SURFACE DRAINAGE of FLAT LAND in the Eastern United States

D. R. Coote and P. J. Zweren
Preface

This bulletin is the result of several years of study of surface drainage in the eastern United States. A study of bedding for surface drainage was carried out from 1961 to 1966. Eighteen states were visited in 1964 for observation, study and evaluation of surface drainage installations, and an investigation of land smoothing techniques has been in progress since 1965. In 1968 an extensive review of the literature and survey of the entire subject was made ("Handbook of Surface Drainage Principles and Practices," Agronomy Mimeo 69-3, Department of Agronomy, Cornell University, February 1969).

This bulletin applies to lands with zero to two percent slopes that are subject to prolonged surface wetness and slight or no wash and erosion. It does not apply to auxiliary works for protection from flooding streams or to the interception and diversion of surface runoff seepage from any adjoining uplands.

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Acknowledgments

The following persons gave general advice, criticism, and/or detailed suggestions:

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Introduction

For many years surface drainage has been considered as a local art. The available literature is scattered and terms are frequently misleading. Poor communications have prevented improved practices from being tried or accepted in regions other than those in which they were developed. Modern land forming concepts, together with efficient earth moving machinery, could make surface drainage an acceptable practice in those regions in which it is needed. Figure 1 shows some of the areas of the Eastern United States which are in need of surface drainage.

Surface drainage has existed in one form or another for centuries. Methods which would now be termed "bedding" were brought to this continent by the early settlers and applied extensively. These methods can be recognized today in the "French plowing" of the St. Lawrence valley, and the "ridges" of the Mississippi flood plains (12). ¹

Around 1950, a serious attempt was made by Beauchamp (2), Saveson (32), Wojta (46) and others to improve the methods for surface drainage on impervious and low-lying soils, while at the same time increasing the efficiency of mechanized field operations. In subsequent years many improvements have been made which have enhanced the acceptability of surface drainage as a modern field drainage technique.

The purpose of this publication is to present information about surface drainage to conservation contractors, engineers and farmers. It is hoped that with this information they will be better prepared to design and construct effective and economical surface drainage systems.

Surface Drainage Benefits

Surface drainage will usually bring three types of benefits: direct and indirect yield increase; increased efficiency of machinery; and increased efficiency in the use of fertilizers.

Direct and indirect yield increases may result from earlier planting, often as much as three weeks in the Northern states (47); elimination of many small drowned out areas; more even distribution of rain water; better and more uniform results from weed control measures; and ability to grow better varieties (32). Yield increases from these factors combined often amount to

¹ Numbers in parentheses in the text identify works in the list of selected references.
as much as 20 percent (5, 10). In many regions, crops that had been impossible to grow produced average yields after surface drainage of wet land.

Machinery efficiency is almost always increased by surface drainage, except by the bedding method. Up to 30 percent faster operation, less maintenance, fewer weeds, and less likelihood of becoming stuck in wet spots at harvest time, all contribute to greater machinery efficiency (4, 11, 32).

The recovery of fertilizers by the crop is frequently increased by surface drainage, due principally to more uniform stands.

Surface drainage is sometimes practiced on land which is tile drained as a form of insurance against a particularly wet year. Tile spacings can be made up to 50 percent wider on fields which have been surface drained.

Benefit-cost ratios computed in Ohio were higher for surface drainage than for tile drainage (35). Studies in New York have shown benefit-cost ratios of about 6:1 (10). Surface drainage installations in Louisiana have been paid for in the first year with increased sugar cane yields (32): winter killing of alfalfa in Maine was reduced from 90 percent to five percent after surface drainage.

Fig. 1. Flat lands in the Eastern United States requiring surface drainage. Adapted from Gain (12).
Definitions of Terms

Surface drainage is defined by the American Society of Agricultural Engineers as: “The diversion or orderly removal of excess water from the land by means of improved natural or constructed channels, supplemented when necessary by shaping and grading of land surfaces to such channels.” (1)

Publications dealing with the subject of surface drainage show great variation in terminology. Attempts have been made to standardize terms (1, 18, 42), but some of these attempts have unintentionally added to the existing confusion. The terms defined below have been selected for use in this bulletin in an attempt to eliminate local and regional bias and colloquialisms. These terms represent the best judgment of the authors.

Surface field drain: A shallow graded channel having flat side slopes which can be easily crossed by machinery. Its function is to collect surface runoff from within the field. [Also known as diversion (1); row drain (1); field ditch (42); row ditch (42); drainage terrace (47); cross slope ditch (2); eave troughs (7); diversion ditch (42); field drain (17).]

Collection drain: A graded channel which may have flat side slopes which can be crossed by machinery. Its function is to collect surface runoff from the surface field drains and adjacent areas and conduct it to an outlet. [Also known as field lateral (1, 18); collection system (42); and field ditch (42).]

Interceptor ditch: A ditch located along the upslope field boundary which may be deep enough to intercept sub-surface seepage as well as surface runoff from adjacent upslope areas. It should divert this water to a collection drain or field outlet. [Also known as diversion ditch (42); and interceptor drain (1).]

Field outlet ditch: A ditch leading away from the surface drained field carrying water from the collection drains or direct from the surface field drains.

Row grade: The slope in the direction of the crop rows, usually the prevailing slope on the field carrying water to the surface field drains.

Cross slope: A slope perpendicular to the crop rows.

Land forming: Any man-made change of the natural surface of soil that alters the movement of surface water.
Land grading: Forming the surface of the field to conform to particular specifications of row grade and cross slope.

Land leveling: Precision land grading primarily for the purpose of surface irrigation.

Land smoothing: Forming the surface of the field without altering the general topography to eliminate minor ridges and depressions.

Bedding: Forming the surface of the field into lands separated by surface field drains, collection drains or dead furrows.

Soil-Surface Drainage Relation

The USDA New Soil Classification System groups soils of similar genesis together according to observable characteristics (38). Nomenclature is concise. Once familiar with the system, a reader can learn most of the major characteristics of a soil at once, and he can get all the information he needs without having to master all the categories in the system. The engineer or farm planner can use the new system to gain an understanding of the soil with which he works and have some idea of soil problems and limitations. To expedite the exchange of information between regions with similar soil types, the New Soil Classification System will be used as much as possible in this bulletin. Italicics indicate parts of the nomenclature critical to the discussion.

Soil types which benefit from surface drainage

Poor surface drainage conditions usually result from slowly permeable soils, or shallow soils over a restricting layer in combination with an unfavorable topographic position. There are over 100,000,000 acres of such land in the Eastern United States (12).

The suitability of surface drainage of a soil depends on the climate, the topography and the physical properties of the soil as well as on the economics of crop production.

Climate. Heaviness of rainfall and temperature both influence soil moisture. The beating action of the raindrops in a heavy rain tends to seal the surface of many soils and reduce infiltration (45). It may reduce infiltration so much that ponds form on the surface after heavy rains. Regions of heavy rains, such as the South, frequently encounter surface drainage and erosion problems in spring while suffering from inadequate rainfall in the summer months. Under these conditions, irrigation as well as surface drainage

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3 For an explanation of it see: “Soil Classification, A Comprehensive System,” 7th Approximation, Soil Survey Staff, S.C.S., USDA, August 1960; and subsequent supplements.

4 The placement of any soil series in the new system can be obtained from lists published by the USDA — S.C.S., Regional Technical Service Centers, covering the region in which the soil is located.
are required, so systems must be designed for both.

In the North, problems are caused by ponding of melted snow over a frozen soil, followed by water running over erosion control structures. Often the ponded water freezes and damages crops. Soils with low mean annual temperatures such as the Borals and Borolls of North Dakota, Minnesota and Wisconsin often need surface drainage in the spring. Surface water is unable to percolate through the frozen soil and tile drainage systems are ineffective. Almena silt loam (Aquic Glossoboralf; fine silty, mixed, frigid) of northern Wisconsin has responded well to surface drainage (47).

Topography. Soils in low lying areas may receive excess moisture from runoff and seepage water from adjacent higher areas. These soils are frequently developed from alluvial deposition. Soil parent materials deposited under deep quiet water, such as lacustrine deposits, may be high in clay and silt content, while soils resulting from the overflows of streams and rivers are frequently variable in texture. Floodplain soils may have very slowly permeable horizons beneath the surface which restrict the percolation of water to subsurface drains.

Where rivers are contained within levees, outlets for subsurface drains are difficult to develop without pumping installations. Artificial drainage is usually essential under these conditions. Due to the inadequacy of outlets and the impermeable nature of the soils, tile drainage is usually ineffective. Therefore, great emphasis is placed on surface drainage.

In New York, Panton silty clay loam (Aeric Ochraqualf; very fine, illitic, mesic) and Livingston silty clay loam (Mollic Haplaquept; very fine, illitic, mesic) developed on old glacial lake beds. They usually receive runoff from adjacent higher areas and are subject to high water tables. They are very fine textured, and although difficult to tile drain economically, they have been very successfully surface-drained (10). There are many similar soils in regions of old lake beds, for example those of northwest Ohio and much of Minnesota.

Soil physical properties. In fine textured soils, tile drains are effective for only short distances from the center line of the drain, and close spacings are necessary to make substantial drainage improvements. When hydraulic conductivities in the soil profile are lower than 0.1 inch/hour (0.2 feet/day) tile drain spacings of less than 50 feet are recommended (31, p. 442) which could make the cost too high except for high value crops such as vegetables. Surface drainage is usually more economical than tile drainage for very fine textured soils.

Marine sediments of the Coastal Plains of the East Coast are frequently very variable in texture, containing some horizons of very
low permeability. Surface drainage is the only effective means of draining soils of the Bladen series (Typic Ochraquult: clayey, mixed, thermic) which contain low-permeability horizons (39).

Clay soils in which montmorillonite is predominant, such as Luton clay and Wabash clay loam (Vertic Haplaquolls: fine, montmorillonitic, non-calcareous, mesic) of the Missouri bottomlands are subject to cracking and heaving, and consequently are difficult to work except within a narrow range of moisture content. These properties can interfere with the construction of surface drainage and irrigation facilities. However, subsurface drainage is not generally effective because of the high clay content and low hydraulic conductivities.

Sandy soils underlain by heavy textured horizons may benefit from surface drainage. These soils may be worked over a broader range of moisture conditions than those with clay at the surface, but soils in which there is an impervious horizon such as a claypan or fragipan are often difficult to tile drain. Soils such as Clermont silt loam (Typic Fragiaquult: fine silty, mixed, mesic) of Indiana have been surface drained with great success (37). There are many fragipan soils in the Northeast on which surface drainage has not yet been attempted.

Field observations

Soils need surface drainage when (28):

1. Water stands in tracks and low places for more than a few hours after a heavy rain.
2. The color of the subsoil starting from 8 to 14 inches down is marked by gray or blue with mottlings of brown and yellow.
3. A hardpan or tight layer exists in the upper subsoil.
4. The subsoil within a depth of 40 inches is surprisingly dry even after an extended rainy period.
5. Rushes, reeds and other high-moisture plants gradually take over old dead furrows and other slight depressions.

Much information can be obtained from modern soil survey reports. The reports contain accurate values of hydraulic conductivity, depth to water table at different seasons, mechanical analyses and chemical properties.

Surface Drainage Principles

Three distinct methods for improving surface drainage can be recognized. They are land grading, land smoothing and bedding. In addition to these methods there are systems involving both land smoothing and land grading, systems in which both tile drainage and surface drainage supplement each other, and diversion systems in which surface drainage is applied to slopes greater than two percent.

Land grading for surface drainage is most often practiced in situ-
ations where surface irrigation is contemplated as well as surface drainage. Land grading may be done to create a slope on a very flat field, or it may be used to alter rough topography such that the slope is suitable for surface drainage and/or irrigation (see Figures 2 and 3).

Grading land for surface drainage is a new practice that developed from irrigation techniques in the West (12). According to Soil Conservation Service figures, 61 percent of the land grading for drainage purposes before 1968 had been done in the last five years (41).

Land smoothing for surface drainage is the elimination of ridges and depressions which impede the flow of surface water to the drains. It is usually done where the field has an existing slope (Figure 4). The ridges and depressions may be several tenths of a foot high and deep respectively.

Bedding is forming a field into slightly ridged land in order to cre-
ate slopes that surface water will run down. It was once very useful, especially for improving pastures (Figure 5), but the size and speed of modern agricultural machinery are making the practice obsolete.

Table 1 is a guide for choosing the most suitable system on the basis of soil permeability, topography and crops.

**The effect of ponded water**

The length of time that a plant can tolerate standing water depends on the kind of soil, the kind of plant, stage of growth and temperature. Soils with neutral pH, high organic matter and high temperature become depleted of oxygen rapidly when waterlogged, and plants are injured. Sandy soils can remain

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**Fig. 4. Land smoothing with random surface field drains.**

**Fig. 5. Bedding system of surface drainage.**
Table 1. Guide to selection of surface drainage methods (Based on data found in selected references).

<table>
<thead>
<tr>
<th>Topography</th>
<th>Very flat 0-0.2% no depressions</th>
<th>flat 0-1% few depressions</th>
<th>gently rolling 0-2% many depressions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydraulic conductivity inches/hour</td>
<td>very slow</td>
<td>very slow</td>
<td>very slow</td>
</tr>
<tr>
<td></td>
<td>0.03</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>High value crops</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>e.g. vegetables</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northern states</td>
<td>grading + tile</td>
<td>smoothing + tile</td>
<td>smoothing + tile</td>
</tr>
<tr>
<td>Southern states</td>
<td>grading + tile</td>
<td>grading + tile</td>
<td>grading</td>
</tr>
<tr>
<td>Field crops, e.g. corn, soybeans</td>
<td>grading + tile</td>
<td>smoothing or grading</td>
<td>smoothing or grading</td>
</tr>
<tr>
<td>Northern states</td>
<td>grading + tile</td>
<td>grading or grading</td>
<td>grading</td>
</tr>
<tr>
<td>Southern states e.g. cotton, sugar cane</td>
<td>grading</td>
<td>grading</td>
<td>smoothing</td>
</tr>
<tr>
<td>Pasture and hay crops</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northern states</td>
<td>grading or bedding</td>
<td>smoothing</td>
<td>smoothing</td>
</tr>
<tr>
<td>Southern states</td>
<td>grading or bedding</td>
<td>smoothing</td>
<td>smoothing</td>
</tr>
</tbody>
</table>
waterlogged longer than fine-textured soils.

Sugar cane and many grasses are fairly tolerant of standing water, but legumes, particularly soybeans and alfalfa, are easily damaged. Corn and cotton seem moderately tolerant. Any small plant can be easily damaged by just a few hours in standing water. In general, water must be removed within 24 hours, or sooner if temperatures are high, to prevent damage to crops (10).

Perennial crops and winter annuals suffer the most damage in late winter and early spring when ice alternately thaws and freezes in surface depressions.

**Land Grading for Surface Drainage**

The surface of the field can be graded to conform to a single plane, to a number of planes or to a “warped surface” design.

**Land grading to a single plane** is used almost exclusively for irrigation. Where drainage and irrigation or drainage alone is desired, the field is usually divided into several planes to reduce the volume of earth moved (8, 27). Planes can be selected from an inspection of contour patterns on a topographic map or by plotting average profiles across the field (29).

A “warped surface” design results from allowing row grades and cross grades to vary within acceptable limits. The volume of earth moving can be 20 to 30 percent less than that for a plane or series of planes (19). The design can conform in some degree to the original surface and thereby keep down costs of construction and also minimize the loss of crop production resulting from the exposure of subsoil.

It is usual to use a parallel design for the surface field drains when land is graded. Slopes may be graded in one or two directions from a crown located between two drains (Figures 2 and 3). Grading from a crown is especially good if the field is also to be irrigated. Gated pipe or a feeder ditch can be located along the top of the ridge, and irrigation water can flow in two directions. The surface field drains then became tail water ditches. Crop rows are run in the direction of greatest slope which should be perpendicular to the surface field drains.

**Land grading design:** Choosing a land grading design involves estimating, from a topographic survey, the best slope of the field and choosing locations for surface field drains and outlets. Then the cuts and fills can be determined.

It is often desirable to divide the field into smaller areas to utilize the existing topography as far as possible and keep earth moving to a minimum (27). The row lengths (distances between surface field drains) and the slopes of graded fields vary widely throughout the East. Table 2 shows some recommended slopes and row lengths, and Appendix A gives two methods of determining the cuts and fills once
the slope or slope limits have been decided.

Soils with a very silty texture should be graded to a less erosive grade than those with surface clay or which are coarse-textured. Grades of 0.1 percent or less are difficult to build, particularly by inexperienced operators, or in deep cuts or fills. Grades may be permitted to become zero for short distances (less than 100 feet) but reversals in grade cannot be tolerated (16). Depressions as small as 0.05 feet deep have caused crop damage on poorly graded clay soils (16). Grades of about 0.2 percent seem to be suitable for most soils and conditions. Grades steeper than one percent bring risks of erosion.

The field strip drained by surface methods can be made into many lengths depending on circumstances. It can be much longer on a coarse-textured soil, which has a high infiltration rate, than it can on a fine-textured soil, which has a low infiltration rate. But if the field is also to be irrigated, then the field strip must be shortened on the coarse-textured soil and lengthened on the fine-textured soil.

Table 2. Row grades and row lengths for land grading for surface drainage

<table>
<thead>
<tr>
<th>Region</th>
<th>Soil type</th>
<th>Grade in %</th>
<th>Row length (ft.)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Humid regions</td>
<td>Sandy</td>
<td>0.1-0.3</td>
<td>1000</td>
<td>(1) (40)</td>
</tr>
<tr>
<td>Minnesota Red River Valley</td>
<td>Clayey</td>
<td>400</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fargo clay (Vertic Hapludoll)</td>
<td></td>
<td>0.1-0.3</td>
<td>660 (v. flat)</td>
<td>(21, 22)</td>
</tr>
<tr>
<td>Iowa River bottomlands</td>
<td>medium textured</td>
<td></td>
<td>1320 (gently sloping)</td>
<td></td>
</tr>
<tr>
<td>fine textured</td>
<td></td>
<td>0.05-0.25</td>
<td>1000</td>
<td>(29)</td>
</tr>
<tr>
<td>Indiana</td>
<td>Clermont silt loam (Typic Fragiargil)</td>
<td>0.3</td>
<td>480</td>
<td>(37)</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>Almena silt loam (Aquic Glossoboralf)</td>
<td>0.2 (min.)</td>
<td>200</td>
<td>*</td>
</tr>
<tr>
<td>Virginia</td>
<td>Elkton silt loam (Typic Ochraqualf)</td>
<td>0.15 (min.)</td>
<td>600</td>
<td>(44)</td>
</tr>
<tr>
<td>Louisiana</td>
<td>alluvial flatlands</td>
<td>0.1-0.3</td>
<td>800-1400</td>
<td>(33)</td>
</tr>
</tbody>
</table>

(29). Disregarding differences in soil, flatter slopes are generally drained in shorter lengths. In creating slopes by grading, a long field strip requires deeper cuts and more earth moving than a short field strip (21). In general, limits of length of the field strip is determined by dangers of erosion from too much slope at one extreme and the risks of standing water from too little slope at the other.

Subsoil exposure from land grading: Crop yields are generally reduced if more than 0.25 feet of surface soil is removed by grading when the underlying horizons are poorly drained. Causes are often low pH and deficiencies of minor elements in the exposed subsoil (3, 15). The soil should be tested and the needed lime, fertilizer and/or manure and deficient elements applied.

There are two methods of retaining topsoil in the grading process to avoid yield reduction due to subsoil exposure. One is to remove, stockpile and then return all or part of the topsoil to the cut areas after grading. The other is to deep plow or invert the topsoil before grading. Comparisons of yield between deep plowed and stockpiled areas have shown 50 percent less on the deep plowed, but the cost is only one-tenth as much (26). Final restoration of productivity depends upon management of the soil.

Compaction of the soil during grading: Grading should be carried out in summer when the soil is dry and therefore less compacted by the wheels of earth-moving machinery (14). Compaction is also less when earth is carried shorter distances. Compaction is relieved by ripping the area with a spring-shanked cultivation or chisel plow after grading (20). It is also relieved by deep tillage, frost and growth of crops. Land smoothing should always be done after ripping.

Cut-fill ratio: To allow for the settlement of soil in the filled areas, and for the relief of the compacted soil in the cut areas, the computed cuts and fills must be adjusted prior to grading. This is usually done by applying a cut-fill ratio for the particular soil and depth of cut. Table 3 gives some recommended cut-fill ratios. The cut-fill ratio for moving topsoil alone should be higher than that for deep cuts. If a computer is used to calculate the cuts and fills, the program should include the application of a cut-fill ratio appropriate to the soil conditions.

Land Smoothing for Surface Drainage

A smoothed surface is not necessarily a graded surface. The smooth-
Table 3. Cut-fill ratios for various conditions

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Proportion of volume of cut to volume of fill</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic soils</td>
<td>2.0:1 or 200%</td>
</tr>
<tr>
<td>very shallow cuts</td>
<td>(less than 0.4 ft.)</td>
</tr>
<tr>
<td>Shallow cuts</td>
<td>1.7:1 170%</td>
</tr>
<tr>
<td>(greater than 0.4 ft.)</td>
<td></td>
</tr>
<tr>
<td>Average cuts, clay loam soil.</td>
<td>1.2:1 to 120% to 190%</td>
</tr>
<tr>
<td>(300-500 cu. yds. acre)</td>
<td>1.4:1 145% to 170%</td>
</tr>
<tr>
<td>Clay soils</td>
<td>1.3:1 130% to 190%</td>
</tr>
<tr>
<td>Medium textured soils</td>
<td>1.5:1 140%</td>
</tr>
<tr>
<td>Sandy soils, compacted</td>
<td>1.2:1 to 120% to 190%</td>
</tr>
<tr>
<td>Mississippi bottomland soils in Arkansas</td>
<td>1.25:1 125%</td>
</tr>
<tr>
<td>average cuts</td>
<td></td>
</tr>
</tbody>
</table>

...ing operation removes small humps and depressions and ensures a continual slope from all points in the field to a surface field drain. Land smoothing on irregular topography improves surface drainage and allows efficient mechanization, but does not usually allow surface irrigation. (17)

Smoothing does not alter the topography of a field, but it should eliminate ponding of water or at least reduce it to tolerable levels.

Random surface field drains: Many poorly drained soils have natural depressions which can be utilized in the improvement of surface drainage. These depressions are often not apparent until a topographic survey has been made, but they may show up on an air-photo. If they are clearly visible from the ground, a topographic survey may be unnecessary (Figure 4). Wherever possible, crops should be planted in rows that form right angles with random surface field drains so it won't be necessary for machinery to cross them at acute angles.

Parallel surface field drains: Parallel surface drains² are not recommended if it is necessary to dig more than two feet in order to keep the drains parallel (10).

Surface design: In land smoothing, it is not possible to construct predetermined grades on the field.

² Where there is more than two percent slope on the field these systems are often termed “surface diversion drain systems.” Such systems have been applied to wet land on slopes up to 10 percent in Minnesota, and New York, and four percent in Wisconsin without excessive erosion problems (10).
Where there is not sufficient slope on the field for the movement of water to the drains after smoothing, the careful dumping of spoil from the construction of the drains can be used to increase slope. Where there is a small but inadequate slope, dumping the spoil and smoothing it on the down-slope side of the drains will increase the slope to the next drain. On very flat fields, it may be better to dump the spoil between the drains, thus forming a roof-top effect. This is not to be confused with bedding.

**Bedding**

Many involved in surface drainage work in the East clearly feel that bedding is incompatible with modern agricultural machinery, but it still has some value for pasture production (Figure 5). With cultivated crops, beds are often no more than plowed lands, the dead furrows forming the drains. For pasture, and for permanently established bedding systems, the beds should be 0.5 feet to 2.0 feet higher at the center than at the drains. This elevation difference can be achieved either by repeated plowing, placing the opening furrows in the same location each time, or by using earth moving machinery.

Beds should be parallel to the direction of greatest slope on the field. With row crops it is necessary to dig shallow drains across the beds at regular intervals (usually 300 feet apart on very flat fields). Beds are generally from 30 to 100 feet wide. For row crops, the width should be a multiple of the width of planting machinery to avoid inefficient use of machinery and land.

Bedding is a somewhat illogical practice. The density of drains per acre of land is high, and unless these drains are carefully graded, they become an inconvenient network of wet depressions. If incorrectly oriented in respect to the slope of the field, they are likely to have an effect similar to bench terraces and hold moisture on the land.

**Surface Field Drains**

The requirements for a surface field drain are that:

1. It must be crossable by machinery with minimum inconvenience, and no danger to the equipment.

2. It must have enough depth to allow for the filling action of machinery and erosion deposits.

3. The grade must be adequate to dispose of water without ponding or prolonged wetness of the drain bottom. It must not be steep enough to cause scouring.

4. It must have adequate capacity to carry runoff from the area which it serves.

**Side slopes:** Side slopes must be flat. Slopes of 8:1 are still used in some regions, but modern machinery dictates the use of 12:1 to 15:1 or flatter side slopes (Table 4). Shallow side slopes cause less erosion and fewer maintenance problems than steeper side slopes (Figure 6).
Depth: Under most conditions, 0.5 feet should be considered a minimum depth for a surface field drain, and 1.5 feet should be considered a maximum. It is often necessary to dig a drain to a deeper than optimum depth in order to maintain grade. Drain lengths should be reduced where possible to avoid this problem on very flat land. Deep drains require the movement of a large volume of soil in order to maintain the recommended side slopes and cause excessive exposure of subsoil which contributes to reduced yields. Where there is a claypan or subsoil of high clay content, it is sometimes desirable to construct a drain to a depth that will expose a small area of subsoil in the bottom of the drain. This will reduce scouring of the drain bottom.

Grades: Recommended grades for surface field drains range from 0.5 percent to one percent. A grade of 0.3 percent has been found to be the maximum which could be used without scouring some alluvial soils (16). Grades of less than 0.1 percent are difficult to construct and often result in ponding. Permanently vegetated drains can tolerate steeper grades than cultivated drains (Table 5). The velocity of flow and erodibility of the soil are

Fig. 6. Surface field drain showing desirable side slope. Photo by P. J. Zwerman.
the controlling factors in grade specifications. Appendix B, Appendix C and Table 5 give information about velocity of flow in drains.

Cross sections: Surface field drains may have either trapezoidal, "\"V\"" shaped or "\"W\"" shaped cross sections. The "\"V\"" shaped cross section is usually preferred because it involves less earth moving than the others. Trapezoidal drains are sometimes easier to construct than "\"V\"" drains because it is easier to control a scraper operating on the flat bottom of the drain and thus keep on grade. "\"W\"" drains are used mainly when there is no convenient place to dump spoil or when the machinery available cannot carry soil (Figure 7).

It is important that the distance between the two drains in a "\"W\"" design be great enough to provide adequate space to dump and smooth the spoil from the drains while keeping the side slopes at 12–15:1.

Collection Drains, Outlets and Structures

Collection drains, outlets and water control structures should be designed to handle the maximum amount of water expected as runoff from the surface drained area in a time period equal to the expected rain storm frequency. This period will usually be 10 years, but for some down-stream outlet structures, a longer interval may be chosen. The amount of runoff to be expected under different soil and slope conditions can be calculated in the manner described in Appendix B. Appendix C describes how

<table>
<thead>
<tr>
<th>Table 4. Surface field drain or ditch side slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade of slope</td>
</tr>
<tr>
<td>Ratio of horizontal distance to vertical distance in feet</td>
</tr>
<tr>
<td>Utility</td>
</tr>
</tbody>
</table>
to determine if the drain, ditch or structure has adequate capacity for the amount expected.

**Collection drains** usually run down the major slope on the field. The design is usually similar to that of the surface field drains, but they may be deeper, and, if crop rows do not cross the collection drain, the side slopes need not be as flat. If the grade is steeper than about 0.3 percent, the drains must be permanently vegetated according to local recommendations.

Outlet ditches* are not usually

* Outlets and structures for handling large quantities of water should be designed only by competent engineers. A concise discussion of design factors can be found in *Soil and Water Conservation Engineering*, by G. O. Schwab, R. K. Frevert, T. W. Edminster and K. K. Barnes; John Wiley and Co., New York, 1966. Consult your local Soil Conservation Service for assistance.

### Table 5. Maximum permissible velocities for different channels

<table>
<thead>
<tr>
<th>Channel condition</th>
<th>Mannings 'n' *</th>
<th>Maximum velocity ft/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-vegetated **</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fine sand (colloidal)</td>
<td>0.02</td>
<td>1.5</td>
</tr>
<tr>
<td>Sandy loam (non-colloidal)</td>
<td>0.02</td>
<td>1.75</td>
</tr>
<tr>
<td>Alluvial silt loams</td>
<td>0.02</td>
<td>2.0</td>
</tr>
<tr>
<td>(non-colloidal)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Common firm loam</td>
<td>0.02</td>
<td>2.5</td>
</tr>
<tr>
<td>Stiff clay (colloidal)</td>
<td>0.023</td>
<td>3.75</td>
</tr>
<tr>
<td>Alluvial silts (colloidal)</td>
<td>0.023</td>
<td>3.75</td>
</tr>
<tr>
<td>Shales, hardpans</td>
<td>0.025</td>
<td>6.0</td>
</tr>
<tr>
<td>Vegetated (30)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annuals used as temporary cover</td>
<td></td>
<td>2.5</td>
</tr>
<tr>
<td>Alfalfa, kudzu, yellow bluestem,</td>
<td></td>
<td>2.5</td>
</tr>
<tr>
<td>* weeping lovegrass * Lespedeza</td>
<td></td>
<td></td>
</tr>
<tr>
<td>sericea</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grass mixture (e.g. orchard grass,</td>
<td></td>
<td>4.0</td>
</tr>
<tr>
<td>redtop, Italian ryegrass)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buffalo grass, Kentucky bluegrass,</td>
<td></td>
<td>5.0</td>
</tr>
<tr>
<td>* smooth brome</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bermuda grass</td>
<td></td>
<td>6.0</td>
</tr>
<tr>
<td>Centipede grass</td>
<td></td>
<td>7.0</td>
</tr>
</tbody>
</table>

* Manning's 'n' varies from 0.03 to 0.3 for vegetated channels depending on the velocity and depth of water, and the height and condition of the vegetation. When product of velocity and hydraulic radius exceeds 2.5, use 'n' of 0.05 or less for design purposes.

crossed by machinery, and thus may have steeper side slopes. The ditches may be vegetated or not. Table 5 gives maximum safe water velocities for unvegetated ditches and drains in different soils, and for vegetated ditches. This table should be used with Appendix B and Appendix C to determine the need for vegetation.

Structures include drop inlets, spillways and culverts. These are not discussed here, except to note that engineering assistance should be sought when they are necessary to ensure safe construction. Drop inlets are commonly used to conduct water from a surface field drain or collection drain down to an outlet ditch when these are at different elevations. Concrete box inlets or galvanized steel pipes are also frequently used for this purpose (Figures 8 and 9).

Although water need not flow from the field immediately, only in time to prevent crop damage, culverts and downstream structures such as grade control spillways must be able to handle the expected peak flows.

Turn Strip
A surface drain in a turn strip breaks down quickly under the wheels of turning farm machinery, so it is important to locate the drain well within the field away from the down slope field boundary. The turn strip should be at least 60

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**Fig. 7. Cross section of some surface field drains.**

SIDE SLOPES 15:1

"V" DRAIN

SIDE SLOPES 15:1

TRAPEZOIDAL DRAIN

SIDE SLOPES 15:1

"W" DRAIN
feet wide and drained with a back slope to the surface drain. The turn strip is a useful place to spread spoil from the drains in periodic clearing operations.

**Construction and Machinery**

**Field preparation:** Fields must be free of old sod, matted roots and crop residue to assure the efficient operation of earth-moving machinery. If the last crop was clean-cultivated, it may only be necessary to disc the surface. In other circumstances, however, it may be necessary to follow the often recommended practice of planting no crops one season, plowing the field in the fall and allowing it to settle

---

**Fig. 8. Concrete box drop inlet.**
Photo by P. J. Zwerman.

**Fig. 9. Outlet pipe from drop inlet and roadside outlet ditch.** Photo by P. J. Zwerman
before starting work the following summer. An established sod must usually be killed with a herbicide and the field disced and plowed. Preparation of the field is especially important if land smoothing is to be the only treatment. Land levelers are unable to operate effectively if they build up a dead load of matted roots and vegetation.

**Graded surfaces**

**Surveying and staking:** A complete topographic survey is needed for grading. The grid survey is preferred because it permits staking the field according to the grid and marking the cuts and fills on the stakes. Squares of 100 feet per side are the most common, but there is nothing to prevent the use of other sizes. Driving a vehicle in a line where the stakes will go creates an evenly compacted base for the rod on freshly plowed ground. Placing the first line of stakes at a distance of half the grid size from the boundary (50 feet on a 100 foot grid) makes earth-moving computations easier (Appendix A). The stakes should be four foot lengths of one by two inch wooden lath or similar material.

After the cuts and fills are computed from the topographical survey with the cut-and-fill ratio for the kind of soil figured in, the computations can be translated into marks on the stakes. One method is to mark each stake exactly three feet or, perhaps, exactly four feet above the desired surface and mark the amount of cut to take or fill to add at that spot. Another method is to drive a hub stake into the ground until its top is level with the desired surface.

Numbering the stakes according to some plan makes it easier to find and correct mistakes. A sketch map of the field showing areas of cut and of fill should be given to the machine operator. A contractor doing the job should be given the entire survey showing cuts and fills.

**Construction and machinery:** The choice of machinery depends on hauling distances, depth of cut and soil conditions. Scrapers propelled by crawler tractors (Figure 10) are too slow for hauls over one-eighth of a mile. They are best for making short hauls, pushing rubber-tired scrapers, bulldozing small, rough areas and working in wet soil.

Large self-powered rubber-tired scrapers (Figure 11) have the capacity (10 to 20 cubic yards) for deep cuts and speed for long hauls. But, in general they are uneconomical to operate unless they can be filled within a run of 100 feet. They and tractor-drawn scrapers with capacities over five cubic yards

(continued on page 26)
Fig. 10. Large-capacity, crawler-drawn bucket scraper. Photo by Caterpillar Tractor Co.

Fig. 11. Medium-capacity, self-powered elevating scraper. Photo by F. N. Swader.
Fig. 12. Small tractor-drawn, self-loading scraper. Photo by P. J. Zwerman.

Fig. 13. Tractor-drawn rotary scraper. Photo by P. J. Zwerman.
have to be pushed during loading. Elevating or self-loading scrapers (Figure 12) have better traction. Smaller, lighter scrapers (Figure 13) are well suited for finishing work because they can be kept to grade more easily, especially in wet or rubbery soil.

Before the graded surface is finished, the soil should be loosened with a spring shanked cultivator, a Graham plow or a ripper, both to relieve compaction caused by machinery, and to supply the land leveler with loose soil for the finishing operation. A bottomless scraper or a land leveler can finish the surface, but the land leveler is better because it is longer (Figure 14).

**Checking the grade:** During construction the stakes should be left undisturbed to facilitate checking the grade. Grade checking during construction is done either by sighting onto the grade stakes with a hand level, or by using a levelling rod and level. The elevation should be checked at the mid points between each stake, and in the center of each grid square. Only then can the stakes be removed and the islands on which they stand smoothed off with a land leveler. Tolerance of 0.05 to 0.1 foot high or low is usually allowed, depending on the steepness of the final graded surface.

**Smoothed surfaces**

**Surveying and staking:** It is advisable but not essential to begin with a complete topographic survey of the field. It is impossible to cut and fill with a land leveler to predetermined depths so staking is not necessary. Any survey method will do which gives elevations from which a contour map can be drawn. Unless slopes and depressions are clearly visible in the field, it will be difficult to design a suit-

---

**Fig. 14.** Land leveler being used to smooth a turn strip. Photo by F. N. Swader.
able layout of surface field drains and crop rows without the topographic survey mentioned above.

**Construction and machinery:** Construction is usually done with a land leveler or smoother. The longer the machine, the smoother will be the final surface. Land levelers which hinge in the middle are preferable for use in small fields. Automatic land levelers, on which a crank axle controls the blade, create the desired surface with fewer passes than a rigid leveler. Most levelers are from 20 to 50 feet long, but some are as long as 80 feet. Blades are usually about 12 feet wide. (Figure 14).

The blade, suspended between the front and rear wheels of the leveler, cuts off high spots and drops soil into depressions. In general the land leveler will not alter the elevation at any point by more than half a foot. Cuts average 0.2 feet and fills 0.4 feet (5). Small "automatic" levelers can be pulled by a regular farm tractor equipped with a two-way hydraulic system.

The leveler should cross the field on the diagonals and in the direction of crop rows. Three passes is the minimum; on rough surfaces it may take many more. The blade should maintain itself at about 2/3 full. After each pass with the leveler, a spring tooth cultivator should cross the field to loosen fresh soil for the next pass. Rough surfaces should be smoothed off with a bulldozer, motor patrol grader or scraper before smoothing with the land leveler. If the soil is too moist, the leveler will build up a dead load, as it does with trash, and severely impair the smoothing action.

**Checking the grade:** It is practically impossible to check a field for adequate smoothing by using surveying instruments. The most useful check is studying the field closely after a heavy rain to locate any ponded or eroded areas. Further smoothing is necessary if either is present. Areas of ice that develop during the winter also indicate low spots.

**Surface field drains and collection drains**

**Surveying and staking:** With land smoothing it is necessary to construct the surface field drains in advance. With land grading, the drains may be dug before, during, or after the construction of the graded surface.

The locations of the drains should be selected from the topographic survey and then staked out, preferably at 50 foot intervals, along the center lines. A second row of stakes is set far enough off to one side of the drain to be out of the way of the construction. For a drain one foot deep with 15:1 side slopes, this will dictate a minimum distance of 15 feet. These stakes are marked the same as grade stakes. The cut is either marked as such, or a line is drawn at an elevation three or four feet above the drain bottom at that point. The ma-
chine operator can sight across a rod with a hand level to determine if he is above or below grade.

If clearly visible depressions can be utilized for surface field drains, it may not be necessary to make a topographic survey. Instead, the following steps can be taken: Select a suitable outlet and measure the difference in elevation between it and the bottom of the most distant depression. Determine the distance between these points, divide by the elevation difference and decide whether the slope is suitable. Then pace out the drain center line, placing a stake every 50 feet and determining the elevation of the bottom of the proposed drain at each point. Set off grade stakes to one side of the drain and mark them directly in the usual manner (43).

**Construction and machinery:** Usually the drain is dug to about the final depth and the side slopes then removed. Finally the bottom of the drain is cleaned out and the final grade established. "V" shaped drains can be constructed with a motor patrol grader if soil can be left on one side of the drain. If not, a scraper which can lift and carry is required. Tractor-drawn two to three-cubic yard scrapers are ideal and easy to operate (Figure 15 and Table 6). Scrapers are best for trapezoidal drains. Motor graders or even plows or terracers can construct "W" drains.

If seepage into a surface field drain is likely to be a problem it is advisable to lay a tile drain beneath and to one side of the center.

**Checking the grade:** The grade and side slopes should be checked every 25 feet. If a surface field drain has been cut too deep at any point it is generally necessary to recut all or part of the drain. Fill areas in a drain bottom frequently become mud holes. There must be no ridge along the side of a surface field drain.

**Outlets and structures:** Outlet ditches may be constructed with a bulldozer, grader, dragline or any one of a number of machines, depending primarily on what is available and on soil conditions. Scrapers are not efficient in wet soil and vegetation. Drop inlet structures and culverts can be constructed from concrete poured into homemade forms, or they can be purchased ready made of concrete or galvanized steel. The Soil Conservation Service or local construction companies should be consulted for more details.

**Table 6. Tractor sizes for different capacity scrapers**

<table>
<thead>
<tr>
<th>Tractor size</th>
<th>Capacity of scraper (pulled type)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-3 plow</td>
<td>1 1/2-2 cu. yds.</td>
</tr>
<tr>
<td>3-4</td>
<td>2-3</td>
</tr>
<tr>
<td>4-5</td>
<td>3-4</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
</tr>
</tbody>
</table>

Fig. 15. Small (2½ cubic yard) scraper digging a surface field drain. Photo by George Lavris.

Maintenance of Surface Drainage Systems

Graded and smoothed surfaces: If the cut-fill ratio was correct at the beginning, there should be very little maintenance for several years. A pass or two with a land leveler a year after construction will probably suffice. With land smoothing however, it is necessary to resmooth the field several times, a year or two after construction to allow for settling of the filled areas. For this reason it is imprudent to plant a perennial crop in the year following construction as this will interfere with plans for re-smoothing.

In general, careful plowing does the most to maintain a good surface. Two-way plows leave no dead furrows or ridges. With one-way plows, it is important to fill the dead furrow at the next plowing to prolong the life of the surface. Using the land leveler regularly in the fall reduces maintenance problems, but using it for tillage in the spring brings on the risk of soil compaction. Many problems arise when farmers are unaware of the direction of major slope on the field. Fields of less than two percent slope should be plowed up and down the slope to avoid interfering with surface drainage. One bad plowing can ruin a well constructed surface.
Surface field drains and collection drains: Surface field drains are easily damaged by careless plowing and cultivation. The sides may be plowed, but not the bottom. The direction should be across the drains. Machinery should be slowed coming out of the sides of the drain to prevent dragging large quantities of soil to the bottom.

Drains will have to be cleaned each year where they are filled by wind-blown soil, but the problem can be checked by planting a soil cover of spring grain in the fall. Drains can be cleaned by a scraper or motor grader. The half-cubic yard tractor-mounted scraper is ideal for cleaning drains.

Outlets: Outlets tend to be neglected and overgrown with brush. They should be inspected and cleaned regularly to avoid damage to crops in a wet year. They can be maintained by grazing if animals are kept out of them when the soil is wet. Herbicides can frequently be used to advantage. Drop inlets and culverts should be regularly inspected for choking by debris.

Surface Drainage Costs

In general, land grading is more costly than bedding, which is more costly than smoothing, but there are exceptions.

Usually, grading involves hiring an engineer to do the surveying and cut-and-fill computations and a contractor to do the construction. Surveying is sometimes done as a public service by the Soil Conservation Service. Grading costs vary widely, reportedly from $22 to $130 an acre with volumes of earth moved varying from 70 to 600 cubic yards per acre depending on design (6, 8, 20, 23, 24, 25, 33, 36, 44).\(^{11}\)

Grading to a single plane usually requires moving from 50 to 100 percent more earth than grading to a variable or warped surface. The cost for surveying and computations varies from $3 to $7 per acre (about three to seven man-days per 40 acres) excluding the cost of staking the field. Grade checking usually takes about two man-days per 40 acres.

Bedding done by a contractor can be relatively costly. Surveying costs are usually low, except where a precision graded bedding system is desired. Bedding costs of from $11 to $100 per acre (1950–1961) are common (31, 33). Information regarding the quantity of soil moved for these costs is not available.

Smoothing is probably the least expensive surface drainage practice. Surveying costs are low, and there is very little staking to do. Most of the construction work is done with a farm tractor and a scraper and a leveler. A scraper and leveler in 1968 cost about $2,500. The total cost

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\(^{11}\) See also: G. D. Rose: Economics of land forming in the Eastern United States; Ph.D. Thesis, Iowa State University, 1964.
of installing surface drainage by smoothing in New York for seven different locations varied from $14 to $40 per acre, excluding the cost of surveying (1968). About four or five acres can be smoothed per hour (one pass) at a cost of about $1 to $3 per acre per pass. Surface field drains cost about 9¢ to 12¢ per cubic yard of soil moved, using a small scraper and farm tractor operating at about 60 cubic yards per hour.
Appendix A

Methods of determining the cuts and fills to create the desired surface in land grading

Profile Adjustment Method

This procedure for computing cuts and fills should be easier to follow than the plane method. It is not as accurate, but for surface drainage it should be adequate.

The field should be surveyed by the grid method. The size of the grids is not critical, but 100 feet is customary. Calculations are simpler when the first line of grid points in each direction is started at half the grid size from the boundaries (See Figure A:1). Now each grid point becomes the center of a square, and the field is made up of such squares.

The elevations of the grid points should be plotted along each grid line on the direction of greatest slope or the direction in which row drainage is desired. A profile should be drawn for the existing land surface along the grid line. Limits should be decided upon, within which the slope of the surface may be allowed to vary. Using these slope limits, a new profile can be drawn in for each grid line, in such a way as to have more cut off area, than area to be filled in, to allow for the cut-fill ratio. Existing topography should be followed as much as possible to keep soil movement to a minimum.

When this has been done for each grid line, the cuts and fills should be added for each line. Compute the total cuts and total fills. The ratio:

\[
\frac{\text{Total cuts}}{\text{Total fills}} \times 100 \text{ can be determined.}
\]

If this ratio is greater or smaller than that required for the soil (see Table 31), the cuts and fills will have to be adjusted by raising or lowering the new surface profiles by an amount which will give the desired cut-fill ratio.

The grid survey will probably have been done to the nearest 0.05 foot. This means that calculations to any greater accuracy than to the nearest 0.05 foot are timewasting. Grid points should all be raised or lowered by 0.05 foot until the cut-fill ratio which is closest to that desired is obtained. This is accurate enough for drainage work.

If necessary, one grid line can be adjusted at a time until an overall cut-fill ratio is arrived at which is close to that desired.

At this point the profiles across the field perpendicular to those already drawn should be plotted. This is a check to see if the cross slopes exceed the
limits which have been decided upon. These limits need not be the same as those chosen for the row grade, and frequently more variation is allowed for the cross slope than for the row grade. If the cross slopes do exceed the permissible variations, then the row grade profiles will have to be further adjusted until the cross slopes are acceptable.

Example:

Figure A:1 is an example of a field which is to be graded and which has been surveyed on a 100-foot grid system. Profiles along the lines A, B, C, D and E have been plotted and shown in Figure A:2.

Assume that the row grade may vary between 0.05 percent and 0.3 percent, and that the cross slope may vary 0.5 percent. The cut-fill ratio is to be 150 percent.

Now new profile lines are sketched in as shown.

The cut and fill is determined for each station and put on the original survey sheet. These are figures to the right and below each grid point in Figure A:1. Now the cuts and fills are totaled.

The cut-fill ratio is:

\[
\frac{2.20}{1.65} \times 100 = 133\%.
\]

This is too low, and therefore it will have to be increased. Line A is the only line where cut does not exceed fill. Line A is now lowered by 0.05 ft., keeping to the same grade, and the new cuts and fills totaled. Now the cut-fill ratio is:

\[
\frac{2.40}{1.55} = 154\%.
\]

No more adjustment is necessary.

The cross slopes have been plotted in Figure A:3 and are all within the limits which were previously determined.
Fig. A-1. Topographical survey sheet.

Fig. A-2. Profiles in row direction. (Distance between horizontal lines equal to one foot.)
Fig. A-3. Cross-slope profiles. (Distance between horizontal lines equal to one foot.)
Plane Method

As in the profile adjustment method, the field should be surveyed on a grid system. The size of the grids is not critical, but 100 feet is customary. Calculations are simpler when the first line of grid points in each direction is started at half the grid size from the boundaries placing the “origin” outside the field by 50 feet in each direction.

The equation \( E = a + S_x X + S_y Y \) where: \( E \) = elevation at any point \((X,Y)\):

- \( a \) = elevation of origin:
- \( S_x, S_y \) are slope
- in \( X \) and \( Y \) directions respectively.

will give the elevation of any point in a plane once \( S_x \) and \( S_y \) are determined.

However, this will not give a plane which will balance the cut area with the fill or best fit the surface. To give equal cut and fill, the plane must pass through the centroid. Determine the position of the centroid of the field as follows: Multiply the number of grid positions in each grid line, by the distance of that line from the origin in each direction. Total these products in each direction and divide each figure thus obtained by the number of grid positions in that direction. This will give two figures, \( X_c \) and \( Y_c \), representing the distance along each boundary from the origin, which will locate the centroid in the field.

The elevation of the centroid will be:

\[
E_c = \frac{\text{sum of all elevations}}{\text{total no. of grid positions}}
\]

The elevation of the origin will be:

\[
a = E_e - S_x X_e - S_y Y_e
\]

With known \( X \) and \( Y \) slopes, the grid point elevation for any plane can be calculated such that total cut = total fill. From the new elevations the cut and fill can be determined.

To avoid unnecessary earth moving, it is of value to know the best fitting plane to any particular field.

For rectangular fields the best-fit slope in the \( X \) direction, \( S_x \), can be found from:

\[
S_x = \frac{\Sigma(XE) - nXE_e}{\Sigma X^2 - nX_e^2}
\]

(Reference 34)

where \( n = \) no. of grid positions (stations);

36
E = Elevation at any station;
X = Station no. in X direction. Xc = X distance of centroid. To find Sx, substitute Y and Yc for X and Xc respectively.

For non-rectangular fields, the problem can be solved more accurately by using the following simultaneous equations:

\[ S_x(\Sigma X^2 - nX_c^2) + S_y(\Sigma (XY) - nX_cY_c) = \Sigma XE - nX_cE_c \]
\[ S_y(\Sigma Y^2 - nY_c^2) + S_x(\Sigma (XY) - nX_cY_c) = \Sigma YE - nY_cE_c \]

(Reference 9)

Example (See Figure A:4)

Fig. A-4. Cut-and-fill sheet for plane method of grading.

In the field in figure A:4, which is non-rectangular:

\[ n = 34 \]
\[ X_c = \frac{104.0}{34} = 3.1 \quad X_c^2 = 9.6 \]
\[ Y_c = \frac{133.0}{34} = 3.9 \quad Y_c^2 = 15.2 \]
\[ E_c = \frac{335.2}{34} = 9.9 \]
\[
\Sigma XY = 1(1+2+3+4+5+6) + 2(1+2+3+4+5+6+7) + \ldots + 7(1+2+3+4+5+6+7) = 413.
\]
\[
\Sigma X^2 = 6(1) + 7(4) + 7(9) + 7(16) + 7(25) = 384.
\]
\[
\Sigma Y^2 = 5(1) + 5(4) + 5(9) + 5(16) + 5(25) + 5(36) + 4(49) = 651.
\]
\[
\Sigma XE = 58.2 + 2(68.9) + 3(69.2) + 4(69.8) + 5(69.1) = 1028.3
\]
\[
\Sigma YE = 45.8 + 2(47.5) + 3(49.5) + 4(50.4) + 5(49.5) + 6(51.1) + 7(41.0) = 1332.0
\]

Now; substituting in the simultaneous equations:
\[
S_x (384 - 326) + S_y (413 - 411) = 1028.3 - 1044.0 = -13.7
\]
\[
S_y (651 - 517) + S_x (413 - 411) = 1332.0 - 1312.0 = 20.0
\]
\[
58 S_x + 2 S_y = -13.7
\]
\[
2 S_x + 134 S_y = 20.0
\]
\[
58 S_x + 2 S_y = -13.7
\]
\[
58 S_x + 3890 S_y = 580
\]
\[
3888 S_y = 593.7
\]
\[
S_y = .153 \text{ ft/100 ft.}
\]
\[
S_x = .236 \text{ ft/100 ft.}
\]

If the slopes of the best fit plane are outside the limits imposed by erosion hazard, then they will indicate at which end of the limits the slopes should be chosen.

The best fit plane, once determined, can be varied or lowered until the difference between cut and fill volumes is appropriate to give the desired cut:fill ratio.

Thus the best fitting plane would have a slope in the Y direction of .15 ft/100 ft. and a slope of .24 ft/100 ft. in the X direction.

Since the plane must pass through the centroid, the elevation of the origin can be computed:
\[
\begin{align*}
a &= E_c - S_x X_c - S_y Y_c \\
   &= 9.9 - (.24) (3.1) - (.15) (3.9) = 8.6
\end{align*}
\]

Now best fit plane is:
\[
E = 8.6 + .24 X + .15 Y.
\]

Each new elevation is computed and the cut or fill noted (See Figure A:4).
The cuts and fills are totaled and the ratio determined:

\[
\frac{\text{Total cuts}}{\text{Total fills}} = \frac{4.10}{4.85} = 85\%
\]

The figure is not 100% due to rounding off of numbers to the nearest .05 ft. which is the limit of accuracy for this work. However, we need a cut:fill ratio of 150%.

If the whole plane is lowered by .05 ft. then the new cuts and fills will give a ratio as follows:

\[
\frac{5.00}{4.05} = 123\% \text{ which is not adequate if we}
\]

assume a 150% cut:fill ratio is needed. Lowering the plane by a further .05 ft. will give:

\[
\frac{6.05}{3.40} = 178\% \text{, which is too much.}
\]

For drainage work it is not necessary to maintain an exact plane, so simply lower half of the points by .10 ft. and the remainder by .05 ft., which would result in the desired 150%. This should be done across the slope, rather than along the length of the slope, so as not to interfere with the desired row grade.

**Earthwork Volume Calculations**

When grading land for drainage, it is almost impossible to determine volume of soil moved precisely. This is due to the degree of accuracy used in surveying.

When the grid points are positioned such that they are in the center of a square, the following formula is used:

\[
\text{Volume of cut (} V_c \text{)} = \frac{(\Sigma \text{cuts}) \times \text{Area of grid square.}}{27} \text{ cu. yds.} \quad (27)
\]

In the example used in this appendix, by the profile adjustment method the volume of soil moved would be:

\[
V_c = \frac{2.40 \times 100 \times 100}{27} = 888 \text{ cu. yds.}
\]

By the plane method, the volume would be:

\[
V_c = \frac{5.50 \times 100 \times 100}{27} = 2037 \text{ cu. yds.}
\]
Appendix B

Methods of determining runoff

Peak Runoff


The method for determining peak runoff given here has been chosen for its simplicity and relative accuracy. It is not claimed that this method is superior to those listed above.

The runoff curves given in this appendix will not give the peak runoff. They have been developed to predict runoff rate which can be used in the design of drainage installations where peak rates are of little interest.

A method derived from Potter*, which is used by the Highway Department, is given here to determine the peak runoff. The basic equation is

\[ q = R \times L \times F \times Q \]

where:  
- \( q \) = design peak runoff in c.f.s.,
- \( R \) = rainfall factor (from Figure A:6)
- \( L \) = land use and slope factor (Table A:1)
- \( F \) = frequency of occurrence factor (Table A:2)
- \( Q \) = unadjusted peak runoff (from Figure A:5)

Example:

A 20-acre field of continuous corn on a slope of 0.5% in New York State is to be surface drained. Assume a return period of 10 years.

From Figure A:6, \( R = 0.8 \); from Table A:1, \( L = 1.0 \); From Table A:2, \( F = 0.8 \); and from Figure A:5, \( Q = 65 \).

Substitute in the equation:

\[ q = 0.8 \times 1.0 \times 0.8 \times 65 = 41.6 \text{ c.f.s.} \]

Thus the peak rate of runoff, to be expected once in 10 years, is 41.6 c.f.s.

Table A:1. Land use and slope factor "L".

<table>
<thead>
<tr>
<th>Land Slope</th>
<th>Steep 2%</th>
<th>Flat 0.2%</th>
<th>Very flat no ponds</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% cultivated (row crops)</td>
<td>1.2</td>
<td>0.8</td>
<td>0.25</td>
</tr>
<tr>
<td>Mixed cover</td>
<td>1.0</td>
<td>0.6</td>
<td>0.2</td>
</tr>
<tr>
<td>Pasture</td>
<td>0.6</td>
<td>0.4</td>
<td>0.1</td>
</tr>
<tr>
<td>Woods (deep forest litter)</td>
<td>0.3</td>
<td>0.2</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Table A:2. Frequency factor "F".

<table>
<thead>
<tr>
<th>Frequency in years</th>
<th>Factor (F)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>50</td>
</tr>
</tbody>
</table>

Fig. A-5. Peak runoff curve for mixed cover, 25-year frequency, and rainfall factor of 1.0.
Fig. A-6. Rainfall factors (R) for use with equation 
\[ q = R \times L \times F \times Q. \]

Fig. A-7. Surface drainage curves for the North Central and Northeastern United States (1).

Curve 1 is for "excellent" farm drainage.
Curve 2 is for "good" farm drainage.
Curve 3 is for "fair" farm drainage.
Curve 4 is for farm drainage in the Red River Valley in Minnesota, North Dakota, and South Dakota.
Appendix C

Method of determining the capacity of a surface drain or ditch

The quantity of water to be handled by the drain or ditch can be determined from the curves or by the method described in Appendix B, or any other method.

The remaining calculations are based on the Manning’s equation:

\[ v = \frac{1.486}{n} R^{2/3} S^{1/2} \]  \[1\]

where:  \( v \) = average velocity in ft/sec
\( n \) = roughness coefficient, given in Table VI:6
R = hydraulic radius. A/P, in ft.
A = cross section area in ft².
P = wetted perimeter in ft.
S = channel slope in ft/ft

and the equation of continuity:

$$Q = Av$$  \[2\]

where: $Q = \text{flow in ft}^3/\text{sec}$

For a given quantity of flow, drain or ditch dimensions can be obtained from these equations by trial and error solution, or for some cross sections direct solution of the two simultaneous equations [1] and [2]. Hydraulic tables have been prepared for many commonly used ditch shapes, and these may also be used to obtain ditch dimensions.

In most surface drainage situations the available slope is small and cannot be increased. If this should not be the case, control structures may be needed to prevent the stream velocity from becoming greater than the maximums listed in Table 5.

The nomograph shown in Figure A.9 can be used to solve Manning's equation.

**Example:**

Assume that a peak flow of 20 c.f.s. has been determined to be handled by a proposed drain. The drain is on a grade of 0.25% or 0.0025 ft/ft, and is on stiff colloidal clay (See Table 5).

Assume that it is desired to have a drain of trapezoidal cross section, with 3 ft. bottom width, 1 ft. deep and 10:1 side slopes.

The cross sectional area will be 13 ft², and the wetted perimeter will be $3 + 2 \times (101^{1/2})$ ft, which is approximately 23 ft.

Now:

$$R = \frac{13}{23} = 0.565 \text{ ft.}$$

The nomograph is now used with $S = 0.0025$, $R = 0.565$, and $n = 0.025$. This indicates a velocity of 2.0 ft/sec. This is less than the maximum permissible velocity for this soil as given by Table 5 and is therefore acceptable.

To determine if the drain has adequate capacity, the volume of flow must be determined as follows:

$$Q = Av = 13 \times 2 = 26 \text{ c.f.s.}$$

The peak flow which is to be handled is 20 c.f.s., and so it can be seen that the drain has adequate capacity.
Fig. A-9. Nomograph for solving Manning’s equation: \[ V = \frac{1.486 \, R^{2/3} \, S^{1/2}}{n} \]
From Schwab and others (1).

Selected References

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