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13.1 Introduction to the Community Model

The Phase 5.3 Community Watershed Model is an open source, public domain model that is freely distributed through website sites of the EPA Chesapeake Bay Program Office and the Chesapeake Bay Community Model Program.
http://www.chesapeakebay.net/phase5.htm
http://ches.communitymodeling.org/models/CBPhase5/index.php

Phase 5.3 has been developed by a broad coalition of model practitioners, environmental engineers, scientists, and environmental managers from the Environmental Protection Agency, U.S. Geological Survey, Virginia Department of Conservation & Recreation, Maryland Department of the Environment, University System of Maryland, and Interstate Commission on the Potomac River Basin. The Chesapeake Bay Program, principally through its modeling and nutrient work groups, provided technical guidance and review of the Phase 5.3 Model development and application.

Among the users of the Phase 5.3 Community Watershed Model are Chesapeake Bay watershed states and local governments, which use the Phase 5.3 Model as a starting point for small-scale TMDL and other pollutant load modeling. Using the same model that already provides guidance to the regional Chesapeake TMDL for local TMDL development has obvious advantages of efficiency and consistency. Other community model users include consultants, river basin commissions, and universities that can use the Phase 5.3 analysis capability to their advantage.

Phase 5.3 Model code, documentation, calibration data, data libraries, list servers, the Model Operations Manual (MOM), model scenario output, and more can be found on the links above. These websites are dynamic and are intended to be responsive to user needs. As Phase 5.3 Model development and application expand, the information on these websites will continue to be updated.

13.2 Community Model Structure

The Chesapeake Bay Program has used HSPF to simulate nutrients loads in the Bay watershed since the Phase 1 Watershed Model in 1985 (Linker et al. 2002). Over time, the Watershed Model has increased in complexity, commensurate with the increased management challenges associated with Chesapeake Bay restoration. The increased complexity would pose challenges to the standard application of HSPF, particularly for efficiently operating the model in a large-scale watershed, as well as incorporating changes in management practices and land uses over time. In response, the Chesapeake Bay Program developed a software solution that enhances the existing HSPF model structure. The software system, consisting of preprocessors, an External Transfer Module, and postprocessors, was devised to conveniently generate and update parameter files essential to operating a large and complex modeling system and to implementing land use and nonpoint source management changes on any time scale. The developed software allows an opportunity to achieve a more accurate calibration by providing a method to represent the key forcing functions in more detail and to address issues of flexibility that are difficult to manage in traditional HSPF applications.

In response to the needs of developing small-scale TMDL models consistent with the large-scale assessment of the Chesapeake Bay TMDL, the CBP developed the Phase 5.3 Model with a longer simulation period, from 1984 to 2005; finer spatial segmentation of 1,063 segments; more land use types; and more detailed input data. The Phase 5.3 Model represents an exponential increase in complexity over its predecessors, posing challenges to a standard application of HSPF. One challenge is the logistics. Given the scale of the Chesapeake Bay watershed, the number of input files that must be modified during calibration and scenario runs is large. The situation becomes further complicated with multiple land-segments feeding each river-segment and land-segments each feeding multiple river-segments, and more than one million individual applications in the entire watershed that must be specified or changed for model runs. Creating all these input files and land-water connections as usually done in standard HSPF applications is infeasible.

Another challenge is that land use and management practices have changed during the 21-year simulation period. The Phase 5.3 Watershed Model is calibrated over all available data to achieve the best calibration possible. Over the two-decade calibration period (1985–2005), land uses and management practices have changed considerably. The standard application of HSPF, however, does not easily allow for these changes in the simulation. To better implement land uses and management changes over time in the Phase 5.3 Model, the standard HSPF model structure was augmented.

13.2.2 Standard HSPF (Hydrologic Simulation Program – FORTRAN) Application and the Need for Expanded Capability in Phase 5.3

HSPF is a widely used watershed model that is in continual development and supported by several federal agencies (Bicknell et al. 1997; Donigian et al. 1995a; Donigian et al. 1995b; Bicknell et al. 2001). HSPF is a continuous, physically based, lumped-parameter model that simulates hydrology, sediment, and chemical pollutants in the soil and in streams. The model uses meteorological information, land surface characteristics, application data, and management practices to simulate the processes that occur in a watershed. The result of simulation is a time series of flow, sediment load, and nutrient and pesticide loads at any segment in the watershed. An HSPF model is normally calibrated to observed flow and water quality data measured at the river-segment outlet.

For simulation with HSPF, a basin is represented as land-segments and reaches/reservoirs. A land-segment is a subdivision of the simulated watershed, generally defined as an area with similar hydrologic characteristics. Often, in practice a land-segment is defined by county boundaries because this is the finest scale for certain key model inputs, such as manure loads and crop types. Water, sediment, and water quality constituents from the land-segments are discharged to a reach/reservoir. The hydraulic and water quality processes that occur in the river channel network are simulated by reaches, which are assumed to completely mixed reactors, i.e., the river reaches and reservoirs are completely mixed in width and depth.

The Phase 5.3 Model divides the Chesapeake Bay watershed into 308 land-segments, primarily county-based. The Phase 5.3 Model expands land uses to 26 types, including 10 types of cropland, 3 types of woodland, 4 types of pasture, 4 types of urban land, and provisions for other special land uses such as surface mines and land in construction. Each land use is simulated on an hourly time step tracing the fate and transport of input nutrient loads from atmospheric deposition, fertilizers, animal manure, and point sources. Each land use is simulated as a single acre in each segment, and this single acre is then multiplied by the acres of each land use draining to each river-segment.

Phase 5.3 Model river segmentation has 1,063 segments with an average area of about 170 km^2. This increases the number of calibration stations to 296, representing an order of magnitude increase compared to the 20 stations used for Phase 4.3. Increased segmentation improves characterization of spatial variation within the limitations of the "lumped-parameter" HSPF model in the land-segment as well as the completely mixed reactors of the river-segments.

The model simulation period is 21 years, from 1985 to 2005, and it takes advantage of recent and expanded monitoring. The expansion of model simulation period to more than two decades requires changes in land uses and management practices to be incorporated into the model simulation. The greater segmentation and increased number of land use types require that more than 7,000 input files for independent land simulations, 930 input files for river simulations, and 45,000 land use/river connections be modified during the calibration and scenario runs. Also, there are more than one million individual nutrient applications of fertilizer or manures to different crops simulated in the entire watershed during a 22-year simulation that must be specified for the calibration or changed for a scenario run.

13.2.3 Enhanced Phase 5.3 Model Structure

An enhanced HSPF model structure was developed for the Phase 5.3 Model. The enhancement consists of preprocessors, an External Transfer Module (ETM), and postprocessors. The preprocessors were developed to automatically generate input files for land and river simulations; the ETM is a device that links land simulation to river simulation; and the postprocessors are programs that compile and display model outputs. The preprocessors and the ETM are discussed in this paper.

13.2.3.1 Preprocessors for Input File Generation

HSPF uses a User-Controlled Input (UCI) file to specify all information relevant to a simulation. In most HSPF applications, all land and river simulation modules are parameterized within a single UCI file. The water, nutrient, and sediment exports of each land use are multiplied by a single factor for land use acreage and another factor for translation between land variable types and units to river variable types and units. IN a standard Version 11 HSPF application neither the land use nor the translation factors can be changed during the simulation; thus, HSPF lacks the flexibility necessary for a large-scale watershed simulation.

To incorporate changes in land uses and management over time and provide overall flexibility in model simulation, the Phase 5.3 Model is structured to simulate land- and river-segments in separate UCIs. Accordingly, the preprocessors developed to generate UCI files consist of two parts: a Land UCI Generator (LUG) and a River UCI Generator (RUG).The LUG is a group of programs that were designed to automatically generate UCI files for land simulations. To create a UCI file, the LUG (1) obtains operation instructions from a user-defined control file; (2) reads input data and parameter information from predeveloped databases; and (3) writes all information into a standard UCI format. The operation instructions specify HSPF modules and data sets relevant to a particular land simulation and can be easily modified to accommodate a specific user need. Three databases—a nutrient application database, a module specification database, and a process parameter database—are preprocessed to store information on nutrient input to land surfaces, specific input and format of each HSPF module, and parameter information required for each HSPF module, respectively. These databases are a group of ASCII files whose formats are devised in accordance with the read/write functionality of the LUG. Each land use simulation within each land-segment requires a unique UCI file.

Similarly, the RUG is a group of programs that provide the functionality of automatically generating UCI file for each river. Like the LUG, the RUG reads operation instructions from a user-defined control file, obtains module and parameter information from a module specification database and a process parameter database, and then creates a standard river UCI file. Each river simulation also requires a unique input file. Before a river simulation is run, local land-segments/land use types and upstream rivers that drain to it must be identified. A program was developed to track the land-river connections and river network, which are preprocessed through GIS tools and stored in an ASCII file for the entire watershed. This program is outside the RUG structure but functions as an integrated part of it. The program enables one to conveniently generate river UCI files for any sub-basins of interest.

Separating land and river simulation into different UCIs provides great flexibility in model simulation. With this structure, each land use type simulation for each land-segment is completely independent of any other land or river simulation, and each river simulation is dependent on only the local land use type simulations and the upstream river simulations. This provides an efficient and meaningful way to deal with the complicated land-river/river-river logistics of a large-scale watershed simulation.

13.2.3.2 External Transfer Module

A software solution was devised to connect the land simulation to the river simulation. The software, called the External Transfer Module (ETM), consists of a group of routines that direct the appropriate water, nutrients, and sediment from each land use type within each land-segment to each river-segment. The ETM translates land variables to river variables, multiplying by appropriate coefficients to account for units and type conversions. Relationships between land variables and river variables are stored in easily accessed databases that can be user-modified for each land use. Similarly, the ETM can multiply the land variables by time series of land use and management practice efficiency coefficients to incorporate changes in land use and management over time within a continuous simulation. Routines were also developed within the ETM to read and write directly to binary Water Data Management (WDM) files, which are the most efficient method of input/output for HSPF.

In the real world, change in land use is continual; however, land use data are generally available for specific points in time. Therefore, the ETM was programmed to accept land use data at several points in time and interpolate and extrapolate through time as necessary. Likewise, management practice data are generally known on a snapshot basis at best. The ETM similarly interpolates and extrapolates management data. The land use and management practice data are stored in databases that are spatially complete but represent one point in time. The user can specify as many of these as are needed to describe the change over time. Interposing non-HSPF software between the land and river simulation allows for opportunities to address issues of flexibility that are difficult to manage in traditional HSPF applications.

13.2.3.3 Overall Functionality of Software System

A typical application of the developed model structure to run a complete HSPF simulation follows the process illustrated in Figure 13:

1. Land UCIs are generated through the LUG.
2. HSPF is run on the land UCIs, and output is stored in individual WDMs.
3. The ETM is run, converting land output to river input, incorporating changes over time in land use and BMPs, and also land-to-water delivery factors. Output is stored in river-formatted WDMs.
4. River UCIs are generated using the RUG.
5. HSPF is run on the river UCIs, and output is written back to the WDMs.
6. The postprocessor reads the river WDMs and writes ASCII output.

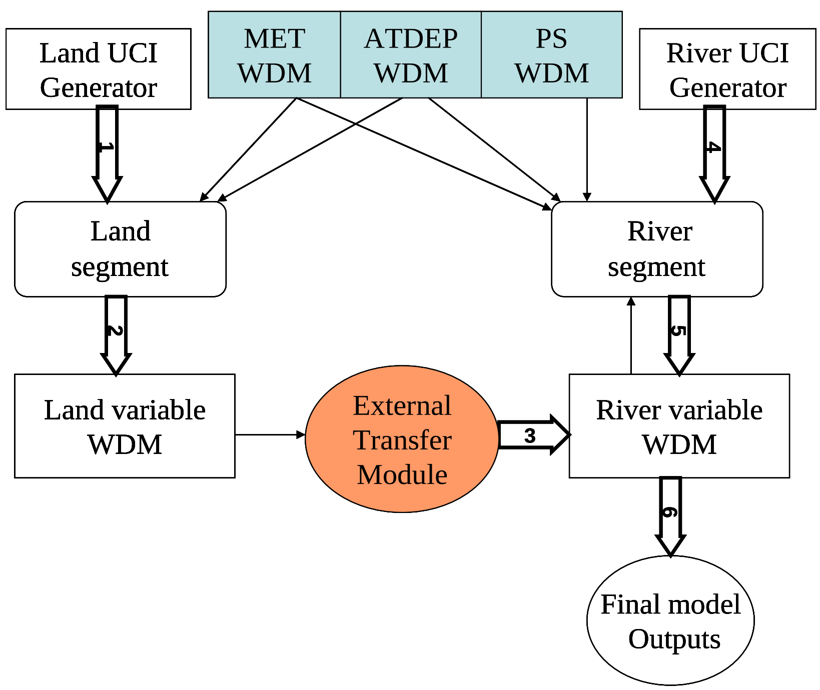

Figure 13-1. Information flow of the Phase 5.3 Model structure.

The devised software system has several advantages over a traditional HSPF application: (1) it easily allows for large-scale parameter adjustments during calibration; (2) parallel computing operations become convenient, and thus simulation can be arranged more efficiently; (3) adding new land use types is handy and convenient, which enables model simulation to be easily expanded; and (4) it can be easily integrated into outside databases for scenarios. The system is run on personal computers with the Linux operating system. All supporting programs, as well as HSPF, are open sources and written primarily in Fortran 77.

The LUG, RUG, and ETM model system can improve HSPF calibration by incorporating time-varying anthropogenic forcing functions, and there are other benefits of this type of system as well. With the proliferation of inexpensive Linux systems that can be clustered together, computing power that is normally reserved for large simulation projects is now affordable and generally accessible to more users. A watershed model is inherently parallel because all land uses can be run independently. The Phase 5.3 Watershed Model system, with one land use or river reach per file, allows the user to apply any degree of parallelization available.

Calibration and scenario run times are reduced significantly. During the calibration of a watershed model with several land uses, land uses are typically calibrated by themselves and then the entire model is calibrated together after reasonable estimates of model parameters are reached. Separating the land simulation from the river simulation allows the user to store the calibrated land simulation in WDM files, running only the river module for the river calibration. Scenario run time can also be reduced if land use simulations have the same precipitation, meteorology, and nutrient applications as a previous scenario. In this case the user only needs to apply different land use acreage and management practice reduction factors.

Another possible benefit of the modularization of Phase 5.3 is the ability to integrate models other than HSPF into the system. If it were found that another stream model was more appropriate for a particular application, routines that would provide input in the necessary format could be written. Specialized land uses models, such as wetland or more detailed forest simulation could be included. The system could also provide an interface to other modeling or optimization frameworks.

Further detail can be incorporated into the description of management actions as well. The management practice simulation can use information from the land simulation. For example, the effectiveness of a management practice could be a function of the rainfall or runoff, since some management practices become less effective during very low frequency storm events. Urban stormwater management practices could be directly simulated by storing the output of a land surface over a storm event and then releasing it more slowly, with appropriate reduction in pollutants.

The devised model structure also makes the Phase 5.3 Model particularly suitable for serving as a community model. A community model consists of open source, public domain programs of model code, preprocessors, post processors, and input data that are freely distributed, often over the web. With the specifically designed model system, the Phase 5.3 Model may be used in a direct, straight-up, as-is application or may be used as a point of departure for more detailed, small-scale models. The use of the LUG, RUG, and ETM model system in the community model approach provides the potential for state-wide consistency of water quality analysis and TMDL development, as well as consistency of local TMDLs with the large-scale regional TMDL of the Chesapeake Bay, and should be more effective, cost efficient, and equitable.

13.2.4 Overview of Phase 5.3 Model System

The modeling system developed for the Phase 5.3 Watershed Model is a versatile method that uses the strengths of HSPF and incorporates more time-dependent information than would be possible in a standard application. The Land UCI Generator and River UCI Generator allow the generation and modification of large numbers of input files in a convenient format, which is essential to calibration and scenario operations in a large and complex modeling system. The ETM allows for the opportunity to simulate a watershed over an extended period by providing a method to change land use acreage and management practices over time. This system, applied to the Chesapeake Bay watershed, has been shown to produce a superior calibration to the observed data by incorporating the changes in land uses and management practices. The software system allows the Chesapeake Bay watershed model to increase spatial segmentation by an order of magnitude, while maintaining the ability to administer the model efficiently and to simulate the effects of land use and management change through time. The enhanced model structure provides an opportunity to achieve a more accurate and efficient HSPF simulation for any large-scale watershed modeling.

13.3 Scenario Builder

Scenario Builder Version 2.2 is a free online decision-support tool designed to provide estimates of county-level nitrogen and phosphorus loads. Combined with the Phase 5.3 Model, the tool provides rapid scenario development and application. Scenario Builder allows local governments and watershed organizations to translate land use decisions such as zoning, permit approvals, and BMP implementation into changes in nitrogen, phosphorus, and sediment loads from a particular county or watershed. Figure 13.2 is a graphical representation of a Scenario Builder application.

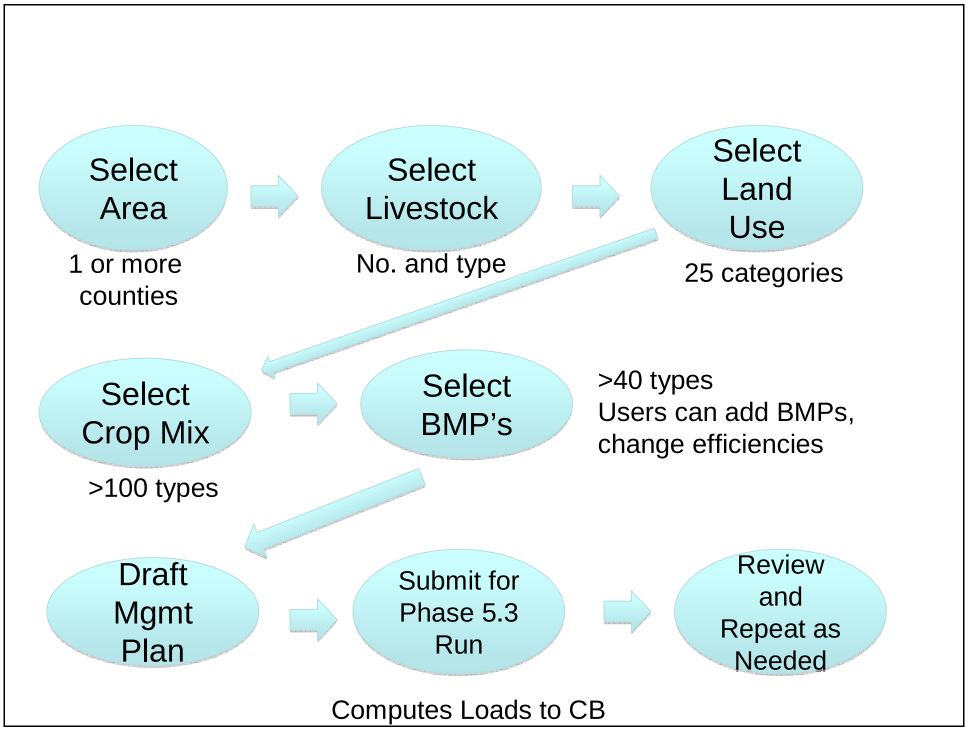

Figure 13-2. Work flow in a Scenario Builder application linked to the Phase 5.3 Model.

Detailed information on Scenario Builder can be found at
http://www.chesapeakebay.net/phase5.htm

References

Bicknell, B.R., J.C. Imhoff, J.L. Kittle Jr., A.S. Donigian, Jr. and R.C. Johanson. 1997. *Hydrological Simulation Program – FORTRAN: User's Manual for Version 11*. U.S. Environmental Protection Agency, Athens, GA.

Donigian, A.S., Jr., B.R. Bicknell, A.S. Patwardhan, L.C. Linker, C.H. Chang, and R. Reynolds. 1994. Chesapeake Bay Program Watershed Model Application to Calculate Bay Nutrient Loadings. U.S. Environmental Protection Agency, Chesapeake Bay Program Office, Annapolis, MD.

Bicknell, B.R., J. C. Imhoff, J. L. Kittle, Jr., T. H. Jobes, and A. S. Donigian, Jr. 2001. *Hydrologic Simulation Program – Fortran, HSPF Version 12 Users Manual.* U. S. Environmental Protection Agency, Office of Research and Development, Athens, GA. USGS Hydrologic Analysis Software Support Program, Reston, VA.

Donigian, A.S., Jr., B.R. Bicknell, and J.C. Imhoff. 1995. Hydrologic Simulation Program – FORTRAN (HSPF). Chapter 12 in *Computer Models of Watershed Hydrology*, ed. V.P. Singh. Water Resources Publications, Littleton, CO.

Donigian, A.S., Jr., J.C. Imhoff, and R.B. Ambrose, Jr. 1995. Modeling Watershed Water Quality. Chapter 11 in *Environmental Hydrology*, ed. V.P. Singh. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Greene, K.A., L. Linker. 1998. *Chesapeake Bay Watershed Model Application and Calculation of Nutrient and Sediment Loadings*. Appendix A: Phase IV Chesapeake Bay Watershed Model Hydrology Calibration Results. Chesapeake Bay Program Office, Annapolis, MD. <http://www.chesapeakebay.net/modsc.htm>.

Hopkins, K., B. Brown, L. Linker, R.L. Mader, Jr. 2000. *Chesapeake Bay Watershed Model Land Use and Model Linkages to the Airshed and Estuarine Models*. U.S. Environmental Protection Agency, Chesapeake Bay Program, Annapolis, MD. <http://www.chesapeakebay.net/modsc.htm>.

Hunsaker, C.T., C.T. Garten, and P.J. Mulholland, 1994. Nitrogen Outputs from Forested Watersheds in the Chesapeake Bay Drainage Basin. EPA Oak Ridge National Laboratory, Oak Ridge, TN. Draft.

Langland, M.J., P.L. Lietman, and S. Hoffman. 1995. *Synthesis of Nutrient and Sediment Data for Watersheds within the Chesapeake Bay Drainage Basin.* Water-Resources Investigations Report 95-4233. U.S. Geological Survey, Reston, VA.

Linker, L., G. Shenk, R. Dennis, and J. Sweeney. 2000. Cross-media models of the Chesapeake Bay watershed and airshed. *Water Quality Ecosystem Modeling* 1(1–4): 91–122.

Linker, L.C., G. Shenk, P. Wang, and J.M. Storrick. 1998. *Chesapeake Bay Watershed Model Application and Calculation of Nutrient and Sediment Loadings*. Appendix B: Phase IV Chesapeake Bay Watershed Model Water Quality Results. Chesapeake Bay Program Office. Annapolis, MD. <http://www.chesapeakebay.net/modsc.htm>.

Linker, L., G. Shenk, P. Wang, K.J. Hopkins, and S. Pokharel. 2002. A short history of Chesapeake Bay modeling and the next generation of watershed and estuarine models. In *Water Environment Federation Watershed Conference Proceedings.*

Linker, L., C.G. Stigall, C.H. Chang, and A.S. Donigian, Jr. 1996. Aquatic accounting: Chesapeake Bay Watershed Model quantifies nutrient loads. *Water Environment and Technology* 8(1):48–52.

Cite as:
USEPA (U.S. Environmental Protection Agency). 2010. *Chesapeake Bay Phase 5.3 Community Watershed Model*. EPA 903S10002 - CBP/TRS-303-10. U.S. Environmental Protection Agency, Chesapeake Bay Program Office, Annapolis MD. December 2010.

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