Appendix 11-D
STORMWATER COMPUTER MODELS

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11-D.0. INTRODUCTION

In urban stormwater management there are typically three types of models used commonly: *hydrologic*, *hydraulic* and *water quality* models. There are also a number of other specialty models to simulate ancillary issues (some of which are sub-sets of the three main categories) such as sediment transport, channel stability, lake quality, dissolved oxygen and evapotranspiration. This Appendix includes information about a number of useful models, some in the public domain and available for free, and others that are proprietary, for which prices can vary dramatically. The models described in this Appendix are some of the most popular models in current use, but inclusion of their descriptions does not constitute any endorsement of their use by DEQ or the Commonwealth of Virginia.

Hydrologic Models attempt to simulate the rainfall-runoff process to tell us “how much runoff, how often.” They use rainfall information or simulations and land cover characteristics to provide runoff characteristics including peak flow rates, flood hydrographs and flow frequencies. Hydrologic models can be:

- ***Deterministic*** **–** giving one answer for a specific input set, OR
- ***Stochastic*** – involving random inputs giving any number of responses for a given set of parameters.

- ***Single Event*** **–** simulating one storm event.
- ***Continuous*** **–** simulating many storm events over a period of time, OR

- ***Lumped*** **–** representing a large watershed by a single set of parameters, OR
- ***Distributed*** – watersheds are broken into many small homogeneous subwatersheds, each of which has a complete hydrologic calculation made on it.

Hydraulic Models take a known flow amount (typically the output of a hydrologic model) and provide information about flow height, location, velocity, direction and pressure. Hydraulic models share some of the differing characteristics of hydrologic models (continuous vs. single event) and add:

- ***One-dimensional*** – calculating flow information in one direction (e.g. downstream) only, OR
- ***Multi-dimensional*** – calculating flow information in several dimensions (e.g. in and out of the channel and downstream). Two-dimensional models are particularly useful when the overall channel pattern changes and bank erosion are concerns.

- ***Steady*** **–** having a single unchanging flow velocity value at a point in the system, OR
- ***Unsteady*** **–** having flow velocities that change with time at a point in the system.

- ***Uniform*** – a state of steady flow when the mean velocity and cross-sectional area remain constant over distance in all sections of a reach (assuming the channel slope and energy slope are equal), OR
- ***Non-uniform*** – a state of dynamic flow over distance (derived by solving a more complex formulation of the energy and momentum equations).

For most problems encountered in hydraulics, a simple one-dimensional, steady model will work well. But if the volume and time distribution of flow are important (for example, in a steeper stream with storage behind a series of high culvert embankments) or the behavior of a channel over a storm hydrograph is needed, then an unsteady model is called for. If there is a need to predict with accuracy the ebb and flow of floodwater out of a channel (for example in a wide, flat floodplain where there are relief openings under a road) or bank erosion potential, then a 2-dimensional model becomes necessary. If pressure flow and the accurate computation of a hydraulic grade line are important, then an unsteady, non-uniform model with pressure flow calculating capabilities is needed.

Water Quality Models: The goal in water quality modeling is to adequately simulate the various processes and interactions of stormwater pollution. Water quality models have been developed with an ability to predict loadings of various types of stormwater pollutants.

Water quality models can become very complex if the complete cycle of buildup, wash-off and impact are determined. These models share the various features of hydrologic and hydraulic models in that it is the runoff flow that carries the pollutants. Therefore, a continuous hydrologic model with estimated pollution concentrations becomes a continuous water quality pollution model. Water quality models can reflect pollution from both point and nonpoint sources.

Water quality models tend to have applications that are targeted toward specific pollutants, source types or receiving waters. Some models involve biological processes as well as physical and chemical processes. Often great simplifications or gross assumptions are necessary to be able to model pollutant accumulations, transformations and eventual impacts. Such simplifications cannot be disregarded when interpreting model results.

Simple spreadsheet-based loading models involve an estimate of the runoff volume which, when multiplied by an event mean concentration, provide an estimate of the total pollution loading. Because of the lack of ability to calibrate such models for variable physical parameters, such simple models tend to be more accurate when they reflect a longer time period over which the pollution load is averaged. An annual pollutant load prediction may tend toward a central estimate, while any specific storm prediction may be grossly in error when compared to actual loadings because antecedent conditions vary widely from week to week. In reality, it is easy for one storm to discharge a lot of P and N that can then get masked by a lot of smaller storms. Unless each storm’s loading is considered (which can also be done rather simply using spreadsheet programs), we may not be able to accurately identify the actual sources of these inputs, which must be addressed to effectively reduce stormwater pollution.

On the other hand, simulation models have the ability to adjust a number of loading parameters for calibration purposes and can simulate pollution accumulation over a long period. They can then more reliably predict loadings for any specific storm event.

Calibration data is always recommended in hydrologic or hydraulic models for an acceptably accurate answer. In water quality models the non-calibrated prediction is often off by orders of magnitude. Water quality predictions are not credible without adequate site-specific data for calibration and verification. However, even without specifically accurate loading values, the relative effects of pollution abatement controls *can* be tested using uncalibrated models. But actual site-specific data should be incorporated whenever possible. Sampling is at a point where a small amount of localized data can be easily collected, and will significantly improve the model's results.

Computer Model Applications. Stormwater computer models can also be categorized by their use or application:

- ***Screening-level models*** are typically equations or spreadsheet models that give a first estimate of the magnitude of urban runoff quality or quantity. Sometimes this is the only level that is necessary to provide answers, when the answer needs to be only approximate or because there is no data to justify a more refined procedure. The user should then consider efforts to collect more data in order to utilize more sophisticated models to achieve a more robust answer.
- ***Planning-level models*** are used to perform "what if" analyses, comparing design alternatives or control options in a general way. They are used to establish flow frequencies, floodplain boundaries, and general pollution loading values.
- ***Design-level models*** are oriented toward the detailed simulation of a single storm event for the purposes of urban stormwater design. They provide a more complete description of flow or pollution values anywhere in the system of concern and allow for adjustment of various input and output variables in some detail. They can be more exact in the impact of control options, and tend to have a better ability to be calibrated to fit observed data.
- ***Operational models*** are used to produce actual control decisions during a storm event. They are often linked with SCADA systems. They are often developed from modified or strongly calibrated design models, or can be developed on a site-specific basis to appropriately link with the system of concern and accurately model the important physical phenomena.

11-D.1.0. THE MODELING PROCESS

The overall modeling process involves: (1) development of study or model objectives, (2) identification of resources and constraints, (3) selection and implementation of the model itself, and finally, (4) identification of the data needed to run the model.

11-D.1.1. Model Objectives

It is important to know specifically what answers are needed, to what accuracy, and in what format. Requiring a simple peak flow is far different from needing to know the timing of peaks from several different intersecting watersheds. Estimating future floodplain elevations along a reach is a fundamentally different problem than finding the probability of roadway overtopping.

A review of the problem begins the process of determining the model objectives. These objectives also establish a performance or design criteria for the model. Must the system handle the 25-year storm? Are future conditions important? Which ones? Are annual loadings of pollution adequate? Which pollutants?

Those aspects of the system to be modeled will dictate what models are appropriate for use. For example, if storm sewers are present then an open channel model can be ruled out as an appropriate model for the entire system. If a specific type of hydraulic structure is present that a standard model cannot handle, an alternate way to simulate that structure will be necessary. Model objectives also explain how the numbers generated from the model will relate to the needs of the study. For example, if a cost-benefit analysis is required, the model results must be interpreted in terms of overall life-cycle cost and not simply in terms of discharge rate.

11-D.1.2. Model Constraints

Availability of data, funds, time and user ability can potentially constrain modeling solutions. The goal of any modeling effort is to develop an approach that stays within the constraints dictated while addressing the needs of the study identified in the previous step. Data collection/availability and cost are usually the chief constraints.

Sources of existing available data should be researched. Look for data that tends to “ground truth” model outputs. Even partial data can be useful if it helps to validate the model or modeling results. After existing data sources have been identified, the need to gather additional data is assessed. Automated processes and systems such as GPS can reduce both cost and human error. A consideration of the long-term use of data and its maintenance is necessary. For example, if the model is to eventually become an operational model, the ability to maintain the data in a cost effective way becomes of paramount importance.

Accuracy and the corresponding necessary level of detail are of overriding importance. Accuracy depends on both the accuracy of the input data and the degree to which the model adequately represents the hydrologic, hydraulic or water quality processes being modeled. For example, if lumped hydrologic parameters are adequate, then the cost of the modeling effort can be reduced. However, the ability to determine information within the sub-basin represented by a single parameter is lost. Changing model needs from an average 500-acre sub-basin size to a 50-acre size can increase the cost of a model almost 10-fold. Is the additional information derived worth the additional cost?

Both risk and uncertainty affect the modeler’s ability to predict results accurately. Risk is an estimated chance of an occurrence, such as flooding. Uncertainty is the error associated with measuring or estimating key parameters or functions. Uncertainty arises due to errors in sampling, measurement, estimation and forecasting, and modeling. For hydrologic and hydraulic analysis, stage and discharge are of prime importance. Uncertainty in discharge is due to short or non-existent flood records, inaccurate rainfall-runoff modeling, and inaccuracy in known flood flow regulation where it exists. Stage uncertainty comes from errors and unknowns in roughness, geometry, etc.

Accuracy developed in one area can be impacted by rough estimates in another, negating the technological gains. For example, the gains in accuracy from very precise field surveys of cross sections can be lost if the estimates of roughness coefficients or discharge rates are very approximate.

Sensitivity analysis involves holding all parameters constant except one and assessing the change in the output variable of concern based on a certain percent change in the input variable. Those variables that are amplified in the output should be estimated with higher accuracy and with a more detailed consideration of the potential range of values and the need for conservative design. The modeler must try to assess how accurate estimates are and account for risk and uncertainty through estimating the range of potential error and choosing values that balance conservative engineering with cost consciousness. The designer typically develops a "most likely" estimate of a certain design parameter (for example, 10-year storm rainfall or Manning's roughness coefficient) and then uses sensitivity analysis to test the impact of variability in the parameter estimate on the final solution.

11-D.1.3. Selection and Implementation

Once the model objectives and constraints have been evaluated, the model (or models) is selected and the study or design is implemented. Typical steps in model implementation include validation, calibration, verification and production.

Validation involves a determination that the model is structured and coded as intended for the range of variables to be encountered in the study. Validation tests key algorithms for accuracy. For example, if a hydrologic model cannot handle short time steps or long time periods it cannot be used without modification. If a certain model begins to lose accuracy at high or low imperviousness or cannot accurately handle backwater situations, and these will be encountered in practice the model cannot be used. Often validation is a one-time effort, after which the modeler is comfortable with the model’s “quirks” and knows how to deal with them. Validation often involves pushing parameters to the limit of reasonable extent to test an algorithm. For example, in a hydrologic model infiltration can be reduced to zero to test if the input and output hydrographs are equal. Or the model can be run with small rainfalls using porous soils to determine if no runoff is generated, or only runoff from directly connected impervious areas.

Calibration is the comparison of a model to field measurements, other known estimates of output (e.g. regression equations), or another model known to be accurate, and the subsequent adjustment of the model to best fit those measurements. ***Verification*** then tests the calibrated model against another set of data not used in the calibration. This step is not always possible due to the general shortage of data of any sort in stormwater management. Goodness of prediction is done through a simple comparison of the difference in observed and predicted peaks, pollution loads, flood elevations or volumes divided by the observed values and expressed as a percentage, or as simple ratio. Assessing the goodness of fit of a hydrograph is done by calculating the sum of the squares of the difference between observed and predicted values at discreet time steps.

Once the model is prepared for use, attention shifts to efficient ***production*** methods that minimize the potential for errors while maximizing efficiency. Often “production line”-type efforts are used for large modeling projects. However, constant attention must be paid to ensure the execution of correct procedures, detailed documentation of efforts and input/output data sets, and recognition of anomalies that would invalidate a particular model run.

While it may be enticing to use simple user interfaces and black box approaches that simplify the input and output processes, there is an inherent danger that the modeler will not be aware of errors or problems that these may mask in the modeling process. For example, in hydraulic modeling, shifts from super-critical flow to sub-critical flow happen at sharp break points and are reflected in a jump in water surface elevation. If these changes are not detected, a model may under-predict flow elevation. Numeric instability in mathematical algorithms may give oscillating answers that have nothing to do with reality. Therefore, it is very important to understand the governing equations and principles that form the basis of the model being used. A structured review process must be established to ensure that accurate input values are being used in order to ensure a reasonable output. Labeling of data sets should be systematic and exact.

The consideration of all that is involved in using models can seem to be daunting. However, the complexities involved do not inhibit individuals who understand models and have experience using them. Furthermore, the benefits of using models may provide worthwhile cost-efficiencies in program implementation. So the use of models should not be easily discounted just because of their complexities.

11-D.2. SUMMARY OF COMMONLY USED MODELS

Computer models can be simple, representing only a very few measured or estimated input parameters or can be very complex involving twenty times the number of input parameters. The “right” model is the one that: (1) the user thoroughly understands, (2) gives adequately accurate and clearly displayed answers to the key questions, (3) minimizes time and cost, and (4) uses readily available or collected information. Complex models used to answer simple questions are not an advantage. However, simple models that do not model key necessary physical processes are inadequate and practically useless.

There is no one engineering model or software that addresses all hydrologic, hydraulic and water quality situations. Design needs and troubleshooting for watershed and stormwater management occur on several different scales and can be either system-wide (i.e., watershed) or localized. System-wide issues can occur on both large and small drainage systems, but generally require detailed watershed models and/or design tools. The program(s) chosen to address these issues should handle both major and minor drainage systems. Localized issues also exist on both major and minor drainage systems, but unlike system-wide problems, flood and water quality solution alternatives can usually be developed quickly using simple engineering methods and design tools.

Table 11-D.-1 below lists several widely-used computer programs and modeling packages. The programs have been examined for their applicability to both system-wide and localized issues, the methodologies used for computations, and ease-of-use.

Table 11-D.1. Stormwater Modeling Programs and Design Tools

Model	Major System Modeling	Minor System Modeling	Hydrologic Features	Hydraulic Features	Water Quality Features
Hydrology Software					
HEC-GeoHMS	X		X		
HEC-HMS	X		X		
TR-55			X		
TR-20			X		
PondPack*		X	X	X	
WMS*	X		X		
Watershed Modeling*	X		X		
Hydraulic Software					
HEC-GeoRAS	X			X	
HEC-RAS	X			X	
WSPRO	X			X	
EPA SWMM	X	X	X	X	X
FHWA HY-8 Culvert Analysis		X		X	
CulvertMaster*		X		X	
FlowMaster*		X		X	
Water Quality Software					
VA Runoff Reduction Method		X	X		X
HSPF	X		X		X
BASINS	X		X	X	X
QUAL2E	X			X	X
WASP5	X			X	X
SLAMM*	X		X		X
NOTES: * Proprietary Model					

Source: Adapted from ARC (2001)

For the purposes of this table, major drainage systems are defined as those draining to larger receiving waters. These are typically FEMA-regulated streams, or lakes or reservoirs. Minor drainage systems are smaller natural and man-made systems that drain to the more major streams. Minor drainage systems can have both closed and open-channel components and can include, but are not limited to, neighborhood storm sewers, culverts, ditches, and tributaries. Following the Table, a brief description of each program's capabilities and methodologies is presented.

11-D.2.1. Hydrology Programs

11-D.2.1.1. HEC-GeoHMS: Geospatial Hydrologic Modeling System

HEC-GeoHMS is a user-friendly Windows-based geospatial hydrology toolkit developed by the U.S. Army Corps of Engineers and partners for engineers and hydrologists with limited GIS experience. The program allows users to visualize spatial information, document watershed characteristics, perform spatial analyses, delineate sub-basins and streams, construct inputs to hydrologic models, and assist with report preparation.. HEC-GeoHMS, which interfaces with the ESRI ArcGIS 9.3 software.

Hydrologic modeling has evolved to represent the sub-basin in more detail than the traditional approach, where hydrologic parameters are averaged over large watersheds. With the availability of radar rainfall and spatial data, hydrologic modeling using smaller sub-basin areas or a grid system has introduced a more detailed representation of the watershed. HEC-GeoHMS is designed to meet the needs of both modeling approaches.

HEC-GeoHMS creates background map files, basin model files, meteorologic model files, and a grid cell parameter file that can be used by HEC-HMS to develop a hydrologic model. The basin model file contains hydrologic elements and their hydrologic connectivity. The basin model file includes sub-basin areas and other hydrologic parameters that could be estimated using geospatial data. To assist with estimating hydrologic parameters, HEC-GeoHMS can generate tables containing physical characteristics of streams and watersheds. The grid cell parameter file is required in order to use the ModClark transform method, grid-based precipitation (like radar rainfall), or gridded loss methods.

HEC-GeoHMS allows the user to analyze digital elevation models (DEMs) in a number of coordinate systems and projections. It also allows users to use a more sophisticated technique to impose the stream network and watershed boundaries onto the terrain.

11-D.2.1.2. HEC-HMS: Hydrologic Modeling/Flood Hydrograph System

HEC-HMS replaces HEC-1, which is no longer used. It has more user-friendly input and output processors and graphical capabilities than HEC-1. It is considered by many in the engineering and regulatory communities to be a leading model for major drainage system applications such as Flood Insurance Studies and watershed master.

In the HEC-HMS model, the watershed is represented as an interconnected system of hydrologic (e.g., sub-basins, reservoirs, ponds) and hydraulic (e.g., channels, closed conduits, pumps) components. The model computes a runoff hydrograph for each component, combining two or more hydrographs as it moves downstream in the watershed. The model has a variety of rainfall-runoff simulation methods, including the popular USDA-NRCS (formally SCS) Curve Number methodology. The user can define rainfall events using gage or historical data, or HEC-GeoHMS can generate synthetic storms. Hydrograph generation is performed using the unit hydrograph technique. Clark, NRCS Dimensionless, and Snyder Unit Hydrographs are the available methodologies. Several common channel and storage routing techniques are available as well.

HEC-HMS is not considered a “design tool.” However, there are other hydrologic applications developed within the software that have been used with much success. Multiplan-multiflood analyses allow the user to simulate a number of flood events for different watershed situations (or plans). The dam safety option enables the user to analyze the impact of dam overtopping or structural failure on downstream areas. Flood damage analyses can be used to assess the economic impact of flood damage.

11-D.2.1.3. USDA-NRCS Technical Release 55 (TR-55)

The TR-55 model was originally a DOS-based software package used for estimating runoff hydrographs and peak discharges for small urban watersheds. There is now a MS-Windows based version (WinTR55). The model was developed by the USDA-NRCS and therefore uses NRCS hydrograph methodology to estimate runoff, derived from TR-20 (discussed next). No other methodology is available in the program. Four 24-hour regional rainfall distributions are available for use. Rainfall durations less than 24-hours cannot be simulated. Using detailed input data entered by the user, the WinTR55 model can calculate the area-weighted CN, time of concentration and travel time. Detention pond (i.e., storage) analysis is also available in the WinTR55 model, intended for initial pond sizing. Final design requires a more detailed analysis. TR-55 has become a more robust model that can provide quick estimated answers.

WinTR55 is easy-to-use. Haestad Methods, Inc., included most of the TR-55 capabilities in its PondPack program, described below.

11-D.2.1.4. USDA-NRCS Technical Release 20 (TR-20)

TR-20 was actually the pre-cursor to TR-55 and is more complex. In addition to the outputs generated by TR-55, TR-20 (which has been converted into WinTR20) will also generate storm routings and both the rising and falling curves of hydrographs at specified time intervals. Like WinTR55, WinTR20 is a more robust model now that can also provide quick estimated answers.

11-D.2.1.5. PondPack

PondPack, by Haestad Methods, Inc., is Windows-based software developed for modeling general hydrology and runoff from site development. The program analyzes pre- and post-development watershed conditions and sizes detention ponds. It also computes outlet rating-curves with consideration of tailwater effects, accounts for pond infiltration, calculates detention times and analyzes channels.

Rainfall options are unlimited. The user can model any duration or distribution, for synthetic or real storm events. Several peak discharge and hydrograph computation methods are available, including NRCS, the Rational Method and the Santa Barbara Unit Hydrograph procedure. Infiltration can be considered, and pond and channel routing options are available as well. Like TR-55, PondPack allows the user to calculate hydrologic parameters, such as the time of concentration, within the program.

PondPack has limited, but useful hydraulic features, using Manning's equation to model natural and man-made channels and pipes. A wide variety of detention pond outlet structure configurations can be modeled, including low flow culverts, weirs, riser pipes, and even user-defined structures.

11-D.2.1.6. Watershed Modeling System (WMS)

WMS was developed by the Engineer Computer Graphics Laboratory of Brigham Young University. WMS is a Windows-based user interface that provides a link between terrain models and GIS software, with industry-standard lumped parameter hydrologic models, including HEC-1, TR-55, TR-20 and others. The hydrologic models can be run from the WMS interface. The link between the spatial terrain data and the hydrologic model(s) gives the user the ability to develop hydrologic data that is typically gathered using manual methods from within the program. For example, when using NRCS methodologies, the user can delineate watersheds and sub-basins, determine areas and curve numbers, and calculate the time of concentration at the computer. Typically, these computations are done manually, and are laborious and time-consuming. WMS attempts to use digital spatial data to make these tasks more efficient.

11-D.2.1.7. Watershed Modeling

The Watershed Modeling program was developed to compute runoff and design flood control structures. The program can run inside the MicroStation CAD system. Like WMS, this feature enables the program to delineate and analyze the drainage area of interest. Area, curve number, land use and other hydrologic parameters can be computed and/or catalogued for the user, removing much of the manual calculation typically performed by the hydrologic modeler.

Watershed Modeling contains a variety of methods to calculate flood hydrographs, including NRCS, Snyder and Rational methods. Rainfall can be synthetic or user-defined, with any duration and return period. Rainfall maps for the entire U.S. are provide to help the user calculate IDF relationships. Several techniques are available for channel and storage routing. The user also has a wide variety of outlet structure options for detention pond analysis and design.

11-D.2.2. Hydraulics Programs

11-D.2.2.1. HEC-GeoRAS: Geospatial River Analysis System

HEC-GeoRAS creates a file of geometric data for import into HEC-RAS and enables viewing of exported results from RAS. The import file is created from data extracted from ArcGIS layers and from a digital terrain model (DTM). HEC-GeoRAS requires a DTM represented by a triangulated irregular network (TIN) or a GRID. The layers and the DTM are referred to collectively as the *RAS Layers*. Geometric data are developed based on the intersection of the RAS Layers.

Prior to performing hydraulic computations in HEC-RAS, the geometric data must be imported and completed, and flow data must be entered. Once the hydraulic computations are performed, exported water surface and velocity results from HEC-RAS may be imported back to the GIS using HEC-GeoRAS for spatial analysis. GIS data is transferred between HEC-RAS and ArcGIS using a specifically formatted GIS exchange file.

11-D.2.2.2. HEC-RAS: River Analysis System

HEC-RAS is a Windows-based hydraulic model developed by the Corps of Engineers to replace the popular, DOS-based HEC-2 model. RAS has the ability to import and convert HEC-2 input files and expounds upon the capabilities of HEC-2. Since its introduction several years ago, the user-friendly HEC-RAS has become known as an excellent model for simulation of major systems (i.e., open channel flow) and has become the chief model for calculating floodplain elevations and determining floodway encroachments for Flood Insurance Studies. Like HEC-2, HEC-RAS has been accepted for FIS analysis by the FEMA. However, HEC-RAS is a much easier model to use than HEC-2 as it has an extremely useful interface that provides the immediate capability to view model input and output data in graphical, tabular, and report formats.

HEC-RAS performs one-dimensional analyses for steady, unsteady, and mixed flow water surface profiles, using the energy equation. Energy losses are calculated using Manning's equation. Contraction and expansion changes in the specific energy are considered around bridges, culverts, etc. Rapidly varied flow (e.g., hydraulic jumps) is modeled using the momentum equation. The effects of in-stream structures (e.g., bridges, culverts, weirs and floodplain obstructions) and in-stream changes (e.g., levees and channel improvements) can be simulated. The model allows the user to define the geometry of the channel or structure to the level of detail required by the application. One popular and useful feature of the HEC-RAS model is the capability to easily facilitate floodway encroachment analysis. Five encroachment methods are available to the user.

HEC-RAS4 provides the ability to conduct steady, unsteady, and mixed flow analyses. RAS4 includes sediment transport analysis with choices for the analyzing using surface or substrate bed sediments and simulating up to 5 layers within the channel bed. There are 5 choices of computation including those better suited to cohesives, non-cohesives, predominantly sand and gravel bedload, and predominantly suspended sediment transport. There is an analysis option that will allow the user to use a range of sediment transport equations within a single simulation to be sure that the different grain sizes are treated appropriately. *RAS4 also includes water quality simulations*. Linked with HEC-GeoRAS, the HEC-RAS model provides the capability to import GIS data for channel geometry and export HEC-RAS output for floodplain and floodway delineation.

11-D.2.2.3. WSPRO

WSPRO was developed by the USGS to compute water surface profiles for one-dimensional, gradually varied, steady flow. Like HEC-RAS, WSPRO can develop profiles in subcritical, critical and supercritical flow regimes. WSPRO is designated HY-7 in the Federal Highway Administration (FHWA) computer program series and its original objective was analysis and design of bridge openings and embankment configurations. Since then, the model has been expanded to model open channels and culverts.

Open channel computations use standard step-backwater techniques. Flow through bridges is simulated using an energy-balancing technique that uses a coefficient of discharge and estimates an effective flow length. Pressure flow under bridges is simulated using orifice-type flow equations developed by the FHWA. Culvert flow is simulated using FHWA techniques for inlet control and energy balance for outlet control.

WSPRO is considered a fairly easy-to-use DOS-based model applicable to water surface profile analysis for highway design, flood insurance studies, and establishing stage-discharge relationships. However, the original form of the model is not Windows-based and therefore does not have the useful editing and graphical features found in HEC-RAS, nor does it do anything that HEC-RAS doesn’t do. Like HEC-RAS, a third party software developer (the Scientific Software Group) has designed SMS (Surface Water Modeling Software) to support both pre- and post-processing of WSPRO data.

11-D.2.2.4. EPA-Storm Water Management Model (SWMM)

EPA-SWMM was developed by the Environmental Protection Agency (EPA) to analyze storm water quantity and quality problems associated with runoff from urban areas. For many years EPA SWMM has been the model of choice for simulation of minor drainage systems primarily composed of closed conduits. The model can simulate both single-event and continuous events and has the capability to model both wet and dry weather flow. The basic output from SWMM consists of runoff hydrographs, pollutographs, storage volumes and flow stages and depths.

SWMM's hydraulic computations are link-node based, and are performed in separate modules, called blocks. The EXTRAN computational block solves complete dynamic flow routing equations to simulate backwater, looped pipe connections, manhole surcharging and pressure flow. SWMM is the most comprehensive model with respect to its capabilities to simulate urban storm flow, and many cities have used it successfully for storm water, sanitary, or combined sewer system modeling. Open channel flow can be simulated using the TRANSPORT block, which solves the kinematic wave equations for natural channel cross-sections.

Although represented here as a hydraulic model, SWMM has both hydrologic and water quality components. Hydrologic processes are simulated using the RUNOFF block, which computes the quantity and quality of runoff from drainage areas and routes the flow to the major sewer system lines. Pollutant transport is simulated in tandem with hydrologic and hydraulic computations, which calculate pollutant buildup and washoff from land surfaces and pollutant routing, scour and in-conduit suspension in flow conduits and channels.

EPA SWMM is a public domain, DOS-based model. For large watersheds with extensive pipe networks, input and output processing can be tedious and confusing. Because of the popularity of the model, third-party commercial enhancements to SWMM have become more common, making the model a strong choice for minor system drainage modeling. Examples of commercially enhanced versions of EPA SWMM include MIKE-SWMM, distributed by BOSS International, XPSWMM by XP-Software, and PCSWMM by Computational Hydraulics Inc (CHI). CHI also developed PCSWMM-GIS, which ties the SWMM model to a GIS platform.

11-D.2.2.5. FHWA HY-8 Culvert Analysis

HY-8 is a computerized implementation of FHWA culvert hydraulic approaches and protocols. The FHWA has been producing computerized culvert hydraulic software since the early 1960's (with the HY-1 program). HY-8 Culvert Analysis automates the design methods described in FHWA publications HDS-5, "Hydraulic Design of Highway Culverts," HEC-14, "Hydraulic Design of Energy Dissipators for Culverts and Channels," and HEC-19, "Hydrology." The FHWA released the initial DOS-based version of the HY-8 program in the early 1980's. FHWA released the original Windows version (7.0) in March 2007 and the latest phase update (7.2) in August 2009). The HY-8 program has successfully operated on all current "flavors" of the Windows operating system. The HY-8 program is available at no charge to the hydraulic and transportation communities.

11-D.2.2.6. CulvertMaster

CulvertMaster, developed by Haestad Methods, Inc., is an easy-to-use, Windows-based culvert simulation and design program. The program can analyze pressure or free surface flow conditions and subcritical, critical and supercritical flow conditions, based on drawdown and backwater. A variety of common culvert shapes and section types are available. Tailwater effects are considered and the user can enter a constant tailwater elevation, a rating curve, or specify an outlet channel section. Culvert hydraulics are solved using FHWA methodology for inlet and outlet control computations. Roadway and weir overtopping are checked in the solution of the culvert.

CulvertMaster also has a hydrologic analysis component to determine peak flow using the Rational Method or the SCS Graphical Peak Method. The user also has the option of entering a known peak flow rate. The user must enter all rainfall and runoff information (e.g., IDF data, rainfall depths, curve numbers, C coefficients, etc).

11-D.2.2.7. FlowMaster

FlowMaster, also developed by Haestad Methods, Inc., is a Windows-based hydraulic pipe and channel design program. The user enters known information on the channel section or pipe, and allows the program to solve for the unknown parameter(s), such as diameter, depth, slope, roughness, capacity, velocity, etc. Solution methods include Manning's equation, the Darcy-Weisbach formula, Hazen-Williams formula, and Kutter's Formula. The program also features calculations for weirs, orifices, gutter flow, ditch and median flow and discharge into curb, grated, and slot inlets.

11-D.2.3. Water Quality Programs

11-D.2.3.1. Virginia Runoff Reduction Method

The Virginia Runoff Reduction Method (RRM) is a compliance tool developed for DEQ by the Center for Watershed Protection. The RRM is based in a Microsoft Excel spreadsheet format. It is quick and easy to use, allowing the user to enter basic development site cover and area data to compute a runoff volume and phosphorus load from the site after development. Then the user chooses various combinations of BMPs to provide a phosphorus reduction necessary to meet the discharge load limit criteria in the Virginia Stormwater Management Regulations (9 VAC 25-870-63).

The methodology accounts for treatment trains (i.e., BMPs arranged in sequence) and generates a modified CN based on the site conditions and BMPs selected. A detailed discussion of the RRM is provided in **Chapter 12** of this Handbook.

11-D.2.3.2. Hydrologic Simulation Program FORTRAN (HSPF)

The HSPF model was developed by the EPA for the continuous or single-event simulation of runoff quantity and quality from a watershed. The original model was developed from the Stanford Watershed Model, which simulated runoff quantity only. It was expanded to include quality components, and has since become a popular model for continuous non-point source water quality simulations. Non-point source conventional and toxic organic pollutants from urban and agricultural land uses can be simulated, on pervious and impervious land surfaces and in streams and well-mixed impoundments. The various hydrologic processes are represented mathematically as flows and storages. The watershed is divided into land segments, channel reaches and reservoirs. Water, sediment and pollutants leaving a land segment move laterally to a downstream land segment, a stream or river reach, or reservoir. Infiltration is considered for pervious land segments.

HSPF model output includes time series information for water quality and quantity, flow rates, sediment loads, and nutrient and pesticide concentrations. To manage the large amounts of data associated with the model, HSPF includes a database management system. To date, HSPF is still a DOS-based model and therefore does not have the useful graphical and editing options of a Windows-based program. Input data requirements for the model are extensive and the model takes some time to learn. Users link HSPF to the BASINs model (discussed below); together they provide robust advantages. The EPA continues to expand and develop HSPF, and still recommends it for the continuous simulation of hydrology and water quality in watersheds.

11-D.2.3.3. Better Assessment Science Integrating Point and Nonpoint Sources (BASINS)

The BASINS watershed analysis system was developed by the EPA for use by regional, state and local pollution control agencies to analyze water quality on a watershed-wide basis. BASINS databases, assessment tools and models integrate directly with the ArcView GIS environment, national databases containing watershed data, and modeling programs and water quality assessment tools into one stand-alone program. The program, which has a use-friendly graphical interface, will analyze both point and non-point sources and supports the development of total maximum daily loads (TMDLs). The assessment tools and models utilized in BASINS include TARGET, ASSESS, Data Mining, HSPF, TOXIROUTE and QUAL2E.

11-D.2.3.4. QUAL2EU: Enhanced Stream Water Quality Model

QUAL2EU was developed by the EPA and intended for use as a water quality planning tool. The model actually consists of four modules:

- QUAL2E, the original water quality model;
- QUAL2EU, the water quality model with uncertainty analysis;
- A pre-processing module; and
- A post-processing module.

QUAL2EU simulates steady state or dynamic conditions in branching streams and well-mixed lakes, and can evaluate the impact of waste loads on water quality. It also can enhance a field sampling program by helping to identify the magnitude and quality characteristics of non-point waste loads. Up to 15 water quality constituents can be modeled. Dynamic simulation allows the user to study the effects of diurnal variations in water quality (primarily DO and temperature). The steady state option allows the user to perform uncertainty analyses.

QUAL2EU is a DOS-based program, and the user will require some length of time to develop a QUAL2EU model, mainly due to the complexity of the model and data requirements for a simulation. However, to ease user interaction with the model an interactive pre-processor (AQUAL2) has been developed to help the user build input data files. A post-processor (Q2PLOT) also exists to display model output in textual or graphical formats.

11-D.2.3.5. Water Quality Analysis Simulation Program (WASP5)

The WASP5 model was developed by the EPA to simulate contaminant fate in surface waters. Both chemical and toxic pollution can be simulated in one, two, or three dimensions. Problems studied using WASP5 include biochemical oxygen demand and dissolved oxygen dynamics, nutrients and eutrophication, bacterial contamination, and organic chemical and heavy metal contamination. WASP5 has an associated stand-alone hydrodynamic model, called DYNHYD5, that simulates variable tidal cycles, wind and unsteady flows. DYNHYD4 supplies flows and volumes to the water quality model. The model is DOS-based. However, WASP packages can be obtained from outside vendors that include interactive tabular and graphical pre- and post-processors.

11-D.2.3.6. Source Loading and Management Model (SLAMM)

The SLAMM model was originally developed as a planning tool to model runoff water quality changes resulting from urban runoff pollutants. The model has been expanded to included simulation of common water quality best management practices such as infiltration BMPs, wet detention ponds, porous pavement, street cleaning, catch basin cleaning and grass swales. Unlike other water quality models, SLAMM focuses on small storm hydrology and pollutant washoff, which is a large contributor to urban stream water quality problems. SLAMM computations are based on field observations, as opposed to theoretical processes. SLAMM can be used in conjunction with more commonly used hydrologic models to predict pollutant sources and flows.

11-D.3. REFERENCES

Atlanta Regional Commission (ARC). 2001. *Georgia Stormwater Management Manual*. Prepared by AMEC, the Center for Watershed Protection, Debo and Associates, Jordan Jones and Goulding, and the Atlanta Regional Commission. Atlanta, Georgia.