# ESTIMATION OF SUSPENDED-SEDIMENT AND NUTRIENT FLUXES AND ASSOCIATED TRENDS ACROSS THE CHESAPEAKE BAY WATERSHED

## EXTENDED ABSTRACT

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Chesapeake Bay is the largest of the Nation's estuaries and one of the most ecologically productive in the world. Excessive transport of suspended sediment and nutrients from the Chesapeake Bay watershed has had a detrimental effect on the habitat available to the living resources throughout the entire bay. Considerable effort has been taken by the Chesapeake Bay Program (CBP), comprised of Federal, State, and local governments, academic institutions, and non-profit organizations to reduce the amount of suspended-sediment and nutrients delivered annually to the bay. In 2010, the Environmental Protection Agency mandated the development of a total maximum daily load for the bay watershed as part of continued effort to reduce suspended-sediment and nutrient delivery to the bay. Improvement is expected in bay habitat as measured by improvements in water clarity, submerged aquatic vegetation, and dissolved oxygen. The CBP supports the operation of the CBP Nontidal Monitoring Network, which is a 120-station monitoring network, in the bay watershed. Data from this network are used to monitor current water-quality (suspended sediment and nutrients) conditions and track how these conditions change over time. Suspended-sediment and nutrient fluxes and changes in fluxes over time are key indicators that water resource managers use to assess the progress being made towards improving the structure and function of the bay ecosystem.

The U.S. Geological Survey (USGS), as a partner of the CBP, is responsible for the estimation of suspended-sediment and nutrient fluxes at all CBP Nontidal Monitoring Network stations as well as quantifying long- and short-term changes in suspended-sediment and nutrient fluxes. This flux and trend information is essential to the CBP to (1) assess progress made towards meeting water-quality goals, (2) efficiently allocate resources to areas of the watershed with degrading water-quality conditions, and (3) forecast conditions in the estuary for upcoming critical periods. The USGS ensures the integrity of the observed suspended-sediment and nutrient flux results by meeting three objectives:

1) Provide training for and evaluation of agencies monitoring water-quality conditions across the 120-station CBP Nontidal Monitoring Network to verify that all agencies are monitoring the full range of hydrologic conditions, while utilizing depth- and width-integrating isokinetic sampling techniques;

2) Evaluate and improve the statistical tools used to estimate fluxes and trends; and

3) Assess the quality of the observed water-quality data used to drive the statistical analyses to ensure that the flux and trend results are as accurate and defensible as possible.

The U.S. Geological Survey serves as the technical lead for the collection of suspended-sediment and nutrient data, across the CBP Nontidal Monitoring Network. They are responsible for ultimately ensuring that monitoring data are comparable from station-to-station and are appropriate for generating representative observed suspended-sediment and nutrient fluxes. Historically, our CBP monitoring partners (i.e. State agencies and River Basin Commissions) collected suspended-sediment and nutrient samples on a monthly basis by collecting a single grab sample from the centroid of flow. These samples were typically part of a larger ambient water-quality monitoring program. However, these monitoring techniques are not sufficient for the determination of suspended-sediment and nutrient fluxes because they do not capture the vertical and/or horizontal heterogeneity that often exists during high-flow conditions. The USGS, working with each of the CBP monitoring partners, added two critical sampling elements required for a monitoring station to be included in the CBP Nontidal Monitoring Network: targeted storm-flow monitoring and sample collection using isokinetically collected width- and depth-integrating techniques. The USGS annually evaluates how well each monitoring partner has represented water-quality conditions across the full range of each site's flow regime. Additionally, routine field audits are performed of all CBP monitoring agencies to ensure that monitoring is being performed consistently.

The U.S. Geological Survey annually estimates the total monthly and annual fluxes of suspended sediment and nutrients at each nontidal monitoring station as well as estimates the extent to which these fluxes are changing over time. Historically, USGS utilized a multiple-regression approach (ESTIMATOR) (Cohn and others, 1989) to estimate daily suspended-sediment and nutrient concentrations based on daily streamflow, time, and season. Two shortcomings of this historical approach were (1) the functional form of the ESTIMATOR model forces the relation between concentration and discharge to be linear or quadratic which makes ESTIMATOR susceptible to considerable over- or under- prediction of flux at stations that exhibit sigmoidal (s- shape) relations between concentration and discharge; and (2) the inability of ESTIMATOR to determine trends in flux estimates which the CBP require to directly measure progress towards reducing suspended-sediment and nutrient delivery to the bay.

The U.S. Geological Survey recently completed an evaluation of a new approach used to estimate suspended-sediment and nutrient fluxes and associated trends in fluxes, to address the shortcomings of the ESTIMATOR model. This new approach, Weighted Regression on Time, Discharge, and Season (WRTDS) is similar to ESTIMATOR in that it estimates daily concentrations based on daily streamflow, time, and season; however, instead of predefining the relation between concentration and flow as only linear or quadratic, WRTDS allows the relation between concentration and streamflow to be more flexible (Hirsch and others, 2010). The greatest effect of using WRTDS for flux estimates is an overall reduction in flux bias (the tendency to over- or under-predict observed flux) compared to flux estimates from ESTIMATOR (Moyer and others, 2012; Hirsch, 2014). Additionally, WRTDS allows for direct determination of trends in monthly and annual fluxes which provides CBP managers

more relevant information regarding how much annual fluxes of suspended-sediment and nutrients have changed (Moyer and others, 2012).

The U.S. Geological Survey routinely reviews the water-quality record, for each nontidal monitoring station, for the presence of non-environmental heterogeneities that may bias resulting flux and trend estimates. Causes for these heterogeneities typically fall into three categories, which are: (1) inconsistent storm sampling whereby targeted storm sample collection is added to a fixed-frequency monitoring record (2) changes in analytical laboratory censoring levels, and (3) changing analytical laboratory procedures (e.g. switching from total suspended solids to suspended-sediment concentration analysis). Using subsampling experiments on densely- sampled records, the USGS is characterizing the potential effects of the first of these heterogeneities in water-quality records. Preliminary experiments indicate that inconsistent storm sampling can result in deviations in estimated annual fluxes on the order of +/- 10 percent for dissolved inorganic nitrogen, +/- 15 percent for total phosphorus, and +/- 30 percent for suspended sediment, relative to a temporally homogenous baseline dataset containing both monthly and targeted storm samples. The USGS has developed simple screening-level indicators to identify which records may have been collected using inconsistent storm sampling methods. The analysis of the potential effects of inconsistent storm sampling can serve as a model for quantifying the effects of the other methodological heterogeneities listed above, and help to assure the quality of USGS and CBP monitoring partners' water-quality records, and the resulting flux and trend estimates provided to the CBP.

The U.S. Geological Survey is currently pursuing future enhancements to implemented data-collection and data- analysis techniques that will continue to reduce uncertainty in and improve the accuracy of each nontidal monitoring station's suspended-sediment and nutrient flux estimates and associated trends in estimated fluxes. Data-collection enhancements include: (1) continuous *in situ* monitoring of water-quality field parameters including pH, specific conductance, dissolved oxygen, turbidity, and water temperature; (2) use of those continuous water-quality parameters as surrogates for estimating suspended-sediment and/or nutrient fluxes, and (3) continuous *in situ* monitoring of dissolved nutrients (i.e. nitrate and orthophosphorus). Jastram and others (2009) demonstrated that suspended-sediment and nutrient fluxes, estimated using continuous *in situ* water-quality field parameters, exhibited reduced uncertainty when compared to suspended- sediment and nutrient fluxes estimated using streamflow. Data-analysis enhancements include: (1) utilization of continuous observed water-quality field parameters, for the estimation of suspended-sediment and nutrient fluxes, and (2) development of a weighted-regression approach similar to WRTDS that allows for the estimation of concentrations and fluxes at sub- daily time intervals, which is essential for small (~ less than 100 square miles) flashy watersheds.

These steps taken by the U.S. Geological Survey help to ensure that the most appropriate monitoring and analysis techniques are being used to support the determination of suspended-sediment and nutrient fluxes and associated trends in flux across the bay watershed. These steps also serve to distinguish the CBP Nontidal Monitoring Network as one of the most robust water-quality monitoring networks in the Nation.

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