Chapter 5

Hydrology for Drainage Crossing Design

"Base drainage structure size on some rational or statistical design process."

DRAINAGE STRUCTURE SIZE should be based on some reasonable design flow, as well as site characteristics and environmental considerations such as fisheries (*Photo 5.1*). Determining the correct or a reasonable design flow for any engineered drainage structure is critically important, both for the structure to perform properly and to prevent failures of structures. A reasonable design flow is commonly based upon a storm event that will have a recurrence frequency (return interval) of 20 to 100 years, depending on type and value of the structure and local regulations. Any culvert has a finite flow capacity that should not be exceeded. Bridges also have a specific capacity for the given cross-sectional area, but typically it is large. Low-water crossing design is based upon estimates of both low flows and peak flows for that specific drainage, but are less sensitive to flow estimates.

Most flow determination methods require that the drainage area be defined or estimated. This work is typically accomplished by delineating the area of the watershed on a topographic map (*Figure 5.1*). Ideally, topographic maps with a scale of 1:10,000 to 1:24,000 should be used for drainage project design. However, the most detailed map commonly available in many countries is a 1:50,000 scale, so that map should be used.

Photo 5.1 Determine an adequate design storm flow at any site using available, appropriate hydrological methods. Install drainage crossing structures based upon design flows and other site characteristics.
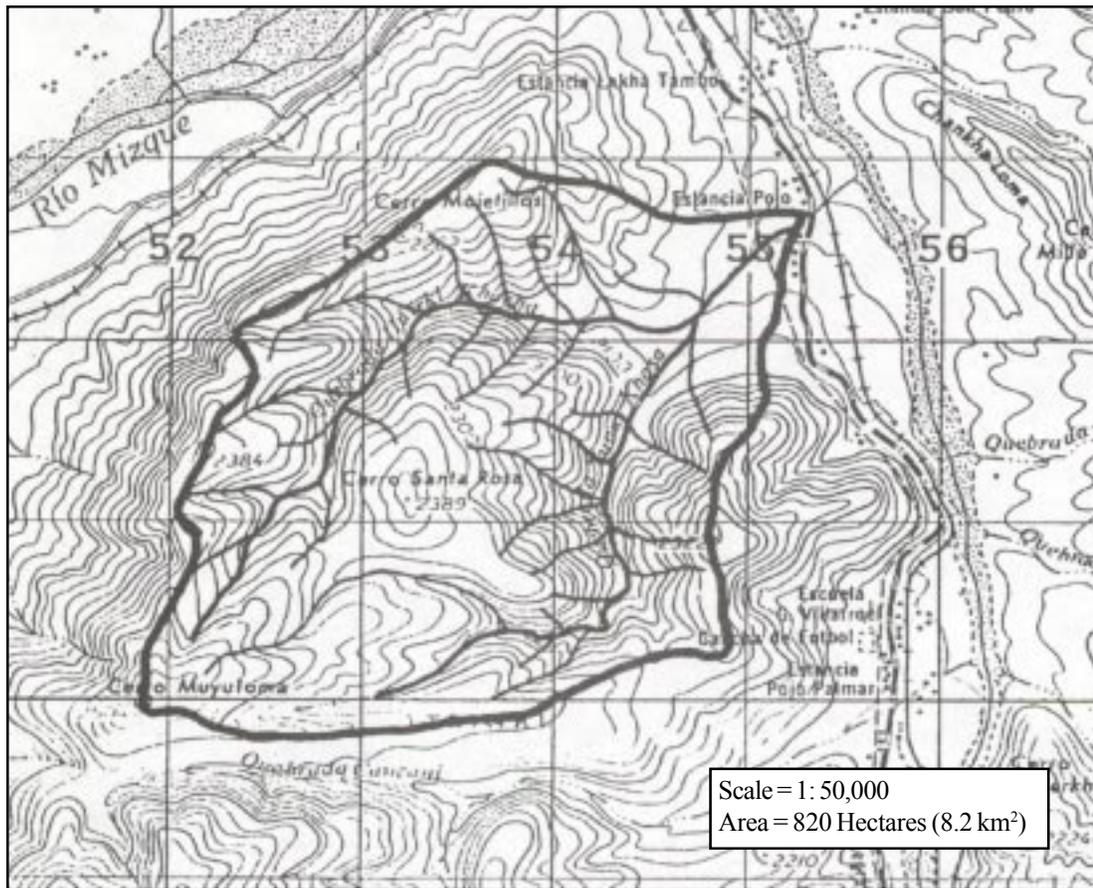
Figure 5.1 Determine the drainage area of watersheds on a topographic map to help determine appropriate flows for drainage structure design.

At a minimum, the Rational Method, a rainfall based method, should be used to determine the discharge from small watersheds, with a drainage area of up to around 120 hectares. The Talbot Method directly uses the Rational Method and can be useful in making a preliminary estimate of the pipe size needed as a function of drainage area. However, the Talbot Method does not consider varying rainfall intensity or return interval, so the method is not precise. Ideally, statistical methods based upon regression analysis of regional stream flow data, or actual local stream flow data will be available and can be used.

Large watersheds may have specific gauging station data that can be examined statistically and used for hydraulic design to determine flows at different return intervals. High water marks and measurements of the channel geometry can be used in conjunction with Manning's Equation (see Chapter 6) to determine flow velocity and thus flow volume (discharge, or capacity) through the channel for that given high-water level. A variety of methods may be available to the designer to determine design flows. At least some analytical method should be used, and ideally, several methods should be used and compared to gain confidence in your design flow values. Typical analysis methods for varying sizes of watersheds are shown in *Table 5.1*.

Rational Method

The Rational Method is commonly used for the determination of flows from small watersheds, and it can be applied in most geographic areas. It is particularly useful if local stream flow data do not exist, and it can be used to make a rough estimate of flow from large watersheds if other options do not exist. Thus, the Rational Formula is presented and briefly explained on the next page. More detailed information on its use is presented in references such as the *Minimum Impact Low-Volume Roads Manual* or the FHWA Manual *HDS4 - Introduction to Highway Hydraulics*.

THE RATIONAL FORMULA

To determine flow volume...

$$Q = \frac{CiA}{362}$$ where:

Q = Quantity of Flow (Runoff), in Cubic Meters per Second (m³/s).

C = Runoff Coefficient. This coefficient is selected to reflect the watershed characteristics, such as topography, soil type, vegetation, and land use.

i = Average Rainfall Intensity for the selected frequency and for a duration equal to the Time of Concentration, in millimeters per hour.

A = Area of the watershed, in Hectares.

Runoff Coefficient (*C*) values are presented in *Table 5.2*. These values reflect the differing watershed characteristics that influence runoff. The designer must develop experience and use judgment to select the appropriate value of C within the range shown. Note that the value of C may change over the design life of the structure due to changes in land use such as a forest converted to agricultural land or from a fire in the watershed. Flow quantity is directly proportional to the selection of this coefficient.

Area (*A*) is simply the area of the watershed that contributes runoff to the drainage crossing. Its boundaries go from drainage divide to drainage divide and down slope to the crossing. On a roadway surface, the "drainage area" is the cut slope and road surface area between cross-drains or leadoff ditches.

Rainfall intensity (*i*) is the third factor, and the one often most difficult to obtain. It is expressed as the average rainfall intensity in millimeters per hour (mm/hr) for a selected recurrence frequency and for a duration equal to the Time of Concentration of the watershed. At the beginning of a storm, runoff from distant parts of the watershed have not reached the discharge point (such as a culvert). Once water has reached the discharge point from **all** parts of the watershed, a steady state flow will occur. The estimated time when water from all parts of the watershed reaches the discharge point is the Time of Concentration (TOC). TOC depends on the overland flow rate of water in that watershed. For very small watersheds, a minimum TOC of 5 minutes is recommended for finding the intensity used in determining design flows. TOC can be estimated by dividing the length of the runoff route by the average runoff velocity (usually 0.1 [flat, wooded] to 1.0 m/s [steep, barren]).

Figure 5.2 shows a typical family of rainfall intensity-duration curves for a recurrence frequency of 2 to 50 years. Such curves, developed from local rainfall data, should be located or generated when working in any particular area. The typical maximum intensity values for a 25 to 50-year event for desert regions are around 75 to 100 mm/hr; some coastal and jungle, or tropical regions have maximum intensities from 200 to 400 mm/hr, or more; and most areas, including semi-arid regions, mountain forests, and coastal areas typically have values of 100 to 250 mm/hr. Because of the wide range of values, and the amount of local variation that can occur around islands and mountains, local data is desirable for project design work.

RECOMMENDED PRACTICES

- Use the best available hydro-logic methods to determine design flows.

- Where appropriate, use drainage structures that are not sensitive to exact flow predic-tions, such as low water crossings (fords) and drivable dips versus culvert pipes.

- Add freeboard or extra capacity to structures in drainages with uncertain flow or for debris passage in watersheds with changing land uses, usually on the order of 120% to 150%.

- To minimize risk to structures, the recommended storm frequency (return period) for design of culverts is 20 to 50 years, and 100 to 200 years is recommended for bridges or drainages with sensitive environmental concerns.

- For culverts installed in areas with limited or inadequate hydrologic data or designs, include overflow (overtopping) protection to reduce risk of total failure or stream diversion (see Figure 7.10).

- Involve hydrologists, fisheries biologists and engineers in the process of hydrologic and hydraulic design.

PRACTICES TO AVOID

- Installing drainage structures without some rational or statistical assessment of the expected flow.

Table 5.1

DESIGN FLOW ANALYSIS METHODS FOR VARIOUS WATERSHED SIZES	
Watershed Size	**Typical Type of Analysis**
Small (to 120 ha) (300 acres)	Rational Method, Talbot Method, Local Experience
Medium (to 4,000 ha) (10,000 acres)	Regression Analysis, High Water Marks + Manning, Local Experience
Large (over 4,000 ha)	Gauging Data, High Water Marks, Statistical or Regression Analysis

Table 5.2

RATIONAL METHOD VALUES OF "C"	
Land Use or Type	**"C" Value**
Agriculture	
Bare Soil	0.20-0.60
Cultivated Fields (sandy soil)	0.20-0.40
Cultivated Fields (clay soil)	0.30-0.50
Grass	
Turf, Meadows	0.10-0.40
Steep Grassed Areas	0.50-0.70
Woodland/Forest	
Wooded Areas with Level Ground	0.05-0.25
Forested Areas with Steep Slopes	0.15-0.40
Bare Areas, Steep and Rocky	0.50-0.90
Roads	
Asphalt Pavement	0.80-0.90
Cobblestone or Concrete Pavement	0.60-0.85
Gravel Surface	0.40-0.80
Native Soil Surface	0.30-0.80
Urban Areas	
Residential, Flat	0.40-0.55
Residential, Moderately Steep	0.50-0.65
Commercial or Downtown	0.70-0.95
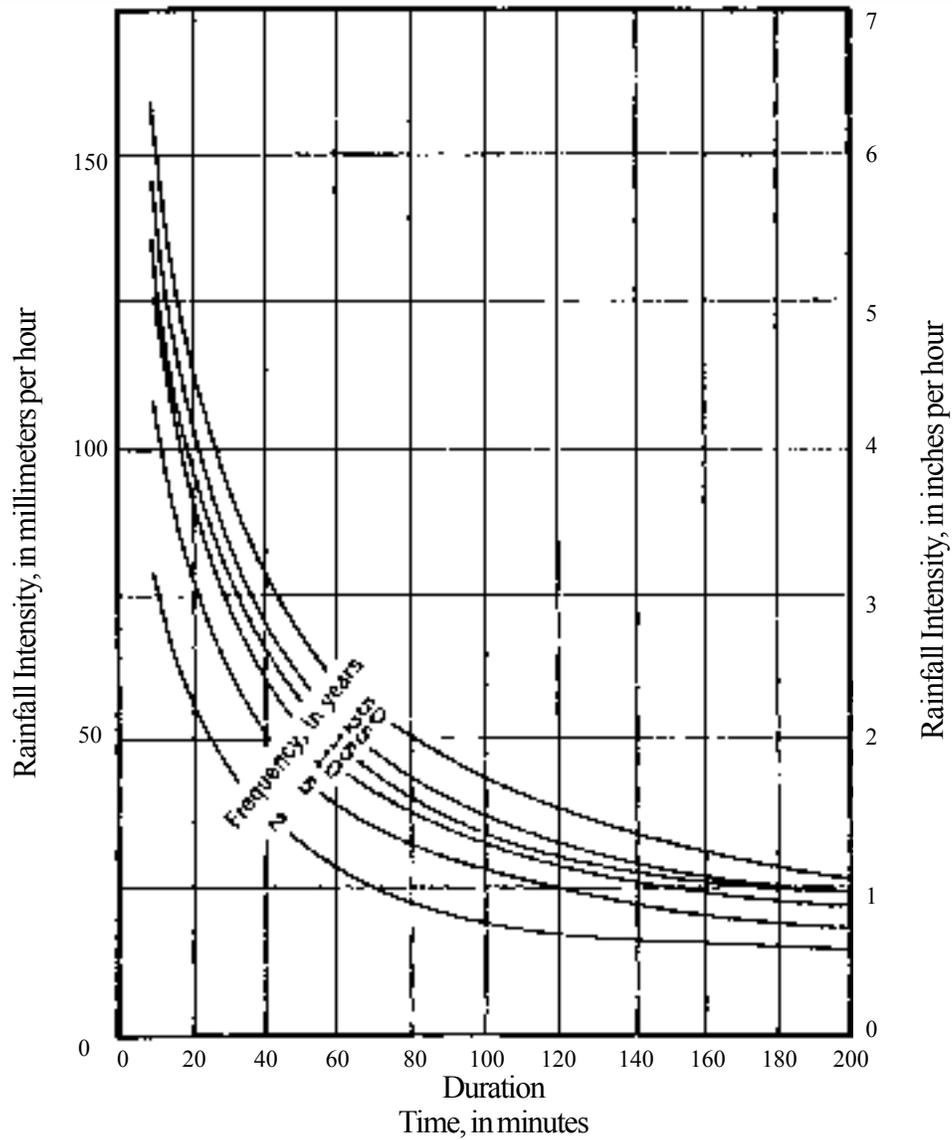
Note: Common Maximum Intensity Values for 25-50 Year Frequency of Events:
- Jungle Areas: 200-400 mm/hr
- Deserts: 50-100 mm/hr
- Most Areas (Semi-Arid, Mountains, Coastal Areas): 100-250 mm/hr

A drainage crossing can be a critical and vulnerable point in the road if the drainage structure fails. Thus, drainage crossings must be designed to pass the appropriate storm flows plus debris or to survive overtopping.