Chapter 18

HYDRAULIC SOFTWARE

SOUTH DAKOTA DRAINAGE MANUAL

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Table of Contents

List of Figures

Figure **Page**

Chapter 18
HYDRAULIC SOFTWARE

18.1 OVERVIEW

18.1.1 Introduction

SDDOT uses a variety of computer software for hydrologic/hydraulic analysis and design. The benefits of using software include the capability of quickly analyzing several alternative designs, of reducing the probability of mathematical errors and of saving time by avoiding laborious hand calculations. 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 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 unconservative 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.

18.1.2 Chapter Content

This Chapter includes hydraulic software that is acceptable for use by SDDOT for 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 18.2.1;
- evaluating channels, Section 18.2.2;
- designing culverts, Section 18.2.3;
- designing storm drainage systems, Section 18.2.4;
- designing storage facilities, Section 18.2.5;
- assessing stream stability, Section 18.2.6;
- designing bridge waterway openings, Section 18.2.7; and
- designing bank protection, Section 18.2.8.

Other software may be used if the methodology used with the software is consistent with the procedures in this *Manual*, and if acceptable to SDDOT. Contact the SDDOT Bridge Hydraulic Engineer for approval.

18.1.3 Coordination with *Drainage Manual*

Throughout the *South Dakota Drainage 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 Chapter 18. For example, Chapter 10 "Culverts" references the use of HY-8, FHWA Culvert Analysis Program for the hydraulic design of culverts.

18.2 SOFTWARE

The software is grouped by *Manual* chapters. The software version that was available when the *Manual* was prepared is included. For current versions of software and software documentation, the designer should consult the following web sites:

- FHWA;
- USGS Software;
- USGS Stream Stats;
- USACE, HEC;
- USACE, CHL;
- NRCS;
- USBR; and
- NDOR.

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 (e.g., WMS, SMS, HY-8).

18.2.1 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.

18.2.1.1 Gaged Streams

The PeakFQ program (see Figure 18.2-A) is used to analyze a continuous series of annual peak discharges 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, which is under development, will simplify this process.

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-exceedance 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 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 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 (References (1), (2) and (3))
StreamStats	StreamStats makes streamflow statistics for gaged sites available without the need to locate, obtain and read the publications in which they were originally provided. Examples of streamflow statistics that can be provided by StreamStats include the 100-year flood, the mean annual flow and the 7-day, 10-year low flow. Examples of basin characteristics include the drainage area, stream slope, mean annual precipitation and percentage of forested area. Basin characteristics are the physical factors that control delivery of water to a point on a stream. StreamStats is undergoing development for South Dakota.	USGS website (Reference (4))

Figure 18.2-A — FLOOD FREQUENCY ANALYSIS BASED ON BULLETIN 17B

18.2.1.2 Ungaged Streams

The primary software for estimating peak discharge for ungaged streams is the USGS National Streamflow Statistics (NSS) software; see Figure 18.2-B. Similar software based on the National Flood Frequency (NFF) is also available in the Watershed Management System (WMS) software; see Figure 18.2-B. If a hydrograph is needed, WMS can be used to generate a hydrograph using either the HEC-HMS or TR-20/TR-55 procedures. These procedures can also be used directly; see Figure 18.2-B.

Software Name	Features	Source
NFF 3.2	The USGS published peak flow regression equations for every State were first compiled into the NFF software that was last updated in 2004. The functionality of the software has been incorporated into the USGS NSS software and WMS.	USGS website (Reference (5))
NSS 4.0b	The NSS software developed by the USGS contains peak flow regression equations for every State (Reference (6)). The software can be used to: • obtain estimates of flood frequencies for sites in rural (non-regulated) ungaged basins, • obtain estimates of flood frequencies for sites in urbanized basins, • estimate maximum floods based on envelope curves developed by Crippen and Bue (1977), • create hydrographs of estimated floods for sites in rural or urban basins and manipulate the appearance of the graphs, and • create flood-frequency curves for sites in rural or urban basins and manipulate the appearance of the curves.	USGS website (Reference (7))
WMS 8.3	The Watershed Modeling System (WMS) is a comprehensive graphical modeling environment for all phases of watershed hydrology and hydraulics. WMS includes powerful tools to automate modeling processes such as automated basin delineation, geometric parameter calculations, GIS overlay computations (e.g., CN, rainfall depth, roughness coefficients), cross-section extraction from terrain data and many more. With the release of WMS 8, the software now supports hydrologic modeling with HEC-1 (HEC-HMS), TR-20, TR-55, Rational Method, NFF, MODRAT, OC Rational and HSPF. The FHWA has licensed WMS for State DOTs until 2012.	Aquaveo website (Reference (8))

Figure 18.2-B — SOFTWARE FOR UNGAGED WATERSHEDS

Software Name	Features	Source
HEC-HMS 3.4	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 (Reference (9))
WinTR20 1.11	The WinTR-20 model is a storm event surface water hydrologic model applied at a watershed scale. The model can be used to analyze current watershed conditions, as well as assess the impact of proposed changes (alternatives) made within the watershed. Multiple storms (i.e., rainfalls by frequency) can be analyzed within one model run. A summary table for all alternatives and storms within the run can be produced. Direct runoff is computed from watershed land areas resulting from synthetic or natural rain events. The runoff is routed through channels and/or impoundments to the watershed outlet. The model assists in the hydrologic evaluation of flood events for use in the analysis of water resource projects.	NRCS website (Reference (10))
WinTR-55 1.00.09	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 and/or reservoirs. 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 (Reference (11))

Figure 18.2-B — SOFTWARE FOR UNGAGED WATERSHEDS
(Continued)

Software Name	Features	Source
StreamStats	The output from StreamStats for ungaged sites appears in a pop-up Web browser window. The ungaged site reports list only the basin characteristics that are used in the NSS regression equations for the hydrologic region in which the site is located. The reports will always include at least one table for peak-flow basin characteristics and one table for peak-flow statistics. StreamStats is undergoing development for South Dakota.	USGS website (Reference (4))

Figure 18.2-B — SOFTWARE FOR UNGAGED WATERSHEDS
(Continued)

18.2.2 Channels

Computer software is available for computing the hydraulics of open channels. If the flow is steady uniform flow in a constructed channel or one with a cross section that does not vary within the reach of interest, Chapter 9 "Roadside Channels" and Chapter 14 "Bridge Hydraulics" provides the assumptions and procedures that are used. Chapter 15 "Bank Protection" provides background information on the procedures that should be used when the flow is assumed to be gradually varied in a natural channel.

18.2.2.1 Steady, Uniform Flow

Roadside channels, (see Chapter 9 "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. Software for calculating steady, uniform flow using Manning's equation combined with the continuity equation is the FHWA Hydraulic Toolbox (see Figure 18.2-C) or the WMS channel calculator.

18.2.2.2 Gradually Varied Flow

Natural channels or streams are represented by a series of cross sections that are taken perpendicular to the assumed flow direction; see Chapter 14 "Bridge Hydraulics." The primary software for computing a steady, gradually varied flow profile is HEC-RAS (see Figure 18.2-D). The hydraulic properties for the cross sections of interest can be averaged and used to design bank protection (see Chapter 15 "Bank Protection" and Section 18.2.8) or other countermeasures to bank erosion.

Software Name	Features	Source
FHWA Hydraulic Toolbox 1.0	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. Five calculators are available: • Channel Analysis (HEC 15, 1988) • Weir Analysis (HEC 22) • Rational Basin Analysis (HDS 3) • Detention Basin Analysis (HEC 22) • Curb and Gutter Analysis (HEC 22)	FHWA website (Reference (12))
WMS 8.3, Channel Calculator	The Channel Calculator is a feature of the WMS, Hydrologic Modeling Module (see WMS discussion in Figure 18.2-B). Click on Calculators on the Menu Tool Bar to display the available calculators. The Channel Calculator determines the shear stress for the given discharge and uses the allowable shear stress for the lining selected to determine the safety factor.	Aquaveo website (Reference (8))

Figure 18.2-C — SOFTWARE FOR CALCULATING STEADY, UNIFORM FLOW

Software Name	Features	Source
HEC-RAS 4.1	HEC-RAS computes one-dimensional steady flow, unsteady flow, sediment transport/mobile bed computations and water temperature modeling. For steady flow water surface profiles, 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. Also: • 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 bridge and/or culvert opening analyses and split-flow optimization.	HEC website (Reference (13))

Figure 18.2-D — SOFTWARE FOR STEADY, GRADUALLY VARIED FLOW

18.2.3 Culverts

Computer software is available for computing the hydraulics of culverts and energy dissipators in open channels that follow the procedures outlined in Chapter 10 "Culverts" and Chapter 11 "Energy Dissipators." The primary software used is HY-8 (see Figure 18.2-E). HY-8 assumes a headwater pool at the entrance (no approach velocity) and that all the velocity head is loss at the exit. If the culvert being designed is for a constructed channel where energy conservation is important, the HEC-RAS software (see Figure 18.2-E) should be used. If the site conditions warrant the use of a broken-back culvert, the BCAP software (see Figure 18.2-E) should be used.

Software Name	Features	Source
HY-8 7.2	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 includes: • all culvert shapes in HDS 5, plus Con/Span and user-defined shapes; • buried invert design; • USU outlet transition loss; • improved inlet analysis; • energy dissipator analysis; and • project documentation.	FHWA website (References (14) and (15))
HEC-RAS 4.1	See HEC-RAS listing in Figure 18.2-D. For culverts, HEC-RAS *Hydraulic Reference Manual* confirms that the HDS 5 procedures are used. HEC-RAS includes: • all culvert shapes in HDS 5, plus Con/Span; • buried invert analysis; and • outlet transition loss (e.g., coefficient times velocity head difference).	HEC website (Reference (13))
BCAP 4.11c	Broken-back Culvert Analysis Program provides hydraulic analysis for steep culverts having one (single broken-back) or two (double broken-back) breaks in the vertical profile. BCAP uses the same routines as the FHWA HY-8 culvert program to determine headwater depth at the culvert entrance. BCAP then calculates the water surface profile through the entire culvert, using Gradually Varied Flow equations and boundary conditions at each vertical break. The program tests for the occurrence of a hydraulic jump in each culvert segment to help determine outlet depth and velocity.	NDOR website (References (16) and (17))

Figure 18.2-E — CULVERT DESIGN SOFTWARE

18.2.4 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 evaluating the entire system with WMS or StormCAD (see Figure 18.2-F). The software listed is consistent with the procedures in Chapter 12 "Storm Drainage Systems." Neither the FHWA Hydraulic Toolbox nor WMS include a circular deck drain in their Curb and Gutter Calculator.

Software Name	Features	Source
FHWA Hydraulic Toolbox 1.0	The FHWA Hydraulic Toolbox Program is a stand-alone suite of calculators that perform 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. Five calculators are available: • Channel Analysis (HEC 15, 1988); • Weir Analysis (HEC 22); • Rational Basin Analysis (HDS 3); • Detention Basin Analysis (HEC 22); and • Curb and Gutter Analysis (HEC 22).	FHWA website (Reference (12))
WMS 8.3, Curb and Gutter Calculator	The Curb and Gutter Calculator is a feature of the WMS, Hydrologic Modeling Module (see WMS discussion in Figure 18.2-B). Click on Calculators on the Menu Tool Bar to display the available calculators. The Curb and Gutter Calculator determines the width of spread for a given discharge or the discharge for a given spread.	Aquaveo website (Reference (8))
WMS 8.3, Storm Drain	After the Map Module is selected, the entire storm drain model is developed from the storm drain and optional drainage coverages. The storm drain coverage is used to define the pipe network system and the attributes associated with each node. The storm drain coverage can be connected to a surface drainage coverage to pass the computed hydrograph (or use the defined Rational Method parameters) to the linked nodes.	Aquaveo website (Reference (8))

Figure 18.2-F — SOFTWARE FOR DESIGNING STORM DRAINS

Software Name	Features	Source
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 (2nd 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 (Reference (18))

Figure 18.2-F — SOFTWARE FOR DESIGNING STORM DRAINS
(Continued)

18.2.5 Storage Facilities

An overview of storage facility design is discussed in Chapter 13 "Storage Facilities." The effect of existing storage facilities on flood peaks can be evaluated using the FHWA Hydraulic Toolbox or WMS Detention Basin Analysis (see Figure 18.2-G). If the inflow hydrograph and proposed storage facility size is known, the WMS Detention Basin Hydrograph Routing Calculator (see Figure 18.2-G) can be used to determine, by trial-and-success, the sizes and types of outlets that are needed. 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 1.0	The FHWA Hydraulic Toolbox Program is a stand-alone suite of calculators (see Figure 18.2-C) 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 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 (Reference (12))
WMS 8.3	Routing is discussed in the Help topic "Storage," which focuses on including storage in a HEC-1 run. However, a similar process is followed for including storage in a TR-20 run. After the Hydrology Module is selected, an outlet point is established in the model. If the reservoir routing option is specified, then one method for volume and one method for outflow must be defined.	Aquaveo website (Reference (8))
WMS 8.3, Detention Basin Hydrograph Routing	The Detention Basin Hydrograph Routing Calculator is a feature of the WMS, Hydrologic Modeling Module (see WMS discussion in Figure 18.2-B). Click on Calculators on the Menu Tool Bar to display the available calculators. After an outlet has been established, the calculator can be selected. The calculator performs a reservoir routing after a user-defined volume elevation curve for storage and user-defined headwater elevation curve for the outlet have been entered.	Aquaveo website (Reference (8))
HEC-HMS 3.4	The Hydrologic Modeling System (HEC-HMS) summary in Figure 18.2-B. The *User's Manual*, Chapter 6, discusses how to model a reservoir.	HEC website (Reference (9))
PondPack V8i	PondPack is commercially available software for the design of storage facilities. Rainfall or hydrograph information can be used for input. The storage facility can be specified or designed. The outlet culvert hydraulics is calculated using HDS 5 procedures.	Bentley.com (Reference (19))

Figure 18.2-G — SOFTWARE FOR RESERVOIR ROUTING

18.2.6 Stream Stability

Software is available for assessment of the lateral and vertical stability of streams. A summary of the methods for assessing stability is found in Chapter 14 "Bridge Hydraulics" and a summary of stabilization techniques is found in Chapter 15 "Bank Protection." Stream stability is routinely assessed visually in the field. If the visual inspection indicates a concern, a quick evaluation can be accomplished using SAMwin, and a cross section of interest (see Figure 18.2-H). For evaluating a reach of floodplain that includes multiple cross sections, HEC-RAS and SRH-1D models can be used (see Figure 18.2-H).

Software Name	Features	Source
SAMwin	The SAM Hydraulic Design Package for Channels is designed to provide hydraulic engineers a smooth transition from making hydraulic calculations, to calculating sediment transport capacity, to making sediment yield determinations. The three main modules of the package can be used in series, as described, or their separate capabilities utilized to aid in various hydraulic design situations: • SAM.hyd calculates the width, depth, slope and n-values for stable channels in alluvial material. (The riprap size can also be calculated using Equation 15.4). • SAM.sed calculates sediment transport capacity according to a wide range of sediment transport functions, usually using the hydraulic parameters calculated in SAM.hyd. • SED.yld uses the sediment transport capacity calculated in SAM.sed to calculate the sediment yield. Channel stability can then be evaluated in terms of the cost of maintaining the constructed channel.	Ayres Associates (Reference (19))
HEC-RAS 4.1	See HEC-RAS listing in Figure 18.2-D. For sediment routing, see Chapter 13 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 (Reference (13))
SRH-1D	Sedimentation and River Hydraulics - One Dimension (SRH-1D), formerly known as GSTAR-1D, is a hydraulic and sediment transport numerical model developed to simulate flows in rivers and channels with or without movable boundaries. 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.	USBR website (Reference (21))

Figure 18.2-H — SOFTWARE FOR ASSESSING STREAM STABILITY

18.2.7 Bridge Hydraulics

Software is available for computing the hydraulics of bridge waterways (Chapter 14 "Bridge Hydraulics") using both one-dimensional (1-D) and two-dimensional (2-D) models.

18.2.7.1 1-D Bridge Hydraulics

The 1-D models are consistent with the procedures outlined in Chapter 14 "Bridge Hydraulics." The primary software used is HEC-RAS (see Figure 18.2-I), which uses multiple cross sections to compute a steady flow water surface profile. HY-8 may also be used for structures that are considered bridges (see Figure 18.2-I). Because HY-8 assumes that the headwater is ponded at the entrance (i.e., no approach velocity) and that all the velocity head is loss at the exit, the computed headwater should be more conservative than a HEC-RAS solution.

18.2.7.2 2-D Bridge Hydraulics

The 2-D models simulate flow in two directions, longitudinal and transverse, at a series of user-defined node points. Flow in the vertical direction is assumed to be negligible. These models can account for transverse flow due to lateral velocities and water surface gradients that cannot be accounted for with 1-D models. Examples of such conditions include:

- skewed bridges,
- floodplain crossings with multiple openings,
- channel bifurcation,
- flow around channel bends, and
- flow around islands.

A 2-D model, such as SMS (see Figure 18.2-J), should be considered for major projects with complex flow patterns that 1-D models cannot adequately analyze. Examples of situations where 2-D models should be considered are as follows:

- wide floodplains with multiple openings, particularly on skewed embankments;
- floodplains with significant variations in roughness or complex geometry (e.g., ineffective flow areas, flow around islands, multiple channels);
- sites where more accurate flow patterns and velocities are needed to design better and cost-effective countermeasures (e.g., riprap along embankments, abutments); and
- high-risk or sensitive locations where losses and liability costs are high.

Software Name	Features	Source
HEC-RAS 4.1	See HEC-RAS listing in Figure 18.2-D. For bridges, HEC-RAS *Hydraulic Reference Manual* Chapter 5 discusses the bridge modeling approaches available. For low flow (e.g., water surface is below the maximum low chord of the bridge deck), the user can select any or all of the four available methods (e.g., energy, momentum, WSPRO, Yarnell). For high flows, the user must choose between energy based methods or the pressure and weir approach. HEC-RAS can analyze multiple openings that share the same headwater and tailwater.	HEC website (Reference (13))
HY-8 7.2	See HY-8 listing in Figure 18.2-E. HY-8 enables users to analyze bridge sized culverts performance for a highway crossing. In addition, multiple openings (e.g., bridge-sized culvert with culverts on the floodplain) that share the same tailwater and roadway overtopping may be analyzed.	FHWA website (References (14) and (15))

Figure 18.2-I — 1-D BRIDGE DESIGN SOFTWARE

Software Name	Features	Source
SMS 10.1	The Surface Water Modeling System (SMS) is a comprehensive environment for one-, two- and three-dimensional hydrodynamic modeling. A pre- and post-processor for surface water modeling and design, SMS includes 2D finite element, 2D finite difference and 3D finite element modeling tools. Supported models include RMA2, RMA4, FESWMS, TUFLOW, HYDRO AS-2D, ADCIRC, CMS-Flow, CMS-Wave STWAVE, BOUSS-2D and CGWAVE, models. The FHWA analysis package FESWMS includes options for modeling bridges and highways. The FHWA has licensed SMS for State DOTs until 2012.	Aquaveo website (Reference (23))

Figure 18.2-J — 2-D BRIDGE DESIGN SOFTWARE

The NCHRP "Criteria for Selecting Hydraulic Models" (Reference (22)) has developed a decision tool in the form of a decision matrix and guidelines for its application. This tool provides a formal procedure for selecting the most appropriate model for a particular application incorporating site conditions, design elements, available resources and project constraints.

18.2.8 Bank Protection

An overview of bank protection design is discussed in Chapter 15 "Bank Protection," which contains procedures for the design of riprap that are similar to Section 15.7 and gabions (Section 15.8). Both of these revetment systems can be designed using the USACE CHANLPRO software (see Figure 18.2-K). Bank protection for uniform channels can be designed using the FHWA Hydraulic Toolbox, channel analysis or WMS, channel calculator (see Figure 18.2-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 Reference (25). For underwater placement, riprap thickness from CHANLPRO should be increased by 50 percent. • Gabion mattress design for the same flow conditions as the riprap design guidance. The gabion sizing guidance is based on Reference (26). • Estimating scour depth in erodible channels based on guidance given in Reference (27).	USACE, CHL website (Reference (24))

Figure 18.2-K — SOFTWARE FOR BANK PROTECTION

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