Chapter 16

HYDRAULIC SOFTWARE

ODOT ROADWAY DRAINAGE MANUAL

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16.1 OVERVIEW

16.1.1 Introduction

ODOT permits the use of a variety of computer software for hydrologic analysis and hydraulic design. The benefits of using software include the capability of quickly analyzing several alternative designs, of reducing the probability of mathematical errors, saving time by avoiding laborious hand calculations and by providing reproducible results. However, the user of any computer software should consider the following:

1. Understand the Principles Behind the Analysis Method. This understanding is essential to adequately discern whether the software provides an appropriate method of evaluating a problem. Engineering judgment and experience are often critical to this understanding.

2. Choose Inputs that are Consistent with Site Conditions. This usually requires thorough and careful field exploration and sometimes laboratory testing programs. Computer software provides the hydraulics designer with efficient tools for conducting parametric analyses and for evaluating uncertainties associated with input parameters.

3. Select Geometries and Boundary Conditions that are Representative of the Field Condition. For example, each channel cross section should contain the calculated highwater elevation. If this is not the case, the model may provide an inaccurate result.

4. Validate Results Using Simple Analytical or Empirical Checks or Alternate Analyses Methods. Sometimes, validations can be made using simpler geometries or conditions to confirm that the analysis is reasonable. Often, a simple hand calculation can be used to confirm whether the results are reasonable.

5. Obtain an Independent Review of the Results by Another Knowledgeable Person. This review should confirm the reasonableness of the problem being modeled, and the validity of the input information.

6. Ensure the Appropriate Units are Used in the Software. Review the software manual to ensure that the unit of measurement (e.g., in vs. ft, US Customary vs. metric) used is consistent with the input values.

7. Use Appropriate Number of Significant Digits when Presenting Results. Results from computer analyses can be obtained with several decimal points of accuracy. However, the uncertainty of input information usually does not justify this level of accuracy. In reports, present the results of the computer analyses to appropriate significant digits.

16.1.2 Chapter Content

This chapter is based on the AASHTO *Drainage Manual* (1), Chapter 5 Software and includes hydraulic software that is acceptable for use for ODOT drainage design applications. The chapter provides a brief description of the application and function of the software that can be used for

- estimating runoff (hydrology), Section 16.2.1;
- evaluating channels, Section 16.2.2;
- designing culverts, Section 16.2.3;
- designing storm drainage systems, Section 16.2.4;
- designing storage facilities, Section 16.2.5;
- assessing stream stability, Section 16.2.6; and
- designing bank protection, Section 16.2.7.

Other software may be used if the methodology used with the software is consistent with the procedures in this *Manual*.

16.1.3 Coordination with Other Chapters

Throughout this *Manual*, the text identifies, where applicable, any computer software that may be used for a specific drainage appurtenance or the text references the applicable section in this chapter. For example, Chapter 9 “Culverts” references the use of HY-8, FHWA Culvert Analysis Program for the hydraulic design of culverts, which is discussed in Section 16.2.3.

16.2 SOFTWARE

The software version that was available when this *Manual* was prepared is included. For current versions of software and software documentation, the hydraulics designer should consult the following web sites using a search engine:

- FHWA, Hydraulics Engineering;
- USGS Software;
- USGS StreamStats;
- USACE, HEC;
- USACE, CHL;
- NRCS, WinTR; and
- USBR, SRH.

User's and reference manuals are indicated with the software source and listed in the references. However, many software developers provide extensive help within the software in place of a user's manual. The software listed is public domain software or is software that state DOTs typically have licensed, or both.

16.2.1 Hydrology

Computer software is available for estimating the discharge for a given design frequency event from watersheds that are gaged or ungaged. Chapter 7 "Hydrology" provides background information on the procedures used within these software programs.

16.2.1.1 Gaged Watersheds

The PeakFQ program (see Figure 16.2-A) is used to analyze a continuous series of annual peak discharges for a gaged site so that the discharge for the design frequency can be obtained. The software reads annual peaks in the WATSTORE standard format and in the Watershed Data Management (WDM) format. Annual peak flows are available from NWISWeb. (Retrieve data in the WATSTORE standard format, not the tab-separated format). The StreamStats website provides access to data that has already been analyzed for gaged sites.

16.2.1.2 Ungaged Watersheds

The primary software for estimating peak discharge for ungaged streams is the USGS National Streamflow Statistics (StreamStats) software; see Figure 16.2-B.

Software Name	Features	Source
PeakFQ 5.2	Program PeakFQ provides estimates of instantaneous annual-maximum peak flows for a range of recurrence intervals, including 1.5, 2, 2.33, 5, 10, 25, 50, 100, 200 and 500 years (annual-exceedence probabilities of 0.6667, 0.50, 0.4292 0.20, 0.10, 0.04, 0.02, 0.01, 0.005 and 0.002, respectively). The Log-Pearson Type III frequency distribution is fit to the logarithms of instantaneous annual peak flows following Bulletin 17B guidelines of the Interagency Advisory Committee on Water Data. The parameters of the Log-Pearson Type III frequency curve are estimated by the logarithmic sample moments (e.g., mean, standard deviation, coefficient of skewness) with adjustments for low outliers, high outliers, historic peaks and generalized skew.	USGS website (2) (3) (4)
StreamStats	StreamStats program computes stream discharges for gaged sites at 7 frequencies: 2, 5, 10, 25, 50, 100 and 500-year flood. Basin characteristics, which are requires factors to run this program, including but not limited to: the drainage area, stream slope, mean annual precipitation, area controlled by NRCS flood retarding structures and percentage of forested area.	USGS website (5)

Figure 16.2-A — SOFTWARE FOR ANALYZING GAGED WATERSHEDS

Software Name	Features	Source
HEC-HMS 3.5	The Hydrologic Modeling System (HEC-HMS) is designed to simulate the precipitation-runoff processes of watershed systems. It is applicable to large river basin water supply and flood hydrology and small urban or natural watershed runoff. Hydrographs produced by the program are used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation and systems operation. Unit hydrograph methods include Clark, Snyder and NRCS techniques.	HEC website (6)
WinTR-20 1.11	The Computer Program for Project Formulation Hydrology (WinTR-20) is a single event watershed scale runoff and routing model. It computes direct runoff and develops hydrographs resulting from any synthetic or natural rainstorm. Developed hydrographs are routed through stream and valley reaches as well as through reservoirs. Hydrographs are combined from tributaries with those on the main stream. Branching flow (diversion) and baseflow can also be accommodated. WinTR-20 may be used to evaluate flooding problems, alternatives for flood control (e.g., reservoirs, channel modification, diversion) and impacts of changing land use on the hydrologic response of watersheds.	NRCS website (7)
WinTR-55 1.00.10	WinTR-55 is a single-event rainfall-runoff small watershed hydrologic model. The model generates hydrographs from both urban and agricultural areas and at selected points along the stream system. Hydrographs can be routed downstream through channels or reservoirs, or both. Multiple sub-areas can be modeled within the watershed. Use WinTR-20: • for watersheds with more than 10 sub areas, or • for watersheds larger than 25 sq mi.	NRCS website (8)

Figure 16.2-B — SOFTWARE FOR ANALYZING UNGAGED WATERSHEDS

Software Name	Features	Source
FHWA Hydraulic Toolbox 4.07	The FHWA Hydraulic Toolbox Program is a stand-alone suite of calculators that performs routine hydrologic and hydraulic computations. The program allows a user to perform and save hydraulic calculations in one project file, analyze multiple scenarios and create plots and reports of these analyses. The computations can be carried out in either CU or SI units. Nine calculators are available (see Figure 16.2-C). The calculator of interest for hydrology are: • Rational Method Hydrologic Analysis (HDS-2) • Detention Basin Analysis (HEC-22)	FHWA website (9)
StreamStats	StreamStats program computes stream discharges for un-gaged sites at 7 frequencies: 2, 5, 10, 25, 50, 100 and 500-year flood. Basin characteristics, which are requires factors to run this program, including but not limited to: the drainage area, stream slope, mean annual precipitation, area controlled by NRCS flood retarding structures and percentage of forested area.	USGS website (5)

Figure 16.2-B — SOFTWARE FOR ANALYZING UNGAGED WATERSHEDS (continued)

16.2.2 Channels and Floodplains

16.2.2.1 Roadside Channels (Uniform Flow)

Roadside channels, culvert tailwater channels and constructed channels that have a uniform cross section can be assessed using a single representative cross section and the channel slope (see Chapter 8 “Channels”). Software for calculating steady, uniform flow using Manning’s equation combined with the continuity equation is the FHWA Hydraulic Toolbox (see Figure 16.2-C). If the channel does not have a uniform cross section in the direction of flow, then a gradually varied flow analysis program as described in the next section may need to be used.

16.2.2.2 Natural Channels (Gradually Varied Flow)

Natural channels or streams that can be represented by a series of cross sections that are taken perpendicular to the assumed flow direction (one-dimensional flow) can be analyzed with a computer program that utilizes the step-backwater analysis procedure. The primary software for computing a steady, gradually varied flow profile is HEC-RAS (see Figure 16.2-D). The hydraulic properties for the cross sections of interest can be averaged and used to design bank protection or other countermeasures to bank erosion (see Chapter 14 “Bank Protection” and Section 16.2.9).

Software Name	Features	Source
FHWA Hydraulic Toolbox 4.07	The FHWA Hydraulic Toolbox Program is a stand-alone suite of calculators that performs routine hydrologic and hydraulic computations. The program allows a user to perform and save hydraulic calculations in one project file, analyze multiple scenarios and create plots and reports of these analyses. The computations can be carried out in either CU or SI units. Ten calculators are available: 1. Channel Analysis (HEC-15) 2. Channel Lining Design Analysis (HEC-15) 3. Weir Analysis (HEC-22) 4. Curb and Gutter Analysis (HEC-22) 5. Median/Ditch Drop-inlet Analysis (HEC-22) 6. Rational Method Hydrologic Analysis (HDS-2) 7. Detention Basin Analysis (HEC-22) 8. Riprap Analysis (HEC-23 and HEC-14) 9. Wolman Count Analysis 10. Culvert Assessment Analysis	FHWA website (9)

Figure 16.2-C — SOFTWARE FOR CALCULATING STEADY, UNIFORM FLOW

Software Name	Features	Source
HEC-RAS 4.1	HEC-RAS contains four one-dimensional river analysis components for: (1) steady flow water surface profile computation, (2) unsteady flow simulation, (3) moveable boundary sediment transport computations and (4) water quality analysis. For steady flow water surface profile computation, the system can handle a full network of channels, a branching system or a single river reach. The steady flow component is capable of modeling subcritical, supercritical and mixed flow regimes water surface profiles. The basic computational procedure is based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction (Manning's equation) and contraction/expansion (coefficient multiplied by the change in velocity head). • The momentum equation may be used in situations where the water surface profile is rapidly varied. These situations include mixed flow regime calculations (e.g., hydraulic jumps), hydraulics of bridges and evaluating profiles at river confluences (e.g., stream junctions). • The effects of various obstructions (e.g., bridges, culverts, weirs, structures) in the floodplain may be considered in the computations. The steady flow system is designed for application in floodplain management and flood insurance studies to evaluate floodway encroachments. Also, capabilities are available for assessing the change in water surface profiles due to channel improvements and levees. • Special features of the steady flow component include multiple plan analyses, multiple profile computations, multiple opening analysis (bridge or culvert, or both) and split-flow optimization.	HEC website (10)

Figure 16.2-D — SOFTWARE FOR CALCULATING STEADY, GRADUALLY VARIED FLOW

16.2.3 Culverts

Computer software is available for computing the hydraulics of culverts and energy dissipators in open channels that follow the procedures outlined in Chapter 9 "Culverts" and Chapter 11 "Energy Dissipators." The primary software used is HY-8 (see Figure 16.2-E). HY-8 assumes a headwater pool at the entrance (no approach velocity) and that all the velocity head is loss at the exit (standard method) or conserved Utah State University (USU) method. If the culvert being designed is for a constructed channel where energy conservation is important, the HEC-RAS software (see Figure 16.2-E) should be used. If the site conditions warrant the use of a broken-back culvert, the HY-8 software (see Figure 16.2-E) should be used.

Software Name	Features	Source
HY-8 7.3	The FHWA Culvert Hydraulic Analysis Program (HY-8) enables users to analyze culvert performance for a highway crossing that has multiple culvert barrels that share the same tailwater and roadway overtopping. HY-8 uses HDS-5 procedures and includes: • culvert configurations with constants in HDS-5 Appendix A: Table A.1 (circles, boxes and tapered), Table A.2 (pipe-arches, ellipses, metal boxes and arches), Tables A.3 SDDOT RCB, Table A.4 CON/SPAN, Table A.5 embedded circular and Table A.6 embedded elliptical. User-defined shapes use Chart 52; • embedded or depressed invert design; • Utah State University (USU) outlet transition loss; • energy dissipator analysis (HEC-14); • internal hydraulic jumps; • broken-back barrel analysis; and • project documentation.	FHWA website (11) (12) (13)
HEC-RAS 4.1	See HEC-RAS listing in Figure 16.2-D. For culverts, HEC-RAS *Hydraulic Reference Manual* Chapter 6 references HDS-5 inlet control constants. HEC-RAS includes: • culvert configurations with constants in HDS-5 Appendix A (Tables A.1, A.2 and A.4) ; • embedded invert analysis; and • inlet and outlet transition loss (e.g., coefficient times velocity head difference).	HEC website (10)

Figure 16.2-E — SOFTWARE FOR DESIGNING CULVERTS

16.2.4 Storm Drainage Systems

Storm drain system design starts with collecting surface drainage with inlets and transporting the water collected to an outfall in a system of pipes (i.e., storm drain). Software is available for evaluating inlets (i.e., FHWA Hydraulic Toolbox, curb and gutter calculator) or StormCAD (see Figure 16.2-F). The software listed is consistent with the procedures in Chapter 12 "Storage Facilities."

Software Name	Features	Source
FHWA Hydraulic Toolbox 4.07	The FHWA Hydraulic Toolbox Program is a stand-alone suite of calculators that perform routine hydrologic and hydraulic computations (see Figure 16.2-C). The Curb and Gutter Analysis feature can be used to size inlets.	FHWA website (9)
StormCAD V8i	StormCAD is a commercially available software for the design and analysis of storm drain systems using a peak flow (Rational Method) approach. StormCAD provides calculations for catchment runoff, gutters, inlets, conduit networks and outfalls. Inlet capacity is calculated according to the methodology described in HEC-22 (2^{nd} Edition). Alternatively, users can enter a maximum capacity, percent efficiency, gutter flow—capture curve or gutter depth—capture curve to define the capacity of an inlet. Headloss at junctions are computed according to a number of different methodologies, including HEC-22, flow-headloss curve, standard method and generic method.	Bentley.com (14)

Figure 16.2-F — SOFTWARE FOR DESIGNING STORM DRAINS

16.2.5 Storage Facilities

An overview of storage facility design is discussed in Chapter 12 "Storage Facilities." The effect of existing storage facilities on flood peaks can be evaluated using the FHWA Hydraulic Toolbox (see Figure 16.2-G). If a culvert outlet is used, HY-8 can be used to determine a headwater-elevation curve that can be imported into the calculator so that the storage facility can be fine-tuned.

Software Name	Features	Source
FHWA Hydraulic Toolbox 4.07	The FHWA Hydraulic Toolbox Program is a stand-alone suite of calculators that performs routine hydrologic and hydraulic computations (see Figure 16.2-C). The Detention Basin Analysis option uses the procedures in HEC-22. Hydrograph coordinates, stage storage information and culvert performance curve can be input by hand or copied from a spreadsheet. The output is a routed hydrograph.	FHWA website (9)
HEC-HMS 3.5	The Hydrologic Modeling System (HEC-HMS) summary in Figure 16.2-B. The *User's Manual*, Chapter 6, discusses how to model a reservoir.	HEC website (6)

Figure 16.2-G — SOFTWARE FOR STORAGE FACILITIES

16.2.6 Stream Stability

Software is available for assessment of the lateral and vertical stability of streams. A summary of stabilization techniques is found in Chapter 14 “Bank Protection.” Stream stability is routinely assessed visually in the field. For evaluating a reach of floodplain that includes multiple cross sections, HEC-RAS and SRH-1D models can be used (see Figure 16.2-H).

Software Name	Features	Source
HEC-RAS 4.1	See HEC-RAS listing in Figure 16.2-D. See Chapter 13 Sediment Modeling of the *Hydraulic Reference Manual*. HEC-RAS uses a quasi-unsteady flow assumption to approximate a continuous hydrograph with a series of discrete steady flow profiles. For each record in the flow series, flow remains constant over a specified time window for transport. The steady flow profiles are easier to develop than a fully unsteady model and program execution is faster. (An unsteady version of sediment transport is planned for a future release).	HEC website (10)
SRH-1D V3.0	Sedimentation and River Hydraulics - One Dimension (SRH-1D) is a one-dimensional mobile boundary hydraulic and sediment transport computer model for rivers and manmade canals. Simulation capabilities include steady or unsteady flows, internal boundary conditions, looped river networks, cohesive and non-cohesive sediment transport and lateral inflows. The model uses cross section based river information. The software includes a manual and example files.	USBR website (15)

Figure 16.2-H — SOFTWARE FOR ASSESSING STREAM STABILITY

16.2.7 Bank Protection

An overview of bank protection design is discussed in Chapter 14 “Bank Protection,” which contains procedures for the design of riprap and gabions. Both of these revetment systems can be designed using the FHWA Hydraulic Toolbox or the USACE CHANLPRO software (see Figure 16.2-I). Bank protection for uniform channels can be designed using the FHWA Hydraulic Toolbox, channel analysis or channel calculator (see Figure 16.2-C).

Software Name	Features	Source
CHANLPRO	The CHANLPRO numerical modeling system was developed by the US Army Corps of Engineers (USACE), Coastal and Hydraulics Laboratory (CHL). CHANLPRO replaces RIPRAP15 and addresses three areas pertinent to the design of channel protection: Riprap design guidance for placement in the dry for channels subjected to velocity forces in low turbulent flow based on guidance found in (16). For underwater placement, riprap thickness from CHANLPRO should be increased by 50%. Gabion mattress design for the same flow conditions as the riprap design guidance. The gabion sizing guidance is based on (17). Estimating scour depth in erodible channels based on guidance given in (18).	USACE, CHL website (19)
FHWA Hydraulic Toolbox 4.07	The FHWA Hydraulic Toolbox software is a stand-alone suite of calculators that performs routine hydrologic and hydraulic computations (see Figure 16.2-C). The Channel Lining Design Calculator uses HEC-15 tractive force methods for determining rock size for rock lining and for assessing gabions. The Riprap Design Calculator includes the HEC-23 riprap sizing equations for channel revetment, bridge piers, bridge abutments or guide banks, channel spur, embankment overtopping, open bottom culvert and wave attack. The calculator also includes culvert outlet riprap sizing equation from HEC-14 and filter design.	FHWA (9)

Figure 16.2-I — SOFTWARE FOR DESIGNING BANK PROTECTION

16.3 REFERENCES

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