## Chapter Six

## DRAINAGE AND EROSION CONTROL

Surface runoff water is a serious threat to both the physical integrity and the serviceability of highway facilities. There is need to make certain that runoff water is adequately controlled so that it may pass through and be removed from the roadway area without damage to the roadway or adjacent properties.

Drainage design has two principal objectives: (1) to determine the amount of design storm runoff that can be expected at various points along the roadway, and (2) to determine the most appropriate type and size of facility that will effectively handle the estimated quantities of runoff. Guidelines and procedures are presented in this chapter for both of these objectives. The figures referred to in the text are presented at the end of the chapter.

### General Policies and Criteria

Several basic policies, procedures and criteria have been adopted by the Department with regard to drainage design. These are described in the following paragraphs.

#### Design Responsibilities

Responsibilities for drainage design are divided between the Bridge Design Section and the Road Design Section -- based principally on the size of the drainage area involved and the type of structure to be provided.

The Bridge Design Section is responsible for:

- all locations requiring bridges,
- all concrete box culverts, and
- all drainage areas in excess of 300 acres.

The Road Design Section is responsible for:

- all locations with drainage areas up to 300 acres,
- storm sewer systems,
- open drain systems, and
- subsurface drainage.

Design of bank and channel protection should be performed by the unit responsible for design of the drainage structure.

## Storm Design Frequency

The expected intensity of rainfall is a critical factor in drainage design. Normally, the intensity is measured in terms of inches per hour. Predicting the intensity of rainfall should be statistically based on actual recorded data over a considerable period of time.

Analysis of these data provides a reasonably realistic base for predicting the the maximum rainfall that might occur during design periods of various lengths of time. Statistically, the runoff resulting from a maximum storm during a 100-year, 30-minute storm will be greater than the runoff expected if only a 50-year, 30-minute storm is considered. For periods of 25 years or 10 years, the runoff from a maximum storm will probably be even less.

This approach gives an indication of what to expect. However, a 100-year storm might occur during the first 10 years of a design period. Another way of expressing the likelihood of a particular size storm is in terms of probability (expressed as a percentage) that the storm might occur in any one year. The probability that a 100-year storm may be exceeded is 1 percent for

any given year. At the other extreme, there is a 10-percent probability that a 10-year storm may be exceeded in any given year.

The reasons for the concern about probability are economics and serviceability. A drainage structure designed for a 100-year storm will be much larger and more expensive than if it was designed for a 10-year storm. The extra cost of the larger structure must be compared with the potential damages resulting from occasionally exceeding the capacity of the smaller structure.

To establish uniformity and consistency, the Department has established several basic criteria for storm design frequency for particular situations. These are shown in Figure 6-8. These criteria represent guidelines for general application. Normally they should be used. However, unique local conditions or the permit requirements of other agencies may suggest use of a different design frequency at specific locations.

This is particularly true where the installation involves encroachment on an established flood plain. Such flood plains in Delaware are identified in a series of maps published by the Federal Emergency Management Agency (FEMA) for administering the National Flood Insurance Program. For projects within the established flood plains, designers shall always prepare a preliminary assessment of the potential effects of encroachments. Figure 6-9 shows an example form for documenting such assessments. Refer to "Procedures for Coordinating Encroachment on Flood Plains with FEMA."

## Risk Analysis

When a preliminary assessment of local conditions indicates that alternative storm design frequencies should be considered, a formal risk analysis should be performed.

For example, a large and expensive drainage structure, designed to the prescribed storm design frequency, might be re-evaluated. What would be the consequences (both economic and environmental) of accepting a shorter design period and reducing the size of the structure? Is it worth the risk?

On the other hand, some areas adjacent to the highway facility may have a significant amount of critical and costly development. What risk is taken by using the adopted standard policy for the storm design period? Would it be justified to select a longer storm design period at this location, even though construction costs would be increased?

General policies and procedures for risk analysis are set forth in FHPM 6-7-3-2. A flow chart showing the procedures for compliance with waterway and flood plain management regulations is presented in Figure 6-10.

## Minimum Sizes of Culverts

Department policy has established minimum sizes of culverts for particular installations -- even though these sizes may have capacity exceeding the design discharge requirements. The minimum permissible size for open-ended pipe culvert cross drains is 18". For all other pipe culvert installations for surface drainage (side drains, median drains, etc.) the minimum size is 15". The purpose of the minimum size is to facilitate pipe cleaning maintenance operations.

## Documentation of Drainage Analysis

Designers must prepare drainage analyses for all projects and must maintain appropriate records of all drainage analyses performed. Standard forms have been prepared to facilitate the documentation. Examples are shown in following sections of this chapter. These forms, along with any supplementary worksheets and sketches, should be made a part of the permanent project file.

## Surface Runoff Determination

A first step in drainage design is to estimate the surface runoff (or design discharge) at the location under consideration. Numerous factors influence this estimate, including (1) the rainfall intensity for a selected storm

design frequency, (2) the size of the drainage area, and (3) the characteristics of the drainage area.

Two alternative estimating techniques have been adopted by the Department. The method to be used depends on the size of the drainage area.

1. The Rational Method is used for relatively small drainage areas (up to 300 acres).

2. The U.S.G.S. Method is used for larger drainage areas (over 300 acres).

Each of these two methods is described in the following sections.

## Rational Method

The Rational Method uses an empirical formula relating rainfall to runoff. The formula is simple to use and is generally accepted as reliable for relatively small drainage areas. Because the formula assumes that the rainfall is of equal intensity over the entire drainage area, its use should be limited to drainage areas of up to about 300 acres.

The Rational Formula is given as:

$$Q = C\ I\ A$$

where $Q$ = discharge in cfs;
$C$ = runoff coefficient;
$I$ = average rainfall intensity in inches per hour for the selected frequency; and
$A$ = drainage area in acres.

The formula is based on the approximation that one inch of rainfall per hour per acre equals about one cubic foot per second, if $C = 1$. Thus, the calculation of Q is in terms of c.f.s.

The drainage area (A) is calculated in acres and usually can be measured from one or more of the following sources:

1. plans and actual field measurements,
2. interpretation of aerial photographs,
3. contour plans, and
4. U.S.G.S. maps.

The runoff coefficient (C) may be described as the percentage of the water falling on a given drainage basin that flows off directly. This value is expressed as a decimal and considers the following factors:

1. penetration and absorption by the soil and vegetation,
2. topography and slopes,
3. storage due to ponding, swamps, etc., and
4. evaporation.

These coefficients may vary from 0.10 (10%) in open sandy areas to almost 1.0 (100%) on paved surfaces. Values for C are shown in Figure 6-11. This table considers topography, vegetation and soil -- but does not consider storage due to ponding. The choice of a coefficient must be based on experience and judgment, using the table as a guide. The designer must also consider adjustments for possible changes in runoff characteristics due to land use.

The rainfall intensity (I) is dependent on the storm design frequency, the duration of the storm and the time of concentration. The time of concentration (Tc) is the overland flow time to the inlet plus the time in the drainage facility. The maximum flow at the point will occur when all points in the area are contributing runoff to the point at the same time. This maximum condition can occur only when the duration of the storm is equal to or exceeds the time of concentration. The time of concentration thus identifies the appropriate duration to be used in determining rainfall intensity.

The time of concentration for overland flow can be determined by either of two methods: (1) the nomograph shown in Figure 6-12, or (2) the equation shown below.

$$Tc = \left(60\sqrt[5]{\frac{A^2}{100S}}\right)\left(\frac{L}{5280\sqrt{\frac{4A}{\pi}}}\right)$$

where A = area in square miles;
S = slope in ft. per ft.;
L = length of drainage area in feet; and
Tc = time of concentration in minutes.

With the time of concentration established, the rainfall intensity can be determined from the appropriate Rainfall Intensity-Frequency Curves (Figures 6-13, 6-14, and 6-15).

When the values for C, I and A have been established, as described above, the design discharge is computed using the formula Q = C I A.

## U.S.G.S. Method

For drainage areas of more than 300 acres, the U.S.G.S. Method should be used for determining the estimated surface runoff. Reference is made to the U.S.G.S. publication entitled "Techniques for Estimating Magnitude and Frequency of Floods in Delaware." The report was prepared in cooperation with the Delaware DOT and FHWA and was published in September 1978.

The technique was developed from extensive flood-discharge records at 60 gaging sites. From these data, equations were developed for estimating runoff at both gaged streams and ungaged streams. Separate equations are developed for northern and southern regions of the State, based on physical basin characteristics of each region.

It is not practical for this manual to attempt to reproduce all of the charts, tables, equations and explanations shown in the U.S.G.S. publication. Copies are available in the Office of Preconstruction Engineering. Designers

should refer to and utilize the U.S.G.S. report for determining estimated surface runoff for the larger drainage areas.

## Culvert Pipe Size Determination

After the design discharge has been identified, steps can be taken to determine the proper size of pipe culvert. The Department has adopted the procedures for pipe sizing set forth in Hydraulic Engineering Circular No. 5, "Hydraulic Charts for the Selection of Highway Culverts" (FHWA, 1965).

The publication is quite comprehensive, with detailed explanations of the hydraulic concepts and step-by-step procedures for determining pipe sizes at specific locations with consideration of variable conditions. Therefore, the information and charts are not duplicated in this manual. Reference is made to Hydraulic Engineering Circular No. 5 for pipe size determinations and to Hydraulic Engineering Circular No. 13 for improved inlets.

The procedures described above do not apply to sizing of pipe for storm drain systems. Practices for storm drains are discussed in a following section on storm drain design.

## New Castle County Stormwater Management

It is pointed out that New Castle County has adopted special standards and criteria for Stormwater Management as documented in the publications "Stormwater Management" and "Specifications Guide for Sediment and Erosion Control," dated June 1977.

The purpose is to assure the application of planning, engineering and constructon principles to control the quantity and quality of storm runoff. Stormwater detention techniques (detention ponds, dry detention areas, rooftop ponding, parking-lot ponding, etc.) are prescribed to control the peak rate of surface runoff by temporary storage and controlled release of runoff.

Designers should refer to the described publications for drainage design guidance in New Castle County.

## Storm Drain Design

Within the influence of urban areas, storm runoff waters collected on the roadway normally will be controlled with curb and gutter sections and will run off through storm sewer systems.

Municipal section drainage systems should limit the water ponding along the gutters and behind the curbs to amounts that will not interfere with traffic or damage property. This is accomplished by placing curb inlets, gutter inlets or drop inlets at specific locations so that water may enter the storm drain culverts. Also, inlets and underground drain systems normally are required in depressed medians of divided highways.

Guidelines and criteria for design of storm drain systems are set forth in the following sections.

### Runoff Quantities

Because the drainage areas involved with storm drain systems usually are relatively small, the drainage runoffs normally should be determined by the Rational Method described previously in this chapter. The storm design frequency should be consistent with the values shown in Figure 6-8.

There is need for orderly tabulation of the runoff discharge computations to facilitate the storm sewer design. The form shown in Figure 6-3 (sample design problem) serves this purpose. Beginning in the uppermost reaches of the drainage system, tabulate by drainage area the amount of discharge accumulating along the sewer run. Work from the upper reaches down the system gradient to the point of outfall release.

## Ponding Limits on Roadway

Water flow in gutters should be confined to a width and depth that will neither obstruct nor cause a hazard to traffic. The ponding width will have a corresponding depth, and the quantity of water carried will depend on the gutter gradient, gutter roughness coefficient, roadway cross section and inlet spacing.

The prescribed limits of ponding are:

- arterial highways or streets with full shoulder width or parking lane -- full shoulder width or parking lane width;
- arterial highways or streets with less than full shoulder width -- one half of adjacent lane;
- other multilane streets -- width of adjacent lane; and
- two-lane streets -- one third of adjacent lane.

The chart in Figure 6-16 is used for gutter capacity design. The chart is self-explanatory with instructions and examples. The ponding width (Zy) is set from the criteria above -- and the depth (y) is derived. With given restraints on ponding, determination can be made of the allowable accumulated runoff discharge that the gutter can accommodate; and this, in turn, will indicate the required spacing of inlets.

## Inlet Spacing

Obviously, inlets must be placed at low points (or sags) in the gutterline. Additionally, they should be located at other points along grades where the accumulated runoff will approach the prescribed ponding limits.

Although the computed inlet spacing requirement may be of considerable distance -- possibly 500 to 600 feet -- actual spacing of inlets should be held to a maximum of about 300 feet, and often less, to facilitate pipe