Physical Sciences • Agronomy 7

INFORMATION BULLETIN 108 • $1.00

AN EXTENSION PUBLICATION OF THE NEW YORK STATE COLLEGE OF AGRICULTURE AND LIFE SCIENCES, A STATUTORY COLLEGE OF THE STATE UNIVERSITY, AT CORNELL UNIVERSITY, ITHACA, NEW YORK

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Cover photo. *Land drainage techniques have changed over the last 40 years. Improved trenching machinery, new drainage materials, and the use of laser beams for grade control have made drainage installation faster, more convenient, and less disruptive to the existing land use.*

The technical assistance and editorial criticism provided by numerous colleagues are gratefully acknowledged. H. G. Hirth, P. J. Zwerman, M. M. Weaver, R. D. Black, and R. H. Holcomb reviewed the manuscript and offered many valuable suggestions. H. Schmertzler provided photographs and technical assistance. N. Fidler and B. Lynch typed the manuscript. Many of the illustrations are taken from an earlier bulletin by A. M. Goodman.

Contents

Land Drainage

"Outlets were and are one of the most important parts of a tile system. A wild guess would place the amount of tiling done in New York State, prior to 1900, at upwards of 75,000 miles. A very small portion of this is in operation, and the major cause of failure was lack of outlet." (Weaver 1964)

For the 6-year period from 1969 through 1974, the state's Soil and Water Conservation Districts have been involved in the installation of nearly 300 miles of diversions, 1700 miles of drainage ditch, and 3600 miles of tile drain. These figures emphasize the importance of water control to the state's farmers and reflect their efforts to control runoff and to remove excess water from crop fields.

Figure 1. *No one can guarantee good weather at harvesttime. But subsurface drainage can correct many soil wetness problems and increase the efficiency of farming operations. A single subsurface drain could have prevented this problem.*

Excessive soil water limits the uses of many soils. These limitations can often be removed by improving soil drainage. A number of factors must be considered to effectively improve soil drainage. The purpose of this bulletin is to help to assess drainage problems and to indicate appropriate corrective measures.

Farm numbers have been declining for several decades, but acres of farmland have declined more slowly: fewer farmers are farming more acres. The size of farm machinery has increased correspondingly. The major problems associated with farming larger acreages are weather dependent. A wet spring season frequently delays planting and reduces crop yields. A wet fall can pose many harvesting problems. Field areas needing drainage improvement stay wetter longer than the rest of the field and cause management problems (see figs. 1-3).

The Conservation Needs Inventory (1967) data indicated that over 700,000 acres of rotation cropland needed drainage improvement. These soils are generally suitable for crop production, but poor drainage causes special management problems. They are difficult to farm in a timely manner, are less productive than better-drained soils, and reduce the overall efficiency of the farming operation.

The purpose of drainage is to remove *excess* water from the soil. This water is not useful, and often is detrimental, to plant growth.

Figure 2. *A wet spot in an otherwise good field. Note that the oats were drilled to and from the camera. Two weeks later several drill widths were planted around the pool. One line of tile drain would make it possible to plant the* whole *field early.*

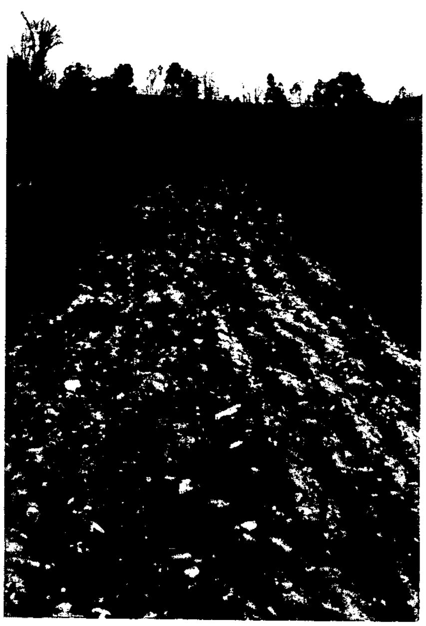

Figure 3. *After trying to plow this field with a wet draw across it, the farmer gave up and waited until later in the season.*

Soil Water

Seasonal differences in temperature, sunlight, and plant growth make soils drier during the summer than in spring or fall; but no months are typically and noticeably wetter than others.

Soil is a combination of solid material and air spaces (pores) much like a sponge. The pores vary in size and shape and influence the rate of water movement in the soil. A well-aggregated soil with many large pores usually transmits water rapidly. Water moves slowly through soils with very small pores or with few pores.

Water is always present in the soil, even during the driest part of the growing season. Some water occurs as very thin films which surround the solids. When water is added to a dry soil, it enters the pores, is absorbed by the existing water films, and makes them thicker. As the films become thicker, they fill the smaller pore spaces. If water is added slowly, it is redistributed through adjacent pores. When the smaller pores are full, the larger ones begin to fill because there is no place else for the water to go. In a well-drained soil, the excess water in the larger pore spaces continues to drain downward until it reaches a permanent ground water level which is usually well below the rooting depth of most crops.

The water may encounter a barrier to movement. This may be a layer of dense soil with few, very small pores (which transmit water very slowly) or a layer of dense rock. The water cannot continue to move downward, but remains in the crop rooting zone or begins to move downslope along the top of the barrier. After seeping downslope, it accumulates at a low point in the landscape and forms a "wet spot"; or it may appear as a "seep" on the soil surface where the layer of overlying pervious soil is thin.

If the water is added rapidly or if the soil is already quite wet, the water may flow over the surface to the nearest low spot. This surface runoff may then continue to flow off the field, or it may accumulate in the low area.

Soil water can be removed by one of several processes:

- It can drain downward out of the crop rooting zone.
- It can be absorbed by plants and used in growth (transpiration).
- It can be evaporated by the heat of the sun.
- It can flow into an outlet.

Deep drainage occurs only on naturally well drained soils. Transpiration and evaporation remove water slowly. Flow into an outlet is the basis of drainage improvement (fig. 4).

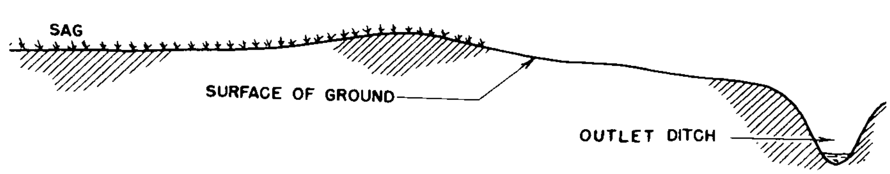

Figure 4. *Cross section or profile showing,* at left, *a sag where water collects and,* at right, *an outlet ditch into which the water can be drained.*

Benefits of Drainage

Drainage facilitates machinery operation. Properly drained fields allow efficient use of modern equipment. Many farms in New York have relatively small wet spots in otherwise good fields. These wet spots interfere with efficient machinery operation, delay tillage operations, and may serve as nurseries for weed species.

Improved drainage will provide more field workable days in the critical spring tillage season. A study in Ohio showed that in 8 out of 10 years, where drainage is impaired, only on 12 days between March 21 and May 10 were the fields dry enough for tillage and planting. But where soil drainage was adequate, 22 days were available for tillage and planting. Similar data from Illinois show that improved drainage doubles the workable days in April (from 2 1/2 to 5) and quadruples the field workable days in May (from 4 1/2 to 18).

Drainage facilitates drainage. After land is drained, deep-rooted crops can be grown on it. These deep roots provide food for soil microorganisms and for other crops. As these roots decay, they leave channels in the soil through which excess water can move to a drainage outlet. Recent research has shown that freezing and thawing of a *drained* soil help to improve its structure so as to allow faster water movement to the drain. Such effects gradually increase the benefits of subsurface drainage.

Drainage reduces heaving of deep-rooted crops. Poorly drained land "heaves" because of freezing of the soil water. This heaving tends to damage deep-rooted crops which can be planted during a favorable season. Alfalfa, birdsfoot trefoil, the clovers, and other crops can be damaged or destroyed by soil heaving.

Good drainage makes crops more drought resistant. Plant roots need air for respiration. Since air is not available in a soil that is full of water, plant roots will not grow into such soil. On well-drained soil, crop roots grow deep and extract nutrients and water from the soil; when dry weather occurs, these deep-rooted crops can continue to extract moisture from these deeper levels. Crops on soil that was poorly drained early in the season develop only shallow root systems in the drier surface soil. When short periods of dry weather occur, the crop shows signs of a moisture shortage.

Drainage admits air to the soils. When excess soil water is removed, air fills the drained pores between soil aggregates. Air is vital to the life of the plant and to the activities of many microscopic forms of

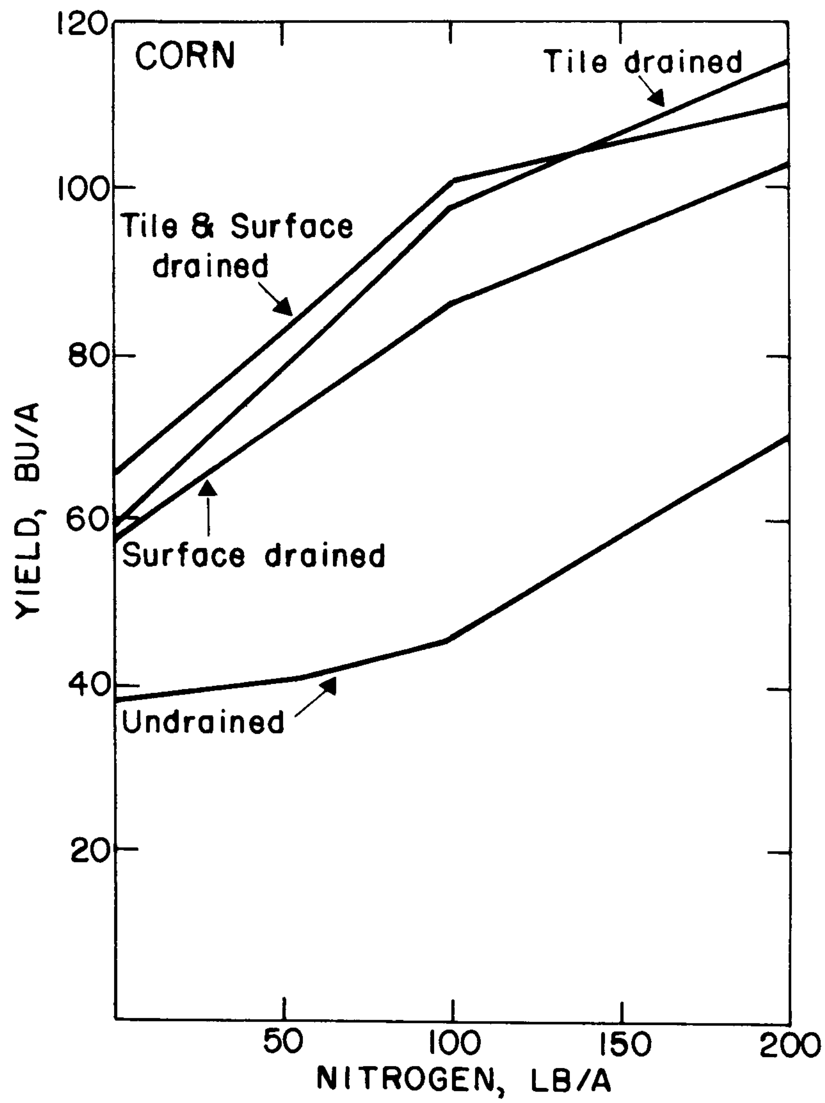

Figure 5. *Drainage produces better yields with less fertilizer. These data from Ohio indicate that drainage is as good as adding 150 lb per acre of nitrogen and that drainage and fertilizer will produce even better crops. The real differences in crop yields would be even greater than shown here because all the experimental plots were planted only when the undrained area was dry enough to till.*

plant and animal life, which convert the nutrients in manure, fertilizer materials, and plant residues into forms usable by growing crops. The air content of the soil must be *at least* 10 percent for good crop growth.

Assessing the Drainage Problem

Where does the water come from? The first step in correcting any drainage problem is to *determine the source of the excess water.* If soils were all uniform in their physical conditions, if the topography was perfectly flat, and if the precipitation was uniform, there would be no differences in soil drainage.

Most drainage problems result from a combination of runoff and seepage. Corrective measures can be applied directly to the wet area, but it is often more effective to divert the excess water away from the problem area. The use of surface interceptor drains (see p. 7) is often overlooked in trying to solve a drainage problem.

Old subsurface drains often contribute to problems of wetness. Many fields have been previously drained, but lack of maintenance has led to drain failure. Water "boiling up" from beneath the surface during the spring is usually good evidence of the presence of an old drain. Many tile lines and stone drains (fig. 6) that may be a hundred years old still work when they are joined to a new line.

Where should the water go? If excess water is to be eliminated, there must be some place for the water to go. *An adequate outlet is the most important requirement for any drainage program.* A commonly used outlet is the roadside ditch which is suitable if it is deep enough. If the water is to be discharged into a stream, care should be taken to insure that the bank is not eroded. Such erosion can cause serious damage to the drainage installation and to the environment.

How will it get to an outlet? The basis for all drainage improvement is to provide channels for excess soil water. These channels conduct the water away from the problem areas to suitable outlets. The channels can be either *open* (ditches or terraces) or *closed* (drain tile, fiber pipe, or plastic tubing).

Open channels to control surface runoff are important parts of a drainage system; subsurface drains should be used to supplement good conservation and erosion control practices.

Drainage Outlet

No system of drainage can be effective without an adequate outlet. The *first* questions to be answered before installing any drainage system are: *What will be done with the water that is collected by the drainage system? Is there a satisfactory outlet, or can one be developed?*

The ideal outlet provides a free flow from the drain at all times and allows the construction of drains of the proper depths and capacities to provide satisfactory drainage to the lands where they are needed. Not every outlet can meet these requirements, but adjustments can be made so that the project can be constructed. Such compro-

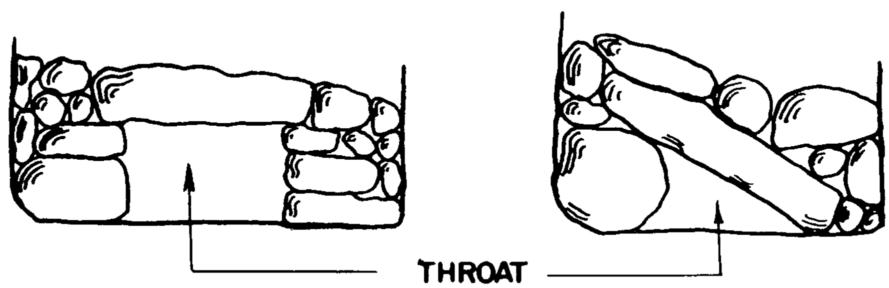

Figure 6. *Cross section of common types of stone drains. Many miles of these were installed in central New York before clay tile became available. They are often encountered when new subsurface drains are installed. Since they are often at least partially functioning, they should be connected to the new subsurface drain whenever possible.*

Figure 7. *A well-constructed outlet ditch. Note that the brush has been removed, the sides have been sloped to reduce, and allow for, maintenance, and the spoil from the ditch has been leveled.*

mises usually involve greater investment or reduced benefits in comparison with an adequate outlet.

Outlet channels convey drainage water to a suitable (usually natural) outlet. They are commonly required where the existing natural channel (if one exists at all) lacks sufficient depth or capacity. The channel grade is controlled primarily by the overall slope of the area through which it passes and the elevation and distance of the lowest point designed to drain into it.

Outlet channels are usually built with trapezoidal cross sections. The side slopes are made flat enough to assure stability and to permit the establishment of vegetative cover. Soils containing a mixture of sand, silt, and clay are usually stable on slopes of 1 1/2 to 1 (1 foot rise in a 1 1/2 feet horizontal distance). Very sandy soils may require slopes of 2 or 3 to 1. Outlet channels should be deep enough to adequately drain the adjacent areas. The minimum depth is usually 4 to 5 feet.

Wherever possible, the spoil material should be spread until it blends in with the field so that the area can be managed (see fig. 8). A strip of land adjacent to the channel should be maintained in sod to prevent channel bank erosion. Spoil banks are unsightly and difficult to manage: they form a barrier to surface water movement and usually become a nursery for weeds.

Outlet channels represent a large investment; they should be designed by a competent engineer. Proper design is a critical matter; performance of a drainage system depends on an adequate outlet.

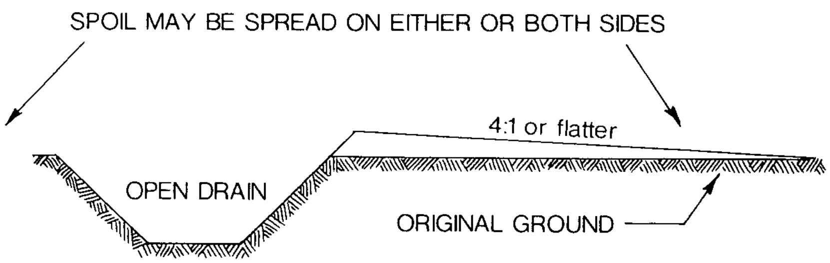

Figure 8. *Open-ditch spoil-bank spreading.*

Figure 9. *Open ditches require regular maintenance for satisfactory performance. The growth of heavy vegetation in the ditch will greatly reduce its capacity to carry drainage water. Continued neglect (as in the photo above) will require the use of a backhoe to completely reconstruct the ditch before it can function as an effective part of a drainage system.*

Kinds of Drains

Drains can be classified according to their function in a drainage system. ***Field drains*** or ***laterals*** are the individual drains that collect the excess water from the wet areas in the fields. ***Collector drains*** are intermediate-sized drains that collect the drainage from a number of field drains and conduct it to a main drain. ***Main drains*** convey the water from the field or farm drainage system to a suitable natural watercourse.

Surface drains or ditches are often used to carry off surface runoff or to serve as outlet ditches for subsurface drainage systems. The size of open ditches depends on their slope, the capacity desired, and the nature of the drainage area. The many variables involved in ditch design require the services of a competent drainage engineer.

Open ditches have several disadvantages:

- If they are deep enough to be effective, they cannot be crossed with machinery.
- Except on land with a uniform slope, they cut fields into irregular patches that are difficult to manage.
- The ditches and the land required for turn strips remove land from production.
- Traffic near the ditches compacts the soil; as a result the movement of water toward the ditches is retarded.
- The cost of maintenance is high. Weeds and brush must be controlled, and the banks and channel must be maintained to prevent the loss of ditch capacity due to siltation. Without regular maintenance ditches soon become useless (see fig. 9).

Maintenance of surface drains is a continuous process and should begin as soon as construction is completed. There are two kinds of maintenance: preventive (before failure) and corrective (after partial or complete failure). Stabilization of the banks with vegetation and the use of soil conservation practices on the watershed to reduce erosion are examples of preventive maintenance; removal of sediment and weed growth from the ditch are examples of corrective maintenance.

Subsurface drains (tile drains, subdrains, underdrains, tube drains) are man-made underground channels that allow excess water to flow to a suitable outlet. Subsurface drain materials include clay or concrete tile, bituminized-fiber pipes, and corrugated-polyethylene tubing. The major advantages of subsurface drains are:

- They do not interfere with the usual tillage operations (see fig. 10).
- They require very little maintenance.

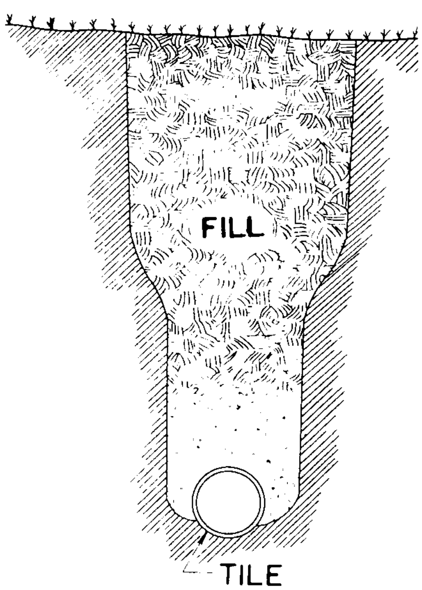

Figure 10. *Cross section of a subsurface drain. The change in the soil drainage is all that is noticeable after the drain is laid and the trench is filled.*

Subsurface Drain Material

The American Society for Testing Materials (ASTM) has adopted standards for both *standard-quality* and *extra-quality* drainage materials. *Standard-quality* material is usually satisfactory for most drainage work.

Since proof marks are not placed on individual pieces of material, the landowner must rely heavily on the reputation of the manufacturer, the dealer, or the contractor who supplies the material. To determine whether material is of suitable quality, contact your local Soil and Water Conservation District, Cooperative Extension agent, drainage contractor, or knowledgeable neighbors. It is false economy to install poor-quality material. A few dollars saved in the initial cost will soon be paid out in poor performance and high maintenance costs.

Clay or concrete agricultural tile is manufactured in diameters ranging from 4 to 24 inches. Four-, 6-, and 8-inch tiles are usually 1 foot long; 10-inch diameter and larger tiles are commonly 24 inches long. Agricultural tile has butt joints. Water enters the system through the joints. Spacing between tiles can range from a neat fit to about 1/4 inch depending on the nature of the soil in which they are placed.

Tile can be cracked in handling. *Cracked tile should be discarded.* A good tile will produce a clear ring when tapped with a metal object.

Bituminous-fiber pipe is available in 4- and 6-inch diameters and 8- or 10-foot lengths. The ends of each pipe length are machined to accommodate a snap coupling resulting in a semirigid conduit. Water enters the pipe through 2 rows of perforations. The perforation diameter can be specified according to expected soil conditions or the type of bedding and backfill material. The pipe should be installed with the perforations facing *downward.*

Corrugated-plastic drain tubing made from polyethylene is available in diameters from 4 to 12 inches and in rolls up to 250 feet long. Snap couplers form continuous lengths of conduit. The tubing is flexible, but the corrugations resist flattening. Water enters the tubing through slits or circular holes.

If good quality materials are used and the drain is properly installed, any of these materials should last indefinitely.

Factors Influencing Type and Location of Drains

The principal factors in drainage design are *soils* and *topography.* An understanding of these factors is helpful in the design and installation of adequate drainage systems. If, for example, the problem site is located in a closed basin, gravity drains cannot be used. Some soils are practically impossible to drain by internal methods; for them subsurface drainage is a futile investment.

Texture and permeability of soils

A vertical slice of soil is called a soil profile. The arrangement and characteristics of the various soil layers (*soil horizons*) greatly influence the effectiveness of various kinds of drainage systems. Soil horizons may differ from one another in their *texture* (the relative contents of sand, silt, and clay) and in *permeability* (the rate at which water moves through a particular soil horizon.)

Coarse-textured soils contain large quantities of sand or gravel, or both. Such soils are usually quite permeable—water moves through them rapidly; so drainage is seldom a problem. If the soil profile contains one or more impermeable horizons, the rate of water movement downward can be greatly reduced.

Fine-textured soils, such as clays, clay loams, or silty clay loams, contain small pore spaces, which conduct water slowly. Surface drainage techniques are often used. Subsurface drains can be used in conjunction with surface drains *if suitable outlets can be developed.*

Many soils in New York are silt loams, neither very coarse textured nor very fine textured. It follows that they often have moderate permeabilities. But many of these soils contain horizons that are less permeable than the topsoil. This situation is often aggravated by soil compaction which can reduce the permeability even further. As the soils become less permeable (for whatever reason), the effectiveness of subsurface drains decreases.

An impermeable soil horizon relatively near the soil surface often limits the effectiveness of subsurface drains. The drain should be installed at the top of such a horizon to be most effective, but it may be necessary to place the drain in or below the impermeable horizon. Covering the drain with permeable topsoil reduces the effects of the impermeable soil horizon.

Topography

Soils that occur on the higher parts of a landscape generally have few drainage problems. As the soils occur at progressively lower positions, the runoff from the higher areas adds to the problem of excess water. The effects of topography on the type of drains commonly used are summarized in table 1.

Table 1. Topographic factors and type of drains.

Steep, hilly	No outlet problem; surface drainage adequate Single-line subsurface drains in swale bottoms Seepage at toe of slope, at outcrops, or along waterways
Rolling	Outlet problems unlikely; surface drainage adequate Random system or herringbone pattern — subsurface drains Single-line subsurface drains along waterways
Gently sloping	May have outlet problem; surface drainage generally adequate Grid system — subsurface or open drains Single-line subsurface drains along waterways
Flat lake bed or flood plain	Outlet drain probably needed Grid system — subsurface or open drains in direction of greatest slope Pumped outlet sometimes needed
Closed basin	Needs outlet facility Pump outlet with sump

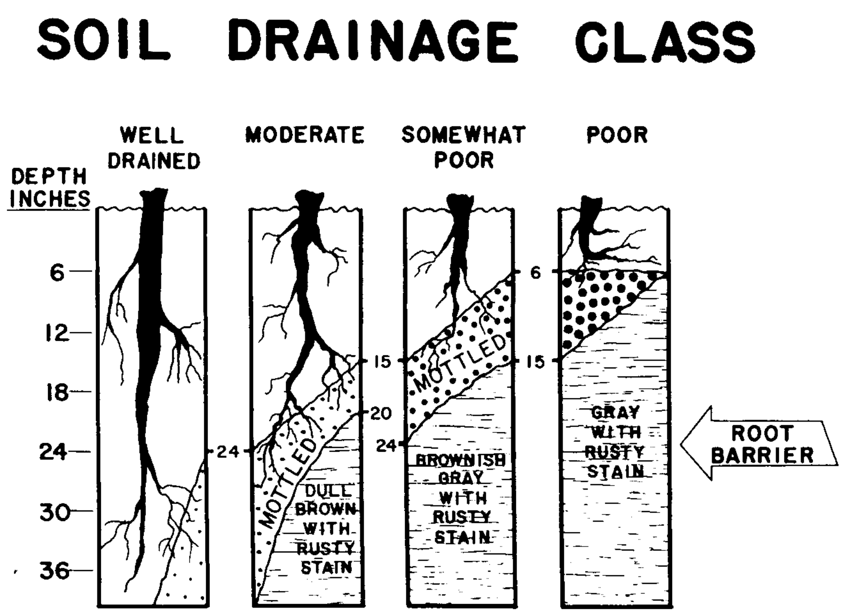

Figure 11. *The rooting depth of plants is often determined by the soil drainage characteristics. The mottled zone is saturated for some part of the year, root growth into the zone being prevented. This periodic wetness is indicated by small rust-colored stains or mottles.*

Diversion and Cropland Terraces

Both erosion control and drainage can sometimes be improved by constructing open channels (terraces) on a slight grade across the general slope of the land. Terraces are designed to intercept surface runoff and may intercept seepage as well. They should be designed to carry the flow from a 10-year frequency storm.

Diversion terraces are designed with a narrow bottom. The side slopes and back slope are seeded and kept mowed. A diversion will often divert both surface runoff and seepage. Soil excavated from the channel is placed on the downhill side of the channel to form a high dike to increase the capacity of the channel. To intercept seepage, the channel bottom must be below the seepage level which is determined by test borings or other observations.

Cropland terraces are used to intercept surface runoff. In contrast to a diversion, cropland terraces have a relatively broad, shallow channel and a low dike. They can be farmed with little difficulty. They are effective in improving drainage and reducing soil erosion.

Outlets for terraces

Surface outlets The water collected in terraces must be discharged into a safe (nonerosive) outlet. Grassed waterways are often used for terrace outlets. Sometimes surface outlets are inconvenient, expensive, or impossible. Since terraces are expensive, few landowners can afford, or are willing, to construct a terrace across a neighbor's property to reach a suitable outlet.

Subsurface drain outlets can solve this problem. The intercepted water is admitted, at a controlled rate, into a subsurface drain. This combination may reduce the cost of obtaining an outlet, it may make construction possible where no surface outlet is available, and it improves soil drainage in the area where the subsurface drain is installed. The subsurface drain should be installed a year before the interceptor is constructed.

For specific information, contact your Cooperative Extension agent or your local SWCD Office.

Steps in Planning a Drainage System

The importance of first determining the source of excess water can not be overemphasized. *Subsurface drainage is only one tool in a water management system.* Practices that encourage the absorption of water where it falls or that divert runoff or seepage from higher elevations will often reduce the need for subsurface drainage on low lying areas. Basic information can be obtained from soil surveys, topographic maps, close observation of surface flow patterns, auger-hole investigations to locate seepage planes, and local experience.

The design of a drainage system includes the selection of a suitable outlet; the layout and arrangement of drain lines; the determination of depth and spacing; the length and size of drains; and the design of the outlet structure. A drainage system will result in a minimum of outlets. *Outlets are the most critical part of any drainage system.*

Selecting an outlet

A suitable outlet has enough capacity to carry the drainage water from the entire drainage area even though only a part of the total area is to be subdrained. If an open channel outlet is used, it should be deep enough so that there is at least 1 foot of clearance between the subsurface drain outlet and the normal low-water stage in the channel. *Inadequate outlets are the most frequent cause of drainage system failures.* The point at which a subsurface drainage system discharges into an open channel should be carefully selected to avoid erosion or sedimentation of the open channel. It should be located where surface water will *not* enter the channel.

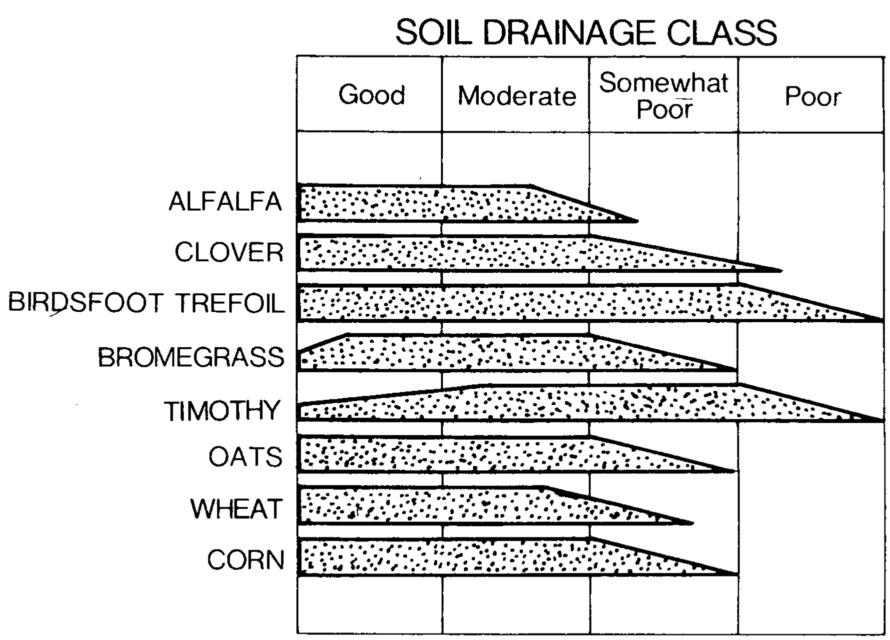

Figure 12. *The adaptation of common field crops to soil drainage. The relative thickness of the bars indicates how well the crop is adapted. Birdsfoot trefoil, for example, is equally well adapted on the three best drainage classes, but timothy does relatively better on moderately well or somewhat poorly drained soils than on well-drained soils.*

Problems of inadequate depth of cover often occur near a subsurface drain outlet. Special precautions may be necessary to protect the drainage system. Steel pipe, extra fill material, or a wider outlet ditch (see fig. 13) may seem expensive, but are cheaper than redoing the job later on. A minimum of 24 inches of cover is necessary to protect subsurface drains from damage.

Layout and arrangement of subsurface drains

Random system. A random system is used where the topography is rolling or undulating and contains wet areas. The main drain is usually located in the swales to avoid making deep cuts through the ridges. If a field is uniformly wet, the submains and laterals can be arranged in more regular patterns.

Herringbone system. This consists of parallel laterals that enter the main at an angle, usually from both sides. The main or submain is usually located in a narrow depression. The system can also be used where the main is located on the major slope and the grade for the laterals is obtained by angling the laterals upslope. Herringbone systems are sometimes advantageous in providing the extra drainage needed for finer-textured soils.

Parallel or gridiron system. These are similar to the herringbone system, but the laterals enter the main from only one side. These systems are used on flat, regularly shaped fields and on uniform soils. Variations of the system are often used with other patterns.

Double-main system. These are used where a depression (frequently a stream) divides the field to be drained. The depressional area may be wet because of seepage. Placing a main on either side of the depression serves two purposes: it intercepts seepage water, and it provides an outlet for the laterals. If the depression is both deep and wide, and only one main is used on the center, a break in the gradeline of each lateral may be necessary to reach the single main. A main on each side of the depression permits a more uniform lateral grade line.

One should resist the temptation to construct only random laterals as needed and discharge them individually into an outlet channel. The main line reduces the number of outlets that must be maintained.

Examples of drainage *systems* are shown in figure 14.

Underground seepage from higher elevations frequently appears on the surface above impervious soil or rock layers. This situation can be anticipated at an abrupt change in land slope. Where a diversion terrace (page 7) might interfere with intended cultural practices, an *interceptor subsurface drain* (cutoff drain) can be an effective solution. Interceptor drains are normally installed *above* the upper edge of the wet area, deep enough to collect seepage before it reaches the surface, and parallel to the general slope. The drain should be at the top of, or only slightly below, the impervious layer.

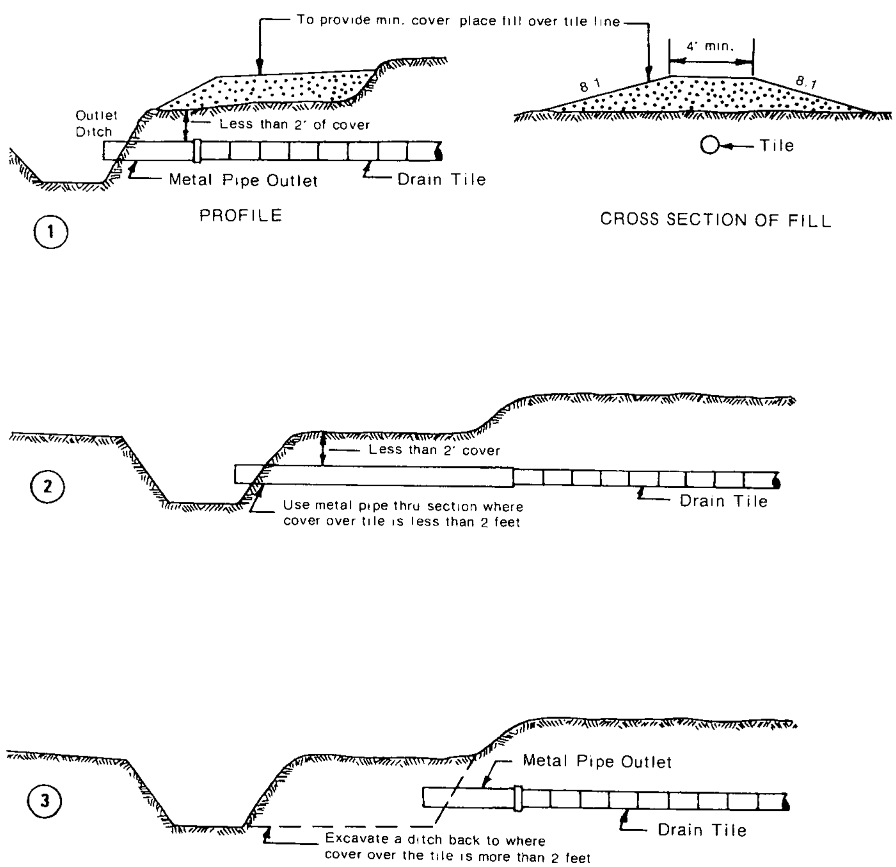

Figure 13. *Methods of handling shallow tile outlets.*

Depth and spacing of subsurface drains

The depth of subsurface drains is influenced by topography, outlet elevation, and expected traffic loads. A *minimum* cover of *2 feet* over drains is required for normal agricultural operations. There is little to be gained by placing drains deeper than 4 feet, but it may be necessary to

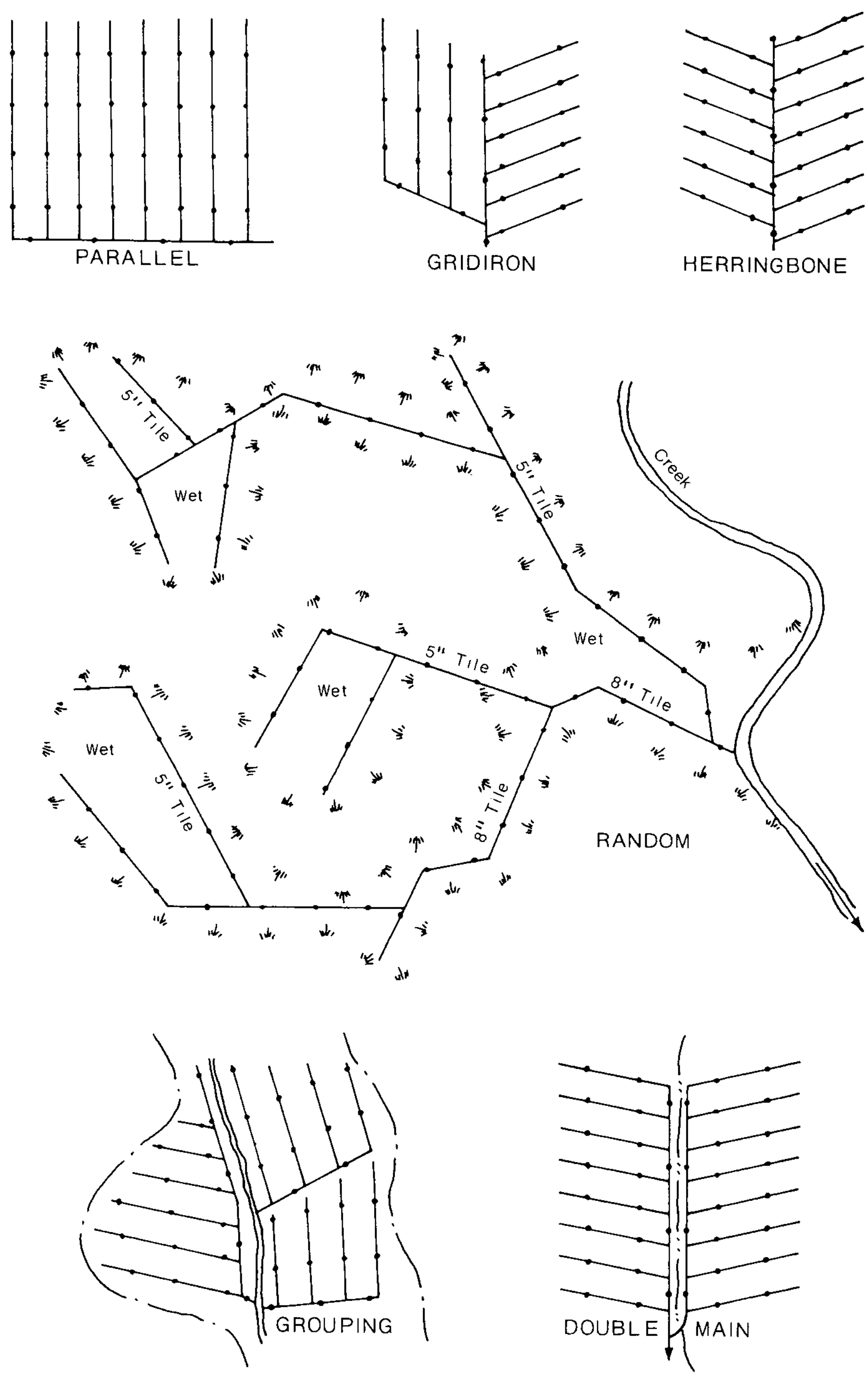

Figure 14. *Types of tile drainage systems.*

exceed this depth for short distances to maintain a continuous grade. Deep cuts should be minimized to keep costs down.

Spacing between laterals is based on experience under similar soil conditions and the intensity of land use. Intensive drainage systems can be installed before planting vineyards or orchards where the spacing is often determined by the row width of the intended planting. Close spacings (60 feet or less) are also used in some intensive vegetable and nursery crops where even short periods of flooding can ruin the crops. Drain spacings closer than 120 feet seldom pay on soils which produce field crops. If closer spacing seems necessary, a combination of surface drains may be a more economical approach. On fields with an average slope of 3 percent or less, subsurface drains can be spaced 300 to 400 feet apart; the land surface can be smoothed to a shallow depression over the drain.

Size of subsurface drains

The diameter of subsurface drains depends upon expected flow and the grade on which they are laid. A system is designed to remove from 3/8 inch to 2 inches of water per acre in 24 hours, depending on the intensity of land use. The rate selected is referred to as the *drainage coefficient.* A drainage coefficient of 3/8 inch is commonly selected for *mineral* soils where field crops are grown. A drainage coefficient of 1/2 inch to 3/4 inch is often used for higher-value crops such as vegetables and nursery stock. Direct surface inlets to a drain system should be avoided; but if they are necessary, the drainage coefficient should be increased to 3/4 inch or more.

Minimum recommended grades have been determined for various diameters of drains to avoid sediment accumulation in clay or concrete tile or bituminized-fiber pipe.

The grade of a subsurface drain system should gradually increase from the upper end of

Table 2. Minimum grades and maximum lengths for subsurface drains

Diameter (inches)	*Minimum Grade (%)*	*Maximum Length (feet)*
4	0.10	1300
6 or larger	0.05	3000

the system to the outlet, but this is sometimes impractical. Where the downstream grade changes from a steeper to a flatter one, the capacity of the flatter section may be exceeded, with blow outs resulting. A larger diameter drain should be installed in the flatter section. The drainage contractor or your local SWCD can provide recommendations for appropriate sizes.

A graphical method of determining the proper sizes of tile or drain tubing is presented on pages 22 and 23.

Digging the trench

Digging a trench requires a strong, heavy machine. The trench must be finished to a suitable grade with a minimum of hand labor. The machine must be readily controlled to dig at specified depths and to dig at the desired depth all the time. Several types of machines are shown on the covers.

One kind of trenching machine is shown in figure 15. The digging is done by the large wheel at the back. This digging wheel is mounted in a frame that can be moved up and down by the operator. Other machines use a chain and elevator mechanism in place of the digging wheel. The essential features of any successful trenching machine are a system for controlling the depth of digging and a long wheelbase, which prevents the machine from rocking up and down as it moves over uneven ground. The machine can be driven by crawler tracks or pneumatic tires. Large stones can cause some digging problems; but trenching machines have been used successfully to install hundreds of miles of subsurface drainage.

Road graders, backhoes, and other machines have been used to dig trenches for subsurface drains with varying degrees of success. The trench cannot be finished to a uniform grade with these machines unless the operator is extremely careful, and hand finishing is usually required.

A subsurface drain functions properly *only* if the grade is uniform. Machines that are suitable for installing pressurized water-supply lines are not necessarily adequate for properly digging a trench for subsurface drainage (see fig. 17).

Installation of subsurface drains

Once an appropriate outlet is developed and a system design has been selected, the installation of the subsurface drain can begin. This can be accomplished by asking your drainage contractor to schedule the installation. The contractor will want to know

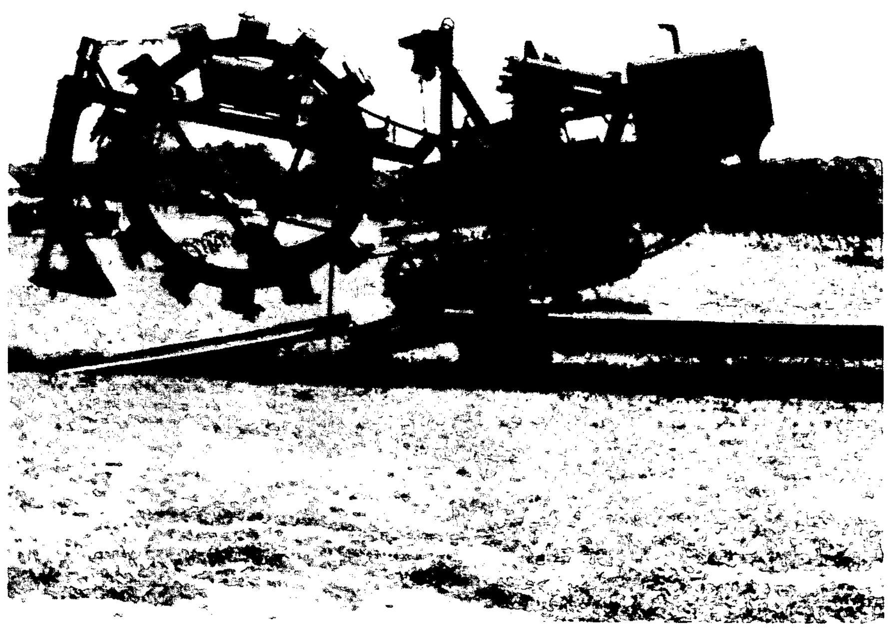

Figure 15. *A wheel-type trenching machine. The long wheel base of the machine reduces "bucking" as the machine moves over an uneven soil surface.*

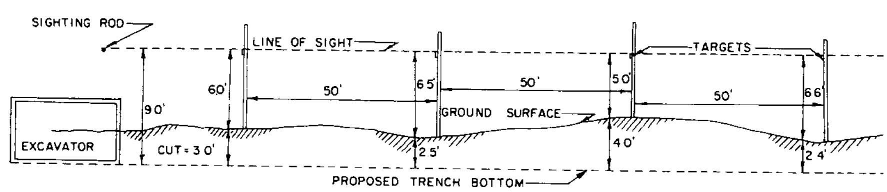

Figure 16. *Diagram of the digging element of a trencher. The operator maintains the desired grade by sighting over a sight rod and a series of targets. In this drawing, the targets are set 9 feet above the trench bottom. The operator can raise or lower the digging element to maintain the proper grade. Laser-controlled digging mechanisms are now available to control the grade automatically. Such control units are shown on the modern machines on the cover and in figure 19.*

how many feet of subsurface drain you want to install and when and will schedule the work load to operate efficiently and keep costs down.

If you do not know, or choose not to hire, a qualified drainage contractor, you should consider the following points:

- Begin digging the trench at the *outlet end.* If water seeps from the soil into the trench, it can flow to the outlet and should not greatly interfere with the digging. Even more important, such flow will identify any high or low spots in the trench bottom. These can be corrected by a little hand digging with a round-pointed shovel.
- It is very important to maintain a uniform grade. Few fields have smooth enough surfaces that a trench dug uniformly 30 inches deep will have a uniform grade. Every deviation from a uniform grade reduces the capacity of the drain.
- The trench bottom should be carefully graded and shaped to support the drain. Shaping the trench bottom reduces the possibility of misalignment and provides mechanical support to the sides of the drain. This mechanical support improves the strength of rigid materials and resists the tendency of bituminous and plastic materials to flatten and bulge. (See fig. 18.) Modern trenching machines can be equipped with a special shoe that forms the desired shape (see fig. 19). Backhoe-dug trenches can be finished by hand with a round-pointed shovel or with a special shaping shoe. A groove angle of 120° is recommended for flexible tubing.
- The drain material (tile, pipe, or tubing) should be laid as the digging progresses. If the trench is left open, soil will fall into the trench from the walls and will require extra shovelling to reestablish the grade of the trench bottom.

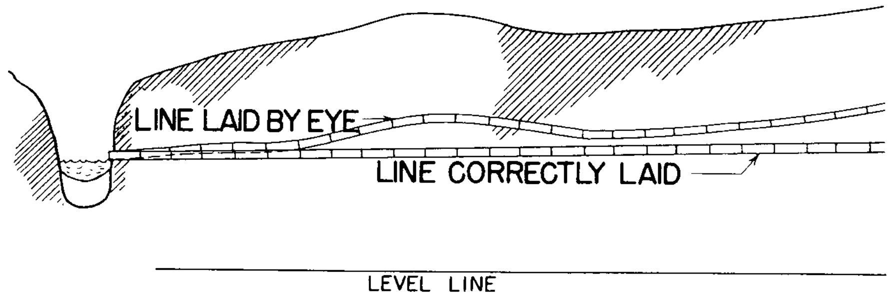

Figure 17. *Water does not flow smoothly in a drain that is laid on an uneven trench bottom. Silt may settle out in the areas where the water flows slowly.*

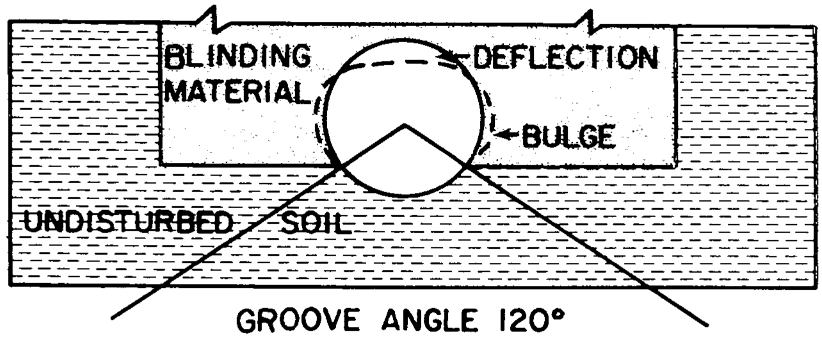

Figure 18. *Plastic drain tubing should be supported by undisturbed soil material for the bottom 1/3 of its circumference. This support reduces the deflection and bulge that occur when the trench is backfilled. Backfilling should be done carefully to insure that large stones are not placed near the tubing. As the backfill settles, such stones could concentrate pressure on the tubing, causing it to deform or collapse.*

Figure 19. *A modern trencher equipped to install polyethylene tubing. The roll of tubing is mounted on the reel at the front. A special shoe that shapes a groove in the trench bottom is fitted on the bottom of the trencher shoe, directly behind the trenching chain. This trencher is equipped with an automatic grade-control system which uses a laser beam as a reference level. This enables the operator to maintain accurate grades in the trench.*

Figure 20. When subsurface drains must make abrupt changes in direction (usually at the junction of two lines), the use of a special fitting is recommended. Such fittings are available for clay or concrete tile (left) *and for corrugated plastic tubing* (right). *The cost of labor and the time required to hand-fit a junction make these fittings economical.*

• Some soil conditions require the use of a layer of gravel backfill over the drain or a fiberglass or nylon cover to keep out soil particles. Subsoils that consist of fine sandy material are particularly troublesome. The sand particles tend to move into the drain with the water and settle out inside the drain, its capacity being reduced.

In such a situation, the joints between clay or concrete tile should be close fitting (as close as you can get them) and wrapped with asphalt-impregnated strips (strips of roofing paper are commonly used); or a continuous strip of special fiberglass mat can be placed over the drain through the area of unstable soil. Plastic tubing can be purchased with factory-installed nylon or fiberglass filters.

• In silt loam and clay soils, where soil stability is not a serious problem, a crack width of up to 1/4 inch is not objectionable.

• When placing clay or concrete tile, *resist* the temptation to lay the tile and then kick it to close the joint. This kind of irresponsible (but convenient) practice results in misalignment as well as broken, chipped, and cracked tiles.

• As soon as the drain is laid, it should be carefully bound in place by putting fine, stone-free soil on both sides to hold it securely. This should be followed by "blinding"—partially filling the trench with stone-free topsoil or the most-porous material available on the site. Careless blinding with stony material can break tiles or collapse plastic tubing.

• Special backfill material may be needed in soils that tend to seal at drain openings. Straw, corn cobs, or wood chips can be used; but crushed stone, gravel, or slag is more durable.

• The upper end of the drain should be blocked with a flat stone (tile or pipe) or with a special plug (plastic tubing) to keep soil (backfill) out of the drain.

• Tree roots can completely plug drains, especially if the drain is fed by springs supplying water during the dry season. Poplar and willow trees should be removed if they are within 100 feet of the drain. If removal is impractical, sealed joints or nonperforated materials should be used in that section of the line.

Subsurface drain outlets

When a subdrainage system empties into an open channel, the end should be protected against erosion and the entrance of small animals. Where no surface water will enter the ditch at the location of the subdrain, a minimum of 8 feet of continuous rigid pipe should be embedded into the ditch bank with enough overhang to discharge water at the toe of the ditch slope. Where surface water will enter the ditch at the location of the tile outlet, an overfall structure of concrete, masonry, or other suitable materials should be used. See figure 21.

Animal guards, consisting of *horizontal* bars or flap gates, should be installed on the outlet pipe at the time of construction (see fig. 22). Bars should be

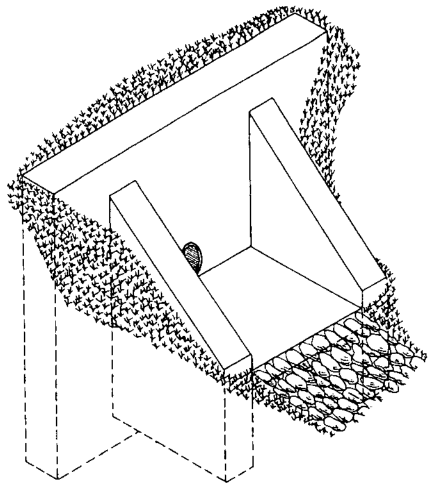

Figure 21a. *A good type of concrete headwall. The wing walls act as braces. They also prevent banks from sliding and thus blocking the outlet.*

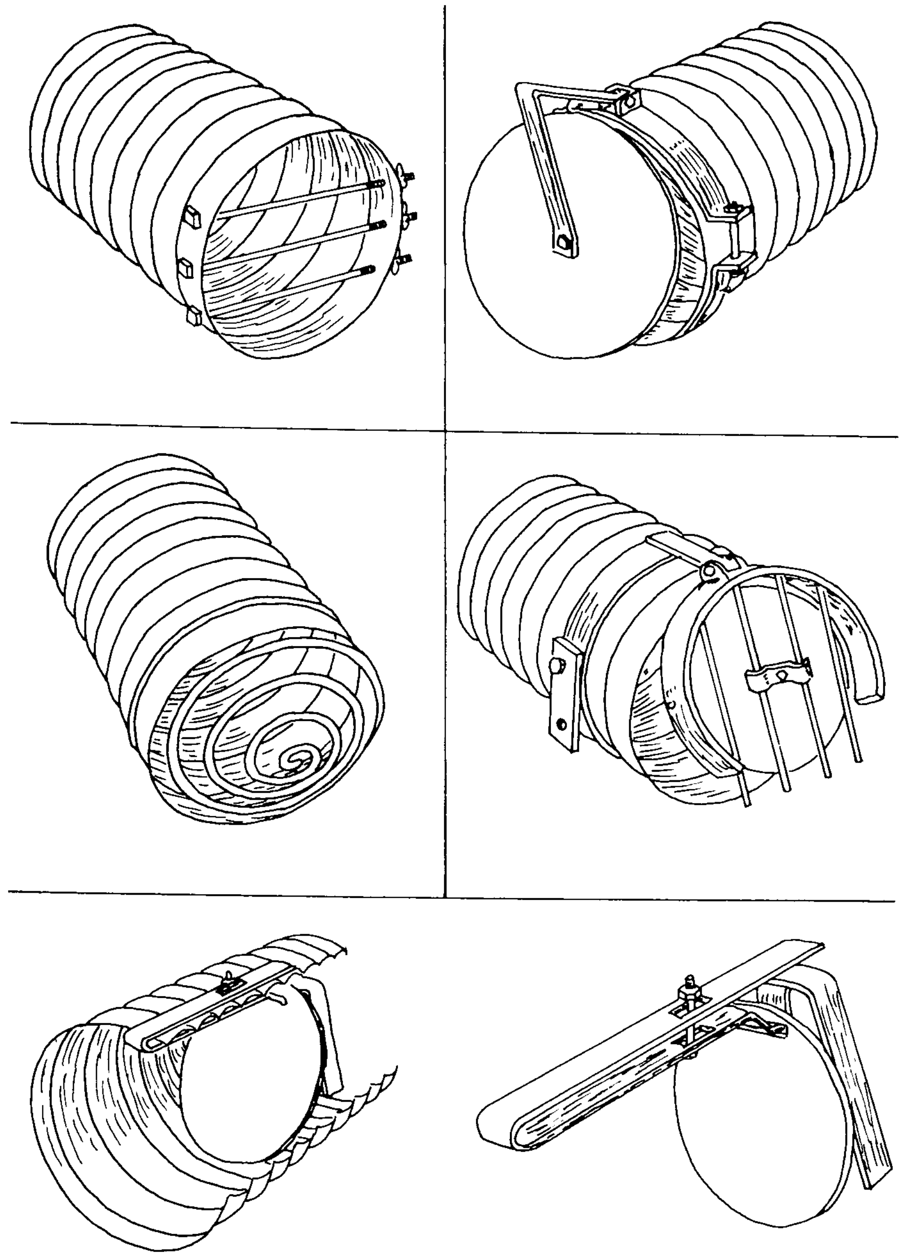

Figure 22. *Rodent protection for outlet pipe.*

Figure 21b. *A rough but effective headwall at outlet of a 4-inch drain. The flat stone on which the water falls prevents it from making holes.*

spaced about 1 1/2 inches apart. Closer spacing can restrict flow.

Surface inlets

Surface water should not be admitted to a subsurface drain if this can be avoided because it usually carries both debris and sediment which can combine to plug a subsurface drain.

In some surface depressions ("sags" or "potholes") the water may stand for a long time because the surface soils may be too impermeable for the water to seep downward to the drain. In such cases a short section of the trench can be backfilled with fine (1/2-inch) gravel topped with 8 to 12 inches of clean, coarse sand. Normal tillage will mix silt and clay particles with the sand, but the sand acts as a filter to protect the drain. The permeable backfill greatly

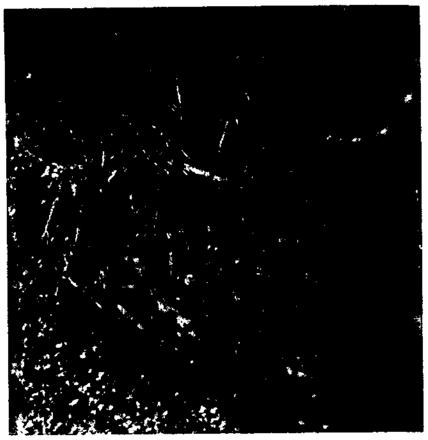

Figure 23. *Iron pipe used as outlet for 4-inch tile. This extends about 4 feet out of a steep riverbank. It is so high above the ground that there is little danger of animals getting to it.*

Figure 24. *A good type of grating for a surface inlet. The heavy bars, parallel to the direction of the flow of surface water, tend to be washed clean rather than to hold trash.*

increases the rate of infiltration.

Flow from road culverts may keep a field wet until well past the normal tillage season. Highway ditches often collect seepage water as well as surface runoff. A surface inlet (fig. 24) can be used to carry the low flow from seepage to a subsurface drain.

Figure 25 shows the construction of a concrete surface inlet with a steel grating to exclude large debris. A simple effective inlet can be constructed of corru-

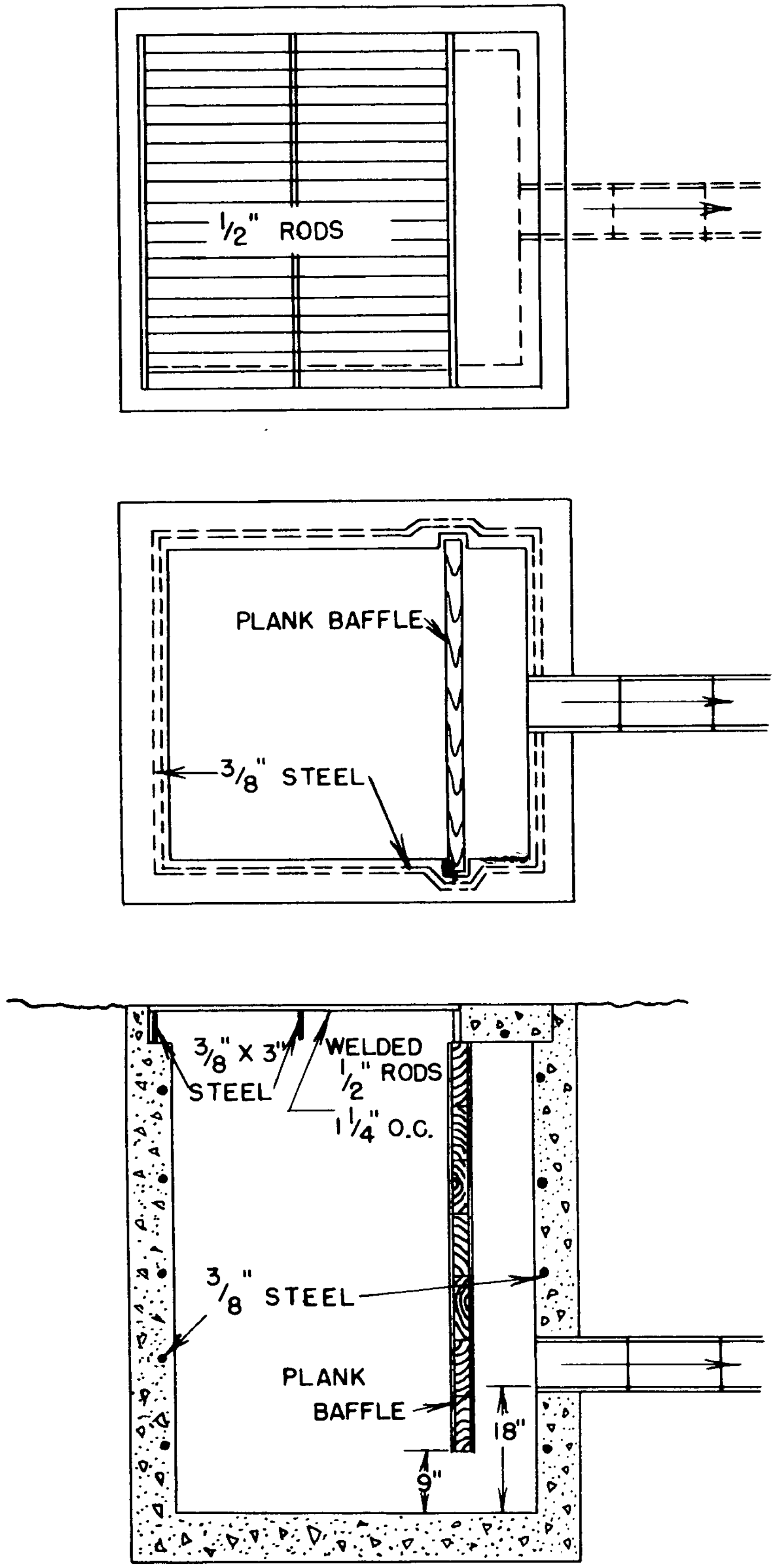

Figure 25. *Cross section of a masonry inlet. Note the depth of the box and the baffle. They help to keep earth and sticks out of the tile.*

gated iron pipe with enough holes to accommodate low flow (fig. 26).

During periods of heavy runoff (storms, snowmelt, hurricanes) the volume of flow through the culvert will be greater than the capacity of the subsurface drain. A grass waterway should be constructed to carry this storm flow. The waterway should be carefully maintained to prevent erosion. Figure 27 shows the placement of the subsurface drain and the grass waterway channel; and figure 28, the outlet structure.

Inspection and Maintenance of Subsurface Drains

Subsurface drains, if carefully planned and properly constructed, are practically permanent. They require relatively little maintenance, *but they are not completely maintenance-free.* Nearly all the trouble with well-laid subsurface drains results from *poorly constructed and(or) neglected outlets.* Outlets should be inspected in early spring every year while they are carrying drainage water. Mud, grass, and weeds should be removed so that water can flow away freely. Any damage to the head wall or to the animal guards should be promptly repaired. Catch basins and surface inlets *should be cleaned.*

"Wash-ins" require immediate attention. These appear as holes over the tile line and indicate a broken tile, excessive spacing between the tiles, or a poorly made junction. The tile should be uncovered, and the situation remedied.

It would also be wise to check with your town or county highway department about the schedule of ditch cleanout projects. Subsurface drain outlets into

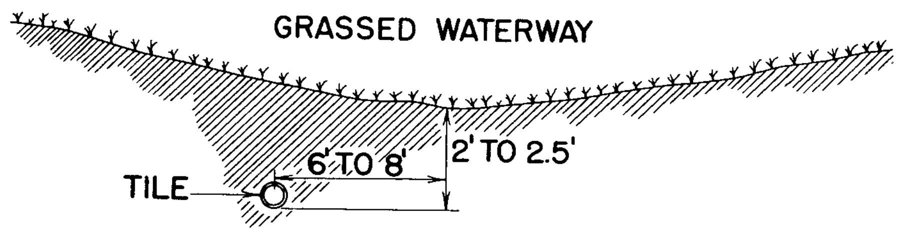

Figure 27. *Cross section of a grassed waterway and subsurface drain. The surface depression carries flood water. The drain removes the excess ground water after the surface flow has ceased.*

Figure 26. *A corrugated metal pipe inlet. The perforations admit ponded surface water. The screen prevents trash from entering the subsurface drain.*

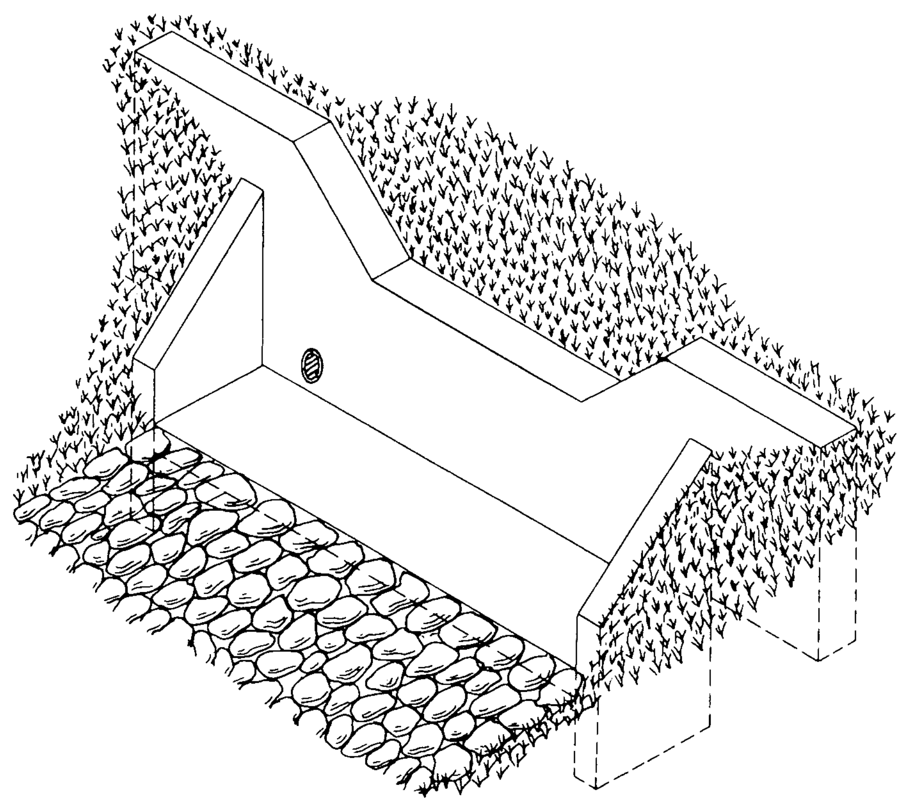

Figure 28. *Headwall suitable for use where grassed waterway and subsurface drain must discharge at same place.*

roadside ditches are often damaged by such operations.

The annual maintenance of a subsurface drainage system is small, especially when compared with the cost of any modern farm implement. Time and money spent on drain maintenance are easily returned in increased ease and efficiency of field operations, higher crop yields, and lower machinery-maintenance costs.

Mapping the drainage system

Subsurface drains improve soil drainage but do not interfere with cultivation. After a few years the surface evidence disappears. Normal tillage practices will erase any indication of the trench location. For future reference, a map should be made and filed with other valuable papers. Such a map will supplement what will soon become vague memories and can save both time (and money) if it is later necessary to add to the system. A good map is also helpful when property is transferred and can be very useful if you are ever approached about selling (or donating) utility right-of-way.

Most aerial photographs (like those used for a farm conservation plan) are too small to record enough information to be helpful in relocating a subsurface drain. A good sketch map is much more helpful. Any such map should include drain size, length of lines, location of junctions, and distances from a permanent marker. A sketch at a scale of about 200 feet per inch is usually adequate.

How to make a sketch map:

1. Select some permanent markers near each end of the drain. These can be a road culvert, a tree, a bridge abutment, or some other relatively permanent kind of marker.
2. If possible, locate 2 such permanent markers at each end of the drain. The markers should be located in opposite directions from the end of the drain.
3. Mark these markers—chisel an *X* in a concrete culvert or abutment or nail an aluminum cantop to a tree.
4. Measure from the markers to the end of the drain.
5. Draw a diagram and record these distances. Describe the markers on the sketch map.
6. Using an ordinary hiking compass, align the needle and the N. Standing at the end of the drain, sight across the compass face along the drain to the first bend. Note the reading along the drain on the compass face (keep the needle and the N aligned).
7. Record the compass reading on the sketch.
8. Measure (or pace off) the distance to the bend. Draw it on the map (1 inch = 200 feet) Mark the length on the map. Also measure (and note) the distances to any junctions, and sketch them on the map.
9. When you reach the bend repeat steps 6, 7, and 8.
10. At any junctions, repeat steps 6, 7, and 8—sighting from the junction along the drain lateral.

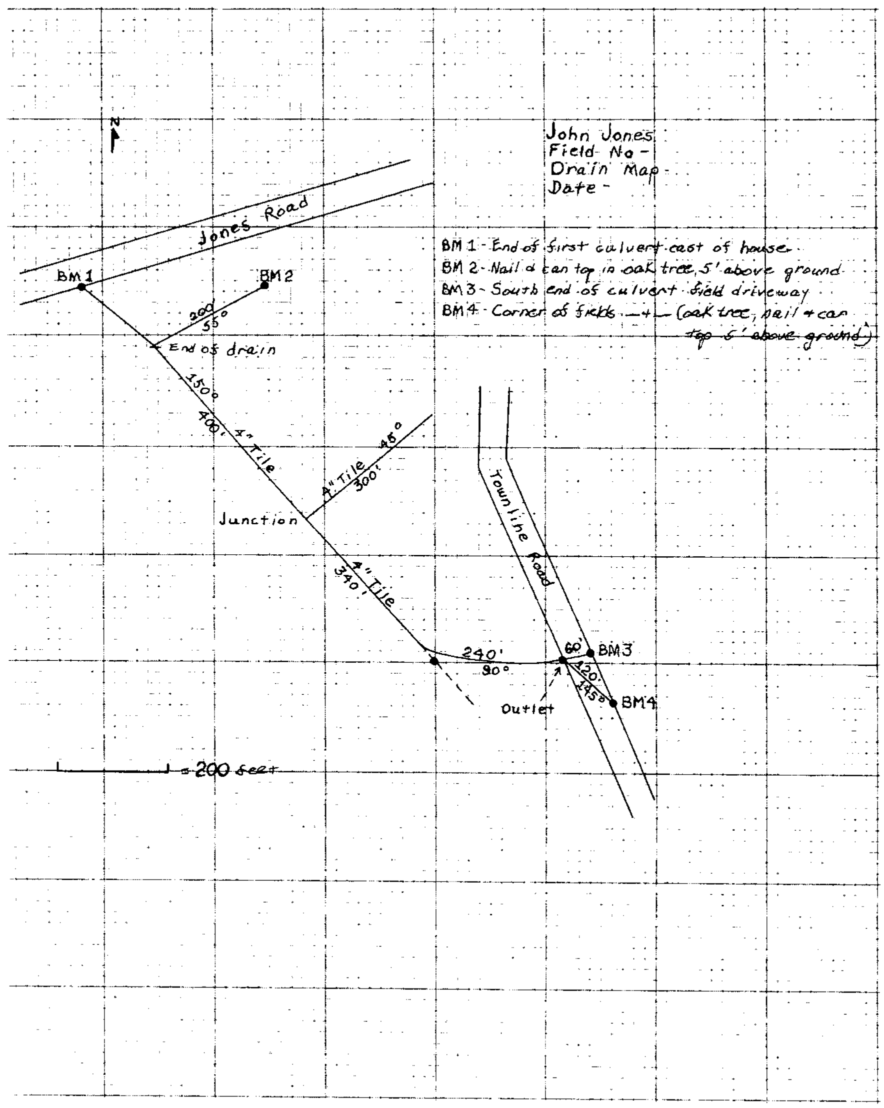

Figure 29. *A sketch map, showing where the drains are located, their compass bearing, and the length. Such a map should be made when the drain is installed and should be filed with important farm records.*

11. Continue until you reach the upper end of the drain.

12. Install 2 markers near the upper end, and record the distances and compass bearings to these markers.

13. Be sure to include the field number on the sketch.

14. A sketch map might look something like the one shown in figure 31. File it with your important farm records. If you hire a drainage contractor, ask and expect to have such a map furnished as part of the service.

Drain plows

Machines to "plow in" drains have become practical with the introduction of flexible plastic drain tubing. The tubing is fed into the ground through a slit opened in the soil by the plow blade. Trenching is eliminated, and backfilling is not required. The soil displaced by the plow blade is sometimes recompacted with the tractor wheel or crawler track.

The speed of installation is faster than for trenching operations: the rate of plowing in drains may range from 60 to 135 feet per minute. In some situations, 1800 feet of drain can be installed per working hour. Obviously, such rates of installation are best suited to large-scale projects. It has been estimated that plowed-in drains can probably be installed for about 1/3 to 1/2 of the installation cost for excavated drains.

Soil moisture content and rocks both affect the operation of drain plows. Smaller rocks are often moved out of the way by the plow blade. Large rocks are often steered around, with a steerable blade on the plow. Up to a point, the draft requirements decrease as the soil becomes wetter. This trend is limited by the ultimate loss of traction when the soil becomes too wet. In cohesive soils, a dry condition can make the power requirements so high that plowing in drains becomes impractical.

These machines have been used extensively in Canada. They are especially suited to installing drain tubing in stone-free soils.

Mole drains

Mole drains are unlined subsurface conduits. They are formed by pulling a bullet-shaped steel plug (mole) through the soil. The mole is usually about 3 inches in diameter and is welded to a steel shank that is attached to a frame similar to a plow. As the machine moves forward, the shank leaves a slot in the soil through which surface water can enter.

Mole drains have been used extensively in England and might be employed in silty soils. Such soils can be quite impermeable and require the installation of subsurface drainage at very close (and very expensive) spacings. In such situations, a permanent subsurface drain is installed at the lowest points of the slope, covered with 6 to 8 inches of coarse gravel, and backfilled in the normal manner. The mole drains are then constructed to intersect the permeable gravel backfill.

Mole drains are usually 18 to 24 inches deep. Spacing between mole drains may vary from 8 to 20 feet. Mole drains should be kept short. They must be constructed to a continuous grade to work properly. Maintaining a continuous grade is the most important and most difficult aspect of mole drains.

Every few years the mole drain is "rediscovered" and heralded as a new, successful, and economical way to improve land. They have been tried many times and are only partially successful. The general objections to mole drains are that they require large quantities of power, the drains can seldom be constructured with a satisfactory slope, they are subject to silting, and they are readily damaged by deep freezing of the soils.

Figure 30. *A modern drain plow*

Drainage on Organic (Muck) Soils

Many interrelated factors must be considered in draining organic soils. A competent engineer should be consulted for feasibility studies and system design.

Subsidence. Peat and muck are accumulations of partially decomposed vegetation in bogs, marshes, and swamp forests where oxidation has been impeded by a high water table. When these areas are cleared and drained, subsidence begins. This is caused by shrinkage due to drying, loss of the bouyant force of ground water, compaction, slow oxidation, tillage, and wind erosion. After a rapid initial subsidence, the rate levels off to slightly more than 1 inch per year in central New York.

The initial profile of organic soils has nearly uniform density, but with prolonged cultivation the surface layer changes into an amorphous mass, the surface becomes darker, and the permeability declines. These inevitable changes can be slowed by retaining the highest practical water table, but they should be considered *before* developing organic soils. Since clearing and draining a potential muck area is costly, a detailed soil investigation should be made to determine whether the muck is deep enough to warrant the investment. Mucks less than 5 feet deep are questionable investments.

Outlet development. Muck areas always occur in depressions that have not developed a natural outlet. It is very important to determine if and how an adequate outlet can be developed. The extent of excavation required and the nature of the material to be excavated must be determined. The cost of developing a pumped outlet (if a gravity outlet is not feasible) must also be considered.

Figure 31. *Since the water level in the outlet ditch is higher than the surface of the muck* (background), *a pumping plant must be used to lift the drainage water to the outlet ditch.*

Flood prevention. A third important consideration is the amount of surface and seepage flow from the higher areas that has to be accommodated to prevent flooding. Whenever possible, flood flow from higher elevations should be diverted around the proposed development area. Peripheral ditches should be deep enough to intercept seepage and large enough to carry runoff. Diverting upland runoff reduces the size and cost of an adequate pumping plant. Over the expected life of a cultivated muck area, the initial investment in drainage is likely to be repeated three or four times.

Management. If a new development is feasible, the usual procedure is to construct the main outlet channel and a minimum of temporary open ditches to lower the water table during the clearing operations. After clearing, the area should be smoothed and planted to coarse crops for several years before attempting to plant fine-seeded vegetable crops. Initial subsidence should occur in 3 years after which time a basic subsurface drainage system can be installed.

Subsurface drainage. The subsurface drainage system is designed to remove from 3/4 inch to 1 1/2 inches of water in 24 hours. Since grades are relatively flat, the minimum recommended drain diameter is 6 inches. Joints between tile should be at least 3/8 inch wide, and perforations in other material should be 5/8 to 3/4 inch in diameter. Spacing between lines on new muck is usually 120 or 200 feet, depending upon local experience. As the surface layer becomes less permeable, intermediate lines are usually required.

The minimum cover required to protect subsurface drains in organic soils from collapse or breakage by equipment is about

2 1/2 feet. The average depth of installation on new muck should be 4 to 4 1/2 feet. When the thickness of the muck subsides to 18 inches or less above mineral soil, the drainage system should be redesigned on the basis of the permeability of the underlying material.

Pumping systems. In time, organic soils may subside to a point where it is no longer feasible to continue deepening a gravity outlet. Sometimes a pumping system can then be designed to prolong the productive life of the muck area (fig. 31).

Figure 32. *Two monuments to tile drainage.* Right, *boulder and plaque on the Johnston farm near Geneva, New York, where some of the earliest tile drains in America were installed in 1835.* Left, *M. M. (Mike) Weaver, SCS-USDA (retired), drainage engineer, author, collector of historical drain tile, consultant, the foremost proponent of tile drainage in the Northeast for many years, and friend.* Background, *Highway ditch into which some of Mr. Johnston's tile drains still flow.*

Community Drainage Efforts

Many areas that have widespread drainage problems also lack adequate drainage outlets. Outlet development is generally more expensive than the installation of field drainage. *But all drainage work must begin with an adequate outlet.*

Community drainage projects can be accomplished in many ways. Federal programs can provide technical or financial assistance or both. These programs are continually changing. An inquiry to the local Cooperative Extension office, Soil and Water Conservation District (SWCD), or Agricultural Stabilization and Conservation Service (ASCS) office will provide up-to-date information.

Cooperative projects between concerned landowners, the county SWCD, and a unit of local government have sometimes been formed. These often provide for the use of town or county highway department equipment and operators for the construction of necessary outlet drains.

Landowners who will benefit from the improved outlet are often expected to pay at least part of the cost of construction; they are usually expected to obtain easements from landowners who are not interested in the project or who may not receive any direct benefits.

Landowners can also organize themselves under the provisions of a state law allowing the formation of special-purpose districts. Such an organization is allowed to assess taxes on the landowners within the district. Legal guidance is required.

Landowner–Contractor Relationships

Much of the drainage work in New York is done by professional land improvement contractors. Employing such a contractor, who knows about appropriate drain slopes, the importance of maintaining constant grades, the relative merits of various materials, how to determine the appropriate drain sizes, and how and where to acquire the proper materials, is usually worth the slight extra initial cost incurred. Remember that the lowest first cost does not guarantee the most economical system.

Professional contractors are often booked well in advance of the drainage season. If you plan to install a drainage system, you should contact the contractor early in the year. This will allow the person to plan the work efficiently and to order the necessary materials in advance. Drainage materials are sometimes in short supply during the summer months.

Since drainage usually represents a considerable investment, it is a good policy to have a written agreement. This should specify the amount and kind of work to be done, the type and quality of materials to be used, who shall supply the materials, who is responsible for installing the material, who is responsible for blinding and backfilling, and the terms of payment for the work to be performed.

Cutting underground utilities (telephone cables, gas, water, or sewer lines) can be disastrous (both physically and financially) for both parties. Buried utilities should be located by the utility owners before any excavation is done. A knowledgeable contractor will know whom to contact for this information. An orderly procedure for obtaining the information should be available in the near future. A "one-call" notification should be implemented by the county or another municipality: a phone call to your town clerk would provide information on how to contact the appropriate authority. Such a procedure would help to alleviate the problem with its ensuing inconvenience, delay, and costs.

Determining drain sizes

The charts given provide a method of determining the appropriate drain size (figs. 33 and 34). Note that there are separate charts for clay tile and for plastic tubing. This is because the corrugations in the tubing tend to reduce the flow rate compared with that for the same nominal diameter of a smooth-walled drainage material (tile or bituminized pipe).

To determine the appropriate drain size, select the desired drainage coefficient at the bottom right of the chart. Proceed upward in the appropriate column to the number of acres you wish to drain. Follow the line horizontally until it intersects the planned slope of the drain. The space between the lines that slope upward from left to right indicates the proper drain size.

Example:

If the drainage coefficient *C* is 3/8 inch and you wish to drain 20 acres, proceed up the left-hand column on the right side of the diagram to the 20-acre mark. Draw a line to the left. The intersection of this line and the desired drain slope (for example, 1 foot per 100 feet or 12 inches per 100 feet) indicates the proper drain size. For this situation you should install a *4-inch*-diameter clay or concrete tile or bituminized pipe, or a *5-inch*-diameter plastic drain tubing.

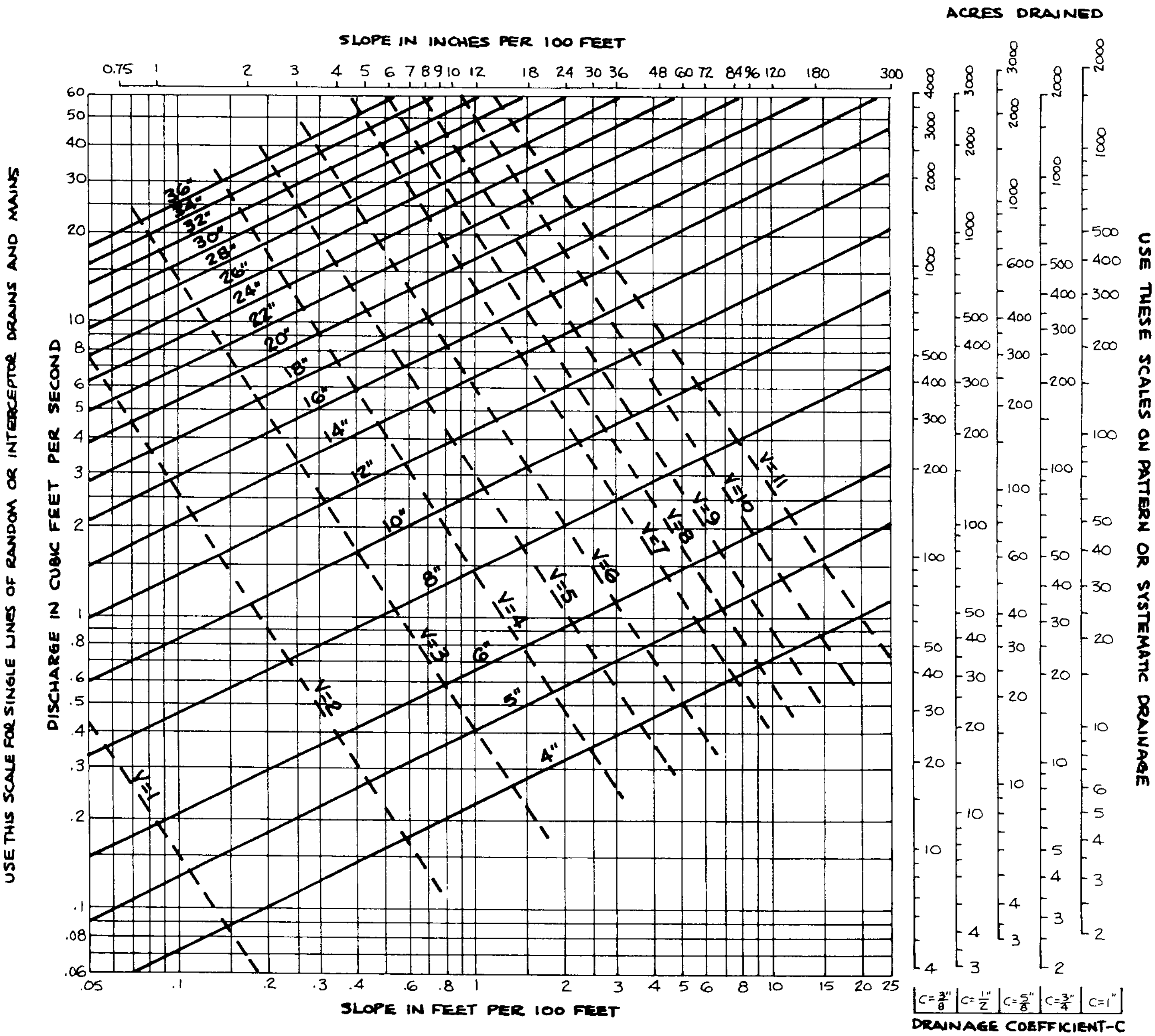

Figure 33. *Drain size chart for smooth-walled materials (clay or concrete tile, bitumenized pipe.) To determine the appropirate drain size, select the desired drainage coefficient at the bottom right of the chart. Proceed upward in the appropriate column to the number of acres you wish to drain. Follow the line horizontally until it intersects the planned slope of the drain. The space between the lines that slope upward from left to right indicates the proper drain size.*

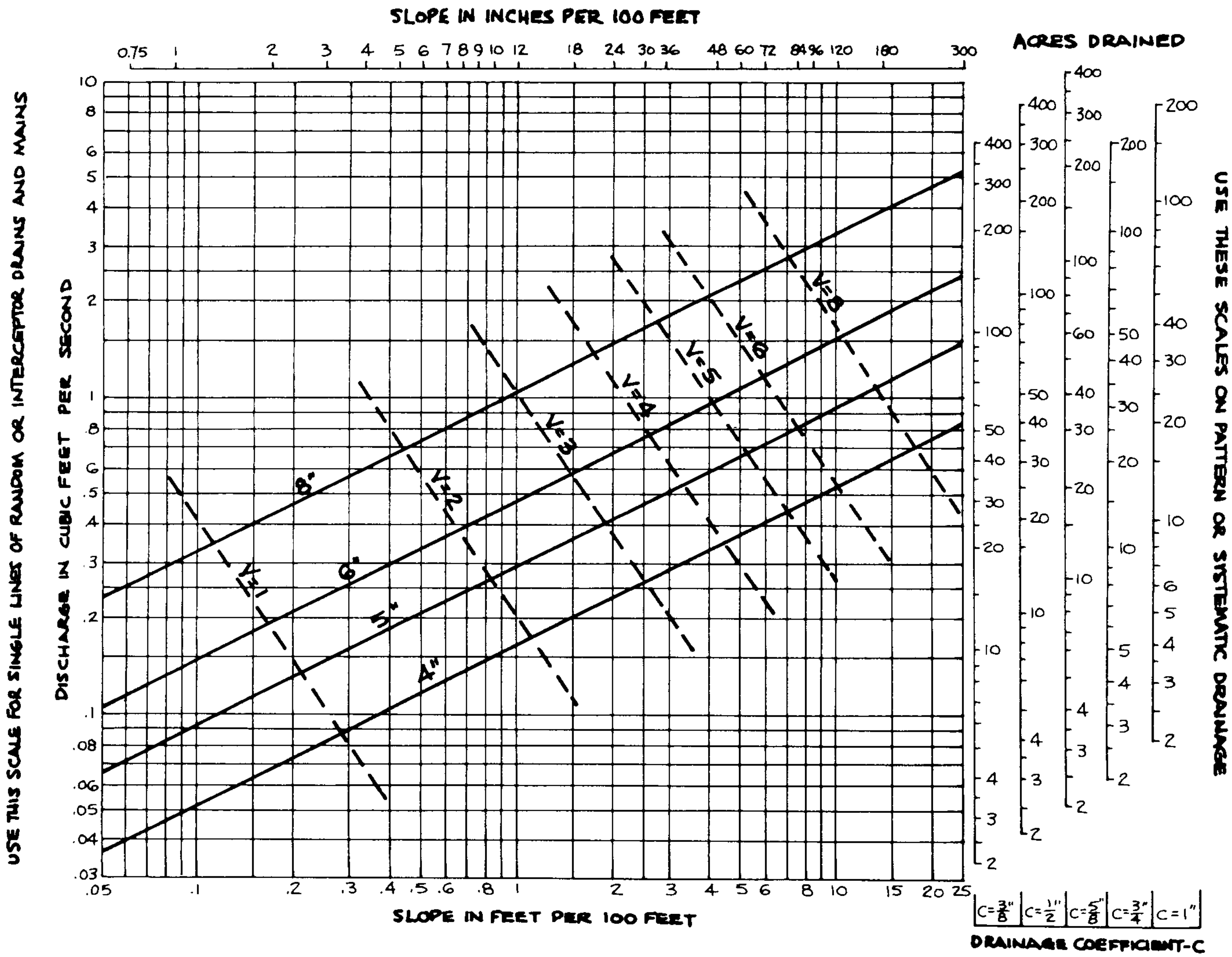

Figure 34. Drain size chart for corrugated plastic tubing. To determine the appropriate drain size, select the desired drainage coefficient at the bottom right of the chart. Proceed upward in the appropriate column to the number of acres you wish to drain. Follow the line horizontally until it intersects the planned slope of the drain. The space between the lines that slope upward from left to right indicates the proper drain size.

Glossary of Terms

Bedding. Plowing, blading, or otherwise elevating the surface of flat land into a series of broad, low ridges separated by shallow, parallel dead furrows or field ditches.

Berm. A strip or area of land, usually level, between the spoil bank and edge of a ditch.

CFS. Cubic feet per second.

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

Drainage coefficients. The depth of water, in inches, to be removed from an area in 24 hours.

Field drain (field ditch). A shallow, graded channel, usually having relatively flat side slopes, that collects water within a field. Water can enter it through crop rows or row ditches or by sheet flow over field surfaces.

Land smoothing. Shaping the land surface with a land plane or land leveler to eliminate minor depressions and irregularities without changing the general topography. The depth of cut in this operation is generally small and limited by the kind of equipment used. Land smoothing is also the finished operation in land grading.

Outlet. The lower terminal point of a drainage system or individual drain.

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

Subsurface drainage. The removal of excess water from below the soil surface by means of drain tile, perforated pipe, mole channels, or other devices,

Water table. The upper surface of a saturated zone within the soil.

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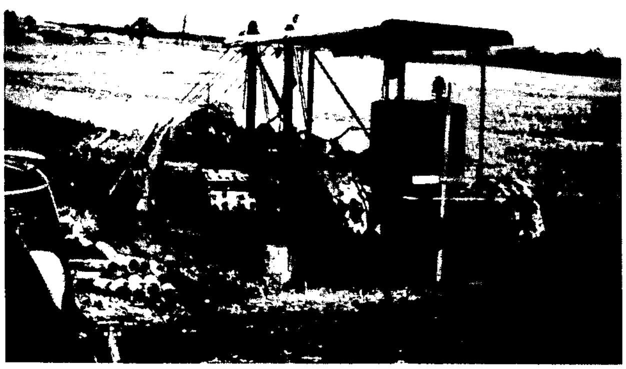
Land drainage techniques have changed over the last 40 years. Improved trenching machinery, new drainage materials, and the use of laser beams for grade control have made drainage installation faster, more convenient, and less disruptive to the existing land use.

(Courtesy Laserplane Corporation)



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