TECHNICAL MEMORANDUM

To: Chesapeake Bay Program Modeling Team

From: Center for Watershed Protection, Inc.
Sediment Reduction and Stream Restoration Coordinator

Date: March 25, 2014

Re: Analysis of Stream Sediment Studies in Support of Objective 1 of the Sediment Reduction and Stream Corridor Restoration Analysis, Evaluation and Implementation Support to the Chesapeake Bay Program Partnership

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An analysis of stream sediment studies was completed as a continuation of the Center for Watershed Protection's work described in the technical memorandum dated April 5, 2013, "Sediment Stream Loading Literature Review in Support of Objective 1 of the Sediment Reduction and Stream Corridor Restoration Analysis, Evaluation and Implementation Support to the Chesapeake Bay Program Partnership" (CWP, 2013).

Several studies have indicated that stream channel and bank erosion can be a substantial source of the total subwatershed sediment load. The purpose of this analysis is to compare and document sediment and nutrient loadings to small, headwater catchments compared to upland sources. This analysis is part of the Chesapeake Bay Program's (CBP's) initial efforts to improve how sediment is modeled in the Chesapeake Bay Watershed Model (CBWM) and to inform Phase 6 of its development. The analysis is guided by the following research questions:

1. What is the percentage of sediment and nutrients from bank and channel sources of streams and the average rate of erosion? What is the variability in these values and what are the key sources of variation?

2. How does the percentage of sediment and nutrient loading from bank and channel sources vary by physiographic region, stream order, land use, and other stream characteristics?

3. Additional optional question: What are the mechanisms governing the deposition, transport, and fate of sediment to the Chesapeake Bay and associated lag times?

Data availability limited this analysis to research question 1. The studies gathered for this analysis only included estimates of sediment from bank and channel sources. Nutrients were not included. Additional approaches may be explored to address questions 2 and 3 more fully.

1.0 Introduction

The scale at which the CBWM simulates sediment dynamics corresponds to basins that average about 60 to 100 square miles in area. The CBWM does not explicitly simulate the contribution of channel erosion to enhanced sediment or nutrient loadings for 0, 1st, 2nd, and 3rd order streams. These streams are not included as part of the CBWM reach network (i.e., between the edge-of-field and edge-of-stream), that is, scour and deposition with the urban stream channel network within these basins are not modeled. Instead, these streams are currently aggregated with upland landcover categories within the model.

Updates for Phase 6 of the CBWM will include an approach to model the smaller 0, 1st, 2nd, and 3rd order streams to improve estimates of stream sediment and nutrient loadings to the Chesapeake Bay. This approach to model these streams will better align with the crediting process for stream restoration projects outlined in the Urban Stream Restoration Expert Panel report, "Recommendations of the Expert Panel to Define Removal Rates for Individual Stream Restoration Projects" (Schueler and Stack, 2013). Resultantly, the need to quantify the amount of sediment loading attributed to in-stream processes such as streambank erosion, in comparison to upland sources, is a key research area for the model update. This would allow separation of in-stream sediment and nutrient loadings from the upland landcover categories associated with these smaller order streams.

The technical memorandum (CWP, 2013) provided an exploratory review of the available published research and data on stream sediment loadings. The purpose of this memo is to critically analyze and build upon the studies documented in that memo. The analysis includes a review of trends that exist between the amount of sediment contributed from in-stream compared to upland sources and variables that include land use, watershed size, study type (modeling/monitoring), and physiographic region.

2.0 Methods

Studies were gathered that investigated the amount of sediment contributed from in-stream sources, including the stream channel bed and banks. These studies were gathered through a literature review, as well as through recommendations by Allen Gellis from the U.S. Geological Survey and members of the Expert Panel that contributed to development of the Stream Restoration Expert Panel report. These studies are summarized in Appendix A.

Selection criteria included location in the mid-Atlantic region and a watershed size of 75 mi^2 or less. All of the identified studies were entered into a Microsoft Excel spreadsheet that recorded the basic data listed below. Some studies included results for multiple watersheds. In these cases, each watershed was listed as a separate entry in the database, even though it originated from the same study. In addition to the data listed below, the analysis was originally designed to collect total phosphorus (TP) and total nitrogen (TN) loading. However, none of the studies investigated included TN and TP loading rates.

- Author(s)
- Title
- Publication Year
- Study Timeframe
- Location (City/County and State)
- Physiographic Region(s)
- Watershed/Subwatershed
- Drainage Area (mi^2)
- Stream Miles
- % Impervious
- % Urban

- % Agricultural
- % Forest
- % Other (land use other than urban, agricultural, or forest)
- Modeling/Monitoring/Fingerprinting (study type)
- Description of Study
- Factors Influencing Results
- Rate of Bank Erosion (ft/yr)
- Rate of Bank Erosion (lb/ft/yr)
- Total Sediment Load (tons/yr)
- Total Sediment Load (lb/ac)
- % Sediment Load from Instream Sources
- % Sediment Load from Upland Sources

The data was analyzed using univariate regression analysis to identify factors influencing the amount or percentage of in-stream sediment compared to upland sources. This analysis focused predominantly on urban land because research has shown increased rates of channel erosion and sediment yield in urbanizing streams (Langland and Cronin, 2003). An estimate of urban land is used in the analysis based on the data provided in the studies. The percent of urban land in the database includes a combination of residential, commercial, industrial, and institutional land uses. Only three studies reported on the type of urban land. Therefore, specific urban land types were not included as part of this analysis and the general percent urban land category was applied.

The three different study types included were modeling, monitoring, and sediment fingerprinting. These three types are described below.

- Modeling - The types of models utilized in the sediment loading studies include the Phase 5 Chesapeake Bay Watershed Model (CBWM), Environmental Fluid Dynamics Code (EFDC), Water Quality Analysis Simulation Program (WASP5), Generalized Watershed Loading Function (GWLF), and Streambank Erosion Simulation Module. The modeling studies were primarily done for the development of TMDLs.
- Monitoring –The techniques used include bank and cross section surveys, erosion pins, etc.
- Sediment Fingerprinting – This approach is based on characterizing each of the potential sediment sources within a watershed by a composite fingerprint, defined by a number of physical or geochemical properties of the source materials, and comparing the fingerprint of suspended sediment sampled at the watershed outlet with the fingerprints of the potential sources. Common isotopic tracers include cesium and beryllium.

The percentage of sediment load from instream and sources was taken directly from the studies with the exception of PA DEP (2004), which was calculated as the streambank sediment load divided by the total sediment load. In addition, several studies (PA DEP, 2004 and 2013; McGeehan, 1989; Gellis et al., 2009; Schenk et al., 2012) did not report the percentage of sediment from upland sources. For these studies, the sediment from upland sources was calculated by subtracting the streambank sediment load from the total load.

3.0 Results and Discussion

A total of 38 entries were included in the database from 16 individual studies. The percentage of sediment yield from instream sources was obtained from 11 studies in the database, corresponding to 16 individual entries. The other entries only reported the rate of bank erosion, but the percentage of sediment from instream sources could not be obtained because they did not include a measurement of total sediment load for comparison. Table 1 below provides a summary of entries in the database. Additional studies will be published soon from Fairfax County, VA and Smith Creek in PA, but were not complete at the time of this analysis to be included in the database.

Table 1. Database Entry Characteristics

Total Entries	38
Individual Studies	16
Modeling Entries	7
Monitoring Entries	25
Fingerprinting Entries	6
Maryland Entries	14
Pennsylvania Entries	23
Virginia Entries	1
Entries that included the % sediment from in-stream sources	16[1]
Entries that reported the rate of bank erosion	22
Entries that reported total sediment load	17

[1]A total of 16 entries in the database include the percentage of sediment from instream sources. However, two entries represent the Pocomoke River watershed from two separate publications. Gellis et al. (2009) includes additional analysis of the Pocomoke River watershed data presented in Gellis and Landwehr (2006). The additional analysis included weighting the sediment sources by the sediment transported for each sampled storm event. However, this analysis was not consistent with the methodology for the other studies included in the database and was excluded from the analysis in this memo. The original results from Gellis and Landwehr (2006) are used.

The findings of this analysis are presented and discussed below as they relate to the key research Question 1 - *What is the percentage of sediment and nutrients from bank and channel sources of streams and the average rate of erosion? What is the variability in these values and what are the key sources of variation?*

An initial exploratory analysis of all entries in the database that included the percentage of sediment from instream sources found no significant relationship at 95% confidence between land use and instream sediment sources. Key regression parameters for these relationships are provided in Table 2 below. Figure 1 shows the percentage of sediment yield from instream sources plotted with the percentage of urban land for all entries in the database.

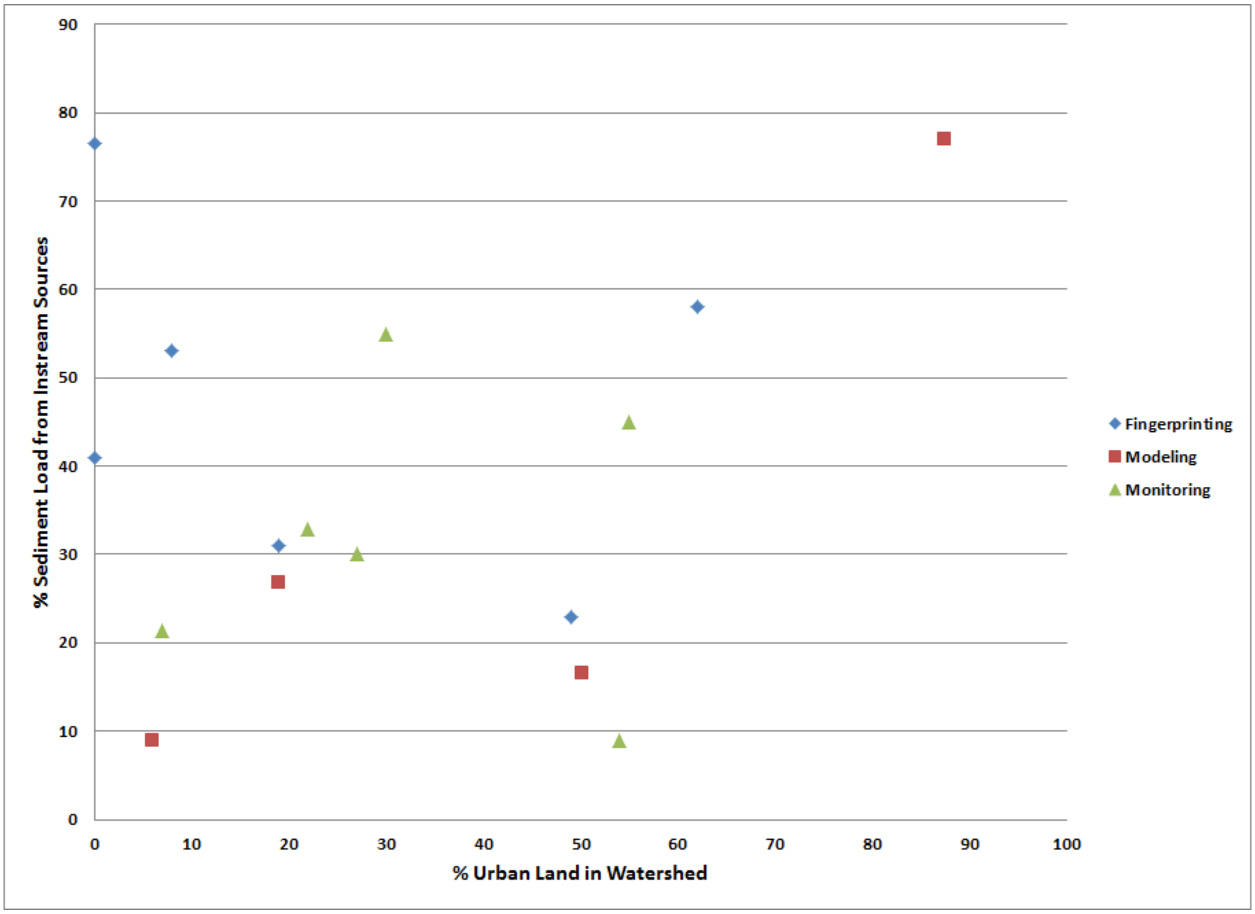

Figure 1. Percentage of sediment load from instream sources compared to the percentage of urban land in the watershed for all entries in the database.

Table 2. Key Regression Parameters for Instream Sediment Sources and Land Use for All Database Entries

Land Use	n[1]	R Square	x-coefficient	P-value (x-variable)
% Urban	15	0.04	0.17	0.49
% Agriculture	14	0.00	-0.04	0.87
% Forest	14	0.09	-0.39	0.31

[1]n=number of entries in the analysis. 15 entries reported the % urban land, but one entry had no data available for the % agriculture and % forest.

Two entries were removed from the analysis as they were determined to be outliers and biasing the results. These outliers include:

- The Pocomoke River watershed (Gellis and Landwehr, 2006) that was predominantly agricultural and forested and had 0% urban land. However, slightly more than 75% of sediment was documented from instream sources, which was attributed to extensive ditching. A standardized residual analysis indicated that this study had a standard residual of 2.17, while all of the other studies fell within ± 1.5 standard residuals.
- The 1.1 mi^2 Pequea Creek watershed was a small, predominantly agricultural watershed with an unusually high total sediment load per acre compared to the other studies in the database. This

is most likely due to the small size of the watershed in combination with legacy sediment issues and livestock access to the stream.

Figure 2 below excludes these two outliers and shows the percentage of sediment yield from instream sources plotted with the percentage of urban land. The studies are categorized by type (modeling, monitoring, and fingerprinting) and the watershed size. The regression indicates that this relationship is significant at the 90% confidence interval (*p-value* = 0.09). The plot shows a general trend that the percentage of sediment from instream sources increases with the percentage of urban land. However, this could be influenced by the data limitation of twelve watersheds available to be plotted after the two outliers were removed. Even so, the data is valuable in that it points to the trend suggested by Langland and Cronin (2003) and is the first analysis of its kind that incorporated all the stream sediment studies available for the Mid-Atlantic Region.

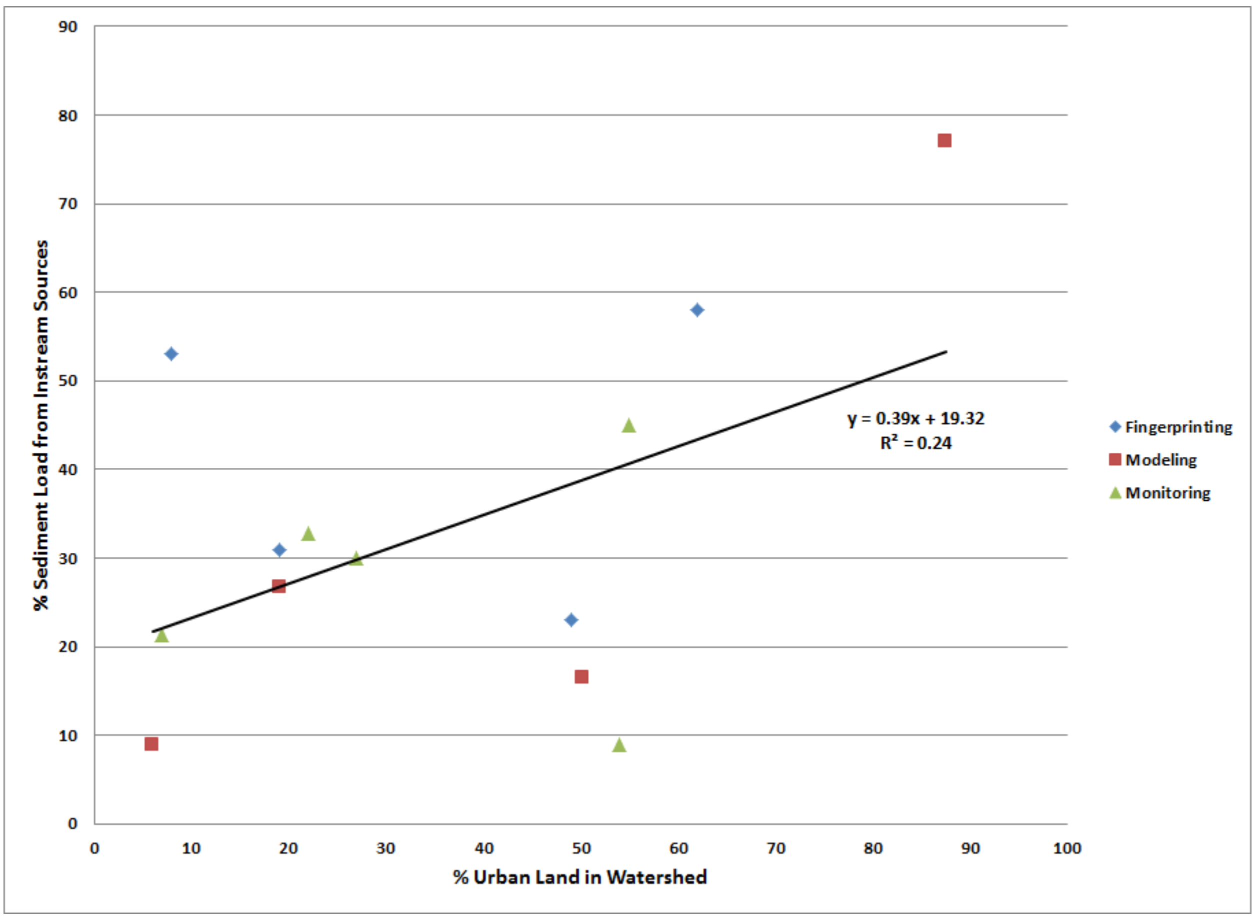

Figure 2. Percentage of sediment load from instream sources compared to the percentage of urban land in the watershed with two outliers removed.

Most of the modeling studies utilized the Generalized Watershed Loading Function (GWLF) for the development of TMDLs. A question was raised by the Modeling Team about the accuracy of the modeling studies and if they should be included as part of this analysis. There are a host of inputs for GWLF (e.g., transport factors, nutrient concentrations, BMPs installed, etc.), and as with any model, the reliability of the result is dependent on the input. Figure 3 below shows Figure 2 with the modeling studies excluded.

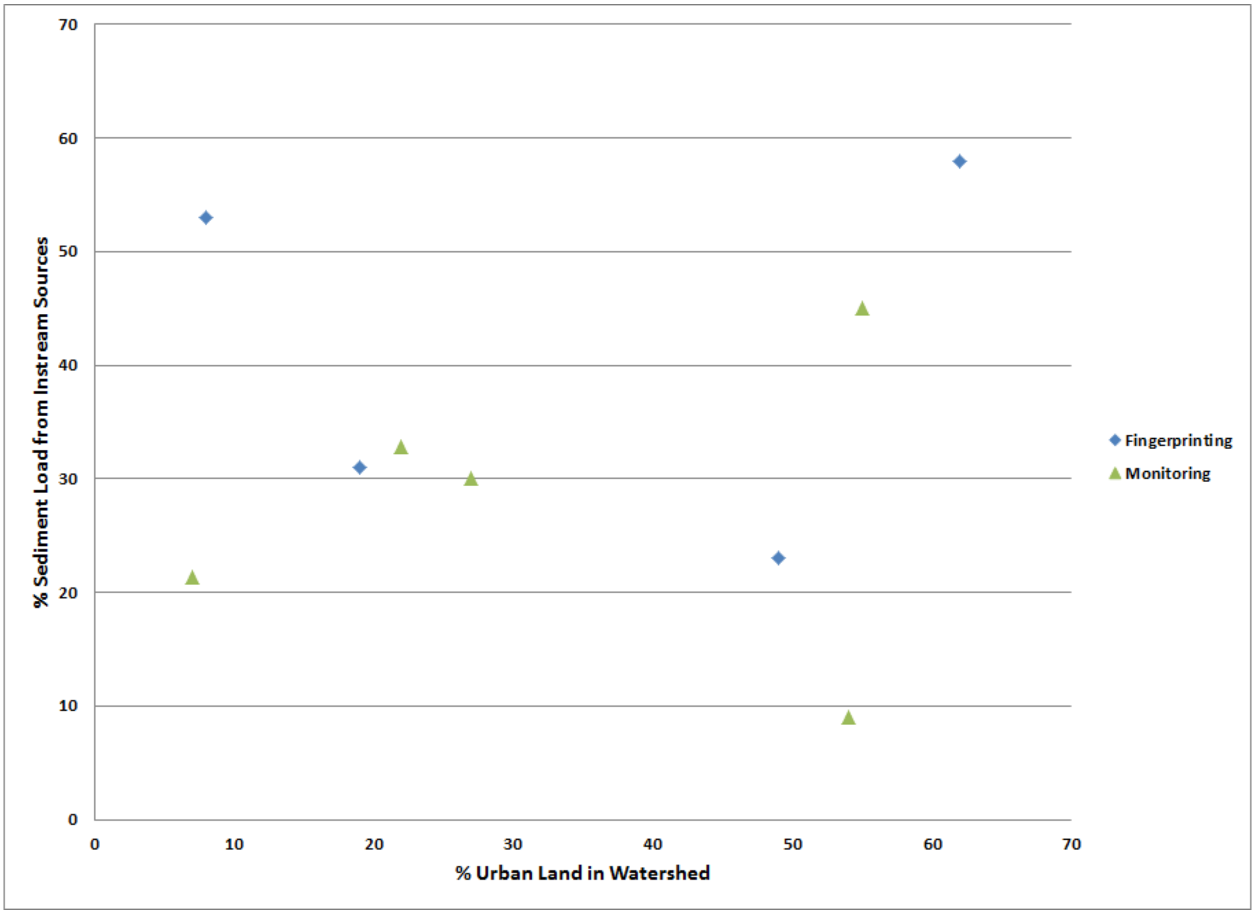

Figure 3. Percentage of sediment load from instream sources compared to the percentage of urban land in the watershed with two outliers and modeling studies removed.

When the modeling studies are removed in Figure 3, the general trend of the percentage of sediment from instream sources increasing with the percentage of urban land no longer exists. However, it is important to note that regardless of the percentage of urban land; most of the percentage of sediment load from instream sources is within the 20-40% range. This is further illustrated by the histogram in Figure 4 below.

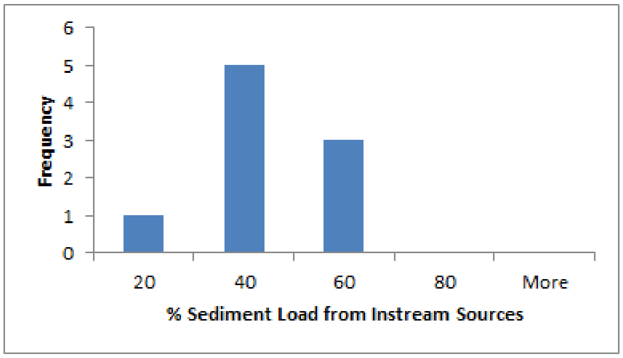

Figure 4. Histogram of the percentage of sediment load from instream sources with two outliers and modeling studies removed.

The total watershed sediment load was also plotted as a function of the percent of urban land in the watershed (Figure 5). Total watershed sediment yield range from approximately 200 lb/ac to 1500 lb/ac for all studies and levels of urbanization. These findings align with those of Langland and Cronin (2003) who provided SWMM Model estimated sediment loads for different developed categories in the Loch Raven and Patapsco River watersheds in Baltimore County. The Chesapeake Bay Program Phase 5.3 Community Watershed Model documentation for sediment simulation (USEPA, 2010) assigned a percent imperviousness to each of these developed land use categories (industrial = 90%, commercial = 80%, low-density residential = 15%, medium-density residential = 25%, high-density residential = 35%, highway/arterial road = 50%, open land/developed park = 2%) to form a relationship between imperviousness and associated sediment load (Figure 6). As can be seen from Figure 6, sediment loads were approximately 700 lb/ac or less.

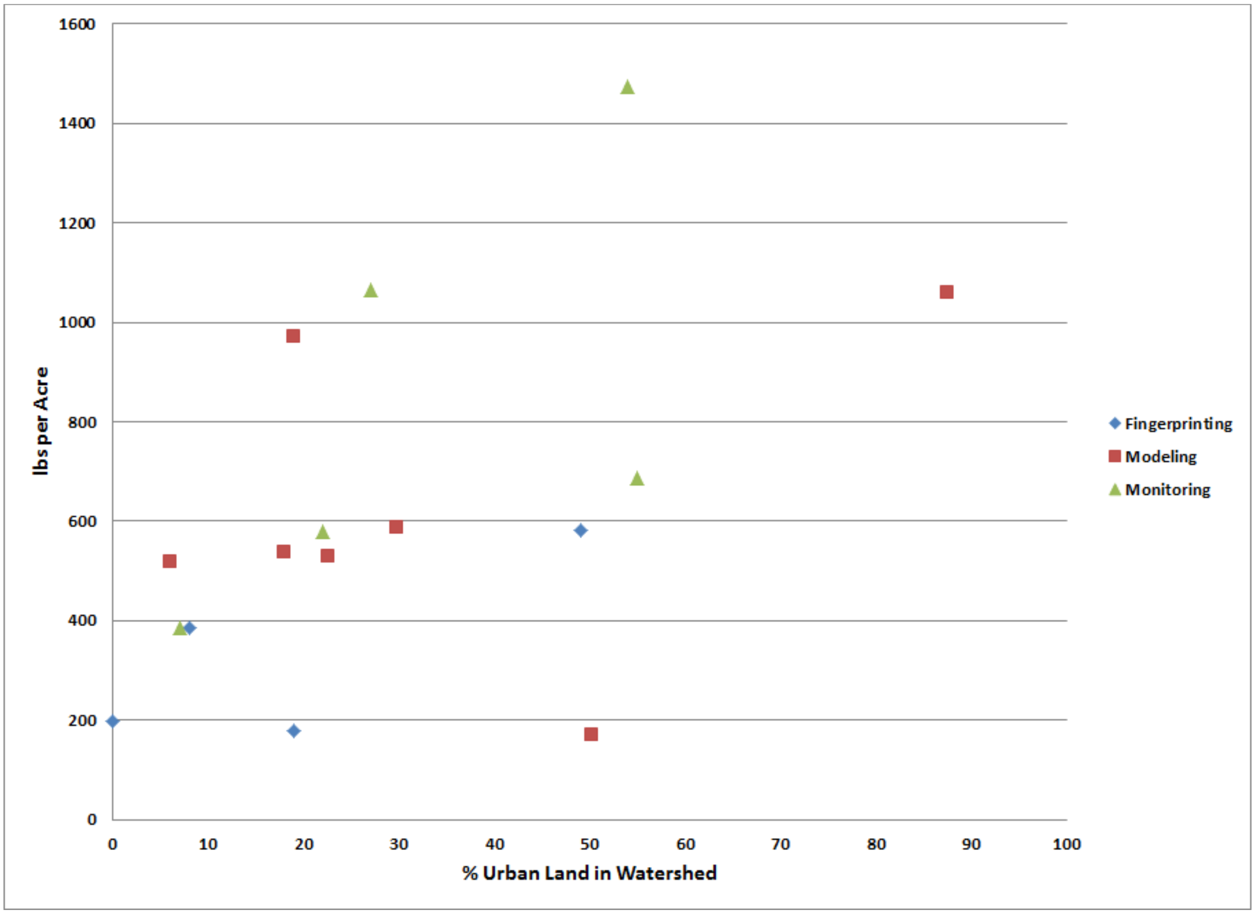

Figure 5. Total sediment yield compared to the percentage of urban land in the watershed.

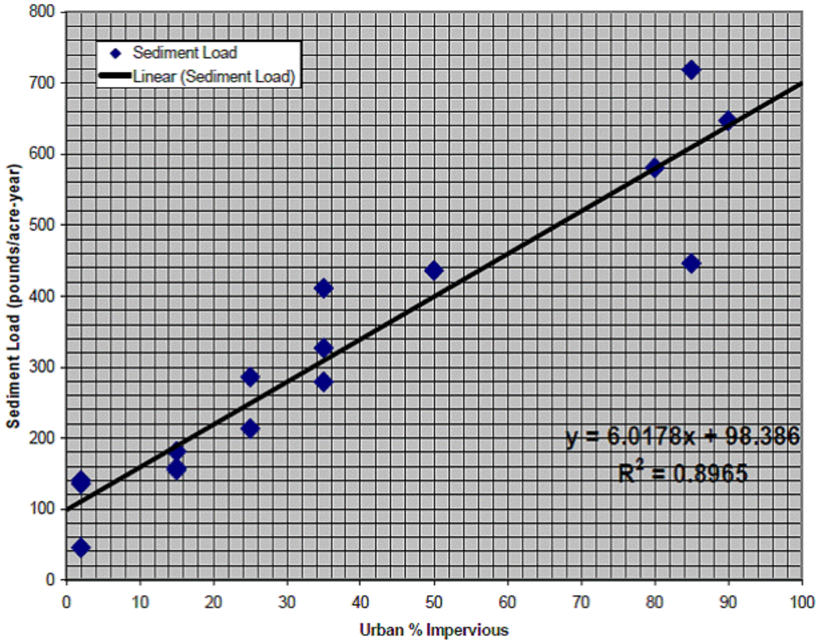

Figure 6. Relationship between Edge-of-Stream Urban Sediment Loads and Watershed Impervious Cover (Source: Langland and Cronin, 2003).

In comparison, the sediment load from instream sources was plotted as a function of the percent of urban land in the watershed (Figure 7). Instream sediment yield was approximately 300 lb/ac or less, with the exception of the Gwynns Falls watershed, which had over 800 lb/ac of sediment from instream sources. For this watershed, the Maryland Department of the Environment developed a formula for estimating the percent of erosional sediment resultant from streambank erosion (i.e., that portion of the total urban sediment load attributed to stream bank erosion) based on the amount of impervious land within a watershed. The highly urban nature of the watershed could be resulting in the high sediment yield from instream sources that were modeled, and/or the method used to estimate sediment yield.

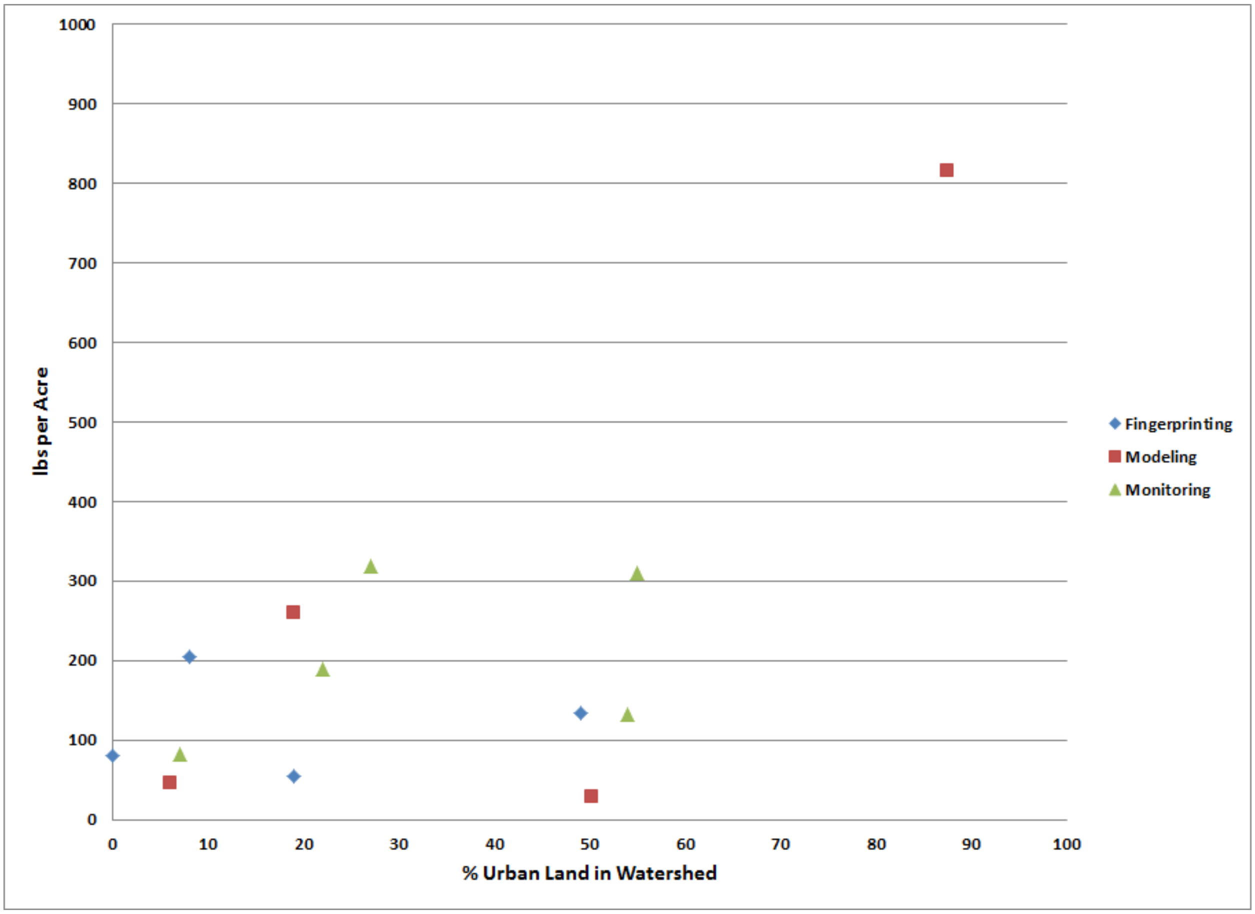

Figure 7. Sediment yield from instream sources compared to the percentage of urban land in the watershed.

The plots of total sediment yield (Figure 5) and the sediment yield from instream sources (Figure 7) provide valuable insights into watershed sediment loadings in the region. The total watershed sediment yield of 1500 lb/ac or less and instream sediment yield approximated at 300 lb/ac or less for all studies provides preliminary sediment yield bounding estimates to consider as part of Phase 6 CBWM.

4.0 Next Steps

The technical memo analyzes stream sediment studies in the Mid-Atlantic region to help quantify in-stream sediment loadings to assist the development of the CBWM. The studies included in this analysis document the significance of instream erosion as a significant component of the total watershed sediment load. Data availability limited this analysis to research question 1. Additional approaches may be explored to address questions 2 and 3 more fully.

Future research that is being considered to build upon the results in this technical memo includes an analysis of stream bank erosion rates. Edge of field bank erosion rates (lbs/ft/yr) were reported for 22 entries in the database across Maryland and Pennsylvania. Further investigation of these erosion rates may provide insight into the influence of physiographic region, stream order, land use, and other stream characteristics on bank erosion. A comparison of historic and recent orthophotos using tools in ArcGIS is also being considered that would determine bank erosion rates over time.

In addition to the analysis of stream sediment studies included in this memo, an analysis of the water quality monitoring data described in the April 5th, 2013 technical memo (CWP, 2013) was conducted. The analysis of stream sediment studies presented in this technical memo adds to the findings of the monitoring data analysis to help estimate the contribution of instream erosion to watershed sediment load and further answer the research questions identified for this study.

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Appendix A – Stream Sediment Studies Identified

Study	Watershed(s) / Subwatershed(s)	Description
A sediment budget for an urbanizing watershed, 1951-1996, Montgomery County, Maryland, USA (Allmendinger et al., 2007)	Good Hope Tributary	Regression equations were used to relate channel cross-section area to the extent of development and used with historical land use data to estimate sediment yield from 1st and 2nd order stream channels. 35 cross-sections were surveyed on 1st order tributaries to develop the regressions. The volumetric sediment yield was converted to an annual mass flux using a nominal value of 30% for the porosity of eroded and deposited sediments and a value of 2,600 kg ⁄m3 for the density of the sediment. These computations result in an annual sediment yield of 135.0 tons⁄km2⁄year. Floodplain sediment storage accounted for half of the total sediment yield, demonstrating that floodplains are an important component of the sediment budget. Erosion of legacy sediments accounts for between 0 and 20% of the total sediment yield of the watershed. These results do not support the hypothesis that erosion of stored ''Agricultural Age'' deposits is responsible for elevated sediment yields in the region.
Quantifying Fine Sediment Sources in the Northeast Branch of the Anacostia River, Maryland, Using Trace Elements and Radionuclides - Master's Thesis (Devereux, 2006)	Northeast Branch of the Anacostia Watershed	Concentrations of 63 elements and two radionuclides were measured in possible sediment sources and suspended sediment collected at the watershed outlet during storm events. Methodology for selecting tracers was developed so the sediment fingerprinting method could effectively determine the relative quantity of sediment contributed by each source to the suspended fraction. Streambank erosion was found to be the primary source of suspended sediment.
Contribution of In-Channel Processes to Sediment Yield of an Urbanizing Watershed (Fraley et al., 2009)	Valley Creek	A study was conducted between September 2003 and September 2006 to obtain baseline sediment inventories and monitor sediment transport and storage along a 3.7 km length of the channel of Valley Creek within Valley Forge National Historical Park, Pennsylvania. Numerous field methods were employed to measure the suspended sediment yield, longitudinal profile, cross-sections, banklines, and particle size distribution of the streambed. Suspended sediment yield for the watershed was measured at a USGS gage located just upstream of the park boundary. The mass of silt, clay, and fine sand derived from bank erosion along the 3.7 km study reach during the field survey period accounts for an estimated 2,340 t, equivalent to about 43% of the suspended sediment load. Although bank erosion appears to be a potentially dominant source of sediment by comparison with annual suspended sediment load, bed sediment storage and potential for remobilization

Study	Watershed(s) / Subwatershed(s)	Description
		is of the same order of magnitude as the mass of sediment derived from bank erosion.
Identifying Sources of Fine-Grained Suspended-Sediment for the Pocomoke River, an Eastern Shore Tributary to the Chesapeake Bay (Gellis and Landwehr, 2006)	Pocomoke River	Sources of fine-grained suspended sediment in the Pocomoke River watershed draining above Willards, Maryland, were identified using a 'sediment-fingerprinting' approach. Potential sediment sources in the watershed were cropland, forest, channel and ditch banks, and ditch beds. Samples of fine-grained suspended sediment were obtained for seven storms between July 2001 and November 2002 and showed that the channel corridor (channel and ditch, banks, and ditch beds) were significant sources averaging 76.5% (46.1% ditch beds and 30.4% channel and ditch banks) of the total sediment sources for the seven storms. The channel bed of the Pocomoke River was not considered to be a source in this study because this sediment may only represent temporary storage from upstream sources and is not a true source by itself. Because the ditch beds are deep and straight, dredged periodically, and extend over much of the watershed, they were considered a potential sediment source.
Sources, Transport, and Storage of Sediment in the Chesapeake Bay Watershed (Gellis et al., 2008)	Pocomoke River, Mattawoman Creek, Little Conestoga Creek	In this study, the sources, transport, and storage of sediment for selected tributaries in the Chesapeake Bay Watershed were determined using field and surrogate approaches. Sediment fingerprinting was used to identify sources of fine-grained suspended sediment in selected watersheds of the Chesapeake Bay. Important sediment sources in the agricultural Pocomoke River Watershed, which were weighted to the sediment transported by each event, were cropland (46 percent), ditch beds (34 percent), streambanks (7 percent), and forest (13 percent). Important sediment sources for the mixed land use (forest, agricultural, and urbanizing) Mattawoman Creek Watershed on the Coastal Plain Western Shore were streambanks (31 percent), followed by forest (29 percent), construction (23 percent), and cropland (17 percent). Important sediment sources for the agricultural and urbanizing Little Conestoga Creek Watershed were cropland (77 percent), followed by streambanks (23 percent).
Unpublished Monitoring Data for Hoffer Creek (Kyler, 2013)	Hoffer Creek	Bank erosion pin data was obtained from Kristen Kyler, the project coordinator of the Lower Susquehanna Initiative at Penn State University. Hoffer Creek is a tributary to the Conewago Creek, which is one of the USDA showcase watersheds. The data has been collected from 8/2012 to 5/2013 and is ongoing. The average bank erosion rate reported here was calculated as an average of all the pins

Study	Watershed(s) / Subwatershed(s)	Description
		installed at 20 sites along Hoffer Creek.
Streambank Erosion as a Source of Pollution: Research Report (LandStudies, 2005)	Choconut, Codorus, Conewego, Cowanshannock, Crabby, Long Draft Branch, Octoraro, Santo Domingo, Spencer Run, Stony Run, Trout Run	According to a number of projects funded by various government agencies and private entities, stream bank erosion is a significant source of nonpoint sediment and nutrient pollution affecting watersheds across Pennsylvania. This report summarizes streambank erosion rates for these DEP-funded projects in the Lower Susquehanna Watershed of Pennsylvania.
Total Maximum Daily Load of Sediment in the Gwynns Falls Watershed, Baltimore City and Baltimore County, Maryland (MDE, 2009)	Gwynn's Falls	In order to quantify the impact of sediment on the aquatic health of non-tidal stream systems, a reference watershed TMDL approach was used and resulted in the establishment of a sediment loading threshold. This threshold is based on a detailed analysis of sediment loads from watersheds that are identified as supporting aquatic life (i.e., reference watersheds) based on Maryland's biocriteria. This threshold is then used to determine a watershed specific TMDL of 13,996.2 tons/yr. The CBP P5 land use GIS framework was used to develop the TMDL. Using CBP P5 urban sediment EOF target values, MDE developed a formula for estimating the percent of erosional sediment resultant from streambank erosion (i.e., that portion of the total urban sediment load attributed to stream bank erosion) based on the amount of impervious land within a watershed. The equation uses the urban sediment loading factors to estimate the proportion of the urban sediment load from stream bank erosion.
Sediment Budget for a Small Agricultural Watershed (McGeehan, 1989)	Pequea Creek	A sediment budget was developed for Pequea Creek, a tributary of the Susquehanna River. Monitoring included cross-section surveys, streambank sediment samples, surveys of bank erosion and water samples collected from cross-sections at 5 sites. Over half of the annual sediment yield in the watershed was found to come from streambanks. Gully erosion is the 2nd biggest sediment contributor.
Sediment and Nutrient Loads from Stream Corridor Erosion along Breached Mill Ponds (Merritts et al., 2010)	Big Beaver Creek, Conoy Creek, Gunpowder Falls, Hammer Creek, Little Conestoga Creek, Mountain Creek, Penns	The study contains sediment production rates, nutrient contents, and erosion mechanisms of stream corridor sediments from the Piedmont and the Ridge and Valley physiographic provinces of the mid-Atlantic Chesapeake Bay Watershed. This report provides evidence that a process given little attention to date—stream corridor erosion from breached millpond reservoirs—is a substantial

Study	Watershed(s) / Subwatershed(s)	Description
	Creek	source of suspended (i.e., fine grained) sediments and nutrients within the Chesapeake Bay watershed. This compilation of data from ten breached millpond reservoirs reveals that stream bank sediment production rates are highest shortly after dam breaching and diminish with time, asymptotically approaching zero for at least a century.
Total Maximum Daily Load (TMDL), Lititz Run, Lancaster County – DRAFT (PA DEP, 2004)	Lititz Run	A sediment TMDL was developed for Lititz Run. PA's 2004 303(d) lists 5.4 miles of Lititz Run as impaired by turbidity and TSS. Soil erosion, livestock access to streams, and limited or no riparian buffers are found in the watershed. Catasauqua Creek was used as a reference watershed along with the ArcView Generalized Loading Function Model (AVGWLF) to develop the Lititz Run TMDL. The targeted TMDL value for the Lititz Run watershed was established based on current loading rates for sediment in the Catasauqua Creek reference watershed. To meet the TMDL, sediment will need to be reduced by 43%. The continuous simulation model used for the analysis took into account seasonal variation through daily time steps for weather data and water balance calculations, specification of growing season, hours of daylight, and times of year when manure is applied.
Hoffer Creek Sediment TMDL (PA DEP, 2013)	Hoffer Creek	A Total Maximum Daily Load (TMDL) for sediment was developed to address impairments noted in Pennsylvania's 303(d) List and the Pennsylvania Integrated Water Quality Monitoring and Assessment Report. A reference watershed approach was used to develop the TMDL. The TMDL for this watershed was calculated using the ArcView Generalized Watershed Loading Function (AVGWLF).
Developing a New Stream Metric for Comparing Stream Function using a Bank-Floodplain Sediment Budget: a Case Study of Three Piedmont Streams (Schenk et al., 2013)	Little Conestoga Creek, Linganore Creek, Difficult Run	A bank and floodplain sediment budget was created for three Piedmont streams tributary to the Chesapeake Bay. The watersheds of each stream varied in land use from urban (Difficult Run) to urbanizing (Little Conestoga Creek) to agricultural (Linganore Creek). Site sediment budgets were normalized by floodplain area and divided by the stream's sediment yield to provide a unitless measure of floodplain sediment trapping. Intensive monitoring sites consisted of surveying floodplain and bank erosion transects. Erosion pins were used along bank transects. Sinuosity was the explanatory variable for site erosion rates (P = 0.079) where sites with lower sinuosity experienced high erosion rates.
Nutrient and Siltation TMDL Development for Wissahickon Creek,	Wissahickon Creek	Land use is a mixture of residential, agricultural, wooded, industrial, commercial, and parkland. To determine a TMDL for Wissahickon Creek, a low-flow, steady-state model was

Study	Watershed(s) / Subwatershed(s)	Description
Pennsylvania (U.S. EPA, 2003)		utilized that included chemical and biological processes associated with nutrient enriched and eutrophic systems. For each stream segment in the Wissahickon Creek basin included in Pennsylvania's 303(d) list due to nutrients, separate TMDLs, WLAs, and LAs were determined and are summarized for both TS and WWF periods, respectively. Total loads were determined for CBOD5, ammonia nitrogen, nitrate-nitrite nitrogen, and ortho phosphate. To develop a siltation TMDL for the impaired reaches in the basin, a "reference watershed approach" was utilized. Once the impaired and reference watersheds were matched, a watershed model was used to simulate the sediment loads from different sources.
Sediment Source Analysis in the Linganore Creek Watershed, Maryland, USA, Using the Sediment Fingerprinting Approach: 2008 to 2010 (Gellis and Noe, 2013)	Linganore Creek	Sediment fingerprinting was used to determine the relative percentage contribution from potential sources of fine-grained sediment. Results of sediment fingerprinting for 194 samples collected in 36 separate storm events indicate that stream banks contribute 53% of the annual fine-grained suspended sediment load, agriculture contributed 44%, and forests contributed 3%. Peak flows and sediment loads for the 36 storms show a significant relation to sediment sources from stream bank erosion. A decrease in agricultural sediment with increasing peak flows may reflect the greater contributions from stream banks relative to agricultural sources during periods of high flow.