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# Long-term seasonal trends of nitrogen, phosphorus, and suspended sediment load from the non-tidal Susquehanna River Basin to Chesapeake Bay

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## HIGHLIGHTS

► Flow-normalized loads of N, P, and SS from the Susquehanna River were evaluated.
► SS and particulate-bound P and N from the Susquehanna to Chesapeake Bay are rising.
► N, P, and SS loads have declined in the Susquehanna River above its major reservoirs.
► The Conowingo Reservoir has neared its capacity to trap SS and particulate P and N.
► The reservoir will pose challenges to attainment of nutrient and sediment reduction.

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## ABSTRACT

Reduction of nitrogen (N), phosphorus (P), and suspended sediment (SS) load has been a principal focus of Chesapeake Bay Watershed management for decades. To evaluate the progress of management actions in the Bay's largest tributary, the Susquehanna River, we analyzed the long-term seasonal trends of flow-normalized N, P, and SS load over the last two to three decades, both above and below the Lower Susquehanna River Reservoir System. Our results indicate that annual and decadal-scale trends of nutrient and sediment load generally followed similar patterns in all four seasons, implying that changes in watershed function and land use had similar impacts on nutrient and sediment load at all times of the year. Above the reservoir system, the combined loads from the Marietta and Conestoga Stations indicate general trends of N, P, and SS reduction in the Susquehanna River Basin, which can most likely be attributed to a suite of management actions on point, agricultural, and stormwater sources. In contrast, upward trends of SS and particulate-associated P and N were generally observed below the Conowingo Reservoir since the mid-1990s. Our analyses suggest that (1) the reservoirs' capacity to trap these materials has been diminishing over the past two to three decades, and especially so for SS and P since the mid-1990s, and that (2) the Conowingo Reservoir has already neared its sediment storage capacity. These changes in reservoir performance will pose significant new kinds of challenges to attainment of total maximum daily load goals for the Susquehanna River Basin, and particularly if also accompanied by increases in storm frequency and intensity due to climate change. Accordingly, the reservoir issue may need to be factored into the proper establishment of regulatory load requirements and the development of watershed implementation plans.



## 1. Introduction

Chesapeake Bay has experienced persistent summertime hypoxia in its bottom waters that has been attributed to a combination of anthropogenic nutrient inputs from the watershed (Boynton and Kemp, 2000; Hagy et al., 2004; Kemp et al., 2005; Malone et al., 1988; Murphy et al., 2011) and naturally occurring vertical stratification (Boicourt, 1992; Murphy et al., 2011; Pritchard and Schubel, 2001). On one hand, high nutrient inputs – primarily nitrogen (N) and phosphorus (P) – can stimulate phytoplankton growth that can exert considerable biochemical oxygen demand when the algal matter sinks to the deep channel (Boynton and Kemp, 2000; Cloern, 2001; Kemp et al., 2009). On the other hand, freshwater flow acts to strengthen water column stratification that can isolate the deep water hypoxic zones, thus preventing oxygen replenishment from the surface water (Boicourt, 1992; Goodrich et al., 1987; Pritchard and Schubel, 2001). In addition, suspended sediment (SS) can reduce light penetration and thus inhibit the growth of beneficial submerged aquatic vegetation (Brakebill et al., 2010). Of the two influences, anthropogenic inputs and stratification, the more attainable means of controlling hypoxia is the reduction of N, P, and SS load, and this has been a principal focus of Chesapeake Bay Watershed (CBW) management for decades. In 2010, the strength of this endeavor was

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increased, with the introduction of regulations of total maximum daily loads (TMDLs) for N, P, and SS (US Environmental Protection Agency, 2010).

To aid the assessment of reduction progress, the U.S. Geological Survey (USGS) and collaborators have been collecting and analyzing water quality data at many monitoring sites in the CBW for decades (Langland et al., 2007; Sprague et al., 2000). For example, the USGS River Input Monitoring (RIM) Program has been monitoring streamflow and water quality at nine stations at the fall-line of major tributaries since the mid-1980s (US Geological Survey, 2012a). In a comprehensive study, Langland et al. (2007) detected significantly decreasing trends in flow-adjusted annual concentration of total N (TN), total P (TP), and SS from 1985 to 2006 at about 74%, 68%, and 32% of 34 selected monitoring sites in the CBW, respectively.

As part of on-going efforts to analyze load trends in the major tributaries to Chesapeake Bay, this study focuses on the Susquehanna River because it is the largest tributary in terms of freshwater discharge (60%), TN load (62%), and TP load (34%) (Belval and Sprague, 1999). Encouragingly, McGonigal (2010) detected significantly decreasing trends in flow-adjusted annual concentration of TN, TP, and SS at most monitoring sites in the Susquehanna River Basin (SRB) from 1986 to 2009 (Fig. 1). Consistent with these findings, a later study by Langland et al. (2012) also reported generally decreasing trends of flow-adjusted annual concentration of these pollutants in the SRB from 1985 to 2010. In addition, Langland et al. (2012) reported reducing trends of TN and SS, but non-significant changes in TP at the Conowingo Station at the fall-line of the Susquehanna River. A common feature of these studies is the adoption of annual resolution in trend analyses. However, in order to capture impacts of seasonality such as variations in temperature and rainfall, fertilizer application, and benthic recycling of P and denitrification in river channels and reservoirs, seasonal trends of these anthropogenic pollutants need to be investigated, and attention needs to be given to calculations not only of concentration but also of load, which is more complex because of the need to temporally match concentration with flow.

With regard to prior estimates of historical load, the USGS has been using a tool developed in 1989 called ESTIMATOR (Cohn et al., 1989) to compute and report daily nutrient and sediment load in Chesapeake Bay tributaries. In recent work, Murphy et al. (2011) combined some of these loading estimates for the Susquehanna River at Conowingo with some interpolations and extrapolations of upstream data that had been previously developed by Hagy et al. (2004) to plot a 60-year history of Susquehanna winter-spring (i.e., Jan–May) TN load, which has been of

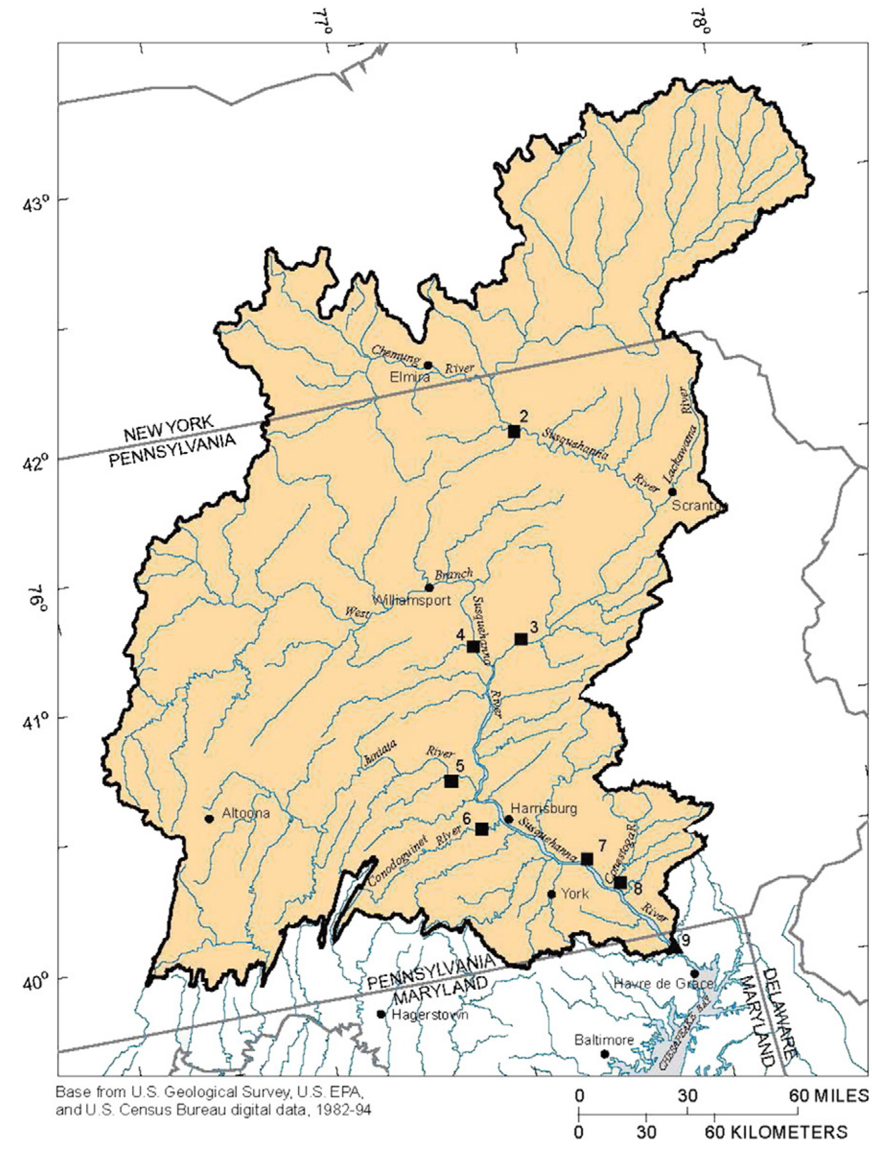


**Fig. 1.** Map of Susquehanna River Basin and long-term monitoring sites. Sites in this study include two main-stem stations, Marietta (No. 7) and Conowingo (No. 9), and one tributary station, Conestoga (No. 8). The non-tidal Susquehanna River Basin, shaded in yellow, covers portions of New York, Pennsylvania, and Maryland.
This figure was reproduced from Fig. 6 in Sprague et al. (2000) with permission.