# CHAPTER 7

# HYDROLOGY

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## 7.1 Introduction

Hydrologic analysis is the most important step prior to the hydraulic design. It is needed to determine the rate of flow or volume of water the facility will need to convey or store. These discharges or volumes are essential to determine the type, size, location, and design of hydraulic facilities. In addition, hydrologic information is needed for many other purposes, such as supporting evidence during litigation.

## 7.2 Definitions

Definitions of many terms used in hydrology are included in the American Association of State Highway and Transportation Officials (AASHTO) glossary in this manual.

## 7.3 Hydrologic Study Types

Hydrologic studies for ODOT projects are usually one of five types:

- studies to determine peak discharge rates,
- studies to calculate peak discharge rates, flow volumes, and the relationship of flow rate and volume versus time,
- studies to calculate consecutive day low flows,
- studies to estimate mean daily exceedance flows, and
- studies to estimate the maximum discharge expected at a site based on flood records.

A hydrologic study to determine peak discharge rate estimates the greatest flow expected through the site or facility. Peak discharge rate is usually expressed as the flow in cubic feet per second (cfs) that is expected to be exceeded, on the average, only once in the specified recurrence interval. The recurrence interval is expressed in years. This peak flow is expected to occur during a moment, only. It is also called the “instantaneous peak flow.” Instantaneous peak flows are often used in the design of stormwater drainage systems, bridges, culverts, energy dissipators, and channels.

A hydrologic study is often done to determine the peak discharge rate, the discharge rate versus time relationship, and the discharge volume. This study is often called a “hydrograph analysis” because a hydrograph is an integral part of the procedure. A hydrograph is a graph or table of the time distribution of a hydraulic characteristic at a specified location. Typically the hydraulic characteristic is shown on the Y-axis and time is shown on the X-axis. The area under the hydrograph curve is the discharge volume when discharge versus time is displayed. Hydrograph studies are often used to design water storage and treatment facilities.

Fish passage designs, temporary water management facility designs, and temporary construction require discharge estimates for a portion of the year. This part of the year is not the flood season, in almost all applications. Discharge estimates are calculated for the months the structures or facilities will be in place. Consecutive daily low flows, exceedance discharges, and maximum predicted discharges are used.

## 7.4 Hydrology in the Design Process

Hydrology is estimated early in the design process. It is good practice to use more than one method as a sensitivity or reasonableness check. The results from these various methods are used as discharges in the hydraulic modeling of the existing site or structure, such as a bridge or culvert. The hydraulic performance of the site or structure shown by the model is compared to the hydraulic history. The hydrology that produces the most reasonable results, based on site history, is selected for the subsequent design.

*Note: Verify the design hydrology is reasonable by comparing with at least two other applicable methods. This is especially important for critical structures. There are local micro-climates in many areas of Oregon that are not well represented by certain methods. This comparison is usually sufficient to detect these circumstances and aid in selecting the appropriate hydrology method.*

Multiple hydrology methods can also be used for storm drain system analysis and design. Typically the drainage area upstream from the system outfall is sufficiently large to allow several methods to be used. The results are compared to each other and to the site history. The discharge at the outfall is estimated. This is done before the system is analyzed in detail. The next step is to analyze the system in detail, and to adjust the model, as needed, to produce an outfall discharge similar to the value calculated in the previous step.

## 7.5 Supporting Data for Hydrologic Studies

Supporting data are needed to perform a hydrologic study. It is available from many sources, such as published references, calculation results, and drainage surveys. These topics are discussed in this chapter and **Chapter 6**.

It is important to obtain or request hydrologic data early in the design process. Some information, such as Flood Insurance Study hydraulic models, need to be ordered well in advance of when they will be needed. Data collection, such as watershed surveys, may take several weeks or months to complete. Considerable hydraulic information is routinely collected during ODOT surveys. Usually additional information will be needed. It is the designer’s responsibility to obtain or request this additional information. A typical procedure to obtain supporting data follows.

**Step 1 -** Determine the type of facility to be designed. Various types of facilities require different kinds of hydrologic studies.

**Step 2 -** Determine the appropriate kind of hydrologic study for the facility. Usually the facility design needs either a study to determine peak flow rate or a hydrograph analysis. Fish passage facilities will need exceedance discharges and a consecutive day low flow analysis. Temporary water management for almost all facilities will require exceedance discharges. Critical features to be in place for a portion of the year may require an estimate of the maximum predicted discharge.

**Step 3 -** Determine suitable study methods. More than one method is used in many studies. The answers from the various methods are compared to each other and to the historic hydraulic performance of the site.

**Step 4 -** Review the procedures for each method and list the data requirements.

**Step 5 -** Obtain the supporting data.

As an example, a detention pond is to be designed. The facility design needs peak discharges, flow versus time relationships, and volume versus time relationships. The USGS Urban Regression Equations and the NRCS TR-55 method will be used to determine peak discharges. The NRCS TR-55 method will also be used to calculate the flow and volume versus time relationships.

The USGS procedure is reviewed. Drainage area characteristics are needed. They will be obtained from a USGS quadrangle map and a local Drainage Master Plan.

The TR-55 procedure is reviewed. It will need soil types and drainage path characteristics in addition to much of the information collected for the USGS method. Soil types will be obtained from the NRCS website. Drainage path characteristics will be obtained from a site visit.

## 7.6 Hydrologic Methods

Many hydrologic methods are available, and some of the more commonly used procedures are summarized in this section and presented in the chapter appendices.

Many of the methods presented in the appendices are available on computer programs. When using computer programs it is important to assure that regional and local data is inputted as much as possible. As an example, user-supplied rainfall intensity data for Oregon is preferred over the national rainfall intensity data included in some of the computer programs.

### 7.6.1 Outside Agency Hydrology

Communities and counties in Oregon adopt Drainage Master Plans to implement solutions to existing drainage problems and to assure that flooding will be minimized after land is developed. In addition, irrigation districts, drainage districts, power companies, and others have plans or procedures for their facility operation. These documents often include data that should be considered in the hydrologic study. This data is often called "outside agency hydrology." Outside agency hydrology almost always provides peak flow data, only.

There are many uses for outside agency hydrology. Its use can reduce the time used for design and save considerable expense. Use of outside agency hydrology may be required for hydraulic modeling to demonstrate the proposed hydraulic design conforms to local floodplain regulations or other standards.

Often the designer will make an independent hydrologic analysis to verify and supplement the outside agency hydrology. The designer should check the following before outside agency hydrology is used.

- Is the outside agency hydrology based on current data?
- Does the hydrology include the expected storm runoff?
- Have there been any changes in the drainage basin or facility since the current study, and do these changes make the outside agency hydrology invalid?
- Does the community or agency anticipate any changes to the current study?

### 7.6.2 Flood Insurance Studies

Flood Insurance Studies (FIS) for many Oregon waterways have been compiled for the Federal Emergency Management Agency (FEMA). The studies develop risk data to establish flood insurance rates and to assist communities in flood plain management. Detailed studies are made of flood prone areas using hydrologic and hydraulic analyses. These studies are used to determine the 10-year, 50-year, 100-year (base flood), and 500-year flood discharges, elevations, and water surface profiles; the 100-year and 500-year floodplain boundaries; and the 100-year floodway elevations and boundaries. The study results are adopted into many local ordinances. Peak discharges are listed in FIS. Hydrographic information, exceedances, or daily data are not included.

All ODOT projects in floodplains must be checked to see if they are in a floodway. The discharges and floodway boundaries in the FIS should be used in the analysis that shows that the project meets the floodway management ordinances if a project is in a floodway established by a detailed FIS. The FIS hydrology can also be used in the project design, except in the following circumstances.

- A credible independent analysis or community drainage master plan lists higher flows than the FIS. In these cases, the higher flows may be the more appropriate design values.

- Land use changes have occurred since the FIS that produce greater discharges than those listed in the FIS. In this instance, the higher discharges would be the design values.
- The project will be built to accommodate future flows that are higher than those listed in the FIS. In this case, the higher flows would be the design values.

A revision of the FIS hydrology can be requested if the FIS flows can be shown to be over or under estimated. The revised hydrology must be done by acceptable methods, and it may be used in the hydraulic study if the revision is approved by the appropriate regulatory agencies. Revision requests should only be undertaken after careful consideration. A revision request takes considerable resources and time to prepare, and an extended period is needed for review and approval. (Assume 1 year to 1.5 years to prepare, review, and obtain approval, if it is approved. Submitting a request to revise FEMA hydrology does not guarantee it will be approved.)

FIS hydrologic data is determined by examining the input or output from the applicable hydraulic model. These models are available from FEMA, and they use the U.S. Corps of Engineers Hydraulic Engineering Center - 2 (HEC-2) or the Hydraulic Engineering Center - River Analysis System (HEC-RAS) computer programs. FIS hydrologic data is also summarized in the FIS study text. The text summaries, however, do not always list all of the locations where the discharge rate changes in the hydraulic model. The designer should independently verify the following items when using FIS discharges.

- Is the hydrology realistic?
- Is the hydrology based on current data?
- Does the study reflect current basin conditions?
- Does the community anticipate any future changes to the current study?

### 7.6.3 Statistical Analysis of Stream Gage Data

Statistical analysis of stream gaging station records should be used if the gage is located on the stream and there are sufficient years of record. Twenty years are the minimum and at least 30 are preferred. The analysis results may need to be adjusted if the study site and the gage are at different locations on the stream, and the ratios of ungaged to gaged drainage areas are within specified limits. Formulae for these adjustments are in the appendices to this chapter, as follows:

- Western Oregon - Appendix B
- Eastern Oregon - Appendix C
- Arid Regions of Eastern Oregon - Appendix D

Statistical distributions based on gage data are periodically published by the USGS for many Oregon streams. The USGS Open-File Report 93-63 "Statistical Summaries of Streamflow in Oregon: Volume 2 - Annual Low and High Flow, and Instantaneous Peak Flow" lists statistical distributions. Distributions were also calculated during the development of the regional regression equations in Appendices B, C, and D, and they are listed in the publications.

The published statistical distributions are sufficiently accurate for most applications if the period of record used to develop the distribution includes all of the available streamflow data. If additional years of record are available, a new statistical analysis of the gage data should be made using the additional data.

The major source of stream gage records is from USGS, which collects flow data throughout the state. Gage data compiled by the USGS are published in an annual Oregon Water Resources Report. These reports are on file in the ODOT Geo-Environmental Section's Engineering and Asset Management Unit. USGS gage data is also available on the USGS website.

When a statistical analysis is desired and enough stream gage data is available, it should be analyzed using a log-Pearson Type III distribution. This method is appropriate, provided there are sufficient years of record. The log-Pearson Type III procedure in HEC-SSP or PEAKFQ provides peak flow estimates, only.

The Corps of Engineers HEC-SSP or USGS PEAKFQ programs use the statistical analysis method preferred by ODOT. The SSP procedure is described in the draft Corps of Engineers publication titled "HEC-SSP Statistical Software Package: User's Manual." The PEAKFQ method is described in the draft USGS publication titled "Users Manual for Program PEAKFQ, Annual Flood Frequency Analysis Using Bulletin 17B Guidelines." Typically, when ODOT uses this program:

- A weighted skew coefficient is used, and it is based on the station skew and the generalized skew coefficients. Generalized skew coefficients are shown on the map included with the March 1982 USGS Bulletin #17B titled "Guidelines for Determining Flood Flow Frequency." A skew map is provided in USGS Scientific Investigations Report 2005-5116 publication titled "Estimation of Peak Discharges for Rural, Unregulated Streams in Western Oregon" may be used for western Oregon, if desired.

- Flows are reported from the "COMPUTED CURVE" curve or table on the HEC-SSP or PEAKFQ output.

Hydrology based on a statistical analysis of gage data should be used with care. Many Oregon gaging stations have a relatively short period of record such as ten to twenty years. During the period when many of these stations were in operation, there was a major flood of 50 to 150-year recurrence interval, such as the 1964-65 flood, and a very dry year, such as 1978. These extreme events can distort a flow versus recurrence interval curve based on a short period of record. An unrealistic flood flow versus recurrence interval relationship can often be detected by a comparison with the statistical analyses in recent USGS publications of nearby gaging stations with longer periods of record. Another indicator of an unrealistic discharge versus recurrence interval relationship is how well the curve fits the plotted position of the gage data.

### 7.6.4 USGS Regression Equations

USGS regression equations are another method of determining flood flow versus recurrence intervals. They are often used when insufficient or no gage data is available, and they are applicable for these situations.

- A typical stream in the region used to develop the equations.
- Streams with no significant regulation or flow diversion upstream from the study site.
- Streams with drainage areas and other characteristics within the limits listed in the studies.

The rural equations calculate the 2-year through 100-year flows. The calculated flows are plotted on logarithmic probability paper and a best-fit line or curve is drawn through the data points to extrapolate the 500-year discharge. The urban equations provide the 2 through 500-year flows and extrapolation is not needed.

The USGS rural and urban regression equations are most often used to calculate peak discharges. The USGS has developed a method to calculate a runoff hydrograph for urbanized basins using the results of the USGS urban regression equations. This method is discussed in the Federal Highway Administration's Hydraulic Design Series No. 2 "Highway Hydrology." This procedure provides an alternative method to compare to the results of NRCS and Santa Barbara Urban hydrograph procedures.

#### 7.6.4.1 Regression Equations for Rural Western Oregon

Regression equations for western Oregon are in the USGS Scientific Investigations Report 2005-5116 "Estimation of Peak Discharges for Rural, Unregulated Streams in Western Oregon." A copy is in Appendix B. These regression equations are recommended for drainage basins with predominately rural land use.

#### 7.6.4.2 Regression Equations for Rural and Urban Eastern Oregon

Regression equations for eastern Oregon are in the USGS Open-File Report 82-4078 "Magnitude and Frequency of Floods in Eastern Oregon." A copy is in Appendix C. Rural and urban equations are included. These equations have been compiled into the USGS National Streamflow Statistics (NSS) Program. These equations are also included in the Hydrologic Modeling Module in the Federal Highway Administration's (FHWA's) Watershed Modeling System program.

#### 7.6.4.3 Regression Equations for Arid Regions of Rural Eastern Oregon

The 1994 USGS Open-File Report 93-419 "Methods for Estimating Magnitude and Frequency of Floods in the Southwestern United States" contains regression equations for a large part of eastern Oregon. The equations, limitations, and example problems are presented in Appendix D.

Regression equations in the USGS publication "Magnitude and Frequency of Floods in Eastern Oregon" can also be used for the area covered by the arid region equations. It is recommended that the discharge versus recurrence interval relationships be calculated by both methods in locations where either procedure can be used. The relationship that most closely matches the flood history of the site should be selected.

#### 7.6.4.4 Regression Equations for Urban Oregon

The nationwide regression equations described in the 1983 USGS Water-Supply Paper 2207 "Flood Characteristics of Urban Watersheds in the United States" by V.B. Sauer et al can be used to estimate peak discharges from urban watersheds. These equations are presented in Appendix E. The equations are used to determine:

- Quick, preliminary estimates for storm drain designs - especially outfalls.
- Checks of hydrology based on other methods. As an example, a check to verify the flows in a drainage master plan, or calculated by another method, are reasonable.
- Calculating peak discharges to use with the USGS urban hydrograph procedure.

This hydrologic method may not be appropriate in all urban situations. Land use development codes in urban areas may require other procedures. In addition, local drainage master plans often list the discharges to be used for proposed hydraulic structures.

### 7.6.5 Rational Method

One commonly used procedure for calculating peak flows from small drainages (200 acres or less) is the Rational Method. This method produces its most accurate results when used for runoff estimates from small drainages with large amounts of impervious area. Examples are housing developments, industrial areas, parking lots, etc. The Rational Method is included in Appendix F. There is also a Rational Method calculator available within the FHWA Hydraulics Toolbox program. It is also included in the Hydrologic Modeling Module in the FHWA Watershed Modeling System program. Input data such as runoff coefficients, rainfall information, etc., should be based on the procedures and information in the ODOT Hydraulics Manual when using this program.

### 7.6.6 Natural Resource Conservation Service Technical Release No. 55

The United States Natural Resources Conservation Service (NRCS), formerly the U.S. Soil Conservation Service (SCS), has developed Technical Release No. 55 (TR-55) method of determining peak flows and discharge versus time relationships for small urban and rural watersheds (watersheds with 24 hour or shorter times of concentration or areas of 25 square miles or less). The TR-55 method can also calculate the volumes of detention basins used to reduce peak flows. The method is presented in Appendix G. The appendix contains two NRCS publications. One publication, the "Oregon Engineering Handbook - Hydrology Guide" contains specific information about using the method in Oregon. The other publication, titled "Urban Hydrology for Small Watersheds" contains a detailed description of the method and its use.

The NRCS procedure can be done by hand calculations using the forms, tables, and graphs in the Appendix. It can also be done by computer using programs such as the NRCS TR-55 "Urban Hydrology for Small Watersheds" program.

The NRCS method requires much of the same basic data as the Rational Method, such as the drainage area, runoff factor, time of concentration, and rainfall characteristics. The NRCS 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 NRCS method, the direct runoff can be calculated for any storm, either real or fabricated, by subtracting infiltration and other losses from the amount of rainfall to obtain the precipitation excess.

This method requires information about soil types from NRCS and SCS soil surveys. Requests to the NRCS for soil type information should include the outline of the drainage basin drawn on a United States Geological Survey 7-1/2 - minute quadrangle map. The NRCS soil survey data is available at the Oregon NRCS website. The address is http://www.or.nrcs.usda.gov/pnw_soil/or_data.html

The TR-55 method requires the 24-hour rainfall data for 2-year through 100-year recurrence intervals. This information is shown on the maps in Appendix H. It is also available on the National Weather Service Western Regional Climatic Center website at this address: https://wrcc.dri.edu/Climate/precip_freq_maps.php

### 7.6.7 Other Hydrograph Methods

The TR-55 hydrograph method produces its best results when used for small to mid-sized basins. In addition, TR-55 cannot analyze some drainage features, such as diversions. Other methods are often used to calculate peak discharge rates and runoff hydrographs from larger or more hydraulically complex basins, such as the NRCS Technical Release No. 20, and the U.S. Corps of Engineers Hydraulic Engineering Center - Hydrologic Modeling System (HEC-HMS). These methods can also be used for smaller basins.

The Santa Barbara Urban Hydrograph procedure and other methods are often used for stormwater drainage, water quality, and water storage system design. These methods, as well as TR-20 and HEC-HMS are not included as appendices to this manual. Guidance in the chapter addressing specific subjects, such as stormwater drainage, storage, and water quality should be considered when using these procedures.

### 7.6.8 2-Year, 7-Consecutive Day Low Flows

A hydrologic analysis to determine consecutive day low flow estimates the lowest daily discharge expected for a period of consecutive days during an average year. ODOT fish passage design uses the two-year 7-consecutive day low flow. This is an estimate of the lowest daily discharge expected during seven consecutive days during the driest time of an average. This low flow is less than the mean daily discharge – except when the discharge does not change during the day. Consecutive day low flows are used in fish passage design. A procedure for estimating this discharge is in Appendix I.

### 7.6.9 Mean Daily Exceedance Discharges

Mean daily exceedance discharges provide statistical information about flows expected each day throughout a typical year. The exceedance discharge is the mean daily discharge that is expected to be exceeded for a specified number of days during the subject month. Usually this is expressed as a percentage of the days in the month. As an example, the 5 percent exceedance discharge is the mean daily flow expected to be exceeded 5 percent of the days of the month, or approximately 1.5 days a month. Exceedance discharges are used in temporary water management and fish passage design. This method is discussed in detail in Appendix J.

The exceedance discharges are, at best, a rough estimate of the discharge expected on any given day. They do not consider the fluctuations that occur throughout the day. There is almost always a daily peak and daily low flow higher and lower than the mean, respectively. In addition, the exceedance discharges represent a typical month in a typical year. They do not consider that the actual time of construction may be in month or year that is a wetter or drier than normal. As a result, extra allowance should be made in the design to account for discharges higher and lower than the listed discharges.

### 7.6.10 Maximum Predicted Discharges

A hydrologic analysis to determine the maximum predicted discharge estimates the greatest mean daily discharge expected through the site for the specified month. This estimate is based on records from nearby gaging stations. This discharge is used to design critical temporary water management facilities or critical temporary construction features to be in place for a portion of the year. The procedure is in Appendix K.

### 7.6.11 Flows Estimated by Flood Elevation Data

Historic flows can be calculated using surveyed high water marks. To do this, a stage versus discharge curve is calculated for the stream cross-section at the location of the high water mark. This process is described in **Chapter 8**. The historic flow is the discharge corresponding to the stage (elevation) of the high water mark. Water surface profiles at various discharges are available in published flood studies of many larger streams and rivers. Often an approximate stage-discharge curve can be calculated from these profiles.

### 7.6.12 Flash Floods

Some areas of Eastern Oregon are subject to occasional summer thunderstorms with high intensity rainfall. Localized flash floods can result when this type of storm occurs in basins with low soil permeability. Many times these floods will discharge out of normally dry draws or canyons. The local ODOT Area Maintenance Manager and/or local residents should be contacted for information on the basin's history of flash floods for drainage basins (less than 15 square miles) in Eastern Oregon.

The hydrology should be calculated with and without considering flash floods if the basin is found to have a high flash flood potential or had past flash floods. The higher discharges should be used in the design.

The design discharge in cubic feet per second considering flash floods can be estimated by the following regression equation:

$$\text{Average Flash Flood} = 300A^{0.637} \qquad \text{(Equation 7-1)}$$

The check flood in cubic feet per second considering flash floods is:

$$\text{High Flash Flood} = 535A^{0.637} \qquad \text{(Equation 7-2)}$$

Where:

A = Basin area in square miles ($mi^2$)

### 7.6.13 Nearby Gage Data Method

The nearby gage data method estimates site hydrology using statistical analyses of measured discharges in similar nearby basins. This procedure can be used to calculate design hydrology, or it can be used to verify the reasonableness of design hydrology calculated by other methods. This method is most appropriate in climatic areas that are not well represented by regional regression equations. This method includes the following steps.

1) Locate one or more nearby gaged basins with similar hydrological characteristics.
2) Analyze the gage data with a log-Pearson Type III distribution using Bulletin 17B procedures. Use a weighted skew based on regional and station coefficients. Calculate discharges and yields at the desired recurrence intervals.

*Note: Published discharges can be used if they are weighted as discussed. Weighted peak discharge in USGS Scientific Investigations Report 2005-5116 "Estimation of Peak Discharges for Rural, Unregulated Streams in Western Oregon, or weighted discharges from the Oregon Water Resources Department website "Estimation of Peak Discharges" program are not recommended for this purpose. They are weighted using a different method.*

3) Plot the relationship between basin yield and drainage area. An individual plot is needed for each recurrence interval. Approximate the data trend for each plot using a line or curve.
4) Calculate yields for the study basin based on the curves and the study basin drainage area.
5) Calculate the study basin discharges for each recurrence interval. This is determined by multiplying the predicted yields by the study drainage basin area.

This procedure is used to calculate 2-year 7-consecutive day low flows in Appendix I.