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Development of a Calibrated Watershed Model, Potomac River Basin

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

Summary

Problem. The National Water-Quality Assessment (NAWQA) Program, Potomac River Basin study unit (1992-95), has 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 has responsibility 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 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.

Problem

The Potomac River Basin encompasses 38,000 square kilometers (14,670 square miles) in four states and the District of Columbia. As a hydrological unit, it includes a complex assemblage of topography, from the Appalachian Plateau to the Coastal Plain, and land uses, including major agricultural, forested, and urban and suburban areas. Surface waters of the Potomac River and its tributaries are the subject of investigation by a number of state and federal agencies; in particular, ICPRB, MDE, and CBP are interested in quantifying nutrient sources and loadings within the Potomac River Basin as part of regulatory and voluntary efforts needed to restore or protect water quality.

The quality of streams and ground water in the Potomac River Basin is affected by a number of natural and human processes. Major types of chemical compounds found in waters in the basin include nutrients (predominantly nitrogen and phosphorus), trace metals, pesticides, chlorinated industrial compounds, and volatile organic compounds (Ator, Blomquist, and others, 1998). Nutrients are of particular interest to environmental managers within the basin. Although the nutrients nitrogen and phosphorus occur naturally and are essential for plant and animal growth, excessive nutrients in water can adversely affect human health and the environment.

The Potomac River Basin is a USGS National Water-Quality Assessment Program (NAWQA) Study Unit. As such, a significant body of data and scientific understanding exists, and continues to be developed, for the basin. Major NAWQA findings that emerged during the last intensive study phase (1992-95) indicated that elevated concentrations of nitrogen and phosphorus in surface and ground water in the Potomac basin often result from human activities such as manure and fertilizer application (Ator, Blomquist, and others, 1998).

The amount and timing of nutrient, sediment, and other inputs to the Potomac River and its tributaries depend on a number of factors. These are summarized below, along with major study questions.

1. **The type of sources of those water constituents, either natural (e.g., atmospheric inputs) or anthropogenic (e.g., manure or fertilizer application).** Nutrients are present in waters of the Potomac River Basin in many forms, often at concentrations suggestive of human-derived sources; while "natural" background concentrations of 0.4 mg/L or less (as nitrogen) for nitrate occur in basin waters, these levels are often exceeded (Ator, Blomquist, and others, 1998). Municipal and industrial wastewater discharges, septic systems, and application of animal manure and commercial fertilizers accounted for an estimated 68 percent of nitrogen inputs to the basin in 1990 (Ator, Blomquist, and others, 1998).

   > *How are temporal and spatial trends in observed nutrient and sediment loading related to trends in sources? Addressing this question will require a dynamic model that incorporates information on time-varying sources, such as manure and fertilizer application and land use.*

2. **The distribution of those various sources (for example, surface versus subsurface sources, point versus nonpoint sources, or proximity to major tributaries), including important land-use influences.** Nutrient inputs to the Potomac River Basin are related to land use. For example, streams draining agricultural areas yield the greatest quantities of nitrogen, while streams draining agricultural and urban areas yield the greatest quantities of phosphorus (Ator, Blomquist, and others, 1998). Less well understood is how proximity of various land applications or other sources of nutrients and sediment to surface waters influences watershed export. Land disturbance producing

sediment runoff might only impact streams that are nearby, rather than several miles away.

> *How does the distance between source and receiving water body affect potential attenuation? Can simulation models incorporate spatially detailed land-use distributions in quantifying edge-of-stream loading or transport of nutrients and sediment?*

3. **Hydrological conditions and the mechanisms active in moving water through the basin.** A variety of mechanisms are responsible for transporting chemicals and supplying water to streams and rivers, including overland flow produced during precipitation or snowmelt events and ground-water discharge that provides baseflow during dry periods (Hornberger, Raffensperger, and others, 1998). For example, during baseflow periods, water quality in many streams in the Potomac River Basin is similar to that of ground water (Ator, Blomquist, and others, 1998), which can be a significant source of water to the total streamflow within the Chesapeake Bay Watershed (Bachman, Lindsey, and others, 1998). Overland flow and other mechanisms that operate during precipitation events may wash chemicals off of the land surface, increasing their concentration in streams, or dilute the concentration of other chemicals that are more concentrated in ground water.

> *How does the lag or time delay inherent in subsurface (ground-water) transport of nutrients affect the timing of nutrient delivery to streams relative to application? This question has important implications for efforts to apply best management practices (BMPs) that may not be immediately beneficial due to this lag time (Focazio, Plummer, and others, 1998; Sprague, Langland, and others, 2000).*

4. **Any processes that might modify their quantity as they are transported through the system, either as ground water or surface water.** Several processes may influence transport of nutrients within the watershed, including chemical sorption denitrification (Bachman and Krantz, 2000), and many others. Once delivered to streams, nutrient concentrations may undergo further modification due to in-stream processes related to algal growth (nutrient uptake), sedimentation, or other chemical processes (e.g., nitrification, denitrification).

> *What are the relative contributions of watershed (edge-of-stream) and in-stream processes to overall changes in nutrient concentrations delivered to the Potomac River and its tributaries, and how does in-stream processing vary with scale?*

A growing body of literature suggests a scale dependency to in-stream processing and export of nitrogen. Nitrogen tracer studies (Peterson, Wollheim, and others, 2001) and statistical modeling of stream nitrogen loads using SPARROW (Smith, Schwarz, and Alexander, 1997) for both the Mississippi River (Alexander, Smith, and Schwarz, 2000) and Chesapeake Bay (Preston and Brakebill, 1999) watersheds suggest that the greatest processing occurs within smaller streams. The important role of ground water, both as a contributor of water and nutrients (especially nitrogen) and as a potential zone of nutrient processing, has similarly received considerable recent study (Dillow and Greene, 1999; Krantz and Powars, 2000; Phillips, Focazio, and Bachman, 1999). These studies and others serve to highlight some of the questions listed above, and argue for the need to better represent these processes in a quantitative, predictive modeling framework.

MDE, in conjunction with USGS, ICPRB, and CBP, has determined that a watershed model is needed to address the questions stated above and to assess the effects of point and nonpoint nutrient and sediment sources on water quality in the Potomac River and its tributaries. The modeling effort proposed here will involve direct collaboration with CBP efforts to develop Phase 5 of the CBWM, using HSPF.

Objectives

The USGS has responsibility for the following objectives:

1. Compile necessary spatial and temporal databases for simulation of Potomac watershed processes (hydrological, nutrient cycling, and sediment transport) using HSPF, in cooperation with ICPRB and CBP staff.

2. Create watershed segmentation, river reach segmentation, and associated control files for HSPF simulation of the Potomac River Basin, following the framework developed by CBP for Phase 5 of the CBWM.

3. Develop and implement innovative calibration procedures, such as inverse modeling and analysis of scaled model sensitivities, to improve HSPF model calibration and provide additional insight into important controls on nutrient and sediment transport and processing within the Potomac River Basin.

4. Calibrate an HSPF model for the Potomac River Basin. Through collaboration with CBP, this model will be nested within the Phase 5 CBWM.

5. Prepare reports on subjects that might include (but are not limited to) the following: calibration of the Potomac Watershed Model; analysis of calibration strategies; Potomac Watershed Model uncertainty; analysis of Potomac Watershed Model results; implications for present and future monitoring and other data collection activities.

In outlining these objectives, two critical elements of the proposed study must be emphasized: 1) the significant effort involved in compiling necessary spatial and temporal databases will be conducted cooperatively by USGS and CBP, with oversight provided by ICPRB and CBP partners; and 2) the goals of the proposed study can and will be achieved within the broader framework of CBP efforts to improve water quality within the Chesapeake Bay Watershed and Estuary.

Benefits and Relevance

The state of Maryland needs tools to evaluate alternative approaches for correcting existing water-quality and water-quantity problems and for forecasting future conditions within the Potomac River Basin. The development and calibration of an HSPF model of the basin will provide insight into processes controlling the processing of nutrients and sediment within the basin. It will also provide necessary information for development of a hydrodynamic and water-quality model for the tidal Potomac River. The calibrated watershed and estuarine water-quality model of the Potomac River Basin will allow resource managers to simulate large-scale effects of land-use changes and best management practices on water-quality. Critical areas needing nonpoint-pollution control measures can be identified, and benefits to be gained by various management strategies can be evaluated.

The proposed study meets several goals of the Water Resources Division (WRD) of the USGS, by: 1) advancing knowledge of the regional hydrological system; 2) advancing understanding of hydrological processes; and 3) providing water-resources information that will be used by multiple parties for planning and operational purposes. In addition, the proposed study will benefit ongoing PODL (Potomac-Delmarva Subunit) NAWQA studies that address questions related to fate and transport of agrochemicals, nutrient enrichment, and nutrient processing within the watersheds and stream.

Study Area

In 1991, the USGS began a comprehensive assessment of water-quality conditions in the Potomac River Basin as part of the NAWQA Program. The results of this study, as well as numerous other USGS and other studies, have been compiled in a number of reports that provide a portion of the information needs for a proposed modeling effort. The monitoring plan proposed here will make use of this existing data, as well as historical and ongoing data collected by MDE, Maryland Department of Natural Resources (DNR), and other agencies.

The Potomac River Basin has an area of 38,000 square kilometers in four states and the District of Columbia (39% in Virginia, 26% in Maryland, <24% in West Virginia, <11% in Pennsylvania, and <0.5% in DC). The Potomac River and its tributaries traverse a number of physiographic provinces, from the elevated headwaters of the North Branch within the Appalachian Plateau through the Valley and Ridge and Piedmont Provinces to the Coastal Plain. The general northeast-southwest strike of the physiographic provinces, and underlying geology, is reflected in the important boundary (fall line) between the relatively flat sediments of the Coastal Plain and the older igneous and metamorphic rocks of the Appalachian Mountains and adjacent Valley and Ridge and Piedmont.

During the first intensive phase of Potomac NAWQA, physiography and geology were determined to be the two most influential natural factors affecting water quality in the basin, and their combination was used to define eight subunits[1] (Figure 1). Land use was considered to be the most influential human factor influencing water quality in the basin (Figure 2, Table 1).

Subunit	Area, in square km	Major land use, in percentage of subunit area		
		Forest	Agriculture	Urban
Appalachian Plateau	1710	83	10	2
Valley and Ridge	13,090	82	15	2
Great Valley (Carbonate/Noncarbonate)	8170	29	58	12
Blue Ridge	2380	82	13	4
Piedmont/Triassic Lowlands	7225	30	43	25
Coastal Plain	5450	34	13	25

Table 1. Selected information about Potomac River Basin NAWQA subunit (Gerhart and Brakebill, 1996; Vogelmann, Sohl, and others, 1997).

As of water year 2000, there are 79 active USGS stream gages in the Potomac River Basin; records from approximately 24 additional inactive gages are also available for the period 1984-2000. Water-quality data are available from a number of sources, and are summarized in Appendix 1 and Figure 3; additional information may be found in Langland, Lietman, and Hoffman (1995). (For the purposes of this proposal we have considered only those sources and data that: 1) can be used to estimate an annual load (for any of total nitrogen, total phosphorus, or suspended sediment), that is, that involve simultaneous continuous flow measurement; 2) were from the period 1980–2000; and 3) included adequate provision for quality assurance.) Information on nine new sites established within the Basin in 2000 to provide necessary data for model development is provide in Appendix 2.

[1] For this proposal, the Great Valley Carbonate and Great Valley Noncarbonate subunits have been combined, as have the Piedmont and Triassic Lowlands.

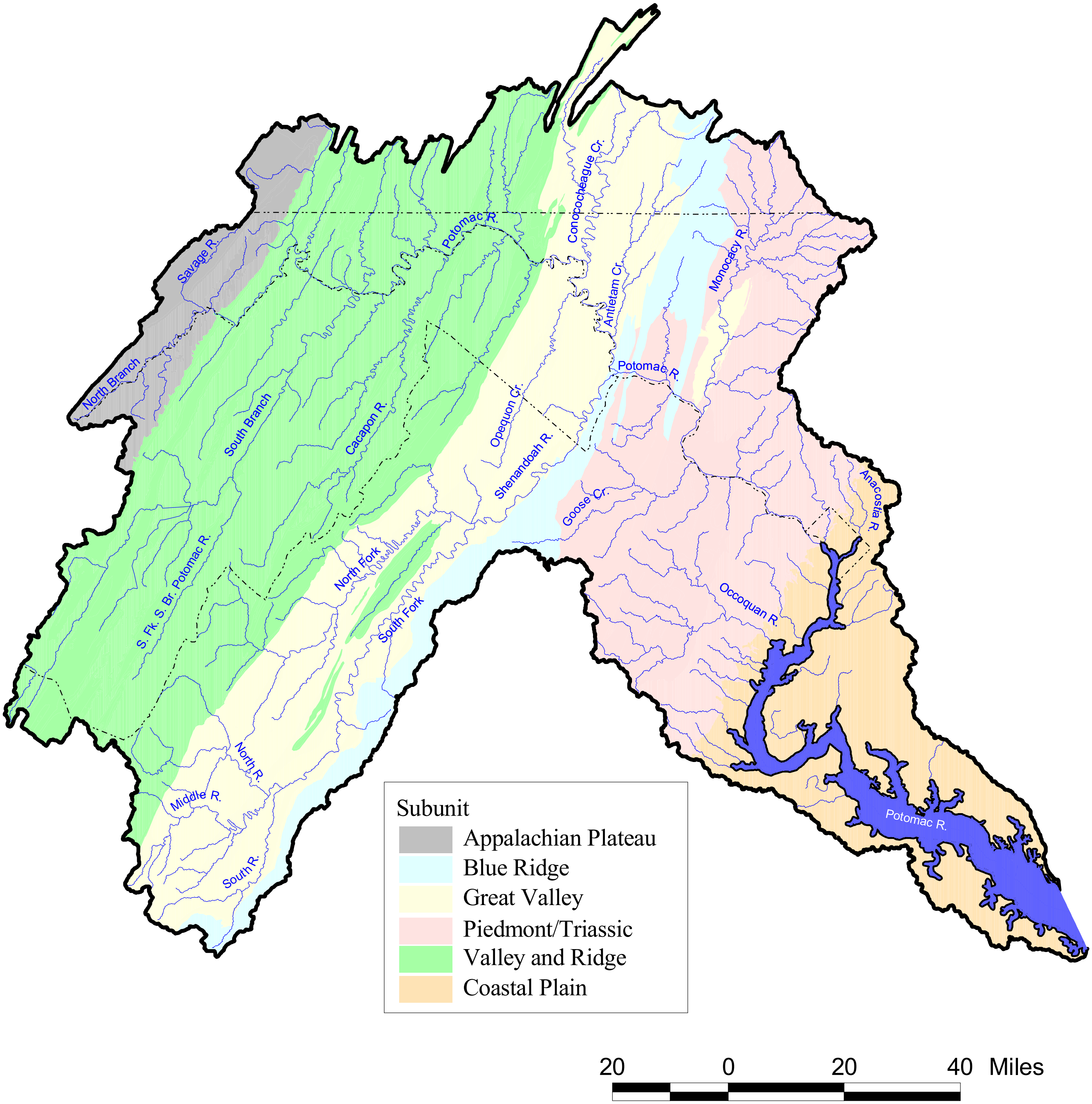

Figure 1. Map of the Potomac River Basin showing geologic-physiographic subunits and major streams and rivers (Gerhart and Brakebill, 1996).

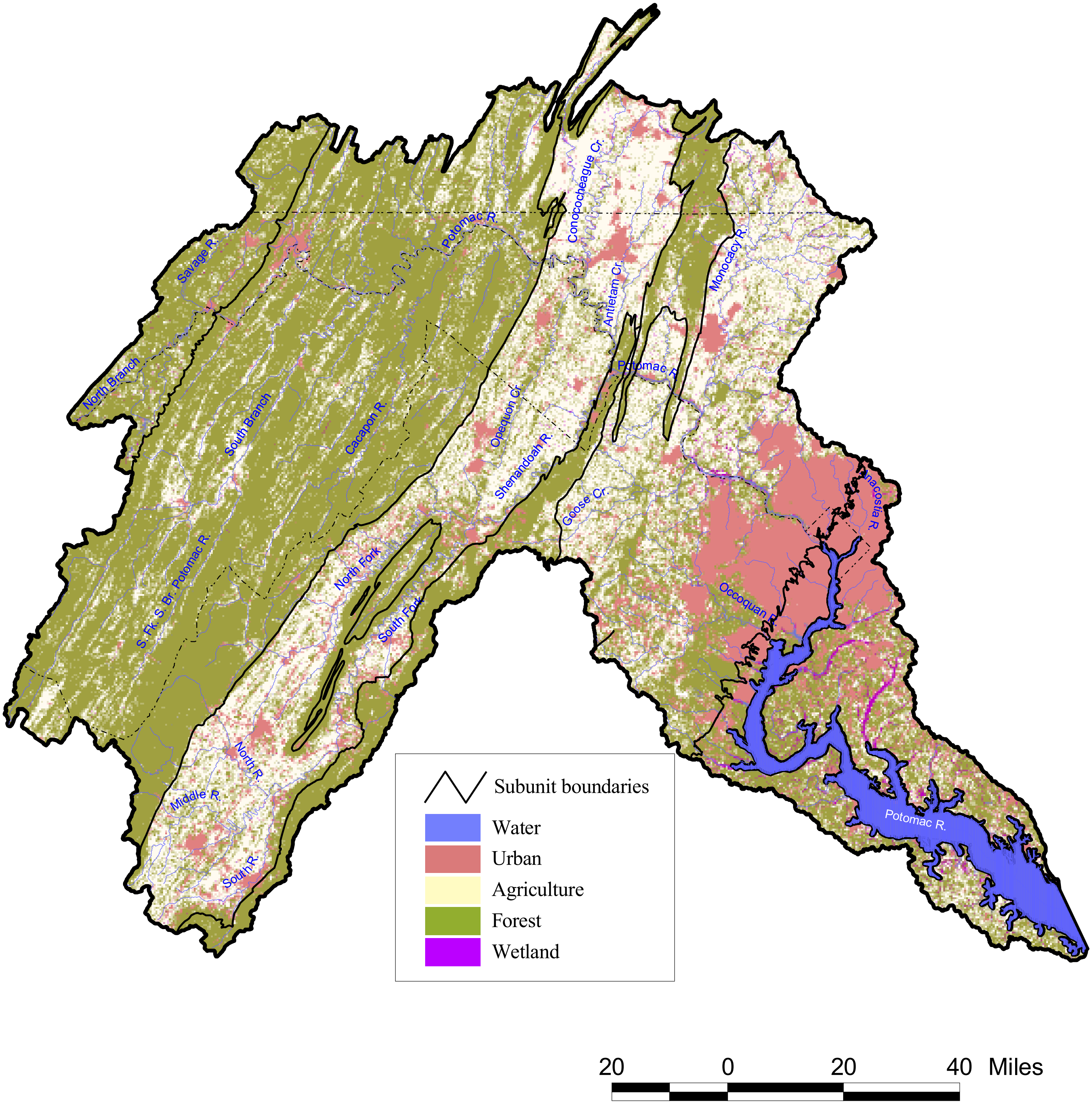

Figure 2. Generalized land use in the Potomac River Basin (Vogelmann, Sohl, and others, 1997).

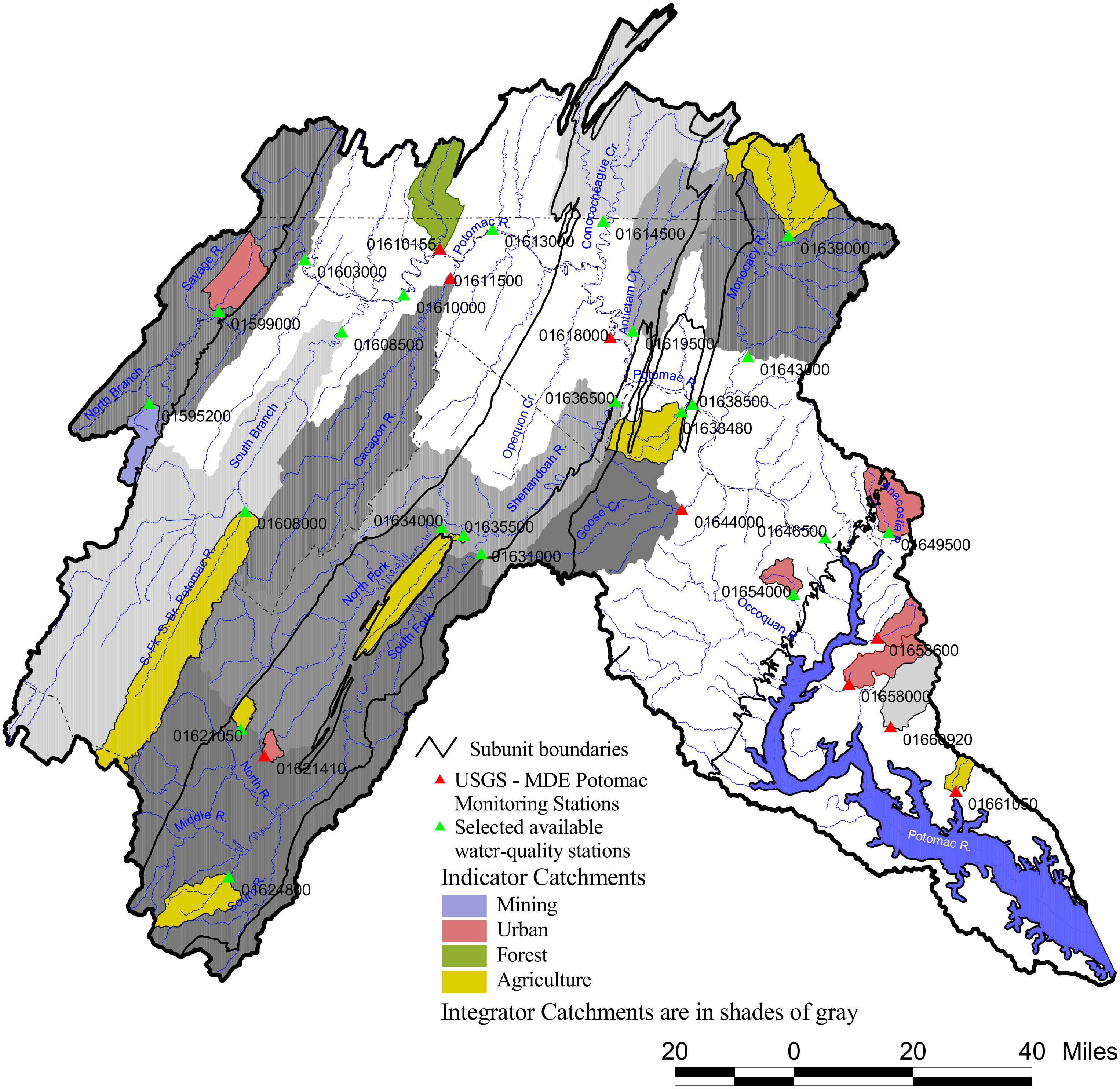

Figure 3. Catchments draining to selected water-quality stations in the Potomac River Basin.

Approach

The hydrological and water-quality model HSPF (Bicknell, Imhoff, and others, 1996) will be used to simulate the runoff of water and transport of suspended sediment and nutrients (nitrogen and phosphorus) within the Potomac River Basin. HSPF is a deterministic lumped-parameter time series model that evolved out of the Stanford Watershed Model (Crawford and Linsley, 1966) and the USEPA Agricultural Runoff Management, or ARM (Donigian and Davis, 1978), and Nonpoint Source, or NPS (Donigian and Crawford, 1979), models. The model requires input information including land use/cover, source (of N and P) data, stream reach characteristics, and time series of precipitation and potential evapotranspiration; additional information may be useful in estimating model parameters. Time series (observational) data, such as streamflow and water-quality, are necessary to calibrate the model.

The proposed study will involve the following tasks:

1. **Data Compilation:** compilation of existing input data (e.g., land use/cover, sources of N and P, and meteorological data); development of model segmentation, model network, and construction of UCI (User's Control Input) files; processing of time-series data to create input WDM (Watershed Data Management) files; compilation of ancillary data and observational data (for model calibration).

2. **Development of Model Calibration Strategy:** implementation of existing software for general inversion and calibration of multi-parameter hydrological models.

3. **Model Calibration:** calibration of hydrological model; calibration of water-quality model (suspended sediment and nutrients, N and P, and their speciation).

4. **Analysis of Model Results:** results of model calibration, examination of model output, and consideration of specific study questions.

5. **Delivery of Results and Final Reports:** dissemination of data sets and model input and output files and preparation of final reports analyzing the model results.

These tasks will be accomplished in collaboration with CBP efforts to refine the CBWM. Output from the calibrated model may be used as input for an estuarine hydrodynamic and water-quality model of the tidal Potomac River. Also, the model may provide a starting point for examination of model scenarios, using software such as USGS's GENSCN.

Responsibilities/Coordination

USGS will work collaboratively with CBP and ICPRB to develop the HSPF Potomac Watershed Model framework (model segmentation and file structure). The framework of the model will be based on geographic-information-system (GIS) data and other spatial and temporal data (stored as ACCESS or SQL SERVER databases) that have been or will be prepared by USGS, CBP, and other state and Federal agencies, and supplemented by ICPRB and other agencies as appropriate. GIS data will include land use/cover, geology, soils, digital elevation model (DEM) data, drainage basins (11-digit HUC), Chesapeake Bay SPARROW (Preston and Brakebill, 1999) model networks, state and county boundaries, stream reach network (RF1), streamflow and water-quality data-collection locations, and point-source discharge locations. The data sets will be properly attributed and include critical information such as fertilizer application rates and timing for agricultural areas and lawns.

USGS will be responsible for development and calibration of the Potomac Watershed Model. USGS will use the GIS data to build the framework of the model and produce appropriate model segmentation, in consultation with ICPRB, MDE, and CBP. USGS will also compile available streamflow and water-quality data and assemble meteorological data for model operation; USGS will use information existing in ADAPS for the development of F-tables use for river reach routing and compile existing information on water diversions.

CBP will be responsible for parallel development of Phase 5 of the CBWM, to be completed by January of 2004; the Potomac Watershed Model developed by USGS will provide one major basin nested within the CBWM. CBP will be responsible for development and testing of scripts and other software necessary to link edge of stream calculations on a county or watershed segment basis with stream reach calculations. CBP will work with USGS staff on data compilation (task 1 above) and provide leadership in aspects of data compilation and processing as necessary. CBP will provide a forum for interaction of model developers and stakeholders, through regularly scheduled Modeling Subcommittee meetings.

ICPRB will be responsible for all aspects of outreach and inter-agency coordination, including annual public meetings and quarterly technical workshops and stakeholder meetings. ICPRB will also prepare reports describing features of the model relevant to MDE's TMDL program in the Potomac River Basin.

Methods

Data Compilation

HSPF has extensive data requirements, depending on the size of the basin, length of time simulated, and level of simulation complexity (number of constituents, spatial and temporal resolution). (***Input data*** are here taken to refer to independently measured or tabulated information, such as land use, manure application rates, or precipitation amounts, as opposed to ***model parameters*** that are determined through the exercise of calibration.)

Compilation of existing input data will proceed in two stages. The first stage will involve information required to build model segmentation, such as 11-digit HUC basin and county boundaries, the RF1 reach network, Chesapeake Bay SPARROW model reach network (MAINC) and DEM-delineated watersheds, Tributary Strategies basins, and the location of sites with time series data (streamflow, meteorological) and other observational data (water quality, published hydrological or chemical mass balance studies). This first stage should be completed in the first quarter of project year 1.

Development of model segmentation, model network (the connections between watershed segments and reaches), and construction of UCI (User's Control Input) files will follow completion of this first stage of data compilation.

The second stage of data compilation will include forcing functions (time series of precipitation and other meteorological measurements) and sediment and nutrient source information. Time-series data will be processed to create input WDM (Watershed Data Management) files, using the tools ANNIE and IOWDM. Much of this data processing (excluding meteorological and streamflow data) can proceed in parallel with model calibration for hydrology.

Development of Model Calibration Strategy

Typically, HSPF simulations will require calibration of a large number of model parameters. For example, each land use, watershed segment or river reach, and process (e.g., runoff simulation, nitrogen cycling) will have several parameters, although not all will be unique in a given model implementation. (A number of assumptions must be made in the course of developing model parameterization, for example, the level of process complexity to be simulated and whether or not spatial homogeneity is assumed for some parameters.) As a result, a given model may have hundreds or thousands of individual parameter values that must be specified by the user. The process of establishing these values can be a difficult and time-consuming task.

One tool that has evolved to aid in model calibration is HSPEXP (Lumb, McCammon, and Kittle, 1994), an expert system that aids in the modification of UCI files to improve model statistics, based on the experience of experts in the use of HSPF and codified into a set of rules to recommend parameters. This is obviously somewhat subjective and can be applied only to hydrological calibration. Therefore, the proposed study will explore recent advances in model calibration and apply them to HSPF.

Hill (1998) has developed a set of guidelines for "effective" model calibration that constitute to some extent an expert system for any type of model. The tool developed to assist in this process is a general framework for inverse modeling ("inverting" the governing equation(s) to solve for the parameters rather than the (unknown) results of a process) that calculates parameter values that minimize a weighted least-squares objective function using nonlinear regression. The method has been built into the most recent version of the USGS ground-water flow and transport model, MODFLOWP, and is also the basis for UCODE (Poeter and Hill, 1997, 1998, 1999). The minimization is accomplished using a modified Gauss-Newton method, and prior, or direct, information on estimated parameters can be included in the regression.

The proposed study will seek to implement UCODE for HSPF, beginning with the simplest case (and most parsimonious parameter set)–hydrological calibration for a small subwatershed. The advantages of this method of model calibration are: 1) it maximizes model accuracy and maintains parameter selection objectivity, while allowing for the influence of an "expert"; 2) it provides additional information on model attributes, such as parameter sensitivities, that can aid in model interpretation and understanding; 3) it provides a mechanism for future model improvement by indicating parameters that need additional information; and 4) once implemented, it offers the possibility of not only improving overall model accuracy and efficiency, but of reducing the time required for model calibration.

Model Calibration

Model calibration will proceed in two stages, with hydrological process calibration preceding calibration for water-quality variables (sediment, followed by nutrients). It will be critical to have all necessary input and calibration (i.e., observational) data related to a particular process or processes finalized by the start of calibration, to avoid time-consuming re-calibration.

It is hoped that inversion-calibration will accelerate the overall process of model calibration; however, the computational demands are extremely high with inverse methods (as well as with almost any objective calibration procedure) and the actual computational time that may be required cannot be accurately estimated *a priori*. The timeline (below) indicates completion of hydrological calibration by September 1, 2002, with further calibration (sediment and nutrients) completed one year later.

Analysis of Model Results

A number of study questions were identified above that will guide our analysis of model results. Not all of these questions may be addressed, and others may arise as the study progresses. The following discussion is meant to provide a tentative, and not definitive, plan for analysis.

> *How are temporal and spatial trends in observed nutrient and sediment loading related to trends in sources? Addressing this question will require a dynamic model that incorporates information on time-varying sources, such as manure and fertilizer application and land use.*

The Potomac Watershed Model, as a subwatershed of the Phase 5 CBWM, will incorporate a number of improvements over Phase 4.3 (the current CBWM) including time-varying land-use and source data (G. Shenk, CBP, oral commun., 2001). This will enable simulation of the effects of trends in these data. In addition, model segmentation will allow comparison between watershed model predicted loads, observed loads, and SPARROW predicted loads for at least two time periods–1987 and 1992, and possibly 1997 (J. Brakebill, USGS, oral commun., 2001).

> *How does the distance between source and receiving water body affect potential attenuation? Can simulation models incorporate spatially detailed land-use distributions in quantifying edge-of-stream loading or transport of nutrients and sediment?*

A second improvement in Phase 5 of the CBWM that will also be incorporated in the Potomac Watershed Model is refinement of model and river reach segmentation. This will improve the utilization of spatially detailed data and provide some opportunity to address the question of within-watershed attenuation related to proximity of streams and sources.

> *How does the lag or time delay inherent in subsurface (ground-water) transport of nutrients affect the timing of nutrient delivery to streams relative to application? This question has important implications for efforts to apply BMPs that may not be immediately beneficial due to this lag time (Focazio, Plummer, and others, 1998; Sprague, Langland, and others, 2000).*

Knowledge of the residence time of the ground-water systems in the Chesapeake Bay Watershed can help resource managers anticipate potential delays between implementation of BMPs and any improvements in water quality (Focazio, Plummer, and others, 1998). HSPF simulates storage and movement of ground water in a relatively simple fashion. Improvement in the model's ability to predict the lag time for chemical transport, between ground-water recharge and discharge as baseflow, is seen as an essential and necessary improvement (S. Phillips, USGS, oral commun., 2001). One avenue that will be explored is the proposed study is the direct inclusion of a lag time in the calculation of ground-water transport of dissolved constituents. Existing data on spring ages (Focazio, Plummer, and others, 1998) and analysis of hydrograph recession (Brutsaert and Lopez, 1998; Szilagyi, Parlange, and Albertson, 1998) might provide a means of estimating these lag times for individual watersheds.

> *What are the relative contributions of watershed (edge-of-stream) and in-stream processes to overall changes in nutrient concentrations delivered to the Potomac River and its tributaries, and how does in-stream processing vary with scale?*

The watershed model will simulate edge-of-stream incremental loadings as well as loadings to receiving water bodies (or at the end of each reach or outlet of each watershed). This allows direct comparison of source to edge-of-stream change and in-stream change. Significantly refining the stream reach network (relative to the existing Phase 4.3 CBWM), and expanding the range of watershed and sizes simulated allows for: 1) possible use of SPARROW-derived in-stream loss rates (Preston and Brakebill, 1999) and RF1 attributes in calibrating attenuation factors for reaches; and 2) examination of in-stream process rates as a function of watershed or river reach size.

Delivery of Results and Final Reports

The model (including all input and output files as well as the programs required to execute the model) will be completed and delivered to ICPRB by October 1, 2003. Provisional data sets and model results will be disseminated (as completed, see timeline below) through three mechanisms: quarterly technical workshops and stakeholder meetings on the Potomac Watershed Model (coordinated by ICPRB), regular CBP Modeling Subcommittee meetings, and, when appropriate, through CIMS (Chesapeake Information Management System).

USGS will prepare reports (to be published in one of the USGS report series) on aspects of model calibration, as well as on analysis of model results.

Timeline and Milestones

The project will run from July 1, 2001 through June 30, 2004. A task timeline is shown in Figure 4. The primary product from the project will be a calibrated model of the Potomac River Basin for hydrology, suspended sediment, and nutrients (nitrogen and phosphorus species). The completed model (including all input and output files as well as the programs required to execute the model) will be delivered to ICPRB by October 1, 2003.

Provisional data sets and model results will be disseminated (as completed) through three mechanisms: quarterly technical workshops and stakeholder meetings on the Potomac Watershed Model (coordinated by ICPRB), regular CBP Modeling Subcommittee meetings, and, when appropriate, through CIMS (Chesapeake Information Management System). Major milestones are as follows:

Model Segmentation	September 30, 2001
Meteorological Data	December 31, 2001
Hydrology Calibration	September 30, 2002
Land-use/Land-cover and Observational Data	December 31, 2002
Sediment Calibration	March 31, 2003
Nutrient Calibration	September 30, 2003

USGS will submit quarterly progress reports to ICPRB. A report or reports describing the Potomac Watershed Model development and analysis and documenting calibration methods and calibrated parameters will be prepared by the USGS in a USGS technical report series.

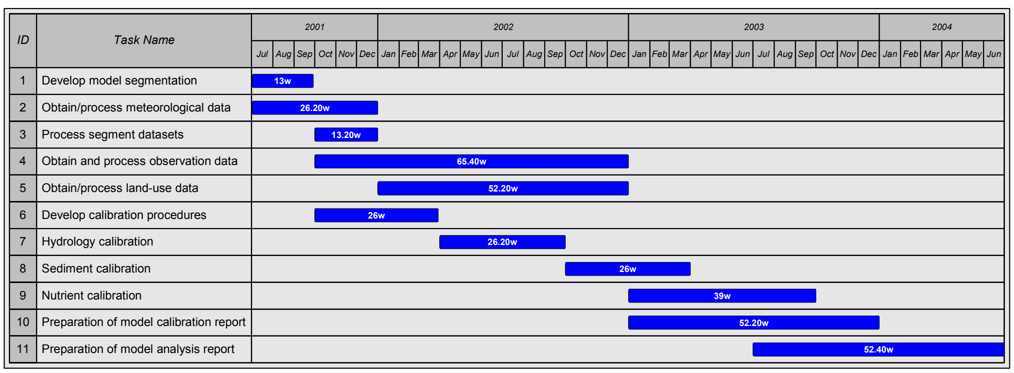

Figure 4. Timeline of activities for the proposed study.

References

Alexander, R.B., Smith, R.A., and Schwarz, G.E., 2000, Effect of stream channel size on the delivery of nitrogen to the Gulf of Mexico: Nature, v. 403, p. 758-761.

Ator, S.W., Blomquist, J.D., Brakebill, J.W., Denis, J.M., Ferrari, M.J., Miller, C.V., and Zappia, H., 1998, Water quality in the Potomac River Basin, Maryland, Pennsylvania, Virginia, West Virginia, and the District of Columbia, 1992-96: U.S. Geological Survey Circular 1166.

Bachman, L.J., and Krantz, D.E., 2000, The potential for denitrification of ground water by Coastal Plain sediments in the Patuxent River Basin, Maryland: U.S. Geological Survey Fact Sheet FS-053-00.

Bachman, L.J., Lindsey, B., Brakebill, J.W., and Powars, D.S., 1998, Ground-water discharge and base-flow nitrate loads of nontidal streams, and their relation to a hydrogeomorphic classification of the Chesapeake Bay Watershed, Middle Atlantic Coast: U.S. Geological Survey Water-Resources Investigations Report 98-4059.

Bicknell, B.R., Imhoff, J.C., Kittle, J.L., Jr., and Donigian, A.S., Jr., 1996, Hydrological Simulation Program-FORTRAN user's manual for Release 11: U.S. Environmental Protection Agency.

Brutsaert, W., and Lopez, J.P., 1998, Basin-scale geohydrologic drought flow features of riparian aquifers in the southern Great Plains: Water Resources Research, v. 34, no. 2, p. 233-240.

Crawford, N.H., and Linsley, R.K., 1966, Digital simulation in hydrology: Stanford Watershed Model IV: Stanford University Technical Report No. 39.

Dillow, J.J.A., and Greene, E.A., 1999, Ground-water discharge and nitrate loadings to the coastal bays of Maryland: U.S. Geological Survey Water-Resources Investigations Report 99-4167.

Donigian, A.S., and Crawford, N.H., 1979, User's manual for the Nonpoint Source (NPS) Model: U.S. Environmental Protection Agency.

Donigian, A.S., and Davis, H.H., 1978, User's manual for Agricultural Runoff Management (ARM) Model: U.S. Environmental Protection Agency.

Focazio, M.J., Plummer, L.N., Bohlke, J.K., Busenberg, E., Bachman, L.J., and Powars, D.S., 1998, Preliminary estimates of residence times and apparent ages of ground water in the Chesapeake Bay Watershed, and water-quality data from a survey of springs: U.S. Geological Survey Water-Resources Investigations Report 97-4225.

Gerhart, J.M., and Brakebill, J.W., 1996, Design and implementation of a sampling strategy for a water-quality assessment of the Potomac River Basin: U.S. Geological Survey Water-Resources Investigations Report 96-4034.

Hill, M.C., 1998, Methods and guidelines for effective model calibration: U.S. Geological Survey Water-Resources Investigations Report 98-4005.

Hornberger, G.M., Raffensperger, J.P., Wiberg, P.L., and Eshleman, K.N., 1998, Elements of Physical Hydrology: Baltimore, The Johns Hopkins University Press, 302 p.

Krantz, D.E., and Powars, D.S., 2000, Hydrogeologic setting and potential for denitrification in ground water, Coastal Plain of southern Maryland: U.S. Geological Survey Water-Resources Investigations Report 00-4051.

Langland, M.J., Lietman, P.L., and Hoffman, S., 1995, Synthesis of nutrient and sediment data for watersheds within the Chesapeake Bay drainage basin: U.S. Geological Survey Water-Resources Investigations Report 95-4233.

Lumb, A.M., McCammon, R.B., and Kittle, J.L., 1994, User's Manual for an expert system (HSPEXP) for calibration of the Hydrologic Simulation Program-FORTRAN: U.S. Geological Survey Water-Resources Investigations Report 94-4168.

Peterson, B.J., Wollheim, W.M., Mulholland, P.J., Webster, J.R., Meyer, J.L., Tank, J.L., Marti, E., Bowden, W.B., Valett, H.M., Hershey, A.E., McDowell, W.H., Dodds, W.K., Hamilton, S.K., Gregory, S., and Morrall, D.D., 2001, Control of nitrogen export from watersheds by headwater streams: Science, v. 292, p. 86-90.

Phillips, S.W., Focazio, M.J., and Bachman, L.J., 1999, Discharge, nitrate load, and residence time of ground water in the Chesapeake Bay Watershed: U.S. Geological Survey Fact Sheet FS-150-99.

Poeter, E.P., and Hill, M.C., 1997, Inverse models: a necessary next step in groundwater modeling: Ground Water, v. 35, no. 2, p. 250-260.

_____, 1998, Documentation of UCODE, a computer code for universal inverse modeling: U.S. Geological Survey Water-Resources Investigations Report 98-4080.

_____, 1999, UCODE, A computer code for universal inverse modeling: Computers & Geosciences, v. 25, no. 4, p. 457-462.

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.

Smith, R.A., Schwarz, G.E., and Alexander, R.B., 1997, Regional interpretation of water-quality monitoring data: Water Resources Research, v. 33, no. 12, p. 2781-2798.

Sprague, L.A., Langland, M.J., Yochum, S.E., Edwards, R.E., Blomquist, J.D., Phillips, S.W., Shenk, G.W., and Preston, S.D., 2000, Factors affecting nutrient trends in major rivers of the Chesapeake Bay Watershed: U.S. Geological Survey Water-Resources Investigations Report 00-4218.

Szilagyi, J., Parlange, M.B., and Albertson, J.D., 1998, Recession flow analysis for aquifer parameter determination: Water Resources Research, v. 34, no. 7, p. 1851-1857.

Vogelmann, J.E., Sohl, T.L., Campbell, P.V., and Shaw, D.M., 1997, Regional land cover characterization using Landsat and other spatial data input [abst.], in Developing the Tools to Meet the Nation's Monitoring Needs - The Evolution of EMAP.

Appendix 1: Preliminary Analysis of Available Water-Quality Sites

In planning a new MDE-USGS monitoring program in the Potomac River Basin that began July 1, 2000 (see Appendix 2), an initial evaluation of existing data was conducted. The steps taken to arrive at a preliminary list of potential sites for model calibration was as follows:

1. Existing data were compiled.

2. Available data-collection sites (including active and inactive gage sites, with or without water-quality sampling) were grouped by subunit.

3. Within each subunit, candidate sites were classified according to their utility as: a) integrator sites; or b) indicator sites, that may be used to calibrate or verify the model for particular land uses within a subunit.

Water-quality site information was compiled into a single GIS coverage from the following sources (there is some overlap between different sources):

- Potomac NAWQA "fixed" sites (Gerhart and Brakebill, 1996): 11 sites

- Sites adopted by SPARROW (SPAtially-Referenced Regression On Watershed attributes), Version 2, 1992 time period (S. Preston, USGS, oral commun., 2000): 40 sites

- Sites adopted by SPARROW, Version 1, 1987 time period (Preston and Brakebill, 1999): 34 sites

- Sites currently monitored by MDE: 27 sites, not all of which coincide with an active stream gage

- DNR Core-Trends monitoring sites: 36 sites, not all of which coincide with an active stream gage

Catchments were examined within each individual subunit (Figure 1) in order to identify those that could be used first as integrators—sites that drain large areas and that represent the combined effects of all natural and anthropogenic water-quality factors in the particular subunits they drain. At least one integrator site was selected for each of the five main subunits. A total of twelve possible integrator sites were identified; of these, eleven had active stream gages and eight had adequate water-quality data available for modeling purposes (this included only those sources and data that: 1) can be used to estimate an annual load (for any of total nitrogen, total phosphorus, or sediment), that is, that involve simultaneous continuous flow measurement; 2) were from the period 1980–2000; and 3) included adequate provision for quality assurance).

Additional sites were chosen within each subunit as indicators—sites that drain relatively homogenous catchments. The intention in choosing this suite of sites is to provide information necessary to calibrate or verify the watershed model for a particular land use within each subunit. The goal was to identify small to intermediate size catchments (although a lower size limit was maintained to avoid some issues of scale dependence and sampling logistics) with a single predominant land use or characteristic land-use combination. This exercise produced twenty additional sites, of which three had inactive gages and ten had adequate water-quality data available for modeling purposes.

Finally, five sites on the main stem of the Potomac River were selected primarily for use as calibration or verification points for in-stream routing and process modeling. A total of 37 sites were determined in this manner; of these, fifteen sites were considered candidates for new or reactivated monitoring, and nine of these were prioritized (Appendix 2). Table 5 presents the list of 31 sites (Figure 3), including the nine new sites. A summary of available analyses is given in Table 6.

Station ID	Station Name	Subunit	Site Type	Gage Reactivation	New Sampling
01595200	Stony River nr Mount Storm, WV	AP	Mining		
01599000	Georges Creek at Franklin, MD	AP	Urban		
01603000	North Branch Potomac River nr Cumberland, MD	AP	Integrator		
01608000	South Fork S. Branch Potomac River nr Moorefield, WV	VR	Ag(poultry)/Forest		
01608500	South Branch Potomac River nr Springfield, WV	VR	Integrator		
01610000	Potomac River at Paw Paw, WV	Main	Main		
01610155	Sideling Hill Creek nr Bellegrove, MD	VR	Forest		X
01611500	Cacapon River nr Great Cacapon, WV	VR	Integrator		X
01613000	Potomac River at Hancock, MD	Main	Main		
01614500	Conococheague Creek at Fairview, MD	GV	Integrator		
01621410	Black's Run at Rt 726 at Harrisonburg, VA	GV	Urban	NEW	X
01618000	Potomac River at Shepherdstown, WV	Main	Main		X
01619500	Antietam Creek nr Sharpsburg, MD	GV	Integrator		
01621050	Muddy Creek at Mt. Clinton, VA	GV	Ag(crop)		
01624800	Christians Creek nr Fishersville, VA	GV	Ag(poultry)		
01631000	South Fork Shenandoah River at Front Royal, VA	GV	Integrator		
01634000	North Fork Shenandoah River nr Strasburg, VA	GV	Integrator		
01635500	Passage Creek nr Bucktown, VA	VR	Ag(non-poultry)/Forest		
01636500	Shenandoah River at Millville, WV	GV	Integrator		
01638480	Catoctin Creek at Taylorstown, VA	PD	Ag(low-intensity)		
01638500	Potomac River at Point of Rocks, MD	Main	Main		
01639000	Monocacy River at Bridgeport, MD	PD	Ag/Urban		
01643000	Monocacy River at Jug Bridge nr Frederick, MD	PD	Integrator		
01644000	Goose Creek nr Leesburg, VA	PD	Integrator		X
01646580	Potomac River at Chain Bridge at Washington, DC	Main	Main		
01649500	Northeast Branch Anacostia River at Riverdale, MD	CP	Urban		
01653600	Piscataway Creek at Piscataway, MD	CP	Urban		X
01654000	Accotink Creek nr Annandale, VA	PD	Urban		
01658000	Mattawoman Creek nr Pomonkey, MD	CP	Urban	X	X
01660920	Zekiah Swamp Run nr Newtown, MD	CP	Integrator		X
01661050	St. Clement Creek nr Clements, MD	CP	Ag/Forest		X

Table 5. Preliminary potential water-quality sites for Potomac River Watershed Model calibration effort. (CP – Coastal Plain; PD – Piedmont; GV – Great Valley; VR – Valley and Ridge; AP – Appalachian Plateau; Main – Potomac main stem; Ag – agriculture.)

Station ID		1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
01595200	TN	0	0	0	0	0	0	0	–	0	0	0	–	–	–	–	–	–
	TP	0	0	0	0	0	0	0	–	0	0	0	–	–	–	–	–	–
	SSC	6	1	0	0	0	0	0	–	0	0	0	–	–	–	–	–	–
	TSS	0	0	0	0	0	0	0	–	0	0	0	–	–	–	–	–	–
01599000	TN	0	0	0	0	0	0	11	10	10	11	10	9	9	11	12	12	12
	TP	23	23	23	23	23	17	9	9	10	11	10	12	8	12	12	12	12
	SSC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	TSS	12	11	10	12	11	12	11	11	12	11	11	11	12	11	11	12	12
01603000	TN	0	0	0	0	0	0	0	0	–	–	–	–	0	0	0	–	–
	TP	15	14	14	12	12	8	0	0	–	–	–	–	0	18	10	–	–
	SSC	12	1	0	0	0	0	0	0	–	–	–	–	0	18	0	–	–
	TSS	0	9	12	9	11	9	0	0	–	–	–	–	0	0	0	–	–
01608000	TN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	–
	TP	0	0	0	0	0	0	0	0	0	0	0	0	0	20	25	14	–
	SSC	0	0	0	0	0	0	0	0	0	0	0	0	0	20	11	14	–
	TSS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	2	–
01608500	TN	0	0	0	0	–	–	–	–	–	–	–	–	–	0	0	0	0
	TP	0	0	0	0	–	–	–	–	–	–	–	–	–	20	21	14	2
	SSC	1	1	0	0	–	–	–	–	–	–	–	–	–	20	21	14	2
	TSS	0	0	0	0	–	–	–	–	–	–	–	–	–	0	0	0	0
01610000	TN	0	0	0	0	0	0	11	10	11	10	10	11	10	10	12	10	12
	TP	23	22	23	24	22	18	9	6	11	10	9	11	10	12	12	10	12
	SSC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	TSS	12	10	12	12	11	10	11	11	12	11	9	10	11	10	12	9	12
01613000	TN	0	0	0	0	0	0	12	11	10	10	11	11	9	12	12	12	12
	TP	0	8	11	13	12	10	12	12	10	10	10	12	9	12	12	12	12
	SSC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	TSS	0	8	11	13	12	10	12	11	11	12	12	12	12	12	12	12	12
01614500	TN	0	0	0	0	0	0	12	11	11	9	10	11	10	12	12	12	11
	TP	8	12	12	10	11	11	13	12	11	10	10	12	12	36	31	95	191
	SSC	0	0	0	0	0	0	0	0	0	0	0	0	0	24	9	19	92
	TSS	7	8	10	10	11	10	12	11	12	12	12	12	12	12	12	12	11
01619500	TN	0	0	0	0	0	0	12	11	11	10	12	13	11	12	11	11	11
	TP	8	12	13	13	12	12	14	12	12	10	9	13	11	11	13	12	12
	SSC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	TSS	7	8	11	13	12	12	12	11	12	11	12	14	12	12	12	12	12
01621050	TN	–	–	–	–	–	–	–	–	–	–	–	–	–	31	11	6	–
	TP	–	–	–	–	–	–	–	–	–	–	–	–	–	31	11	6	–
	SSC	–	–	–	–	–	–	–	–	–	–	–	–	–	29	9	4	–
	TSS	–	–	–	–	–	–	–	–	–	–	–	–	–	0	0	0	–
01624800	TN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	TP	10	11	9	11	8	8	13	10	7	4	6	10	12	12	11	12	12
	SSC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	TSS	10	11	9	11	8	11	13	10	7	6	6	10	12	12	12	12	12

Table 6. Number of water-quality analyses available by station ID, calendar year, and type of analysis (TN - total nitrogen; TP - total phosphorus; SSC - suspended sediment concentration; TSS - total suspended solids; "–" - no data collected that year).

Station ID		1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
01631000	TN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	16
	TP	8	11	9	12	10	6	13	12	6	4	7	11	12	12	14	11	30
	SSC	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	15
	TSS	8	11	9	12	10	12	13	12	7	4	5	9	11	12	12	12	12
01634000	TN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	15
	TP	7	11	9	11	8	8	14	8	4	5	5	12	12	12	14	11	31
	SSC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	17
	TSS	8	11	9	11	8	12	14	8	4	5	5	8	11	12	12	12	12
01635500	TN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	TP	8	11	8	11	9	8	14	8	4	5	5	10	12	12	12	11	12
	SSC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	TSS	8	11	8	11	9	12	14	8	4	5	4	10	11	12	12	12	12
01636500	TN	9	6	5	6	6	7	6	5	5	0	1	6	3	0	0	0	0
	TP	10	6	5	6	6	7	6	5	5	1	6	12	8	38	24	8	6
	SSC	7	6	5	6	6	7	6	6	5	1	8	12	10	34	18	4	6
	TSS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
01638480	TN	–	–	–	–	–	–	–	–	–	–	–	–	–	0	5	0	–
	TP	–	–	–	–	–	–	–	–	–	–	–	–	–	8	17	3	–
	SSC	–	–	–	–	–	–	–	–	–	–	–	–	–	9	9	2	–
	TSS	–	–	–	–	–	–	–	–	–	–	–	–	–	0	0	0	–
01638500	TN	0	0	0	0	0	0	11	11	11	11	11	12	11	11	12	11	12
	TP	13	12	12	12	10	13	10	12	9	11	10	13	11	11	12	11	12
	SSC	0	0	3	1	6	1	1	1	1	1	0	0	2	0	0	0	0
	TSS	7	8	11	12	10	13	12	11	12	12	12	14	12	12	12	11	12
01639000	TN	0	0	1	1	0	0	11	11	12	18	130	25	55	11	11	12	11
	TP	7	10	12	13	12	11	12	11	12	18	179	39	101	242	85	84	17
	SSC	0	0	0	0	0	0	0	0	0	8	85	24	34	36	51	5	6
	TSS	7	10	10	11	12	11	12	11	12	11	12	14	12	12	12	12	11
01643000	TN	0	0	1	1	0	–	–	0	0	–	0	1	0	0	0	0	0
(01643020)[2]	TP	1	4	3	2	0	–	–	0	0	–	0	2	0	18	19	2	6
	SSC	0	1	0	1	2	–	–	2	1	–	8	4	10	18	16	0	6
	TSS	0	0	0	0	0	–	–	0	0	–	0	0	0	0	0	0	0
01646580	TN	50	75	5	6	6	10	12	12	9	14	19	6	6	19	49	41	9
	TP	50	76	5	6	6	10	13	12	11	14	20	19	13	38	63	46	13
	SSC	81	84	6	6	6	8	11	12	11	14	22	17	16	36	17	8	14
	TSS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	39	33	0
01649500	TN	–	–	–	–	–	0	0	0	0	0	0	0	0	0	0	–	–
	TP	–	–	–	–	–	1	0	0	0	0	0		26	16	15	–	–
	SSC	–	–	–	–	–	0	0	0	0	0	0	0	0	0	0	–	–
	TSS	–	–	–	–	–	14	19	20	19	20	20	14	30	16	15	–	–
01654000	TN	–	–	–	–	–	–	–	–	–	–	–	–	–	0	17	0	–
	TP	–	–	–	–	–	–	–	–	–	–	–	–	–	8	42	10	–
	SSC	–	–	–	–	–	–	–	–	–	–	–	–	–	8	25	10	–
	TSS	–	–	–	–	–	–	–	–	–	–	–	–	–	0	0	0	–

Table 6 (continued).

[2] The water-quality site associated with gage site 01643000, Monocacy River at Jug Bridge nr Frederick, MD, is 01643020, Monocacy River at Reichs Ford Bridge nr Frederick, MD.

Appendix 2: MDE-USGS Potomac Monitoring Site Information

Through a joint agreement between MDE and USGS that established new water-quality monitoring stations in the Potomac River Basin in July of 2000, USGS has responsibility for restarting and operate two then-inactive continuous stream-gaging stations, and establishing nine new water-quality monitoring stations.

Candidate sites for new monitoring were chosen based on existing information and modeling needs. Those sites without adequate historical water-quality data were then prioritized to arrive at proposed new monitoring sites. The nine highest-priority sites were selected for new monitoring; of these, two require restart of an inactive gage (Tables 7 and 8). Manual monthly sample collection began in October 2000. Automatic sample collection began in January 2001. Sampling will end in June 2002; the minimum sampling period will be 18 months. It is expected that sampling will continue at each of the nine sites for three months following the end of this sampling period (i.e., July–September 2002) under the auspices of the NAWQA or Federal-State Cooperative Funding Programs. USGS will collect and analyze samples at a rate of approximately 24–36 samples per water year from each site. Samples will be analyzed for nutrients and suspended sediment, as well as selected additional parameters.

Station ID	Station Name	Subunit	Site Type	Gage Reactivation	Sampling Lead
01660920	Zekiah Swamp Run nr Newtown, MD	CP	Integrator	No	USGS-MD
01644000	Goose Creek nr Leesburg, VA	PD	Integrator	No	USGS-VA
01618000	Potomac River at Shepherdstown, WV	Main	Main	No	MDE
01658000	Mattawoman Creek nr Pomonkey, MD	CP	Urban	Yes	USGS-MD
01653600	Piscataway Creek at Piscataway, MD	CP	Urban	No	USGS-MD
01661050	St. Clement Creek nr Clements, MD	CP	Ag/Forest	No	USGS-MD
01621410	Black's Run at Rt 726 at Harrisonburg, VA	GV	Urban	New	USGS-VA
01610155	Sideling Hill Creek nr Bellegrove, MD	VR	Forest	No	MDE
01611500	Cacapon River nr Great Cacapon, WV	VR	Integrator	No	USGS-WVA

Table 7. MDE-USGS Potomac Monitoring site characteristics. (CP – Coastal Plain; PD – Piedmont; GV – Great Valley; VR – Valley and Ridge; Main – Potomac main stem; Ag – agriculture.)

Station ID	Station Name	Area, km^2	Major land use, in percentage of catchment area				
			Urban	Agriculture	Forest	Wetland	Water/Barren
01660920	Zekiah Swamp Run nr Newtown, MD	208	22.6	18.4	**45.8**	11.1	2.1
01644000	Goose Creek nr Leesburg, VA	856	4.7	**54.7**	40.2	0.1	0.2
01618000	Potomac River at Shepherdstown, WV	15,419	2.9	23.0	**72.3**	0.3	1.5
01658000	Mattawoman Creek nr Pomonkey, MD	148	31.7	12.9	**44.7**	8.7	1.9
01653600	Piscataway Creek at Piscataway, MD	93	**55.1**	10.8	27.6	5.2	1.2
01661050	St. Clement Creek nr Clements, MD	47	18.3	29.4	**47.2**	5.0	0.2
01621410	Black's Run at Rt 726 at Harrisonburg, VA	29	**70.2**	17.1	8.4	<0.1	4.3
01610155	Sideling Hill Creek nr Bellegrove, MD	268	0.9	21.5	**76.1**	0.3	1.1
01611500	Cacapon River nr Great Cacapon, WV	1,751	0.5	12.8	**85.7**	0.1	1.0

Table 8. Catchment characteristics for the nine new MDE-USGS Potomac Monitoring sites. Predominant land use indicated in bold (Vogelmann, Sohl, and others, 1997).