the above factors and experience in the area. From actual surveys (6) made on one million acres of irrigated land, it is known that the yield from subsurface drains may range from 0.10 to 40.0 cfs per mile of drain. Recent studies made on eight individual farm projects indicate that the drain yields ranged from 0.13 to 3.90 cfs per mile of drain. Other measurements have been made which indicate a wide variation. With such a wide variation in yield, coefficients must be based upon good investigations and local experience within a given area.

In irrigated areas where there is insufficient experience to establish acceptable drainage coefficients for general use, they can be computed from the following formula based on irrigation application:

$$q = \frac{\left(\frac{P + C}{100}\right) i}{24F} \qquad \text{(Eq. 4-2)}$$

where:

q = drainage coefficient--inches per hour

P = deep percolation from irrigation including leaching requirement--percent (based on consumptive-use studies)

C = field canal losses--percent

i = irrigation application--inches

F = frequency of irrigation--days

The following example illustrates the use of this formula:

1. From consumptive-use studies, deep percolation from irrigation is 20 percent.

2. Field canal losses are estimated to be 8 percent of the water applied.

3. The operator applies a 6-inch irrigation each 14 days.

$$q = \frac{\left(\frac{20 + 8}{100}\right) 6}{(24)(14)} = 0.005 \text{ in./hr.}$$

Figure 4-21 is a chart for the graphical solution of this equation. The previous example can be solved by the chart as follows:

Step 1. Add the percentage deep percolation loss to the percentage canal loss (P + C) and find this value on the left hand vertical scale.

$$P + C = 20 + 8 = 28$$

Step 2. From this point follow horizontally to the right to intercept the irrigation application (i) curve.

$i = 6$

Step 3. Follow vertically up or down as the case may be to intercept the application frequency (F) curve.

$F = 14$

Step 4. Follow horizontally to the right hand vertical scale and read (q) the drainage coefficient.

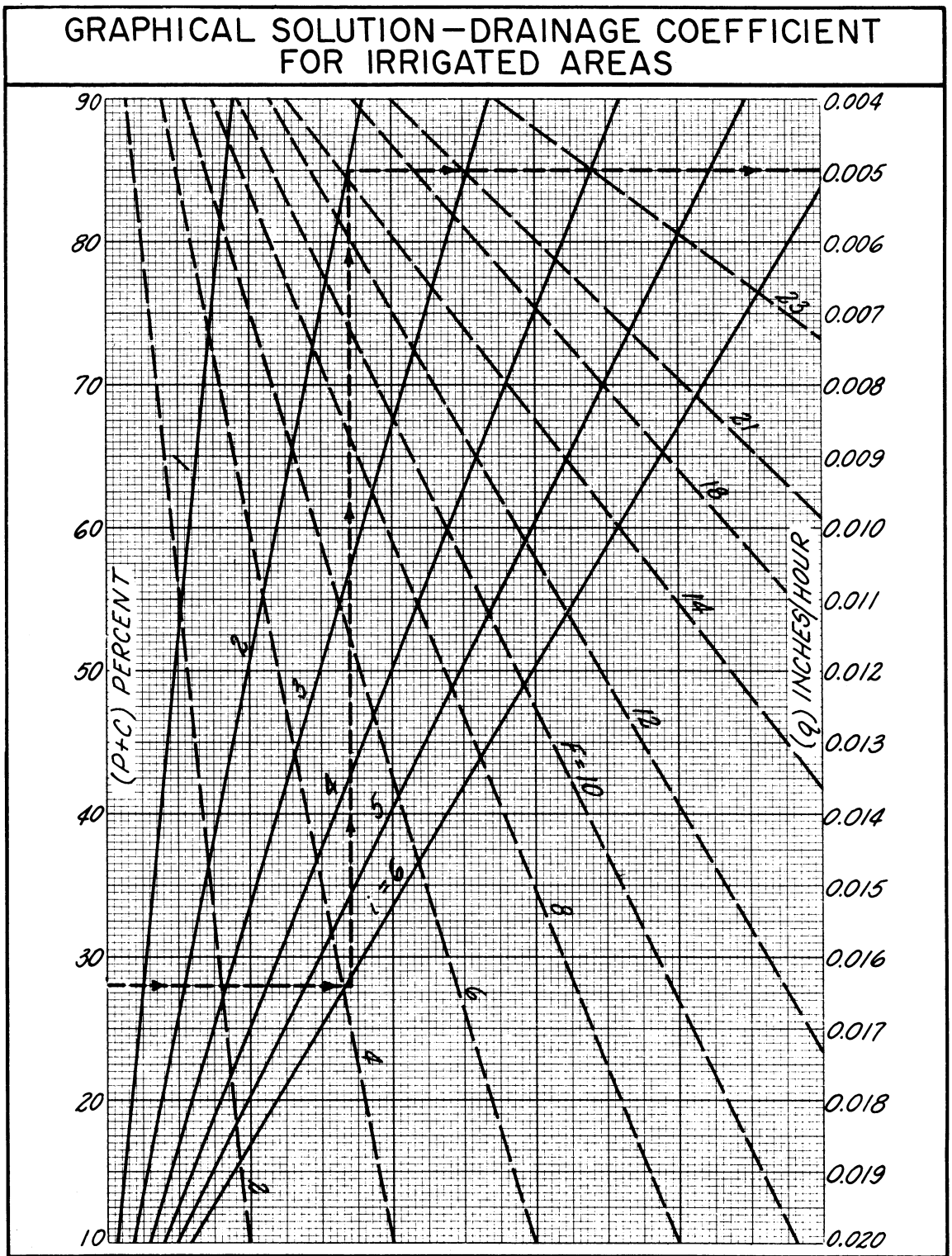
$q = 0.005$

From information and data currently available, it is known that drainage coefficients applicable to irrigated land range from about 0.005 inch per hour to 0.01 inch per hour. Drainage coefficients for irrigated areas are generally smaller than for nonirrigated areas even though the total amount of water applied through irrigation may be the same as precipitation in the nonirrigated areas. The reason for this is that irrigation applications are made at regular intervals and in like amounts, which tends to support a steady and uniform ground-water return flow to the drains. In nonirrigated areas the frequency and intensity of precipitation is highly variable which tends to make the return flow to drains variable with peak flows occurring in the ground-water regime.

In many irrigated areas, drainage systems are planned on a project basis and may encompass entire corporate irrigation enterprises which may include a number of farms and ranches, containing several thousand acres of land needing drainage. In planning drainage systems of this magnitude it is common practice to plan a project-type system of disposal ditches or drains to serve each farm or ranch in the group enterprise.

The disposal system is financed and constructed through the group enterprise and the individual farm or ranch collection systems are financed and constructed by the individual landowner.

In large developments of the type discussed above there are conditions and situations which warrant a reevaluation of the drainage coefficient applicable to design of the disposal system. In general, the design capacity for the disposal system can be based on lower drainage coefficients than those generally applied to the collection system. Experience based on measurements of discharge from scattered projects indicate that the return flow from large irrigated tracts is in the general range of 2 to 4 cfs per square mile. This is about 30 percent less than the return flow directly to the collection system and is due to a number of intangible factors such as: ground-water export through deep percolation to regional aquifers; consumptive use by trees and phreatophytes within the general project area; pumping of ground water for nonagricultural uses; land temporarily removed from irrigation because of economic or cultural management practices, etc., the total of which has a significant effect on regional return flows. Drainage coefficients recommended for drainage of specific soils in a particular area may be found in local drainage guides if available. These are based on local investigations and experience.



REFERENCE: This chart was developed by William F. Long.

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DRAINAGE SECTION

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SHEET 1 OF 1
DATE 8-3-70

Figure 4-21, Graphical solution - drainage coefficient

Design capacity

Relief drains

In the case of parallel relief drains the area served by the drain is equal to the spacing times the length of the drain plus one-half the spacing. The discharge can be expressed by the following formula:

$$Q_r = \frac{q\ S(L + S/2)}{43,200} \qquad \text{(Eq. 4-3)}$$

where:

Q_r = relief drain discharge--cfs

q = drainage coefficient--in./hr.

S = drain spacing--feet

L = drain length--feet

Reference is made to Figure 4-22, which shows a parallel relief drain system. The system contains eight lateral drains and one main drain to the outlet. The shaded area indicates the area drained by one of the lateral drains. The following example illustrates the use of Equation 4-3 in computing the design capacity for one lateral in the system shown.

Example: (Refer to symbols on Figure 4-22)

1. drain spacing--300 feet
2. drain length--1,100 feet
3. drainage coefficient--0.008 in./hr.

$$Q_r = \frac{(0.008)(300)(1,100 + 150)}{43,200} = 0.069$$

This is the design discharge of the lateral at its point of confluence with the main drain. The drainage system illustrated contains eight laterals of the same length and with equal spacing; therefore, the design capacity of the main drain would be (8)(0.069) = 0.552 cfs plus the direct accretion to the main drain.

The main which is 2,250 feet in length is effective on one side only and therefore would collect $\frac{0.5(2,250 + 150)}{1,100 + 150} \times .069 = 0.066$ cfs and the discharge of the main, at the point where it leaves the field would be (0.56) + (0.06) = 0.62 cfs. Each of the lateral drains in the above example has a design discharge that varies uniformly from 0.07 cfs at its outlet to zero at its terminus. The design discharge of the main varies uniformly from 0.62 cfs to 0.07 cfs at its confluence with the last lateral in the system. This immediately suggests that variable size drains might be used in the system and this point will be discussed in a later section of this chapter.

Figure 4-23 is a chart prepared for the graphical solution of the discharge equation (Eq. 4-3).

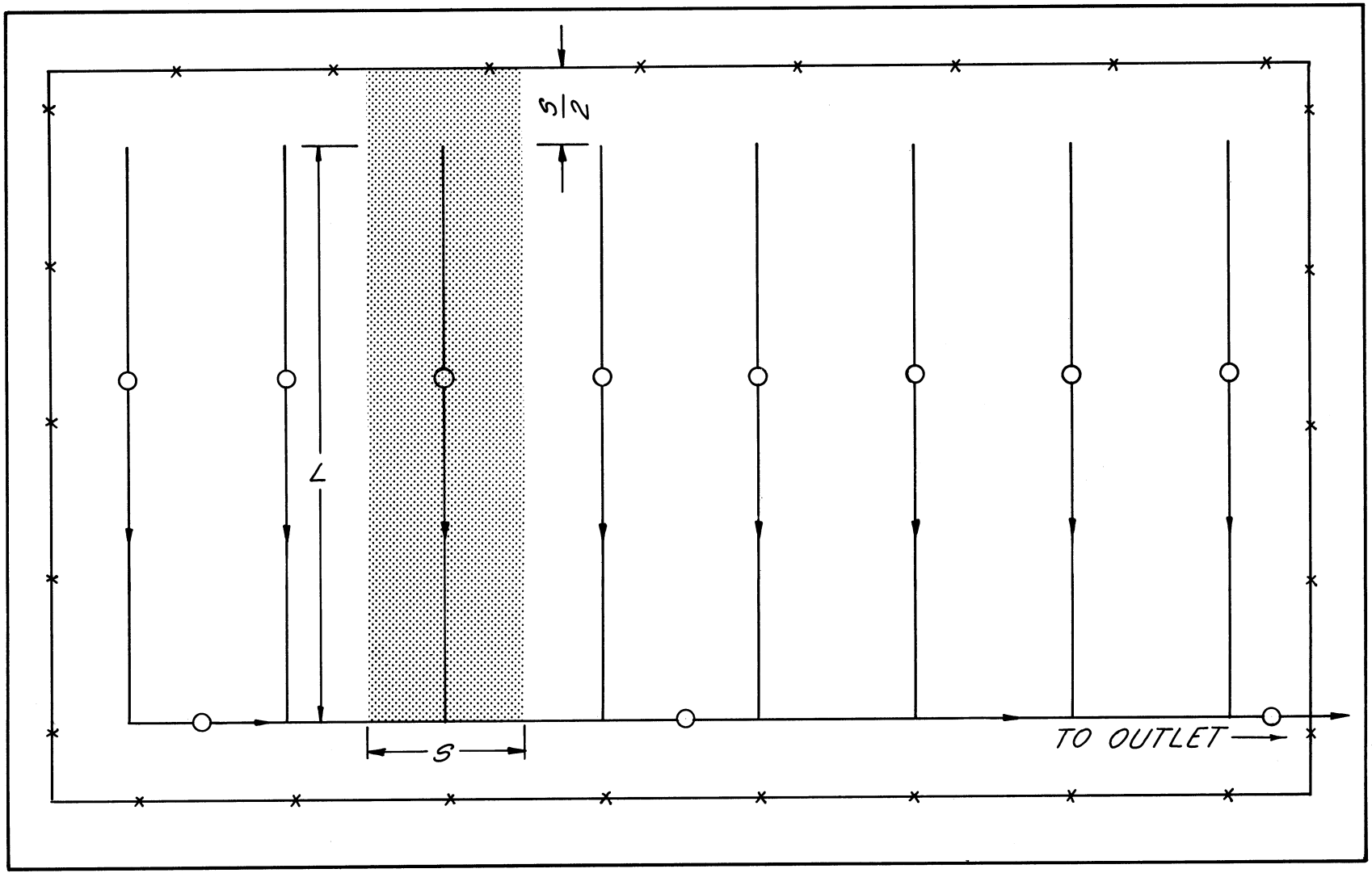


Figure 4-22, Sketch of relief drain system showing symbols in equation 4-3

Example:

1. drain spacing--200 feet

2. drainage coefficient--0.02 in./hr.

3. drain length --3,000 feet

Referring to Figure 4-23, find spacing of 200 feet on the left ordinate; follow horizontally to the right to intersect the drainage coefficient curve for value of 0.02; from this point follow vertically to intersect the drain length curve for the value of 3,000; from this point follow horizontally to the right ordinate to read value of design discharge equal to 0.30 cfs.

Interception drains

The capacity of interception drains must be equal to the ground-water flow intercepted. The rate of flow is in accord with the Darcy Law, which states that the velocity of flow of water through porous material is proportional to the hydraulic conductivity and hydraulic gradient. The equation may be stated:

$$v = Ki \qquad \text{(Eq. 4-4)}$$

where:

v = velocity of flow through the porous medium

K = the hydraulic conductivity

i = the hydraulic gradient (undisturbed state)

The flow of water intercepted (Q) is equal to the average velocity multiplied by the cross-sectional area (A) of the aquifer intersected below the water table. Therefore, the equation for flow through a porous material is as follows:

$$Q = KiA \qquad \text{(Eq. 4-5)}$$

Applying this to an interception drain, the cross-sectional area intersected is equal to the effective depth of the drain (vertical distance from the bottom of the drain to the water-table level) times the length of the drain. Stated in mathematical form it is:

$$A = d_e L \qquad \text{(Eq. 4-6)}$$

where:

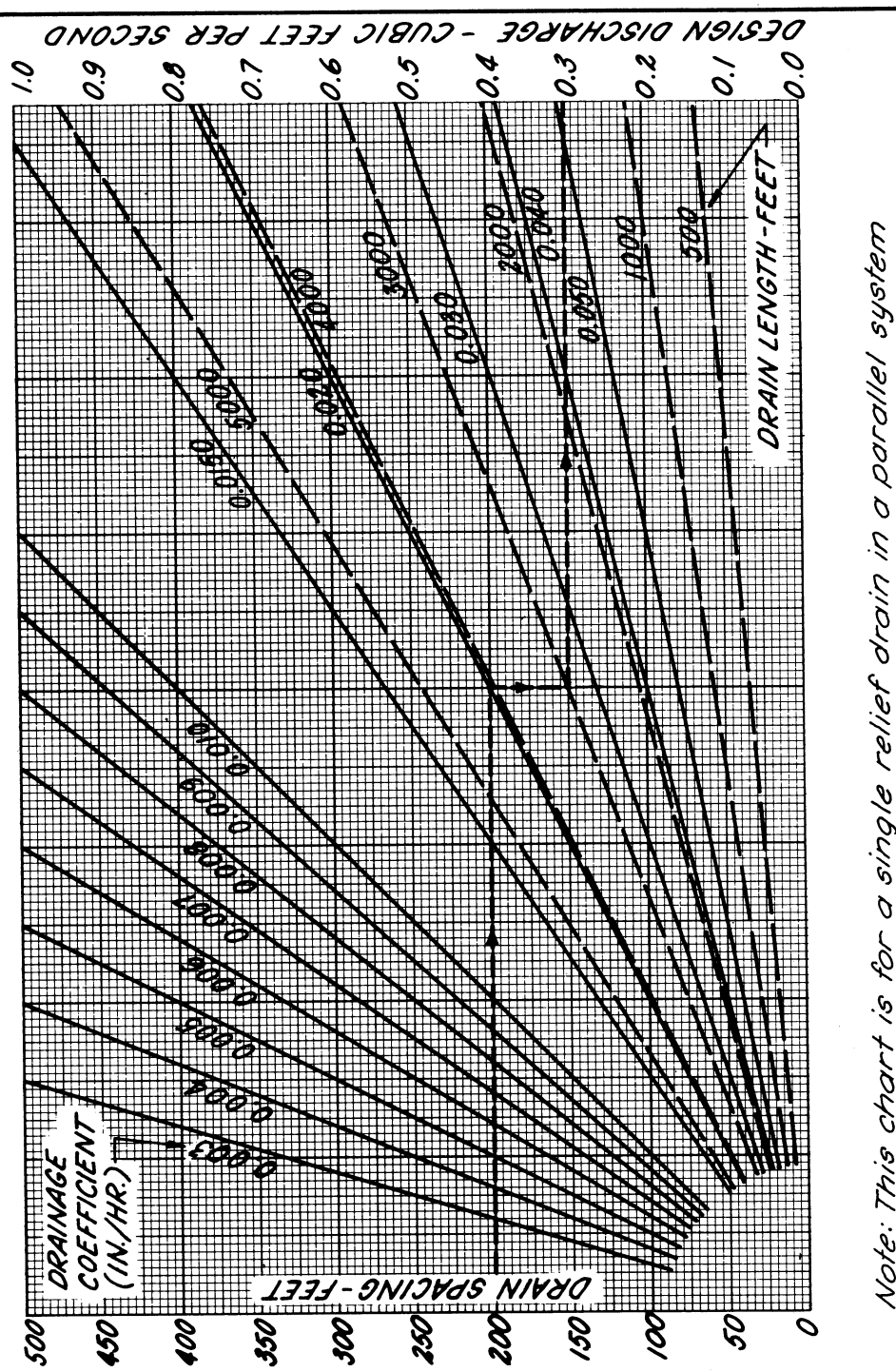
A = cross-sectional area intersected--sq. ft.

d_e = average effective depth of the drain--ft.

L = length of the drain--ft.

Combining equations 4-5 and 4-6 and correcting for units, the equation for the design discharge of an interception drain is:

GRAPHICAL SOLUTION—DRAIN DESIGN DISCHARGE



Note: This chart is for a single relief drain in a parallel system

REFERENCE: This chart was developed by William F. Long.	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DRAINAGE SECTION	STANDARD DWG. NO. ES - 716 SHEET 1 OF 1 DATE 8-3-70

Figure 4-23, Graphical solution, drain design discharge

$$Q_i = \frac{K\ i\ d_e\ L}{43,200} \qquad \text{(Eq. 4-7)}$$

where:

Q_i = design discharge of an interception drain--cfs

K = hydraulic conductivity--in./hr.

i = hydraulic gradient of the undisturbed water table--feet per foot

d_e = average effective drain depth--feet

L = length of drain--feet

The above equation has several limitations when applied in actual practice. The Darcy Law, on which it is based, assumes a homogeneous soil profile, a uniform hydraulic conductivity throughout the soil profile and an accurate determination of the cross-sectional area. The first two assumptions stipulate conditions that are rarely, if ever, found in nature; however, some site conditions may approach these. Use of this formula must be reserved for conditions that approach these idealistic site conditions.

The following is an example illustrating the use of Equation 4-7.

1. The average hydraulic conductivity computed from values measured at various points along the route of the interception drain is 10 in./hr.

2. The hydraulic gradient or slope of the original water-table surface is 0.05 feet per foot.

3. The effective depth of the drain is 7.0 feet.

4. The length of the drain is 4,500 feet.

$$Q_i = \frac{10(0.05)(7)(4,500)}{43,200} = 0.36 \text{ cfs}$$

In areas where use of the formula is not applicable and where there is no experience with interception drains, it is often desirable to construct a pilot ditch. By measuring the discharge from the pilot ditch an accurate discharge figure can be obtained to design the proper drain size. In some areas this two-step method is an accepted practice for installation of interception drains. The cost of installation is usually higher but due to better information on required capacity the correct size of drain can be determined. This may be substantially smaller than would be selected on the basis of less accurate information, and may result in more than enough saving to offset the cost of two-step construction.

Combination surface and subsurface drainage systems

It is common practice to install systems to serve both surface and subsurface drainage needs. In systems employing only open ditches, the ditches are made deep enough for subsurface drainage and surface water is admitted through drop structures of various types. In systems employing buried drains for subsurface drainage, the system includes land forming practices and field ditches for surface drainage and buried drains for subsurface drainage. The larger laterals and mains of the disposal system are open ditches. Surface water is routed to the open ditches where it is admitted to the system through drop

structures. It should not be admitted to buried drains as it carries debris which may plug the drain. In unusual situations where there is no alternative to admitting surface water to a buried drain, the line should be protected from debris and sediment as described later in this chapter.

The required capacity of dual-purpose ditches is the sum of the design discharge from subsurface drains and the design discharge from surface ditches. Surface water includes irrigation tail water, runoff from precipitation, and flooding that may occur in the event of the failure of irrigation canals serving the area. Under normal conditions the capacity of open ditches used in combination systems is more than adequate because of the depth required for subsurface drainage. However, the capacity should be checked.

Depth and spacing of drains

General

Considerable information and data have been collected and studied to develop criteria for computing the depth and spacing of relief-type drains. Conversely, very little has been done to develop technical criteria to compute the depth and spacing for interception-type drains. The design of interception drains is based largely on experience. It is possible to present some of the known and observed characteristics to serve as a guide to the designer.

Figures 4-24a and 24b are sketches to illustrate the change in configuration of the water table before and after the installation of a ditch or drain for relief drainage. Figure 4-24a shows an open relief ditch and Figure 4-24b shows a relief drain. Relief ditches and drains are located approximately parallel to the direction of ground-water flow or where the water table is relatively flat and will develop similar drawdown curves on either side of the ditch or drain. The new hydraulic gradient will be composed of two similar curves on either side of the drain. It follows that lowering of the water table on either side of the drain will be in the same amount at equal distances on either side of the drain. Relief drains are usually installed in series (parallel system) such that their areas of influence overlap and the new hydraulic gradient is a series of curves (ellipses) with the high point in the curves being at the midpoint between drains.

Figures 4-25a and 4-25b are sketches (exaggerated slope) to illustrate the change in configuration of the water table subsequent to installation of an interception ditch or drain. Figure 4-25a shows an interception ditch and 4-25b an interception drain. Interception ditches and drains "skim-off" or divert the upper portion of ground-water flow, and if fully effective, should lower the water table to near the level of the flow line in the drain.

Interception ditches and drains are effective for a considerable distance below or downslope from the ditch or drain but are less effective above or upslope from it. The new hydraulic gradient upslope from the interceptor is much steeper than that downslope. Under average field conditions it usually coincides with the original gradient at a point less than 300 feet above the interceptor, depending on the depth of the drain, etc. For this reason interception ditches and drains are located near the upper edge of the wet area to be protected.

In theory, if there were no accretion to ground water below the location of the interception drain it would be effective an infinite distance downslope. The new downslope hydraulic gradient would be parallel to the original

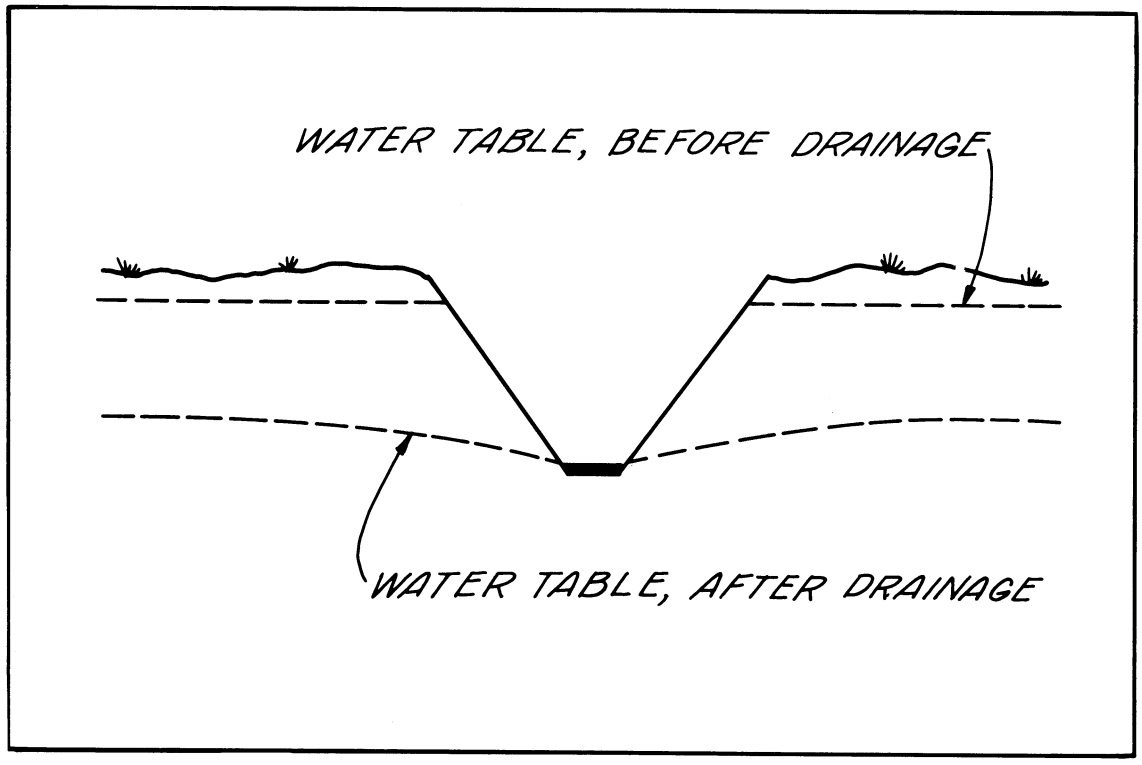


Figure 4-24a, Relief ditch

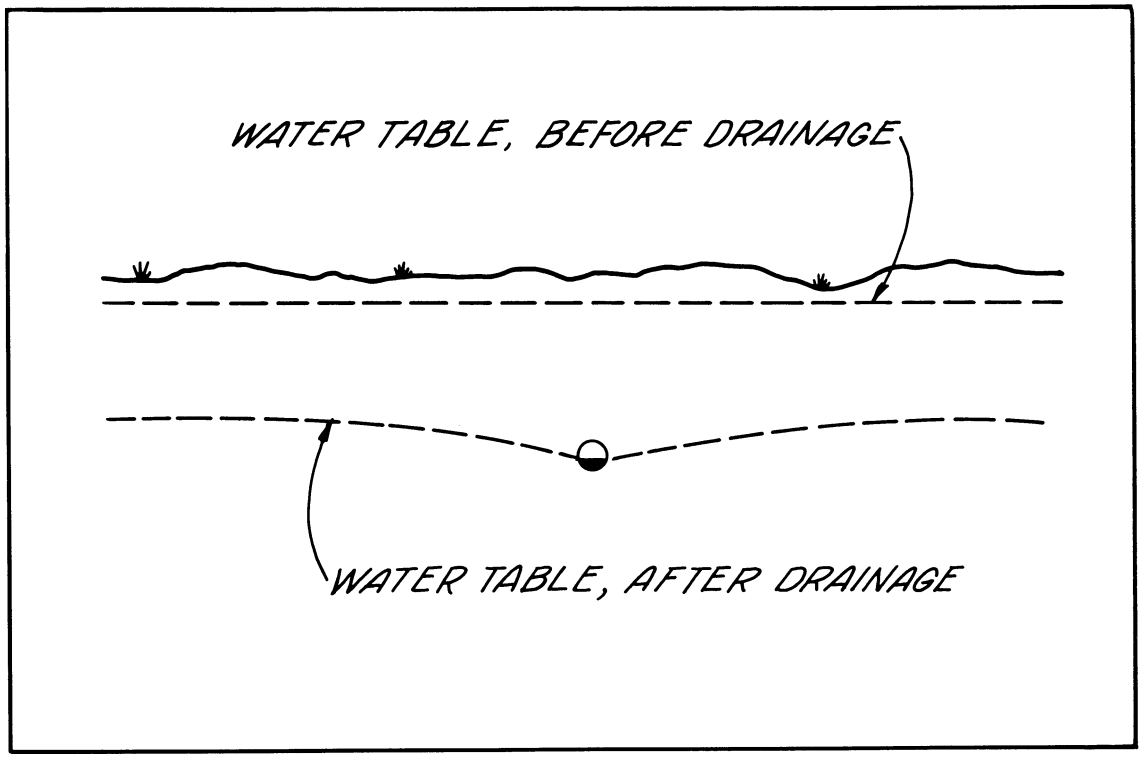


Figure 4-24b, Relief drain

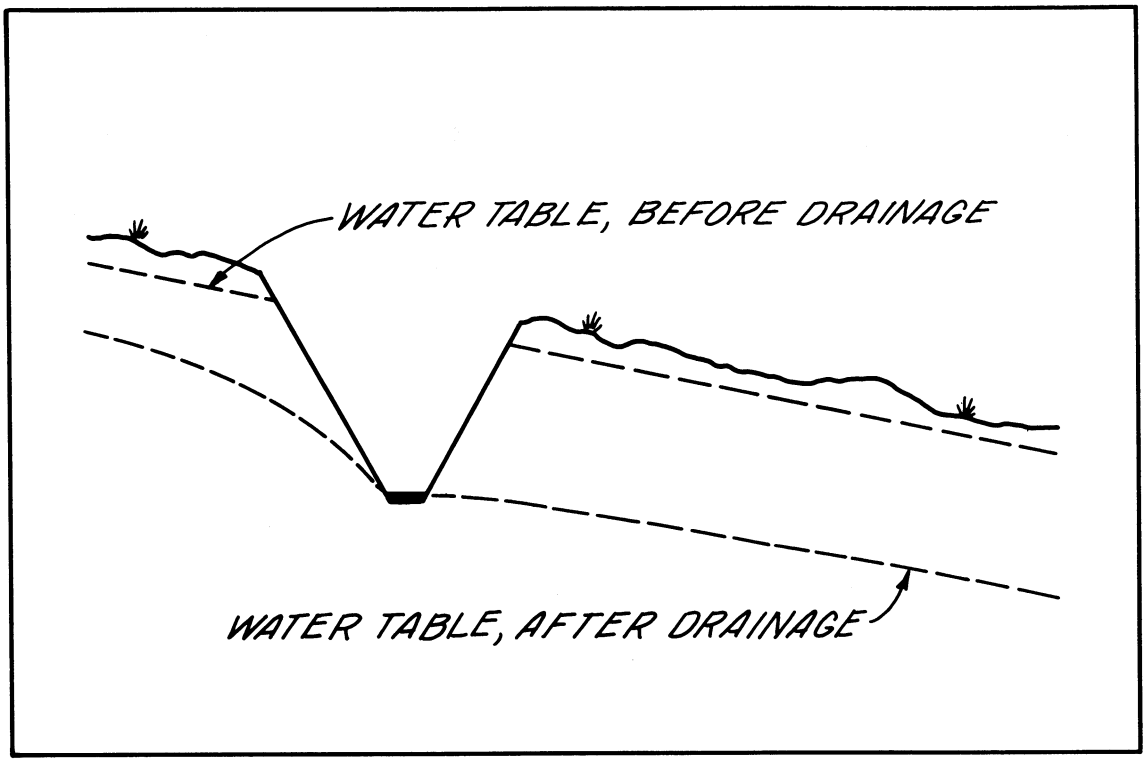


Figure 4-25a, Interception ditch

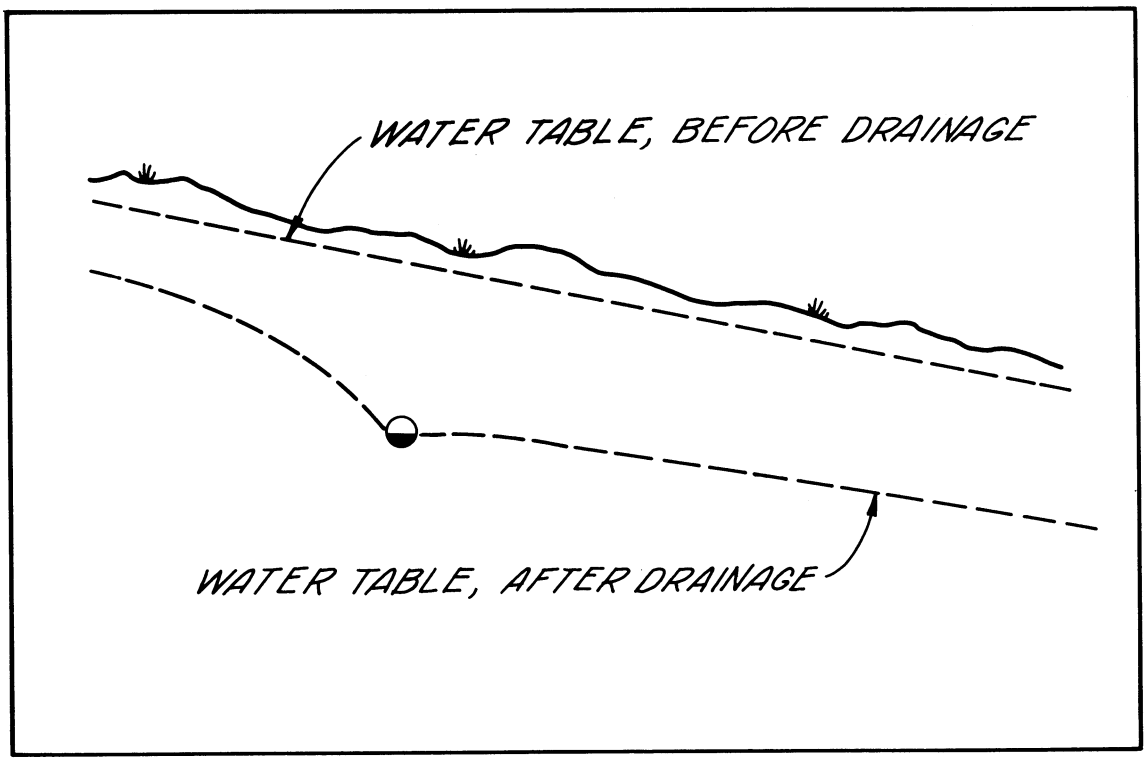


Figure 4-25b, Interception drain

(before drainage) and at a distance below it, equal to the effective depth of the interception drain. Under field conditions this never occurs as there is always accretion from irrigation or percolation from precipitation, and the new hydraulic grade line is a flat curve which is tangential to the original gradient at some point downslope from the drain. The slope of this downslope hydraulic grade line will vary with the amount of accretion from irrigation or precipitation as the case may be. The distance below an interception drain to which it will be effective in lowering the water table involves many factors, but is related primarily to accretions to ground water in the area immediately below the drain. Accretions include general irrigation losses, percolation from rainfall, leaching applications, capillary fringe flows above the phreatic line, and the "bridging-over flow" over the interception drain. These latter two are very difficult to evaluate. They may bè significant for buried drains in steep areas but are not a problem in open ditches. Gravel envelopes and porous trench backfill will reduce these bypass flows. It is reasonable to assume that accretions to the downslope water table will be about the same in areas where irrigation methods, climatic conditions, slope and soil conditions are similar. It follows that the drawdown effect below interception ditches and drains where these conditions are similar, will be about the same.

Figure 4-26 is an isometric sketch showing both relief and interception drains, in situs, to illustrate their effect in altering the configuration of the water table. It will be noted that the hydraulic gradient for the undisturbed state (i), in Figure 4-26, has a positive value, perpendicular to the interception drain but is equal to zero perpendicular to the relief drains as shown. From this it is apparent that the slope of the original water-table surface (i) is a factor in the functioning of an interception drain but has no influence in the way a relief drain functions.

Theoretically, the proportional amount of ground water diverted or removed by the interception drain is the proportion of the depth of the drain to the total depth of the aquifer above the barrier (7). If the interception drain is placed on the barrier and has adequate capacity to collect and remove the ground water present (with no bridging-over effect) it will remove all of the flow from the aquifer.

A barrier is defined as a less permeable stratum, continuous over a major portion of the area to be drained, and of such thickness as to provide a positive deterrent to the downward percolation of ground water. The hydraulic conductivity of the barrier material must be less than 10 percent of that of the overlying material if it is to be considered as a barrier.

As previously stated, relief drains have a drawdown effect equidistant on either side of the drain. The drawdown curves that develop as a result of drainage, are described mathematically by the Modified Ellipse equation as given later in this chapter. This equation has a factor for the depth to the barrier which reduces the spacing as the depth to barrier is reduced.

From the above discussion on relief and interception drains, two significant points have been emphasized. First, the distance to which interception drains are effective in lowering the water table varies with the slope of the hydraulic grade line of the original water-table surface, but is not limited by the position of the barrier. Secondly, the distance to which relief drains are effective in lowering the water table varies with the position of the barrier, but is not influenced by the slope of the hydraulic grade line of the original water-table surface. These points suggest that relief drains may be

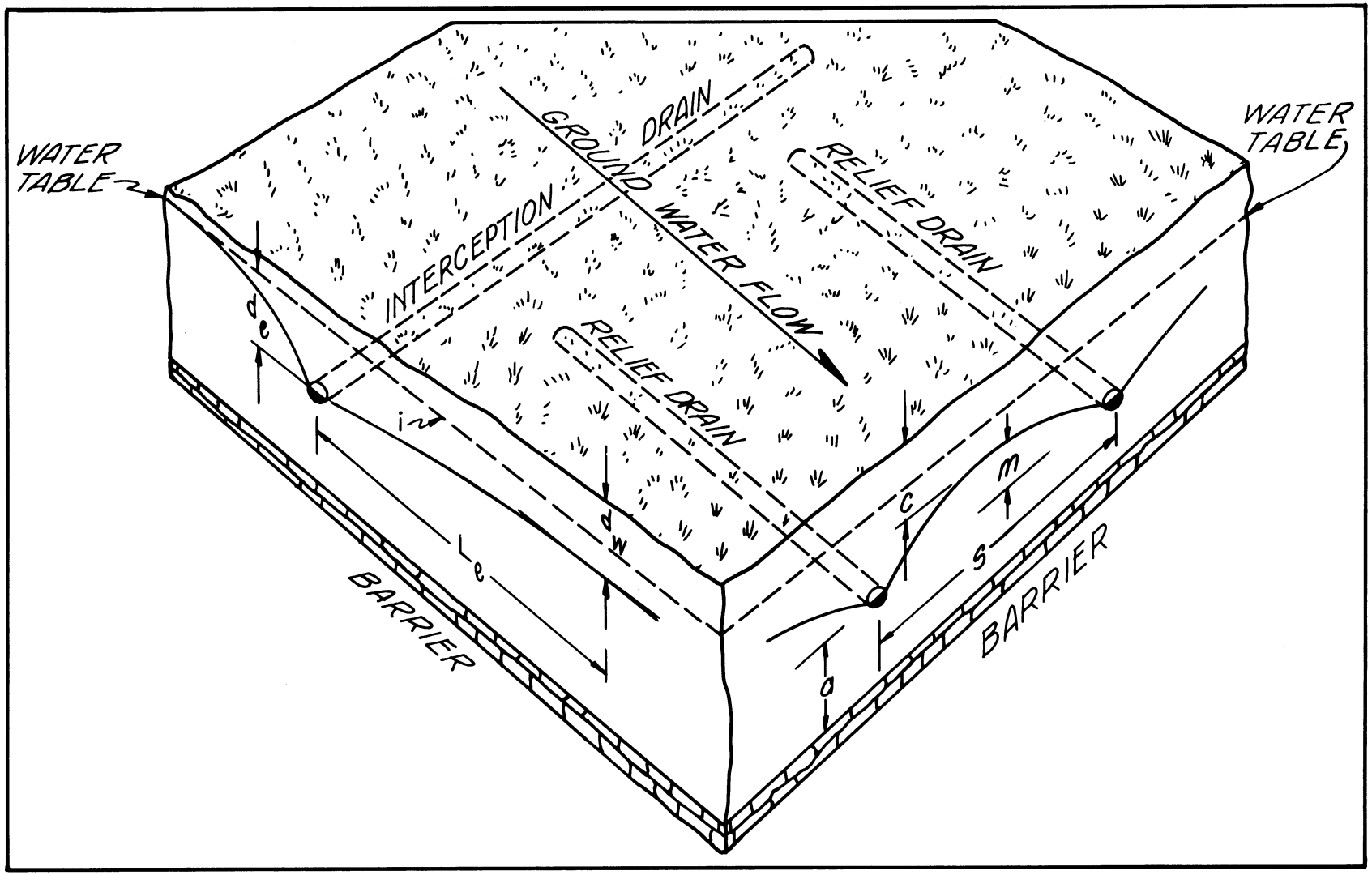


Figure 4-26, Isometric profiles relief and interception drains

more suitable to some site conditions and interception drains more suitable to others, but the choice of which to use will be largely dependent on the depth to barrier and the hydraulic gradient of the water table at the site. Two general rules that have been fairly well established through field experience are as follows:

1. Where a barrier is present at shallow depths (twice the drain depth or less), the effect of relief drains is seriously reduced and interception drains should be considered, other factors being suitable.

2. Where the hydraulic gradient of the water table is low, the effect of interception drains is seriously reduced and relief drains should be considered, other factors being suitable.

Relief drains

Humid areas. - In the humid areas of the United States, depth and spacing of drains have been largely determined by experience and judgment for specific soil conditions. Recommendations have been made in most areas for drain depth and spacing in the majority of soils needing drainage. Optimum drain depth for laterals is influenced by soil permeability, spacing, optimum depth of water table, crops, depth to impervious strata, and outlet depth for the system. In mineral soils the minimum cover over the drain should be 2 feet and in organic soils 2.5 feet. The drain trench depth usually varies from 30 to 60 inches. Increasing the depth of the drain where practical, will permit the use of wider spacing.

Spacing formulas have been used successfully in the humid area. Further correlation between various formulas and results obtained from existing installations are needed to determine the specific formula which can be used most successfully to determine drain spacing on land where experience is lacking.

Irrigated areas. - In irrigated areas of the semiarid and arid part of the United States, the depth of drains depends upon the same factors as in the humid areas with the additional requirement for control of salinity. This usually requires a depth of drains from 6 to 12 feet. Experience with effective installations in specific areas is utilized to select drain depths. Individual investigations are required to determine the most effective depth for drains. In general, drains should be as deep as practical and economical considering equipment available and cost of construction and maintenance. The depth of the outlet should be adequate to permit installation of drains at the depth required and to discharge above low flow in the outlet. This may require a sump and pump. The spacing of drains may be uniform for a given soil and will depend upon the hydraulic conductivity of the soil for the predetermined depth, the required depth of drawdown midway between the drain, on the applicable drainage coefficient, and on the depth to the barrier.

Ellipse equation. - After the depth of the drain has been determined the spacing may be computed by formula. The particular formula selected for computing the spacing of relief drains is influenced by site conditions and experience obtained from drains installed by use of the formula. The ellipse equation is used extensively to determine the spacing of relief-type drains. It is usually expressed in the following form (refer to Figure 4-27).

$$S = \frac{\sqrt{4\ K\ (m^2 + 2\ a\ m)}}{q} \qquad \text{(Eq. 4-8)}$$

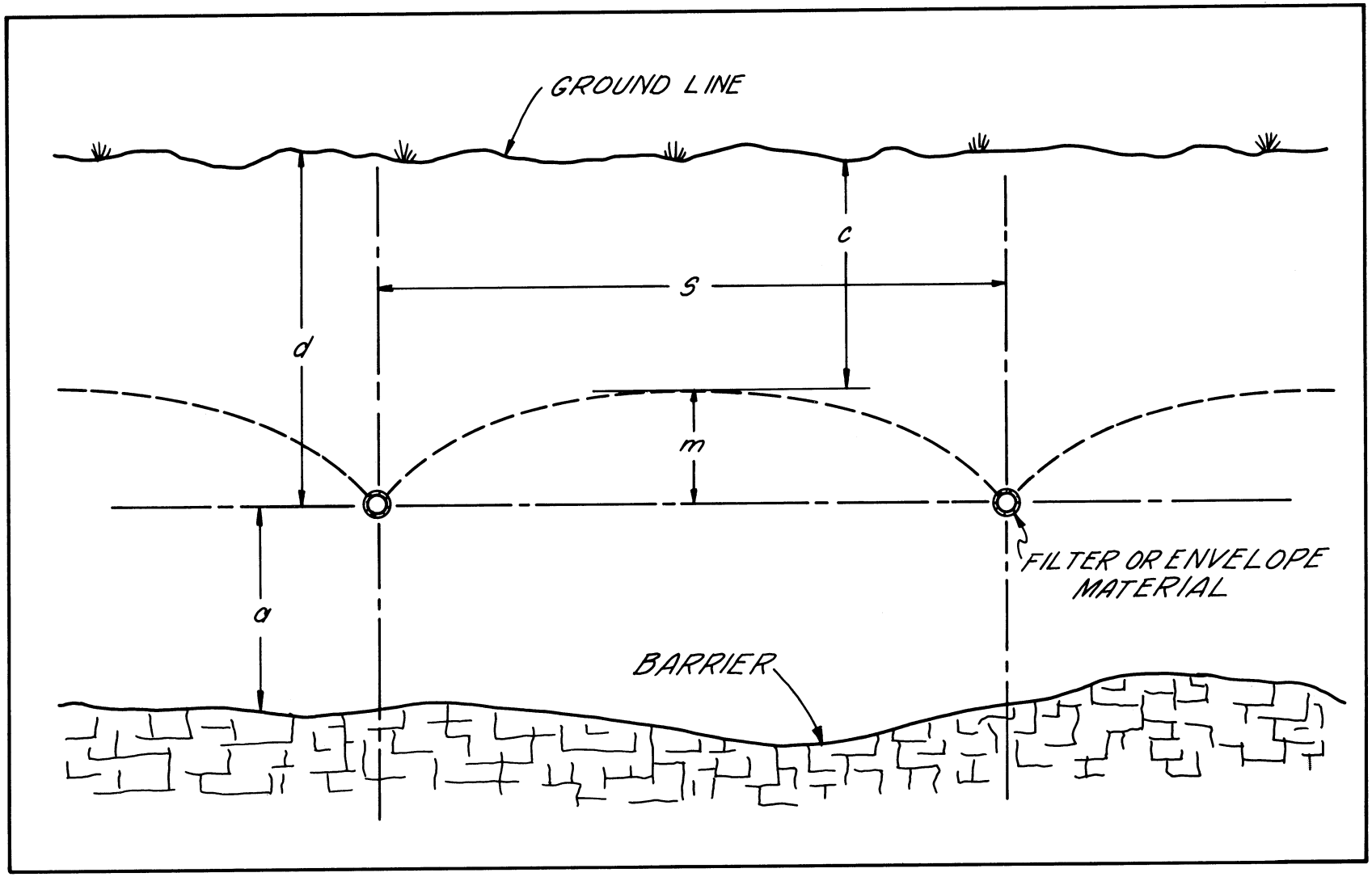


Figure 4-27, Cross-sectional sketch showing symbols used in ellipse equation

where:

S = drain spacing--feet

K = average hydraulic conductivity--in./hr.

m = vertical distance, after drawdown, of water table above drain at midpoint between lines--feet

a = depth of barrier below drain--feet

q = drainage coefficient--in./hr.

d = depth of drain--feet

c = depth to water table desired--feet

NOTE: The units of K and q may be in "inches removal in 24 hours" or "gallons per square foot per day" but both must be in the same units in this equation.

The ellipse equation is based on the assumption that the streamlines of flow in a gravity system are horizontal and that the velocity of flow is proportional to the hydraulic gradient or the free water surface. Although it is known that these assumptions are only approximate, they may approach actual conditions very closely under certain site conditions. For this reason use of the formula should be limited to the following conditions:

1. Where ground-water flow is known to be largely in a horizontal direction. Examples of this are stratified soils with relatively permeable layers acting as horizontal aquifers.

2. Where soil and subsoil materials are underlain by a barrier at relatively shallow depths (twice the depth of the drain or less) which restricts vertical flow and forces the ground water to flow horizontally toward the drain.

3. Where open ditches are used, or where drains with sand and gravel filters or porous trench backfill materials are used. These are conditions where there is a minimum of restriction to flow into the drain itself and where convergence of flow at the drain is slight.

Example 1:

The following example is given to illustrate the use of this equation when variable (a) does not exceed the value of variable (d). (Figure 4-27).

1. Parallel relief drains are to be installed at a depth of 8 feet (d = 8).

2. Subsoil borings indicate an impervious barrier of shale at a depth of 15 feet below the ground surface: a = (15 - d) = 7.

3. The minimum depth to water table desired, after drainage, is 5 feet (c = 5), therefore: m = (d - c) = 3.

4. The average hydraulic conductivity of the subsurface materials is 2 inches per hour (K = 2).

5. The applicable drainage coefficient for the area is 0.01 in./hr. (q = 0.01).

$$S = \frac{\sqrt{4(2)(3^2 + 2(7)\ 3)}}{0.01} = 202 \text{ feet}$$

In actual practice this would be adjusted to conform with field dimensions. The precision of the data is such that an adjustment of 5 percent in the spacing is considered permissible.

Graphical solution of Example 1:

Figure 4-28 (sheets 1 and 2) are charts for the graphical solution of this equation. In order to use these charts it is necessary to know the values of a, m, K, and q. To illustrate the use of the charts the example given above is solved. Vertical scales are on the short dimension of charts.

$a = 7$ feet

$m = 3$ feet

$(m + a) = 10$ feet

$K = 2$ in./hr.

$q = 0.01$ in./hr.

Step 1. Referring to Figure 4-28 (sheet 1), find a = 7 on the left-hand vertical scale. Project this horizontally to the right and find the point where it intersects the curve (m + a) = 10. From this point follow the vertical line up or down, as the case may be, to intersect the radial dashed line K = 2. From this point follow the horizontal line to the right-hand vertical scale and read the index number, 410. Note this index number down for continuation of the solution on Figure 4-28 (sheet 2).

Step 2. Referring to Figure 4-28 (sheet 2), find the index number 410 on the right-hand vertical scale. Project this point horizontally to the left to intersect with the curved line q = 0.01. From this point follow vertically down to read the spacing S = 203. This is the spacing in feet. This spacing is well within the 5 percent error and should be adjusted within acceptable limits to the spacing which will most nearly fit the dimensions of the field to be drained. For example, assume the dimension of the field, perpendicular to the direction of the drains, is 1,320 feet. Six drains will give a spacing of 220 feet, which is too great. Seven drains will give a spacing of 188 feet, which is satisfactory.

Modified ellipse equation. - As previously discussed in the text, the ellipse equation is satisfactory for computing drain spacing where the flow of ground water is largely horizontal, where the depth to barrier is less than twice the drain depth and where open ditches or drains or drains with sand-gravel envelopes or porous trench backfill materials are used. This will result in only a slight convergence of flow at the drains which can be ignored. For conditions where convergence is significant, it is necessary to modify the ellipse equation. This is true for the following site conditions.

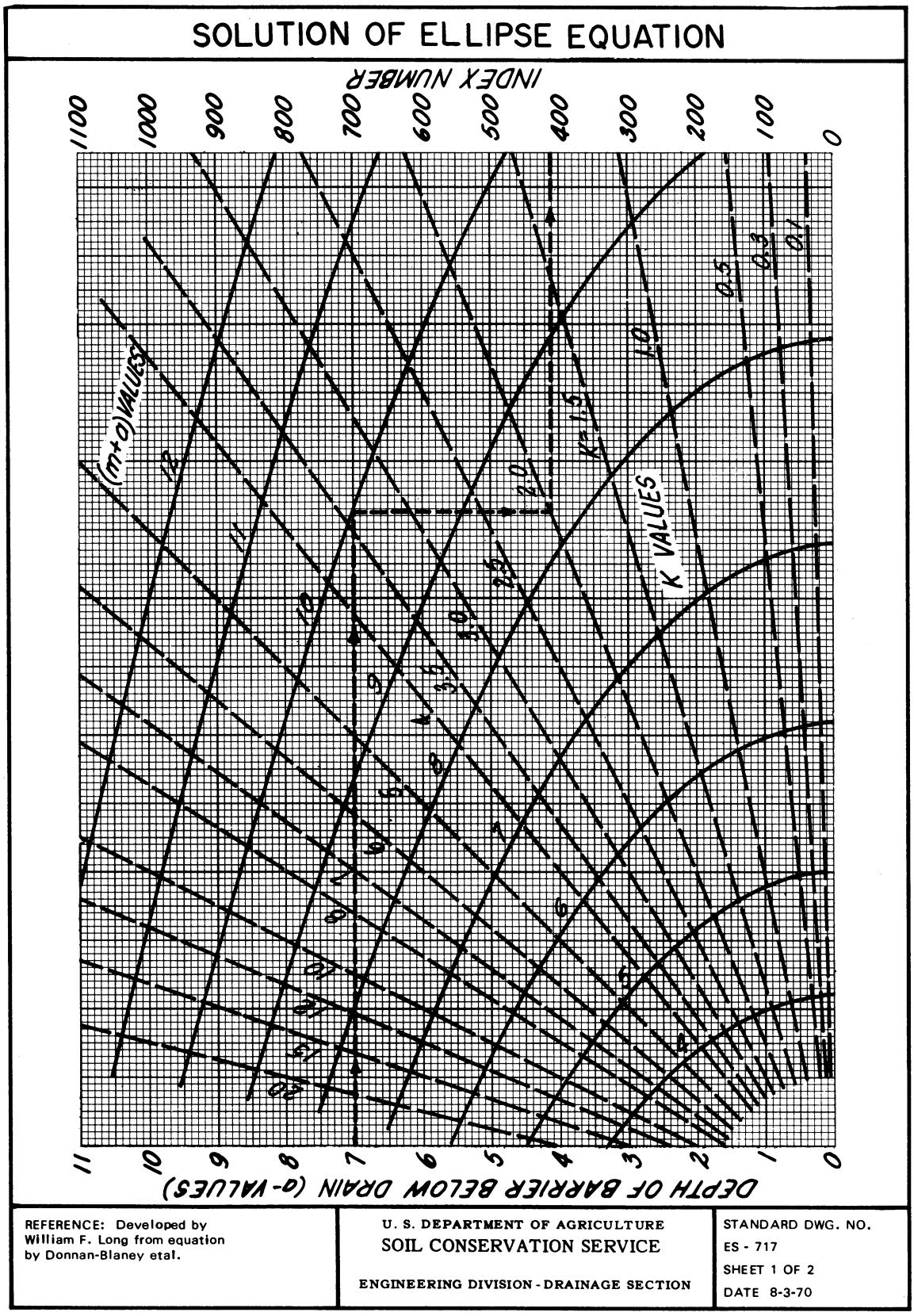
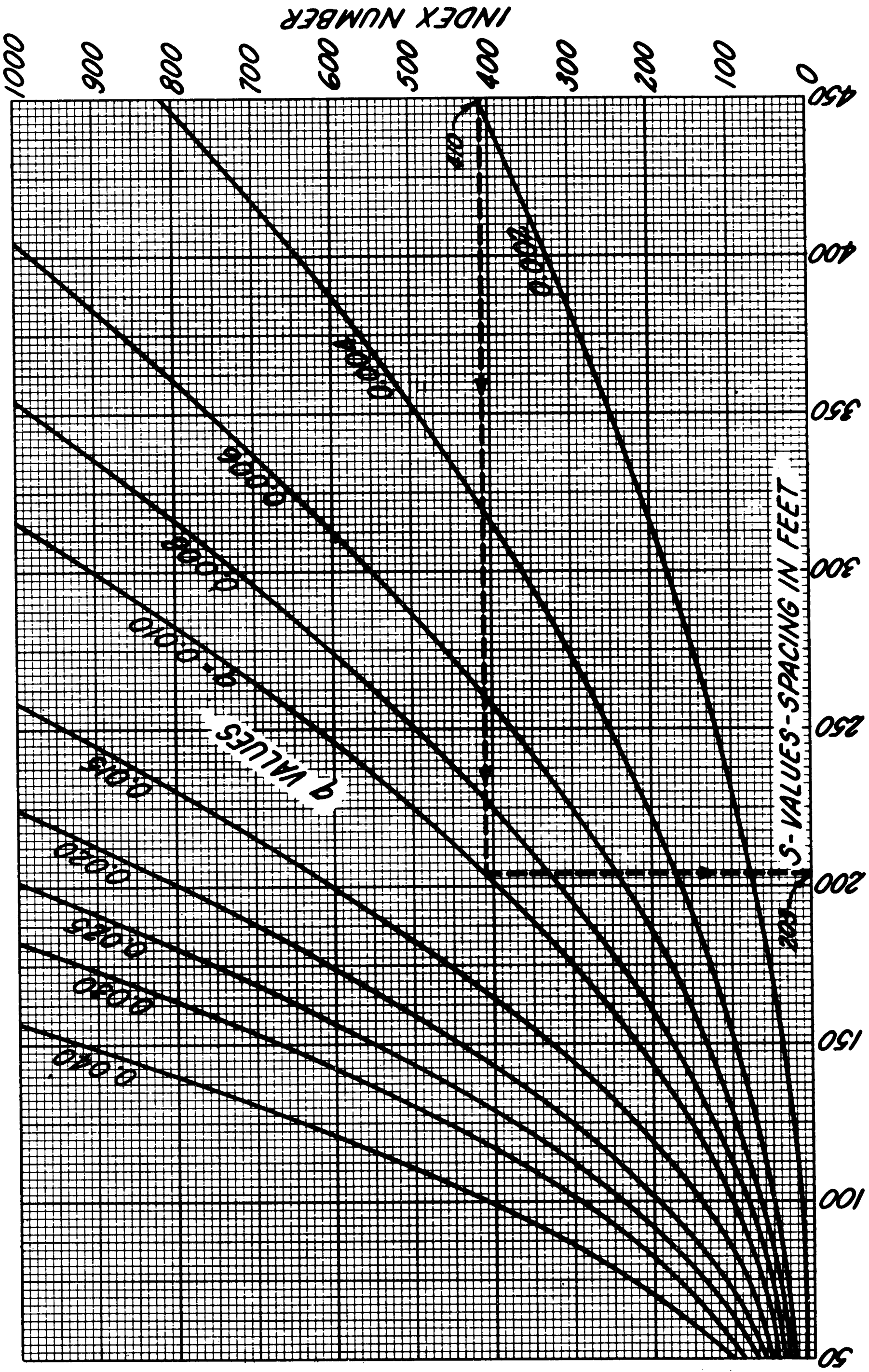


Figure 4-28, Solution of ellipse equation

SOLUTION OF ELLIPSE EQUATION



REFERENCE: Developed by William F. Long from equation by Donnan-Blaney etal.	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DRAINAGE SECTION	STANDARD DWG. NO. ES - 717 SHEET 2 OF 2 DATE 8-3-70

Figure 4-28, Solution of ellipse equation

1. Where soils and subsoils are deep homogeneous materials without horizontal stratification.

2. Where barriers, if present, are at depths in excess of twice the drain depth.

3. Where drains are placed without porous filters and where the trench backfill materials have a low permeability.

These are conditions where there is significant restriction to flow into the drain itself and where convergence of flow at the drain is significant.

Formulas to take into consideration the radial flow around drains have been developed by Hooghoudt and Ernst (see Chapter 1, page 1-21). Soil Conservation Service personnel have prepared charts for the direct solution of drain spacing based on Hooghoudt's tables and the units of measurement listed on page 4-59.

Hooghoudt's procedure (8) involves determination of an "equivalent depth" to the barrier below the drain and substituting this for the actual depth to barrier in the ellipse equation. This procedure is discussed, among others, by Bouwer and van Schlifgaarde (9). The charts mentioned above are not a direct solution of the ellipse equation but give a graphical solution of a modified ellipse equation in which an equivalent depth has been substituted for the depth to barrier.

The value of (a), the depth to barrier, as used in these charts is the actual depth to barrier below the drain.

1. Graphical solution - depth to barrier known. Figure 4-29 (sheets 1, 2, and 3) are actually parts of the same chart which has been subdivided into page-size-sheets for inclusion in this handbook. These charts give a graphical solution of the modified ellipse equation.

   The graphical solution for the modified ellipse equation (using Figure 4-29) is satisfactory where the depth to barrier affects the drain spacing significantly. This is where the spacing is up to about four times the depth to barrier or S/a is greater than four.

   The factors needed for solution by these charts are a, m, K, and q as defined on page 4-59 for the ellipse equation. In using these charts it is necessary to first compute the values of q/K and m/a and then select the appropriate chart. The range of each chart is as follows:

Figure	Values of q/K	Values of m/a
4-29 (sheet 1)	0.0004 - 0.05	0.02 - 0.30
4-29 (sheet 2)	0.001 - 0.10	0.30 - 7.0
4-29 (sheet 3)	0.00001 - 0.001	0.30 - 7.0

   From the proper chart find the point of intersection for values of q/K and m/a and interpolate for the value of S/a from the curves given. Multiply the S/a value obtained times the value of (a) to obtain the spacing. Use of these charts is illustrated by the following example:

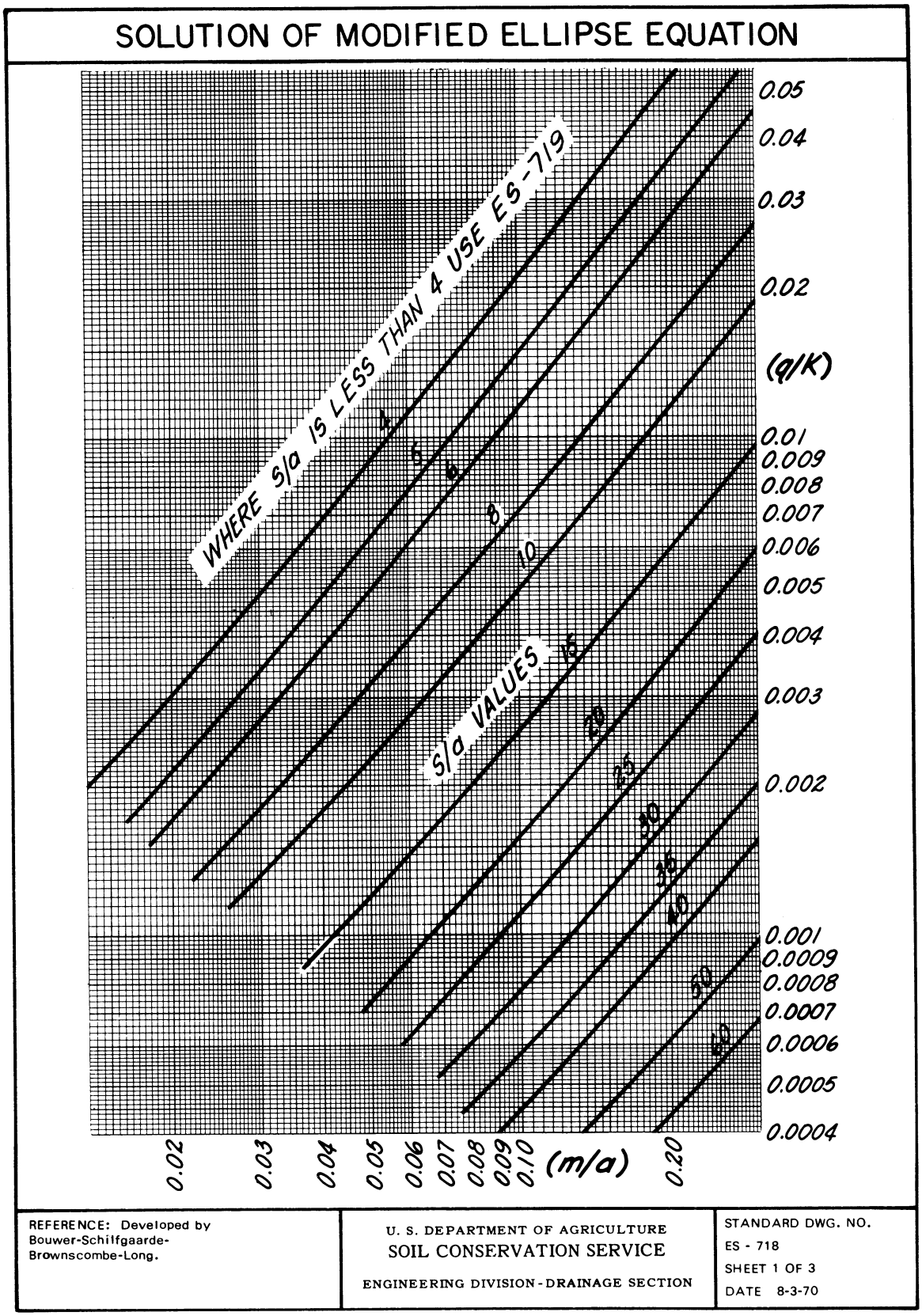
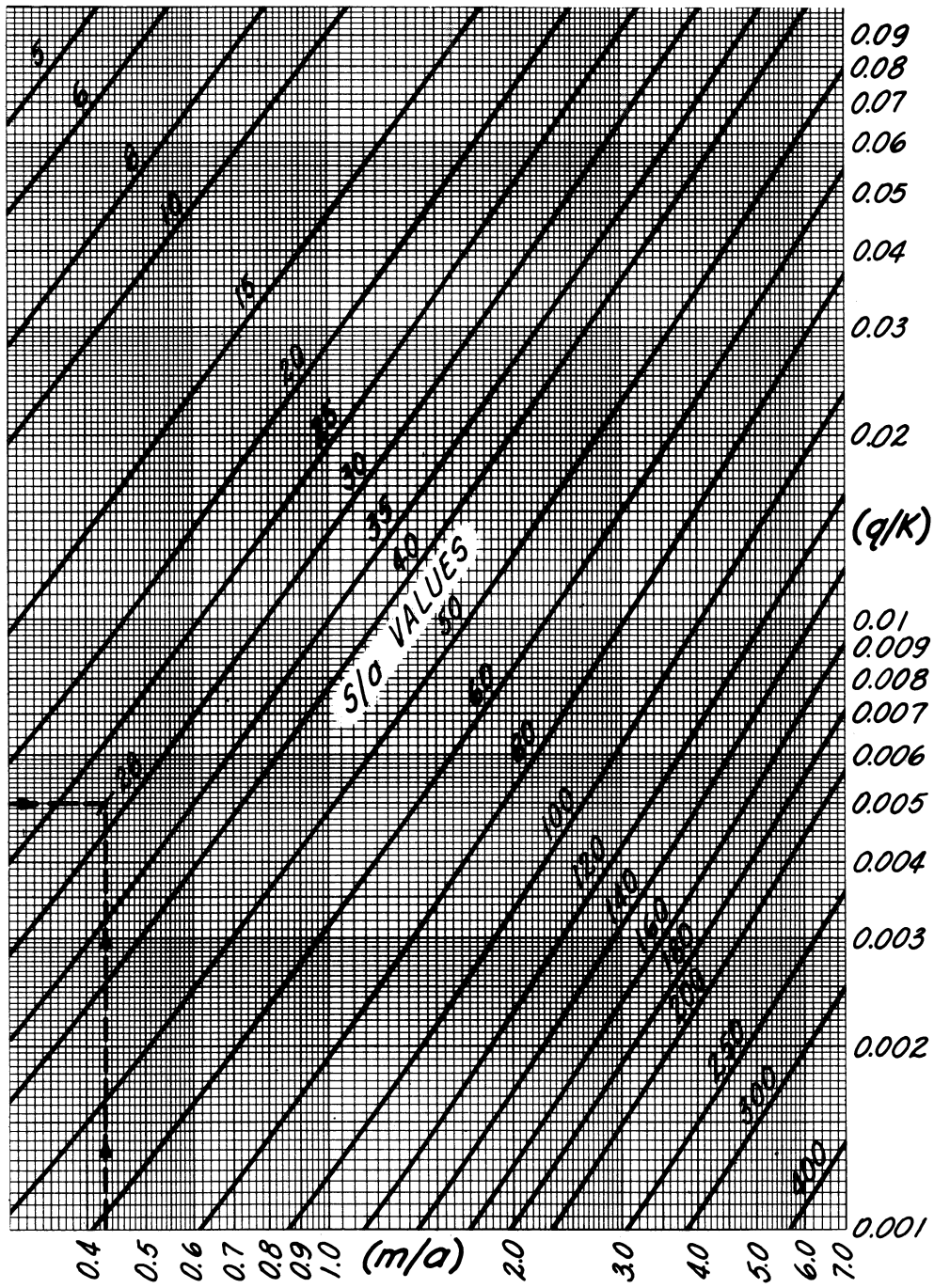


Figure 4-29, Graphical solution of modified ellipse equation

SOLUTION OF MODIFIED ELLIPSE EQUATION



REFERENCE: Developed by Bouwer-Schilfgaarde-Brownscombe-Long.	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DRAINAGE SECTION	STANDARD DWG. NO. ES - 718 SHEET 2 OF 3 DATE 8-3-70

Figure 4-29, Graphical solution of modified ellipse equation

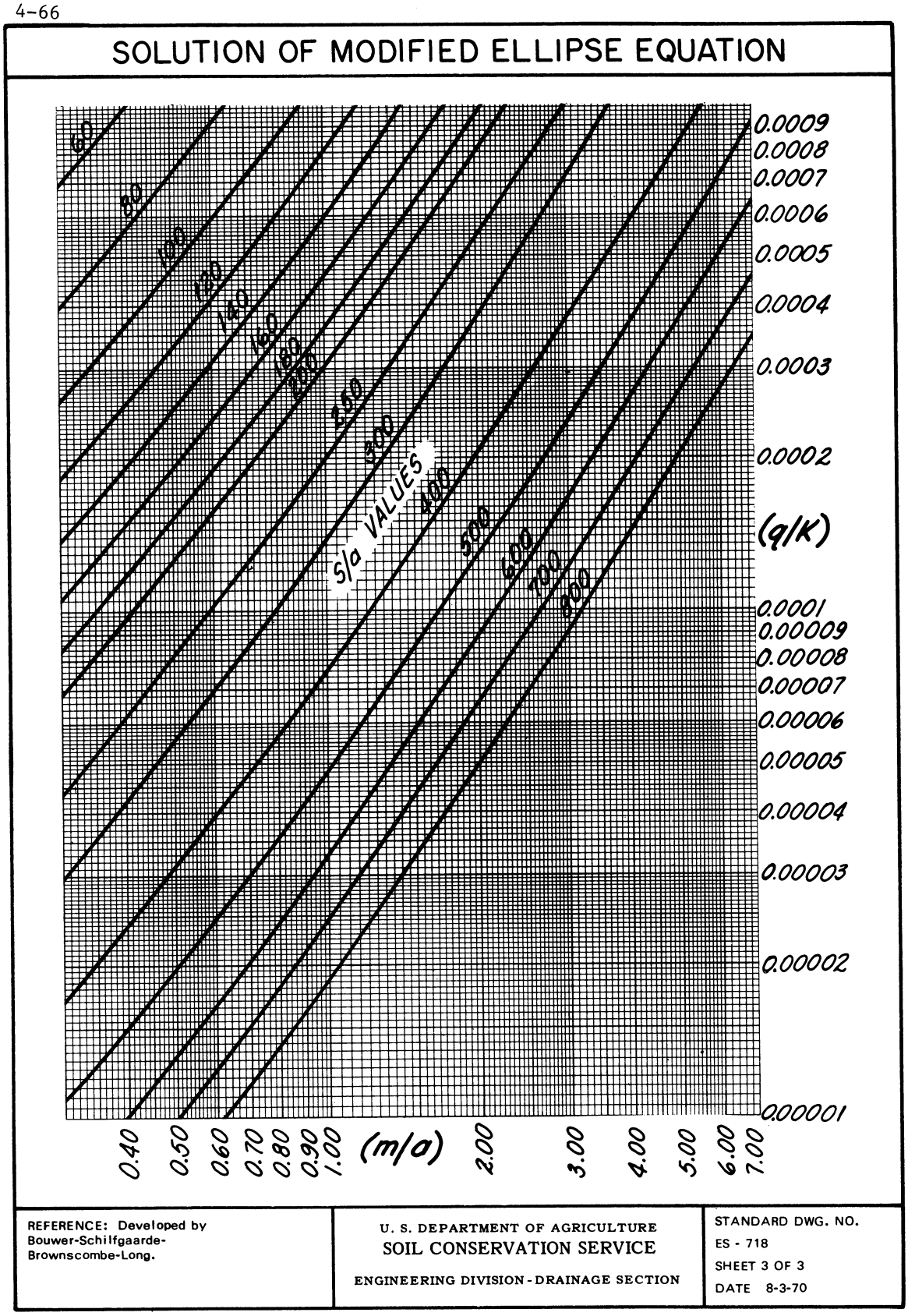


Figure 4-29, Graphical solution of modified ellipse equation

Example 2:

Determine the spacing for the conditions given in Example 1 illustrating use of the ellipse equation, 4-8, page 4-57:

where:

$a = 7$ feet

$m = 3$ feet

$q = 0.01$ in./hr.

$K = 2.0$

Solution:

$$\frac{m}{a} = \frac{3}{7} = 0.43$$

$$\frac{q}{K} = \frac{0.01}{2} = 0.005$$

Refer to Figure 4-29 (sheet 2), find S/a = 28.

$$S = \frac{S}{a} \times a = 28 \times 7 = 196 \text{ feet}$$

The spacing is slightly less than the 202 feet obtained by using the ellipse equation. Differing values will be obtained for most cases where the depth to barrier is less than twice the drain depth as previously discussed. It will not be the case, where the barrier is at a greater depth.

2. Graphical solution - no barrier present or depth to barrier greater than one-fourth estimated spacing. Where there is no known barrier present or where its depth below the tile is greater than one-fourth the estimated spacing, the barrier will have no effect on the operation of the relief drain. For this case the barrier will be considered to be infinitely deep and the method described above is not applicable as there is no realistic value for (a). The smallest S/a value given in Figure 4-29 (sheet 1) is equal to four. If the value of S/a is less than four, the solution can be found by using Figure 4-30, which is discussed below.

The chart shown as Figure 4-30 has been prepared for graphical solution of the modified ellipse equation for the case where the depth to barrier is considered to be infinite. It will be noted that on this chart the vertical scale is in units of q/K and the horizontal scale in units of (S), the drain spacing. The family of curves on this chart is drawn for selected values of (m). To use this chart it is necessary to know the value of q/K and (m). Find q/K on the vertical scale; project this horizontally to the right to the proper curve for the value of (m) and from this point follow vertically down to read the value of (S) on the horizontal scale. This is the spacing in feet.

Example: Determine the spacing for the previous problem, assuming all conditions the same except that there is no barrier present, or that its depth is greater than one-fourth the estimated spacing where:

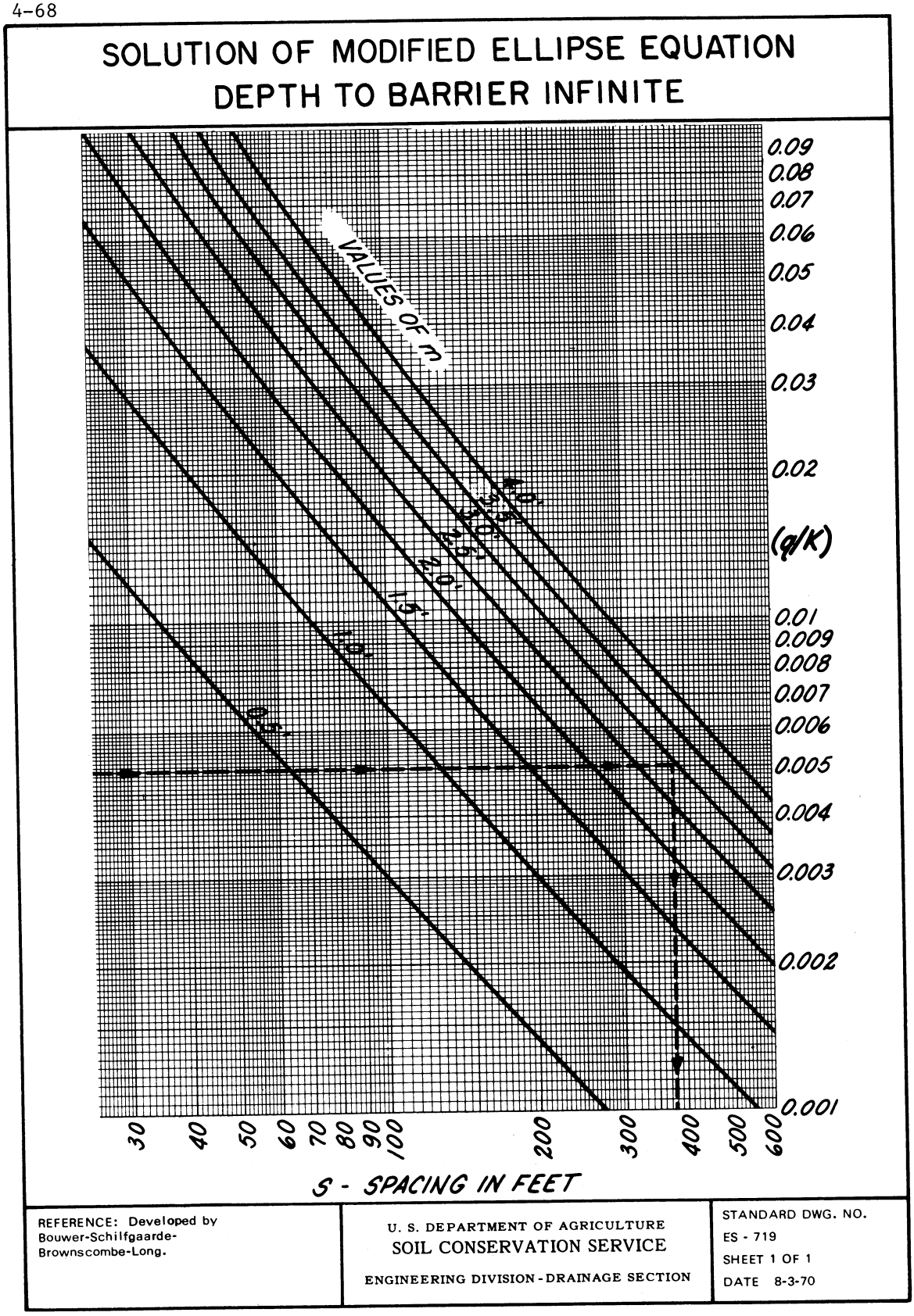


Figure 4-30, Solution of modified ellipse equation

$$\frac{q}{K} = \frac{0.01}{2} = 0.005$$

The value of (m) is given. When m = 3 (from the chart, Figure 4-30)

S = 380 feet.

Nomographs for the calculation of drain spacings have been developed by W. F. J. van Beers, Senior Research Officer, International Institute for Land Reclamation and Improvement, Wageningen, the Netherlands. Nomographs are included for calculation of drain spacing by use of the Hooghoudt and Ernst formulas, and for determination of drain spacing in accord with the transient flow concept developed by Glover and Dumm. See references (6, 7, 8, 10, and 11) in Chapter 1. The nomographs included in Bulletin 8 of the Institute are convenient to use when measurements are in metric units.

Van Beers' nomographs for solution of the Hooghoudt formula are applicable to drains in a homogeneous soil, and where the drains are on or below the interface between two soils of different permeabilities. When the drains are above the interface, the solution given by the Ernst formula is applicable. The nomograph for determination of drain spacing by the Glover and Dumm formula may be used when the nonsteady state or transient flow concept is applicable.

Artesian areas. - In areas that are subject to artesian flow from permeable aquifers, present below the drain, relief-type drains are usually installed to solve the problem. The proper depth and spacing for these drains are computed by using the formulae for relief drains as previously discussed; however, special consideration must be given to selecting drainage coefficients that are applicable to artesian conditions.

In nonartesian areas the drainage coefficient is based on the expected infiltration from precipitation and/or deep percolation from irrigation. In artesian areas ground water moves upward into the root zone in addition to water that infiltrates from the surface, so the amount of ground water to be removed by drainage is greater. For this reason drainage coefficients applicable to artesian areas are always greater than those applicable to nonartesian areas. This usually requires closer spacing of drains in artesian areas.

The rate at which ground water under artesian pressure moves upward into the root zone is a function of artesian pressure, the depth of the artesian aquifer below the drain and the permeability of the subsurface sediments through which the artesian water must flow. Knowing the values of these variables for a given situation, it is possible to compute the rate of artesian flow and to establish a drainage coefficient applicable to the accretion caused by artesian conditions. This, when added to the drainage coefficient locally established for accretion from precipitation or irrigation provides a drainage coefficient applicable to artesian areas. Experience has indicated that this coefficient is in the range of one and one-half to two times the normal values used in nonartesian areas.

Recognizing that we do not currently have a precise method of computing the value of accretions from artesian flow, the design of drainage systems should be conservative. Disposal drains, mains, and important lateral drains should be designed with some excess capacity. Lateral collector drains can be designed on a less conservative basis as additional collector drains can be installed to supplement the system if it is found to be deficient. This approach is often the most practical and least costly method in areas where

ground-water yields from artesian flows are indeterminate. The important consideration is to provide for excess capacity in the disposal system so that additional collector drains can be added later.

Use of open ditches for relief drainage. - Open ditches may be used to provide subsurface drainage and are often considered for use in flat fields where lack of grade, depth of outlet, soil characteristics, or economics do not favor buried drains. The ditches must be deep enough to provide for the escape of ground water found in permeable strata or in water-bearing sediments. Spacing of the ditches varies with soil permeability and crop requirements. Because of their required depth the ditches usually have adequate capacity to carry both surface and subsurface water. Advantages in using open ditches include the following:

1. Open ditches usually have a smaller initial cost than buried drains.

2. Inspection of open ditches is easily accomplished.

3. They are applicable in soils where buried drains are not recommended.

4. Open ditches may be used on a very flat gradient where the depth of the outlet is not adequate to permit gravity flow from drains installed at the required depth and grade.

Disadvantages in using open ditches are as follows:

1. Open ditches require considerable right-of-way which reduces the area of land available for other purposes.

2. Open ditches require more frequent and costly maintenance than buried drains.

Interception drains

Interception drains may be planned as single random drains or as a series of parallel drains. They are used where soils and subsoils are relatively permeable and where the gradient of the water table is relatively steep. Interception drains skim off or divert a portion of ground-water flow thereby lowering the water table in the area below or downslope from the interception drain. The distance that the water table is lowered below the drain is directly proportional to the depth of the drain; therefore it is desirable to make interception drains as deep as possible consistent with other factors. The upslope effect of interception drains varies with the hydraulic gradient, decreasing as the hydraulic gradient increases. This upslope effect of true interception drains is usually small and is often ignored.

Theoretically, a true interception drain lowers the water table downslope from the drain to a depth equal to the depth of the drain, and the distance downslope to which it is effective in lowering the water table is infinite, provided there is no accretion to ground water in that distance. Under field conditions, where there is infiltration from precipitation or deep percolation from irrigation, there is always accretion to ground water. The distance downslope from the drain to which it is effective is governed by the amount of these accretions.

In the design of interception drains it is usually necessary to estimate the downslope effect of interception drains to determine if one or several such drains are needed to lower the water table in the wet area. This is a diffi-

cult problem, but can be approached by use of an empirical equation or by progressive construction.

The equation is based on the assumption that the drain intercepts all the flow upslope from it to the depth of the drain, and the distance downslope to which it is effective is dependent on the depth of drainage required and the accretion to ground water in the area below the drain. Referring to Figure 4-31 this is the reach (L) from the drain to point (m) where the drain is no longer effective. For purposes of this discussion, a true interception drain is defined as one in which all ground-water flow enters the drain from the upslope side. Based on presently available information, true interception is thought to occur when the hydraulic gradient of the undisturbed water table is in the range of 0.01 to 0.03 feet per foot or greater. Where the gradient is less than this the interception drain functions more like a relief drain and the spacing should be computed using the ellipse equation, as previously discussed in this chapter. The equation is:

$$L_e = \frac{Ki}{q} (d_e - d_w + W_2) \qquad \text{(Eq. 4-9)}$$

where:

L_e = the distance downslope from the drain to the point where the water table is at the desired depth after drainage--feet

K = the average hydraulic conductivity of the subsurface profile to the depth of the drain--in./hr.

q = drainage coefficient--in./hr.

i = the hydraulic gradient of the water table before drainage (undisturbed state)--feet per foot

d_e = the effective depth of the drain--feet

d_w = the desired minimum depth to water table after drainage - based on agronomic recommendations--feet

W_1 = the distance from the ground surface to the water table at the drain--feet

W_2 = the distance from the ground surface to the water table, before drainage, at the distance (L_e) downslope from the drain--feet

In Equation 4-9, (L_e) and (W_2) are interdependent variables. In the solution of the equation it is necessary to estimate the value of (W_2) and make a trial computation. If the actual value of (W_2) at distance (L_e) is appreciably different, a second calculation may be indicated. In those cases where the gradient (i) is uniform throughout the area, (W_2) can be considered as equal to (W_1).

Example: Refer to Figure 4-31. Determine the distance downslope from an interception drain that it would be effective under the following given conditions:

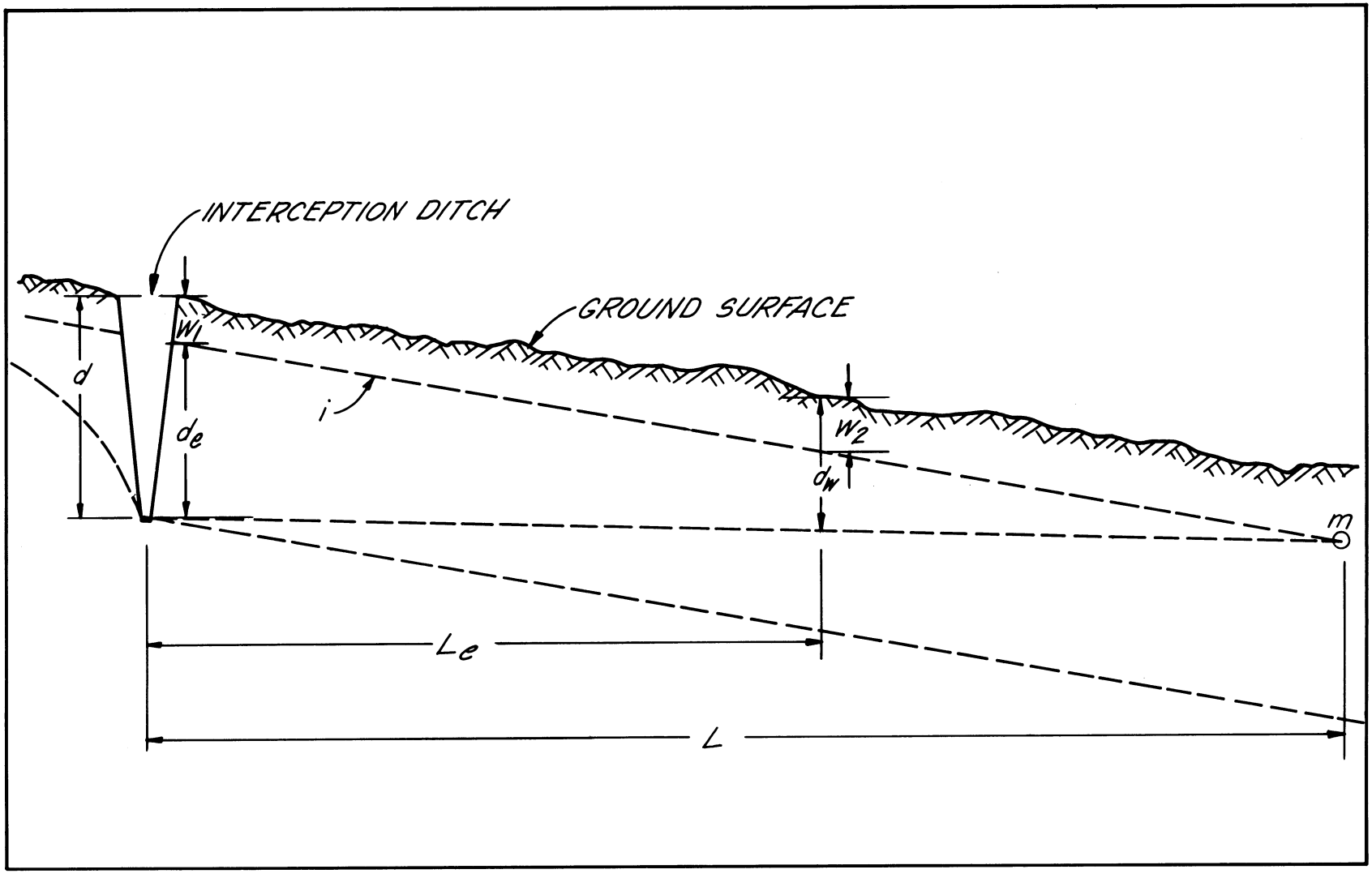


Figure 4-31, Cross-sectional profile, interception drain and area influenced

d = depth of drain--8 feet

W_1 = 1.5 feet

K = 6 in./hr. (from auger hole tests)

i = 0.05 (feet per foot)

q = 0.004 in./hr. (locally established drainage coefficient)

d_w = 3 feet (from local agronomic experience)

$d_e = d - W_1 = 8 - 1.5 = 6.5$ feet

Assume: $W_2 = W_1 = 1.5$ feet

$$L_e = \frac{Ki}{q}(d_e - d_w + W_2)$$

$$L_e = \frac{(6)(0.05)}{(0.004)}(6.5 - 3 + 1.5) = 375 \text{ feet}$$

At a distance of 375 feet downslope from the drain, the depth to water table would be 3 feet. If two or more parallel interception drains are to be used, the spacing between the first and second drains would be 375 feet as computed above. The spacing between the second and third drain; third and fourth; etc. would have to be recomputed using adjusted values for (i) and (d_e) due to the change in the hydraulic gradient caused by the first interception drain.

Multiple interception drains. - Where it is necessary to install multiple interception drains, and site conditions are such that the above equation is not applicable, it may be feasible to install the system progressively and avoid the uncertainties of estimating spacing. This may be accomplished by constructing the first drain to protect the higher portion of the wet area and delaying construction of the lower drains to allow time to evaluate the effect of the first one. Spacing of additional drains can be accurately determined by exploring water table levels below the first drain to establish a spacing interval. Referring to Figure 4-31, the second interception drain would be located a distance (L_e) below the first drain, where the desired drawdown is effected. In actual practice this distance could be extended a short distance to allow for some upslope drawdown.

The upslope drawdown is a function of the depth of the drain and the hydraulic gradient as previously mentioned. As a general rule, it can be considered as equal to the reciprocal of the hydraulic gradient.

Mole drains

Moling should be undertaken only in the heavier mineral soils of fine texture such as clays, silty clays, or clay loams and in fibrous organic soils. The soil through which moles are drawn should be free of stones, gravel, and sand lenses. Clay content of mineral soils at moling depth should be about 40 percent or greater and sand content not over 20 percent. A rule-of-thumb test for appraising suitability of the soil can be made as follows:

Squeeze a sample of soil taken at the proposed moling depth into an approximate 2-1/2 to 3-inch ball. Immerse the ball in a jar of water

and leave undisturbed for about 12 to 14 hours. If the ball remains intact at the end of this time, the soil should be suitable for moling. Soils should be examined over the entire area to be moled.

Drainage area. - Upland surface runoff should not be permitted to collect on moled land. Such flow should be intercepted above the moled area and removed by diversion.

The area of land served by one or a system of mole drains should be limited to small acreages. The limit should not exceed 4 to 5 acres. When drainage of large fields is planned, the resulting layout may require an arrangement of drains involving a number of systems with separate outlets.

Grade. - Mole drains deteriorate rapidly on grades below 1 percent or more than 7 percent. Under 1 percent, moles tend to retain sufficient moisture to keep their walls soft and flaking and they do not flush themselves readily. Scour and erosion with resulting plugging occur on slopes more than 7 to 8 percent. Best grades are between 1 and 2 percent. Lines should be drawn with continuous slope toward the outlet. Land smoothing prior to moling can eliminate minor depressions in grade and remove any abrupt changes. If moles must be drawn through a depression, a buried drain should be installed for the outlet. On steep slopes lines are preferably drawn across slope on grades of 1 to 2 percent. See Figures 4-32 and 4-33 for examples of mole-drainage patterns suitable to steep and comparatively flatland slopes.

Outlets. - Mole outlets must have sufficient depth and capacity to provide continuous free outfall. Standing water or any prolonged inundation softens and collapses the mole cavity. Outlets for mole drains may be open ditches, buried drains, or other mole drains. Due to their importance as outlets to tributary mole drains, special care should be given to locations used for mole mains.

Discharging mole drains directly into open ditches or natural streams is undesirable, because of hazard of overflow and backwater, because of the possible presence of undesirable granular or organic strata, and because of direct exposure of the ends of the mole cavity to the deteriorating effect of frost, drought, rain, and surface waterflow. When moles must be drawn directly from ditches or streambanks, outlet protection should be provided by inserting 4 to 6 feet of pipe, of the same diameter as the mole, into the mole hole. When granular materials in the bank are a hazard, buried drains should be extended into the field or a short ditch opened back into the field from where the mole is then drawn.

Buried main drains provide the most stable outlet for mole drains. These should be installed before the moles are drawn and should be set sufficiently deep so that the mole can be drawn just over the drain without dislodging it. (Figure 4-34). Good entrance conditions between mole and drain may be provided by use of porous backfill material around and immediately over the drain. Buried drain outlets for mole drains should be planned according to the same requirements for the main drain of a subsurface system for similar conditions.

Moles, though less durable than tile, may be used as outlets to other mole lines. When used for mains three to four mole lines should be drawn side-by-side at about 3-foot spacing and at such depth that the tops of the mains will be cleared by the invert of the mole laterals drawn over them later. (Figure 4-35). Connections between the mains and laterals can be assured by opening

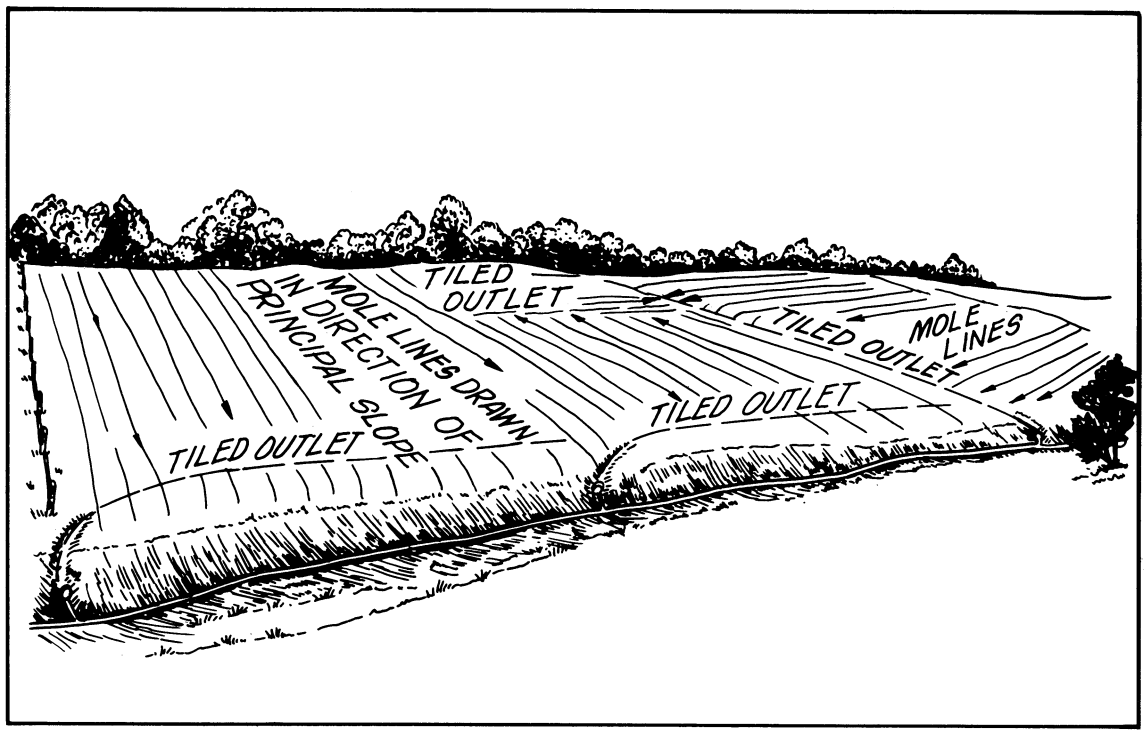


Figure 4-32, Mole drainage system on flatland

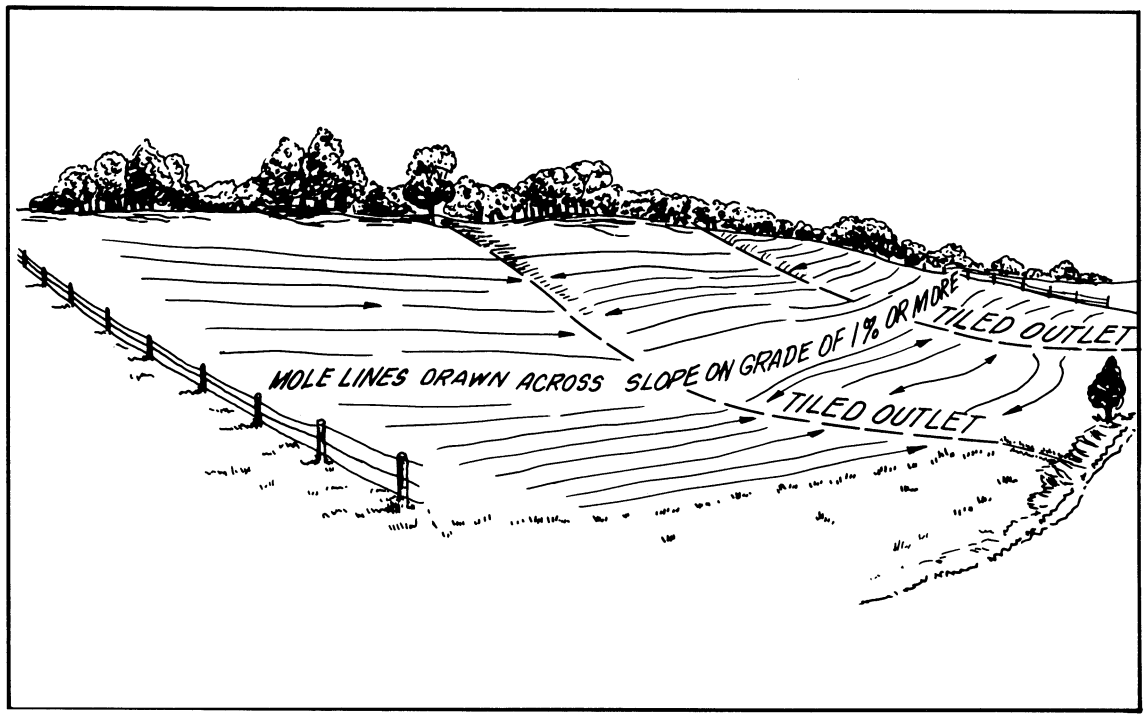


Figure 4-33, Mole drainage system on sloping land

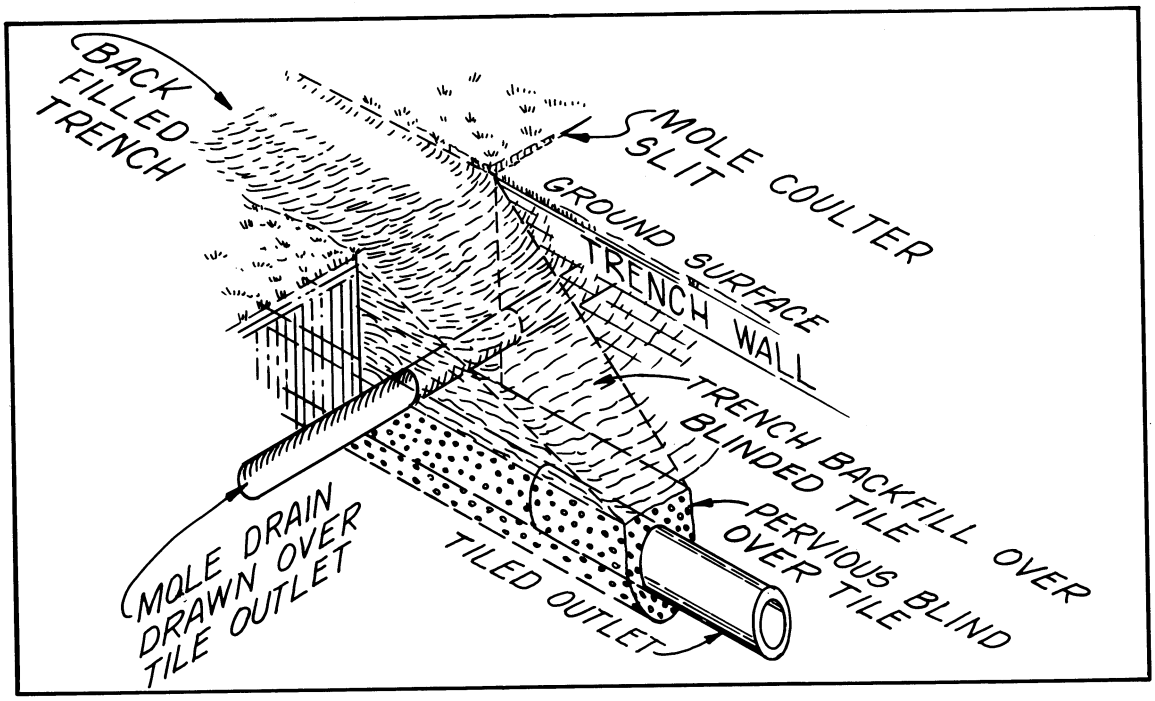


Figure 4-34, Buried drain outlet for mole drain

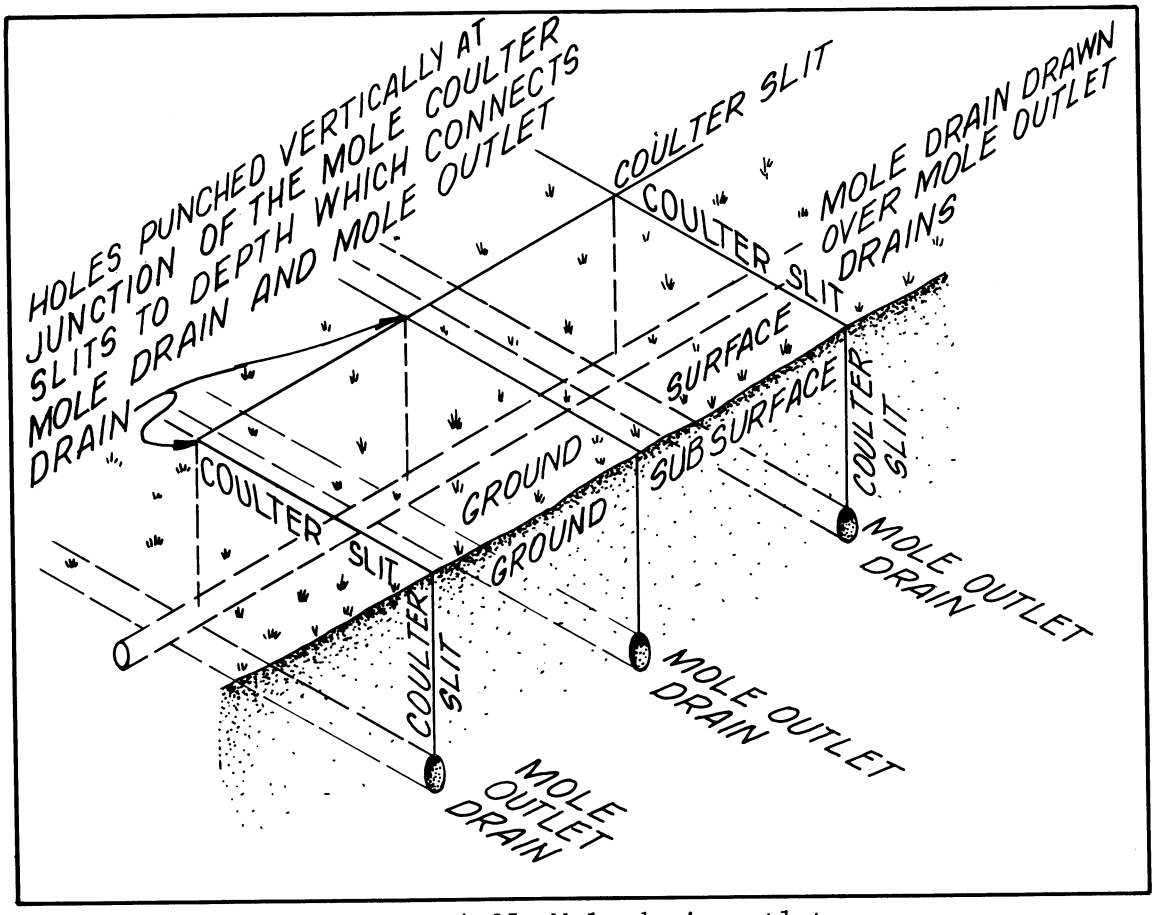


Figure 4-35, Mole drain outlets

up holes with a soil auger or metal bar, inserted over the junction of the two lines to the depth of the main.

Length of lines. - Size of the field to be moled, available outlet, and best location for the mains usually determine lengths of mole lines. Long lines deteriorate more rapidly than short lines. Experience indicates allowable lengths vary with soil type, slope, and area served. Maximum lengths of lines draining in one direction should not exceed 600 to 700 feet on the steeper grades. This length should be reduced as grade is reduced so that 350- to 400-foot lengths should be used on 2- to 4-percent grades and 250 feet or less on grades of 1 percent and less. The length specified above of a single-drawn mole line can be doubled when the grade is carried around the land slope or across ridges to provide fall in two directions. The drawn length of a line on comparatively flat grades of 1/2 to 1 percent can be extended many times by locating them across a series of draws in which mains are located.

Installation Design

General

The location of the main drain and laterals should be planned to obtain the most efficient and economical drainage system. A few general rules to follow are:

1. Provide the minimum number of outlets.

2. When practical lay out the system with a short main and long laterals.

3. Orient the laterals to use the available field slope to the best advantage.

4. Follow the general direction of natural waterways with mains and submains.

5. Avoid locations that result in excessive cut.

6. Avoid crossing waterways wherever feasible. If waterways must be crossed, use as near a right-angle crossing as the situation will permit.

7. Where feasible, avoid soil conditions that increase installation and maintenance cost.

Laterals should be located in the direction for the most effective collection of excess water, with due regard to the grade required for prevention of sedimentation, and following the rule of long laterals with short mains where feasible. Where the trenches are backfilled with permeable material that transmit water rapidly to the drain, it is desirable for laterals to be located at right angles to the direction of crop rows. Where it is desirable for main drains to be located parallel to a ditch deeper than the drain, enough distance should be maintained between ditch and drain to prevent washouts in the drain. Submains may be used to eliminate crossing waterways and to reduce the number of lateral connections to the main.

Alignment

When change in horizontal alignment is required, one of the following methods should be used to minimize head losses in the line:

1. Use of manufactured fittings, such as ells, T's, and Y's.

2. Use of a gradual curve of the drain trench to prevent excessive gap-space.

3. Use of junction boxes or manholes where more than two mains or laterals join.

Connections

Manufactured connections or junctions for joining two lines should be used. It is good practice to lay a submain parallel to a large tile main (usually 10 inches or larger) to prevent tapping the large main for each lateral. Tapping a large tile is difficult, costly, and is frequently the cause of failure. Savings, through the elimination of large connections, usually will offset the extra cost of a submain. Smooth curves in tile lines and manufactured tile connections or junctions of less than 90° have been recommended in the past on the assumption that energy losses at the junction of tile lines would be reduced. Investigations (10), however, show that the variation in energy loss for different angles of entry are insignificant from a practical standpoint when the main and lateral are of the same size and the drains are flowing full.

Loads on drains

General

Drains installed in the ground must have sufficient strength to withstand the loads placed upon them. In subsurface drainage, the load which usually governs the strength required is the weight of the earth covering the drain. The magnitude of the load which the drain can safely support depends upon the unit weight of the soil, the width and depth of the trench, and the method of bedding and installation of the drain. Where the drain is at shallow depths (3 feet or less) there is danger from impact loads from heavy farm equipment. All installations should be checked to insure adequate load-bearing strength.

Frequently drain installations are made in wide trenches and at greater depths than is possible with the average trenching machine. Draglines, backhoes, and other equipment may be used for deep trenches. Trenches excavated by this equipment are wide and the greater loads to be placed upon the drain must be determined so that a drain of adequate strength may be selected.

Underground conduits

Research on loads on underground conduits (including tile) has been carried on by Marston, Schlick, and Spangler and their associates at Iowa State University. The results of their work are used in determining the loads on underground conduits and their supporting strength. Information regarding loads on conduits may be found in the following publications.

"The Structural Design of Underground Conduits," SCS Engineering Division, Technical Release No. 5.

Engineering Handbook, Section 6, "Structural Design," U. S. Department of Agriculture, Soil Conservation Service.

"Soil Engineering," by Merlin Grant Spangler, International Textbook Company, Scranton, Pennsylvania.

"Design Data - Loads and Supporting Strengths," American Concrete Pipe Association, Arlington, Virginia.

"Handbook of Drainage and Construction Products," Armco Drainage and Metal Products, Inc., Middletown, Ohio.

Classification of conduits as to rigidity

Conduits used for subsurface drains may be of several kinds of materials. One characteristic of these various conduits which is important in determining the load-bearing strength is the degree of flexibility. Two classes of conduits according to their flexibility are as follows (11):

1. Rigid conduits, such as concrete, or clay, fail by rupture of the pipe walls. Their principal load supporting ability lies in the inherent strength or stiffness of the pipe.

2. Flexible conduits, such as corrugated metal pipes, and certain types of plastic pipe fail by deflection. Flexible conduits rely only partly on their inherent strength to resist external loads. In deflecting the horizontal diameter increases, compresses the soil at the sides, and thereby builds up passive resistance which in turn helps support the vertically applied load.

Classification of conduits based on installation

Practically all of the conduits installed for drainage will be installed as ditch conduits. A ditch conduit is one which is installed in a relatively narrow trench dug in undisturbed soil and covered with earth backfill. Conduits installed in trenches wider than about two or three times the outside diameter of the conduit may be treated as projecting conduits. Refer to National Engineering Handbook, Section 6, Structural Design, for a comprehensive analysis of loads on underground conduits.

Bedding conditions for rigid ditch conduits. - The supporting strength of a conduit will vary with bedding conditions. Two types of bedding are generally used in drainage work and each has a load factor which, when multiplied by the three-edge bearing strength, will give the safe supporting strength of the conduit.

1. Impermissible bedding is that method of bedding a ditch conduit in which little or no care is given to shape the foundation to fit the lower part of the conduit or to refill all the spaces under and around the conduit with granular material. The load factor for this type of installation is 1.1.

2. Ordinary bedding is that method of bedding a ditch conduit in which the conduit is bedded with ordinary care in an earth foundation shaped to fit the lower part of the conduit for a width of at least 50 percent of the conduit breadth, and in which the remainder of the conduit is surrounded to a height of at least 0.5 foot above its top by granular materials that are shovel-placed and shovel-tamped to

Table 4-5, Maximum allowable trench depths

MAXIMUM ALLOWABLE TRENCH DEPTHS, RIGID CONDUITS

3-EDGE BEARING CRUSHING STRENGTH	TILE DIAMETER	TRENCH WIDTH (INCHES)							
		18	21	24	27	30	36	42	48
800	4,5,6	9	7	7	7	7	7	7	7
800	8	9	7	6	6	6	6	6	6
800	10	10	7	6	5	5	5	5	5
800	12		7	6	5	5	5	5	5
840	14			6	5	5	5	5	5
870	15			6	5	5	5	5	5
1000	6	19	9	8	8	8	8	8	8
1000	8	19	9	7	7	7	7	7	7
1100	4,5,6	25+	11	9	9	9	9	9	9
1100	8	25+	11	8	7	7	7	7	7
1100	10	25+	11	8	7	6	6	6	6
1100	12		11	8	7	6	6	6	6
1100	15			8	7	5	5	5	5
1150	15			9	7	6	5	5	5
1200	12		14	9	7	6	6	6	6
1200	16			10	8	7	5	5	5
1200	18				8	7	5	5	5
1250	4,5,6	25+	16	11	11	11	11	11	11
1300	4,5,6	25+	18	11	11	11	11	11	11
1300	8	25+	18	11	8	8	8	8	8
1300	18				9	7	5	5	5
1350	8	25+	22	11	9	9	9	9	9
1400	4,5,6	25+	25+	12	10	10	10	10	10
1400	10	25+	25+	12	9	8	8	8	8
1400	15			13	9	8	6	6	6
1450	4,5,6	25+	25+	13	11	11	11	11	11
1500	8	25+	25+	14	10	9	9	9	9
1500	12			14	10	8	7	7	7
1550	10	25+	25+	15	11	9	8	8	8
1600	4,5,6	25+	25+	16	12	12	12	12	12
1600	8	25+	25+	16	11	10	10	10	10
1600	10	25+	25+	17	11	9	9	9	9
1600	14			17	12	8	7	7	7
1650	15			19	12	10	7	7	7
1700	8	25+	25+	25	12	11	11	11	11
1700	12			25	12	10	8	8	8
1700	16			25	13	11	8	7	7
1700	18				13	11	8	7	7
1750	15			25	14	11	8	7	7
1800	8	25+	25+	25+	14	11	8	8	8
1800	12			25+	15	11	8	7	7
1800	18				15	11	8	7	7
1850	14				15	11	8	8	8
2000	4,5,6	25+	25+	25+	19	14	14	14	14
2000	8	25+	25+	25+	19	12	12	12	12
2000	10		25+	25+	19	13	10	10	10
2000	18				20	14	9	7	7

Based on: K_u & K_u' = 0.13, Load Factor 1.5, Safety Factor 1.5, weight of soil - 120 lb./cu.ft.

REFERENCE: Technical Release No. 5. This chart was developed by Guy B. Fasken.

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING DIVISION - DRAINAGE SECTION

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completely fill all spaces under and adjacent to the conduit. The load factor for this type of installation is 1.5.

When sand and gravel filter or envelopes are used, the foundation need not be shaped since the filter and envelope material are placed entirely around the conduit and provide for lateral pressures on the conduit. With this type of installation the supporting strength of the conduit is increased above the three-edge bearing strength. Depending on its gradation and the care used in placing the sand-gravel filter or envelope, the load factor will be in the range of 1.2 for a poorly graded envelope of irregular thickness to 1.5 for a well-graded filter of uniform thickness around the drain. To be effective the filter or envelope should have a minimum thickness of 3 inches.

Trench depth for rigid conduits. - Table 4-5 was prepared for various sizes of conduits, types of conduits, trench widths, and types of bedding. The table is based upon a soil weight of 120 pounds per cubic foot and includes a safety factor of 1.5.

Bedding conditions for flexible drainage tubing. - A flexible conduit has relatively little inherent load-bearing strength, and its ability to support soil loadings in a trench must be derived from pressures induced as the sides of the conduit deflect and move against the soil. This ability of a flexible conduit to deform and utilize the soil pressure to support it is the main reason that light-weight plastic drainage tubing can support soil loadings imposed in drainage trenches.

A flexible tubing must be installed in a trench in a way which insures good soil support from all sides. There must be no voids remaining which would permit the soil pressure from backfill to cause deflection of the tubing to the point of buckling. Most installations will be made with machinery, without requiring a man in the trench to position the tubing or place the bedding. Some modification of machinery designed for installation of rigid conduits usually is necessary to install flexible conduits efficiently. See the section on installation of corrugated plastic drainage tubing, page 4-111.

Drain grades and velocities

Subsurface drains are placed at rather uniform depths; therefore, the topography of the land may dictate the range of grades available. There is often an opportunity, however, to orient the drains within the field in order to obtain a desirable grade. The selected grades should, if possible, be sufficient to result in a nonsilting velocity which experience has shown is about 1.4 feet per second, but less than that which will cause turbulence and undermining of the drain. Where siltation is a hazard (refer to Table 4-7, page 4-91), and the velocity is less than 1.4 feet per second, siltation may be prevented by use of filters and silt traps.

Where siltation is not a hazard, the recommended minimum grades are as follows:

	Percent
4" drain	.10
5" drain	.07
6" drain	.05

On sites where topographic conditions require the use of drains on steep grades which will result in velocities greater than shown in the following table, special measures should be used to protect the line.

Soil Texture	Velocity-ft./sec.
Sand and Sandy Loam	3.5
Silt and Silt Loam	5.0
Silty Clay Loam	6.0
Clay and Clay Loam	7.0
Coarse Sand or Gravel	9.0

The protective measures may include one or more of the following:

1. Use only drains that are uniform in size and shape and with smooth ends.

2. Lay the drains so as to secure a tight fit with the inside diameter of one section matching that of the adjoining sections.

3. Wrap open joints with tar impregnated paper, burlap, or special filter material such as plastic or fiber-glass fabrics.

4. Select the least erodible soil available for blinding.

5. Use long sections of perforated pipe or tubing. (Bituminized fiber, plastic, asbestos cement, etc.).

Table 4-6 gives the grades for different sizes of drains which will result in the critical velocities discussed above. Data is given for drains with "n" values of 0.011 to 0.015.

Determining drain size

Drains ordinarily are not designed to flow under pressure and the hydraulic gradient is considered to be parallel with the grade line. The flow in the drain is considered to be open-channel flow. The size of drain required for a given capacity is dependent on the hydraulic gradient and the roughness coefficient--"n" value-- of the drain. Materials commonly used for drains have "n" values ranging from about 0.011 for good quality clay and concrete tile with good joint alignment to about 0.016 for corrugated plastic drainage tubing. When determining the size of drain required for a particular situation the "n" value of the product to be used must be known. The size drain required for a given capacity and hydraulic gradient and for three different "n" values may be determined from Figure 4-36 (sheets 1, 2, and 3). The shaded area in the charts indicates where the velocity of flow is less than 1.4 feet per second to indicate where drain filters may be required.

Example:

A drain on a 0.2 percent grade (s = 0.002) is required to discharge 1.5 cubic feet per second. What size drain will be required if the drain to be used has a roughness coefficient of 0.011? Find the hydraulic gradient of 0.002 on the horizontal scale in Figure 4-36 and follow vertically upward to intersect the line representing a discharge of 1.5 cubic feet per second. This point falls in the space between the lines marked 10 to 12 inches in diameter. A 12-inch drain is required. Since the point of intersection is below the line marked 12 inches, the drain will not flow full. The full capacity of the drain is 1.9 cfs. The drain will flow about 79 percent full for the design discharge. The same procedure is followed when using Figure 4-36 (sheets 2 and 3) for roughness coefficients of 0.013 and 0.015.

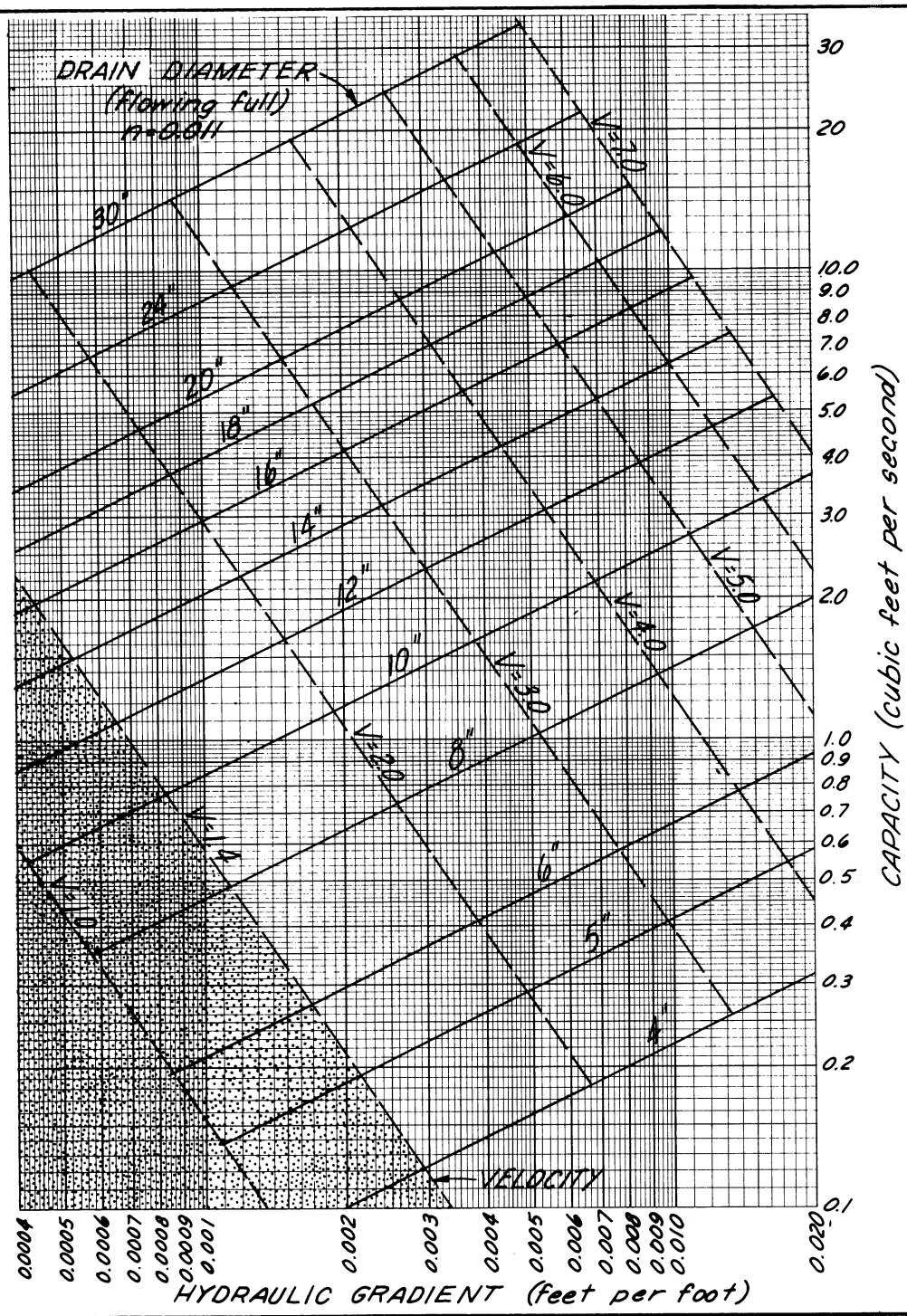
Table 4-6 - Drain grades and velocities

Drain Size Inches	Grade - feet per 100 feet					
	1.4 fps	3.5 fps	5.0 fps	6.0 fps	7.0 fps	9.0 fps
	For drains with "n" = 0.011 1/					
4	.28	1.8	3.6	5.1	7.0	11.5
5	.21	1.3	2.7	3.9	5.3	8.7
6	.17	1.0	2.1	3.1	4.1	6.9
8	.11	0.7	1.4	2.1	2.8	4.6
10	.08	0.5	1.1	1.5	2.1	3.5
12	.07	0.4	0.8	1.2	1.6	2.7
	For drains with "n" = 0.013					
4	.41	2.5	5.2	7.5	10.2	16.8
5	.31	1.9	3.9	5.6	7.7	12.7
6	.24	1.5	3.1	4.4	6.0	10.0
8	.17	1.0	2.1	3.0	4.1	6.8
10	.12	.8	1.6	2.2	3.0	5.0
12	.09	.6	1.2	1.8	2.4	3.9
	For drains with "n" = 0.015 2/					
4	.53	3.3	6.8	9.8	13.3	21.9
5	.40	2.5	5.1	7.3	9.9	16.6
6	.32	2.0	4.0	5.8	7.9	13.2
8	.21	1.3	2.7	3.9	5.3	8.8
10	.16	1.0	2.0	2.9	4.0	6.6
12	.13	.8	1.6	2.3	3.1	5.1

1/ $v = 138\ r^{2/3}S^{1/2}$ - Laboratory "n" value = .01077

2/ $v = 100\ r^{2/3}S^{1/2}\ \frac{1.486}{.015} = 99.06$ - rounded to 100

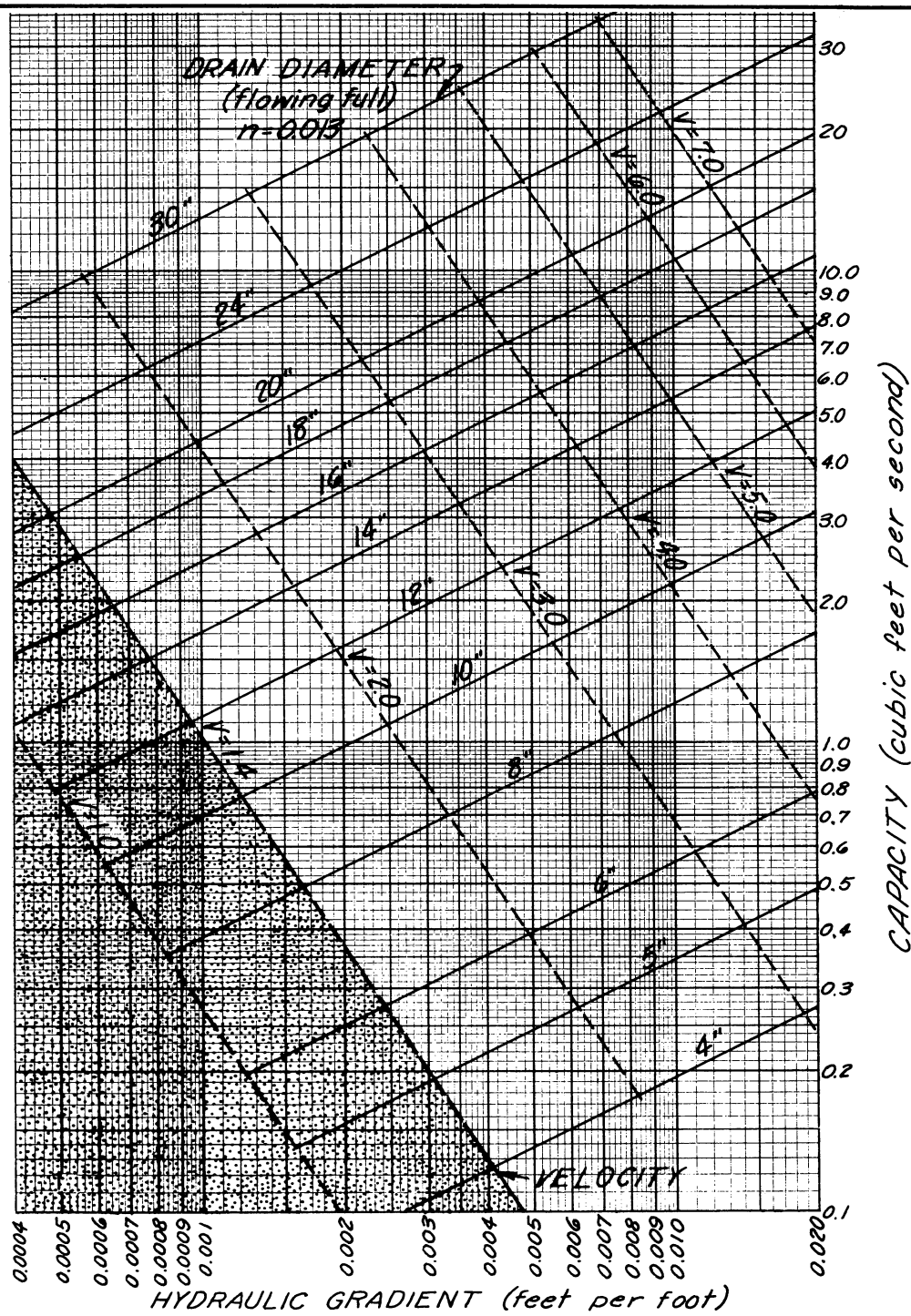
DRAIN CAPACITY CHART – n = 0.011



REFERENCE: This chart was developed by Guy B. Fasken.	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DRAINAGE SECTION	STANDARD DWG. NO. ES - 721 SHEET 1 OF 3 DATE 8-3-70

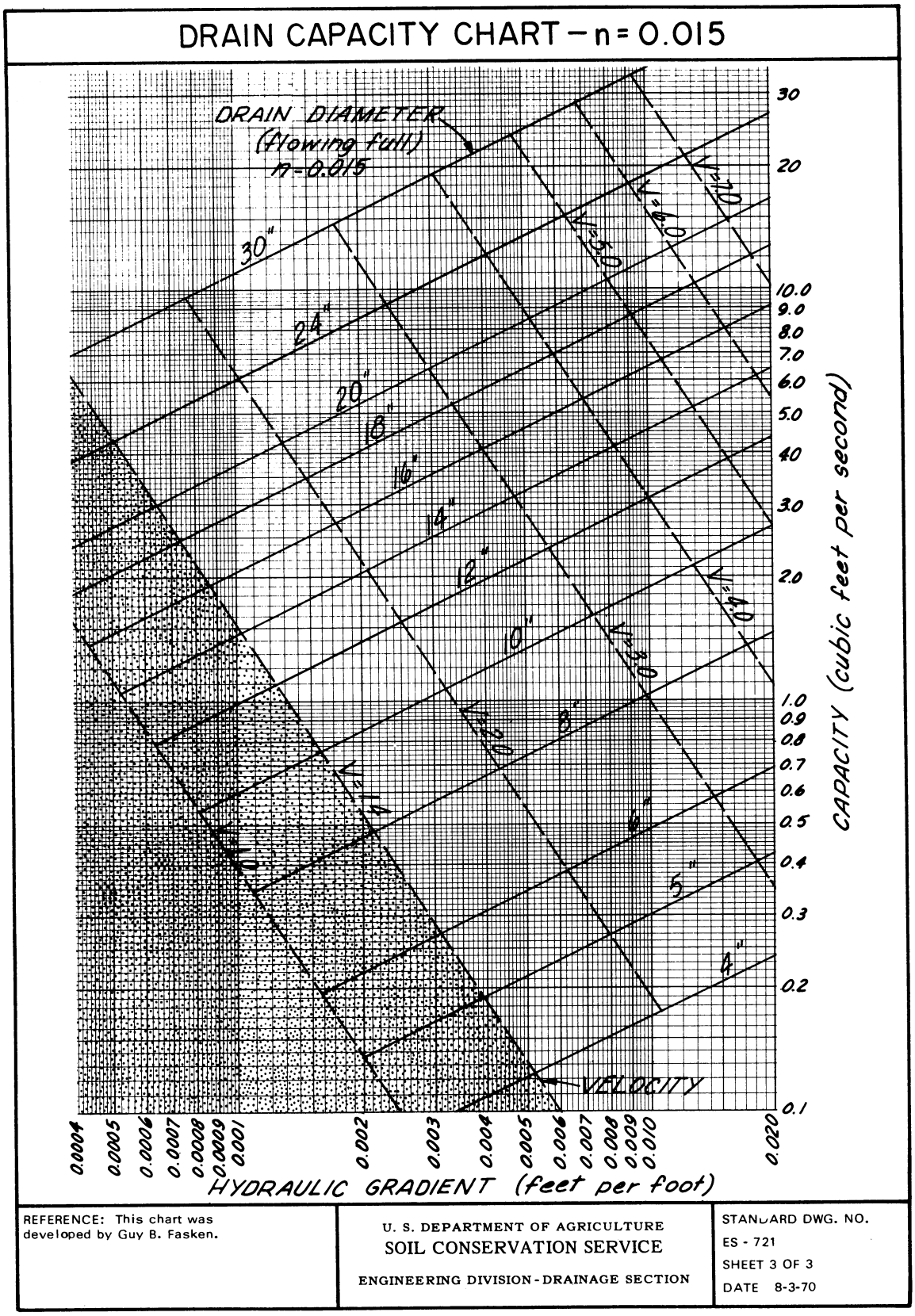
Figure 4-36, Capacity chart - n = 0.011

DRAIN CAPACITY CHART – n = 0.013



REFERENCE: This chart was developed by Guy B. Fasken.	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DRAINAGE SECTION	STANDARD DWG. NO. ES - 721 SHEET 2 OF 3 DATE 8-3-70

Figure 4-36, Capacity chart - n = 0.013



REFERENCE: This chart was developed by Guy B. Fasken.

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Figure 4-36, Capacity chart - n = 0.015

Sizing of drains within the drainage system

The previous discussion on drain size deals with the problem of selecting the proper size for a drain at a specific point in the drainage system. In drainage systems with long laterals or mains, the variation of flow within a single line may be great enough to warrant changing size in the line. This is often the case in long interception drains. The following example illustrates a method for making such a design.

Example:

Assume that the total discharge from 6,000 feet of interception drain was computed to be 2.40 cfs, that no surface water is admitted, and (with similar soils and subsoils) that the accretion to the drain is uniform throughout its length. Assume a constant grade of 0.20 percent. The accretion per 100 feet of drain would be $\frac{2.40}{60}$ = 0.04 cfs. Use Figure 4-36 to determine the sizes of concrete or clay drain tile required. Start computation at the upper end of the drain using a minimum size of 6 inches. Compute the distance down drain that it would carry the flow on the assumed grade. Let (L) equal the distance (in 100-foot stations) down drain that a 6-inch drain would be adequate. Referring to Figure 4-36, a 6-inch drain on a grade of 0.20 percent has a maximum capacity of 0.31 cfs and:

$$L = \frac{0.31}{0.04} = 7.75\text{--100-foot stations}$$

The 6-inch drain is adequate for 775 feet of line. Continuing these computations for the next size drain (8 inch) which has a maximum capacity of 0.65 cfs as follows:

$$L = \frac{0.65}{0.04} = 16.25\text{--100-foot stations}$$

The 8-inch drain would be adequate for 1,625 feet. Of this 1,625 feet, it has already been determined that 775 feet would be 6-inch drain; therefore, the remaining 850 feet would be 8-inch drain. These computations should be continued progressively for the total length of the drain. The following tabulation shows the complete problem:

Tile Size	Maximum Capacity .20% Grade	Accretion per 100' Line	L-Value Number of 100 Foot	Length of Tile Required
inches	c.f.s.	c.f.s.	stations	feet
6	0.31	0.040	7.75	775
8	0.65	0.040	16.25	850
10	1.30	0.040	32.50	1,625
12	1.90	0.040	47.50	1,500
14	2.90	0.040	72.50	1,250 1/
				6,000

1/ Total length of the drain is 6,000 feet, and although the 14-inch tile would be adequate for 7,250 feet, only 1,250 feet are needed.

The example assumes a single line with uniform accretion throughout its length. If investigations indicate a variation in permeability, the accretion rate per 100-foot station may be varied. If laterals enter the drain, the estimated yield of these should be added at the proper station. The example illustrated is for a single interception drain. The same procedure is applicable for mains in a relief system where laterals join at regular intervals. In this case the accretion to the main would be the accumulative discharges of each of the laterals at intervals equal to the drain spacing.

The size of drain for a main drain line can be found by determining the required capacity at various points along the main, and the size required for the capacity and grade at the point. The drainage area or the accretion at each break in the drain grade must be known. Usually the drainage coefficient for a system is the same for the entire system but in some cases the coefficient may vary and this must be considered in determining the drain size.

Materials for drains

General

For many years after subsurface drainage was first introduced in the United States most of the drains were made of ceramic tile. "Tile drain" became the most common term used to refer to a subsurface drain, and it is still used in many parts of the country to refer to subsurface drains manufactured from all kinds of materials.

Materials now commonly used for drains include ceramic tile, concrete, bituminized fiber, plastics, asbestos cement, aluminum alloy, and steel. Some of the products manufactured from these materials are made in such a way that drainage water will enter the conduit through the joint between adjacent sections of the drain, and some are made with perforations through which water enters the drain.

Factors involved in the selection of the drain to be used include: climatic conditions, chemical characteristics of the soil, depth requirements, and installation cost. In northern areas freezing and thawing conditions must be considered in selecting the drain. Where acids or sulfates exist in the soil or drainage water, drains that will resist these conditions must be selected. The method of installation and the depth requirements influence the selection of the type and strength of the drain. The drain must sustain the loads to which it will be subjected. The cost of the drain including the cost of transportation from the manufacturer to the place of installation is a big factor in selection of drains.

Standards and specifications

Specifications covering the physical requirements and testing methods for use in quality control of drains have been developed by several organizations and groups interested in standardization and maintenance of high quality for manufactured products. These include specifications and standards of the American Society for Testing and Materials (ASTM); Product Standards published by the National Bureau of Standards, U. S. Department of Commerce; and Federal Specifications of the Federal Supply Service, General Services Administration.

These specifications and standards are revised as necessary to reflect improved methods of manufacture, new materials, and changed requirements for use of the product. The latest revision, which is indicated by its date, should be used. Specifications for materials which are approved for use in installations for which the Soil Conservation Service is technically responsible are listed in current Engineering Practice Standards of the Soil Conservation Service.

Newly developed products, for which specifications are written by the manufacturer and approved by the Soil Conservation Service, may also be used pending development of standard specifications by one of the organizations listed above.

Clay drain tile

Clay tile may fail due to the freezing and thawing reversals in northern areas where frost penetrates the ground to the depth of the tile or where the tile is stockpiled on the ground during the winter before being installed. Damages due to such exposure may be serious. The absorption of water by tile is a good index of its resistance to freezing and thawing. Tile manufactured from shale usually has lower absorption rates and is more resistant to freezing and thawing than tile made from surface clays. The quality of clay tile is also dependent upon the manufacturing process. Many plants use de-airing equipment which increases the density of the extruded material. Generally color and salt glazing are not reliable indicators of the quality of tile. Clay tile are not affected by acids or sulfates. Low temperatures normally will not affect the use of clay tile provided the tile are properly selected for absorption and that care is taken in handling and storage of the tile during freezing weather.

Concrete drain tile

Concrete tile of high density are not affected by freezing and thawing reversals and freezing temperatures. It will be adversely affected, however, if exposed to the action of acids or sulfates unless the tile has been manufactured to meet these situations. Concrete tile is not recommended for extremely acid or sulfate conditions. Research (13, 14) by Dalton G. Miller and Phillip W. Manson has provided information on which guide lines have been adopted for the quality of concrete in drain tile for installation in acid and sulfate soils.

The following guide may be used for obtaining soil samples and tests for determining acid or sulfate concentration at the site for a tile installation:

1. Take samples where soil conditions indicate the probability of moderate to severe concentration of acids or sulfates in the soil.

2. Take each sample at the average depth of tile at the approximate location of tile line.

3. Take a minimum of three samples but not less than one sample for each 10 acres drained or 1,500 feet of tile.

4. Obtain the pH and sulfate test for each sample. Record individual test values. If the results of most severe acid or sulfate condition appear out of line, obtain additional samples and check results.

Recommendations for a particular type and quality of tile to meet certain conditions of acid or sulfate soils are based on the specifications for the particular type of tile. As these are subject to change, guidance for selection of a type or quality of tile for use under certain conditions may be obtained from engineering practice standards of the Soil Conservation Service.

Bituminized fiber pipe

Bituminized fiber pipe may have a homogeneous or laminated wall structure. The pipe comes in various lengths from 4 to 20 feet. The pipes are connected by tapered couplings to form a watertight joint, or with a sleeve coupling for butt joints. This pipe, without perforations, may be used to protect the outlet of drains of other material. However, the out-of-bank projection of bituminized fiber pipe must be kept short, not more than 3 to 4 diameters in

length to maintain its shape against softening and collapse by exposure to the heat of the sun. Precautions must also be taken against any point loading against the pipe walls by a stone or buried log which can cause failure by cold flow of the bituminous material.

Plastic drains

Various kinds of drains made from different types of plastics have been produced. Plastic drains are flexible conduits that will develop good load-bearing strengths if they are installed in a way which will insure that the drain will be supported by the soil around it as the drain deforms.

Plastics have been used to produce corrugated drains with relatively thin walls which have a high load-bearing strength when properly installed. The depth to which the corrugated plastic drains may be installed depends upon the width of the trench and the manner of bedding the drain.

Metal pipes and others

In drainage work metal pipe is used chiefly for the following purposes:

1. As outlets for tile and plastic drains.

2. As a substitute for other types of drains which do not have enough strength to withstand surface loads where sufficient cover of soil is impossible to obtain.

3. Under road crossings where additional load-bearing strength is required.

4. For auxiliary structures.

5. For installation through pockets of quicksand or similar unstable soils where a continuous pipe without joints is required.

Filters and envelopes

Filters for drains are permeable materials placed around the drains for the purpose of preventing fine-grained materials in the surrounding soils from being carried into the drain by ground water.

Envelopes for drains are permeable materials placed around the drains for the purposes of improving flow conditions in the area immediately surrounding the drain, and for improving bedding conditions.

Determination of need for filters and envelopes

In designing a drainage system one of the first considerations is to determine if a filter is needed. Referring to Table 4-7, it will be noted that soils are separated into three groups (Unified Classification System) according to the need for a filter. The first group always needs a filter. The second group may or may not need filters and the third group seldom needs filters except under unusual conditions.

Determination of the need for envelopes must be secondary to that for filters as filters often will serve the same purpose. The need for an envelope should be considered in those cases where a filter is not specified, and where flexible pipe is used for the drain. Referring to Table 4-7, it will be noted that envelopes may be used in all cases where filters are not recommended.

Table 4-7, The need for drain filters or envelopes

A CLASSIFICATION TO DETERMINE THE NEED FOR DRAIN FILTERS OR ENVELOPES, AND MINIMUM VELOCITIES IN DRAINS

Unified Soil Classification	Soil Description	Filter Recommendation	Envelope Recommendation	Recommendations for Minimum Drain Velocity
SP (fine) SM (fine) ML MH	Poorly graded sands, gravelly sands. Silty sands, poorly graded sand-silt mixture. Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity. Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.	Filter needed	Not needed where sand and gravel filter is used but may be needed with flexible drain tubing and other type filters.	None
GP SC GM SM (coarse)	Poorly graded gravels, gravel-sand mixtures, little or no fines. Clayey sands, poorly graded sand-clay mixtures. Silty gravels, poorly graded gravel-sand silt mixtures. Silty sands, poorly graded sand-silt mixtures.	Subject to local on-site determination.	Not needed where sand and gravel filter is used but may be needed with flexible drain tubing and other type filters.	With filter - none. Without filter - 1.40 feet/second.
GC CL SP,GP(coarse) GW SW CH OL OH Pt	Clayey gravels, poorly graded gravel-sand-clay mixtures Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays. Same as SP & GP above. Well graded gravels, gravel-sand mixtures, little or no fines. Well graded sands, gravelly sands, little or no fines. Inorganic, fat clays Organic silts and organic silt-clays of low plasticity. Organic clays of medium to high plasticity. Peat	None	Optional. May be needed with flexible drain tubing.	None - for soils with little or no fines. 1.40 feet/second for soils with appreciable fines.

REFERENCE: This chart was developed by William F. Long and Ralph Brownscombe.

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Their need should be based on consideration of soil permeability and the bedding requirements of the drain.

The last column in Table 4-7 gives recommendations for the minimum velocity in drains to prevent sediment from being deposited in the drain. It will be noted that where filters are specified there is no recommendation for minimum velocity.

Materials for filters and envelopes

A material may have characteristics which meet the requirements of both a filter and an envelope for a particular site condition. Well graded sand-gravel materials often have these characteristics. Other materials, which may be less costly, may be suitable for only one purpose. It is necessary, therefore, to determine the requirements of a particular installation and specify a material which will meet the requirements.

The specifications for granular filter materials are more rigid than for envelope materials and often it is necessary that they be screened and graded to develop the desired gradation characteristics. Envelope materials usually are available in their natural state at low cost without processing. However, if the envelope material contains fine material which may enter the drain, or seal the joints, these fines should be screened out before using the material. Filter materials with the proper gradation are available in the natural state at some locations but frequently it is necessary to do some processing, which usually increases the cost materially. For this reason it is important that the requirement for sand and gravel filters or envelopes be clearly specified on all plans for buried drains.

In humid areas, where soils have a high content of organic material, it is a common practice to blind the drain with topsoil shaved from the top and sides of the trench. This topsoil often has a high permeability and serves as an envelope and a filter to some degree. Organic materials such as hay, straw, sawdust, wood chips, and ground corncobs also are used to some extent and are effective for a limited period of time. Organic matter should be kept away from the drain in those areas where soil contains iron or manganese compounds. Organic matter around the drain adds to the problem of chemical deposits clogging the soil immediately adjacent to the drain, the joints, and the perforations in the drain. Sand and gravel and fiber glass are used to a limited extent in humid areas for filters.

In arid areas soils generally are mineral soils with a low organic content and generally are not suitable as filter material. Blinding is practiced only to prevent displacement of the drain during backfill operations. Sand and gravel filters and envelopes are used extensively in the arid areas. Fiber-glass filters have been used to a very limited extent.

Organic filters and envelopes. - Of all the organic filter and envelope materials, organic soils are most commonly used. Organic soils used to blind the drain also serve as a partial filter. The exact filtering quality of organic soils is unknown and there is no feasible method of measuring this. From long experience it is known that drains blinded with good organic soils have a better record of performance than those without such blinding. This also is true for drains blinded with other organic materials such as hay, straw, sawdust, wood chips and corncobs. The relative filtering qualities of these materials varies with particle size gradation. The coarser materials such as wood chips and corncobs have a low filter value but do serve as an envelope to improve hydraulic conditions in the area surrounding

the drain. The use of these materials is not objectionable but there is some question as to their value under certain circumstances. The practice of blinding with organic topsoil is recommended except as noted above where there is a problem of chemical deposits around the drain. Blinding is essential to maintain drain alignment and the filtering effect obtained is a cost-free by-product of the blinding operation. In summary, it is recognized that organic filters and envelopes, as discussed above, have some value as a filter but the specific value is unknown and not measurable. For this reason drains in critical soils known to be subject to piping should be protected with other types of filter material with measurable and known qualities.

Fiber-glass filters. - Fiber-glass filters are manufactured from glass products and are commercially available in rolls for various size drain and trench width. There are currently several types of this material available, varying in thickness from paper thin to about 1 inch. Lime-borosilicate glass is the only type of glass suitable for use in underground filters.

Fiber-glass filters, or mats as they are often called, are a nonwoven fabric and the size of openings varies from point to point within the material. For this reason the size of particles that will pass through the filter are not uniform but have some gradation. Recommendations for use of a particular type of fiber-glass filter should be based on experience and available research.

Plastic-fabric filters. - Several new plastic fabrics have recently become commercially available as filter material. Polypropylene, polyvinylidene, and polyethylene filter material also are available. Although research and experience with these to date is limited the product data available indicate that they are useful as filters for drains.

Sand and gravel filters and envelopes. - Sand and gravel filters and envelopes are used extensively in arid areas with mineral soils of low organic content. Sands and gravels suitable for filter and envelope material are readily available in their natural state in many areas. Where pit-run sand and gravel are poorly graded and not suitable for filter material, it is necessary to process it prior to use. On large projects where a considerable volume of filter material is needed, it may be desirable to set up a local screening plant for this purpose. On small projects it usually is more economical to purchase the desired gradation of filter material from a commercial sand and gravel plant. Experience with all types of drain filters indicates that sand and gravel filters have performed the best. This type of filter should be given first consideration for use.

Design of filters and envelopes

Design of sand and gravel filter. - The first step in selecting an acceptable sand and gravel material for a filter is to determine, by mechanical analysis, the gradation curve of the base material. The base material is the soil found at the depth the drain is to be laid. Samples of the base material should be obtained and a mechanical analysis made. The number of samples taken depends on variations in the base material. The following design criteria are based on research by the U. S. Bureau of Reclamation and the Corps of Engineers, U. S. Army. Limits are established which should be met by a filter material for a specific base material. Multiplying the 50-percent grain size of the base soil material by 12 and 58 will give the limits the 50-percent size of the filter should fall within. Multiplying the 15-percent fine size of the base soil material by 12 and 40 gives the limits the 15-percent fine size of the filter should fall within. The gradation curve of the filter material should generally parallel that of the base material. All of the filter

material shall pass the 1 1/2-inch sieve, 90 percent of the material shall pass the 3/4-inch sieve and not more than 10 percent of this material shall pass the No. 60 sieve. The maximum size limitation insures against damage to drains or alignment or too much segregation during placement, and the No. 60 sieve limitation prevents an excess of fines in the filter, which are more easily carried by water percolating into the drain. These limits are summarized as follows:

$$\frac{\text{50-percent size of filter}}{\text{50-percent size of base}} = 12 \text{ to } 58$$

$$\frac{\text{15-percent fine size filter}}{\text{15-percent fine size base}} = 12 \text{ to } 40$$

Where the filter and base material are more or less uniformly graded, a filter stability ratio of less than 5 is generally safe, thus

$$\frac{\text{15-percent fine size filter}}{\text{85-percent fine size base}} = \text{less than } 5.$$

Figure 4-37 illustrates the use of the criteria where three filter materials have been graded to determine their suitability.

In locations where sand-gravel filters are commonly used, it is recommended that gravel pits be selected, mechanical analyses made, and the gradation and limiting curves prepared for each pit. A filter guide may be established by preparing gradation curves of base material, and by comparison with the pit curves, the most desirable pit material can be selected. For routine agricultural-drainage installations, many pit-run gravels are adequately graded to do a reasonably good job of filtering; but sample analyses should be made.

Where sand and gravel filter material is to be placed around perforated drains, consideration must be given to the diameter of the perforations as these are fixed and cannot be varied as the gap-space can in the case of butt-end tile. Where perforated drains are used, the D_{85} (85% fine line) size should be no smaller than one-half the diameter of the perforations and no more than 10 percent of the filter material should pass the No. 60 sieve.

Where sand and gravel filters are used, the thickness of the filter material around the drain should be 3 inches or more. In those cases where the top of the drain is covered with a plastic strip, the requirement for filter above the drain may be waived. This design will reduce the amount of filter material required and may be the most economical in areas where sand and gravel are expensive. Experience to date indicates that this is the best type of filter installation (Figure 4-38).

Design of fiber-glass filters. - All fiber-glass filter material must be fabricated from lime-borosilicate type glass. Experience with other types of glass has indicated that they are not suitable for use underground. Fiber-glass filter material is commercially available in several degrees of thickness, all of which have been used with varying degrees of success. As a general practice, these filters are placed over the top two-thirds of the circumference of the drain; however, in some cases the material has been placed completely around the drain. The use of fiber-glass filters for drains is rather new and at present there is not sufficient experience to indicate the expected life and durability of the material.

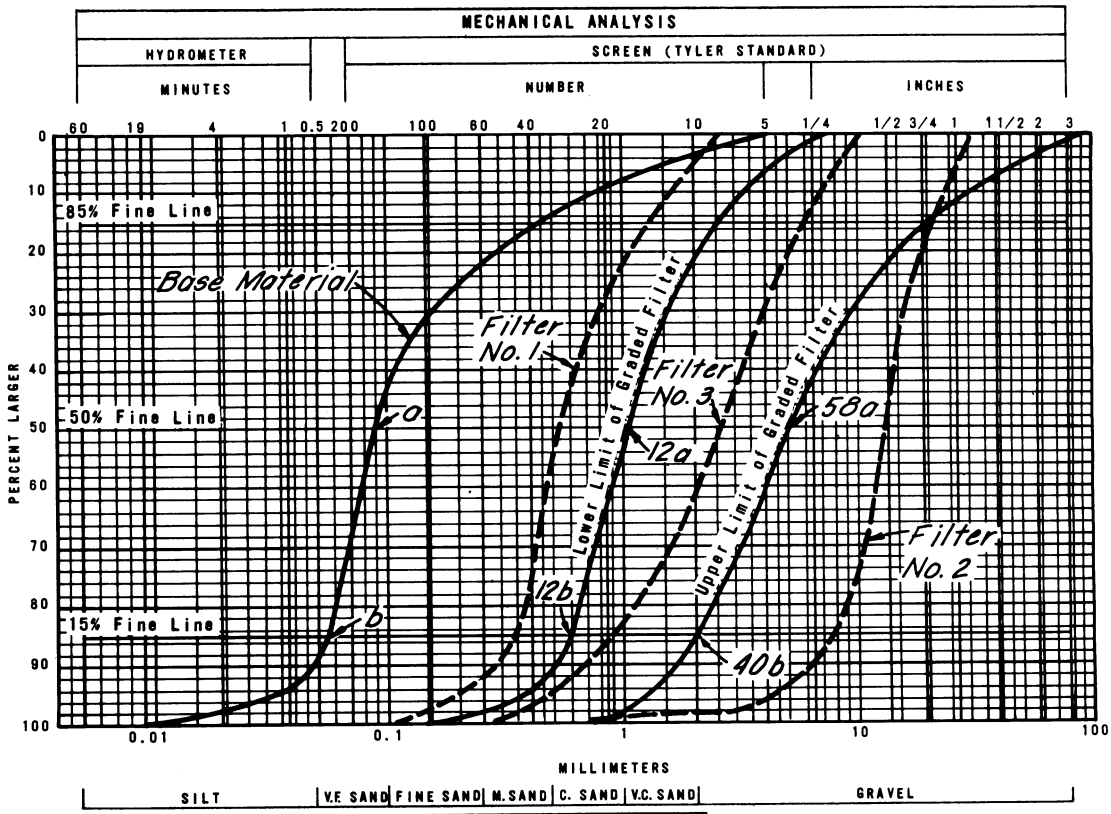
State _____ Area _____ District _____

Property *John Jones*

Location *T.13S., R.10E., SW¼ Sec.8* Date *4-9-70*

Base Soil Sample: No. 1 *4 to 6 Feet* No. 2 _____

Proposed Filters
- No. 1 *McGregor Pit*
- No. 2 *Wilson Pit*
- No. 3 *Jacob Pit*



MECH. ANALYSIS		BASE NO. 1 Ret.	BASE NO. 1 Acc.	BASE NO. 2 Ret.	BASE NO. 2 Acc.	FILTER NO. 1 Ret.	FILTER NO. 1 Acc.	FILTER NO. 2 Ret.	FILTER NO. 2 Acc.	FILTER NO. 3 Ret.	FILTER NO. 3 Acc.
SIEVE	1 1/2							0	0		
	1							2	2		
	1/2							44	46	0	0
	1/4	0	0					44	90	10	10
	5	1	1			0	0	9	99	18	28
	10	2	3			3	3	0	99	36	64
	20	7	10			23	26	0	99	23	87
	40	6	16			44	70	1	100	10	97
	60	6	22			24	94			2	99
	100	8	30			4	98			1	100
	200	34	64			2	100				
HYDROMETER	0.5	23	87								
	1	5	92								
	4	4	96								
	19	4	100								
	60										

Notes: *Filter No. 3 fits the base material curve better than 1 or 2 and should be specified as 1 and 2 do not fall within the 15 and 50 % bracket*

Recommended Filter *No. 3*

Figure 4-37, Mechanical analyses of gravel filter material

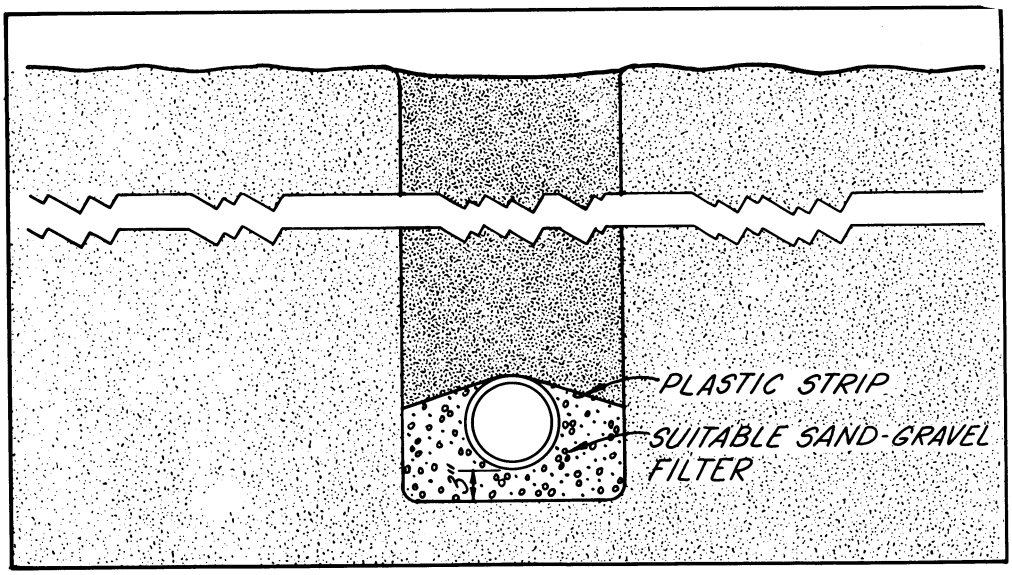


Figure 4-38, Filter installation

Design of organic filters. - Organic filters cover a wide range of materials from organic soils to sawdust and wood chips. The conditions and the results obtained over the country as a whole are so varied and different that it is impossible to discuss them in a limited space. Reference is made to state and local guides and handbooks.

Organic filters are usually thicker than other types. In general they vary from about 6 inches to 1 foot. The information on effectiveness must be based largely on local experience as there are no established methods to determine the filtering action of these materials in advance of design and construction.

Design of sand and gravel envelopes. - One of the basic functions of an envelope is to improve the permeability in the zone around the tile. For this reason the first requirement is that the envelope material have a permeability higher than the base material. All of the envelope material should pass the 1 1/2-inch sieve, 90 percent of the material should pass the 3/4-inch sieve, and not more than 10 percent of the material should pass the No. 60 sieve. The gradation of the envelope material is not important as it does not serve the purpose of a filter. The thickness of the envelope material surrounding the drain should not be less than 3 inches to insure complete placement. Amounts in excess of this are not objectionable but the economic feasibility is questionable.

In the case of interception drains on steep slopes, it may be desirable to place additional envelope material above the drain to prevent bridging-over of ground-water flow above the drain. Very little research information is available on this subject; however, indications are that this may occur where the hydraulic gradient of the water table exceeds 3 percent.

Drain appurtenances

Outlet structures. - When surface water must enter the ditch at the drain outlet, a structure should be used to discharge it into the ditch without erosion and to provide protection for the outlet of the drain. (Figure 4-39).

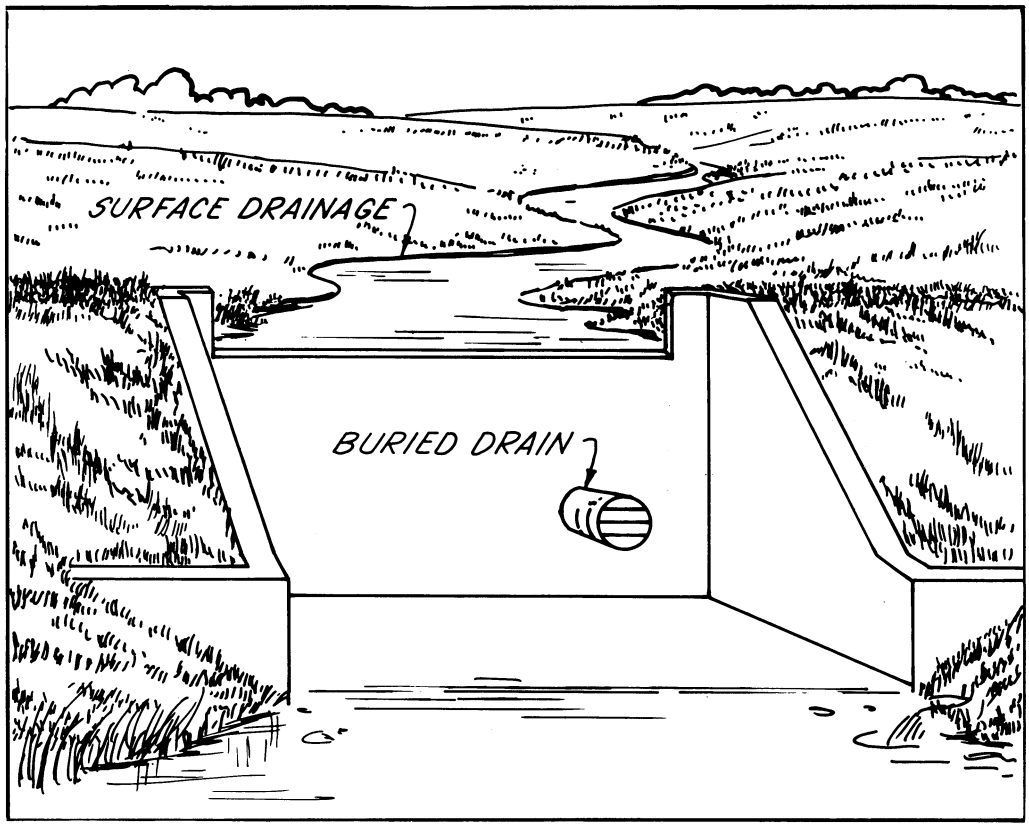


Figure 4-39, Outlet protection

When surface water is not involved, the most practical and economical outlet is a length of continuous pipe without perforations or open joints. The pipe should be sufficiently long to insure that there will be no seepage around the drain which may cause erosion at the outlet. At least two-thirds of the pipe should be embedded in the bank to provide the required cantilever support. An outlet into a recessed area off the ditch minimizes turbulence and provides protection from bank erosion, floating ice, and debris. When sufficient depth of cover is not obtainable at the drain outlet several methods may be used to protect the drain. (Figure 4-40).

Protection from animals. - Automatic flap gates, rods, or similar protection should be used on all drain outlets to exclude small animals unless the outlet is so located that it would be impossible for them to enter the drain. (Figure 4-41). No fixed bar or other type grating shown in this figure should be used where direct entry of surface water or any type debris is possible. Gates should be used in these cases.

Junction boxes. - Junction boxes should be used where more than two main drains join or where two or more laterals or mains join at different elevations. Where possible, junction boxes should be located away from farm traffic. The cover may be above ground so it can be seen and provide easy access for inspection. If the junction point is in a cultivated field, the top of the box should be set at least 18 inches below the surface of the ground, capped, covered with soil, and its location referenced so that it can be found easily. (Figure 4-42).

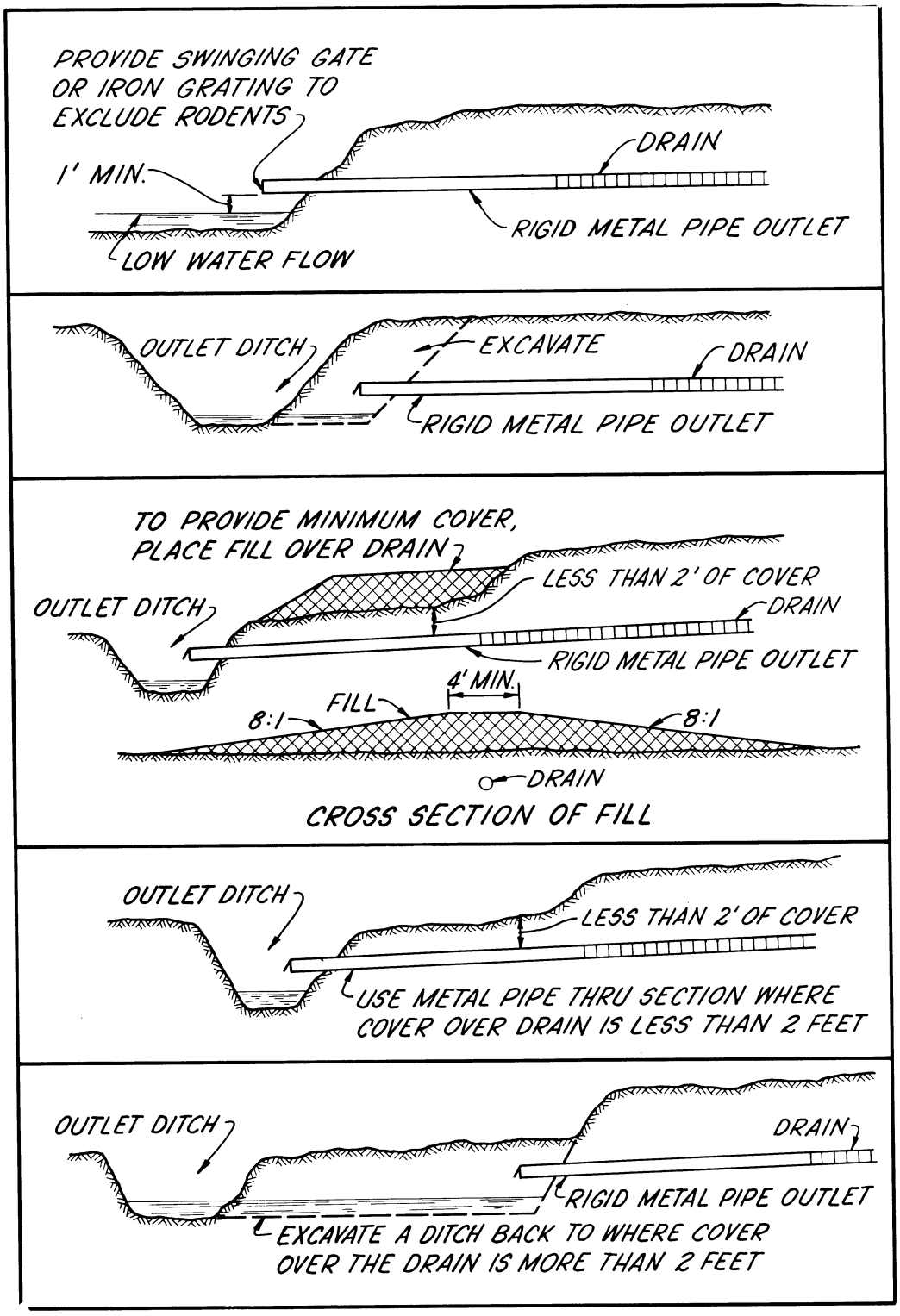


Figure 4-40, Drain outlets

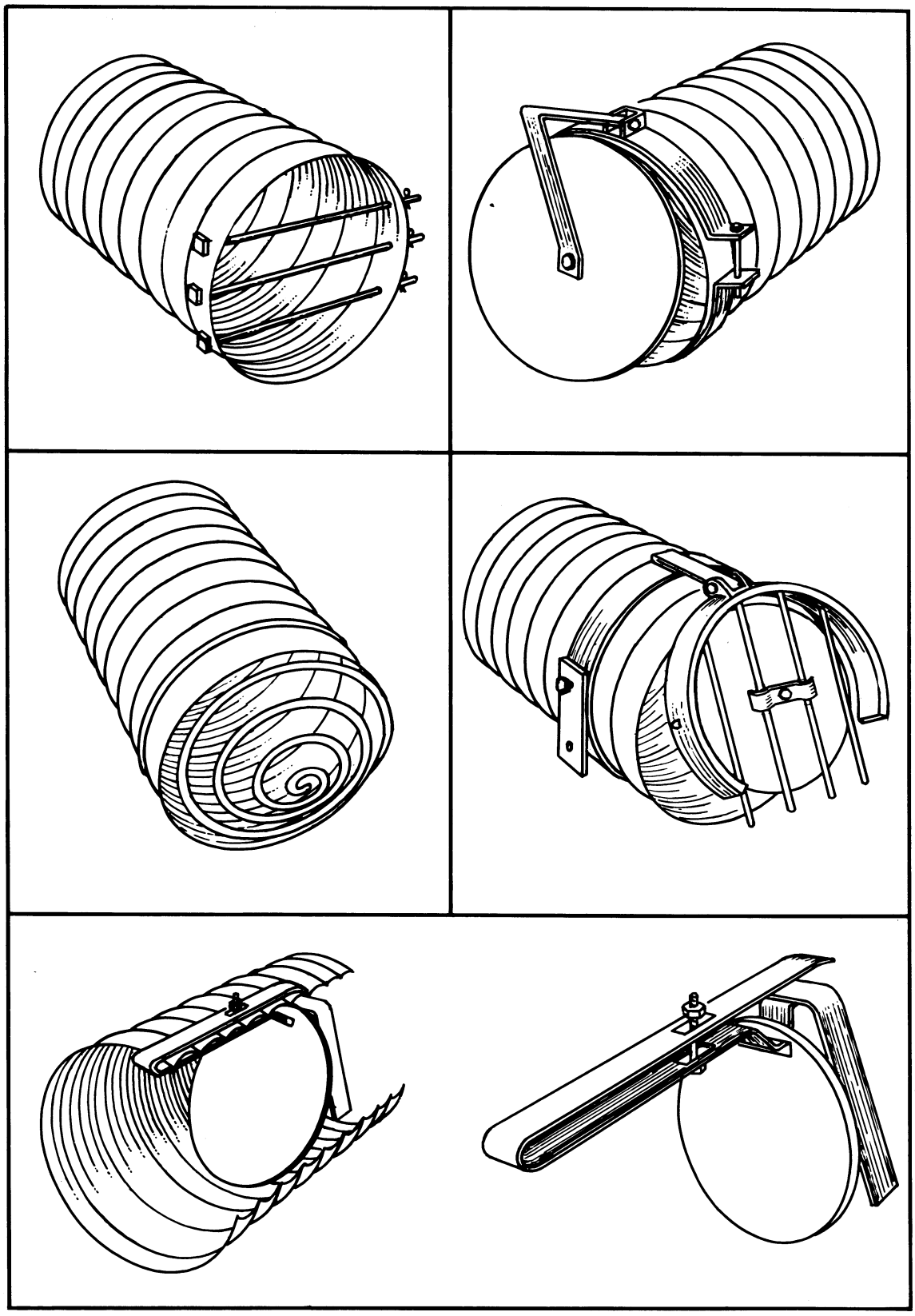


Figure 4-41, Rodent protection for outlet pipe

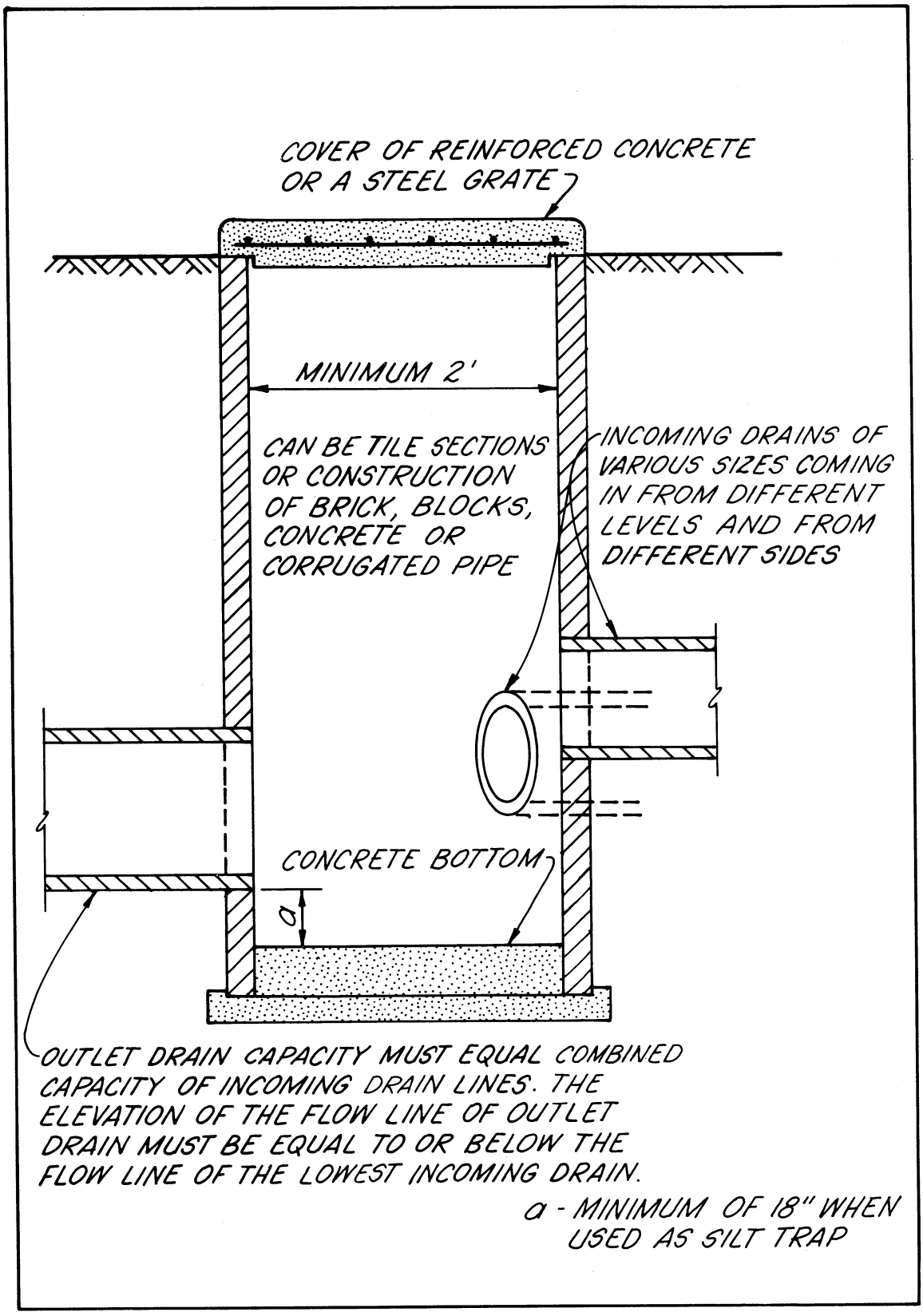


Figure 4-42, Junction box for drains

Pressure relief vent. - Vents serve to relieve pressure in the line that might otherwise cause erosion of the soil over the drain. This erosion results in holes which are known as "blowouts". These vents can be constructed by placing a T-connection in the line and cementing pipe vertically into the T. The relief pipe should extend at least 1 foot above the ground unless the design provides for it to serve also as a surface inlet. (Figure 4-43).

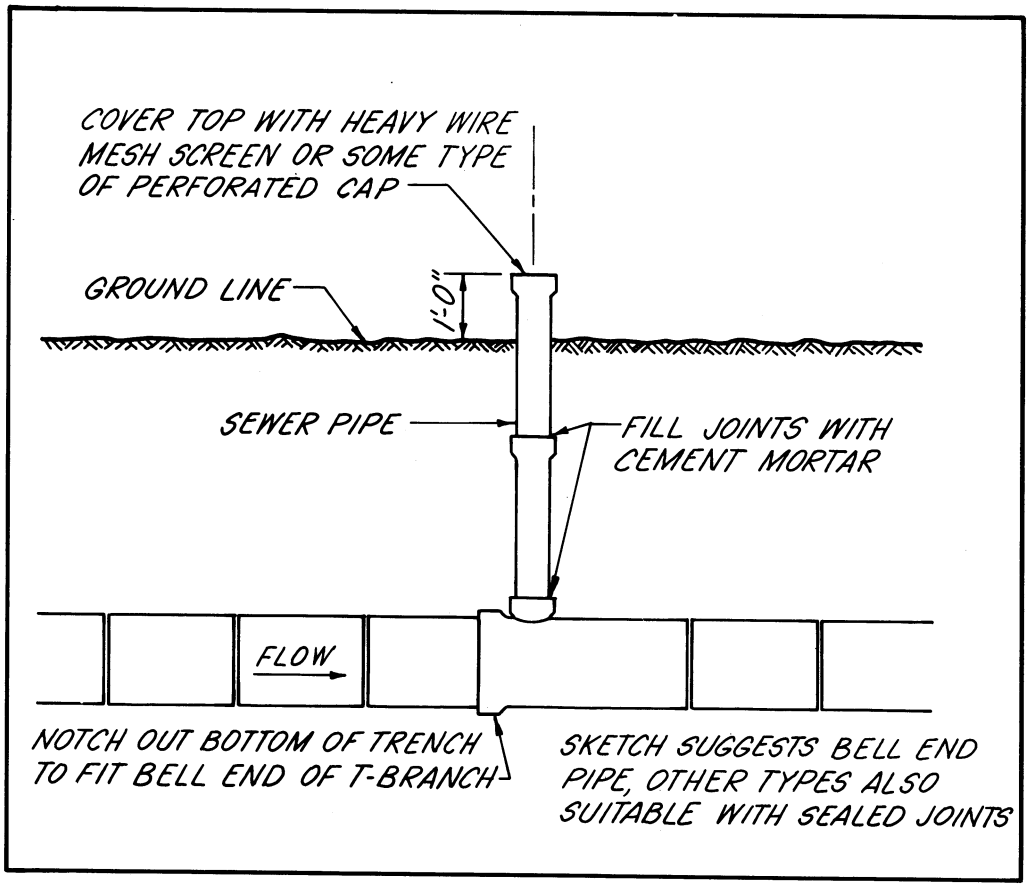


Figure 4-43, Vent

The exposed end of the pipe should be covered with heavy wire mesh or grating and firmly fixed to the pipe. The size of the riser pipe may be equal to or smaller in diameter than the drain. The illustration shows the use of sewer pipe to construct a vent. Other pipe such as concrete, bituminized fiber, or metal pipe may be used.

Vents should be located at points where the drain grade changes from a steep grade to a flat grade to eliminate the possibility of building up excessive pressures. Although the change in drain size is made at the break in grade to take care of the change in velocity, a vent will act as a safety valve and give added protection to these points. It is recommended that pressure relief vents be installed where the difference in grades exceeds 0.5 percent. Pressure relief vents will serve as breathers or inspection wells.

Breathers. - These are constructed the same as a vent and may serve the same purposes. A breather provides air entry to a drain for the purpose of venting the line.

Surface water inlets. - Surface water inlets are used to provide surface water an entry into a drain. Due to the high cost of carrying surface water in buried drains, this practice should be recommended only for draining low areas where a surface drainage system is not feasible or practical. When surface water inlets are used, two or three lengths of sewer pipe should be placed on each side of the riser. The riser should be installed as recommended for relief wells. Surface water inlets should be protected with a beehive or truncate of cone grate. (Figure 4-44).

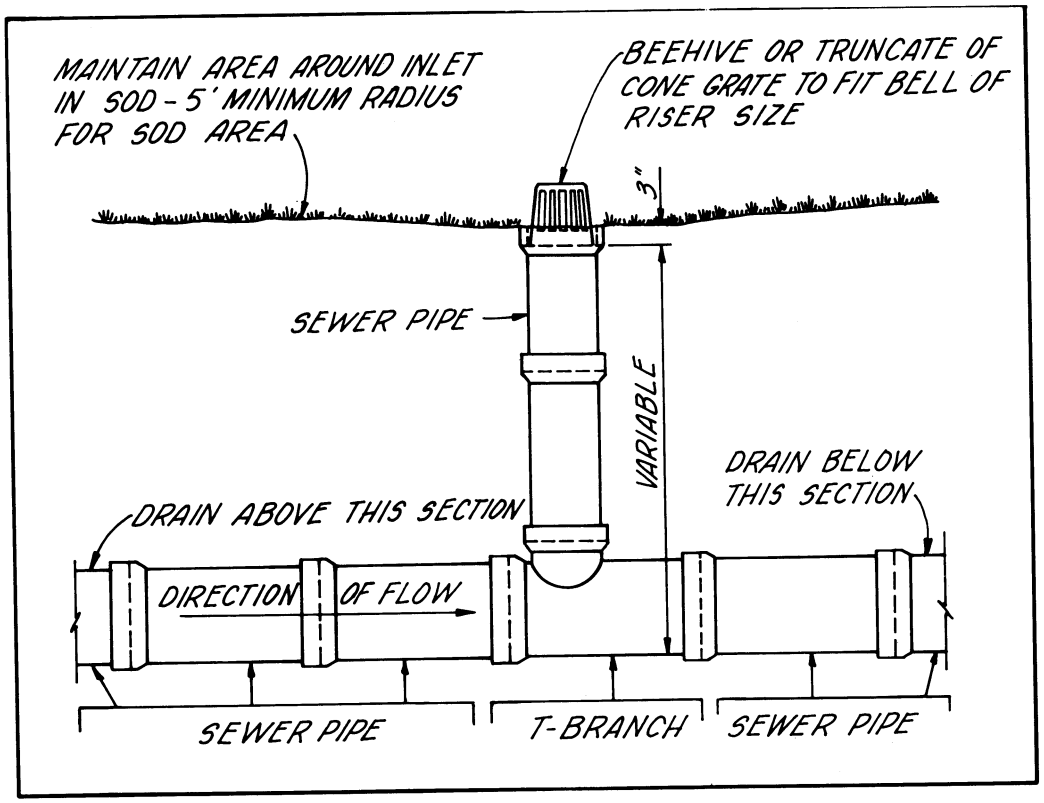


Figure 4-44, Surface water inlet

The cone grate is a desirable protection since it tends to float the flood debris and prevents the debris from closing over the entrance. Metal pipes with holes punched through the pipe at or slightly above ground level may be used as inlets. In some locations a top cover over the pipe prevents debris going down the pipe and a trash screen prevents lodging against the pipe.

Where there is a likelihood of substantial amounts of sediment entering the surface water inlet, it is advisable to use a manhole catch basin and sediment trap. (Figure 4-45). Since surface water inlets may be a source of weakness in a drainage system, offsetting the inlet to one side of the line reduces the hazard to the main line. One method of doing this is to place the surface water inlet on a short lateral so that damages which might occur to the inlet will not disturb the main.

Blind inlet or french drain. - A method of constructing a blind inlet is as follows: A section of the trench above the drain is filled with broken brick or tile, stone, gravel, or crushed rock, or a combination of these materials. The fill should be carefully selected and placed around and about 6 inches

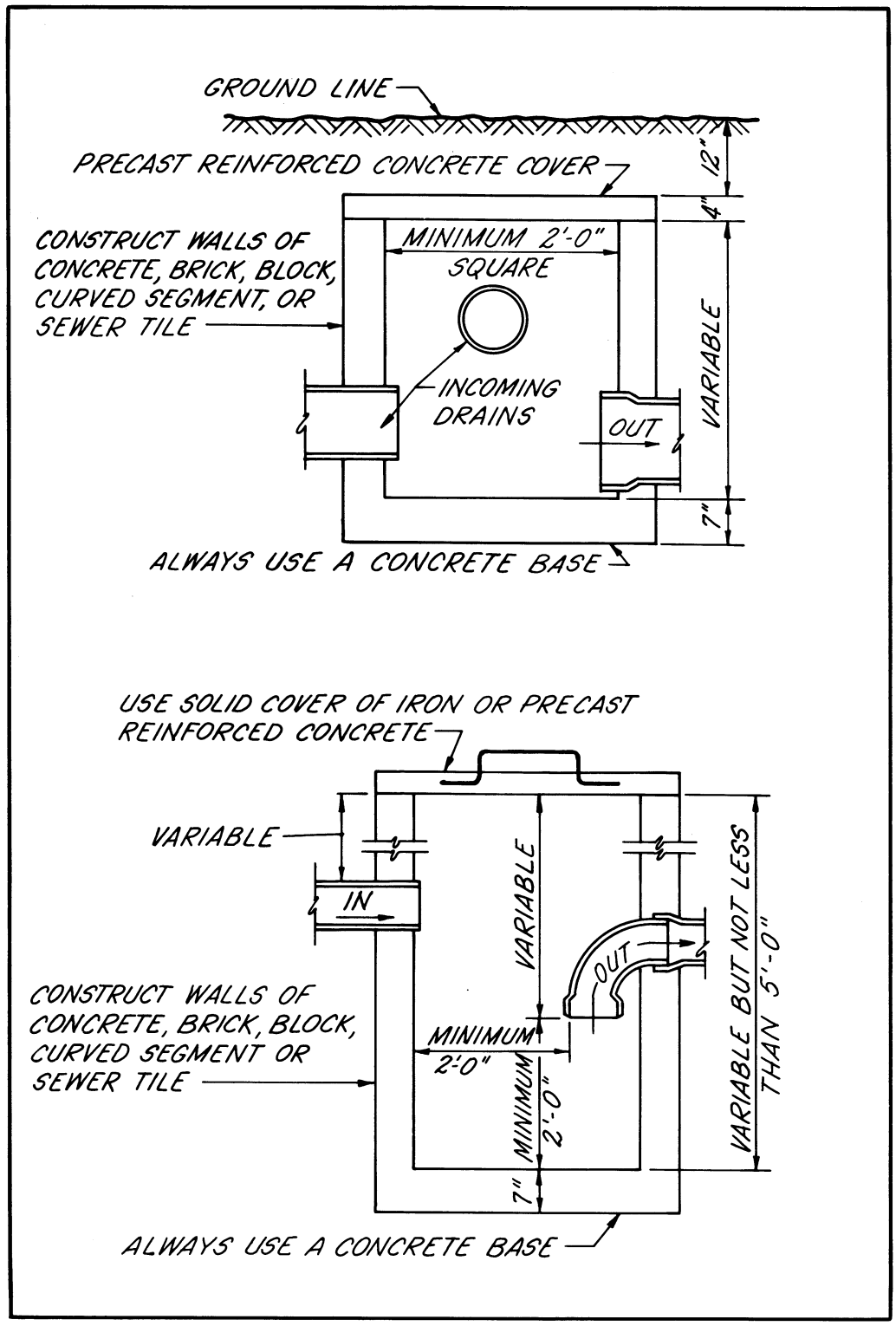


Figure 4-45, Manhole catch basin or sediment trap

above the drain to meet envelope requirements. Above this point up to within 12 or 18 inches of the ground surface, the material should be graded upward from coarse to fine and covered with topsoil. For faster intake of water and in areas where silting is a problem, pea gravel, small stones, or coarse sand may be used in place of the topsoil. Graded gravel also may be used to construct the blind inlet. The length of time for which the blind inlet will be useful depends on proper installation, fill material, and amount of sediment reaching the inlet.

Blind inlets are used to remove both surface and subsurface water and are most useful in open fields as they do not hinder farming operations. The rate of removal of impounded water through blind inlets is much slower than through surface inlets and should not be used where there is a large amount of impounded water.

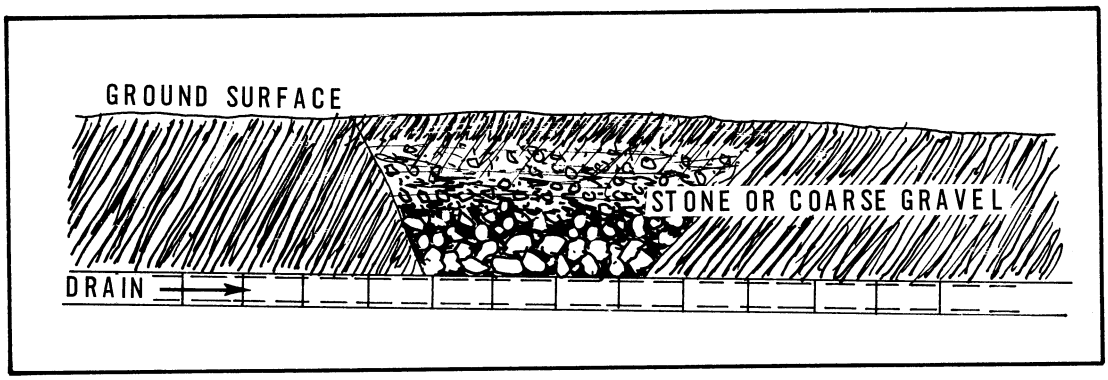


Figure 4-46, Blind inlet

Multiple drains in depressional areas. - Closely spaced multiple drains are occasionally installed in depressional areas to remove both surface and subsurface water. This type of installation (Figure 4-47) is easier to install than the blind inlet and is usually just as effective. Gravel envelopes will improve infiltration into these multiple lines.

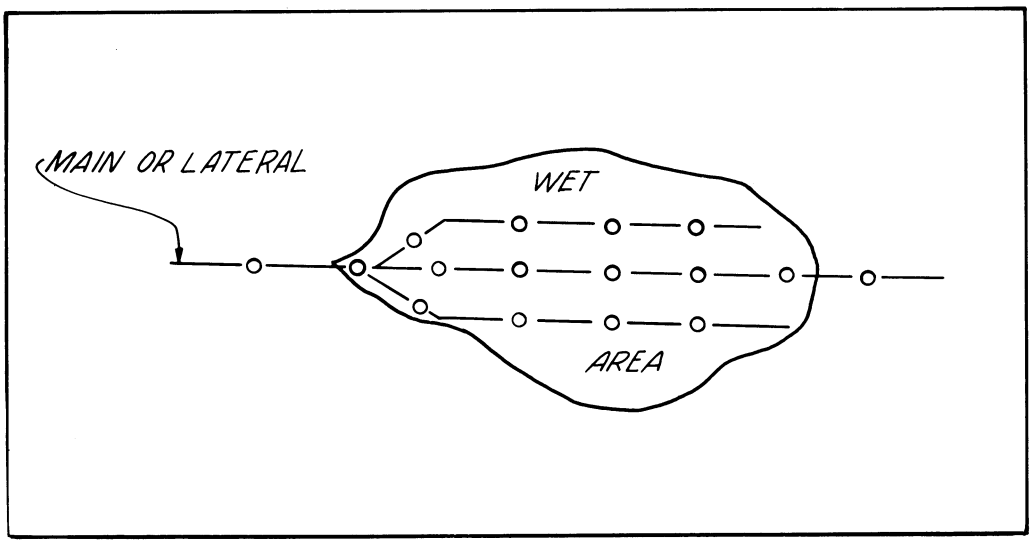


Figure 4-47, Closely spaced drains in wet areas

Drain crossings. - Special precautions should be taken where drains are placed under waterways, ditches, roads, or other crossings. If the cover is 30 inches or less or if unusual soil or load conditions exist, the drain should either be encased in concrete or a special pipe used such as metal or extra strength sewer tile with cemented joints. (Figure 4-48).

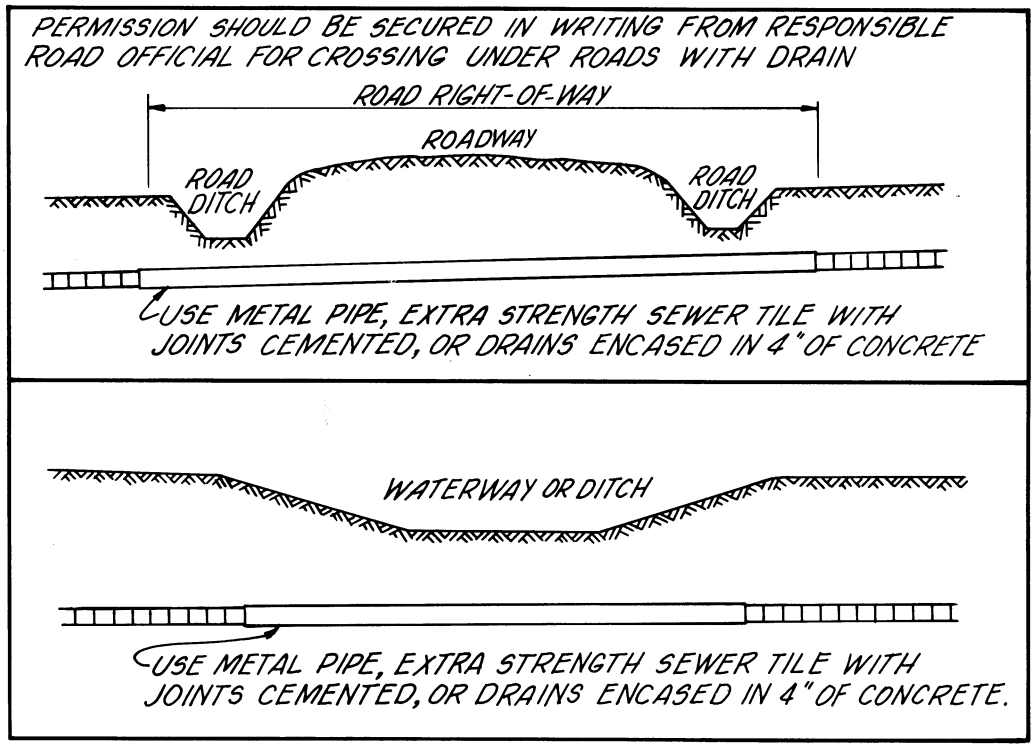


Figure 4-48, Drain crossings

Construction

General

Hand trenching is very seldom practiced except where trenching machinery is not available or where machine operation is impractical due to the small size or location of the proposed project. Both hand and machine trenching are discussed.

Drain installation by hand

The trench is usually staked at 25- to 50-foot intervals. Hubs are offset a short distance from the centerline of the trench and driven to about the ground level. A guard stake is driven near the hub on which is marked the station and the depth of cut from the top of the hub to the trench bottom.

Trenching with a spade

Batter boards

Batter boards are used to assist the tiler to stay on grade. Batter boards are constructed by driving a stake at the hub and one on the opposite side of the proposed trench from the hub. Select a convenient depth (5 to 6 feet) and clamp or nail a horizontal crossbar on the two stakes at an elevation such that the top of the crossbar is the distance selected above the trench bottom. If 6 feet is selected and the cut on the hub is 3.9 feet, the top of the crossbar should be placed 2.1 feet above the top of the hub.

Crossbars are set in the same manner at each hub. A chalk line or wire stretched over the top of the bars shows the slope of the proposed trench bottom. The chalk line should be straight if it does not include a grade break. The trencher can then measure from the chalk line to the bottom of the excavation to see if the trench is on grade. If three batter boards are set, the grade may be checked by sighting over the crossbars. When a grade break occurs, a target must be set at the station where the break is to be made and additional targets set beyond this point to obtain the correct slope of the line of sight.

Equipment used for trenching

Most excavation is done with a tile spade. In heavy, wet, or loose soil the solid tile spade is used, but sometimes a skeleton blade is much easier as it is lighter and the soils fall from it easier. A round-pointed shovel is used to clean out the trench if a drain cleaner is not available. A chalk line or wire of more than 100 feet in length, a rule, and other hand tools may be necessary.

Excavating the trench

Trenching begins at the outlet and proceeds upslope. Two or three spadings may be necessary, the number depends upon the depth of the trench. A trench width of 12 inches is sufficient for 4-, 5-, and 6-inch drains. Careful excavation of the top spading will prevent alignment difficulties later as line and width of the trench are established by the first spading. An accurate line should be stretched between the stakes to insure good alignment. The trencher faces the outlet and casts the first spading well back from the edge of the trench to provide space for the other spadings so the soil will not roll back into the trench. He may cast the excavation on either or both sides of the trench.

The last spading should be to a depth about 2 inches above the finish grade of the trench. The last few inches of the soil should then be removed from the trench by a drain cleaner or round-pointed shovel. The bottom of the trench should be shaped so that about one-fourth of the circumference of the drain will be in contact with the soil. Care must be taken to smooth the trench bottom to the exact grade. If a section of the trench is accidentally excavated below grade, the section should be backfilled, tamped, and shaped to grade. If unstable soil is encountered, the bottom of the trench should be firmed up with stable soil, hay, straw, sod, gravel, or other material. Sometimes it is necessary to cradle the tile by the use of boards using the rail and cleat method of forming the cradle.

Laying drains

The drains may be placed by the use of a hook or by hand. If the drains are slightly warped, they should be turned so they fit tight at the top. Care should be taken to see that the drains are placed in good alignment and that the proper gap recommended in the plan is maintained. Kicking the drain in place may result in too small a gap. Placing the drain with the hook will usually insure more uniform gapping. If a curve in the line is too sharp to lay the drain without causing a wide gap, the drain may be chipped so that it will have the intended gap. A monkey wrench or cutters may be used for this purpose. Junctions of lines are usually formed by manufactured fittings and cutting and concreting the junction is usually not necessary. "Y" fittings are ordinarily recommended. Research has shown that a junction at any reasonable angle will not materially retard flow.

Blinding drains

As soon as the drains are placed and inspected, they should be secured in place by putting friable soil around them and then blinding them with topsoil to a depth of 12 inches to preserve the alignment. Filters should be placed before the blinding is done, provided filter material is to be used. On steep grades or where the topsoil contains very fine sand, use heavier soil from the sides of the trench in blinding.

Backfilling the trench

Backfilling the trench should be done at the end of each day's work to eliminate the possibility of damage from surface water if heavy rainfall should occur. The end of the drain should always be blocked at the end of each day's work to prevent the entrance of silt and debris. The backfilling of a hand installation is frequently done by mechanical means.

Drain installation by machine

Most drain installation is done with trenching machines which have a sighting bar to keep the cutting shoe on grade when excavating the trench. The location and elevation of the sighting bar varies on different machines. The sighting bar may be on either side of the machine and from 2.5 to 5.0 feet to one side of the cutting shoe or buckets. For this reason it is necessary to know the type of machine that is to be used so the stakes can be located properly. Agreement should be reached with the excavating contractor as to the way the construction stakes will be set in order to prevent confusion.

Staking the drain

Staking the drain is started by placing the beginning or the 0+00 station near the outlet end of the line. This may be at the end of the outlet pipe. Hubs should be offset the proper amount and to the correct side of the centerline of the planned trench. They should be set every 100 feet or less and at all changes in grade or direction of the line. A minimum of three stakes is required to sight a grade. In case of a short tangent or change in grade, it may be necessary to set hubs on the extended tangent or extended grade in order to provide three sighting stakes. It is good practice to set hubs at control locations, such as maximum cuts, underground conduits, center of ditches, etc. Under normal conditions hubs are set on long curves but the machine operator will usually take care of the short curves by sighting across to the next tangent.

Setting targets for a trenching machine

The hubs should be driven on the required offset from the trench with sufficient accuracy so that when the targets are set they will line up. The targets generally used are a metal rod upon which is attached an adjustable cross bar painted a bright red. The machine operator usually sets the targets. He presses the rod into the ground at the stake and then adjusts the cross bar to a fixed distance above the grade of the trench.

The elevation of the hubs should be taken to the nearest 0.01 foot and the cut marked on each witness stake. The cut at a point is the difference between the elevation of the hub and the planned grade elevation at that point. Cuts are usually marked in feet and tenths of feet but some operators prefer to have the cut given in feet and inches. Cut sheets should be prepared in duplicate and show stationing, hub elevation, grade elevation and the difference which is the cut that is marked on the stake. The sheet should show the grade and size of drain. Special notes may be put on the sheet to describe any unusual condition such as soils, depth of cuts, underground conduits and any special protection required for the drain.

The cross bars of the targets are set so that the cut shown on the hub plus the distance which the top of the cross bar is set above the hub will equal the distance between the machine-sighting bar and the toe of the cutting shoe. The top of the cross bars of the targets should all line up for a particular grade as they are on the same slope as the proposed trench. If the cross bars do not line up when sighting over them, an error has been made in calculating the cut, setting the target or perhaps in the elevation of the hub. It is good practice to set the targets well ahead of the trenching machine so that a visual check of the grades can be made before excavating. In excavating, the operator keeps the sighting bar on his machine in the same plane as the targets.

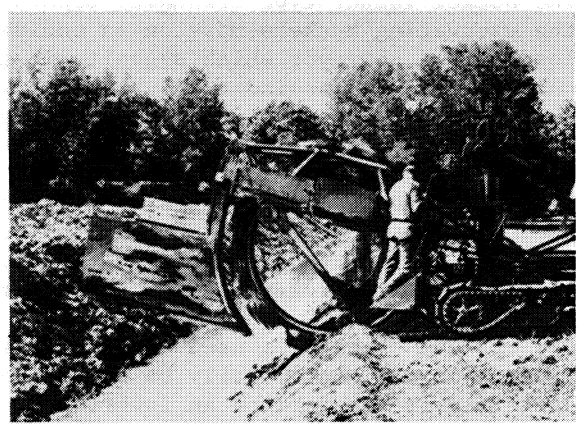
Trenching machines

Drain installation may be done by several types of trenching machines but the two most common types employed by contractors are the bucket-wheel type and the bucket-ladder type. The bucket-wheel type of trencher has a large wheel mounted on a frame at the rear of the machine. The wheel can be moved up and down by power to keep the machine on grade. Attached to the wheel are excavating buckets. Just behind the buckets is a cutting shoe and a shield to keep the loose earth from falling into the trench. The cutting shoe shapes the bottom of the trench for the drain. The shield is long enough to allow the drain to be placed in a clean trench within the shield. The excavating buckets carry the excavated material upward and deposit it on a conveyor which deposits it on the ground at one side of the trench.

Courtesy of Insley Manufacturing Corporation

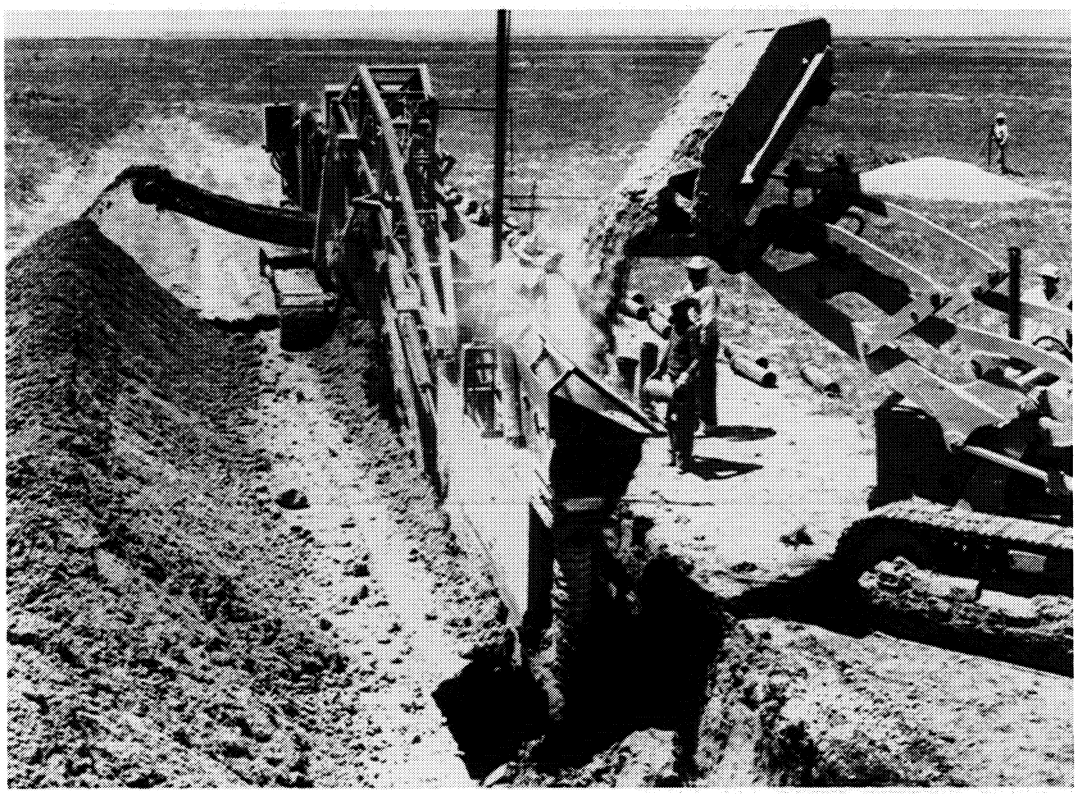
A backhoe machine

Different sizes of bucket-wheel-type trenchers are available for various depths and widths of the required excavation. They may be mounted on wheels or on semi-crawler or full-crawler frames. Buckets may be changed to fit the type of soil in which the excavation is to be made. Some machines are equipped with a tile chute which carries the tile down into the trench shield where the tile layer standing in the shield checks the laying of the tile. Some machines are equipped with various types of cutters to cut the topsoil into the trench after the drain has been laid to blind the drain. Others are equipped with conveyors which catch the excavated material and carry it back of the



A bucket-wheel-type trencher

trench shield to complete the backfilling. Many persons prefer this automatic backfilling as the installation is completed in one operation. The bucket-wheel-type machine is of a somewhat rigid construction and cannot follow a very sharp curve; however, the grade on moderate curves is maintained accurately if rocks are not encountered.



Courtesy of Gar Wood Industries

A bucket-ladder-type trencher

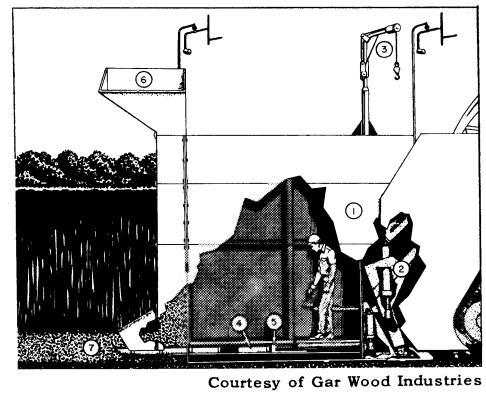
The bucket-ladder-type trenching machine has a ladder-type boom around which the excavating buckets move on an endless chain. The excavated material is loaded on a conveyor which deposits it alongside of the trench. Trench shields are used behind the buckets to keep the spoil and crumbs in the trench so the material can be removed by the buckets. The depth of the trench is maintained by the raising and lowering of the ladder. This machine is a fast excavator and can follow a rather sharp curve but it is difficult to keep on grade on curves and the grade requires constant checking. Various widths of trench can be cut with this type machine as the buckets can be changed as desired. It is capable of excavating deeper trenches than the bucket-wheel-type machine generally used in farm drainage.

The backhoe machine is used where drains are to be laid in trenches deeper or wider than can economically be excavated by other trenchers. The trench-hoe bucket is in the form of an inverted dipper which is drawn toward the operator like a hoe. Usually the smaller sizes are used for drain trenching.

Laying the tile

Tile laying should always start at the outlet and proceed upgrade to permit drainage of any water that accumulates in the trench. On many jobs where tile and a trencher are used the tile are laid within the shield by hand. A helper passes the tile to the tiler who lays the tile with the proper gap between the tile. Some machines are equipped with a chute on which the tile is placed to be lowered to the tiler. Sometimes tile of 8-inch diameter or less are laid by the tiler from the ground level using a tile hook. The tile is lowered by the hook into place and tapped to obtain the proper spacing. Some tilers who stand in the trench prefer to snug the tile up with a tap of the boot heel. Care must be taken when this is done to maintain the recommended spacing. The tiler should reject all tile that are cracked or so ill-shaped that a smooth line cannot be laid.

Some of the larger machines have a hydraulic ram in the shoring cage which presses the tile together and holds them in place. When this type of equipment is used, tile spacers should be employed to insure the proper gap space. These machines are usually used where deep drains 7 feet to 10 feet in depth are installed.



Courtesy of Gar Wood Industries

Hydraulic ram in shoring cage

1. The shoring cage provides protection for the man to lay pipe in the trench as the machine digs.

3. Electric jib crane handles pipe from the ground to lower it into the shoring cage.

4. The pipe layer places the pipe into position as it is lowered.

5. Pipe is positioned in line on rails at the grade line, 6 inches above the trench bottom and the hydraulic ram couples the pipe to the preceding pipe and holds the pipe line under pressure as the machine digs.

6. Wide hopper opening facilitates easy loading of the hopper.

7. Material falls around the pipe providing a 6-inch base and insuring perfect alinement.

Installation of corrugated-plastic-drainage tubing

Corrugated-plastic-drainage tubing must be installed in a way to insure firm soil support for its entire circumference. This may be accomplished by shaping a semi-circular groove in the trench bottom to the size required to fit one-half of the tubing, and using loose, friable soil or sand-gravel material to completely fill around the sides and over the top of the tubing after it is placed in the groove. A satisfactory installation also can be made by bedding the tubing in a sand-gravel material, from which soil materials smaller than the No. 60 mesh sieve and larger than the 3/4-inch sieve should be removed. The bedding should be at least 3 inches thick around the tubing, and no rocks or hard clods should be permitted in it.

The bedding and backfill should be placed in such a way that displacement of the drain will not occur. The bedding or blinding material should be placed

over the tubing before or soon after it leaves the shield. This is especially important if there is water in the trench.

To take advantage of the characteristics of plastic-drainage tubing, equipment specifically adapted to install it is needed. The equipment should cut a trench only as wide as necessary for the tubing and the envelope or filter material required. This considerably reduces the horsepower required for digging the trench and the material required for bedding or filter. A list of useful features for equipment follows:

1. Cutting wheel or ladder with interchangeable blades for cutting 10-inch and 12-inch trenches--with or without groove for 4-, 5-, and 6-inch tubing.

2. Hopper for sand-gravel for envelope-bedding-filter material, with screen on top to remove oversize material and with chutes to deliver material ahead of and under the tubing and to cover the installed tubing. (Some materials may require pre-removal of fines.)

3. Rack for a roll of the tubing located conveniently to deliver the tubing to trench with as little stretch as possible. Guides for tubing should be nonrestrictive.

4. Positioning guides to hold tubing centered in trench while envelope-bedding material is placed.

5. Conveyor for automatic backfill.

6. Holder for roll of plastic sheeting--width depends on method of installation and size of tubing.

Plastic sheeting over the drain serves to force water to enter the drain from below. Installing the drain in a bed of sand-gravel material and covering the installation with a sheet of plastic prior to backfilling is an excellent way to reduce the velocity of flow into the drain and the amount of sediment carried into it (15, 16).

Drain junctions and curves

Factory made fittings are superior to field fabricated junctions and they should be used where obtainable. When not available fittings must be made by cutting the drain. To make a fitting with tile, a sound tile should be filled with dry sand to prevent vibration and facilitate the cutting. The tile ends should be covered with two boards and while holding the sand in place, a prolonged series of light taps in the same spot should be made with a hammer. A small hole will soon be made without cracking the tile, provided care is used and the job not hurried. The hole size can then be increased by use of a monkey wrench. Concrete is usually placed over the junction to be sure that the connection is held in place.

Placing filters and envelopes

Filters and envelopes are of two general types of material. The most commonly used types are granular materials, i.e., gravel or organic particles. The second, and less common type used for filters, is in the form of fabrics or mats which may cover part or all of the drain. Filters and envelopes may be placed by hand or by machine. On large projects, modern machines that excavate the trench, place the filter or envelope, place the drain, and backfill

the trench are in common use. On small isolated projects placement of the drain and filter or envelope material is usually a hand operation.

Trencher placement of granular filters and envelopes

Most of the larger drainage trenchers have a hopper attached to the rear of the shoring case or shield to carry granular materials and feed it through feed tubes to the space around the drain. The hopper is kept supplied with material from storage piles or from a truck which drives along the trench. As the trencher moves forward, the granular material flows through the feed tubes by gravity. One tube feeds material to the bottom of the trench and after the drain is placed the other tubes feed material to cover it. Adjustments on the shoring case and feed tubes make it possible to regulate the depth of material below and above the drain. The thickness of the material on the sides of the drain is governed by the trench width. Generally these trenchers operate well as long as the hopper is well supplied with material and there is free flow through the hopper and feed tubes. The operator must exercise care to insure that foreign objects that would plug the hopper are excluded. Wet, fine grained, or cohesive materials will not flow freely through the feed tubes. Hoppers should be equipped with a grating to exclude oversize materials and foreign objects. To insure that the proper envelope or filter thickness is being obtained, periodic inspections should be made immediately behind the shoring cage prior to backfill operations. Where automatic backfill attachments are used, it is necessary to stop the trencher for a short time during the inspection of filter and envelope installation.

Trencher placement of fabric filters

Where fabric or mat-type filters or plastic strips are used, it is necessary to have a reel attachment on the rear of the trencher. These can be mounted on any type trencher and are usually fastened to the rear of the grading shoe. Fabric or mat-type filters and plastic strips are packaged in continuous rolls that can be mounted in the reel. When installation starts, the free end of the roll of material is fastened to the top of the drain. The filter or plastic strip rolls off the reel as the trencher moves forward. Backfill material tends to shape the material over the top and around the sides of the drain. When in place, the filter material should cover about 70 percent of the outside circumference of the drain. Plastic strips are usually used over the top of the drain with a sand-gravel filter underneath the drain. Plastic should cover the part of the drain above the filter.

Extreme care must be exercised in placing fabric filters to insure that the material is centered over the drain. Difficulty is often experienced under conditions of gusty winds that whip the fabric strip as it leaves the reel. Care must also be exercised in the backfill operation to avoid rupturing the fabric.

In some areas, trenchers have been equipped with two reels; one to feed fabric or mat-type filter in the trench bottom ahead of the drain and one to place it on top as previously discussed. This facilitates complete coverage of the drain with filter material and is considered good practice.

Installing fiber mat base and filter

Hand placement of granular filters

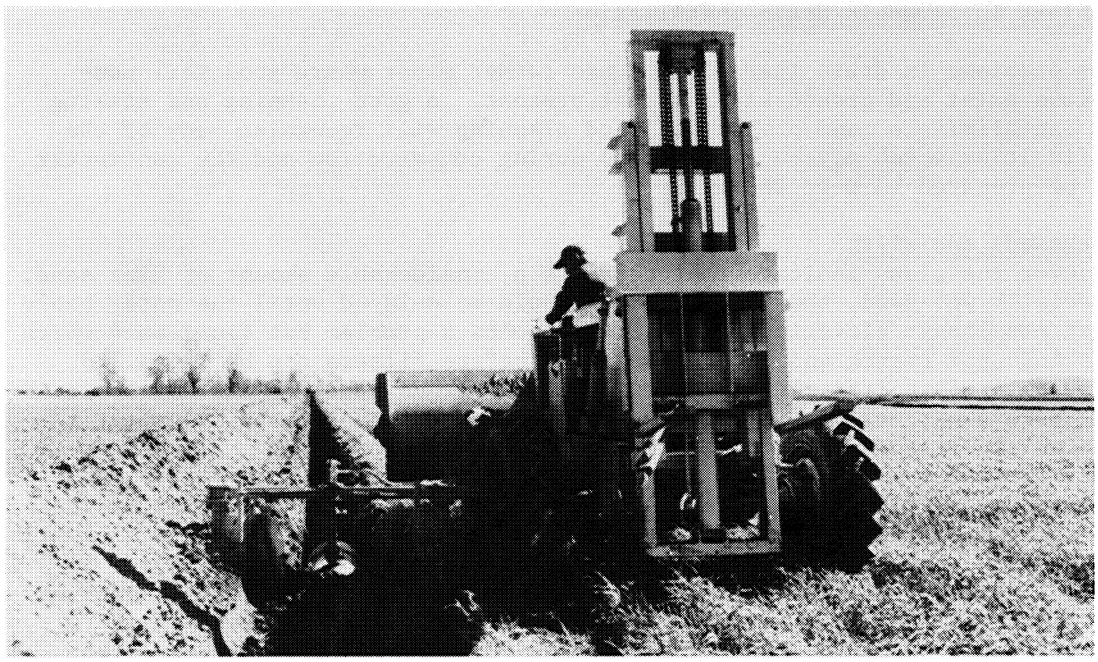
When trenches are excavated with small trenching machines without hopper attachments, by hand, or by other equipment such as backhoes, or draglines, it is necessary to place the filter material manually. Many techniques have been developed for placing filter material in the trench and around the drain. One of the best methods is to use a standard ready-mix truck. The hopper is loaded with the material to be used and then driven along the trench with the chute discharging into the trench. With proper regulation it is possible to deposit the proper amount of filter material uniformly in the trench. Very little hand spreading is needed subsequent to this operation.

Blinding the drain

Careful placing an initial backfill of 6 to 12 inches of soil around and over the drain is referred to as blinding. This is done to insure that the drain will remain in line when the remaining excavated material is placed in the trench. Except in those areas where chemical deposits in and around the drain are a problem, the soil should be topsoil or other porous soil except that fine sands and silts should not be used. Blinding the drain may be done

by shaving off the topsoil at the top of the trench with a spade taking care that the alignment of the drain is not changed. A number of methods have been devised for blinding. One method is the use of a double plow arrangement which straddles the trench and cuts both sides of the trench. This is pulled by a tractor. The plows may be an additional attachment to the trenching machine, or they may be mounted on a separate unit pulled by a tractor. Several different attachments have been made for trenchers for blading topsoil into the trench as the drain is being laid. The use of the attachment does not permit examination of the drain after the drain is laid and it is necessary to stop the trencher periodically for inspection. When a granular filter is being installed, the use of a backfiller is considered as adequate blinding. Blinding is not necessary where drains are placed in sand and gravel filters or envelopes.

Blinding drain with a spade



Blinding drain with machinery

Backfilling the trench

Various methods are used to move the remaining excavated material back into the trench and mound it up over the trench to allow for settlement. This may be done by hand with shovels, or by grader, bulldozer, trench hoe, dragline, auger, or any method which is convenient. Some trenchers are equipped with mechanical backfillers and the excavated earth is moved back on a conveyor and rolls off into the trench behind the trench shield. The soil becomes mixed on the conveyor so that a mixture of topsoil and subsoil is placed over the drain. Blinding the drain is accomplished by this method as the backfill rolls into the trench in such a manner that the alignment is not disturbed.

Backfilling with machinery

Problems involved in drain installation

Most problems in drain installation are rather minor where good soil conditions exist and ground water is not present. A good planning and staking job can eliminate many problems. Good planning will recognize many of the difficulties which may be encountered during construction and the contractor can be prepared to meet them.

Quicksands and silts

Whenever the plans indicate that there is a considerable amount of fine sand, especially wet sand, the installation should be delayed until the water table is at its lowest elevation. Dry sand presents a problem but fluid sand which runs into the trench and covers the drain before filters can be installed presents a most difficult situation. In many lines sand pockets may be found that make construction difficult but if the problem is limited in extent the problem can be solved by using some special procedures.

It may be possible to plan the drain through the sand at a shallower depth so the problem of installation will be decreased. Caving of the trench sidewalls is always a problem. In some cases the drain shield may be made longer to protect a greater length of the trench. The drain should be laid as soon as possible after the shoe has passed. The protection of the shield may give enough time to wrap the joint provided the trencher advances slowly. The drain should be blinded as soon as possible and the trench filled.

When the sands are saturated, the machine should be kept moving. Stopping the machine in saturated sand will permit the sand and water to build up over the drain in the shoe and make it impossible to keep sand out of the drain already installed. If the trencher is stopped, the shoe will settle in the wet sands and cause a low spot in the grade. A poor foundation results when the trencher is again started. Blinding the drain should be done with great care to prevent it from being knocked out of alignment and grade. If the trench walls cave so that the caving material falls vertically on top of the drain very little damage may be done; but if they settle vertically or slip down, the drain will be pushed out of line. The damage should be repaired immediately. The conveyor should be set to throw the excavation as far out from the trench as possible to relieve the weight on the trench side walls and to prevent the wet sands from running back to the cutting wheel.

If laterals are to be installed in this portion of the main drain, sufficient time should elapse to permit the ground water to drain out.

It is important that the drain laying and backfilling should be done quickly following excavation of the trench. It is good practice to have no more than 12 feet of trench open at a time because of the possibility of the banks sliding in and causing the trench bottom to be forced up. If the job is interrupted, the work should be completed as far as the trench is opened.

If it becomes apparent that the foundation cannot be stabilized by placing good mineral soil or gravel in the bottom of the trench, then ladders may be installed using the board and cleat method to install a cradle for the drain. In lieu of this, a continuous plastic, bituminized fiber or metal pipe may be installed. The continuous conduit will usually solve the grade stability problem, but the problem of laying it to grade may be difficult.

Crushed rock has been used in many installations to stabilize the grade. After crushed rock has been placed in the bottom of the trench, the grade must then be established.

Inspection of drain installation

General

Inspection should be carried on periodically throughout the construction stage to insure conformance with plans and specifications. The following items should be checked:

1. Quality of tile, tubing, pipe, and other materials.
2. Alignment, depth, and grade of drain.
3. Trench width at top of drain.
4. Joint spacing of tile.
5. Connections.
6. Bedding.
7. Filter or envelope materials and installation.
8. Blinding methods.

9. Backfilling methods.

10. Outlets.

11. Auxiliary structures.

Checking grade

Reasonable allowance should be made for errors resulting in small variations from planned grade and for slight unevenness in the diameter of individual drains; however, a reverse grade should never be permitted in drain lines.

Mole construction

Equipment

Several basic types of mole plows are used. One is the wheel type where the coulter is attached to a suspended axle on wheels. A second is the beam type where the coulter is attached to a horizontal beam that rides directly on the ground. Both types are mounted on a unit separate from the power unit. The beam-type plows are generally most satisfactory in that greater uniformity is obtained in both alignment and smoothness of the mole wall. A third and more recent type is the plow that is directly mounted on the power unit and depth adjustment controlled hydraulically.

Mole size

Four-inch plugs are commonly used to form the mole. This size provides a channel of ample capacity for the grade, lengths, and areas recommended. Sizes greater than 4 inches are not desirable since they increase the required draft of the plow and tend to develop roughness and less uniform channel walls. Also channels of greater size do not flush themselves as readily as do smaller channels. Six-inch moles, however, have been satisfactory in organic soils where increased size is desired to compensate for reduced cross sections caused by the expansion of the wall material into the cavity.

Depth

Moles must be drawn sufficiently deep for protection against the effects of drought, frost, and loads from heavy farm equipment. Greater depths provide greater protection from inwash of silts through the coulter slit and at the same time provide somewhat better drainage by extending the area of fissures and cracks developed by deeper plowing when the mole is formed. Greater depths require greater power and thus increase installation costs. Best results usually are obtained at depths of 20 to 24 inches, the former being satisfactory when the moled area is in a long rotation of grass and hay. Occasionally some adjustments in depth are necessary in order to draw the mole through the most suitable strata in the soil profile.

Spacing

Since the fractures of the soil profile developed by the mole plow extend only a few feet on either side of the line, uniform drainage requires the moles to be drawn as nearly parallel as possible and at close spacing. Intervals of 9 to 12 feet give good results and a 10-foot interval is commonly used. Somewhat wider spacing of 12 to 15 feet gives equally good results when lines are drawn across sloping land.

Construction

Moles should be drawn when moisture conditions are favorable. This occurs when the surface is sufficiently dry to provide traction for the mole plow

and the subsoil is sufficiently moist to provide plasticity for molding a smooth channel wall. Usually late spring and sometimes late autumn are the times of the year best suited. A dry surface is also essential because any standing water which can enter directly through the coulter slit softens and collapses the thin earth plug which re-forms and seals off the roof of the mole cavity. Collapse of the cavity roof causes deposition of silt into the channel, which usually plugs the drain. A dry subsoil causes the plow to shatter and tear the cavity lining leaving a channel which drops excessive silt with resultant plugging.

Construction procedure. - Best results are obtained when the mole plow is drawn upgrade. Fissures in the soil then open up in the direction of natural drainage and facilitate rather than block the gravitational movement of the water. However, the economy of two-way haulage on some sites may offset any advantage gained by drawing lines upslope only. Moles should not be drawn too rapidly. Venting behind the plow may be desirable to reduce suction and possible collapse of the mole wall.

Coulter slits should be closed at the ground surface as soon after moling as possible. This can be done by harrowing and disking. Water will then seep into the mole rather than wash in. Rainfall, washing into unprotected slits, has been observed to carry in sufficient silt to fill a mole line within several hours. Adequate application of lime and fertilizer should be included in the initial preparation of the land for crops. Adequate lime appears to prolong the life of mole drains.

Construction of open ditches for subsurface drainage

Construction of open ditches for subsurface drainage is similar to construction of open ditches for surface drainage. In most cases both surface and subsurface drainage water are carried in the same ditch. Design, construction, and maintenance of open ditches are covered in Chapter 5 of this handbook.

Maintenance of Buried Drains

General

A subsurface drainage system of adequate design and proper installation, using good material, requires little maintenance to keep it operating. Inspection of the drains, especially after heavy rains, should be made to see if they are working and if maintenance is required.

Outlets

The outlet end of the system must be kept clean if the maximum benefits from the drain are to be obtained. Sediment and debris sometimes gather over the outlet and may entirely plug the outlet. A good subsurface drainage system may fail because the outlet ditch fills up with silt and vegetation. The outlet ditch should be improved to permit free flow from the drain outlet. Outlets are usually protected from small animals by installing a flap gate or a grating. If this is not done, small animals may use the outlet for nesting. The outlet should be inspected to determine if it is clear.

Water-surface inlets

Surface water inlets are subject to damage and may require frequent repairs. If holes wash around the inlets, they should be repaired. Trash which seals over the inlet gratings or trash racks should be removed. Frequent inlet inspection will insure prompt removal of surface water.

Sand traps and catch basins

Where drains are laid in sand, usually sand traps or catch basins are built to catch the sand. Traps will not keep sand from filling drains unless the traps are kept clean. The traps should be checked frequently after the drain has first been installed. Cleanout of the trap may be less frequent as the drain ages.

Blowouts

Quite often holes develop over the drain. These holes, known as blowouts, may be caused in construction by leaving too wide a gap at joints. Other causes might be broken tile or improperly made drain junctions. Blowouts may be caused by insufficient cover and high pressures within the drain. Drains crushed by heavy farm equipment may cause holes which result in the drain filling with soil. If repairs are not made immediately, damage will increase. To make repairs the drain must be exposed at the point of the blowout and the drain replaced, cementing junctions or covering wide joints with tar impregnated paper and tile bats (broken pieces of tile).

Tree roots

If trees near the drain are not removed at the time of construction, the drain may become plugged by tree roots. If the drain is not functioning and the outlet is open, the drain should be checked near trees. To repair the line, dig it up, clean it, and re-lay it. Unless the trees are removed or killed, this is only temporary repair which may have to be repeated periodically. One way to prevent a recurrence would be to replace the part of the drain near the trees with sewer pipe and carefully seal the joints or install a conduit without perforations or joints.

The roots of some trees such as cottonwoods and willows cause more trouble than hardwood, fruit, and nut trees. Many drains through orchards have functioned effectively for many years. The placement of drains at greater depths in orchards will help eliminate the problem of roots clogging the drain. The distance roots travel to a drain depends on the species of the trees, climate, and variations in drain flow. Safe distances from drains of various species of trees should be established locally.

Auxiliary structures

The life and value of a drainage installation often depends on the maintenance and repair of auxiliary structures. These structures are essential to the proper functioning of a drainage system. If they are not maintained, the system will not operate as planned. Regular inspection is required.

Waterways over drains

Drains are often laid under or at one side of waterways. Drains laid under the center of the waterways are not recommended because surface water seeps into perforations or joints in the drain and carries soil into the drain. When enough soil is displaced, a large hole develops. Where it has been necessary to place a drain under a waterway, it should be inspected regularly.

Mineral deposits

Malfunctioning (17) of drains in several parts of the country has been caused by mineral deposits in the drains. Accumulation of insoluble black and/or red materials, mainly manganese or iron oxide (bog ore), may be found in the line. The mineral deposits do not seriously affect the operation of the drain unless the perforations or joints become sealed. Indication of the presence of the deposits may be seen at the outlets or at junction boxes and inspection holes. Sulphur dioxide gas injected into the upper end of the drain from tanks of compressed gas has proved successful in opening the drain. The gas should be held in the line for 24 hours after the air has been replaced by the gas. High pressure hydraulic cleaners are also used to clean the drain.

Miscellaneous

Inspection wells, catch basins, etc., installed in a drainage system may be used to locate the portion of the system which is not operating properly. Examining the drains after heavy flows should give enough information so that the trouble can be located. Where a system does not have inspection wells, the drain must be excavated at intervals until the trouble is located.

Failure of a drain installation to operate as expected may result from other factors such as:

1. Drains installed with insufficient capacity, drains placed too shallow, and lack of auxiliary structures.

2. Drains of insufficient strength or lacking in other qualities necessary for the installation.

3. Poor construction resulting in such inadequacies as too wide or too small a joint spacing; improper bedding; poor grade and alignment; improper backfilling; and substandard appurtenances.

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