CHAPTER 3

HYDROLOGY

NOTE: All questions and comments should be directed to the Drainage Specialist, Design Support Area.

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3.1 INTRODUCTION/PURPOSE

Hydrology is generally defined as a science dealing with the interrelationship between water on and under the earth and in the atmosphere. For the purpose of this manual, hydrology will deal with estimating flood magnitudes as the result of precipitation. In the design of highway drainage structures, floods are usually considered in terms of peak runoff or discharge in cubic feet per second (cfs), and hydrographs are considered in terms of discharge versus time. For structures which are designed to control the volume of runoff, such as detention storage facilities (Chapter 8, Stormwater Storage Facilities) or where flood routing through culverts is used, the discharge hydrograph will be needed. Wetland Hydrology for the design of weather water budgets is addressed in Appendix 3-D.

The analysis of the peak rate of runoff, volume of runoff, and time distribution of flow is fundamental to the design of drainage facilities. Errors in the analysis will result in a structure that is either undersized and causes more drainage problems or, is oversized and costs more than necessary. On the other hand, any hydrologic analysis is only an approximation. The relationship between the amount of precipitation into a drainage basin and the amount of runoff from the basin is complex, and too little data are available on the factors influencing the rural and urban rainfall-runoff relationship to expect exact solutions.

<u>Factors Affecting Floods</u>

In the hydrologic analysis, there are many factors that affect runoff. Some of the factors which need to be considered for each project are:

- Rainfall amount and distribution.
- Drainage area size, shape, and orientation.
- Ground cover and soil type.
- Slopes of terrain and stream(s).
- Antecedent moisture condition.
- Storage potential (overbank, ponds, wetlands, reservoirs, channel, etc.).
- Land use conditions.
- Type of precipitation (rain, snow, hail, or combinations thereof).

3.2 DEFINITIONS

Following are discussions of concepts which will be important in a hydrologic analysis. These concepts will be used throughout the remainder of this chapter in dealing with different aspects of hydrologic studies. Some defined terms are shown in Figure 3-1, Representation of Hydrograph, Hyetograph, and Rainfall Excess.

Antecedent Moisture Conditions - Soil moisture conditions of the watershed at the beginning of a storm. These conditions affect the volume of runoff generated by a particular storm event.

Base Flow - Normal or dry weather flow in a stormwater system.

Depression Storage - The natural depressions within a watershed which store runoff.

Design Discharge - The maximum rate of flow (or discharge) for which a drainage facility is designed and thus expected to accommodate without exceeding the adopted design constraints. Maximum flow a bridge, culvert, or other drainage facility is expected to accommodate without contravention of the adopted design criteria. The peak discharge, volume, stage, or wave crest elevation, and its associated probability of exceedance selected for the design of a road culvert or bridge over a channel, floodplain or along a shoreline. By definition, the design discharge, or wave, does not overtop the road. The design discharge headwater, or wave height, may be at an elevation lower than the road's profile grade in order to meet other design criteria such as the protection of property, accommodating land use needs, lowering of velocities, reducing scour, or complying with regulatory mandates.

Design Storm - Selected storm of a given frequency (recurrence interval) used for designing a design storm system.

Hypothetical storm derived from intensity-duration-frequency curves by reading the rainfall intensity from these curves for various durations for the frequency of interest and rearranging these rainfall intensities to fit an assumed storm pattern and storm duration.

A given rainfall amount, areal distribution, and time distribution used to estimate runoff. The rainfall amount is either a given frequency (25-, 50-year, etc.) or a special large (or specific frequency) value.

Drainage Area - The surface area draining into a stream or drain at a given point.

Evapotranspiration - Surface evaporation of water and transpiration through plants.

Flood Frequency - The number of times a flood of a given magnitude can be expected to occur on an average over a long period of time. Frequency analysis is then the estimation of peak discharges for various recurrence intervals. Another way to express frequency is with probability. Probability analysis seeks to define the flood flow with a probability of being equaled or exceeded in any year, i.e., 2 percent chance flood flow in any given year is a 50-year flood flow. Drainage structures are designed based on specified flood frequencies. However, certain hydrologic procedures use rainfall and rainfall frequency as the basic input. Thus, in those procedures it is commonly assumed that the 10 percent chance (10-year) storm will produce the 10 percent chance (10-year) flood.

Gaged Sites - This is a site at or near a gaging station and the stream flow record is long enough to be statistically analyzed to estimate peak discharges. (Most sites in this category will be greater than the current regulatory drainage area limit and will be determined by the MDEQ's Hydrologic Studies Unit. The log-Pearson Type III probability distribution is used to analyze gaged flows.)

Hydraulic Roughness - A composite of the physical characteristics which influence the flow of water across the earth's surface, whether natural or channelized. It affects both the time response of a watershed and drainage channel as well as the channel storage characteristics.

Hydrograph - A graph of the time distribution of runoff from a watershed. (See Figure 3-1).

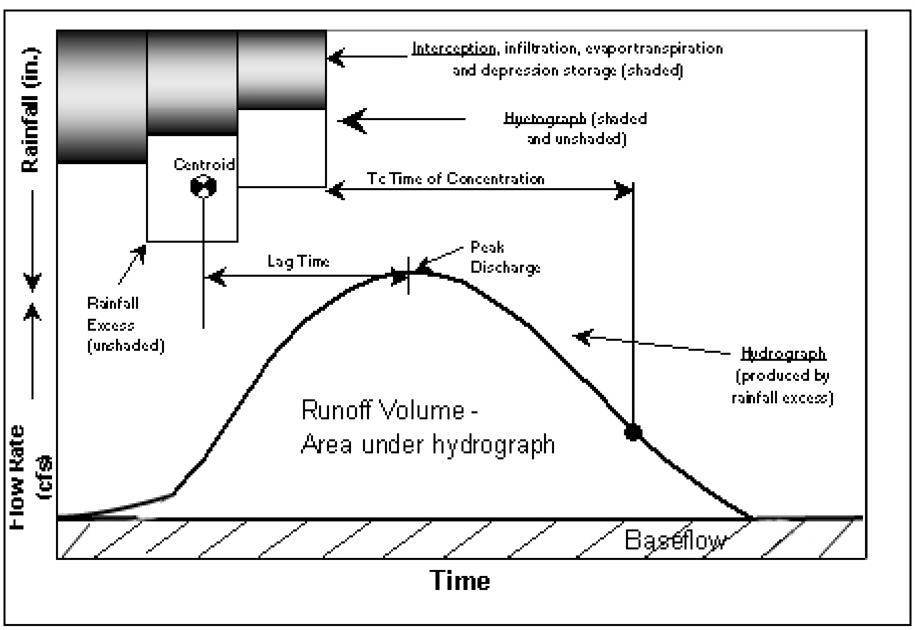


Figure 3-1 Representation of Hydrograph, Hyetograph, and Rainfall Excess

Hyetograph - A graph of the time distribution of rainfall over a watershed. (See Figure 3-1.)

Infiltration - The part of rainfall that enters the soil. The passage of water through the soil surface into the ground. Used interchangeably with percolation.

Interception - Storage of rainfall on foliage and other surfaces during a rainfall event.

Lag Time - The time measured from the centroid of the excess rainfall to the peak of the hydrograph.

Peak Discharge - The maximum rate of flow of water passing a given point as a result of a rainfall event or snowmelt; sometimes called peak flow.

Rainfall Excess - The water available to runoff after interception, depression storage, evapotranspiration, and infiltration have occurred.

Runoff Volume - Area under a hydrograph minus the base flow.

Stage - The elevation of the water surface above some elevation datum at a specific location.

Time of Concentration, T_c - The time it takes water from the most distant point (hydraulically) to reach a discharge point.

Ungaged Sites - Those sites where no recorded stream flow data are available.

Unit Hydrograph - The direct runoff hydrograph resulting from a rainfall event that has a specific temporal and spatial distribution. A unit hydrograph lasts for a specific duration and has unit volume. When a unit hydrograph is shown with units of cubic feet per second, it is implied that the ordinates are cubic feet per second per inch of direct runoff.

To provide consistency within this chapter, as well as throughout this manual, symbols presented in Appendix 3-A will be used. These symbols were selected because of their wide use in hydrologic publications. A list of acronyms used in this chapter is also presented in Appendix 3-A.

3.3 POLICY AND DESIGN CRITERIA

Following is a summary of hydrologic analysis and design. For a more complete discussion of these concepts and others related to hydrologic analysis, the reader is referred to FHWA, *Hydraulic Design Series 2* and AASHTO, *Highway Drainage Guidelines*.

3.3.1 Data Collection and Evaluation of Runoff Factors

For all hydrologic analyses, the following factors should be evaluated and included when they will have an effect on the final results:

- Drainage basin characteristics including: Size, shape, slope, land use, geology, soil type, surface infiltration, and storage.
- Stream channel characteristics including: Geometry and configuration, or natural and artificial controls.
- Floodplain characteristics.
- Meteorological characteristics such as precipitation amounts, type (rain, snow, hail, or combinations thereof), and time rate of precipitation (hyetograph).

Studies considering environmental and ecological impacts of projects should be done because hydrologic considerations can influence the selection of highway corridors and alternate routes. The complexity of these hydrologic studies varies with the analysis. Typical data to be gathered are: topographic maps, aerial photographs, stream flow records, historical high water elevations, flood discharges and locations of hydraulic features, such as reservoirs, and designated or regulatory floodplain areas.

3.3.2 Policy of Flood Hazards/Design Frequency

3.3.2.1 FHWA Requirements

FHWA's Federal Aid Policy Guide (FAPG) Part 650 for Federal-aid projects and state law requires plans to show the following at locations where a highway will encroach on a regulated floodplain:

- magnitude,
- frequency, and
- water surface elevations for the 2 percent chance (50-year) flood and 1 percent chance (100-year) flood.

Conveyance of the 2 percent chance (50-year) flood shall not overtop the roadway. The size of the waterway opening along with hydraulics/hydrology data must be on the plans for The Plan Review Meeting.

3.3.2.2 State Requirements

For the State of Michigan policy on floodplain management, please see the State Executive Order 1977-4, titled “State Flood Hazard Management Plan” in Chapter 2, Legal Policy and Procedure, Appendix 2-F.

MDEQ Requirements

All highways that encroach on the floodplain, both transversely and longitudinally, shall require a hydraulic analysis and shall be designed to permit conveyance of floods up to and including the 1 percent chance (100-year) flood without causing harmful interference such as:

- an adverse impact on natural and beneficial floodplain levels,
- damage to property, or
- a significant increase in potential for interruption or termination of emergency service or emergency evacuation routes

MDOT Requirements

Roadway with Enclosed Drainage: The computed runoff for a roadway with curb and gutter shall be based on a 10 percent chance (10-year) storm. The sewer should be designed to flow full, i.e., with a hydraulic grade line at or near the top of pipe.

When the hydraulic grade line (HGL) is influenced by the receiving water, the HGL will be allowed to rise above the pipe, but should remain at least 1-foot below the gutter.

Depressed Roadways: Methods for designing storm sewers for depressed roadways is the same as for a roadways with enclosed drainage, except that runoff shall be computed using a 2 percent chance (50-year) storm and the hydraulic grade line shall be a minimum of 1-foot below the gutter grade line of the roadway (pressure flow). A depressed roadway will require a pumping station when a gravity drainage system cannot be used to drain the low points. Frequently, the Department must provide a trunk sewer and an adequate and properly designed independent outlet. An existing municipal sewer may only be used by agreement. Contact the Design Engineer - Hydraulics, for assistance or additional guidance.

3.3.3 Coordination

Discharge requests for MDOT projects with drainage areas over two square miles are coordinated by the MDOT Design Engineer – Hydraulics with the Hydrologic Studies Unit of MDEQ and other agencies as necessary. (See Section 3.4.6.)

3.3.4 Documentation

Hydrologic design of highway drainage facilities must be documented. Frequently it is necessary to refer to project design files long after the actual construction has been completed. Thus, it is necessary to fully document the results of all hydrologic analysis. Documentation is retained in either a Hydraulics Unit file, project design file, or on the drainage and vicinity plan sheet (See RDM 1.02.03 and 4.05.06).

3.3.5 Flood History

All hydrologic analysis should consider the flood history of the area and the effect these historical floods would have on existing and proposed structures.

3.3.6 Rainfall Data and Flood Frequency

Since it is not economically feasible to design a structure for the maximum runoff a watershed is capable of producing, a design frequency must be established. The frequency with which a given flood can be expected to occur is the reciprocal of the probability or chance that the flood will be equaled or exceeded in a given year. If a flood has a 20 percent chance of being equaled or exceeded each year, over a long period of time, the flood will be equaled or exceeded on an average of once every five years. This is called the return period or recurrence interval (RI). Thus, the exceedence probability in percent equals 100/RI.

The designer should note that the 20 percent chance flood (5-year flood) is one that will not necessarily be equaled or exceeded every five years. There is a 20 percent chance that the flood will be equaled or exceeded in any year; therefore, the 20 percent chance flood could conceivably occur in several consecutive years. The same reasoning applies to floods with other return periods.

Stream flow measurements for determining a flood frequency relationship at a site are usually not available (ungaged sites); in such cases, it is accepted practice to estimate peak runoff rates and hydrographs using statistical or empirical methods. In general, results from using several methods should be compared, not averaged.

This chapter will address hydrologic procedures that can be used for both gaged and ungaged sites.

A consideration of peak runoff rates for design conditions is generally adequate for conveyance systems such as storm drains or open channels. However, if the design must include flood routing (e.g., storage basins or complex conveyance networks), a flood hydrograph is required. Although the development of runoff hydrographs (typically more complex than estimating peak runoff rates) is often accomplished using computer programs, some methods are adaptable to nomographs or other desktop procedures.

Rainfall data are available for many geographic areas for use in the Rational Method. Appendix 3-B at the end of this chapter contains rainfall data for design of MDOT projects.

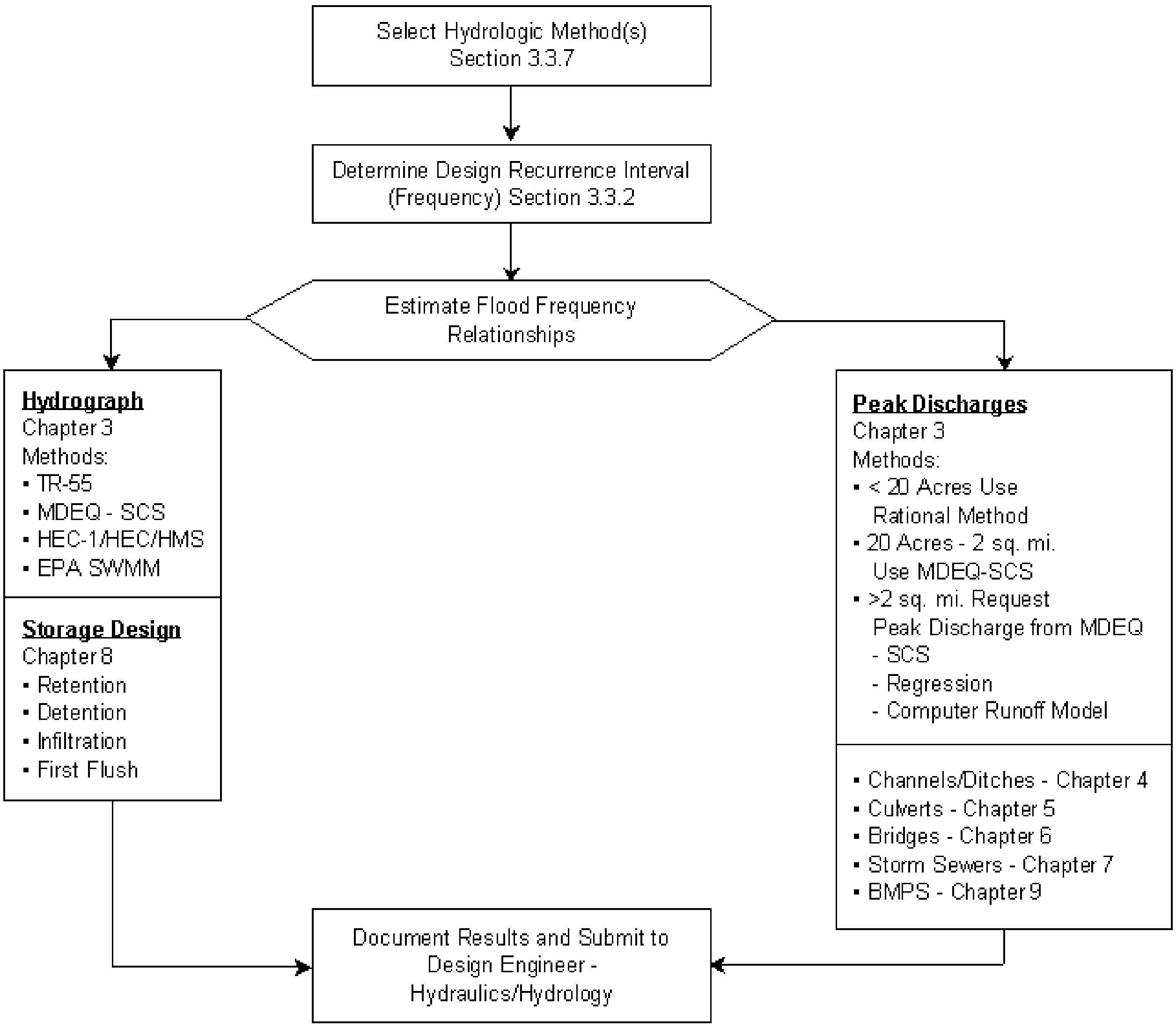
3.3.7 Hydrologic Method Selection

Many hydrologic methods are available. The methods to be used and the circumstances for their use are listed below. If possible, the method should be calibrated to local conditions and tested for accuracy and reliability.

- The Rational Method (Section 3.4.1) shall be used only for drainage areas less than 20 acres, and where only the peak discharge is needed.
- The National Resource Conservation Service's (NRCS) TR-55 can be used for any size watershed, up to the limiting time of concentration of 10 hours. This method will also produce a flood hydrograph. However, the dimensionless unit hydrograph used in this procedure should be the one specified by the Hydrologic Studies Unit of the Michigan Department of Environmental Quality (MDEQ). The coordinates for the dimensionless unit hydrograph are 0, 0.5, 1.0, 0.8, 0.6, 0.4, 0.2, and 0.
- The method in the MDEQ publication, "Computing Flood Discharges for Small Ungaged Watersheds," (Appendix 3-B) can be used for all other watersheds with drainage areas up to the regulated limit (currently two square miles). This method, MDEQ - SCS, produces a peak discharge and runoff volume. For times of concentration up to 10 hours, both this method and the TR-55 procedure should give comparable results.
- For drainage areas equal to or greater than the regulated limit (currently two square miles by Administrative Rule R 323.1312(a) for Part 31 of NREPA), the design discharges will be computed by the MDEQ Hydrologic Studies Unit. The methods used for the regulated drainage areas may include:
  - MDEQ - SCS method,
  - the drainage area ratio method,
  - a log-Pearson Type III probability stream gage analysis, or
  - the State regression equations.

3.3.8 Hydrologic Analysis Procedure Flow Chart

The flow chart shows the steps needed for the hydrologic analysis and the hydraulic designs that will use the hydrologic estimates.



3.3.9 Calibration of Hydrologic Models by MDEQ

MDEQ is responsible for providing hydrologic analysis for drainage areas greater than two square miles. The following section is a discussion of methodology and calibration of hydrologic models used by MDEQ. This discussion is provided for training purposes.

3.3.9.1 Definition

Calibration is a process of varying the parameters or coefficients of a hydrologic method so that it will estimate peak discharges and hydrographs consistent with local rainfall and stream flow data. Calibration is recommended to be performed whenever possible.

3.3.9.2 Hydrologic Accuracy

The accuracy of the hydrologic estimates will have a major effect on the design of drainage or flood control facilities. Although it may be argued that one hydrologic procedure is more accurate than another, practice has shown that all of the methods discussed in this chapter can, if calibrated, produce acceptable results consistent with observed or measured events. What should be emphasized is the need to calibrate the method for local conditions. This calibration process can result in much more accurate and consistent estimates of peak flows and hydrographs.

3.3.9.3 Calibration Process

The calibration process can vary depending on the data or information available for a local area. The following process should be followed during calibration.

1. If stream flow data are available for an area, the hydrologic procedures can be calibrated to these data. The process would involve generating peak discharges and hydrographs for different input conditions (e.g., slope, area, antecedent soil moisture conditions) and comparing these results to the gaged data. Changes in the model would then be made to improve the estimated values as compared to the measured values.

2. After changing the variables or parameters in the hydrologic procedure the results should be checked against another similar gaged stream or another portion of the stream flow data that were not used for calibration.

3. If some agency has data or information for an area based on stream flow data, general hydrologic procedures can be calibrated to these local procedures. In this way, the general hydrologic procedures can be used for a greater range of conditions (e.g., land uses, size, slope).

4. The calibration process should only be undertaken by personnel highly qualified in hydrologic procedures and design.

5. Should it be necessary to use unreasonable values for variables in order for the model to produce reasonable results, then the model should be considered suspect and its use carefully considered (e.g., having to use terrain variables that are obviously dissimilar to the geographic area in order to calibrate to measured discharges or hydrographs).

3.3.10 Rainfall Distribution

Hydrologic techniques that utilize hydrographs generally require the use of a design rainfall distribution. In Michigan, the former Soil Conservation Service (SCS) Type II distribution is appropriate.

3.4 DESIGN GUIDANCE AND PROCEDURE

3.4.1 Rational Method

The Rational Method is recommended for estimating the design storm peak runoff for drainage areas as large as 20 acres. This method, first introduced in 1889, is still used in many engineering offices in the United States. The Rational Method provides peak discharges and is not intended for computation of runoff volumes.

3.4.1.1 Application

Considerations for using the Rational Method (as well as other hydrologic methods) are the following:

- The first step in applying the Rational Method is to obtain a good topographic map and define the boundaries of the drainage area in question. A field inspection of the area should also be made to determine if the natural drainage divides have been altered.
- In determining the runoff coefficient, C, for the drainage area, thought should be given to future changes in land use that might occur during the service life of the proposed facility that could result in an inadequate drainage system. FAPG allows for consideration of land use change 20 years into the future.
- Restrictions to the natural flow (creating storage areas) such as highway crossings and dams that exist in the drainage area should be investigated. Dams may affect the design flows determined by this method, so another method may be warranted.
- The charts, graphs, and tables included in this section are not intended to replace reasonable and prudent engineering judgment.

3.4.1.2 Characteristics

Some precautions should be considered when applying the Rational Method. Characteristics of the Rational Method which limit its use to 20 acres or less include the following:

1. The rate of runoff resulting from any rainfall intensity is a maximum when the rainfall intensity lasts as long or longer than the time of concentration. That is, the entire drainage area does not contribute to the peak discharge until the time of concentration has elapsed.

   This assumption limits the size of the drainage basin that can be evaluated by the Rational Method. For large drainage areas, the time of concentration can be so large that constant rainfall intensities for such long periods do not occur, and shorter more intense rainfalls can produce larger peak flows.

2. The frequency of peak discharges is the same as that of the rainfall intensity for the given time of concentration.

   Frequencies of peak discharges depend on rainfall frequencies, antecedent moisture conditions in the watershed, and the response characteristics of the drainage system. For small and largely impervious areas, rainfall frequency is the dominant factor. For larger drainage basins, the response characteristics control. For drainage areas with few impervious surfaces, antecedent moisture conditions usually govern, especially for rainfall events with a return period of 10 years or less.

3. The fraction of rainfall that becomes runoff is independent of rainfall intensity.

   The assumption is reasonable for impervious areas, such as streets, rooftops and parking lots. For pervious areas, the fraction of runoff varies with rainfall intensity and the accumulated volume of rainfall. Thus, application of the Rational Method involves the selection of a coefficient that is appropriate for the storm, soil, and land use conditions.

4. The peak rate of runoff is sufficient information for the design of storm sewers and culverts.

   Modern drainage practice often includes detention of urban storm runoff to reduce the peak rate of runoff downstream. With only the peak rate of runoff, the Rational Method severely limits the evaluation of design alternatives available in urban and in some instances, rural drainage design.

3.4.1.3 Equations

The Rational Method estimates the peak rate of runoff at any location in a watershed as a function of the drainage area, runoff coefficient, and mean rainfall intensity for a duration equal to the time of concentration (the time required for water to flow from the most remote point of the basin to the location being analyzed). The rational formula is expressed as follows:

$$\mathbf{Q = CIA} \qquad \mathbf{(3.1)}$$

where:
- Q = maximum rate of runoff, cfs
- C = runoff coefficient representing a ratio of peak rate of runoff to rainfall (see Table 3-1)
- I = average rainfall intensity for a duration equal to the time of concentration, for a selected return period, in./hr. (See Appendix 3-B)
- A = drainage area tributary to the design location, acres

A unique aspect of the Rational Method is the units (when utilizing English units). One acre-inch/hour is approximately equivalent to 1 cfs, so conversion of the units is not necessary when using the rational formula.

3.4.1.4 Parameters

The results of using the Rational Method to estimate peak discharges are very sensitive to the parameters that are used. The designer must use good engineering judgment in estimating values that are used in the method. Following is a discussion of the different variables used in the Rational Method.

Time of Concentration

Time of concentration (T_c) is the time it takes for runoff to travel from the hydraulically most distant point in the watershed to the point of design of a highway waterway crossing. In hydrograph analysis, T_c is the time from the end of rainfall excess to the inflection point on the falling limb of the hydrograph. This point signifies the end of surface runoff and the beginning of base flow recession. The T_c may vary between different storms, especially if the rainfall is nonuniform in either aerial coverage or intensity. However, in practice, T_c is considered to be constant.

Measuring from a recorded hydrograph provides the most accurate estimate of T_c. For ungaged watersheds, T_c is calculated by estimating the velocity through the various components of the stream network. The method presented expresses velocity in the form:

$$V = KS^{1/2} \qquad (3.2)$$

Where K is a coefficient depending on the type of flow, S is the slope of the flow path in percent, and V is the velocity in feet per second.

Three flow types are used on the designation on U.S. Geological Survey topographic maps.

- Small Tributary: Permanent or intermittent streams, which appear as a solid or dashed blue line on the topo maps. This also applies to a swamp that has a defined stream channel.
- Waterway: Any over-land route which is a well-defined swale by elevation contours but does not have a blue line denoting a defined channel. This also applies to a swamp that does not have a defined channel flowing through it.
- Sheet Flow: Any over-land flow path which does not conform to a defined waterway. Engineering judgement should be used, but maximum length should be approximately 300 feet.

The K coefficient for each of these types of flow are:

Flow Type	K
Small tributary	2.1
Waterway	1.2
Sheet flow	0.48

These coefficients were derived by Richardson (1969) as a means of estimating velocities when detailed stream hydraulic data are unavailable. Once the velocity is determined, time of concentration can be computed as:

$$\mathbf{T_c = L / (60V)} \qquad \textbf{(3.3)}$$

Where L is the length in feet of the particular flow path and the factor 60 converts T_c from seconds to minutes.

In most watersheds all three flow types will be present. Starting at the basin divide, the runoff may proceed from sheet flow to waterway, back to sheet flow, then waterway again, then small tributary, etc. The T_c for each segment should be computed and then summed to give the total T_c.

It is important that the length used to compute T_c has a uniform slope. As an example, assume a 5,000-foot length of small tributary has a change in elevation of 10.4 feet. This slope of 0.208 percent produced a T_c of 1.45 hours. However, if it is known that the upper 1,000 feet of this stream falls 10 feet, and the lower 4,000 feet only falls 0.4 feet, this would produce a total T_c of 5.42 hours. Therefore, it is best to sum T_c over the smallest possible contour interval, which is usually 5 or 10 feet on most topographic maps. This interval can be enlarged if a visual examination of the topographic map shows a uniform spacing between successive contour crossings.

In the design of storm sewer systems, it is common for the time of concentration for the upstream inlet to be estimated. Past practice has indicated a 15-minute initial or inlet time to be adequate for the design of most highway sewers. However, the steep grades associated with single sag depressions tend to produce more rapid runoff. If construction of a pump station is contemplated at such a location, the use of a 10-minute initial time is warranted.

Common Errors

Two common errors should be avoided when calculating T_c. First, in some cases runoff from a portion of the drainage area which is highly impervious may result in a greater peak discharge than would occur if the entire area were considered. In these cases, adjustments can be made to the drainage area by disregarding those areas where flow time is too slow to add to the peak discharge. Sometimes it is necessary to estimate several different times of concentration to determine the design flow that is critical for a particular application.

Second, when designing a drainage system, the overland flow path is not necessarily perpendicular to the contours shown on available mapping. Often the land will be graded and swales will intercept the natural contour and conduct the water to the streets, which reduces the time of concentration. This is why a field visit should be made, to verify the information presented on the mapping.

Rainfall Intensity

The rainfall intensity (I) is the average rainfall rate (inches/hour) for a duration equal to the time of concentration for a selected return period. Once a particular return period has been selected for design and a time of concentration calculated for the drainage area, the rainfall intensity can be determined from Rainfall-Intensity-Duration tables (given in Appendix 3-B).

Runoff Coefficient

It is often desirable to develop a composite runoff coefficient based on percentage of different types of surface in the drainage area. The composite procedure can be applied to an entire drainage area or to typical blocks as a guide to selection of a reasonable coefficient for the entire area. Table 3-1 lists runoff coefficients for use in the Rational Method.

Table 3-1 Runoff Coefficients for Rational Formula

Type of Drainage Area	Runoff Coefficient, C*
Concrete or Asphalt Pavement	0.8 – 0.9
Commercial and Industrial	0.7 – 0.9
Gravel Roadways and Shoulders	0.5 – 0.7
Residential – Urban	0.5 – 0.7
Residential – Suburban	0.3 – 0.5
Undeveloped	0.1 – 0.3
Berms	0.1 – 0.3
Agricultural – Cultivated Fields	0.15 – 0.4
Agricultural – Pastures	0.1 – 0.4
Agricultural – Forested Areas	0.1 – 0.4

For flat slopes or permeable soil, lower values shall be used. For steep slopes or impermeable soil, higher values shall be used. Steep slopes are 2:1 or steeper.

From Michigan State Administrative Rules R 280.9.

3.4.2 Rational Method Procedure

The Rational Method procedure follows these general steps:

Step 1 Obtain topographic information for the entire area that is contributing runoff. Include drainage area outside of the R.O.W. Useful information may include:

- USGS quadrangle maps
- Construction drawings
- Other topographic maps if available

Step 2 Define the drainage limits to the point where a flow estimate is desired.

Step 3 Define a weighted average “C” value for the tributary area

Step 4 Calculate a time of concentration to the point where a flow estimate is desired.

Step 5 Determine the rainfall intensity that applies to the calculated time of concentration and geographical location (See map in Appendix 3-B).

Step 6 Calculate Peak Flow, Q, using the equation Q = CIA.

A detailed description for using the Rational Method for storm sewer design is contained in Chapter 7, Road Storm Drainage Systems.

3.4.3 Rational Method - Example

Following is an example problem which illustrates the application of the Rational Method to estimate peak discharges.

Preliminary estimates of the maximum rate of runoff are needed at the inlet to a culvert for the 1 percent chance (100-year) and 2 percent chance (50-year) storm events.

SITE DATA

From a topographic map and field survey, the watershed, which is located in Ingham County, Michigan, has a drainage area of 20 acres. In addition, the following data are measured:

Length of channel flow (upstream)	=	400 feet at a slope of 0.0007950 foot/foot.
Length of channel flow (downstream)	=	600 feet at a slope of 0.0007576 foot/foot.
Length of waterway flow	=	300 feet at a slope of 0.0011364 foot/foot.
Length of sheet flow	=	100 feet at a slope of 0.0007576 foot/foot.
Average overland slope	=	1 percent

LAND USE
From existing land use maps, land use for the drainage basin is estimated to be:

Woods	=	20 percent
Cultivated Land	=	60 percent
Pasture	=	20 percent

RUNOFF COEFFICIENT
Since the watershed contains different types of land uses, a weighted runoff coefficient (C) needs to be estimated from the values in Table 3-1.

For the given land uses and average overland slope, the runoff coefficients for woods, cultivated land, and pasture corresponding to the 10 percent chance (10-year) and 2 percent chance (50-year) storm event are listed below.

	C Value
Woods	0.20
Cultivated Land	0.40
Pasture	0.20

The following tabulation illustrates the computation of the weighted runoff coefficient.

Land Use	Percent of Total Area	Runoff Coefficient	Weighted Coefficient
Woods	20	0.20	0.20 (20/100) = 0.04
Cultivated Land	60	0.40	0.40 (60/100) = 0.24
Pasture	20	0.20	0.20 (20/100) = 0.04
Sum			**0.32**

Total weighted runoff coefficient 0.32.

TIME OF CONCENTRATION

The following tabulation shows the T_c calculations, based on the equations in Section 3.4.1.4.

Flow Type	Length (feet)	Slope (percent)	Velocity (fps)	Tc (min.)
Small Tributary (upstream)	400	0.07950	0.59	11.3
Small Tributary (downstream)	600	0.07576	0.58	17.2
Waterway	300	0.11364	0.40	12.5
Sheet Flow	100	0.07576	0.13	12.8
Total				54 min

Calculations:

For the small tributary (upstream):

$V = KS^{1/2} = 2.1(0.07950)^{1/2} = 0.59$ fps — Equation 3.2

$T_c = 400$ ft. / (0.59 fps)(60sec) = 11.3 min. — Equation 3.3

For the small tributary (downstream):

$V = KS^{1/2} = 2.1(0.07576)^{1/2} = 0.578$ fps — Equation 3.2

$T_c = 600$ ft. / (0.58 fps)(60sec) = 17.2 min. — Equation 3.3

For the waterway:

$V = KS^{1/2} = 1.2(0.11364)^{1/2} = 0.40$ fps — Equation 3.2

$T_c = 300$ ft. / (0.40 fps)(60sec) = 12.5 min. — Equation 3.3

For the sheet flow:

$V = KS^{1/2} = 0.48(0.07576)^{1/2} = 0.13$ fps — Equation 3.2

$T_c = 100$ ft. / (0.013 fps)(60sec) = 12.8 min. — Equation 3.3

RAINFALL INTENSITY

The intensity used in the Rational Method is for a rainfall duration equal to the T_c. Since we have computed a T_c of 54 minutes, the intensity for a 54-minute rainfall must be determined.

As seen in Appendix 3-B, we note that Ingham County is located in Michigan's Rainfall Frequency Zone 9. The rainfall intensities listed for this zone during the 1 percent chance (100-year) and 2 percent chance (50-year) storm events are 2.74 inch/hour and 2.47 inch/hour, respectively.

PEAK RUNOFF

Substituting the appropriate values into the Rational Method, Q = CIA:

1 percent chance (100-year) flood peak discharge
= (0.32)(2.74 in./hr.) (20 acres) = 17.5 cfs

2 percent chance (50-year) flood peak discharge
= (0.32)(2.47 in./hr.) (20 acres) = 15.8 cfs

3.4.4 SCS Rainfall - Runoff Relationship

The SCS Techniques developed by the former U.S. Soil Conservation Service (SCS) for calculating rates of runoff require the same basic data as the Rational Method: drainage area, a runoff factor, time of concentration, and rainfall. The SCS approach, however, is more sophisticated in that it also considers the time distribution of the rainfall, the initial rainfall losses to interception and depression storage and an infiltration rate that decreases during the course of a storm. With the SCS method, the direct runoff can be calculated for any storm, either real or fabricated, by subtracting infiltration and other losses from the rainfall to obtain the precipitation excess. The SCS method produces both a peak discharge and a hydrograph, which can be used to estimate runoff volume and be used in routing procedures.

MDEQ has adapted the SCS method for use in Michigan (for calculation of peak flow only). The method referred to as MDEQ-SCS method is contained in the report *Computing Flood Discharges for Small Ungaged Watersheds* (Sorrell, 2001), which is included as Appendix 3-C. The report includes a description of the method's equations and concepts and an example problem.

3.4.5 Other Hydrograph Methods

There are many other methods that can be considered for calculating flow rates in watercourses not under MDEQ's floodplain regulatory authority. These methods are especially useful when a runoff hydrograph for a single event is needed. The majority of these methods can be used to size or confirm sizing of storage facilities (See Chapter 8, Stormwater Storage Facilities). Contact the Design Engineer - Hydraulics for approval prior to their use on MDOT projects.

A summary of some potential methods follows.

Method	Author	Typical Applications
EPA SWMM (Stormwater Management Model)	Environmental Protection Agency	• Urban watersheds • Consider effect of storage in channels, pipes, and basins • Surcharged storm drainage systems
TR-20/TR-55	Natural Resources Conservation Service (formerly SCS)	• Urban or rural watersheds • Consider effect of storage in channels and basins
HEC-1/HEC-HMS	U.S. Army Corps of Engineers	• Urban or rural watershed • Consider effect of storage in channels and basins

3.4.6 Methods Used for Watersheds Regulated by MDEQ

MDEQ will provide design discharge estimates for projects that are regulated under the Floodplain Regulatory Authority found in Part 31, Water Resources Protection, of the Natural Resources and Environmental Protection Act, 1994 PA 451, as amended (Part 31). These projects are typically on watersheds where other methods may be used. These methods may include:

- Regression analysis.
- Statistical analysis of stream flow record, if available.
- Computer runoff model or MDEQ - SCS Method.
- Drainage area ratio method.

Request for discharges from MDEQ must be made by the Design Engineer - Hydraulics/ Hydrology.

References

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U.S. Department of Transportation, Federal Highway Administration, *Urban Drainage Design Manual, HEC-22.* November 1996.

Wahl, Kenneth L. Transportation Research Board. National Academy of Sciences, Record Number 922. *Determining Stream Flow Characteristics Based on Channel Cross Section Properties*. 1983.

Water Resources Council Bulletin 17B. *Guidelines for Determining Flood Flow Frequency*. 1981.

Note: References in bold type are recommended references for the engineer's library.

Weblinks/Sources of Material

Federal Aid Policy Guides:

www.fhwa.dot.gov

Federal Emergency Management Agency:

www.fema.gov/cis/mi.pdf

- List of Michigan `communities participating in National Flood Insurance program

Michigan Department of Environmental Quality:

www.michigan.gov/deq/
go to water link

- Flood flow discharge database
- Flood Flow request form
- *Computing Flood Discharges for Small Ungaged Watersheds* (Sorrell)
- Revised HEC-1 executable code

Michigan Department of Transportation

- Standard plans/details: http://www.michigan.gov/mdot/0,1607,7-151-9622_11044_11357---,00.html
- Road/Bridge design manual: http://www.michigan.gov/mdot/0,1607,7-151-9622_11044_11367---,00.html

National Weather Service – National Climatic Data Center:

http://www.nws.noaa.gov

- Historical rainfall at selected sites

Southeastern Michigan Council of Governments:

www.semcog.org

- Historical rainfall at selected sites in Southeastern Michigan

United States Geological Survey:

www.usgs.gov

- Measured flows at gaged streams
- USGS maps are USGS maps (topographic maps) are available at the Office of Geological Surveys located in Lansing. Also, order them at USGS, Box 25286 Federal Center, Denver, Colorado 80225. The phone number to the Denver location is 1 (888) 275-8747.

United States Department of Agriculture

www.soils.usda.gov/survey/printed_surveys/michigan.html

- Soil surveys, The local office is located in East Lansing.

Natural Resources Conservation Service (formerly the Soil Conservation Service)

- Window TR_55 program is: www.wcc.nrcs.usda.gov/hydro/hydro-tools-models-wintr55.html Change the ordinates of the dimensionless hydrograph before using the program. At the main window, click on the picture of the graph (it is the 11th picture from the left.) A screen labeled "dimensionless unit hydrograph" appears. The ordinates for the dimensionless unit graph are: 0, 0.5, 1.0, 0.8, 0.6, 0.4, 0.2, 0.0. Click on done. Change the dimensionless unit hydrograph to these new numbers whenever using the program by choosing the new hydrograph at the main screen (labeled dimensionless unit hydrograph.

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