NATIONAL ENGINEERING HANDBOOK

SECTION 16

DRAINAGE OF AGRICULTURAL LAND

CHAPTER 5. OPEN DITCHES FOR DRAINAGE - DESIGN, CONSTRUCTION AND MAINTENANCE

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CHAPTER 5. OPEN DITCHES FOR DRAINAGE - DESIGN, CONSTRUCTION AND MAINTENANCE

General

This chapter outlines procedures for designing, constructing, and maintaining open ditches for agricultural drainage. It covers ditches and reconstructed channels used primarily as outlets for drainage systems occupying broad river bottoms, deltas, coastal plains, lake plains and upland prairies where the general topography is flat to mildly sloping and where surface waters are diffused. Where channels extend from such areas into narrowing bottoms and steeper slopes adjoining or into uplands, additional guidance for design and stability checks as covered in SCS Technical Release No. 25 should be used to assure protection against degradation and bank erosion. The procedure and criteria also is applicable to the design of drainage ditches used for interception drainage. Chapter 3, Surface Drainage, deals with small field ditches. Chapter 4, Subsurface Drainage, contains criteria for planning ditches for use in subsurface drainage of agricultural land.

The design of drainage ditches must give due consideration to the equipment and methods to be used for construction, and to the needs for and methods to be used in maintaining the ditches. The design must be based on adequate consideration of the following interrelated factors:

1. The ditch must be designed to meet the project needs without aggradation or degradation of the channel bed or erosion of the channel banks.

2. It must be capable of being maintained to the size and condition required to continually meet the project needs.

3. The cost of construction and maintaining the ditch must be less than the benefits which it is expected to produce.

4. The construction, operation, and maintenance of the ditch must be carried out in a manner which will not contribute significantly to downstream sediment loads or on-site deterioration in quality of the environment.

Design and construction of ditches to meet these requirements are complex jobs. Positive consideration of all factors will result in an improvement to the environment and the agricultural economy of the area served. Inadequate consideration of any of the factors listed will result in disappointment and financial loss to the owners.

Location

Drainage ditches should be located to provide the most effective drainage of the agricultural wetland. Topography, existing ditches and drains, bridges,

farm boundaries and other physical features all influence ditch location. Natural outlets such as estuaries, rivers, lakes or swamps, or old ditches usually fix the general location of an open ditch, but the alignment and efficiency of the channel may be improved by the use of cutoffs, long tangents, and smooth curves.

Open ditches should terminate in an adequate outlet. The capacity of the outlet must be adequate to carry the design discharge from the project without it resulting in stage increases which would cause significant damage downstream. This may require extending the channel improvement further downstream. A comparison of alternate locations of the point of outlet may also be needed. The stage of a stream during the storm when the drainage system is discharging at the design rate determines the adequacy of the stream as an outlet. A study of the frequency of high water stage is needed for large streams, lakes, and tidal waters to determine their adequacy as an outlet and to establish the elevation of the design hydraulic gradeline for the open ditch at the outlet. See chapter 2 for more details regarding the requirements of outlets for agricultural drainage systems.

Channel location under nonerosive conditions

Where the topography is flat and soils and velocity are well within the range of conditions where channel stability will be no problem, alignment changes can be made to fit the area. Some factors to consider when changing alignment of a ditch are: (a) Straight ditches permit rectangular fields and efficient farming. (b) A shorter channel will have more slope, greater velocity and less cross-sectional area and will be less likely to accumulate sediment than a longer channel between the same terminal points. (c) Changing the existing location may require placing the ditch on higher land, crossing farm boundaries, isolating parts of fields from the rest of the farm, and installing new bridges and culverts not otherwise needed. (d) The location may result in placing the ditch in more or less stable soils.

Channel location under erosive conditions

Some drainage ditches may be needed where site conditions are likely to cause stability problems. Flow velocity, position of the water table, soil texture, soil structure, and vegetation are the principal factors influencing channel erosion. A careful study of these factors and the protection which may be needed should be made before constructing any channel. If significant erosion is probable, alternate solutions should be considered. It may be feasible to choose another location using a longer channel on a nonerosive grade; to locate the ditch in more stable soil; or to avoid cutoffs and straightening of natural channels. Use of a wider and shallower channel to decrease the hydraulic radius and the velocity is a possibility.

If these alternatives are not feasible, grade control structures or bank protection may be needed to protect the ditch. The principal practices and structures to control erosion in drainage ditches are: grade-control structures; bank protection by vegetation; riprap; jetties of piling or trees; tetrahedrons; brush mats; and continuous piling. The use of jetties, piling, and tetrahedrons applies only to large channels. These costly measures are not mormally used on drainage ditches and when used in channels with unstable soils may have a high rate of failure.

Location of diversion ditches

Open ditches often serve as diversions to protect land from overflow. Most diversion ditches are located near the edges of hilly or sloping land, and need to be deep enough to intercept seepage as well as surface flow. Excavation from diversions is often placed to form a dike on the lower side for added protection. Where the safety of levees and dikes depends on adequate capacity of the diversion, it is essential to inspect the diversion ditch regularly and perform maintenance as required to keep down undesirable vegetation and remove sediment and other obstructions to flow. Diversion channels usually are designed to handle the peak flow storm of a frequency ranging from two to 10 years. Higher protection will be required when flood protection is a purpose. Economy in channel design results from designing the main diversion to carry part of the peak flow and to route the excess flow through spillways into other channels, sloughs or overflow areas. Often the spillway may be along sections of a channel having no dike, or with the top of a section of the dike below grade of the rest of the dike to provide a fuse plug. This type of construction reduces costs, but is applicable only where site conditions permit the lower level of protection.

Small surface water diversions are used frequently in farm drainage systems to prevent surface waters from adjoining lands from flooding fields to be drained. Deep diversions to intercept ground water are used to lower the water table in the area below the diversion ditch.

Layout of ditches in humid areas

Ditch systems in humid areas provide outlets for farm ditches, buried drains, interception ditches and irrigation return flows. The most common type of drainage system constructed by drainage enterprises in flatland areas consists of a network of laterals or sublaterals spaced at intervals which will provide each farm and ranch with a dependable outlet. Where farm units are small, it may not be feasible for a drainage enterprise to provide a lateral to reach each farm and small groups of farmers may need to construct a group lateral as an outlet for their farm laterals.

Location of drainage ditches in western irrigated lands

Drainage ditches in western irrigated areas serve primarily as disposal ditches for subsurface drains in irrigated areas. Ditches located perpendicular to the flow of ground water are installed to intercept subsurface flow and are called "interceptor ditches." Ditches located approximately parallel to the flow of ground water, or where the water table is relatively flat, and at a depth and spacing required for control of the water table, are called "relief ditches."

The location of ditches is usually fixed by the irrigation or canal system and the depth and location of permeable aquifers. In irrigated areas where high intensity rainfall occurs, channels are designed to serve as dual purpose ditches for the drainage of both surface and ground water.

Curves in ditches

Where feasible, smooth curves should be used for alignment rather than sharp bends in order to improve the hydraulic property and stability of the ditches.

Where this is applicable the recommended minimum radius of curvature may be established in a local drainage guide.

Often the best surface drainage is obtained by a ditch following low swales. To improve alignment, ditches may cut through minor rises in topography. Long tangents and gentle curves facilitate the cultivation of adjoining fields by eliminating odd-shaped areas. Where the design engineer plans to establish a minimum radius of curvature, table 5-1, may be of value. This table has been used widely in design of group drainage jobs.

Table 5-1. Suggested minimum radius of curvature in stable soil without bank protection

Kind of ditches	Fall per mile	Minimum radius of curvature	Approximate degree of curve
	feet	feet	degrees
Small ditches maximum top width 15 feet	Under 3	300	19
	3 to 6	400	14
Medium-sized ditches top width 15 to 35 . . .	Under 3	500	11
	3 to 6	600	10
Large ditches (more than 35 top width)	Under 3	600	10
	3 to 6	800	7

Problems outside the range of table 5-1, and in erodible soils, require special design. Sharp changes in alignment are needed in some locations to decrease waste area in fields. Where this is done, banks should be protected to prevent erosion.

Required Capacities

Drainage coefficients

General

The drainage coefficient is the rate of removal of excess water necessary to provide a certain degree of crop protection. Chapter 1 of this handbook includes a general discussion of drainage coefficients. Some drainage coefficients are for surface drainage, some for subsurface drainage, and some for a combination of the two. Subsurface flow is more uniform and extends over a longer period of time than surface runoff. In areas subject to both excess surface and subsurface water the subsurface drainage coefficient is usually the smaller of the two.

In order to give proper consideration to the characteristics of precipitation and runoff the drainage coefficient for surface drainage is usually expressed as a curve, where the rate of removal per unit of area varies according to the size of the drainage area. Drainage coefficients for subsurface drainage are usually expressed as a certain quantity of water removal from the drainage area per day. This may be expressed as inches per day from the watershed, or cubic feet per second per square mile. For large areas the rate may decrease. Where the need for both surface and subsurface drainage exists in a watershed, consideration must be given to the requirements of each in computing the design capacity for the ditch which serves as the common outlet.

In irrigated areas where the subsurface flow is continuous and generally uniform for extended periods, it should be considered as a base flow in computing the required capacity of the outlet ditch. In those areas where subsurface flow is the result of precipitation and is intermittent, the required capacity of the outlet ditch will be governed by the surface drainage flow. After a rainstorm the surface flow usually passes its peak before subsurface flow begins. In both situations the minimum depth of the outlet ditch will be determined by its required depth for subsurface drainage of its watershed. Any open ditch in an area subject to rainstorms will periodically be subjected to runoff from storms of abnormally high intensity. The type of agriculture and other improvements in the flood plain will determine the feasibility of constructing the ditch to the size required to carry the runoff from these abnormally large rainstorms within banks. Decisions are made on an evaluation of damages which would result from overbank flow and the cost of improvements which would prevent it.

Effect of outlet capacity on selection of drainage coefficient

In selecting criteria for design of drainage improvements, due consideration must be given to the capacity of the outlet into which the drainage ditches must empty. In determining the adequacy of outlets, the following basic requirements should be met.

1. The capacity of the outlet should be such that the discharge from the project watershed, after the installation of proposed improvements, will not result in stage increases that will cause significant damages below the termination of the project ditch.

2. The capacity of the outlet should be such that the design flow from its watershed can be discharged into it at an elevation equal to or less than that of the termination of the hydraulic gradeline used for design of the project ditch. The design flow from the watershed above the outlet should be determined in the same manner as the design discharge from the project. The probability of installing additional ditches in other watersheds which are served by the same outlet, in accordance with watershed or river basin needs, should be considered.

3. Where the outlet is a channel installed by the Corps of Engineers or other federal or state agency, the capacity of the project ditch will be governed by the capacity of the outlet. Criteria for design of the project ditch should be comparable to that of the outlet in such cases.

4. Where subsurface drainage is needed, the depth of the outlet needs to be such that subsurface drains may discharge freely into mains and laterals at normal low water flow.

Coefficients for subsurface drainage

The determination of coefficients for design of subsurface drains is discussed in Chapter 4 of this handbook. In using these coefficients for determining the required capacity of open ditches which serve as outlets for subsurface drains, consideration must be given to the amount of surface flow entering the ditches also.

In computing the subsurface flow from large watersheds the following points should be considered.

1. Percent of the watershed on which subsurface drains are installed, or which is contributing subsurface flow to open ditches.

2. Type of subsurface flow - continuous or intermittent.

3. Leaching requirement in irrigated areas.

4. Effects of precipitation on subsurface flow.

Studies of the yield of drains in arid and semiarid irrigated areas indicate an average flow from areas above one square mile in size to be in the range of 2 to 4 c.f.s. per square mile. Factors favoring use of the smaller figure would be larger areas, a substantial portion of the total area not being irrigated, low to moderate leaching requirement, and a diversity of crops which will result in a more uniform rate of irrigation and therefore of drainage. Experience in the area, observation of flow from existing drainage systems, consideration of the factors affecting flow from subsurface drains, and judgment are needed to develop criteria for required capacity of ditches for drainage of large areas of irrigated land in arid and semiarid areas.

Coefficients for surface drainage

Coefficients for surface drainage of flatland are usually determined by the general formula

$$Q = CM^{5/6} \qquad \text{Eq. 5-1}$$

Q = required capacity of ditch in c.f.s.
C = a coefficient related to the characteristics of the watershed and the magnitude of the storm against which the watershed is to be protected
M = drainage area in square miles

This formula applies to areas where the natural land slopes are about 1 percent or less. The formula may be used for minor portions of steeper land in a watershed which is predominantly flatland.

Stream gage records and studies made of the flow of excess rainfall from flatland watersheds show that the rate of flow, per unit of area, decreases as the total area of the contributing watershed increases. The rate of change, indicated by the exponent of M, varies somewhat between watersheds, and with the intensity and duration of the storm producing the excess rainfall. There is adequate data, however, to justify the use of the 5/6 exponent in the formula for determining surface drainage coefficients for all flatland watersheds in the United States.

Design flow from uplands in the watershed should be computed by procedures covered in Section 4, Hydrology, NEH, or from applicable hill land drainage curves. The design flow from the watershed can then be determined by adding to computed upland flow the flow of flatland increments computed from drainage curves.

Determination of coefficient "C" for use in surface drainage formula. - In many areas of the country the value of the coefficient for use in the general formula for surface drainage, $Q = CM^{5/6}$, has been determined by many years of experience. Values which are related to the kind of protection needed by different types of agriculture and kinds of crops have been determined for

specific climatic areas in the country. This experience data is invaluable and should continue to be used. Figure 5-1 indicates the area where these drainage coefficients which are shown in figures 5-2 and 5-3 are applicable. In cases where a drainage coefficient is needed in the area west of the north-south dividing line it should be based on the characteristics of the watershed and crops to be grown and somewhat lower than the coefficients in use for similar conditions to the east of the north-south line.

There are some areas, though, where the type of agriculture is changing, or improvements are being made in the watershed which indicate the need for a more precise determination of runoff than that provided by use of the applicable drainage coefficient. In other situations there may be a need to develop a coefficient which is adapted to the specific needs of a particular watershed and the experience with similar conditions is not adequate to indicate the best coefficient to use.

Where this is the case the coefficient "C" for the surface drainage formula may be determined by the following procedure which is a combination of the recommendations of Stephens and Mills (1)* and the procedures given in NEH 4, Hydrology, for determining runoff rates.

Values of the coefficient "C" for the flatland portion of the watershed may be determined from the relationship

$$C = 16.39 + 14.75\ R_e \qquad \text{Eq. 5-2}$$

Where "R_e" is the rainfall excess in inches. See figure 5-4 for solution of the above equation. "R_e" should be determined in accordance with procedures in NEH 4, Hydrology, Chapter 10. An example of determining "Re" and "C" is given on page 5-14.

In determining "R_e" for flatland watersheds the following factors should be considered.

It is normal, and not necessarily damaging, for water to accumulate to shallow depths on flatland during intense or extended periods of rainfall. Such accumulations should extend to relatively short periods of time. It is not feasible to contain all runoff within ditchbanks on flatland except for extremely low intensity and short duration storms. The level of protection on flatland refers to the duration and frequency of storms against which protection is afforded, to the extent that flooding to the depth and duration which will cause significant crop loss will not occur. Drainage formulas, with coefficients ranging from 15 to 50, generally provide this kind of protection against storms of recurrence frequency of once in 2 to 5 years, depending on the kind of crop.

In determining the degree of protection to be provided, the topography and soils need to be investigated. Land which is a foot or two higher receives a much higher degree of protection than the land at general field level on which channel design is based. Lands at the lowest elevations adjoining channels frequently are classed as "heavy" soils and are best suited to pasture or water-tolerant crops. Often the "lighter" soils, best suited for row crops, lie slightly higher in elevation. This is usually true of land built up by stream overflow. In such situations, channels designed on drainage curves

* Numbers in parentheses refer to references listed at the end of the chapter.

KEY MAP SHOWING DRAINAGE COEFFICIENTS FOR USE IN DRAINAGE DESIGN

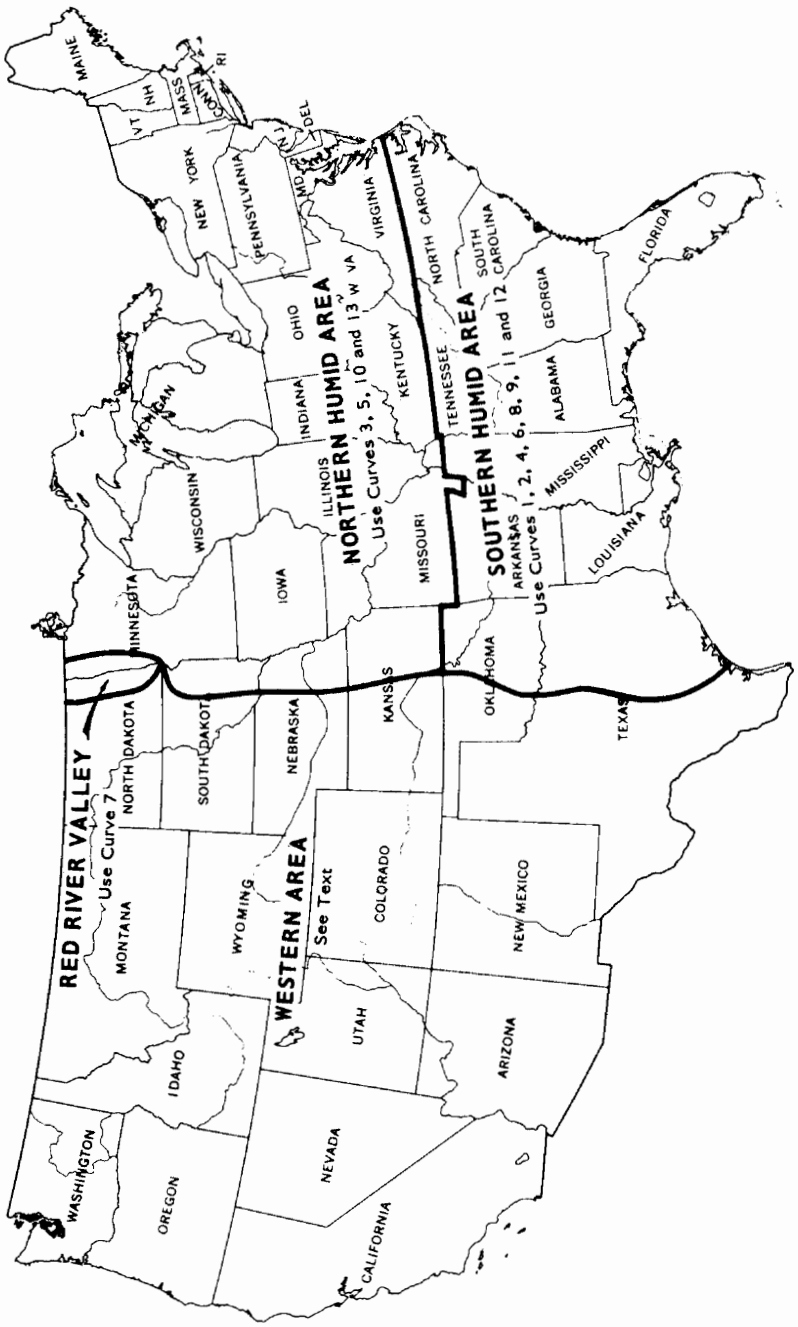

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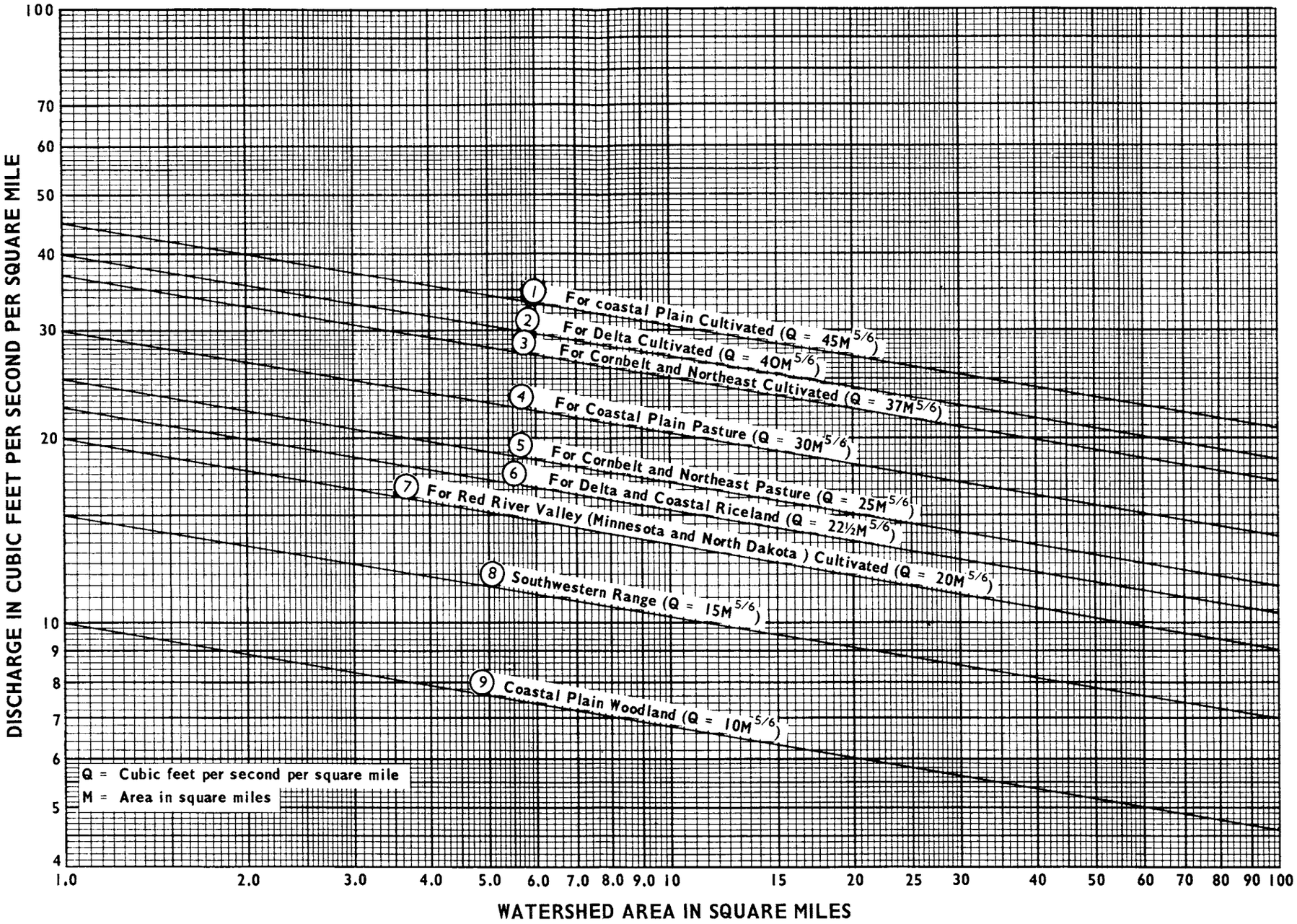
Figure 5-1, Key map showing drainage coefficients for use in drainage design

DRAINAGE RUNOFF CURVES



REFERENCE			
Curves 1, 2, 4, 6, 8 and 9 – Fort Worth, Texas and Spartanburg, South Carolina Engineering and Watershed Planning Units Curves 3 and 5 – John G. Sutton, "Hydraulics of Open Ditches," Agr. Eng., Vol. 20, No. 5, May 1939 Curve 7 – Minnesota Dept. of Drainage and Waters	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	STANDARD DWG. NO. ES–700 SHEET 2 OF 3 DATE 3–71

Figure 5-2, Drainage runoff curves

Figure 5-2, Drainage runoff curves
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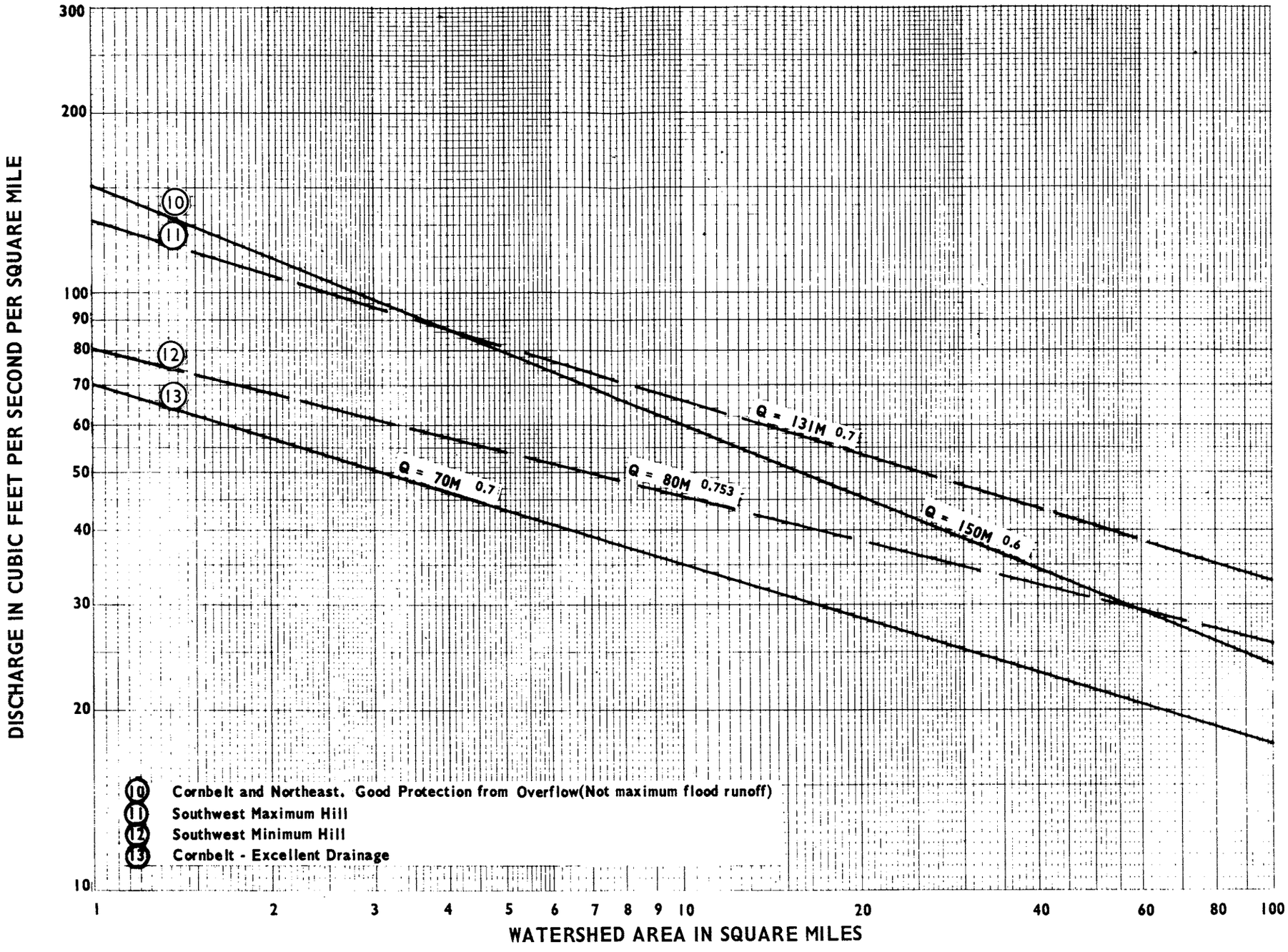
DRAINAGE RUNOFF CURVES



REFERENCE

Curves 10 and 13 – John G. Sutton, "Hydraulics of Open Ditches," Agr. Eng., Vol. 20, No. 5, May 1939.
Curves 11 and 12 – Fort Worth, Texas Engineering and Watershed Planning Unit

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Figure 5-3, Drainage runoff curves

Figure 5-3, Drainage runoff curves

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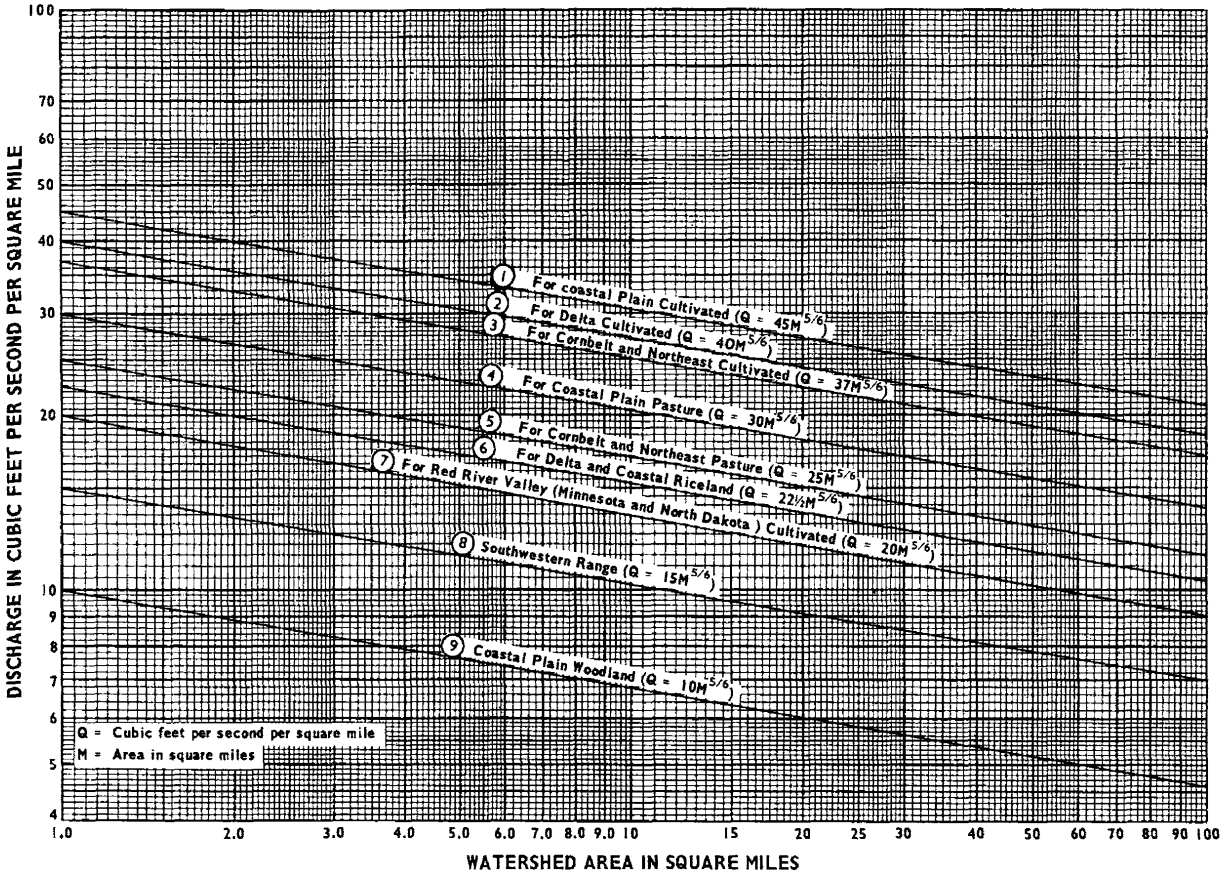
DRAINAGE RUNOFF CURVES



REFERENCE

Curves 1, 2, 4, 6, 8 and 9 – Fort Worth, Texas and Spartanburg, South Carolina Engineering and Watershed Planning Units
Curves 3 and 5 – John G. Sutton, "Hydraulics of Open Ditches," Agr. Eng., Vol. 20, No. 5, May 1939
Curve 7 – Minnesota Dept. of Drainage and Waters

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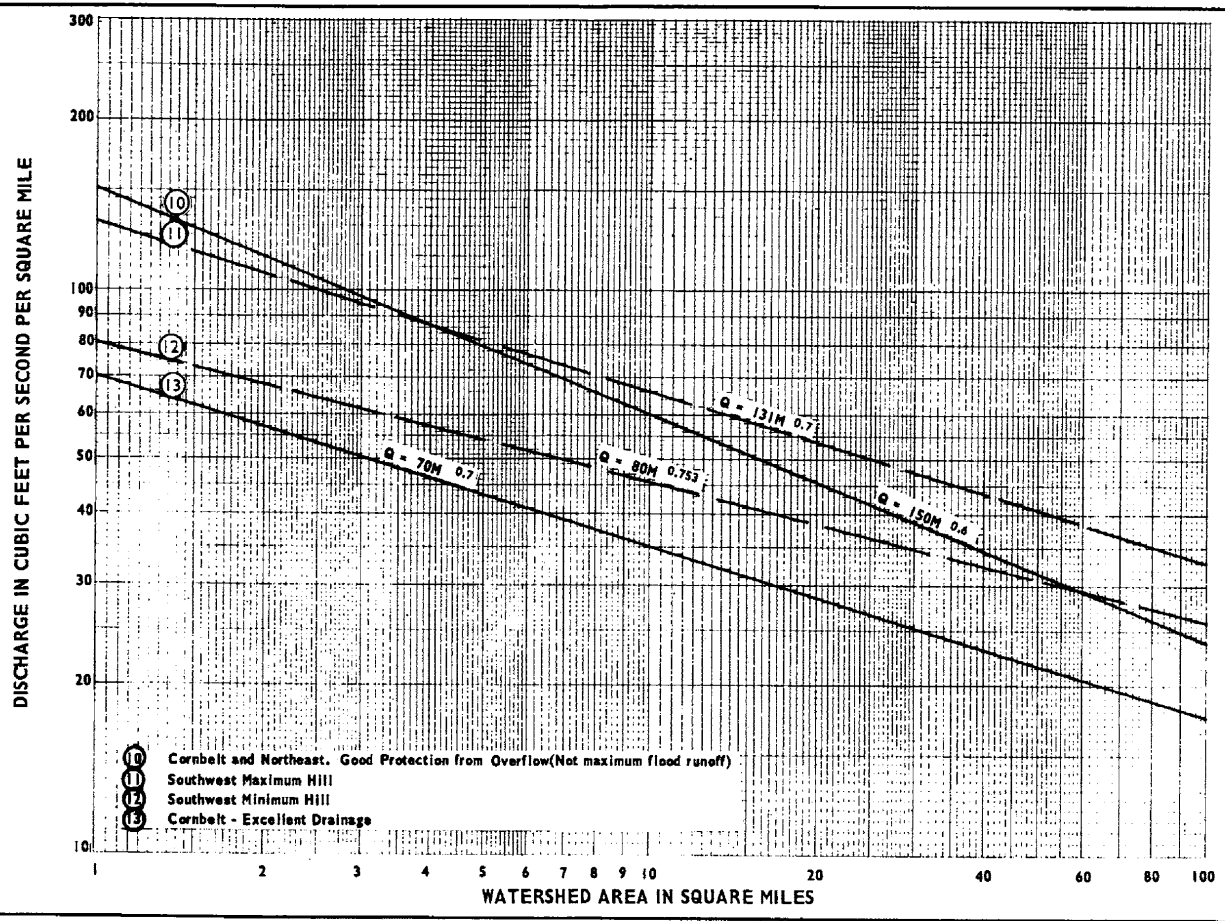
Figure 5-2, Drainage runoff curves

DRAINAGE RUNOFF CURVES



REFERENCE

Curves 10 and 13 – John G. Sutton, "Hydraulics of Open Ditches," Agr. Eng., Vol. 20, No. 5, May 1939.
Curves 11 and 12 – Fort Worth, Texas Engineering and Watershed Planning Unit

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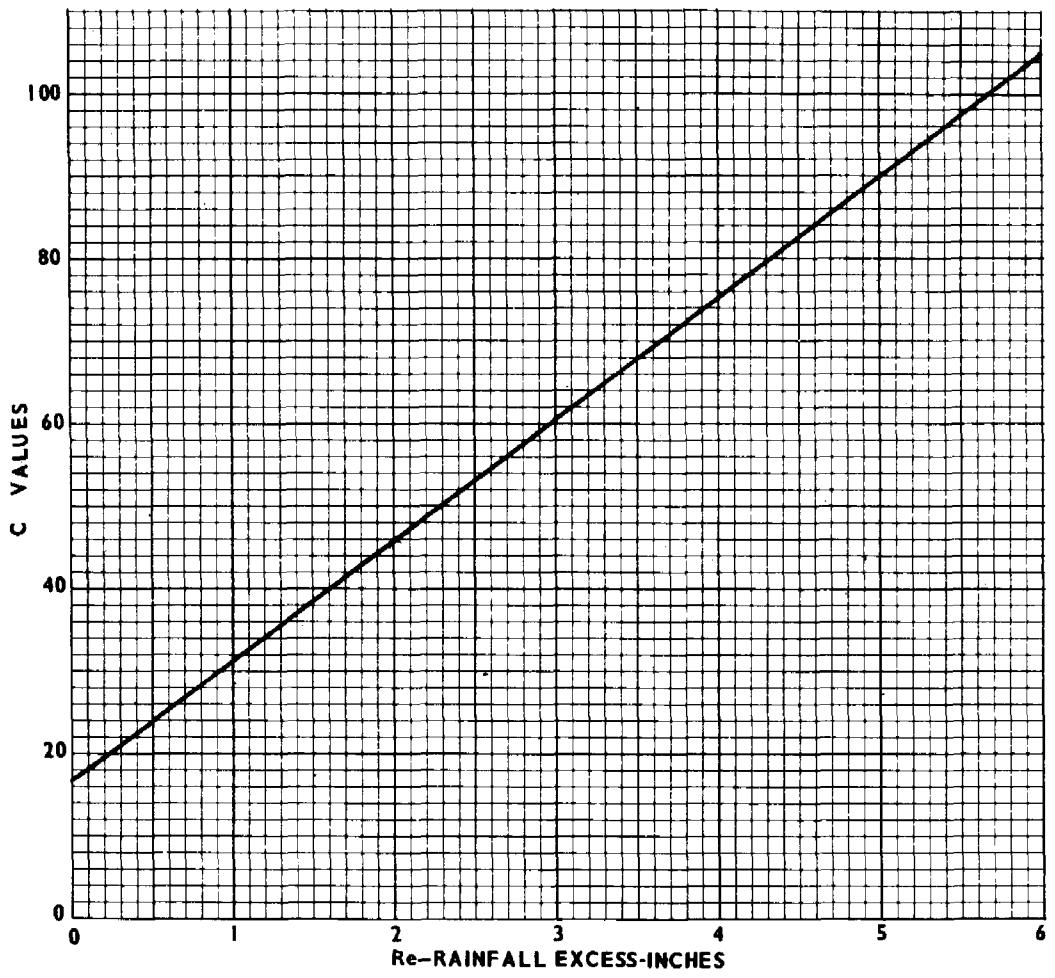
Figure 5-3, Drainage runoff curves

DETERMINATION OF THE COEFFICIENT C IN THE DRAINAGE FORMULA: $Q = CM^{5/6}$



REFERENCE		STANDARD DWG. NO.
Stephens, J. C. and Mills, W.C. A.R.S. 41–95, USDA-ARS $C = 16.39 + 14.75\ Re$	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	ES–733 SHEET 1 OF 1 DATE 3–71

Figure 5–4, Determination of coefficient, C, in the drainage formula: $Q = CM^{5/6}$

with coefficients in the range of 15 to 30 may provide adequate protection for the lower lying lands in a watershed and also provide a much higher degree of protection for lands which are a foot or two higher than the design hydraulic gradeline. In many watersheds, flood routing may be needed to determine the required channel size.

A common understanding of "24-hour removal" is that the rainfall excess from a particular storm is removed from the watershed within 24 hours after the cessation of rain. Actually, removal begins as soon as an excess develops. And since the critical storm for flatland areas may occur over an extended period of time - often 2 or 3 days - the analysis for determining the rainfall excess should be made by taking the maximum 48-hour rainfall for the recurrence frequency against which protection is desired, divide the excess from such a rain by two, and use this value in equation 5-2 to determine the coefficient for the surface drainage formula Eq. 5-1.

For general farm crops the level of protection normally planned is from a storm of 48 hours duration and with a frequency of occurrence of from 2 to 5 years. For high value crops with low tolerance to excess water, protection from the 10-year frequency storm may be desirable, or a special analysis may be warranted to remove, for example, the excess from a 24-hour rainfall in a 24- or 36-hour period. This will result in higher "C" values.

Example for computing "C" values. - Use of the above described procedure for computing a "C" value for the drainage formula first requires a decision on the level of protection to be provided the watershed. Then the characteristics of the specific watershed and the local climatic conditions must be considered. Assume that protection is to be provided against the maximum 48-hour storm of 5-year frequency. For example, U. S. Weather Bureau Technical Paper 49 shows that in southern Louisiana the 5-year, 2-day precipitation is about 8.0 inches. In this area the soil type places it in the D hydrologic soil group (see NEH 4, Chapter 7). Eighty percent of the area is in row crops having a runoff curve number 82 (contoured and terraced being used for flatland) and 20 percent is in permanent meadow having a runoff curve number of 78 (NEH 4, Chapter 9). This gives a weighted value of 81, which results in 5.74 inches of runoff for the 2-day storm (NEH 4, Figure 10.1). Use half of this or 2.87 inches in Equation 5-2 and obtain a value of 59 for "C" for use in the formula $Q = CM^{5/6}$.

Computation of design flow

The computation of the total design flow at a particular point on a ditch may involve combining the flow from tributaries or combining the flow from areas in the watershed on which different coefficients were used to compute the drainage flow. Methods used to combine flows from the various parts of any watershed should be directed to the objective of providing the desired protection for each part and for the watershed as a whole.

Combining flows from areas on which different coefficients are used to compute design flow

Within a particular watershed there may be sloping upland, flat bottom land, forest land, highly developed general cropland, or even some urban land. The characteristics of each distinct type of land and land use within the watershed determines the coefficient to be used in design of improvements on that parcel of land and in computing the drainage flow from it. In order to comply with one of the principles of the surface drainage formula: that the rate

of removal per unit of area varies according to the size of the drainage area, it is necessary to maintain the same relation of total flow to total area as the formula specifies. This can be done within tolerable limits by the simple device of determining the acreage of one type of land which by use of its proper coefficient will produce the same flow as a different acreage of another type of land using its proper coefficient. Then as the addition of flow proceeds downstream in a watershed each subsequent determination is based on the addition of area as well as water.

Drainage coefficients for steep and other areas

Where established drainage coefficients do not directly apply to steep and other areas, the drainage coefficient should be estimated after studying the following:

1. Determine the water tolerance of the predominant crops in the area and arrive at a time factor within which drainage should be provided. Determine depth of flooding permissible during this time.

2. Determine volume of runoff for the time period, determined according to item one, for rainfall to be expected in accordance with the level of protection planned. This may be a 48-hour rain to be expected once in 5 years for the first trial for general crops. For procedures to be used in computations see section on total storm runoff and peak flow and NEH 4.

3. Estimate the drainage coefficient from data obtained under items 1 and 2 from comparison with established drainage curves which apply to conditions most nearly similar.

4. Determine the hydrograph of runoff for the selected storm. Use this hydrograph to determine if the limits of permissible depth and time of flooding are exceeded with the channel capacity as estimated under item 3.

5. Adjust the drainage coefficient if results appear out of line with drainage requirements.

   Where flow from a stream or channel, which carries runoff from hill land, enters a ditch designed on a drainage curve, the equivalent watershed area is computed and used in design as described on page 5-24.

   Where protection of urban or other valuable property is required, the design of channels and other facilities should be based on holding depths of flooding to the level which can be tolerated in accord with the level of protection selected.

Determination of drainage coefficients for subsurface drainage is described in Chapter 4 of this handbook.

Total storm runoff and peak flow

In computing flow from steep or other areas where drainage curves are not applicable, the total volume of runoff and the peak flow need to be determined.

Volume of runoff. - For approximate results, the volume of runoff may be computed by the following procedures. These procedures are based on the use of

(a) U. S. Weather Bureau Technical Papers 40, 42, 43, 47, and 49, and (b) United States Department of Agriculture, Soil Conservation Service Engineering Handbook, Section 4, Hydrology.

The procedures described in NEH Section 4 should be used for computing volume of runoff based on soil-cover groups or complexes defined in the guide. Table 9.1 in the handbook prescribes curve numbers for various soil-cover groups and figure 10.1 (ES-1001) is a solution of the runoff equation for various curve numbers and amounts of rainfall. Hydrologic groups for various soils are given in table 7-1.

These procedures can be used to determine the volume of runoff from a storm of a specified duration and a given frequency.

The approximate total runoff may be computed as follows:

Step 1. Determine watershed area and areas of parts of watershed in various soil-cover groups.

Step 2. Select runoff removal time for drainage based on local crops and area to be protected. Normally the 24-hour duration storm is used.

Step 3. Select rainfall intensity-frequency chart. Rainfall intensity-frequency charts in Weather Bureau Technical Bulletins, Paper 40, 42, 43, 47 or 49, whichever is applicable, should be used.

Step 4. Determine rainfall to be used from the selected rainfall intensity frequency chart, according to the location of the job.

Step 5. Select curve number to be used for each soil-cover group. Use Table 9.1, NEH 4, with antecedent moisture condition II for usual design.

Step 6. Tabulate data in columns and compute total runoff.

List and description of columns needed:

a. Area of each soil-cover group--square miles (table 9.1, NEH 4)

b. Land use or cover--row crops, small grain, woods, etc. (table 9.1, NEH 4)

c. Treatment of practice--straight row, contoured, etc. (table 9.1, NEH 4)

d. Hydrologic conditions, good or poor (table 9.1, NEH 4)

e. Hydrologic soil group, A, B, C, or D (table 7.1, NEH 4)

f. Curve No. (table 9.1 and figure 10.1, ES-1001), NEH 4, Hydrology

g. Storm runoff in inches (from selected runoff curve number and rainfall as determined in step 4).

h. Storm runoff from each soil-cover group obtained by multiplying column above by area square miles (result in inch-miles).

Step 7. Add column obtained in item h above to obtain total storm runoff from watershed in inch-miles.

Step 8. Divide by watershed area (square miles) to obtain volume of runoff in inches for watershed for storm period.

Example using the above procedure to determine the volume of runoff. - -

Step 1. The area for which the volume is to be determined is 5 square miles of flatland located where Texas, Arkansas, and Louisiana join. The runoff curve numbers and the soil cover groups as classified in table 9.1 are:

COVER				Hydrologic Soil Group			
Land Use	Area Sq.Mi.	Treatment or Practice	Hydrologic Condition	A	B	C	D
Row crops	2.0	Contoured	Good		75		
Row crops	1.0	Contoured	Good			82	
Pasture	1.0		Fair			79	
Woods	1.0		Poor		66		

Step 2. The time established to drain the composite area is 24 hours.

Step 3. A 24-hour, 5-year storm is selected.

Step 4. Using Weather Bureau Technical Paper 40, the rainfall from a 5-year, 24-hour storm in the area is 5.8 inches.

Step 5. The curve numbers to be used for each soil cover group using hydrologic condition II are selected from table 9.1 and are shown in step 1 under Hydrologic Soil Groups.

Step 6. Using rainfall determined in step 4 the total runoff is determined from ES-1001 as follows:

Curve No.	Runoff, inches	Area, sq.mi.	Inch Miles
75	3.11	2	6.22
82	3.80	1	3.80
79	3.50	1	3.50
66	2.29	1	2.29

Step 7. Total 5 15.81

Step 8. Inches per square mile $\frac{15.81}{5}$ = 3.16 inches.

Peak runoff and hydrographs. - The peak runoff may be estimated by one of the methods described in NEH 4. The method to be used depends upon the accuracy and expense justified in making the required determination. NEH 4 discusses both approximate and detailed methods of estimating peak runoff and construction of hydrographs.

Design Standards

Requirements for side slopes, berm widths and maximum velocities of drainage ditches are based primarily on water table elevations, soil conditions and maintenance requirements. These and other design standards are established in most State handbooks and local drainage guides.

Channel design

Determination of required channel dimensions for a given rate of flow (Q), hydraulic gradient (s), and channel roughness (n) is usually made by a solution of the Manning equation to determine the mean velocity (v) and by use of the relation: Q = Av where Q = rate of flow in cubic feet per second, A = cross-sectional area of the channel in square feet. The Manning equation is usually written:

$$v = \frac{1.486}{n} r^{2/3} s^{1/2} \qquad \text{Eq. 5-3 (2)}$$

v = mean velocity of water in feet per second
r = mean hydraulic radius in feet - cross-sectional area of the channel divided by its wetted perimeter
s = the energy loss per foot of length and for open channels with very small slopes it may also be defined as the slope of the energy gradient. For uniform flow, s is also the drop in the channel per foot of length, and for very small slopes it becomes nearly equal to the slope of the channel.
n = coefficient of roughness for use in the Manning equation.

Value of "n" for design

The proper design of a ditch requires the selection of the value of "n", the coefficient of roughness that will exist after it is in use and well maintained. A useful guide for the selection of "n" for the design of drainage ditches is given in table 5-2.

Table 5-2.--Value of "n" for drainage ditch design

Hydraulic radius	"n"
less than 2.5	0.040 - 0.045
2.5 to 4.0	.035 - .040
4.0 to 5.0	.030 - .035
more than 5.0	.025 - .030

These values are an interpretation of results reported in United States Department of Agriculture Technical Bulletin 129, Flow of Water in Drainage Channels, 1929. (Also refer to the U. S. Department of Agriculture, Soil

Conservation Service, Engineering Handbook, Section 5, Hydraulics, Supplement B.) Values here are based on the assumption that obstructing vegetation in channels will be kept down by maintenance. If vegetation is not kept down, the value of "n" may be 0.100 or higher.

In newly excavated channels the values of "n" are lower and velocities higher than design values. Where the design velocity is near an erosive value, this may need to be studied and corrective measures planned. The velocity may be lowered within narrow limits by making a ditch wider and shallower. Excavation may be planned during the growing season and banks may be seeded to avoid exposure of raw banks unnecessarily.

Channel section

The channel section selected should be (a) large enough to permit the required discharge, (b) as deep as required to provide a satisfactory outlet for both surface and subsurface drainage needs of the area served, and (c) of a width-depth ratio and side slopes which will result in a stable channel which can be maintained in a satisfactory condition at a reasonable cost.

Depth. - The minimum depth of ditches acting as disposal ditches for subsurface drains unless otherwise specified, should be about 5 feet in the humid area and 8 feet in western irrigated areas. Drainage guides should specify depth standards.

Bottom width. - Capacity required, soil materials, velocity and the type of construction equipment to be used are factors which affect the minimum bottom width which should be planned. Excessively wide and shallow ditches are not hydraulically efficient and are usually more difficult to maintain than are ditches with a more efficient hydraulic section.

Side slopes. - Side slopes to be recommended for local site conditions should be specified in drainage guides for the area. The side slope of old ditches should be examined to determine their stability in the usual soil types.

Maintenance requirements also should influence the selection of side slopes. Ditch side slopes which may be used with various maintenance methods are given in table 5-3.

Table 5-3.--Ditch side slopes for use with various maintenance methods

Type of Maintenance	Usual Recommended Minimum Side Slopes	Remarks
Mowing	3:1	Flatter slopes desirable for ordinary farm wheeled tractors. Special equipment may be used on steeper slopes (see p. 5-50).
Grazing	2:1 or flatter	For ditches greater than 4 feet deep, use ramps.
	1/2:1 or flatter	For ditches less than 4 feet deep, use ramps.
Dragline	1:1	Suitable for use in stable soils on ditches greater than 4 feet deep.
Blade equipment	3:1	Flatter slopes desirable.

In locations, where field laterals are used for subsurface drainage, the deep ditches require so much right-of-way that ditchbanks need to be constructed with side slopes as steep as possible to conserve land. Such ditches may justify an on-site study to determine the natural angle of repose of the soil and to observe old ditches, so that stable side slopes can be determined. Water must not be allowed to run over the banks of the deep ditches.

Stability of bank slopes on noncohesive soils such as fine sands are usually not obtained immediately after initial excavation because of sloughing from seepage before the normal water table recedes to new levels. Construction procedure may require an early followup to reshape the banks. It may be desirable on some jobs to require initial excavation of a pilot channel of lesser width than the designed section and later completion of the excavation and the shaping of the banks. This will allow the water table to become adjusted to the deeper ditch before the final shaping.

Ditch stability. - The velocity selected for the ditch design may be acceptable for the depth of flow and the condition expected after the channel has aged but the velocity must be also satisfactory for bank-full flow and the conditions which will exist immediately after construction. Bank-full flow is the flow that will create a water surface at or near the normal ground elevation for a significant length of a reach of the ditch. Excess ditch depth resulting from a cut through high ground is not considered.

Recommended procedures for designing stable channels are given in SCS, Engineering Division, Technical Release No. 25, Planning and Design of Open Channels.

Berms and spoil banks. - Adequate berms are required to:

1. Prevent sloughing of ditchbanks caused by heavy soil loads too near the edge of the ditch.

2. Provide travelways for maintenance equipment.

3. Eliminate the need for moving spoil banks in future operations.

4. Provide for work areas to facilitate spoil bank spreading.

5. To prevent excavated material from washing or rolling back into ditches.

If the spoil banks are to be spread the berm required during construction and the method of spreading the spoil need to be specified in the construction contract. The best use of the spoil and how far it can be spread are determined by the type of excavated soil, the adjacent land use, the need for roads, and the method of maintenance to be employed. In some locations spoil can be shaped and used to good advantage for farm roads. In all cases a travelway should be established on the berm or on the spread spoil which is adequate for movement and operation of the type of equipment needed for maintenance of the ditch.

In humid areas, the spoil banks usually should be spread so they can be cultivated or kept in hay or pasture. The spoil should be spread to slope away from the ditch and left so ordinary farm equipment may operate over the spoil.

Spoil banks should not be spread where infertile soils, rock, gravel, or irrigation practices do not permit cultivation of spoil material, or where they will be covered with timber or brush. Where not spread, the spoil bank should be in as small a right-of-way as possible consistent with berm requirements, and side slopes should be as steep as the soil permits. Where unproductive soils occur at lower depths in large ditches, the good soil should be segregated during construction, and then spread to use it to better advantage. Fertile spoil may be used for land grading, smoothing, or land leveling in adjacent fields or as topsoil of the spoil banks.

Safe entry of surface water through the spoil into the ditch should be provided. In placing and spreading the spoil, points of entry and type of inlet structure to be used need to be determined.

Spoil material should be disposed of in a manner which will improve the esthetic appearance of the site to the extent feasible.

In areas where soils and climatic conditions are favorable, planting of hay or pasture crops on berms, travelways and spoil disposal areas is good practice. On suitable sites, plantings should be made for shelter and food for wildlife. When the plan provides for planting trees or shrubs along a ditch the plantings should be placed so that they will not interfere with channel flow, maintenance operations, or the maintenance travelway.

Local technical guides should recommend desirable types of vegetation and methods of establishment since vegetation is of primary importance in reducing maintenance and preservation of wildlife.

Design Procedure

General

The basic procedure for drainage ditch design includes the following:

1. Check all basic field information such as field elevations, control points, soil borings, bridge footing, etc. for completeness. Also check the elevation of the water in the outlet. A stage-frequency curve should be obtained wherever possible.

2. Establish control points and set hydraulic gradeline for design.

3. Determine watershed areas and equivalent watershed areas if required at the lower ends of selected design reaches.

4. Compute design discharge in c.f.s. for the lower end of each reach.

5. Select and record appropriate design criteria including values of "n", side slopes, minimum bottom width, and minimum depth below hydraulic gradeline.

6. Design ditch section below the established hydraulic gradeline.

In applying this procedure several problems arise such as combining flow from different types of watershed areas and at junctions of ditches, at culverts and bridges. This chapter discusses methods of handling these situations.

Drainage ditches should be designed to pass the design drainage flow throughout the length of the ditch with the hydraulic gradeline sufficiently below the elevations of land to provide good drainage. The hydraulic gradeline represents the surface of the water when the ditch is operating at design flow. Its slope "s" is used in the Manning formula to determine velocity. The grade of the ditch bottom may have a different value because the ditch bottom is not always parallel to the hydraulic gradeline.

Uniform flow is ordinarily assumed in the design of drainage channels except above culverts and at locations where the design requires backwater computations. With these exceptions the ditch bottom may be established parallel to the hydraulic gradeline and a uniform channel section used. Even though nonuniform flow results where minor obstructions occur or where minor local drainage enters it is of little practical significance and the general efficiency of the system is not impaired.

The Manning formula is recommended for open-ditch design because of its simplicity and range of tables available. The Corps of Engineers publication, Hydraulic Tables, permits an easy and rapid solution of the Manning formula for values of "n" from 0.010 to 0.175. These tables may be bought from the United States Government Printing Office, Washington, D. C. 20401.

Establishing the hydraulic gradeline

The hydraulic gradeline is established after determining land use, the elevation of control points along the ditch, and plotting the control points on the ditch profile. Usually control points are established below the elevation of principal fields so they can be adequately drained and at hydraulic gradelines of lateral ditches or streams entering the ditch. Where it is impractical to establish control points low enough to drain the land, the land use may need to be adjusted to more water-tolerant crops, such as pasture or trees. The control points are established low enough to allow for headloss by surface flows from the field through the bottom of the row furrows and surface drains to the outlet.

Additional control points are determined from culverts, bridges, buildings, roads, and other property within the area to be drained. The hydraulic gradeline is drawn through or below as many control points as possible based on their importance and after studying (a) the profile of the natural ground surface, (b) critical elevations established by surveys, and (c) channel obstructions such as culverts and bridges.

The hydraulic gradeline often is drawn above some control points to save excavation. The importance of control points depends on the agricultural area or property values they represent and on the extent and results of poor drainage if the hydraulic gradeline is above the control point. All control points representing the elevations of the hydraulic gradeline of lateral ditches must be established and used in drawing in the hydraulic gradeline of the main ditch. The hydraulic gradeline of the main and all laterals should coincide at points of intersection before the ditch sections are designed.

Where the hydraulic gradeline needs to be established above the levels of lowlying land, such land will not receive the same degree of drainage benefit as fields lying above the hydraulic gradeline. This may limit the land use of lowland to crops such as hay, pasture, or woodland. Lower drainage assessments may need to be placed because of the limitations in land use. Establishing the

best hydraulic gradeline for good economical drainage requires practical experience. Perfection in this should be a major goal of a drainage engineer. Drawing a line through the control points on the profile fixes the hydraulic gradeline. It will often need to be drawn more than once to obtain the best balanced results.

The design of a drainage system may begin at either the upstream or downstream end. The elevation of the hydraulic gradeline for the lowest design reach needs to be at the controlling elevation of the outlet. For many ditches, it makes little difference where the design commences. Where there is limited grade it may be necessary to use bridges in lieu of culverts to minimize head loss at structures.

Computing ditch sizes at junctions - 20-40 rule

One method of computing the required capacity of a ditch below a junction is to add the design flows (c.f.s.) of the two ditches above the junction. A second method is to add the tributary areas of the two ditches and compute the size based on the drainage coefficient for the total watershed area. The first method gives a higher discharge than the second method. Method 1 should be used where ditches draining almost equal areas join. Here the time of concentration is likely to be about the same if topography is the same and peak flows ordinarily will reach the junction at about the same time. Method 2 is used where the ditch draining a small area joins a ditch that is much larger. This is because the peak discharge from the small ditch passes before the peak flow of the larger ditch reaches the junction. For intermediate conditions a transition from one method to the other should be applied.

A recommended method for determining the design discharge below a junction is by use of the following empirical procedure termed the 20-40 rule:

1. Where the tributary area of one of the ditches is from 40 to 50 percent of the total tributary area, determine the required capacity of the channel below the junction by adding the required design capacities of the ditches above the junction.

2. Where the watershed area of a lateral is less than 20 percent of the total watershed area, determine the design capacity of the ditch below the junction from the drainage curve and for the total watershed area below the junction at the end of the design reach.

3. Where the watershed area of a lateral is in the range of 20 to 40 percent of the total watershed area, the discharge shall be proportioned from the smaller discharge obtained by use of method 2 at 20 percent to the larger discharge obtained by use of method 1 at 40 percent. In this range compute the discharges by both methods 1 and 2 above and obtain the difference in cfs by the two methods. Then interpolate to obtain the design discharge for the channel below the junction.

Illustrating this, assume that a lateral draining 3,200 acres joins an outlet draining 10,200 acres above the junction with 13,400 acres watershed area below the junction. A curve developed from the formula $Q = 45\ M^{5/6}$ is to be used to calculate runoff. Since the watershed area of the lateral is between 20 and 40 percent of the total watershed, the flow will be computed as follows:

Step 1.	Runoff from 3,200 acres	170 c.f.s.
	Runoff from 10,200 acres	460 c.f.s.
	Total discharge from the two watersheds	630 c.f.s.
Step 2.	Runoff from total watershed 13,400 acres . . .	580 c.f.s.
Step 3.	Subtract step 2 from step 1	50 c.f.s.

Step 4. Percent of small watershed (3,200 acres) of total watershed (13,400 acres) is $\frac{3200}{13400} \times 100 = 23.8$ percent.

Step 5. Difference between 23.8 and 20 = 3.8.

Step 6. $\frac{3.8}{20} \times 100 = 19$ percent.

Step 7. From step 3, 50 x 19 percent = 9.5.

Step 8. Add 580, from step 2, and 9.5, from step 7 . . 589

This is the final interpolated discharge from this watershed below the junction.

NOTE: Computations in method 2 assume a short design reach below the junctions with no increase in watershed area below the junction. Often the design reach may be long enough to require an added discharge from the area below the junction.

If the 20-40 rule increases the ditch section above normal for the watershed, the enlarged section is carried downstream without changing size until additional watershed requires a larger ditch section based on total watershed area.

In the example of design, figure 5-9 and table 5-4, method 3 is illustrated at station 360+00 where lateral A has a watershed of 37.5 percent of the total and the design discharge is obtained by interpolation. Laterals B, C, D and E have watershed areas less than 20 percent of the total watershed area below the respective junctions. Here, method 2 with design Q based on watershed areas below the junction applies.

Computing equivalent drainage area

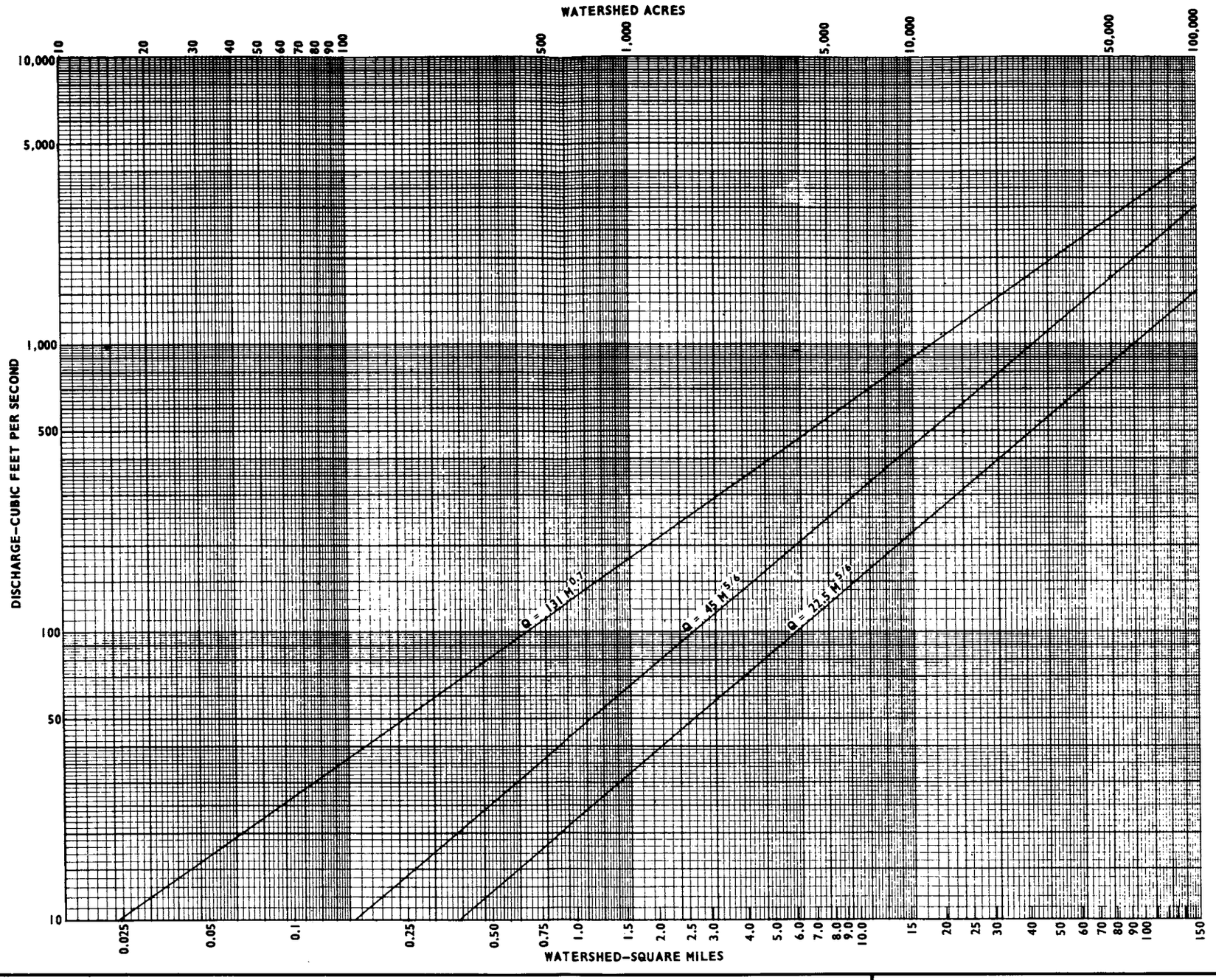
When runoff is removed at different rates on various parts of the watershed it will be necessary to find either equivalent areas or equivalent discharge so the correct design capacity can be carried downstream without confusion. This can best be done by compiling drainage coefficient curves based on total discharge for the area rather than by discharge per square mile. Such curves are shown in figure 5-5. Equivalents can be read directly from these curves.

Example of use: (based on figure 5-5)

2,000 acres of land requiring the curve developed from $Q = 45\ M^{5/6}$ joins
1,000 acres of land requiring the curve developed from $Q = 22\frac{1}{2}\ M^{5/6}$

It will be necessary to convert to either $Q = 45\ M^{5/6}$ or $Q = 22\frac{1}{2}\ M^{5/6}$

DRAINAGE RUNOFF CURVES FOR SAMPLE DRAINAGE DITCH DESIGN



REFERENCE

DRAINAGE DESIGN PROBLEM CHAP. 5, SEC. 16

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SOIL CONSERVATION SERVICE

ENGINEERING DIVISION - DESIGN SECTION

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Figure 5-5, Drainage runoff curves for sample drainage ditch design

Figure 5-5, Drainage runoff curves
for sample drainage ditch design

depending on the use below the junction. This is found to be predominantly land use requiring runoff removal rate of $Q = 45\ M^{5/6}$. The discharge from 1,000 acres on $Q = 22\frac{1}{2}\ M^{5/6}$ is 32.5 c.f.s. This is equivalent to 425 acres on the $Q = 45\ M^{5/6}$ curve. Hence, we would assume a total watershed below the junction of 2,000 acres plus 425 acres which equals 2,425 acres. The total discharge from 2,425 acres on the $Q = 45\ M^{5/6}$ curve (considering the 20-40 rule given on page 5-23) is found to be 140 c.f.s. Therefore, 140 c.f.s. is the design flow below the junction.

Flow from reservoirs into drainage systems

In most situations the flow from flood-prevention reservoirs may be handled in drainage design by subtracting the watershed area upstream from the dam from the total watershed area and adding the outflow through the principal spillway. The outflow should be added as a constant flow to the drainage flow computed from the watershed below the dam. The effect of weir-type dams may be disregarded under most conditions and the drainage design based on the entire watershed area contributing to the channel.

The effect of flood-prevention reservoirs may be disregarded, for drainage-design purposes, at some point downstream. This point may be determined by figuring the average outflow of the reservoir in c.f.s. per square mile of watershed area above the dam. If this rate of flow is below the minimum rate in the drainage curve applicable at the outlet and based on the entire watershed area, the reservoir affects the entire drainage system. If the rate of outflow from the reservoir intersects the drainage curve, the effect may be disregarded for drainage-design purposes below the point and watershed acreages considered as if no dam existed.

For example, the principle is illustrated by the following problem: Assume a reservoir with a single stage principal spillway has a drainage area of three square miles. The channel below the structure will be designed using drainage curve No. 5, figure 5-2. The average outflow from the reservoir during 24 hours is computed at 14 c.f.s. per square mile or 42 c.f.s. The average outflow is approximately 80 percent of the maximum principal spillway outflow. Drainage curve No. 5 at a watershed area of 30 square miles gives a flow of 14 c.f.s. per square mile.

Therefore, economy in drainage design is obtained by considering the reservoir effect in designing the drainage channel between the reservoir and the point where the total watershed area equals 30 square miles. In this stretch the watershed area above the reservoir equaling 3 square miles should be deducted and the flow of 42 c.f.s. should be added for the drainage channel design. Below this point where the total watershed reaches 30 square miles it would be economical here to disregard the reservoir effect and design the channel based on the total watershed area.

Hydraulic design at culverts

Culverts usually obstruct the flow of water in ditches and cause a loss in head. This must be accounted for in designing drainage ditches. Figure 5-6 gives the steps applicable for designing most drainage ditches at culverts. With this, the hydraulic gradeline is set low enough at the culvert to compensate for loss in head through the culvert unless local land use will permit flooding. If the permissible culvert loss (2-3) is computed correctly (NEH, Section 5, Hydraulics) and other steps are followed, the profile of the water

surface will be about the backwater curve (2-6) and well within bank capacity during the design-drainage flow.

Ordinarily precise computations of backwater curves at bridges and culverts need not be made where only agricultural drainage is considered.

In applying the method in figure 5-6, control point 1 should be established. This point should be far enough upstream from the culvert to make the difference in elevation between 1 and 8 at least twice the loss of head at the culvert (2-3).

For low gradient channels, less than 5 feet per mile, computations indicate the backwater curve may be as much as 0.2 or 0.3 foot above point 1 if distance 1-8 is twice the culvert loss 2-3 for typical drainage ditches. If there are bridges, culverts, or obstructions in the stretch 1-2 or if a hydraulic gradeline a few tenths above point 1 for design flows would be serious, then a backwater curve should be computed by the simplified method given in NEH, Section 5, Hydraulics, Supplement A.

Many highway departments have specified methods of computing their culvert capacities. Culvert capacities may be based on peak-flood flows determined for specific frequencies or by a designated method of estimating runoff. Where a peak flood for a 5- to 10-year, or longer, frequency is used as a basis for design of channel capacity without flooding and where the depth is adequate, the culvert will ordinarily be ample for agricultural drainage.

The permissible culvert head loss depends on grade of ditch, erosion, land use, and other local conditions. Culverts not governed by more exacting highway requirements should meet one of the following conditions:

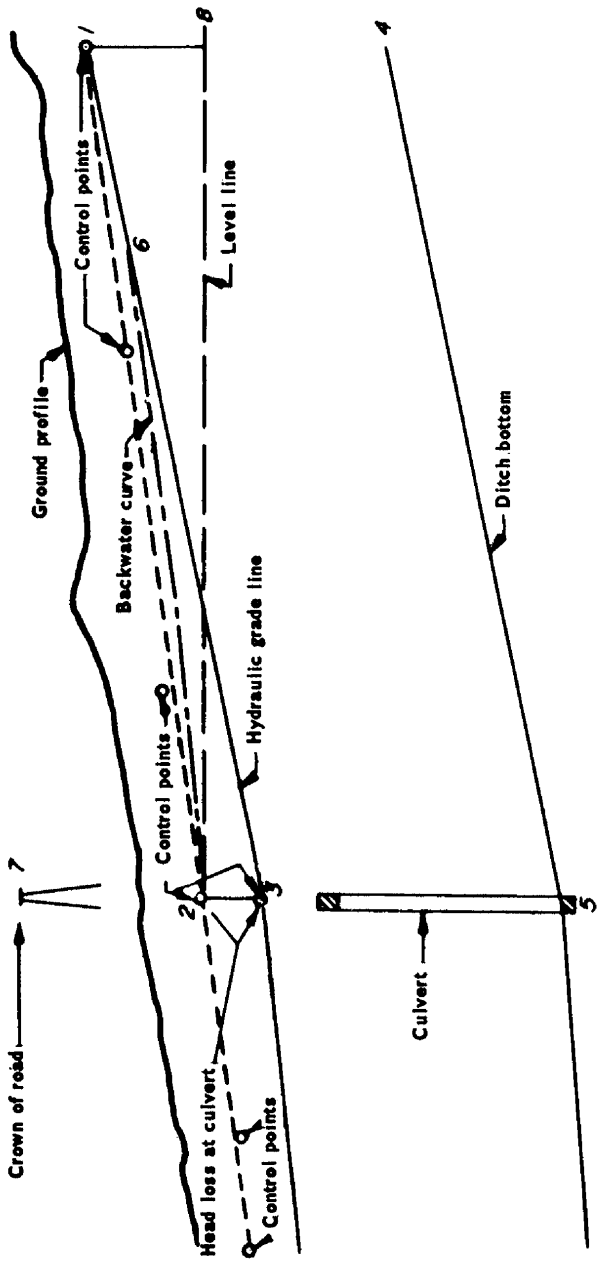
1. In large outlet ditches on flat slopes, a culvert may obstruct flow seriously if not properly designed. Keep the hydraulic losses as low as possible. Generally such losses should not exceed 0.5 to 1.0 foot. Check for excessive velocities through the culvert. Excess velocity on the outlet end will cause serious erosion problems.

2. Where the ditch has excess grade, grade control may be incorporated in a culvert.

   Allowable culvert losses may be increased depending on drainage requirements. However, avoid excessive velocities. Often culvert losses of as much as 2 feet are permissible but higher losses need to be studied with care. Where needed, provide downstream protection against erosion due to high velocities. A self-cleaning velocity also may be an advantage for culvert maintenance if protection is provided against erosion.

3. In important installations, make channel routing and determine hydrographs, amounts of storage, and estimates of height and duration of flooding caused by floodflows in excess of drainage flow. The importance of the highway, size and value of culvert, value of land, crops to be grown, flood damages incurred, and drainage-design factors all need to be accurately determined for design of important structures obstructing flow.

PROCEDURE FOR DESIGN OF DRAINAGE DITCHES AT CULVERTS



a - Set "control points" 1, 2, etc. as though no culvert is to be installed. Compute head loss at culvert 2 to 3; measure down from upper "control point" 2 at culvert and set lower "control point" 3. Make distance 2 to 8 large enough so that 1 to 8 is two or more times greater than 2 to 3. Point 1 is approximately at limit of backwater curve which may be established by standard methods of computing backwater curves.

b - Normal hydraulic gradient would be line 1 to 2.

c - Draw hydraulic gradient for ditch section above culvert from "control point" at 1 to lower "control point" at 3.

d - Compute ditch section required based on drainage flow and hydraulic gradeline 1 to 3 and set ditch bottom 4 to 5.

e - Culvert will cause heading-up along typical backwater curve 2 to 6; generally close to line 1 to 2, provided 1 is far enough upstream.

f - Check floodflows over crown of road depending on elevation at point 7.

REFERENCE

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ENGINEERING DIVISION - DESIGN SECTION

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Figure 5-6, Procedure for design of drainage ditches at culverts

In installing culverts, carefully check the elevation of the crown of the road to be sure the road is well protected against overtopping. Bypassing floodflows over low stretches of roadways serving as spillways may need to be provided for farm roads.

Flooding, caused by water impounding back of a culvert during excessive flows, frequently influences land use. Land use above a culvert may have to be restricted to water-tolerant crops or pasture. Cultivation of truck and other crops susceptible to large damage by flooding may need to be avoided. Here, installing a bridge instead of a culvert or enlarging a culvert to reduce flooding may be required.

The upstream end of the culvert should have a rounded entrance. This type of entrance greatly reduces the entrance losses and results in a much more efficient structure.

Principles of computing culvert losses are discussed in NEH, Section 5, Hydraulics, King and Brater's Handbook of Hydraulics (2), and the Bureau of Public Roads Hydraulic Engineering Circular No. 5 (3).

Hydraulic design at bridges

Bridge openings should have as near the required cross-sectional area of the ditch as possible. Center piers should be avoided if possible in preference to side abutments. Upstream faces of piers and foundation walls need to be rounded to reduce friction loss and obtain streamline flow. The stringers of the bridge should be set above the probable flood height to avoid collecting debris as well as for the safety of the bridge. (Photographs page 5-31.)

Significant losses in head at bridges are estimated and taken into account in design. Serious losses may occur if bridges are close together and restrict the flow. A ditch design that fails to take care of such losses may be inadequate.

The following references should be consulted in determining losses in head due to bridges and trestles in drainage channels and floodways:

Pile Trestles as Channel Obstructions, D. L. Yarnell (4)
Bridge Piers as Channel Obstructions, D. L. Yarnell (5).

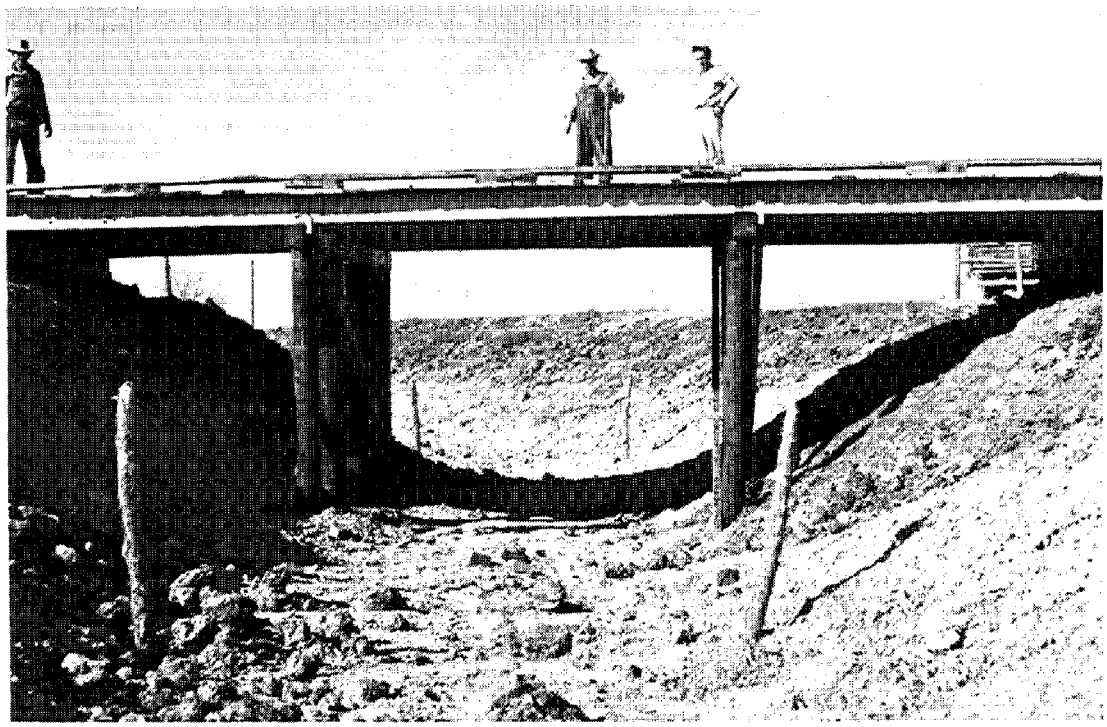
Computing cross section of ditch

Where the cross section of the ditch is based on the required quantity of flow the cross-sectional area is determined from the formula:

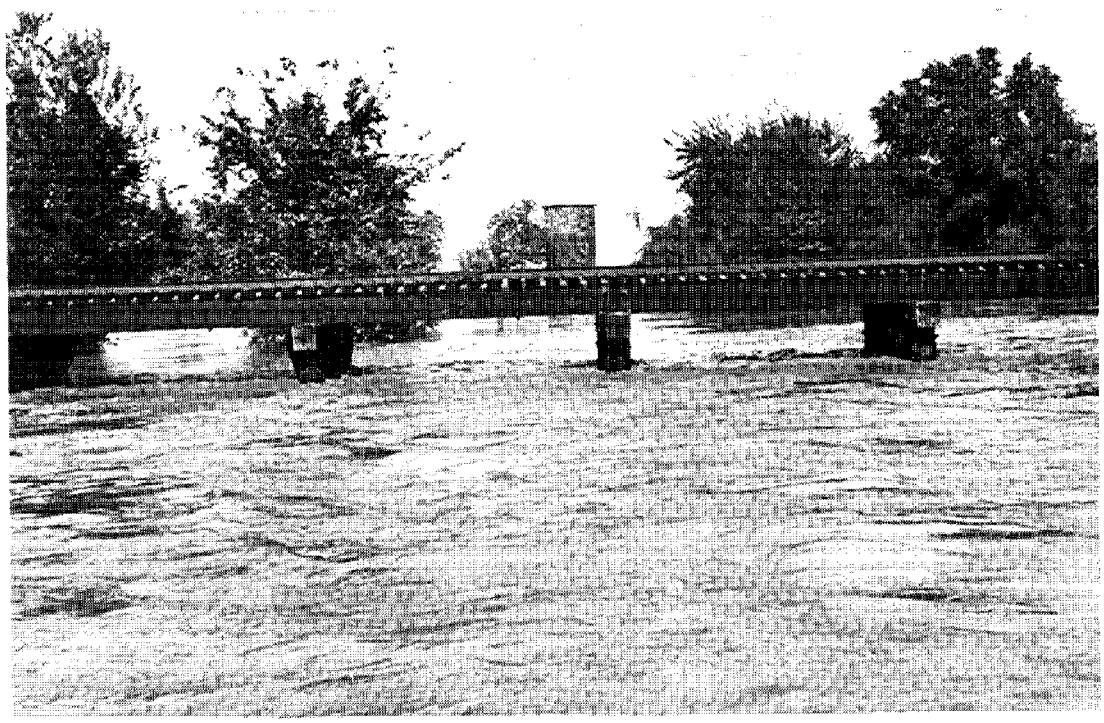
$$Q = av$$

where Q = design capacity in c.f.s.
a = cross-sectional area of ditch below the established hydraulic gradeline in square feet.
v = mean velocity of flow, feet per second, usually computed by use of the Manning formula and the Corps of Engineers' Hydraulic Tables or King and Brater's Handbook of Hydraulics.

In addition to the factors discussed under channel section, page 5-19, the following factors should be considered by the designer in adjusting depth,



Piers are placed on each side of ditch bottom



Stringers are set above the probable flood height

bottom width, and side slopes to obtain the required cross-sectional area:

1. A deeper ditch gives a higher velocity than a shallow one.

2. A deeper ditch may provide a better opportunity for future subsurface drainage in the drainage area.

3. A deeper ditch requires less right-of-way than a shallow ditch.

4. A deeper ditch may uncover unstable layers of soil which a shallow one would not.

5. A shallow ditch may be more practical to maintain by pasturing or by mowing flat side slopes.

Allowance for initial sedimentation

It is good practice to allow for initial sedimentation in a ditch during the first 2 or 3 years after construction. This allowance is to obtain the designed capacity after the ditch stabilizes and is provided by increasing the design size. The amount of this allowance depends on the erosion from adjoining lands, the erosiveness of soils exposed in the ditch, and the sediment from laterals and tributaries. The principal sources of sediment usually are the raw ditchbanks containing sand and silt, cultivated fields, and silt-carrying tributaries. After ditchbanks are stabilized by vegetation, sedimentation decreases.

Various practices in use to take care of initial sediment include the following:

1. Provide increase in depth or bottom width but no increase in top width.

2. Overexcavate the ditch (in depth only) as a construction practice. In some locations this may average 6 to 12 inches and is included in the quantities paid for.

Establishing bottom grade of ditch

The following should be determined in establishing the bottom grade of the ditch:

1. Locate the ditch bottom deep enough so that buried drains can outlet above the expected low flow. The invert elevation of the drains should be at least 1 but preferable 1½ feet above the ditch bottom. Where the bottom grade of the ditch will remain stable the local drainage guide may specify a clearance of less than 1 foot below the invert of the drain. Allow sufficient depth for sediment to accumulate so that a free outlet is possible for at least 10 to 15 years before reconstruction. Too often ditches are designed with little or no thought given to this. Frequently, during the first two years, the bottom grade is raised so much through accumulation of sediment that drains are adversely affected.

2. In arriving at the required depth to provide good drainage, determine the elevation of the distant low areas. Compare this with the

elevation of the hydraulic gradeline at the point where the low area will drain into the outlet. Then starting at the low area with sufficient depth below the hydraulic gradeline for drainage of that area, project a reasonable grade for an open ditch or drain to the outlet ditch. The required elevation of the bottom of a lateral needed to provide drainage for the distant low area can then be determined.

3. To obtain greater capacity at critical points, such as junctions, increase the depth and/or width of the ditch for design purposes. Avoid actual abrupt change in grade by constructing the ditch bottom upstream at a grade which will not result in erosion. A grade-control structure may be required to stabilize the grade if erosive soil, such as loess, is involved.

4. Show the bottom grade on the profile in percent and show the slope of the hydraulic gradeline on the profile as the tangent of the slope.

Design of large open-ditch system

An example of procedures used in the design of a large open ditch is shown in figure 5-7 and in table 5-4.

Figure 5-7 shows the schematic layout of the ditch system. The watershed areas at the upper and lower end of each section and at intermediate points as required are noted. These areas should be determined from maps or surveys.

On large drainage jobs of this kind it is desirable to plot a condensed profile (figure 5-7). For preliminary surveys, elevations of the ground level at 500 feet to half-mile intervals may be used. The low elevations of the fields to be drained and other points should be shown on the profile.

The design and numbering of the ditch may begin at either the upstream or downstream end. The practice used locally by private engineers or drainage districts for numbering sections should be followed since such plans may be used in legal proceedings. In the example (figure 5-7) the station numbering starts at the lower end. The computation of watershed areas and equivalent areas should proceed from the upper end toward the outlet. The elevation of the water in the outlet controls the elevation of the hydraulic gradeline of the ditch at its outlet. In the example, the average elevation for a 24-hour period for a flood of 2-year frequency is 23.7.

In the example, it is assumed the drainage engineer has examined the watershed area and determined the drainage coefficients as outlined previously. $Q = 131\ M^{.7}$ is used to calculate runoff from the hill land and $Q = 45\ M^{5/6}$ is used to calculate runoff from flatland.

The required depth of the ditch is determined at control points for the discharges at these points. This assumes that the runoff throughout the reach enters uniformly. The depth at the beginning and end of the reach will differ. The depths are established below the hydraulic gradeline and the bottom normally will not be parallel to the hydraulic gradeline. At points where concentrated flows enter a change in either depth, width or both may be required.

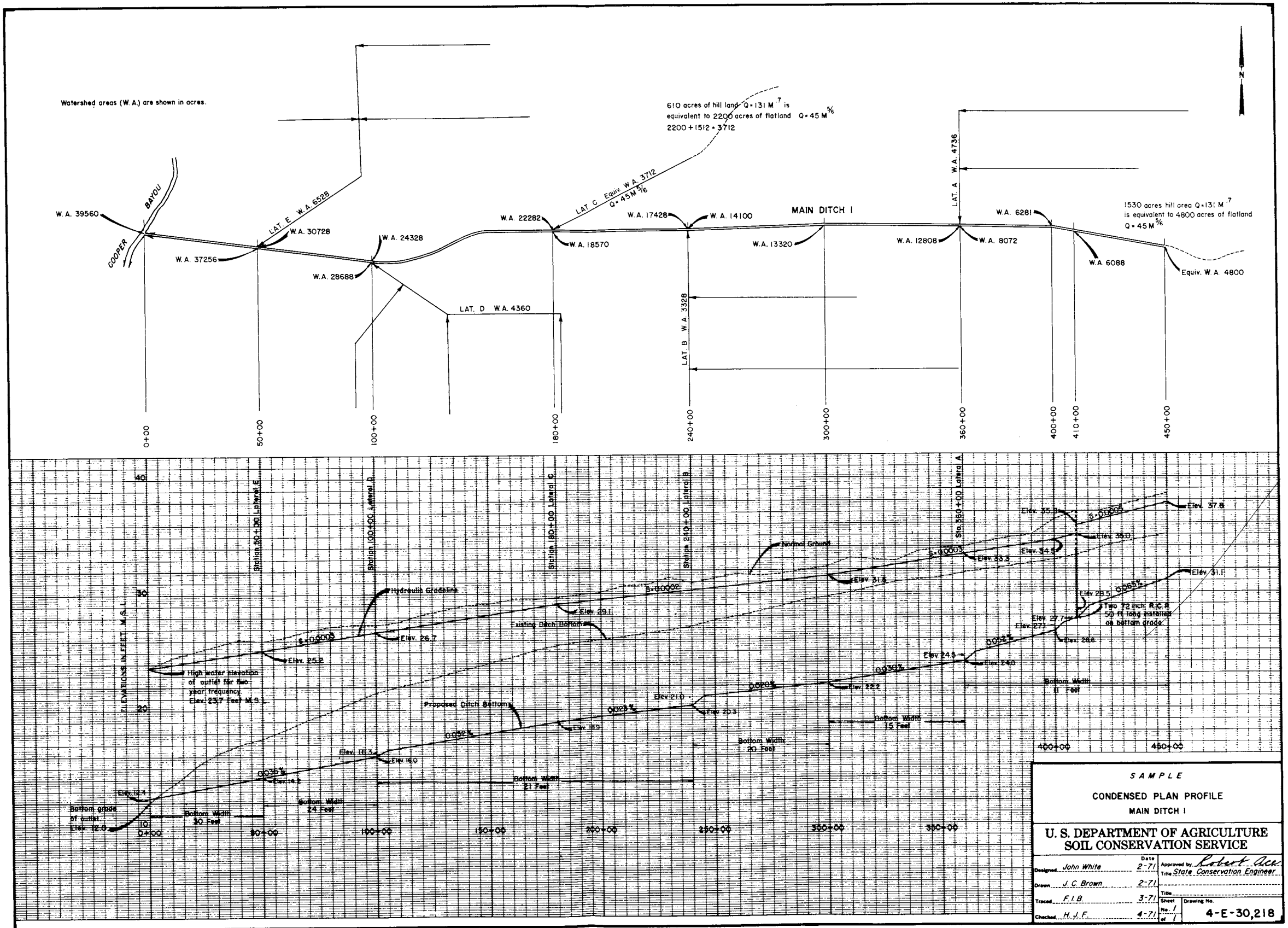


Figure 5-7, Sample--Condensed plan profile

Figure 5-7, Sample--Condensed plan profile

EWP-34F (Rev. 6-68)
Fort Worth, Texas

SAMPLE DRAINAGE DITCH DESIGN

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

SOIL CONSERVATION DISTRICT Middle Delta WORK UNIT Magnolia, La.

COOPERATOR Cooper Drainage District LOCATION Blue Lake PAGE 1 OF 2

SCD AGREEMENT NO. ——— ACP NO. ——— FIELD NO. ———

DESIGNED BY John White DATE 2/10/71 CHECKED BY ——— DATE ——— APPR'D BY ——— DATE ———

Ditch No.	Sta.	Location	Area Acres	Drain Curve	Equ. A. 45 Curve	Runoff % Area	Runoff M'thd	Req'd Q	s	n	s/s	b	d	A	P	r	v	Des'nd Q	H.G. Elev.	Actual d+20% Depth	Actual Bottom Elev.	Actual Bottom Width
1	450+00	Upper end	1530	131	4800			240	0.0005	0.040	1½:1	14	5.6	125.44		3.67	1.97	247.1	37.8	6.7	31.1	11
		As built velocity at bankfull flow								0.025	1½:1	11	7.3	160.23		4.29	3.50					
	410+00	Above culvert	1088	45	5888			285	0.0005	0.040	1½:1	14	6.1	141.22		3.92	2.06	290.9	35.8	7.3	28.5	11
										0.025	1½:1	11	8.0	184.00		4.62	3.69					
		culvert		Q+25	%			354			2-72 inch R.C.P. 50 feet long											
											operating under 0.8 foot head											
											will carry 361 c.f.s.											
	400+00	Above grade change	193	45	6081			295	0.0005	0.040	1½:1	14	6.2	144.46		3.97	2.08	300.5	34.5	7.4	27.1	11
										0.025	1½:1	11	8.2	191.06		4.71	3.74					
		Below grade change						295	0.0003	0.035	1½:1	14	6.6	157.74		4.17	1.90	299.7	34.5	7.9	26.6	11
										0.025		11	8.7	209.23		4.94	2.98					
	360+00	Above Lat A	1791	45	7872			365	0.0003	0.035	1½:1	14	7.3	182.14		4.52	2.01	366.1	33.3	8.8	24.5	11
										0.025	1½:1	11	9.6	243.84		5.34	3.14					
		Lat A	4736	45	4736			240														
		Below Lat A			12608	(37.5)	3	596	0.0003	0.030	1½:1	19	7.8	239.46		5.08	2.53	605.8	33.3	9.3	24.0	15
										0.025	1½:1	15	10.1	304.51		5.92	3.36					
	300+00	Above grade change	512	45	13120			560	0.0003	0.030	use above section								31.5	9.3	22.2	15
		Below grade change						560	0.0002	0.030	1½:1	24	7.8	278.46			2.14	595.9	31.5	9.3	22.2	20
										0.025	1½:1	20	10.1	355.01			2.86					
	240+00	Above Lat B	780	45	13900			580	0.0002		use above section								30.3	9.3	21.0	20
		Lat B	3328	45	3328	(19.3)	(2)															

USDA-SCS FORT WORTH, TEX 1968

Table 5-4, sheet 1 of 2, Sample--Drainage ditch design

EWP-34F (Rev. 6-68)
Fort Worth, Texas

SAMPLE DRAINAGE DITCH DESIGN

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

SOIL CONSERVATION DISTRICT Middle Delta WORK UNIT Magnolia, La.

COOPERATOR Cooper Drainage District LOCATION Blue Lake, La. PAGE 2 OF 2

SCD AGREEMENT NO. ——— ACP NO. ——— FIELD NO. ———

DESIGNED BY John White DATE 2/10/71 CHECKED BY ——— DATE ——— APPR'D BY ——— DATE ———

Ditch No.	Sta.	Location	Area Acres	Drain Curve	Equ. A. 45 Curve	Runoff % Area	Runoff M'thd	Req'd Q	s	n	s/s	b	d	A	P	r	v	Des'nd Q	H.G. Elev.	Actual d+20% Depth	Actual Bottom Elev.	Actual Bottom Width
	240+00	Below Lat. B			17228			700	0.0002	0.030	1½:1	26	8.3	319.13		5.71	2.23	711.6	30.3	10.0	20.3	21
										0.025	1½:1	21	10.8	401.76		6.59	2.95					
	180+00	Above Lat. C	1142	45	18370			740	0.0002	0.030	1½:1	26	8.5	329.37		5.81	2.26	744.3	29.1	10.2	18.9	21
										0.025	1½:1	21	10.8	401.76		6.59	2.95					
		Lat. C	3712	45	3712	(164)	2															
		Below Lat. C	22082					860	0.0003	0.030	1½:1	26	8.5	329.37		5.81	2.77	912.3	29.1	10.2	18.9	21
										0.025	1½:1	21	10.8	401.76		6.59	2.95					
	100+00	Above Lat. D	2046	45	24128			940	0.0003	0.030	1½:1	26	8.7	339.73		5.92	2.80	951.2	26.7	10.4	16.3	21
										0.025	1½:1	21	11.0	412.50		6.80	3.70					
		Lat D	4360	45	4360	(153)	2															
		Below Lat D			28488			1070	0.0003	0.030	1½:1	29	8.9	374.91		6.13	2.87	1075	26.7	10.7	16.0	24
										0.025		24	11.3	426.73		7.14	3.81					
	50+00	Above Lat. E	2040	45	30528			1130	0.0003	0.030	1½:1	29	9.1	388.11		6.28	2.92	1133	25.2	10.9	14.3	24
										0.025	1½:1	24	11.7	486.13		7.34	3.88					
		Lat. E	6528	45	6528	(176)	2															
		Below Lat. E			37056			1330	0.0003	0.030	1½:1	35	9.2	448.90		6.58	3.01	1351	25.2	11.0	14.2	30
										0.025	1½:1	30	11.8	562.97		7.76	4.03					
	0+00	Outlet	2304	45	39360			1400	0.0003	0.030	1½:1	35	9.4	461.54		6.69	3.04	1403	23.7	11.3	12.4	30
										0.025	1½:1	30	11.3	530.53		7.49	3.93					

Field examination indicates that ditch excavation will be in CL to CH material with plasticity indexes over 20.

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Table 5-4, sheet 2 of 2, Sample--Drainage ditch design

Design sheet table 5-4 illustrates several points. At station 450+00 there is a contributing watershed area of 1,530 acres of hill land to which the curve developed from $Q = 131\ M^{.7}$ applies: Since the majority of the watershed is flatland the ditch will be designed on the curve developed from $Q = 45\ M^{5/6}$. This calls for an initial conversion to an equivalent area as follows: Enter figure 5-5 with 1,530 acres, intersect the runoff curve developed from $Q = 131\ M^{.7}$ and read a discharge of 240 c.f.s. Using this discharge draw a horizontal line and intersect the curve developed from $Q = 45\ M^{5/6}$; from this point draw a vertical line to the watershed in acres and read the equivalent area of 4,800 acres.

Above the culvert at station 410+00 we have 5,888 acres drainage area. This gives 285 cubic feet per second runoff on the curve developed from $Q = 45\ M^{5/6}$. This is a farm road crossing and some flooding at the culvert can be tolerated. The culvert is given a safety factor of 25 percent and this applied to the runoff at the culvert gives a Q of 354 c.f.s. To pass this amount of runoff through two 72-inch reinforced concrete culverts 50 feet long will require a head loss of 0.8 foot. In the example figure 5-7, this head loss is shown by dropping the hydraulic gradient 0.8 foot on the lower side of the culvert. The culvert is planned to be installed on this bottom grade.

In combining the flow of laterals the 20-40 rule should be used. One example is station 360+00 where the watershed of the main ditch above the station is 7,872 acres and the watershed lateral is 4,736 acres. The watershed area of lateral A is 37.5 percent of the total watershed area. The application of the 20-40 rule gives 596 c.f.s. for design flow below station 360+00.

The drainage area above lateral B at station 240+00 is 13,900 acres and the watershed of lateral B is 3,328 acres. The watershed of lateral B is 19.3 percent of the total watershed. Since the watershed of lateral B is less than 20 percent of the total watershed, the design flow below station 240+00 is based on the total watershed area of 17,228 acres. Laterals C, D, and E all have watersheds less than 20 percent of the total area and are all handled similar to lateral B.

Auxiliary Structures and Practices

The hydraulics and design of structures are discussed in NEH, Sections 5, Hydraulics, and 6, Structural Design. The following covers application and use of structures for open-drainage ditches. State handbooks should include typical plans and standards for design and installation of auxiliary structures and practices.

Pipe drops, chutes, drop spillways, and other suitable structures need to be installed where necessary to prevent serious erosion where surface water enters a ditch or where a shallow lateral joins a deep main. Grade control structures sometimes are required to stabilize the bottom grade of drainage ditches.

On drainage ditches in cultivated or pasture land the spoil usually should be spread and suitable vegetation established on the banks, berm and spread spoil. Where the ditch is in or adjacent to land which has been graded or leveled, or is surface irrigated, the spoil should be used for roads or worked into the grading plan for the field. Local technical guides should cover the best ways to establish suitable vegetation in drainage ditches, and on berms and spoil area.

Riprap, revetment, and other measures for controlling ditchbank erosion are frequently required. Ramps are used to protect the ditchbanks where ditches are open to pastures and livestock. Watergates are needed where fences cross ditches.

Junctions of lateral ditches

Where there is a significant drop from a lateral to a main ditch or other outlet, the lateral should be cut back on a level grade as specified and then graded back on a slope. This recessed area is to store sediment and protect the outlet ditch until the lateral stabilizes. Satisfactory results may usually be obtained by excavating the lateral on a grade level with the bottom grade of the outlet for a distance of 50 to 300 feet; then use a bottom grade out of the recessed area of from 0.5 to 1.0 percent until it intersects the normal bottom grade of the lateral. Where the drop from the lateral to the main is too great to control by the above method, structural protection must be provided.

In many areas, where irrigation waste water flows into open ditches, the accumulation of waste water from several fields may constitute a small but steady flow for as much as 90 days or more. This flow is comparable to perennial flow. Where soils are erodible it is essential to provide proper surface water inlets at points where waste water flows into deep drains.

State drainage guides should cover dimensions of level grades, maximum grade, and vegetative or structural protection necessary for various ditches, drainage areas, and soils.

Overfall pipes and structures

Pipe drops, drop spillways, chutes, and sod flumes are the usual measures used to drop surface water and flow from shallow field ditches into deeper open ditches. Unless effective measures are installed, rapid erosion of ditchbanks and rapid sedimentation of the ditch are likely to occur. In installing any overfall structure a minimum amount of excavation should be done at the structure. This reduces the backfill. There must be no seepage along or under a pipe or other overfall structure.

Sometimes it is more economical to construct a lateral ditch to collect surface runoff from several fields or lateral ditches and to drop the water into an open ditch at one point instead of installing several overfall pipes or structures at each of the field or lateral ditches. Such collecting ditches may parallel the spoil bank and should not interfere with cultivation.

To drop surface water from the land side of spoil banks into drainage ditches or from small laterals into deeper ditches, pipe drops may be used advantageously. Where an open ditch passes through an area of flatland having poorly defined drainage, surface water from the adjacent land may usually be handled by standard pipe-drop inlets. These inlets should be placed at the low points along the ditch. This may require a half-dozen or more structures per mile of ditch.

Pipe-overfall structures need to empty into areas recessed in the banks of the open ditch. This is particularly important if the ditch periodically carries heavy debris or ice. When installed in this manner, the pipes will not likely

be damaged by the movement of floodwater, debris, or ice in the outlet ditch and will not retard the flow in the ditch. (Photographs page 5-42.)

The outlet end of a pipe-overfall structure may extend a short distance over the embankment without support (cantilever installation). The cantilever section should be a minimum where subject to the flow of ice or debris in the ditch. Where debris and ice are not likely to damage corrugated metal, this type of pipe may be cantilevered without support as much as 10 feet. Where the cantilever length is greater than the allowable span for the ultimate load at the end of the pipe, the pipe should be supported. This may be done with two posts and a cross member or on a post and cradle set beneath the pipe. When not supported, it is well to extend the pipe into the bank a minimum distance of twice the overhang. To prevent excessive undercutting, the cantilever section generally should be not less than 4 feet.

Pipe-overfall structures may be installed with standard inlet sections or with reinforced concrete headwalls and wingwalls to give more stability. Antiseep collars along the pipe should be used where needed. Installing pipe-overfall structures on fills should be avoided wherever possible. All joints should be watertight.

The pipe should be well bedded. The bottom part of the excavation should conform to the shape of the pipe. Accurate shaping of the trench should extend up the sides of the pipe to a point where the backfill can be easily reached with a hand or mechanical tamper.

Careful tamping of the backfill by hand or a mechanical tamper should be specified. The soil used for backfill should contain sufficient moisture to insure high density when compacted. The backfill should be mounded over the pipe in such a way as to prevent surface wash along the pipe.

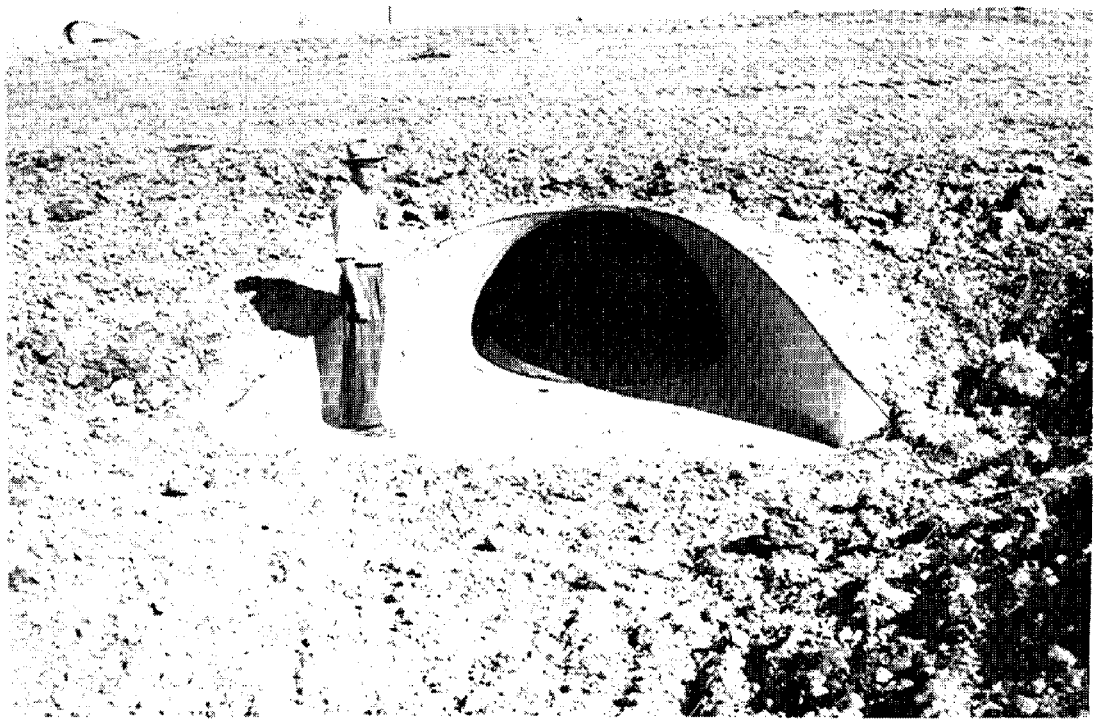
Hydraulic design of "island-type construction"

Pipe drops and overfall structures ordinarily should be of a capacity in excess of the design discharge of the drainage ditch. A capacity 25 percent greater than the design capacity of the drainage ditch is often used. Floodflows in excess of drainage flow may be bypassed over vegetated emergency spillways along the spoil bank. The spillway areas should be placed upstream and downstream from the drop at approximately 25 to 50 feet from the structure. Fill should be placed above the flood stage around the wingwalls of drop structures and pipe drops, and sodded to protect the structure. This installation is called the "island-type construction." Floodflows may need to be stored temporarily behind the spoil or dike when it is not possible to bring them safely back into the channel.

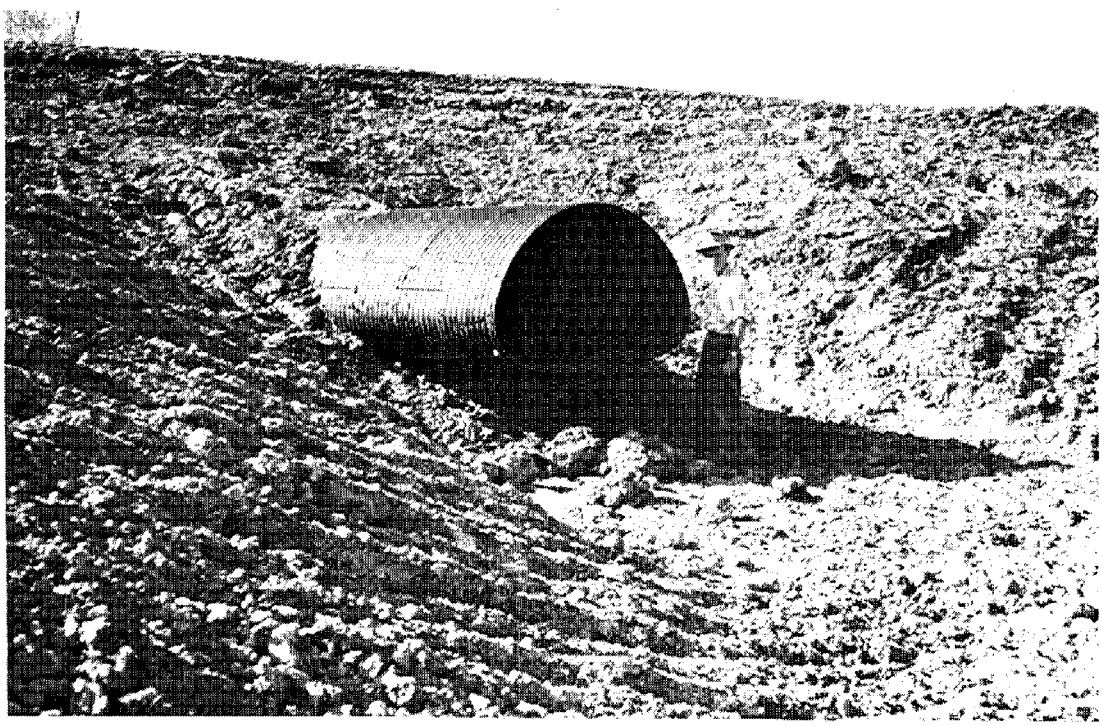
In some cases the island-type design is not applicable and the capacity of the structure may need to be large enough to pass the flow from a desired frequency storm.

Drop spillways

The design of drop spillways is covered in NEH, Section 11, Drop Spillways. Frequently drainage ditches fill with sediment, and the downstream toe of a spillway rests on a stable grade. Design requirements may be less exacting as a result of a stable or aggrading channel.



Prefabricated entrance section on pipe drop



Recessed area at outlet of pipe drop

Concrete drop spillways usually are more costly for initial installation than pipe drops with vegetated spillways, and their use is limited in drainage work to exceptional conditions often involving a combination drop spillway and drain-outlet structure.

Chutes

Under some conditions reinforced concrete chutes may be more economical than drop spillways. Each chute requires a detailed plan. The design of chutes is covered in NEH, Section 14, Chutes.

Sod chutes

Under favorable conditions, sod chutes instead of a structure may be used to drop water into open ditches. Conditions favoring sod chutes include low drops, small drainage areas, ditchbanks having a fertile soil and subsoil, a climate and soil that support a dense grass and sod, and the absence of layers of soil that erode readily.

Grade-control structures

Where the velocity is excessive in open ditches, grade-control structures may be required. Occurrence of serious erosion after construction of drainage ditches cannot always be predicted. In large and important drainage work where serious erosion may occur, an on-site study is made of the factors affecting erosion and causing sedimentation. Similar drainage ditches should be studied to determine the probability of excessive erosion. Many drainage channels in loess and noncohesive or poorly graded soils have eroded and caused extensive damage.

Use of grade-control structures often may be avoided by adjusting the hydraulic gradeline or the bottom grade of the open ditch. On sections of the ditch having considerable slope, it may be possible to depress the hydraulic gradeline at the upper end of the reach and raise it at the lower end to obtain a nonerosive velocity. This usually involves added excavation, and any extra cost is balanced against cost of other means for grade control.

It should be remembered the velocity is influenced by three factors: (1) Grade of the ditch, (2) the value of "n", and (3) hydraulic radius. The designer has limited control over the grade of major channels except by adjusting the hydraulic gradeline. However, he may locate a longer meandering channel and reduce the average fall.

State and local guides should indicate the physiographic areas and soils subject to accelerated erosion that may require grade-control structures in open ditches. These guides should prescribe maximum velocity for specific soil types where there is information to substantiate velocities that exceed those allowable in T.R. 25.

Culverts and bridges

Wherever possible, bridges should be used in open ditches designed to capacity on low gradients in preference to culverts that offer serious resistance to the flow of water. However, culverts are economical near the upper ends of open ditches carrying a small flow. Culverts are generally used in many drains for western irrigated land where there is excess grade and small flow in deep

ditches. Culverts permit the installation of many economical farm-road crossings where more costly bridges could not be justified.

Culverts and bridges for state and county highways usually are constructed under the supervision and to the specifications of the state or county highway departments. Wherever appropriate, personnel of the Soil Conservation Service engaged in drainage design should explain the drainage requirements to state and county highway engineers responsible for such structures.

Failure to maintain ditches can cause culverts to fill rapidly with sediment. Where new road culverts are being installed, depth and capacity should be checked against drainage requirements. It is important to maintain the depth and capacity of these open ditches.

Culvert depth

The bottom grade of the upstream end of a culvert should be flush with the design bottom grade of the open ditch or possibly a few tenths lower. The upstream end of the culvert may be higher than the lower end or it may be level throughout its length.

If the bottom grade of the culvert is above the bottom grade of the ditch, it will back up water at low stages and cause rapid sedimentation in the ditch above the culvert. The bottom grade of the culvert should be based on future drainage requirements. A culvert set at the grade of a shallow ditch may be too high when the ditch is cleaned out or enlarged.

Watergates, cattle guards and ramps

Where applicable, plans for open ditches should include plans for watergates and ramps to be installed as aids in pasturing and to protect the ditches. (Photographs page 5-45.) Ramps should not be installed on the outside of curves or in low places where water will flow through them.

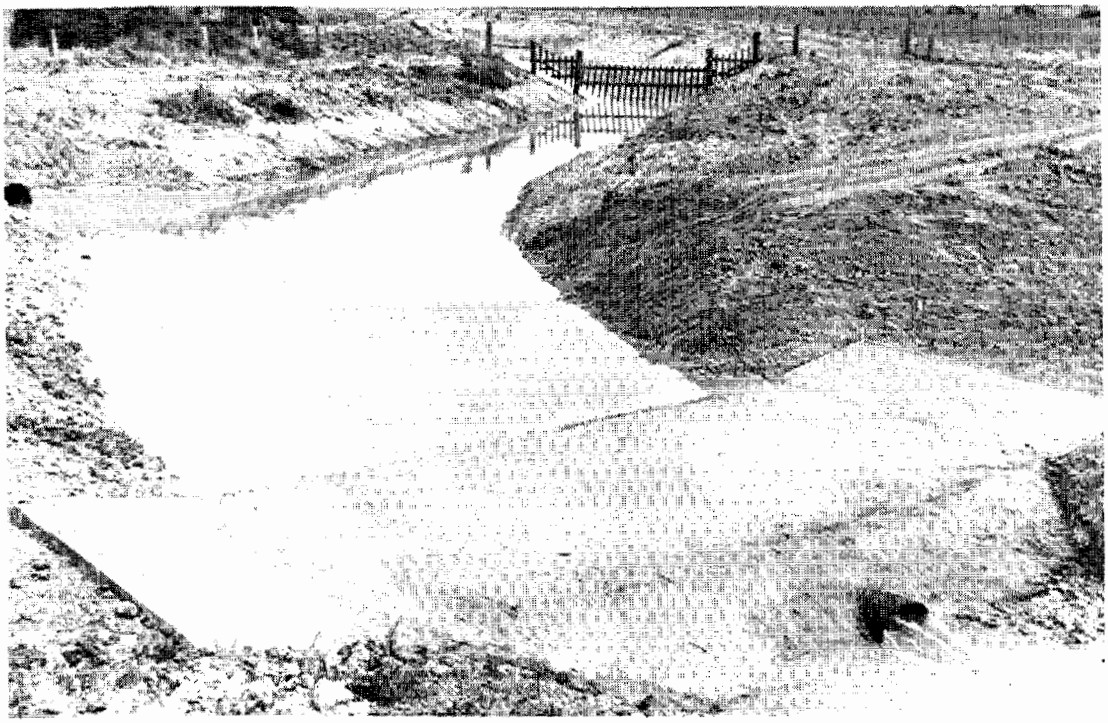
Construction Plans

General

Construction plans for drainage work usually form the basis for a contract. They must be clear, complete, and specific. They are often used by other agencies, private engineers, and individuals long after construction. They should be neat, reflect sound design, and be a credit to the Soil Conservation Service. All separate items of the plan should be identified with the name of the job(s), landowner(s), and location of farm(s). The scale used should be shown. The signature of the designer and the approving engineer and the date of signature should appear on all drainage plans.

Construction plans for individual farm ditches usually include:

1. Drainage plan map
2. Profiles
3. Cross sections
4. Ditch designs



Low water crossing, watergate and pipe drop

Watergate showing hinged section

5. Structural details

6. Specifications

The plans should be discussed with the landowner or his representative to make sure he fully understands the proposed work. Cost estimates should be provided on request. Maintenance also should be discussed, and methods of maintenance and location of a travelway agreed upon.

The maintenance plan for group jobs should show an annual maintenance schedule and the practices to follow. It should cover details for carrying on maintenance operations and for periodic inspection. The method for payment of maintenance costs needs to be agreed upon and included in the group agreement when a group job is involved.

Drainage plan maps

Drainage construction plans for large jobs should include a map of the proposed improvement. The completed map should show the location of proposed ditches, bridges, culverts, farm boundaries, and names of owners where necessary, watershed boundaries and areas, existing land use, irrigation facilities, nearby towns, roads, railroads, township and section lines, and other features affecting the design, construction, and maintenance of the planned improvements.

On many jobs it is convenient to show the detailed plans on standard plan-profile sheets. Where this is done, the scale for the plan should be the same as horizontal scale used in plotting profiles. In such cases a general location map should be included to show the general layout of the system and to index plan-profile sheets. This map should show the entire watershed area within which the drainage-problem area is located.

Profiles

Plans for all ditches of the drainage system down to farm laterals should include profiles. The completed profiles should show the following:

1. Normal ground line and elevation of isolated low points in the field which the ditch will drain

2. Existing ditch bottom

3. Hydraulic gradeline

4. Proposed ditch bottom

5. Existing and proposed culverts, flumes, and other structures, and proper identification of each structure. Also note if an existing structure is to be removed

6. Points of entry of significant ditches

7. Elevation of high water for design storm at outlet

8. Width of ditch right-of-way to be cleared - notation by reaches

9. Datum used and description of important bench marks

10. Logs of soil borings

11. Elevations of water table and dates of reading if encountered in the soil borings.

Profiles should be plotted on standard-size, transparent, profile or plan-profile paper.

Cross sections

The number of cross sections required depends on the variations in cross section of existing ditches and on uniformity of topography along the proposed ditch location. The manner of payment also governs this.

Cross sections of proposed ditches are superimposed on original cross sections and the amount of excavation computed. At least one typical ditch cross section should be shown on construction plans.

Where the land surface is reasonably uniform the depth for new ditches may be obtained from the profile and excavation computed from yardage tables. Typical cross sections are plotted directly on the profile sheet when yardage is computed from tables or by computer from field notes. For others, cross sections should be plotted on standard-size transparent cross-section paper.

Soil borings

Sufficient soil profile information should be obtained through soil borings to locate any unstable soil conditions that may exist along the planned ditch route. It may be possible to reroute the ditch to bypass the unstable area.

Ditch-design calculations

The calculations made for the design of all ditches of the drainage system should be recorded on a standard ditch-design sheet and made a part of the plans. (Table 5-4.)

Structure details

Usually the structures for small to moderate-size drainage projects will be of standard size and design. For these, a copy of the detail design should be obtained and included in the plans. If a structure is to be designed by another agency, it may be so noted on the profile or plan map and the required elevation of the invert, or flow line, and the minimum capacity required should be specified.

If a structure is not standard and plans are prepared by the Soil Conservation Service, a set of plans and specifications should be included.

Plans for structures such as bridges, culverts, chutes, flumes, floodgates, drop structures, watergates, levees, dikes, and pumping plants, which are a required part of the drainage project, should be included. For bridges and culverts to be used for public roads, size, and the invert and road elevations are all that need to be shown.

Specifications

Written specifications are prepared for each item in a job proposal and standard specifications are desirable for the more common types of work.

On contract work along with the plans specifications become a part of the contract. On force account work they should be used by the person in charge of the job to insure that construction is in accord with the plan and required standards.

Specifications need to be detailed enough so there can be no reasonable misunderstanding as to the type of job desired. Nonessential details should be omitted.

Each work unit engaged in open ditch drainage work should have available standard specifications for the following items of construction.

1. Clearing
2. Clearing and grubbing
3. Channel excavation
4. Spoil bank spreading
5. Structure excavation
6. Concrete culvert pipe
7. Installation concrete pipe conduits and drains
8. Zinc-coated iron or steel corrugated pipe
9. Aluminum alloy corrugated pipe
10. Installation corrugated metal pipe conduit
11. Concrete
12. Steel reinforcement
13. Seeding ditchbanks

Maintenance of Open Ditches

Open ditches rapidly lose their effectiveness unless they are properly maintained. A good maintenance program is just as necessary as proper design and construction. Drainage systems often become clogged with uncontrolled growth of vegetation and partially fill with sediment soon after installation. Since maintenance is so important for successful drainage, every effort should be made to work out a maintenance program with the drainage enterprise, group, or landowner responsible for the system.

Responsibility for maintenance

The owners and elected officials of drainage projects must assume the responsibility for planning, financing, and execution of needed maintenance of the drainage improvements. Their investment in the improvements will be repaid by benefits from the project only if it is maintained over the years to function as planned. Training in maintenance requirements and methods should be provided to owners and sponsors of drainage projects.

Experience has shown that successful maintenance of group drainage projects requires:

1. An organization with authority to collect necessary funds.

2. Adequate funds on hand to start operations as soon as the project is accepted from the contractor.

3. A manager to direct maintenance operations.

The need for proper maintenance is especially important during the first two years after a ditch is constructed. It is desirable to establish adapted grass for erosion control on the ditchbanks as soon as possible. And during the first year or two the ditchbanks are especially susceptible to the growth of undesirable woody vegetation. Timely maintenance during this period will lessen the work needed later.

In cooperating with informal groups it is especially important to provide a written plan of maintenance, which covers maintenance requirements, methods of maintenance to be used and cost estimate. An adequate travelway supported by right-of-way easement should be provided.

In providing assistance to individual owners on open ditches a definite plan of maintenance is worked out and included in the conservation farm plan. Emphasis should be placed on practical and economical methods that maintain the effectiveness of open ditches.

Practices that reduce the need for maintenance should be given full consideration. A number of such points are included in the section on design. Others that have proved worthwhile include:

1. Developing farm conservation plans with landowners and operators to obtain best land use and erosion control practices on the area served by the system.

2. Installing erosion control measures in the watershed such as grade stabilization and critical area treatment.

3. Early establishment of erosion-controlling vegetation on ditch right of way.

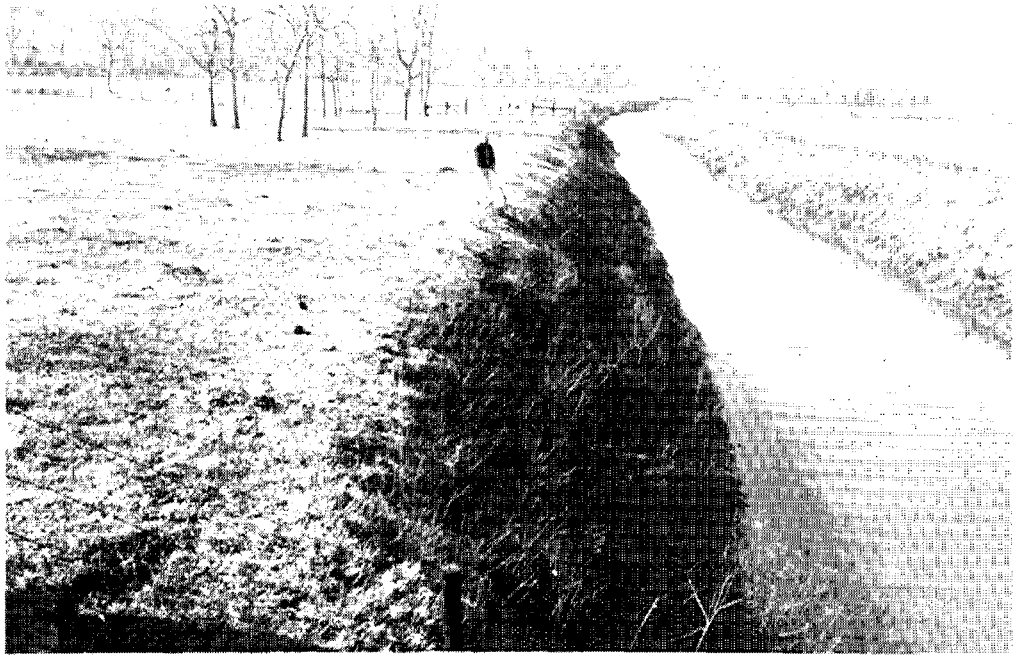
Working out a maintenance plan

Maintenance work includes control of vegetation by mowing, pasturing, or chemicals, timely removal of sediment bars as they form, removing sediment after a few years accumulation, repairing structures, and doing such other work as necessary to retain the original effectiveness of the systems.

The following are some of the major considerations in working out a plan for maintenance:

Past history of maintenance
Knowledge of past maintenance efforts, or lack of them, should be available in the area. Maintenance methods which have been successful should be good guides in developing maintenance plans for similar work.

Economics of maintenance
A maintenance program must be effective or it cannot be justified economically. If ditches are allowed to be overgrown with brush and small trees they may have only one-half to two-thirds of the designed capacity. Land suffering from poor drainage produces poor crops and the cost/benefit ratio calculated to justify the drainage system will not be reached. Maintenance must be carried out effectively for the drainage system to operate as planned.



Channel with established vegetation and good maintenance

Methods of maintenance
Using construction equipment for maintenance. - Usually the same equipment used in construction can be employed economically for removal of sediment and reshaping of spoil at intervals as needed after construction. The high cost of hand labor and difficulties in obtaining effective maintenance work by hand-tools emphasize the need for efficient equipment for maintenance work.

Mowing. - Mowing is effective in most locations in the humid areas for controlling brush and encouraging grass on ditchbanks, travelways and spoil disposal areas. Rotary mowers mounted on booms extending from tractors can handle 1½:1 side slopes with no particular hazard. Highway-type mowers on which the blade can be raised or dropped by 45 degrees are generally well adapted to ditch maintenance work. For maintenance by mowing with standard farm equipment 4:1 or flatter side slopes are preferable.

Pasturing. - Controlled pasturing is one of the most economical and effective methods of maintaining ditches. In some locations pasturing is not practical because of the type of farming adjoining the ditches. Pasturing should be controlled to keep cattle off ditchbanks during freezing and thawing and wet weather. Hogs should be kept out of ditches. A good pasture arrangement usually requires carefully placed gates and fences with watergates across ditches.

Burning undesirable vegetation. - In some locations controlled burning in the winter is useful to remove dead weeds, tall grass and small brush. This type of maintenance should be limited to channels through open areas and must comply with local antipollution regulations.

Chemical control of vegetation. - Chemicals to control undesirable vegetative growth have produced some excellent results. Caution should be used in their application to prevent damage from the drifting chemicals. Information on appropriate chemicals usually may be obtained from local dealers. Major chemical companies have prepared information relative to usage of specific products.

The most up-to-date information available, including data on new herbicides, should be followed.

Federal, State and local laws and regulations governing use of chemicals must be followed.

REFERENCES

(1) STEPHENS, JOHN C., and MILLS, W. C.
1965. Using the Cypress Creek Formula to Estimate Run-off Rates in the Southern Coastal Plain and Adjacent Flatwoods Land Resource Areas. U. S. Dept. of Agriculture, ARS-41-95.

(2) KING, HORACE WILLIAMS, and BRATER, ERNEST F.
1963. Handbook of Hydraulics, Fifth Edition. McGraw-Hill Book Company, Inc., New York.

(3) BUREAU OF PUBLIC ROADS
1965. Hydraulic Charts for the Selection of Highway Culverts. Hydraulic Engineering Circular No. 5. U. S. Government Printing Office, Washington, D. C. 20402.

(4) YARNELL, DAVID L.
1934. Pile Trestles as Channel Obstructions. U. S. Dept. of Agriculture, Tech. Bul. 429.

(5) _____
1934. Bridge Piers as Channel Obstructions. U. S. Dept. of Agriculture, Tech. Bul. 442.