Development of a Calibrated Watershed Model, Potomac River Basin

A Cooperative Project between the U.S. Geological Survey (USGS), the Interstate Commission on the Potomac River Basin (ICPRB), the Maryland Department of the Environment (MDE), and the U.S. Environmental Protection Agency Chesapeake Bay Program Office (CBP)

Progress Report October 1–December 31, 2001

Water Resources Division
MD-DE-DC District Office
8987 Yellow Brick Road
Baltimore, MD 21237

Phone: 410-238-4200
Fax: 410-238-4210
Website: http://md.water.usgs.gov

Personnel

Angélica Gutiérrez-Magness, Hydrologist (Project Chief)
Jeff Raffensperger, Hydrologist (Chief, Watershed Studies Section)
Sarah Martucci, Geographer
Jon Dillow, Hydrologist
Mick Senus, Hydrologist
Joe Vrabel, Hydrologist

Project Description

Problem. Work performed by the National Water-Quality Assessment (NAWQA) Program Potomac River Basin study unit (1992-95) indicated that elevated concentrations of nutrients in surface and ground water in the basin often result from human activities such as manure and fertilizer application. A watershed model of the basin is needed to assess the effects of point and nonpoint nutrient and sediment sources on water quality in the Potomac River and its tributaries.

Objectives. The USGS is responsible for the following objectives: 1) compile necessary data for simulation of Potomac watershed processes, using the Hydrologic Simulation Program-FORTRAN (HSPF); 2) create necessary control files for HSPF simulation of the Potomac River Basin, following the framework developed by CBP for Phase 5 of the Chesapeake Bay Watershed Model (CBWM); 3) develop and implement innovative calibration procedures to improve HSPF model calibration; 4) calibrate an HSPF model for the Potomac River Basin; and 5) prepare reports on calibration and analysis of model results.

Benefits and relevance. The calibrated Potomac Watershed Model will allow resource managers to simulate the effects of land-use changes and best management practices on water quality and evaluate alternative approaches for correcting existing water-quality and water-quantity problems within the Potomac River Basin. The proposed study also meets several goals of the USGS Water Resources Division (WRD).

Approach and methods. The proposed study will involve the following tasks: 1) compilation of existing input data, development of model segmentation and network, processing of time-series data, and compilation of ancillary data and observational data for model calibration; 2) development of a model calibration strategy through implementation of existing software for general inversion and calibration of multi-parameter hydrological models; 3) calibration of hydrological and water-quality model (sediment and nutrients); 4) analysis of model results, including consideration of specific study questions; and 5) dissemination of calibrated model and preparation of final reports analyzing the model results.

USGS will be responsible for development and calibration of the Potomac Watershed Model. CBP will be responsible for parallel development of the CBWM (Phase 5); the Potomac Watershed Model developed by USGS will be one major basin nested within the CBWM. ICPRB will be responsible for all aspects of outreach and inter-agency coordination, and prepare reports for MDE on model aspects relevant to Total Maximum Daily Loads (TMDL) needs.

Timeline and personnel. The project will run from July 1, 2001 through June 30, 2004. The primary product from the project will be a calibrated model of the Potomac River Basin for hydrology, suspended sediment, and nutrients. The completed model will be delivered to ICPRB by October 1, 2003. Intermediate provisional data sets and model results will be disseminated as completed. Progress will be reported by the USGS quarterly; final reports describing the model development and analysis and documenting calibration methods and calibrated parameters will also be prepared by the USGS. Project personnel include a project chief and one other modeler, as well as part-time GIS and database support.

Progress During Reporting Period

During the past 3 months, the following tasks were completed by the USGS:

1. Completion of the model reach, watershed, and precipitation segmentation.

2. Development of an approach to spatially and temporally model (distribute) precipitation fields.

3. Development of F-tables for gaged stream reaches.

Model segmentation
In general, model segmentation consists of several tasks. For the Potomac Watershed Model (PWM), as well as the CBWM, sources (e.g., fertilizer application) will be distributed over counties, precipitation will be distributed to counties broken by major topographic features (precipitation-county segments), and edge-of-stream loads will be calculated for watershed-county segments and delivered to individual stream reaches.

During the reporting period (October 1, 2001 through December 31, 2001), the stream reach network and associated watersheds or drainage areas were developed. These areas (intersected with counties) will constitute the model land segments for delivery of edge-of-stream loads to stream reaches.

The reach network was based on the U.S. Environmental Protection Agency (USEPA) RF1 and the USGS Chesapeake Bay SPARROW model (Preston and Brakebill, 1999). Reaches with average annual discharge less than 100 ft^3/s (according to RF1) were not used, in order to reduce the total number of stream reaches to a manageable number. (A number of exceptions to this rule were made, for streams with load data or those that were being monitored under MDE's TMDL program.) Reaches were split at USGS stream-gaging stations that had at least 8 years of record for the period 1985-2000. This produced the final reach network for simulation. Watersheds were created from Digital Elevation Model (DEM) data for the Chesapeake Bay Watershed and southwestern Virginia.

In the Potomac River Basin (Figure 1), the DEM basins were spot checked with the Maryland State 12-digit Watersheds. USGS worked with CBP staff to substitute, where appropriate, Virginia and Maryland watershed divides for DEM-delineated divides.

Coverages were created for the precipitation-county segments (counties broken by major topographic features) by visually inspecting topographic maps and making decisions concerning where best to split counties so that precipitation variability across a segment would be minimized. The entire modeling team participated in this task.

Spatial and temporal modeling (distribution) of precipitation fields
A critical aspect of the model refinement envisioned for the Potomac Watershed Model and Phase 5 CBWM is the need to improve estimation of daily and hourly precipitation and other meteorological time series. We will use an approach developed by researchers at the USGS National Research Program in Denver (see box, "Spatial distribution of climate variables," below). The following initial steps in this process have been taken, in collaboration with Lauren Hay of the USGS in Denver.

1. Stations with hourly and/or daily data within the modeled domain and extending 25 km outside of the domain boundary have been identified and the data have been compiled.

2. The region has been subdivided into six regions for analysis. The data have been subdivided into seven weather types on a daily and regional basis.

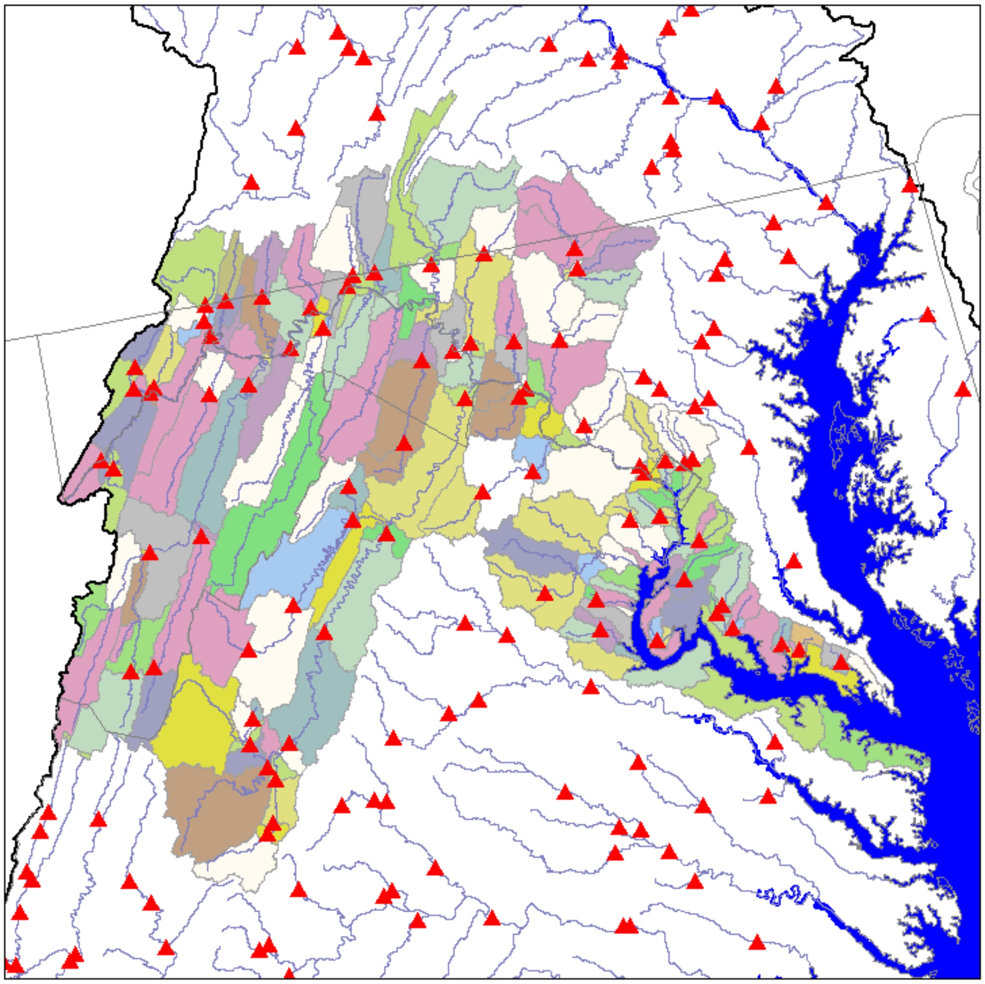

Figure 1. Model reach and watershed segmentation (without county breaks) for the Potomac River Basin. Triangles represent USGS stream gaging stations.

Development of F-tables for gaged streams

In order to route water and chemicals through individual stream reaches, HSPF uses simple convex routing that requires designation of the relations among stream cross-sectional area, depth, velocity, and reach volume. These relations are provided in the form of F-tables that require (where available) measurements of stream cross sections, velocities, and depths. This information is available for all sites gaged by the USGS in hard-copy files.

During the reporting period, bankfull width, bankfull height, and bottom width of the main channel were derived from trapezoidal cross-sectional information for Potomac River Basin stations. The primary source of this information was found in hard-copy Indirect Measurement (IDM) files. Both the "3-section slope-area" and "contracted-opening" methods found in the IDM files provided sufficient cross-sectional information. These files were obtained from the Maryland Department of the Environment, the USGS Maryland-Delaware-D.C. District, the USGS West Virginia District, and the USGS Virginia District (Table 1).

IDM files, station files, oral communications with station hydrologic technicians, and photographs were used in conjunction with "values of roughness of coefficient" to provide Manning's *n* values for both the stream channel and the right and left bank flood plains.

Reach identification number, reach length, upstream elevation, and downstream elevation for each station were derived from DEMs in a Geographic Information System.

Spatial Distribution of Climate Variables

The hydrological model HSPF needs an estimate of hourly precipitation and other meteorological variables for each model segment. To compute reliable estimates of these quantities, researchers at the USGS National Research Program in Denver have developed a method whereby observed data are interpolated across a basin to better represent basin climate variability. Significant physical factors affecting the spatial distribution of climate variables within a river basin are latitude (x), longitude (y), and elevation (z). In the method, multiple linear regression (MLR) equations are developed for each dependent climate variable (e.g., precipitation) using the independent variables of x, y, and z from the climate stations. The general form of the MLR equation for daily precipitation (p) is:

$$p = b_0 + b_1 x + b_2 y + b_3 z \qquad (1)$$

The resulting fit from equation (1) describes a plane in three-dimensional space with "slopes" b_1, b_2, and b_3 intersecting the p axis at b_0. Similar equations may be used for temperature and other meteorological variables. Use of the station x and y coordinates in the MLR provides information on the local-scale influences on the climate variables that are not related to elevation (for example, the distance to a topographic barrier). To account for geographic, seasonal, and weather-type-dependent climate variations, MLR equations are developed for each month and weather type using mean values from a set of selected stations in and around each subregion (the Chesapeake Bay Watershed and southwestern Virginia have been divided into six subregions for analysis). The monthly MLRs are computed to determine the regression surface that described the spatial relations between the monthly dependent variables and the independent variables (x, y, and z). Note that for each month the best MLR relation will not always include all the independent variables. To estimate daily precipitation for each precipitation-county segment in the modeled region the following procedure will be followed: (1) mean daily p and corresponding mean xyz values from a selected station set (determined using an Exhaustive Search analysis) will be used with the "slopes" of the monthly MLR to compute a unique b_0 for that day; (2) the MLR equation will then be solved using the xyz values of points on a 5-kilometer (km) grid; and (3) these gridded estimates will be integrated over the precipitation-county segment area.

Plans for Next Quarter

1. Complete watershed-county segmentation work, including Quality Assurance/Quality Control, for the entire modeled domain (Chesapeake Bay Watershed and southwestern Virginia).

2. Complete *xyz*-MLR analysis of stratified data to develop spatial interpolation relations for the entire modeled region.

3. Estimate daily and hourly precipitation for the time period 1984-2001 on a 5-km grid; integrate values to obtain time series for individual precipitation-county segments; perform QA/QC analysis of modeled precipitation fields.

4. Extend *xyz*-MLR analysis to temperature and other meteorological variables.

5. Build WDM (HSPF format) time series files of all discharge and precipitation data.

6. Calculate flood plain slope for each USGS stream-gaging station from stream cross sections.

7. Compile stream channel cross-sections for the Patuxent River Basin using the same methods that were used for the Potomac River Basin.

8. Use stream channel geometry measurements to build F-tables for Patuxent and Potomac River Basin stations.

9. Begin process of extrapolating existing information necessary for F-tables to ungaged reaches.

10. Begin implementation of PEST (Parameter ESTimation) software for parameter estimation.

References

Preston, S.D., and Brakebill, J.W., 1999, Application of spatially referenced regression modeling for the evaluation of total nitrogen loading in the Chesapeake Bay Watershed: U.S. Geological Survey Water-Resources Investigations Report 99-4054, 8 p.

NORTH BRANCH POTOMAC RIVER at STEYER, MD	USGS- MD
SAVAGE RIVER near BARTON, MD	USGS- MD
SAVAGE RIV BL SAVAGE RIV DAM near BLOOMINGTON, MD	USGS- MD
NORTH BRANCH POTOMAC RIVER at LUKE, MD	USGS- MD
WILLS CREEK near CUMBERLAND, MD	USGS- MD
NORTH BRANCH POTOMAC RIVER near CUMBERLAND, MD	USGS- MD
POTOMAC RIVER at HANCOCK, MD	USGS- MD
CONOCOCHEAGUE CREEK at FAIRVIEW, MD	no data
ANTIETAM CREEK near SHARPSBURG, MD	USGS- MD
CATOCTIN CREEK near MIDDLETOWN, MD	USGS- MD
POTOMAC RIVER at POINT OF ROCKS, MD	no data
MONOCACY RIVER at BRIDGEPORT, MD	USGS- MD
BIG PIPE CREEK at BRUCEVILLE, MD	USGS- MD
MONOCACY RIVER at JUG BRIDGE near FREDERICK, MD	no data
SENECA CREEK at DAWSONVILLE, MD	USGS- MD
POTOMAC RIVER (ADJUSTED) near WASH, DC	no data
ROCK CREEK at SHERRILL DRIVE WASHINGTON, DC	USGS- MD
NORTH EAST BRANCH ANACOSTIA RIVER at RIVERDALE, MD	USGS- MD
NW BRANCH ANACOSTIA RIVER near HYATTSVILLE, MD	USGS- MD
PISCATAWAY CREEK at PISCATAWAY, MD	USGS- MD
ZEKIAH SWAMP RUN near NEWTOWN, MD	no data
ST CLEMENT CREEK NEAR CLEMENTS, MD	USGS- MD
ST MARYS RIVER at GREAT MILLS, MD	USGS- MD
Allen's Fresh	no data
Antietam Creek @ Rocky Forge @ discontinued US	MDE
Cabin John Creek near Glen Echo, MD south of C	MDE
Chaptico Creek	no data
Clark's Run	MDE
Evitts Creek @ Hazen Road bridge near PA state	MDE
Georges Creek @ Westernport, MD UGGS gaging st	MDE
Gilbert's Swamp	MDE
Licking Creek @ Hollow Road just north of PA s	MDE
McIntosh Run	MDE
Burgess Creek/Mill Run	no data
Nanjemoy Creek	MDE
Port Tobacco Creek	no data
Tonoloway Creek @ LR29004 just north of PA lin	MDE
Town Creek @ May Camp Lane bridge crossing bel	MDE
Wards Run	no data
Wills Creek @ Forest Grove bridge near PA stat	MDE
OPEQUON CREEK near BERRYVILLE, VA	no data
NORTH RIVER near BURKETOWN, VA	USGS- VA
MIDDLE RIVER near GROTTOES, VA	USGS- VA
SOUTH RIVER near WAYNESBORO, VA	no data
SOUTH RIVER near DOOMS, VA	no data
SOUTH RIVER at HARRISTON, VA	USGS- VA
S F SHENANDOAH RIVER near LYNNWOOD, VA	USGS- VA
S F SHENANDOAH RIVER near LURAY, VA	no data
S F SHENANDOAH RIVER at FRONT ROYAL, VA	no data
N F SHENANDOAH RIVER at COOTES STORE, VA	no data
N F SHENANDOAH RIVER at MOUNT JACKSON, VA	no data
N F SHENANDOAH RIVER near STRASBURG, VA	no data
CEDAR CREEK near WINCHESTER, VA	no data
CATOCTIN CREEK at TAYLORSTOWN, VA	USGS- VA
GOOSE CREEK near MIDDLEBURG, VA	no data
GOOSE CREEK near LEESBURG, VA	USGS- VA
CAMERON RUN at ALEXANDRIA, VA	no data
ACCOTINK CREEK near ANNANDALE, VA	USGS- VA
CEDAR RUN near CATLETT, VA	no data
S F QUANTICO CREEK near INDEPENDENT HILL, VA	no data
AQUIA CREEK near GARRISONVILLE, VA	USGS- VA
STONY RIVER near MOUNT STORM,WV	USGS- WV
PATTERSON CREEK near HEADSVILLE, WV	USGS- WV
SOUTH BRANCH POTOMAC RIVER at FRANKLIN, WV	USGS- WV
SO. BRANCH POTOMAC RIVER nr PETERSBURG, WV	USGS- WV
SO FK SO BR POTOMAC R at BRANDYWINE, WV	USGS- WV
SO FK SOUTH BRANCH POTOMAC R nr MOOREFIELD, WV	USGS- WV
SOUTH BRANCH POTOMAC RIVER near SPRINGFIELD, WV	USGS- WV
POTOMAC RIVER at PAW PAW, WV	no data
CACAPON RIVER near GREAT CACAPON, WV	no data
OPEQUON CREEK near MARTINSBURG, WV	no data
POTOMAC RIVER at SHEPHERDSTOWN, WV	no data
SHENANDOAH RIVER at MILLVILLE, WV	no data

Table 1. Potomac River Basin sites and source of channel geometry information.