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)

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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.

Progress During Reporting Period

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

1. Modeling of daily and hourly precipitation, hourly temperature, and Hamon (1961) estimates of daily and hourly potential evapotranspiration (PET) on a 5-km grid; integration of hourly values to the model land segments; creation of WDM files for all data.

2. A graphical post-processor for visualization and statistical evaluation of model output was initially developed and demonstrated by Joe Vrabel.

3. An approach to hydrology calibration was developed and presented at the August Modeling Subcommittee meeting.

Modeling of Precipitation, Temperature, and Potential Evapotranspiration (Lauren Hay, USGS, Denver, Colorado)

The methods used have been described in previous progress reports (see box below). The model developed by Lauren Hay was run with the following options: beginning and end dates, January 1, 1984, and December 341, 1999, respectively; the search distance for hourly disaggregation was set to 1,000 km, and the percent daily volume to match for selection of a disaggregation site was et to 75%; PET was distributed over daylight hours and a Hamon coefficient of 0.0055 was used.

Daily and hourly precipitation, hourly temperature, and daily and hourly PET time series were converted to WDM files, and monthly and annual summaries prepared. Average annual values modeled over the entire region are shown in Figure 1and Figure 2. We are in the process of preparing a report that summarizes the statistical fit of the model to the observational data and summarizes the results.

Development of a Graphical Post-Processor

A graphical post-processor has been developed in MATLAB by Joe Vrabel that provides a number of plots of simulated and observed data and statistical tests that provide insight into the accuracy of the simulation (Figure 3). This tool will see continued development over the project period, through calibration and analysis of the model results. At present, for hydrology calibration, the summary statistics that are incorporated include:

1) Observed daily discharge, *o*: *N* daily values

2) Simulated daily discharge, *s*: *N* daily values

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 are used for temperature. 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 and seasonal climate variations, MLR equations are developed for each month 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 describes 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 land segment in the modeled region the following procedure was followed: (1) mean daily p and corresponding mean xyz values from a selected station set (determined using an Exhaustive Search analysis) were used with the "slopes" of the monthly MLR to compute a unique b_0 for that day; (2) the MLR equation was then solved using the xyz values of points on a 5-kilometer (km) grid; and (3) these gridded estimates were integrated over the land segment area.

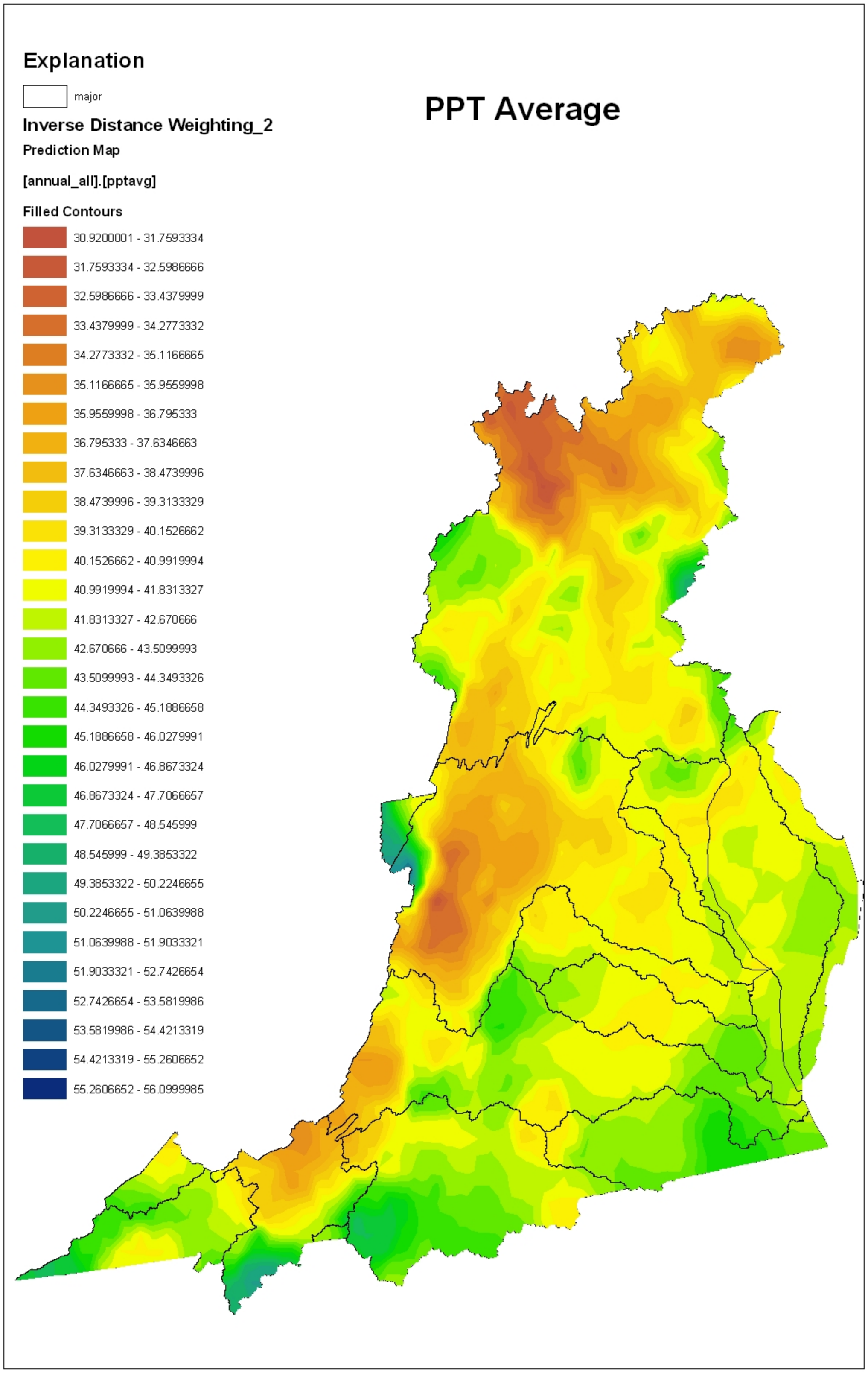

Figure 1. Modeled average annual precipitation, 1984-1999. Values are in inches.

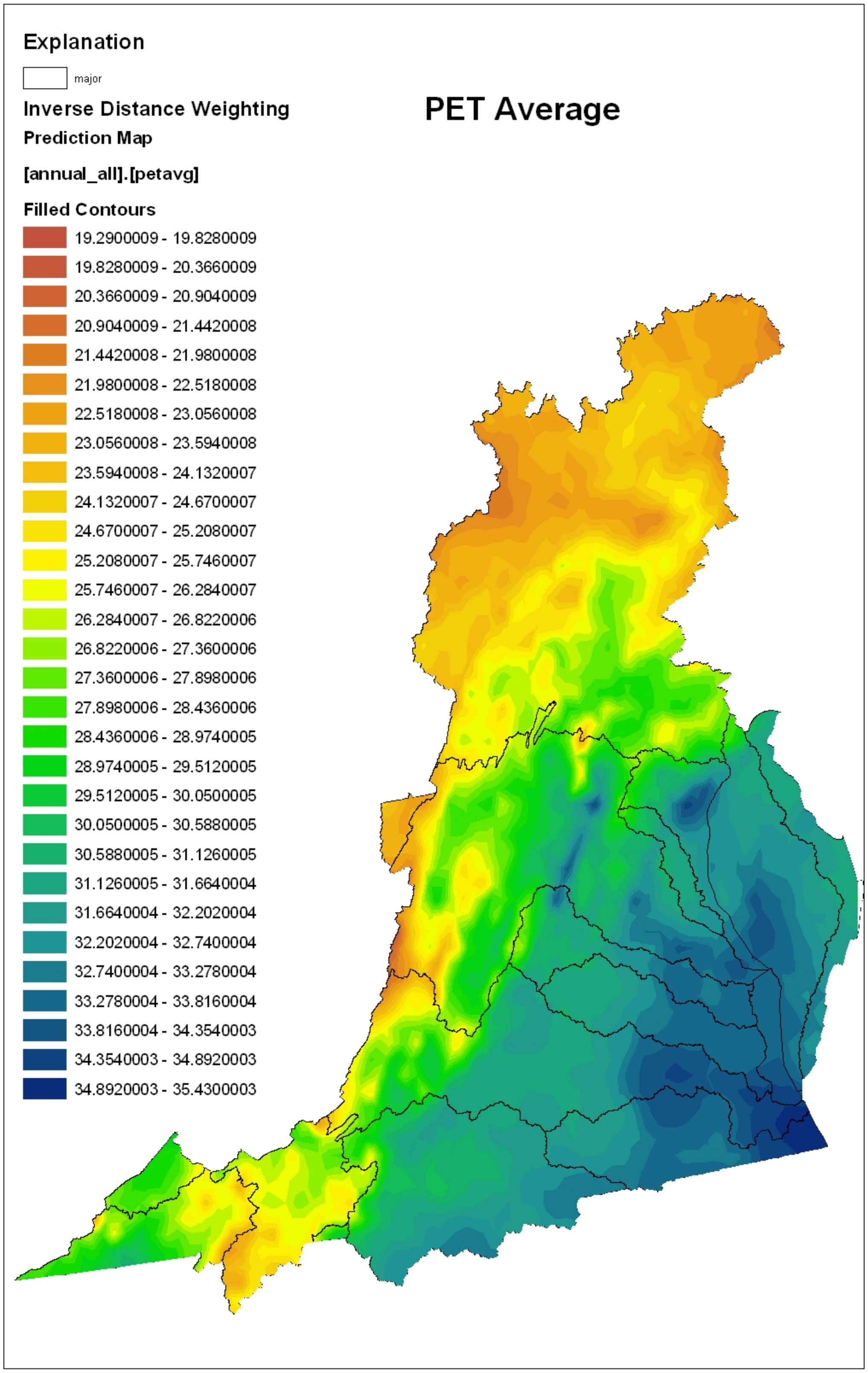

Figure 2. Modeled average annual potential evapotranspiration, 1984-1999. Values are in inches.

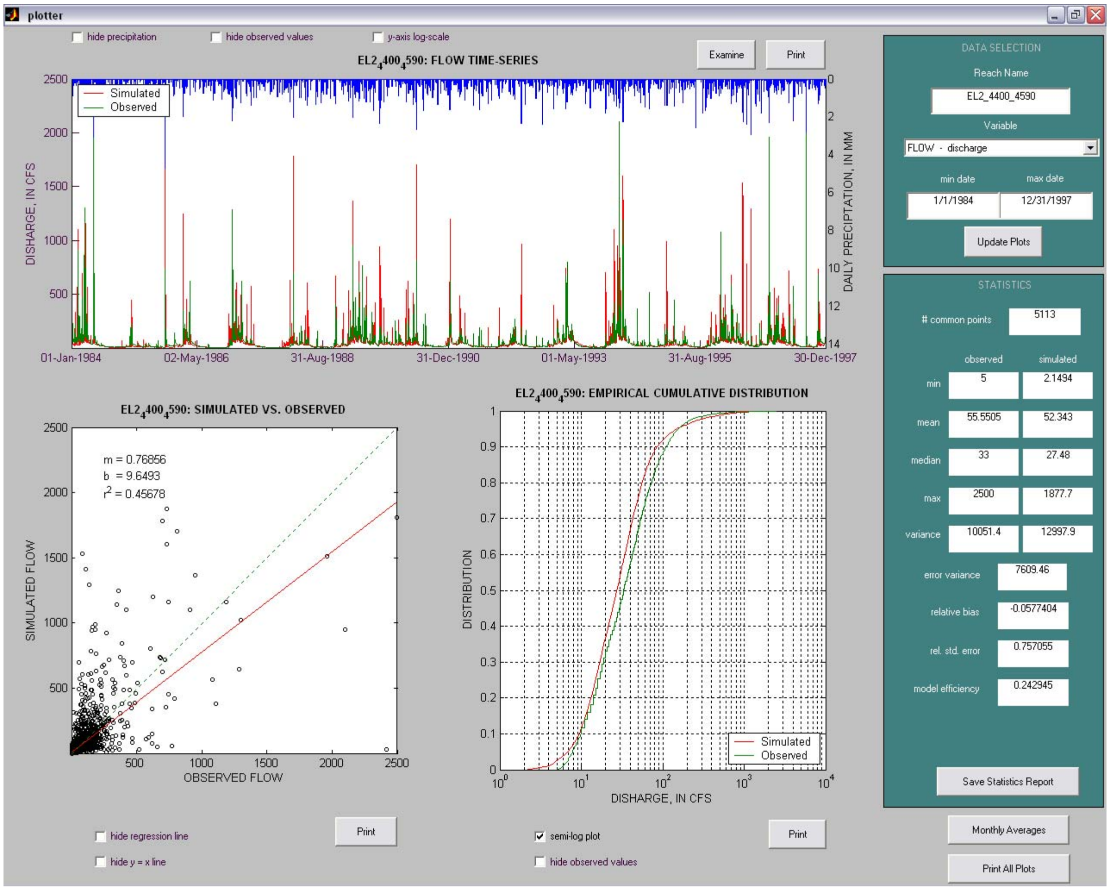

Figure 3. A screen shot of the MATLAB graphical post-processor.

3) Mean, $\bar{o}$, $\bar{s}$:

$$\bar{o} = \frac{1}{N}\sum_{i=1}^{N} o_i \qquad \bar{s} = \frac{1}{N}\sum_{i=1}^{N} s_i$$

4) Median: the middle value in a series of ranked values.

5) Variance, σ_o^2 , σ_s^2 :

$$\sigma_o^2 = \frac{1}{N-1}\sum_{i=1}^{N}(o_i - \bar{o})^2 \qquad \sigma_s^2 = \frac{1}{N-1}\sum_{i=1}^{N}(s_i - \bar{s})^2$$

6) Error variance, σ_ε^2 :

$$\sigma_\varepsilon^2 = \frac{1}{N-1}\sum_{i=1}^{N}(s_i - o_i)^2$$

7) Relative bias, r_b :

$$r_b = \frac{1}{\bar{o}}\left[\frac{1}{N}\sum_{i=1}^{N}\left(s_i - o_i\right)\right]$$

8) Relative standard error, ε_s :

$$\varepsilon_s = \frac{\sigma_\varepsilon^2}{\sigma_o^2}$$

9) Nash-Sutcliffe model efficiency, *E*:

$$E = 1 - \varepsilon_s$$

The efficiency is like a statistical coefficient of determination (Beven, 2001), or r^2 value. It has a value of one for a perfect fit when σ_ε^2 = zero; it has the value of zero when $\sigma_\varepsilon^2 = \sigma_o^2$, which is to say that the model is no better than a one-=parameter "no-knowledge" model that gives a prediction of the mean of the observations for all time steps. Negative values of *E* indicate that the model is performing worse than the "no-knowledge" model.

Hydrology Calibration Approach

An approach to hydrology calibration has been developed by USGS and CBP. We will focus on calibration of different aspects of streamflow in the following order, based on guidance from Lumb and others (1994):

1. Annual water balance.

2. Partitioning of quickflow and base flow.

3. Annual base flow volume and base-flow dynamics.

4. Annual quickflow volume and base-flow dynamics.

5. Seasonal changes.

The general principles that we will follow, or the procedure that we will adopt is as follows:

1. We will begin by assuming the same parameter value everywhere.

2. If further refinement is necessary, as it generally will be, then we will use spatial data (slope, latitude) to determine parameter values *a priori*.

3. If we can determine a regional pattern, then we will set a regional parameter.

4. If further refinement is necessary or we have not achieved the desired model accuracy everywhere throughout the region, we will set land-use specific values.

5. The final step will involve site-specific calibration as a last resort for land segments or river reaches whose simulations after the previous steps still do not meet our desired model accuracy.

Plans for Next Quarter

1. Create F-tables for reservoirs.

2. Complete first draft of a report on the model segmentation (Martucci and others).

3. Analyze modeled meteorological fields (precipitation, temperature, PET).

4. Complete analysis of recession for the initial estimates for AGWRC (active ground-water recession parameter).

5. Complete initial version of MATLAB-based post-processor for hydrology calibration. Expand statistical tests that are available to include variance and other measures on log-transformed variables, and tests of normality for both raw and log-transformed data.

6. Develop an approach for improved ground-water transport.

References

Beven, K.J., 2001, Rainfall-Runoff Modelling: The Primer: Chichester, John Wiley & Sons, LTD, 360 p.

Hamon, W.R., 1961, Estimating potential evapotranspiration: Journal of the Hydraulics Division, American Society of Civil Engineers, v. 87, p. 107-120.

Lumb, A.M., McCammon, R.B., and Kittle, J.L., Jr., 1994, Users manual for an expert system (HSPEXP) for calibration of the Hydrological Simulation Program-Fortran: U.S. Geological Survey Water-Resources Investigations Report 94-4168, 102 p.