Science Summary—Sediment and Nutrient Trapping in the Flood Plain of Difficult Run, Virginia, and Implications for the Restoration of Chesapeake Bay

Prepared by Gregory B. Noe, Cliff R. Hupp, Edward R. Schenk, and Nancy R. Rybicki

(Released June 2013)

Introduction

As the largest and most productive estuary in North America, Chesapeake Bay is a vital ecological and economic resource. The bay and its tributaries have been degraded in recent decades, however, by excessive inputs of nutrients (nitrogen and phosphorus) and sediment, causing poor water-quality conditions for fish and wildlife. Nitrogen and phosphorus cause algae blooms, fish kills, and poor water quality, whereas large amounts of sediment bury oyster beds and destroy young fish habitat, in addition to causing other adverse effects. A Total Maximum Daily Load (TMDL) has been established to reduce nutrient and sediment inputs to the bay (U.S. Environmental Protection Agency, 2010). As part of its scientific efforts in support of the restoration of Chesapeake Bay, the U.S. Geological Survey (USGS) is working with partners to improve the understanding of the sources, storage, and transport of nutrients and sediment to help resource managers select and implement the most effective management practices (Phillips, 2011).

Role of Flood Plains in Trapping Nutrients and Sediment

Flood plains naturally intercept and trap contaminants that are transported in streams, including nutrients and sediment, and help protect sensitive downstream ecosystems. Flood plains in the part of the Chesapeake Bay watershed that lies in the Coastal Plain Physiographic Province (fig. 1) are effective at removing much of the streams' load of nitrogen, phosphorus, and sediment before it reaches the bay (Noe and Hupp, 2009); however, the source of most of the river sediment in the bay watershed is the Piedmont Physiographic Province, which is upstream from the Coastal Plain (Gellis and Brakebill, 2012; Gellis and others, 2009). To help resource managers consider and implement actions to meet the TMDL, scientists are working to determine (1) whether flood plains in urban Piedmont areas effectively trap contaminants, and (2) whether flood plains can be managed to increase their contaminant-trapping capacity.

Much of the sediment that was eroded from uplands and streambanks in the past, known as "legacy" sediment, is still stored in the flood plains of the Chesapeake Bay watershed (Meade and others, 1990). Erosion is a constant process in uplands and the streambanks of flood plains. Knowing where rates of erosion exceed rates of deposition in stream and river valleys allows resource managers to tailor specific management actions to the right places in order to have the greatest impact on reducing the contaminant load. Other questions that need to be answered include whether flood plains trap nutrients in addition to sediment and, if so, whether the nutrients remain trapped for extended periods or whether they are quickly recycled back to the stream. This information will help resource managers and policy makers understand the sources, transport, and retention of contaminants in the bay watershed and ultimately will provide them with the information needed to improve downstream water quality.

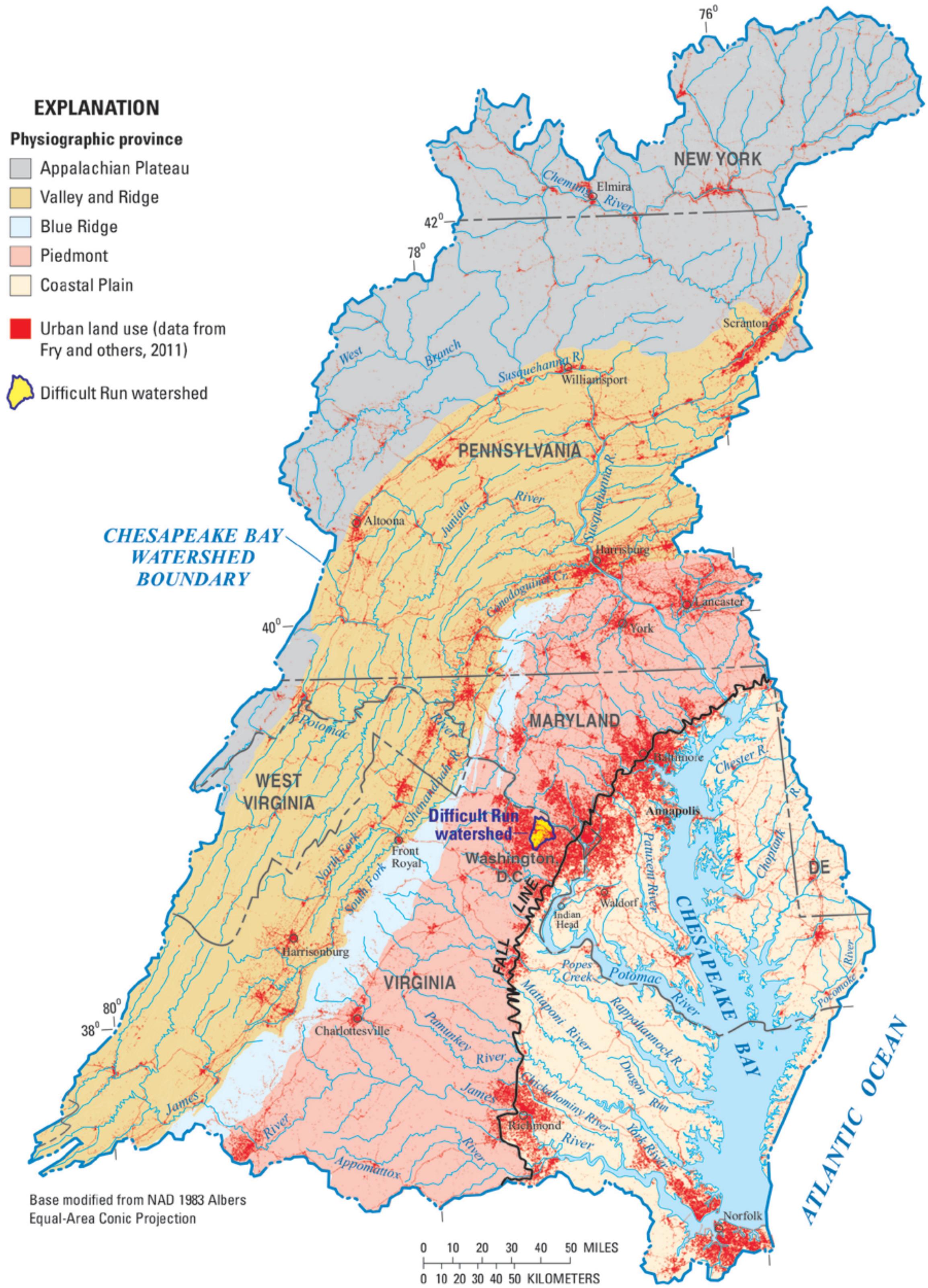

Figure 1. Map of the Chesapeake Bay watershed showing urban land use in each of the physiographic provinces and the location of the Difficult Run watershed in the urban Piedmont region of Virginia.

USGS Studies of Flood Plains in an Urban Area

In an effort to address these questions, the USGS is studying a small, urban watershed, Difficult Run, in the part of the Chesapeake Bay watershed that lies within the Piedmont region in Virginia (fig. 1). The watershed is being used as a laboratory to help Fairfax County, Virginia, identify appropriate management actions, determine their effectiveness, and optimize efforts to improve water quality. The USGS is also working with partners to study sediment and nutrient sources, storage, transport, and changes in other small watersheds. The results will help resource managers consider and implement management practices in suburban and agricultural areas to address the bay TMDL.

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 presents a brief overview of the most recent published work by the USGS and its collaborators on the role of flood plains in reducing the load of nutrients and sediment that is transported downstream to the bay; provides an understanding of how this information can be used to develop effective management policies and practices; describes the role of flood plains as a source of, and in the transport and retention of, sediment and other contaminants in Difficult Run; and includes a list of references for additional information.

The **Key Findings** and **Implications for Management Policies and Practices and Next Steps** listed below are derived from several USGS reports and other published studies.

Key Findings

Flood plains are important traps for sediment and associated nutrients

- In the Difficult Run watershed (fig. 1), rates of sediment deposition on downstream flood plains exceed rates of sediment erosion from streambanks in the stream’s headwaters. The rate of sediment deposition in the flood plain of this watershed generally increased with distance downstream (fig. 2), as the width of the flood plain increased, relief decreased (fig. 3), and flooding increased. The rate of sediment erosion from streambanks, in contrast, was greatest at headwaters sites, where impervious watershed area and relief are sufficiently great to generate large stormflows.

- The balance between rates of sediment storage and loss in the stream valley changed from upstream to downstream in the watershed (fig. 2). The rate of flood-plain sediment deposition was similar to the rate of bank erosion at the uppermost site, bank erosion exceeded flood-plain deposition at the next two sites farther downstream, and flood-plain deposition greatly exceeded bank erosion at the three sites farthest downstream (Hupp and others, 2013).

- High sedimentation rates in the flood plain of Difficult Run result in high rates of nutrient trapping [about 3 kilograms (kg) of sediment, 8 grams (g) of nitrogen, and 1.4 g of phosphorus per square meter per year]. These rates are much higher than those in the flood plains of rivers in the parts of the Chesapeake Bay watershed that are in the Coastal Plain (about 1 kg of sediment, 6 g of nitrogen, and 1.0 g of phosphorus per square meter per year) (Noe and Hupp, 2009). The typical flood plain traps 29 times as much sediment as the equivalent area of the Difficult Run watershed contributes in sediment loading to the river (flood-plain trapping factor) (Schenk and others, 2012).

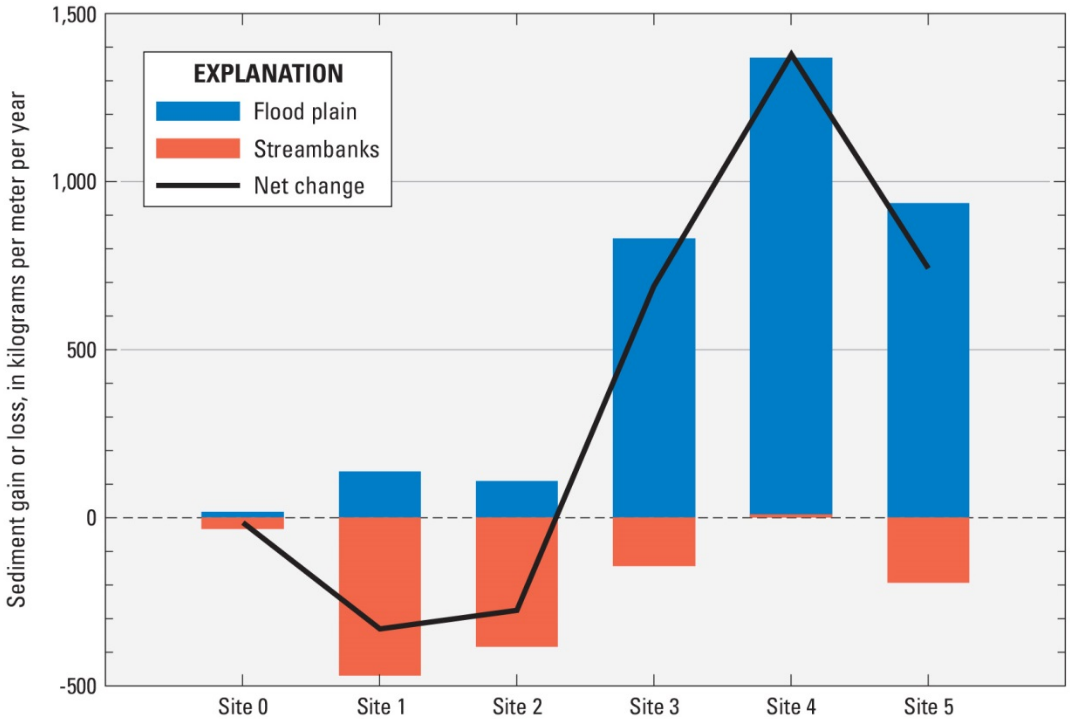

Figure 2. Rates of sediment gain (positive values) and loss (negative values) per meter of stream length associated with streambank and flood-plain erosion and deposition, and their sum (net change, with positive values indicating net trapping and negative values indicating net erosion), at six study sites located along Difficult Run, Virginia, from near the headwaters (site 0) to the mouth (site 5). (Modified from Hupp and others, 2013.)

- The nutrients trapped in the flood plain of Difficult Run generally are retained in the soil or taken up by plants. Inputs of new sediment to flood-plain soil stimulated production of nitrate, ammonium, and phosphate—forms of nitrogen and phosphorus that can be remobilized and transported downstream (Noe and others, 2013); however, the masses of inorganic nutrients produced over the course of a year were substantially less than the masses that had been deposited during sedimentation. The average atom of nitrogen in flood-plain soil is converted to nitrate or ammonium after 22 years, whereas the average atom of phosphorus remains immobile for 369 years before being converted to phosphate (Noe and others, 2013).

- Over the course of a year, all of the nitrate, ammonium, and phosphate produced in flood-plain soil was taken up by plants during the growing season and returned to flood-plain soils as organic nutrients when the deciduous trees dropped their leaves and the herbaceous plants died back in the autumn. The conversion of soil nitrogen, primarily to nitrate (which can be transported downstream), was greatest where herbs and grasses grew in this forested flood plain (Noe and others, 2013).

Large amounts of legacy sediment are stored in the Difficult Run stream valley

- Historical changes in land use from forest to agriculture to urban have increased erosion of upland soils that were subsequently stored as “legacy” sediment in flood plains (Meade and others, 1990). The increase in impervious surface area and in the energy and intensity of storm flooding associated with land-use change has contributed to an increase in rates of erosion from streambanks. Because almost all sediment eroded from streambanks is legacy sediment that had been stored in flood plains, both historical and modern land uses are influencing sediment erosion in the stream valleys of the watershed.

- The depth of legacy sediment in the stream valley of the Difficult Run watershed increases from about 1 meter (m) in the stream's headwaters to about 2 m near its mouth (Hupp and others, 2013). The volume of stored legacy sediment increases from about 20 cubic meters per meter of stream length at the headwaters to 280 cubic meters per meter of stream length at the mouth of the watershed, primarily because the flood plain widens downstream.

- The construction of grain and lumber mills with their associated dams and impoundments may have contributed to the storage of legacy sediment in stream valleys (Merritts and others, 2011). Forty percent or less of Difficult Run likely was impounded by mill dams (fig. 3); however, the large volume of legacy sediment currently stored in the flood plain does not appear to be related to the presence of impoundments, and the flood plain is still frequently inundated by the river (Hupp and others, 2013).

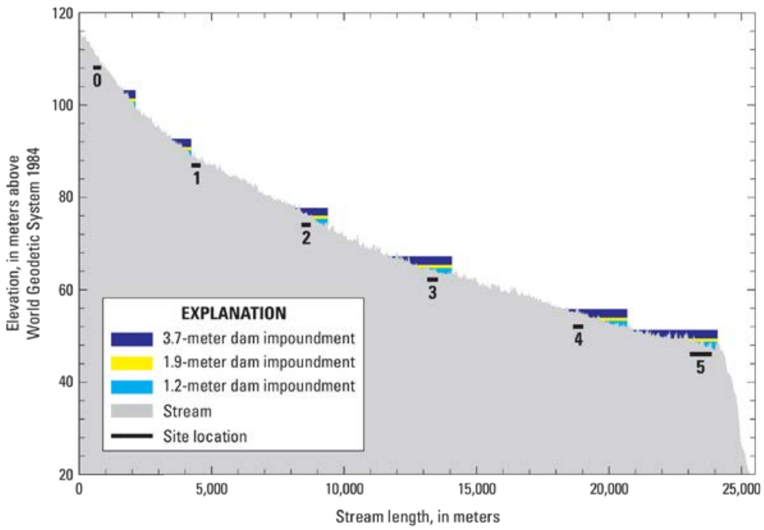

Figure 3. Elevation profile of the water surface of Difficult Run showing the locations of the six study sites (site 0 to site 5) and the simulated impoundment effects of known historical mill locations. (Each impoundment is simulated with 1.2-, 1.9-, and 3.7-meter-tall dams, the range of likely dam heights in the region (see Merritts and others, 2011). Historical mill locations were identified by John Rutherford (Fairfax County Park Authority, written commun., 2008). The width of the black bar at each of the six study sites indicates the length of the study reach. Elevations determined by light detection and ranging (LiDAR). (Modified from Hupp and others, 2013.)

Implications for Management Policies and Practices and Next Steps

- Flood plains currently trap large quantities of sediment, nitrogen, and phosphorus and store legacy sediment and associated nutrients. Efforts to prevent or capture upland erosion in a watershed will likely have a much smaller effect on stream contaminant loads than the rates of streambank erosion and flood-plain deposition.

- The long residence time of the legacy sediment stored in flood plains and its associated nutrients will likely result in a long lag time between the implementation of management actions and stable, long-term decreases in downstream contaminant loading to streams and, ultimately, to Chesapeake Bay. Efforts are currently underway to quantify sediment lag times in the flood plains and stream channel of Difficult Run.

- Efforts to reduce streambank erosion would be most effective near the headwaters, where erosion rates are greatest as a result of the high-energy runoff generated by high discharge and steeper slopes.

- Managing flood plains to be as natural as possible, with minimal infrastructure to allow flooding, will maximize the trapping of contaminants. Trapping is most effective where the flood plain is hydrologically connected to (inundated by) the stream during floods.

- Vegetation management that favors trees over meadow plants in riparian restoration efforts would maximize the ability of flood plains to retain nitrogen. Nitrate production by flood-plain soils is minimized where the forests are shady, trees are most abundant, and herbs and grasses are least abundant.

- The USGS continues to conduct research in small watersheds to identify the most beneficial management actions, determine their effectiveness, and enable managers to optimize efforts to improve water quality. The importance of flood-plain trapping will be investigated in other small watersheds with different land use and in other physiographic provinces within the Chesapeake Bay watershed.

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Suggested citation:

Prepared by Noe, G. B., Hupp, C. R., Schenk, E. R., and Rybicki, N. R., 2013, Science summary—Sediment and nutrient trapping in the flood plain of Difficult Run, Virginia, and implications for the restoration of Chesapeake Bay: available online only at http://chesapeake.usgs.gov/sciencesummary-sedimentnutrienttrapping.html.

For additional information about this research, please contact Gregory B. Noe (gnoe@usgs.gov), Cliff R. Hupp (crhupp@usgs.gov), Edward R. Schenk (eschenk@usgs.gov), or Nancy R. Rybicki (nrybicki@usgs.gov).

For additional information about USGS Chesapeake Bay studies, please contact Scott Phillips (swphilli@usgs.gov).