EVALUATION AND APPLICATION OF REGIONAL TURBIDITY-SEDIMENT REGRESSION MODELS IN VIRGINIA

EXTENDED ABSTRACT

Kenneth Hyer, Hydrologist, USGS, Richmond, VA, kenhyer@usgs.gov; John Jastram, Hydrologist, USGS, Richmond, VA, jdjastra@usgs.gov; Douglas Moyer, Hydrologist, USGS, Richmond, VA, dlmoyer@usgs.gov; James Webber, Hydrologist, USGS, Richmond, VA, jwebber@usgs.gov; Jeff Chanat, Hydrologist, USGS, Richmond, VA, jchanat@usgs.gov

INTRODUCTION

Conventional thinking has long held that turbidity-sediment surrogate-regression equations are site specific and that regression equations developed at a single monitoring station should not be applied to another station; however, few studies have evaluated this issue in a rigorous manner. If robust regional turbidity-sediment models can be developed successfully, their applications could greatly expand the usage of these methods. Suspended sediment load estimation could occur as soon as flow and turbidity monitoring commence at a site, suspended sediment sampling frequencies for various projects potentially could be reduced, and special-project applications (sediment monitoring following dam removal, for example) could be significantly enhanced.

The objective of this effort was to investigate the turbidity-suspended sediment concentration (SSC) relations at all available USGS monitoring sites within Virginia to determine whether meaningful turbidity-sediment regression models can be developed by combining the data from multiple monitoring stations into a single model, known as a “regional” model. Following the development of the regional model, additional objectives included a comparison of predicted SSCs between the regional models and commonly used site-specific models, as well as an evaluation of why specific monitoring stations did not fit the regional model.

METHODS

All USGS Virginia Water Science Center monitoring stations with paired turbidity (measured with a YSI 6136 sensor) and SSC data were retrieved from the USGS National Water Information System database and considered for this analysis. Data from 64 stations were initially retrieved; however, the data were filtered to ensure that only sites with sufficient observations and only sites with sampling over an extended range of hydrologic conditions were considered. A total of 29 stations met the project-assigned criteria of (1) at least 24 paired turbidity-suspended sediment concentration measurements, and (2) water-quality sampling over most of the observed range of hydrologic conditions (Table 1).

Table 1 Turbidity monitoring station identifiers, names, and watershed areas.

Station identifier	Station name	Watershed area (mi^2)
02042500	Chickahominy River near Providence Forge, VA	251
02041650	Appomattox River at Matoaca, VA	1,342
01627500	South River at Harriston, VA	212
01634000	NF Shenandoah River near Strasburg, VA	770
01631000	SF Shenandoah River at Front Royal, VA	1,634
01668000	Rappahannock River near Fredericksburg, VA	1,595
01632900	Smith Creek near New Market, VA	94
01626000	South River near Waynesboro, VA	127
02035000	James River at Cartersville, VA	6,252
02037618	James River at Boulevard Bridge at Richmond, VA	6,776
01621050	Muddy Creek at Mount Clinton, VA	14.32
01671020	North Anna River at Hart Corner near Doswell, VA	462
02024752	James River at Blue Ridge Pkwy near Big Island, VA	3,076
02054750	Roanoke River at Route 117 at Roanoke, VA	352
01667500	Rapidan River near Culpeper, VA	468
03524740	Clinch River at Route 65 at Dungannon, VA	820
0165389480	Accotink Creek Below Old Lee Hwy at Fairfax, VA	4.87
02055080	Roanoke River at Thirteenth St Bridge at Roanoke, VA	390
01654000	Accotink Creek near Annandale, VA	23.87
01673000	Pamunkey River near Hanover, VA	1,078
01646305	Dead Run at Whann Avenue near Mclean, VA	2.05
01646000	Difficult Run near Great Falls, VA	58
01656903	Flatlick Branch above Frog Branch at Chantilly, VA	4.20
01645762	SF Little Difficult Run above Mouth near Vienna, VA	2.71
01654500	Long Branch near Annandale, VA	3.72
01645704	Difficult Run above Fox Lake near Fairfax, VA	5.49
01674500	Mattaponi River near Beulahville, VA	602
02034000	Rivanna River at Palmyra, VA	663
01658500	SF Quantico Creek near Independent Hill, VA	7.62

This collection of 29 stations represents a diverse group of sites (Figure 1) that provide a range of watershed areas (from 2.05-6,776 sq miles) and locations throughout the state, which allows for a reasonable investigation of whether a regional model can be developed for the state of Virginia.

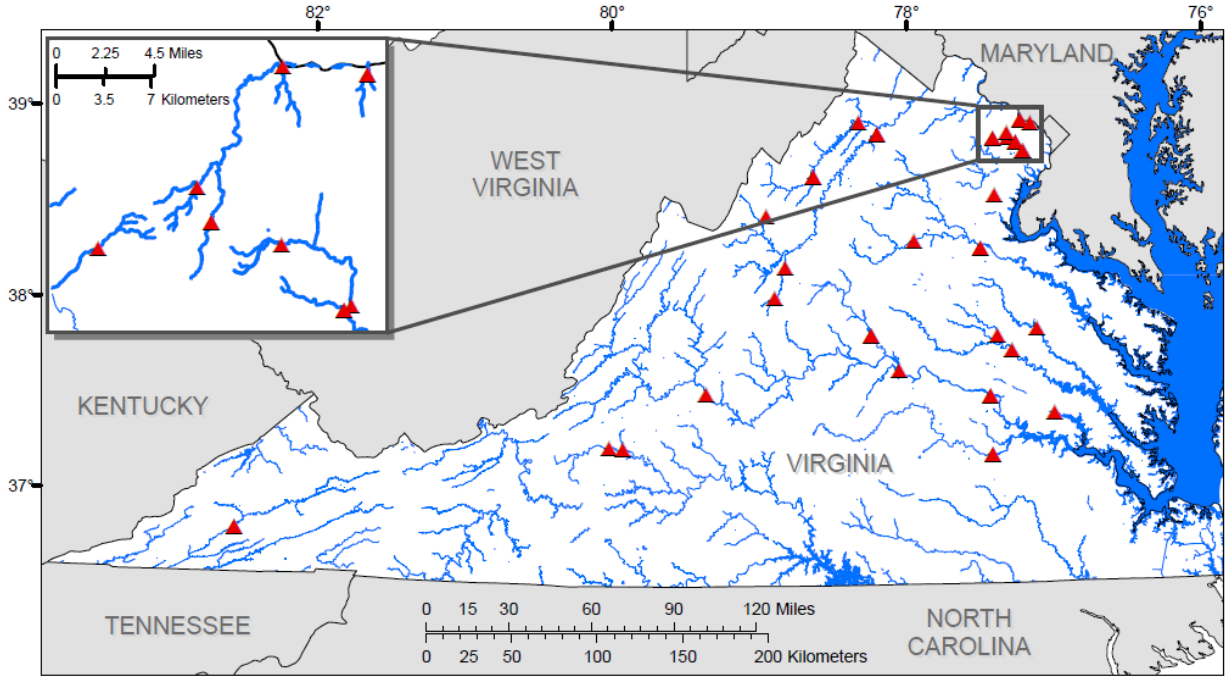

Figure 1 Map of turbidity-monitoring stations included in the study analysis.

For all 29 sites, simple linear regression models to predict SSC from turbidity were developed following standard methods for the development of regression models (Helsel and Hirsch, 2002; Jastram and others, 2009). Because of skewed distributions, both the turbidity and SSC variables were natural log transformed prior to the development of the regression models. All developed models were inspected to ensure they met the assumptions of simple linear regression.

RESULTS

Statistically significant, site-specific regression models were developed for all 29 stations (Figure 2); regression strength and quality varied among regression models. Most coefficients of determination (R^2) ranged from 0.80 to 0.95, with greater and lesser values being observed for some stations. Particularly low R-squared values were noted for station 02042500, Chickahominy River near Providence Forge, VA, and station 02041650, Appomattox River at Matoaca, VA. The Chickahominy River is a typical Coastal Plain blackwater river, with an extremely low river gradient, a broad floodplain, and extensive wetlands that yield low, and relatively uniform turbidity levels and SSCs. The Appomattox River station is located 2.2 miles downstream of a major dam, which likely acts as a sink for sediment, and causes a highly variable turbidity-sediment response.

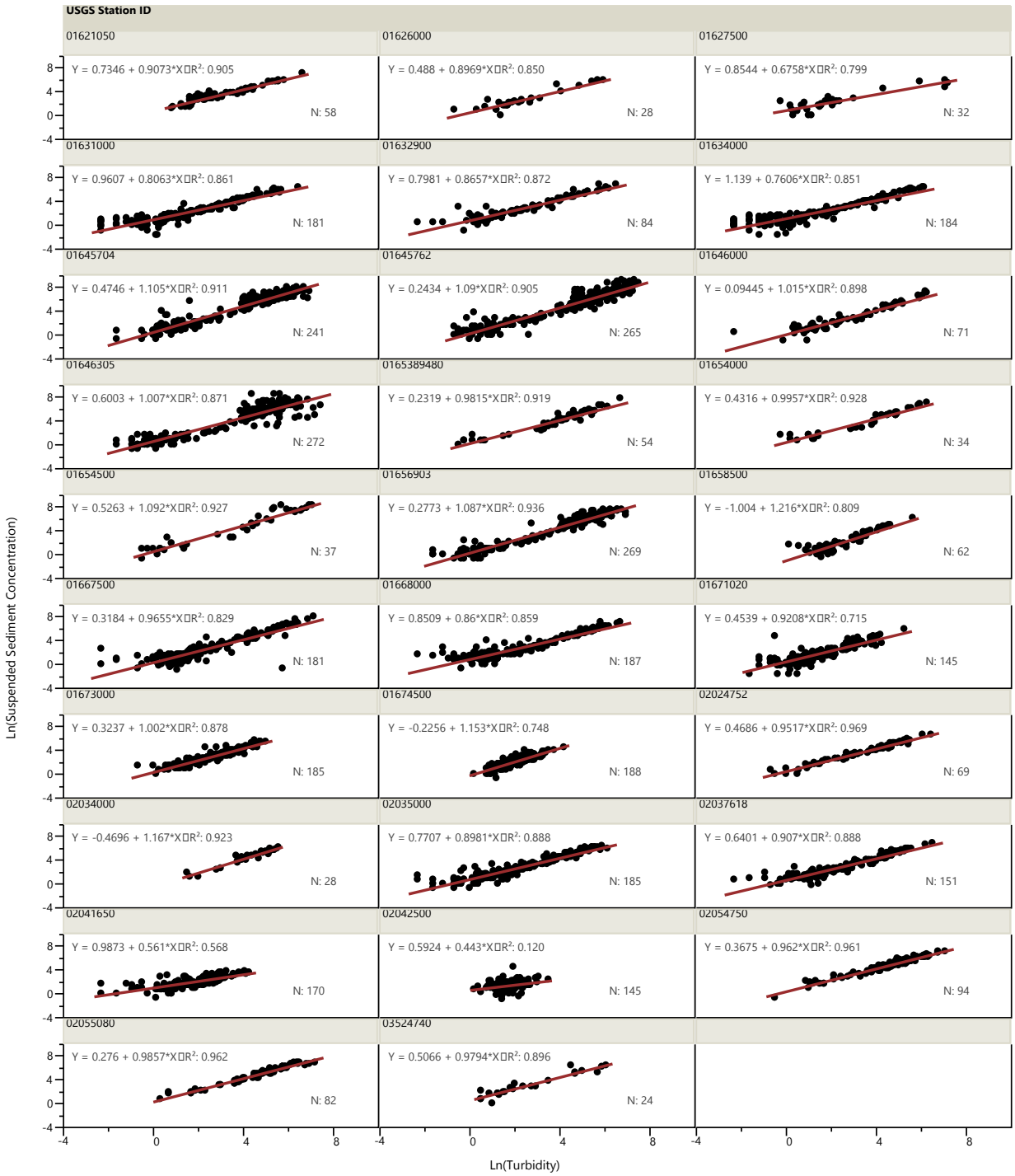

Figure 2 Site-specific turbidity-sediment regression equations for 29 monitoring stations, including model equation, the coefficient of determination (R^2) for each model, and the number of observations (N).

A single robust regional model was desired for the group of site-specific regression models that had relatively similar slope and intercept terms, so a comparison of these terms for all 29 stations was performed. The 99-percent confidence interval (CI) for the slope and intercept for each site-specific model was compared to the 99-percent CIs of the overall mean slope and intercept values for the collection of the 29 site-specific models (Figure 3). Sites where both the slope and intercept CIs of the site-specific model intersected the CIs of the overall mean slope and intercept were deemed not significantly different from the overall mean – effectively an analysis of covariance – and were included in the computation of a new regional turbidity-SSC model. A total of 19 monitoring stations (colored red in Figure 3) were included in the regional turbidity-SSC regression model for the combined data set from all 19 sites. A statistically significant regional model was developed, having an R^2 of 0.89 (Figure 4). Overall, the regional model demonstrates a strong correlation between turbidity and SSC for a diverse range of monitoring stations, however, subsequent comparisons between the regional- and site-specific models were performed.

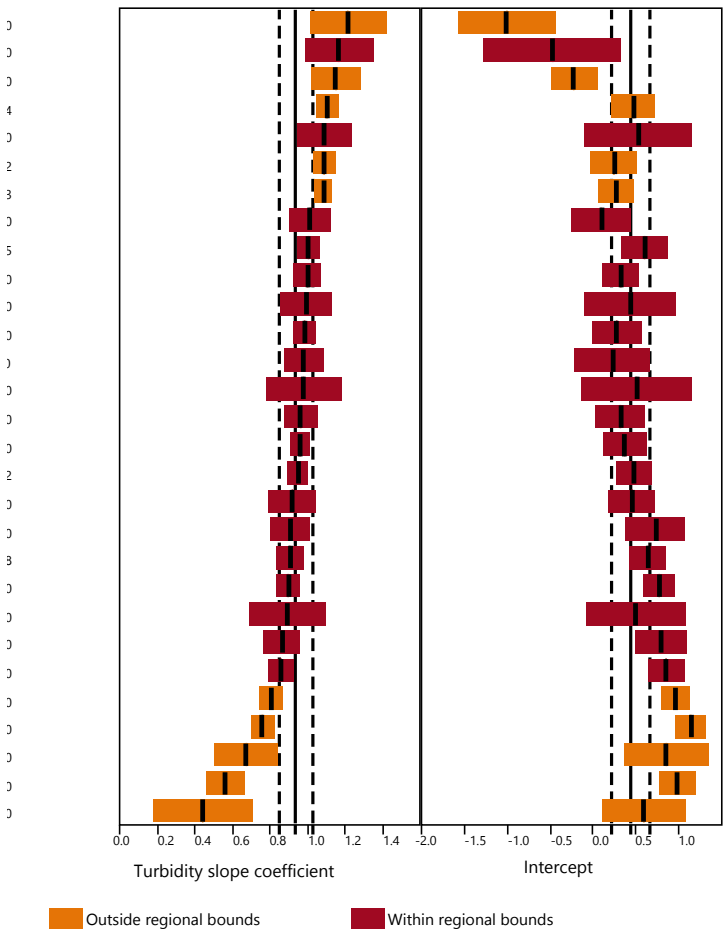

Figure 3 Site-specific model slope and intercept coefficients with 99-percent confidence intervals for 29 stations evaluated, and overall mean slope and intercept (solid line) and 99-percent confidence intervals (dashed lines).

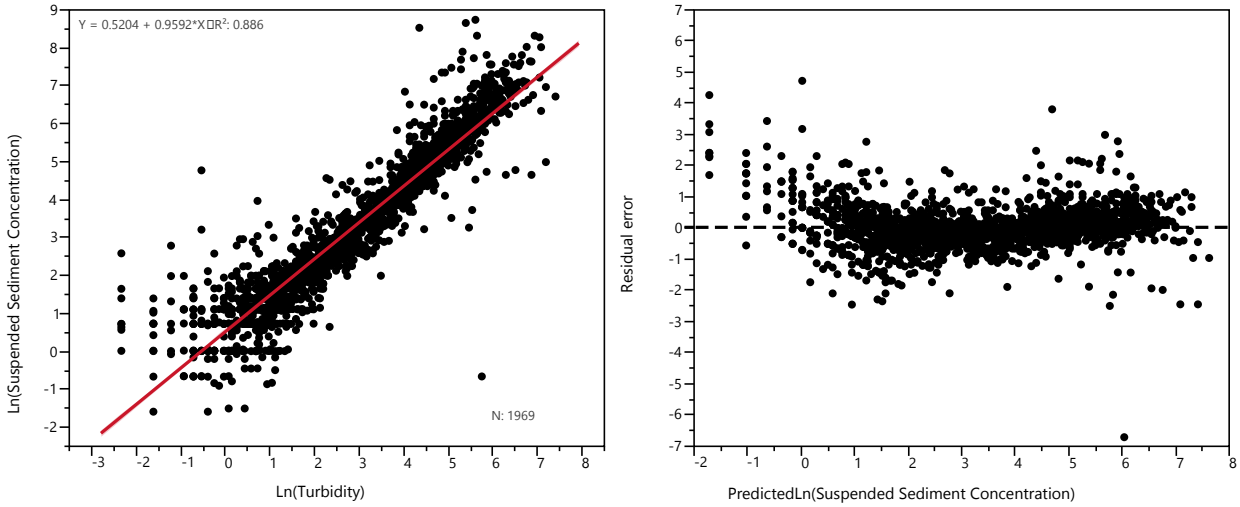

Figure 4 The regional turbidity-suspended sediment model and residuals, based on the combined datasets from 19 monitoring sites.

Direct comparisons of the predicted values between the regional- and site-specific regression models demonstrate good agreement between both models (Figure 5). Comparison of model errors demonstrates that while the regional model has slightly higher mean square error (MSE) in a few cases, overall the MSEs are comparable, regardless of model used (Figure 6).

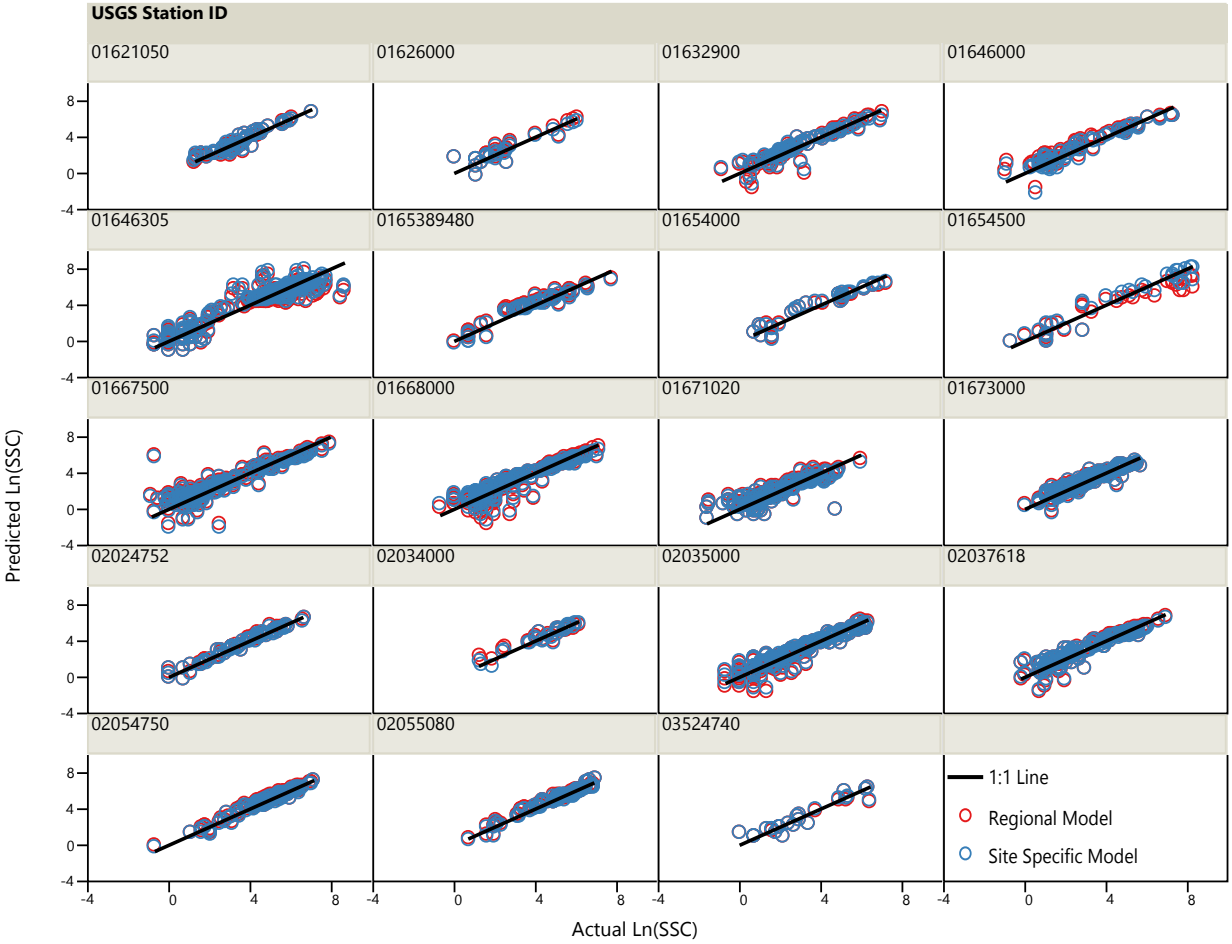

Figure 5 A comparison of actual and predicted values between the site-specific and regional models.

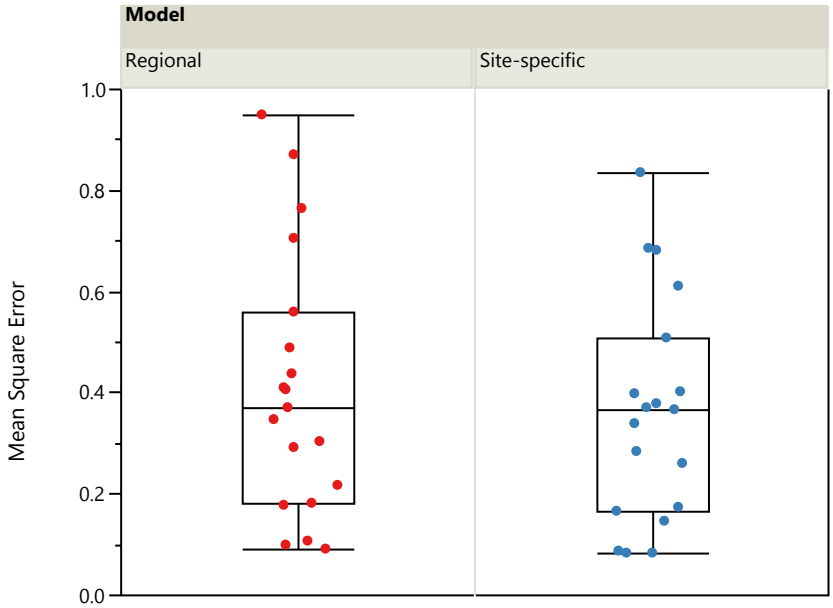

Figure 6 A comparison of the mean square errors between the site-specific and regional turbidity-sediment models.

Ten stations were not included in the regional model because their site-specific regression models were significantly different from the overall mean of the slope and intercept coefficients. The reasons for these differences are still under investigation, but are generally believed to be related to transport processes and physical characteristics of the available sediments, which may be further related to, and modeled by, watershed characteristics such as soil type, basin slope, and land-use. Overall, the sites with elevated slope coefficients generally had smaller intercept values (see the sites at the top of Figure 3) than sites with lesser slopes. These elevated slopes indicate that such streams are moving relatively more sediment per unit of turbidity than the regional model, which would be indicative of higher gradient streams, with greater energy for entrainment of sediments, flowing through more erodible soils or soils with physical characteristics that impart less turbidity per unit mass (coarse particles). The smaller intercepts of these models indicate that these are clear waters with little to no suspended material present at the low end of the turbidity range. Conversely, the sites with smaller slope coefficients had larger intercept values (see the sites at the bottom of Figure 3). These smaller slopes are indicative of streams which are moving relatively less sediment per unit of turbidity than the regional model and the greater intercepts indicate that there is some amount of fine suspended material or other turbidity-causing substance, such as organic matter, present at the low end of the turbidity range. Such streams would be expected to have lower gradients, with less energy for entrainment of sediments, to be flowing through soils less available for entrainment or that impart greater turbidity per unit mass (fine particles), or have controls on sediment transport such

as dams. Both the Chickahominy River and the Appomattox River, the sites with the poorest turbidity-sediment model fit, are in this category, and both generally move less sediment than other rivers included in the regional model. Future work will continue to explore, in more detail, how improved models could be developed to regionally model these 10 stations that were not included in the initial regional model.

SUMMARY

A robust regional turbidity-SSC regression model has been developed from data collected from 19 diverse watersheds across Virginia, supporting the idea that regional turbidity-SSC models can be developed in many areas. Subsequent investigations are planned to explore why some sites did not fit the regional model, and whether a regional model can be expanded beyond Virginia, perhaps to the entire Chesapeake Bay Watershed. Potential future applications of the regional turbidity-SSC regression model are promising, given that most of the existing streamgages within Virginia do not currently have continuous turbidity monitors or suspended sediment sampling. As sediment management strategies are implemented and regulators require reduced sediment loadings to major rivers, more efficient sediment monitoring and load estimation techniques are required to track progress towards these goals, and the use of regional turbidity-SSC models could both increase the efficiency and decrease the cost of such efforts.

REFERENCES

Helsel, D.R., and Hirsch, R.M., 2002. Statistical Methods in water resources: U.S. Geological survey Techniques of Water-Resources Investigations., book 4, chap. A3, 523 p.

Jastram, J.D., Moyer, D.L., and Hyer, K.E., 2009. A comparison of turbidity-based and streamflow-based estimates of suspended sediment concentrations in three Chesapeake Bay tributaries: U.S. Geological Survey Scientific Investigations Report 2009-5165, 37 p.