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 — January 1–March 31, 2002

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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. Watershed-county segmentation work, including quality assurance, is complete for the entire modeled domain (Chesapeake Bay Watershed and southwestern Virginia); a GIS coverage of the segmentation has been distributed for final approval.

2. Spatial relations for precipitation data the entire modeled region have been developed.

3. WDM (HSPF format) time-series files of all mean daily discharge data have been created.

4. Flood plain slopes for each USGS stream gaging station in the Patuxent and Potomac River Basins have been determined from topographic maps.

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.

The reach network used in developing model segmentation 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.

During the reporting period (January 1, 2002 through March 31, 2002), DEM-delineated watershed linework was modified (as necessary) to make use of the Maryland State 12-digit Watershed boundaries (and, in Virginia, the Virginia 14-digit Watershed boundaries). USGS worked with CBP staff to accomplish 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.

3. The spatial regression (MLR) relations have been developed for the daily precipitation data.

4. The model has been built to create daily and disaggregate hourly records for any grid within the modeled domain, and using a number of different disaggregating schemes.

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. 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.

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

3. Build WDM (HSPF format) time series files of all precipitation data.

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

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

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.