Sediment Sources and Transport in the Chesapeake Bay Watershed

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Impact of Sediment on Chesapeake Bay and its Watershed

As the largest and most productive estuary in North America, Chesapeake Bay is a vital ecological and economic resource. In recent decades, however, the bay and its tributaries have been degraded by excessive inputs of nutrients (nitrogen and phosphorus) and sediment from contributing watersheds, and in 1998, the bay was classified as “impaired” according to guidelines set forth in the Clean Water Act. Consequently, a Total Maximum Daily Load (TMDL) was established to reduce inputs of nutrients and sediment to meet water-quality standards in the bay (U.S. Environmental Protection Agency, 2010). The TMDL requires that all practices designed to reduce nutrients and sediment be implemented by 2025 to achieve progress toward meeting standards for dissolved oxygen, water clarity, and chlorophyll in the bay. The six states in the watershed and the District of Columbia have each prepared a Watershed Implementation Plan (WIP) to provide details about the types of management practices that will be used to meet the TMDL requirements. Additional information on the TMDL and WIPs can be found at http://www.epa.gov/chesapeakebaytmdl/.

Sediment is a major contributor to ecological degradation in Chesapeake Bay. Excessive sediment has an adverse effect on the health of streams in the bay watershed, on submerged aquatic vegetation, and on living resources in the estuary; it results in degraded water quality, loss of habitat, and population declines in biological communities. Sediment also is associated with and transports other contaminants, such as phosphorus.

Sediment sources in the Chesapeake Bay watershed include agricultural areas, forests, roads, urban areas, construction sites, gullies and ditches, mines, and streambeds and banks. Management strategies to reduce sediment inputs differ depending on whether the sediment is eroded from upland areas or from streambeds and banks. Therefore, it is important to identify the location of the sediment source in the watershed as a first step in designing management strategies. Sediment “fingerprinting” studies, particularly in small watersheds, help to identify these sources and determine the types of management practices that will most effectively reduce sediment erosion and transport in these watersheds (Gellis and Walling, 2011).

U.S. Geological Survey Studies of Sediment Sources and Transport

The U.S. Geological Survey (USGS) has developed approaches and tools that can be used in the TMDL framework to help determine the sources, transport, storage, and residence time of sediment in watersheds of various sizes. Suspended-sediment monitoring and modeling are used to identify the locations that generate the greatest sediment loads and yields (loads per unit watershed area). A calibrated suspended-sediment model, the Spatially Referenced Regression on Watershed Attributes (SPARROW) model, is used to compile sediment data for nontidal parts of the Chesapeake Bay watershed and predict sediment loads and yields at watershed scales averaging 75 square kilometers (km^2). Model results are used to identify and evaluate the geographic distributions of sediment sources, yields, and transport to the bay (Brakebill and others, 2010). At the small-watershed scale (less than 250 km^2), sediment source areas are specifically identified by using field techniques such as sediment fingerprinting (using tracers) and sediment budgeting. (See Gellis and Walling, 2011, for an explanation of these techniques.)

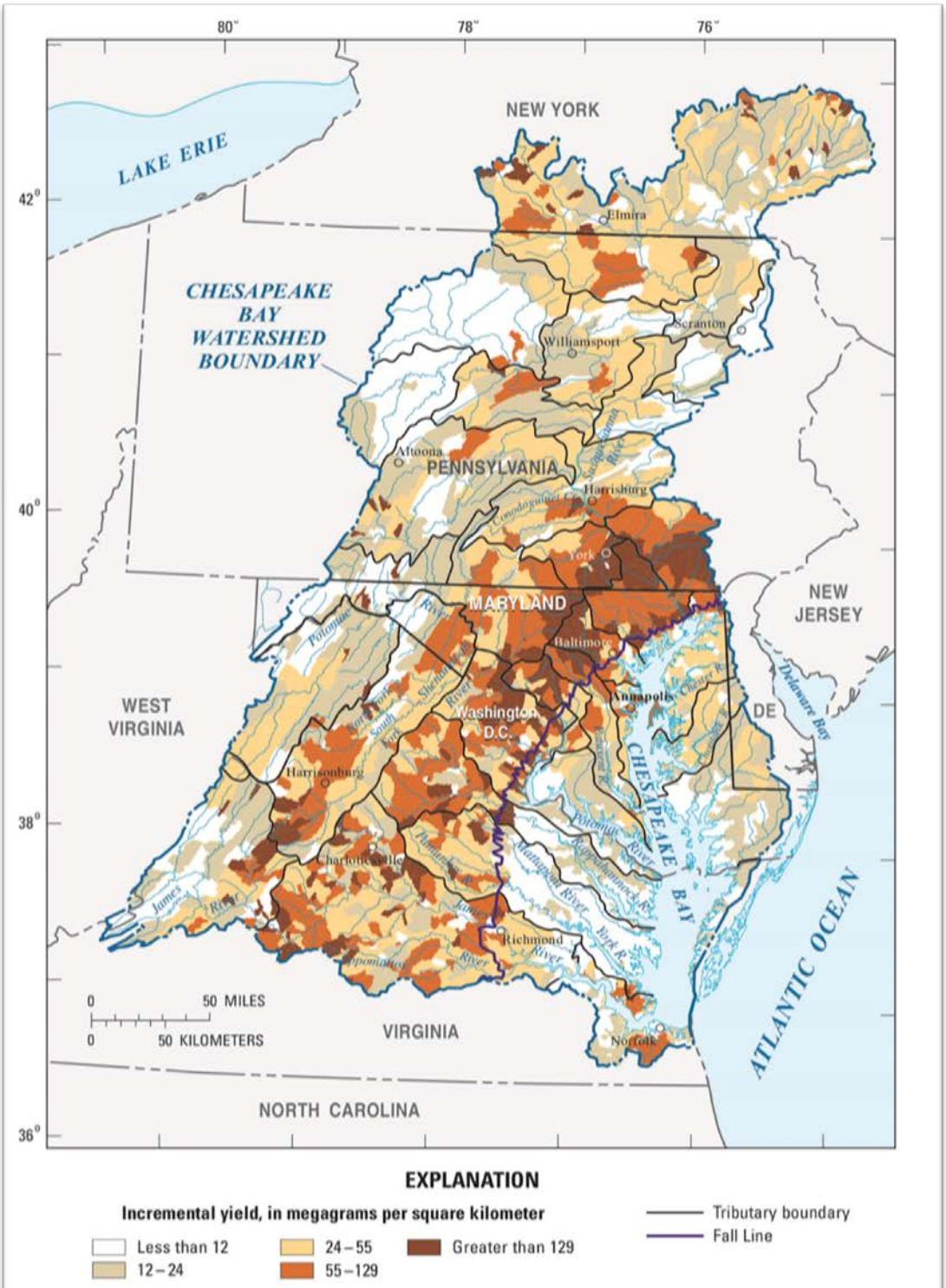

Figure 1. Spatial distribution of incremental sediment yields (the sediment derived from individual watersheds) in the Chesapeake Bay watershed determined from results of the U.S. Geological Survey SPARROW model. Incremental sediment yields are smallest in the Coastal Plain Physiographic Province (the area east of the Fall Line) and greatest in the Piedmont Physiographic Province (the area just west of the Fall Line) (modified from Brakebill and others, 2010, fig. 4).

This Science Summary is one in a series that is designed to facilitate the understanding and application of results of relevant USGS studies by Chesapeake Bay resource managers and policy makers. It provides a brief overview of the key findings on (1) the spatial variability of sediment yields and sources in the entire bay watershed and in selected smaller watersheds, and (2) the transport and delivery of sediment to the bay. The Summary also provides information about how these findings can be used to

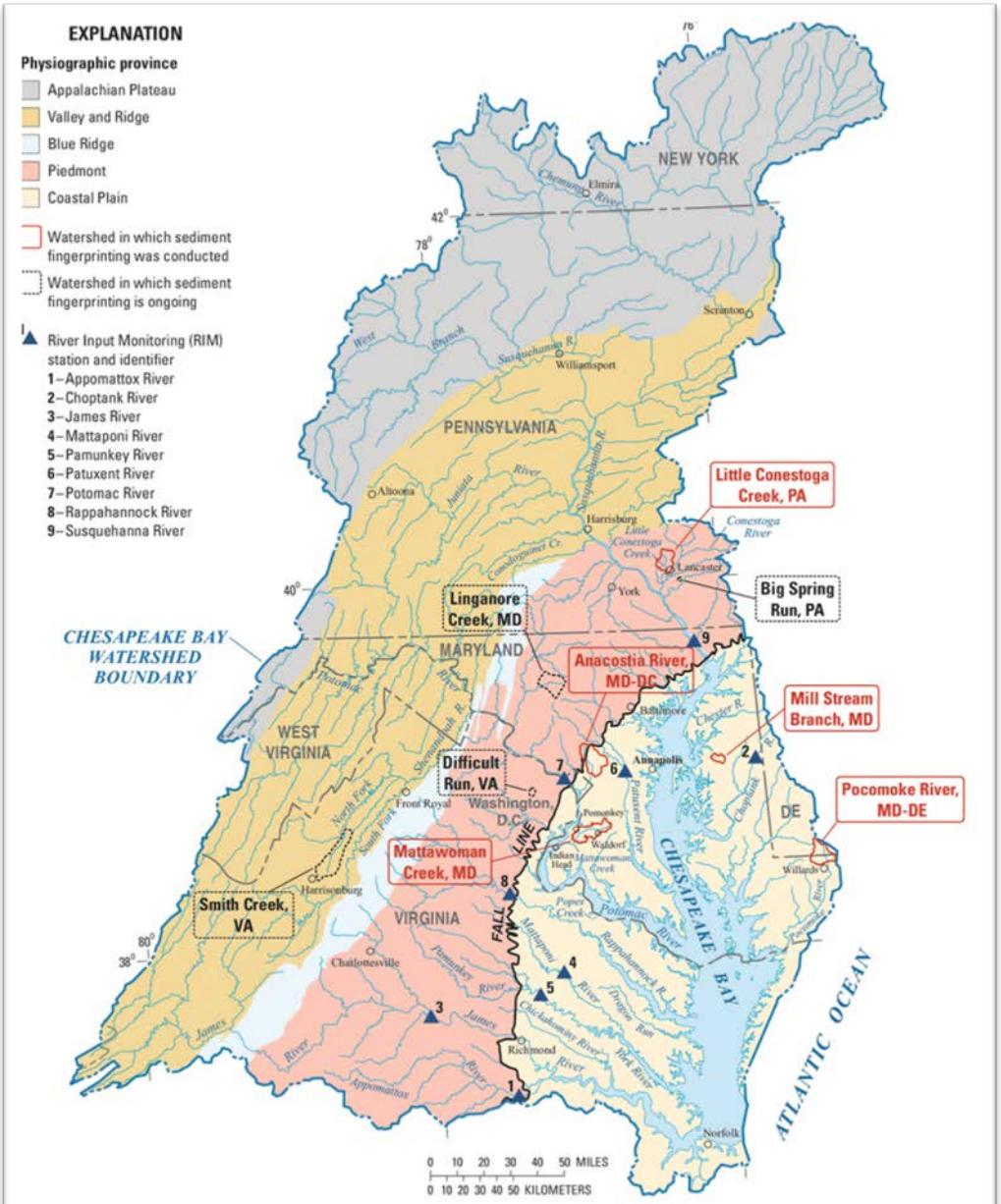

Figure 2. Small watersheds within the Chesapeake Bay watershed where U.S. Geological Survey sediment fingerprinting studies were conducted or are ongoing (modified from Gellis and others, 2009). Also shown are the River Input Monitoring (RIM) stations where monitoring of suspended sediment is occurring at nine major tributaries to the Chesapeake Bay.

support the development and implementation of management policies and practices in the Chesapeake Bay watershed.

The **KEY FINDINGS** and the **IMPLICATIONS FOR MANAGEMENT POLICIES AND PRACTICES AND NEXT STEPS** listed below are derived from several USGS reports and other published studies.

KEY FINDINGS

Sediment Yields and Sources in the Bay Watershed

- Sediment is derived from erosion of both upland areas and stream corridors. The amount of erosion in a watershed is dependent on multiple factors including geology, land use, climate variability, and vegetation, as well as degree of current and historical land disturbance and topographic relief.

- Suspended-sediment yields in the Chesapeake Bay watershed are highest in the Piedmont Physiographic Province and lowest in the Coastal Plain. The geographic distribution of annual suspended-sediment yields throughout the bay watershed is shown in figure 1.

- Land disturbance from urbanizing areas generates the greatest suspended-sediment yields.

- The SPARROW model indicates that the overall contribution from suspended-sediment sources to the bay is 51 percent from agricultural land; 39 percent from developed areas; 8 percent from small, non-Coastal Plain streams; and 2 percent from forested areas. The proportion of sediment derived from each source differs within and among individual watersheds.

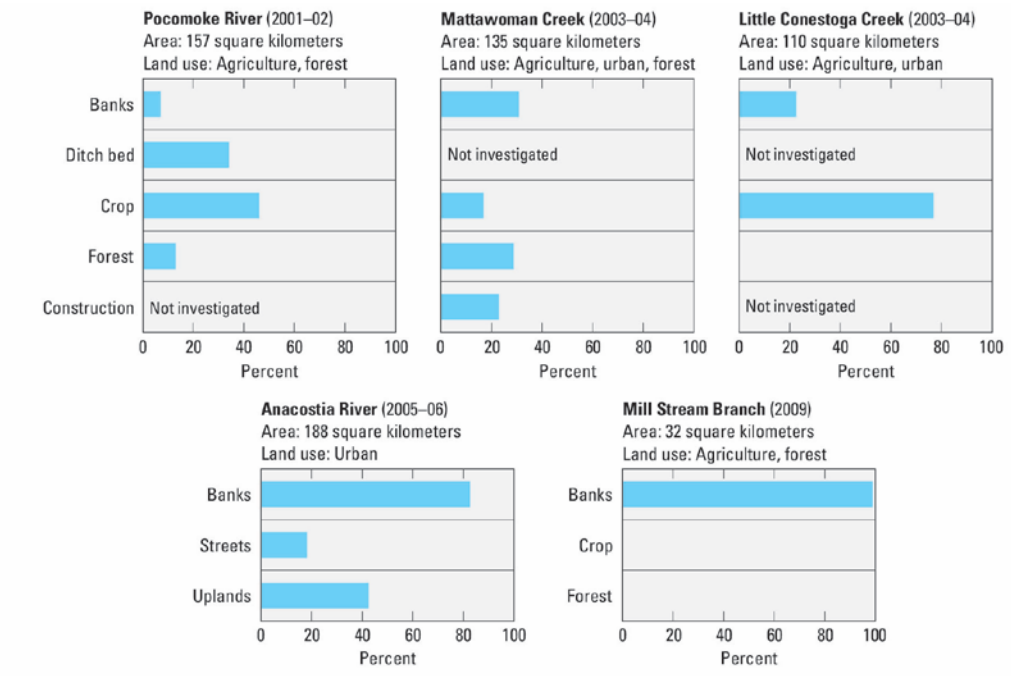

Figure 3. Sediment sources in small watersheds in the Chesapeake Bay watershed in which U.S. Geological Survey sediment fingerprinting studies were conducted or are ongoing (modified from Gellis and Walling, 2011; Devereux and others, 2010; Gellis and others, 2009).

Field Studies to Identify Sources of Sediment

- Results of sediment fingerprinting in five small watersheds (32–188 km^2) draining to Chesapeake Bay (locations shown in fig. 2) indicate that sediment sources vary among the watersheds, partly as a result of differences in past and present land use and geology (fig. 3). In the agricultural watersheds, primary sediment sources include (1) streambanks, and (2) crop lands. Streambanks, streets, and upland areas are the primary sources in the urban watershed (fig. 3).

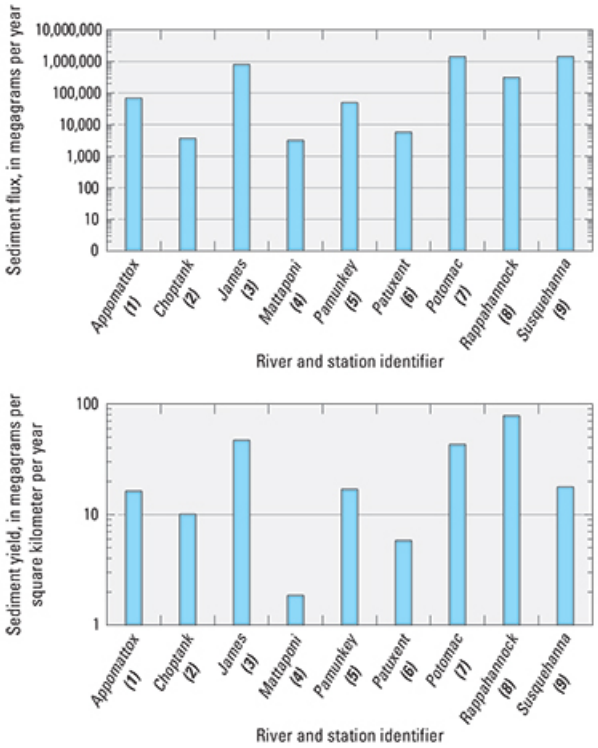

Figure 4. Sediment loads and yields at River Input Monitoring (RIM) stations on the nine rivers in the Chesapeake Bay watershed monitored by the U.S. Geological Survey (modified from Brakebill and others, 2010). Locations of the RIM stations are shown in figure 2.

Transport, Storage, Residence Time, and Delivery of Sediment to Chesapeake Bay

- Multiple factors affect the amount of sediment stored in the watershed, the time required to transport the sediment to the bay, and the amount that is ultimately delivered to the bay.

- Factors affecting sediment transport from uplands to streams include basin slope, presence of reservoirs, physiography, and soil permeability. On average, 59 percent of suspended sediment that is eroded from uplands is stored temporarily along large rivers draining the Coastal Plain or in reservoirs throughout the watershed.

- Coastal Plain flood plains and their bottomland hardwood systems are large areas with low gradients that help to maintain water quality by trapping and storing large amounts of sediment and associated contaminants, especially nutrients (nitrogen and phosphorus), that otherwise would be delivered to Chesapeake Bay. These flood plains are among the last places that sediment storage and natural biogeochemical remediation can occur before the sediment and other contaminants enter critical estuarine nursery areas for fish and wildlife (Hupp, 2000).

- Sediment traveltimes through the watershed to the bay are dependent on flow conditions, grain size, and travel distance and may be hours (during large storms, for example) to decades or longer (Langland and others, 2003). Results obtained by using the SPARROW sediment model indicate that in-stream sediment-storage and reservoir-retention processes may occur over time scales of two to three decades.

- At the nine River-Input Monitoring (RIM) stations (locations shown in fig. 2), the Potomac, Susquehanna, James, and Rappahannock Rivers transport the highest average annual suspended-sediment loads (fig. 4). Suspended-sediment yields, however, are far greater for the Rappahannock River than for any of the other eight monitored rivers.

- Agriculture contributes the greatest amount of sediment at RIM stations except Patuxent, where development is the greatest contributor (fig. 5). Forested areas contribute very little sediment to the streams in any of the monitored watersheds.

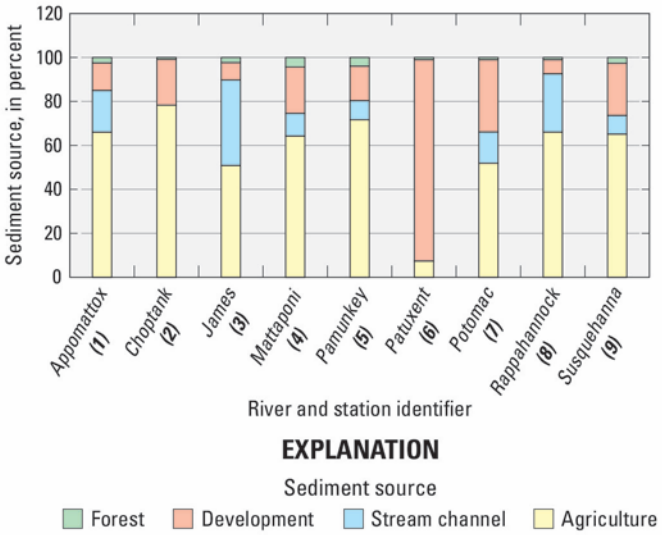

Figure 5. Sources of sediment at River Input Monitoring (RIM) stations on the nine rivers in the Chesapeake Bay watershed monitored by the U.S. Geological Survey (modified from Brakebill and others, 2010). Locations of the RIM stations are shown in figure 2.

IMPLICATIONS FOR MANAGEMENT POLICIES AND PRACTICES AND NEXT STEPS

- In order to reduce sediment loads to Chesapeake Bay, management actions must be designed to target the sources and storage areas of sediment.
- Management actions designed to reduce the transport of sediment to the upper reaches of the estuary are likely to be most effective in both urban and agricultural areas and in the stream corridor in the Piedmont Province.
- Practices to reduce sediment will have an immediate beneficial effect on local streams, but improvements in water clarity in the tidal waters may require decades as a result of sediment transport time from the watershed to the bay.
- Maintaining the ability of the flood plains to retain sediment and associated nutrients is an important management practice that is critical to improving water quality in the bay.
- The availability of additional, detailed information on the source of the sediment (stream corridors or upland erosion) in local watersheds would facilitate more effective planning and implementation of sediment-reduction actions.
- The USGS is conducting studies in small watersheds and refining regional models to improve understanding of the sources and transport of sediment and their implications. This improved understanding will enhance the development and implementation of practices designed to reduce sediment inputs to the bay.

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Contact Scott Phillips (swphilli@usgs.gov) for additional information about USGS Chesapeake Bay studies.

REFERENCES CITED

Brakebill, J.W., Ator, S.W., and Schwarz, G.E., 2010, Sources of suspended-sediment flux in streams of the Chesapeake Bay watershed--A regional application of the SPARROW model: Journal of the American Water Resources Association, v. 46, no. 4, p. 757-776, DOI: 10.1111/j.1752-1688.2010.00450.x.

Devereux, O.H., Prestegaard, K.L., Needelman, B.A., and Gellis, A.C., 2010, Suspended-sediment sources in an urban watershed, Northeast Branch Anacostia River, Maryland: Hydrological Processes, v. 24, p. 1,391–1,403, DOI: 10.1002/hyp.7604.

Gellis, A.C., Hupp, C.R., Pavich, M.J., Landwehr, J.M., Banks, W.S.L., Hubbard, B.E., Langland, M.J., Ritchie, J.C., and Reuter, J.M., 2009, Sources, transport, and storage of sediment at selected sites in the Chesapeake Bay watershed: U.S. Geological Survey Scientific Investigations Report 2008-5186, 95 p.(also available online at *http://pubs.usgs.gov/sir/2008/5186/).*

Gellis, A.C., and Walling, D.E., 2011, Sediment source fingerprinting (tracing) and sediment budgets as tools in targeting river and watershed restoration programs, *in* Simon, A., Bennett, S.J., and Castro, J.M., eds., Stream restoration in dynamic fluvial systems--Scientific approaches, analyses, and tools: American Geophysical Union Monograph Series 194, p. 263-291.

Hupp, C.R., 2000, Hydrology, geomorphology, and vegetation of Coastal Plain rivers in the south-eastern USA: Hydrological Processes, v. 14, nos. 16-17, p. 2,991--3,010, DOI: 10.1002/1099-1085(200011/12).

Langland, M.J., Cronin, Thomas, and Phillips, S.W., 2003, Executive summary, *in* Langland, M.J., and Cronin, Thomas, eds., A summary report of sediment processes in Chesapeake Bay and watershed: U.S. Geological Survey Water-Resources Investigations Report 03-4123, 109 p., accessed September 20, 2011, at *http://pa.water.usgs.gov/reports/wrir03-4123.pdf.*

U.S. Environmental Protection Agency, 2010, Final Chesapeake Bay TMDL, accessed February 6, 2012, at *http://www.epa.gov/chesapeakebaytmdl/.*

FOR ADDITIONAL INFORMATION

Ator, S.W., Brakebill, J.W., and Schwarz, G.E., 2010, Mapping vulnerability to upland erosion in the Chesapeake Bay Watershed *in* Proceedings, 2nd Joint Federal Interagency Conference, Las Vegas, Nev., June 27—July 1, 2010, accessed February 1, 2013 at *http://chesapeake.usgs.gov/pubs/ator_fisc_paper_final.pdf.*

Banks, W.S.L., Gellis, A.C., and Noe, G., 2009, Sources of fine-grained suspended sediment in Mill Stream Branch watershed, Corsica River Basin, a tributary to the Chesapeake Bay, Maryland, *in* Proceedings, 2nd Joint Federal Interagency Conference, Las Vegas, Nev., June 27—July 1, 2010: CD-ROM ISBN 978-0-0779007-3-2, 6B, 12 p.

Collins, A.L., Walling, D.E., Webb, L., and King, P., 2010, Apportioning catchment scale sediment sources using a modified composite fingerprinting technique incorporating property weightings and prior information: Geoderma, v. 155, nos. 3-4, p. 249–261, accessed January 30, 2013 at *http://dx.doi.org/10.1016/j.geoderma.2009.12.008.*

Gellis, A.C., Hupp, C.R., Landwehr, J.M., and Pavich, M.J., 2007, Sources of transport and sediment in the watershed, *in* Phillips, S.W., ed., Synthesis of U.S. Geological Survey science for the Chesapeake Bay ecosystem and environmental management: U.S. Geological Survey Circular 1316, chap. 6, p. 28–31 (also available online *at http://pubs.usgs.gov/circ/circ1316/*).

Hirsch, R.M., 2012, Flux of nitrogen, phosphorus, and suspended sediment from the Susquehanna River Basin to the Chesapeake Bay during Tropical Storm Lee, September 2011, as an indicator of the effects of reservoir sedimentation on water quality: U.S. Geological Survey Scientific Investigations Report 2012-5185, 17 p. (also available online at *http://pubs.usgs.gov/sir/2012/5185/*).

Hirsch, R.M., Moyer, D.L., and Archfield, S.A., 2010, Weighted Regressions on Time, Discharge, and Season (WRTDS), with an application to Chesapeake Bay River Inputs: Journal of the American Water Resources Association, v. 46, no. 5, p. 857-880, accessed February 1, 2013 at *http://onlinelibrary.wiley.com/doi/10.1111/j.1752-1688.2010.00482.x/full*.

Moyer, D.L., Hirsch, R.M., and Hyer, K.E., 2012, Comparison of two regression-based approaches for determining nutrient and sediment fluxes and trends in the Chesapeake Bay watershed: U.S. Geological Survey Scientific Investigations Report 2012-5244, 118 p. (also available online at *http://pubs.usgs.gov/sir/2012/5244/*).

Phillips, S.W., ed., 2007, Synthesis of U.S. Geological Survey science for the Chesapeake Bay ecosystem and implications for environmental management: U.S. Geological Survey Circular 1316, 63 p. (also available online at http://pubs.usgs.gov/circ/circ1316/*)*.

Walling, D.E., Collins , A.L., Jones, P.A., Leeks, G.J.L., and Old, G., 2006, Establishing fine-grained sediment budgets for the Pang and Lambourn LOCAR catchments, UK: Journal of Hydrology, v. 330, nos. 1-2, p. 126-141.