HEC-RAS Sediment Transport Simulation of Three Reservoirs in the Lower Susquehanna River Basin, Pennsylvania and Maryland

Michael Langland, Hydrologist, US Geological Survey, Pennsylvania Water Science Center, New Cumberland, PA, langland@usgs.gov

Abstract

The U.S. Environmental Protection Agency (USEPA) recently (2010) listed the nation's largest estuary, the Chesapeake Bay, as impaired and established sediment and nutrient load allocations for the six states and the District of Columbia waters draining into the Bay. The Susquehanna River is the largest tributary to the Chesapeake Bay and transports about one-half of the freshwater and substantial amounts of sediment, nitrogen, and phosphorus. The loads transported by the Susquehanna River to the Bay are affected by the deposition of sediment and nutrients behind three large hydroelectric dams on the Lower Susquehanna River in Pennsylvania and Maryland. The three consecutive reservoirs (Lake Clarke, Lake Aldred, and Conowingo Reservoir) formed behind the three dams (Safe Harbor, Holtwood, and Conowingo) involve nearly 32 miles of the river and have a combined design capacity of 510,000 acre-feet at their normal pool elevations.

Previous studies by Ott and others (1991), Hainly and others, (1995), Reed and Hoffman (1996), Langland and Hainly (1997), Langland (2009), Hirsch (2012) and Gomez and Sullivan (2012) have indicated the two upstream reservoirs have minimal sediment storage capacity and have been in a "dynamic equilibrium" with respect to sediment transport since the 1950's. The most downstream reservoir (Conowingo) is nearly at sediment storage capacity and transitioning to a "dynamic equilibrium" state. Dynamic equilibrium implies there will be no change in long-term (decades) sediment retention resulting from the loss of storage capacity, however short-term (years) deposition and erosion cycles will continue. When capacity is reached, increased flow velocities through the reservoirs will result in less time for transported sediments to deposit resulting in increased sediment loads to receiving waters, including the Chesapeake Bay.

In order to simulate the sediment transport out of the reservoir system and into the lower Susquehanna (2008-11), the U.S. Geological Survey (USGS), in cooperation with the U.S. Army Corps of Engineers (USCOE) and the Lower Susquehanna River Watershed Assessment Team (LSWA, a consortium of Federal, State, and private organizations), completed the development of a one-dimensional (1-D) model (HEC-RAS). The USGS constructed new geometric and hydraulic boundaries to align with previous bathymetric cross sections. USGS also constructed sediment transport curves and utilized historical bathymetric data, existing sediment core samples, particle–size and sheer stress data, and current (2008-2011) hydrology and load information to help calibrate the model.

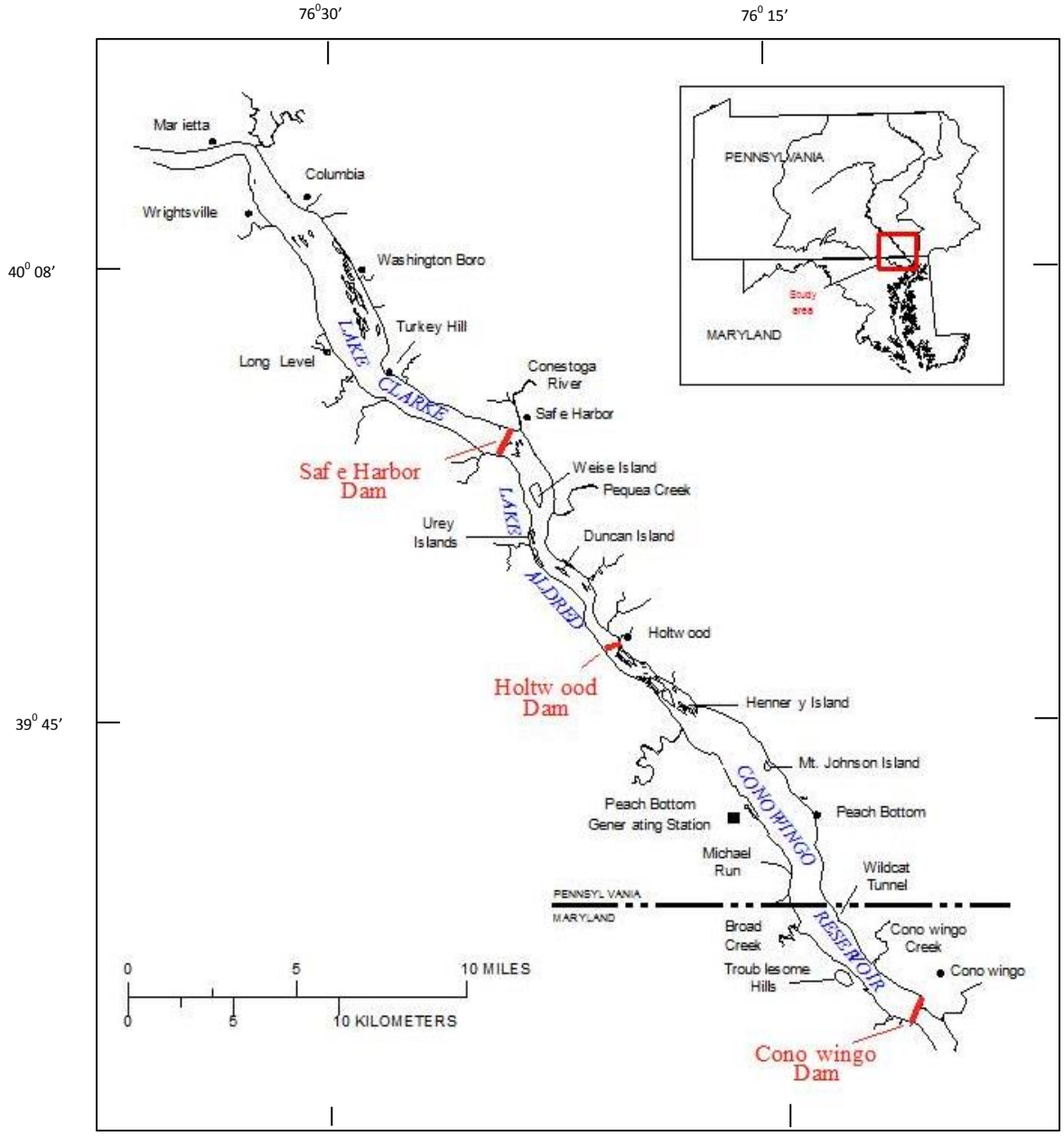

Figure 1 Location of three Hydroelectric Dams and associated reservoirs in the Lower Susquehanna River, Pennsylvania.

The 4-year simulation period was generally normal (10 percent above or below the long-term mean streamflow) for 2 of the 4 years, and above and below normal the other 2 years. In addition, a flood event that produced the second highest daily mean streamflow since 1968 occurred in September 2011. Numerous model iterations of the model were performed and checked to determine bed movement, bed shear, estimated sediment loads, particle size transport, and energy dispersion. During model development, it became apparent that the HEC-RAS model

did moderately well at simulating reservoir deposition over the 4-year simulation period (figure 2A) but did not represent the increased sediment loads from scour during the large storm event that occurred during the simulation period (September 2011). To simulate erosion (scour), two model parameters (fall velocity and bed sorting method) were changed to predict increased sediment loads from larger storm events (figure 2B).

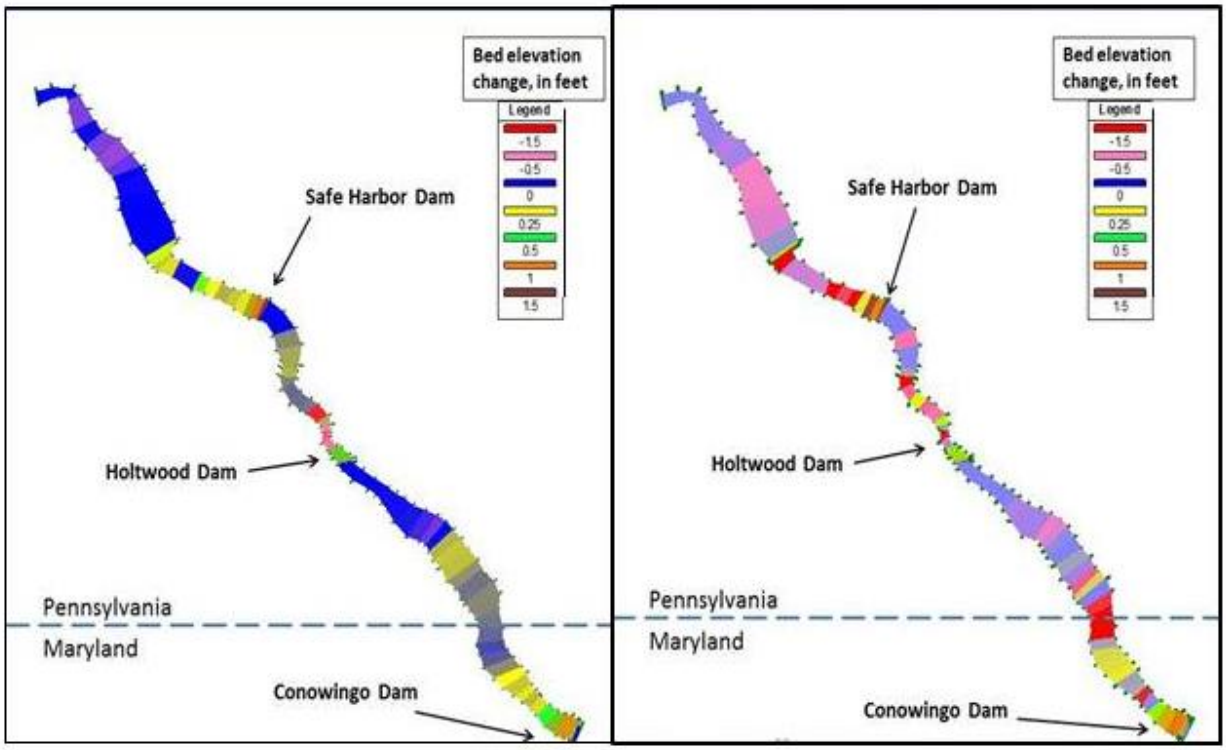

Figure 2 Changes in bed elevation using a HEC-RAS depositional model (A-left), and changes in bed elevation using a HEC-RAS scour model (B-right) for simulation period 2008-2011.

Overall, the two models (deposition and scour) allowed for a range in uncertainty and generally simulated the deposition or scour to about one-half of the expected sediment when compared to estimates from bathymetric change and load results. Lower than expected load estimates were attributed to three likely reasons. First, the HEC-RAC model is limited to simulating either sediment deposition or removal, not both, along a single transect. Comparisons of the 2008 and 2011 bathymetry data showed within individual transects where sediment was both deposited and removed. Second, the modeled "fall velocity" of the fines was about two times lower than literature values and 2-D model runs performed by the USACE. Third, the 1-D model allows one shear stress value when laboratory stress studies on the sediment core data indicate an eight-fold range in variability.

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