TECHNICAL MEMORANDUM

To: Chesapeake Bay Program Modeling Team

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

Date: April 8, 2013

Re: 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

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This literature review was conducted as per request of the Chesapeake Bay Program Modeling Team to inform Phase 6 of the Chesapeake Bay Watershed Model.

1.0 Introduction

The Urban Stream Restoration Expert Panel report, "Recommendations of the Expert Panel to Define Removal Rates for Individual Stream Restoration Projects" is almost finalized. Given that the sediment reduction credit of stream restoration could be greater than the existing approved rate by an order of magnitude, it is critical that the effect of this on the Chesapeake Bay Watershed Model (CBWM) be clearly understood. In an effort to incorporate the new protocols into the model, the Center for Watershed Protection is working with the Chesapeake Bay Program Modeling team on revisions that include a better method to model sediment loading from the smaller 1st through 3rd order streams that are currently aggregated with upland landcover categories within the model.

Identification of the amount of sediment loading attributed to streambank erosion in comparison to upland sources is a key research need in the model update. Several studies have indicated that stream channel and bank erosion can be a substantial source of the total subwatershed sediment load. Identifying the degree of stream sediment contribution is important for addressing how the CBWM attributes sediment load reduction to stream and upland BMPs. The purpose of this memo is to provide an exploratory review of the available research and data on stream sediment loadings. Subsequent phases of this research will critically analyze the data found during this initial review, as described in the Next Steps. Data summaries are provided where available.

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2.0 Methods

Research for this technical memo was done through a literature review, as well as through contacting local monitoring data coordinators in Maryland and Virginia. The literature review studies consist of those found through an internet search, in addition to studies collected by members of the Expert Panel that were used in development of the Panel report. These studies are summarized below. Monitoring databases were also researched to determine if they contain data that would be useful for identifying the amount of sediment loading attributed to streambank and channel erosion. Data analysis was not conducted, but a discussion of how this data could be utilized is provided in Section 5 – Potential Methods to Estimate Streambank Loading.

3.0 Streambank Loading Studies

3.1 Streambank Erosion Rates

The studies listed in Table 1 below were gathered from Expert Panel members, as well as through an internet search. Most define rate of bank retreat and estimate the mass of eroded sediment using bank pins and cross-sectional measurements. Some studies also sample the soil nutrient content in bank and floodplain sediments to determine the mass of nutrients lost via channel erosion. This measurement approach provides robust long-term estimates for urban streams that are actively incising or enlarging. Table 1 provides streambank erosion rates for several studies in MD and PA provided in tons/length/yr. These erosion rates were converted to lbs/ft/yr and plotted in Figure 1, along with the original and interim Chesapeake Bay Program approved rates for urban stream restoration. The graph shows that the original rate was too conservative and that the interim rate is more representative of the higher sediment and nutrient export rates typical of urban streams undergoing restoration.

Table 1. Streambank Erosion Rates for Monitoring Studies in MD and PA

Location	Erosion Rate (mass/length/year)	Study	Notes
Valley Creek (Valley Forge, PA)	919 t/km/yr (total) 632 t/km/yr (portion of the total that is silt, clay and fine sand)	Fraley et al., 2009	Study conducted along the downstream section of Valley Creek within the national park. Many reaches have high banks, as the stream is cutting through legacy deposits from an old mill dam. The erosion rate is expressed as a total and as the portion that is silt, clay, and fine sand, which is the particle size range most comparable to suspended sediment.
Hammer Creek (Southeastern PA)	0.72 t/ft/yr	Merritts et al., 2010	Erosion rate averaged over the 7 years after a mill dam was breached in 2001.
Mountain Creek (Southeastern PA)	1.5 t/ft/yr (representative of 2003-2006) 11 t/ft/yr (long-term average production rate if sediment were eroded at a constant rate since the time of dam breaching)	Merritts et al., 2010	Mill dam breached in 1984.

Conoy Creek (Southeastern PA)	0.27 t/ft/yr	Merritts et al., 2010	Stream bypassed the mill dam in 1972. Erosion rate is representative of 2001-2005.
West Branch Little Conestoga Creek (Southeastern PA)	0.2 t/ft/yr (long-term average production rate)	Merritts et al., 2010	Dam was breached sometime between 1919 and 1940. Note that this is a long-term average production rate if sediment were eroded at a constant rate since the time of dam breaching. It is likely that the rate was actually much higher during the years immediately after breaching, and has diminished with time.
Big Beaver Creek (Southeastern PA)	0.6 t/ft/yr (2001-2005) 0.24 t/ft/yr (2005-2009)	Merritts et al., 2010	Dam was breached in 1972.
Penns Creek (Southeastern PA)	0.24 t/ft/yr	Merritts et al., 2010	Dam was breached in 1968. Note that this is a long-term average production rate if sediment were eroded at a constant rate since the time of dam breaching. It is likely that the rate was actually much higher during the years immediately after breaching, and has diminished with time.
Gunpowder Falls (Southeastern PA)	0.35 t/ft/yr	Merritts et al., 2010	Dam was breached in 1932. Note that this is a long-term average production rate if sediment were eroded at a constant rate since the time of dam breaching. It is likely that the rate was actually much higher during the years immediately after breaching, and has diminished with time.
Choconut (Susquehanna County, PA)	6.3 t/ft/yr	LandStudies, 2005	From a table of “problem area” erosion rates in the LandStudies report. The reference for the original study is provided in the report, but couldn’t be located based on a quick Google search.
Codorus – East Branch (York County, PA)	0.4 t/ft/yr	LandStudies, 2005	From a table of “problem area” erosion rates in the LandStudies report. The reference for the original study is provided in the report, but couldn’t be located based on a quick Google search.
Codorus Creek – South Branch Granary Rd (York County, PA)	1.3 t/ft/yr	LandStudies, 2005	From a table of “problem area” erosion rates in the LandStudies report. The reference for the original study is provided in the report, but couldn’t be located based on a quick Google search.

Codorus Creek – South Branch SBCC 026 (York County, PA)	1.1 t/ft/yr	LandStudies, 2005	From a table of "problem area" erosion rates in the LandStudies report. The reference for the original study is provided in the report, but couldn't be located based on a quick Google search.
Codorus Creek – South Branch SBCC 015 (York County, PA)	1.1 t/ft/yr	LandStudies, 2005	From a table of "problem area" erosion rates in the LandStudies report. The reference for the original study is provided in the report, but couldn't be located based on a quick Google search.
Codorus Creek – South Branch SBCC 025 (York County, PA)	2.0 t/ft/yr	LandStudies, 2005	From a table of "problem area" erosion rates in the LandStudies report. The reference for the original study is provided in the report, but couldn't be located based on a quick Google search.
Codorus Creek – South Branch Phase 1 (York County, PA)	0.6 t/ft/yr	LandStudies, 2005	From a table of "problem area" erosion rates in the LandStudies report. The reference for the original study is provided in the report, but couldn't be located based on a quick Google search.
Codorus Creek – South Branch Phase 2 (York County, PA)	0.2 t/ft/yr	LandStudies, 2005	From a table of "problem area" erosion rates in the LandStudies report. The reference for the original study is provided in the report, but couldn't be located based on a quick Google search.
Codorus Creek – South Branch Phase 3 (York County, PA)	0.5 t/ft/yr	LandStudies, 2005	From a table of "problem area" erosion rates in the LandStudies report. The reference for the original study is provided in the report, but couldn't be located based on a quick Google search.
Conewego (Adams County, PA)	10 t/ft/yr	LandStudies, 2005	From a table of "problem area" erosion rates in the LandStudies report. The reference for the original study is provided in the report, but couldn't be located based on a quick Google search.
Cowanshannock (Armstrong County, PA)	0.4 t/ft/yr	LandStudies, 2005	From a table of "problem area" erosion rates in the LandStudies report. The reference for the original study is provided in the report, but couldn't be located based on a quick Google search.
Cowanshannock (Armstrong County, PA)	1.0 t/ft/yr	LandStudies, 2005	From a table of "problem area" erosion rates in the LandStudies report. The reference for the original study is provided in the report, but couldn't be located based on a quick Google search.

Crabby (Chester County, PA)	3.6 t/ft/yr	LandStudies, 2005	From a table of “problem area” erosion rates in the LandStudies report. The reference for the original study is provided in the report, but couldn’t be located based on a quick Google search.
Long Draught Branch (Maryland)	0.3 t/ft/yr	LandStudies, 2005	From a table of “problem area” erosion rates in the LandStudies report. The reference for the original study is provided in the report, but couldn’t be located based on a quick Google search.
Octoraro – West Branch (Lancaster County, PA)	0.7 t/ft/yr	LandStudies, 2005	From a table of “problem area” erosion rates in the LandStudies report. The reference for the original study is provided in the report, but couldn’t be located based on a quick Google search.
Octoraro WBR Headquarters (Lancaster County, PA)	0.1 t/ft/yr	LandStudies, 2005	From a table of “problem area” erosion rates in the LandStudies report. The reference for the original study is provided in the report, but couldn’t be located based on a quick Google search.
Santo Domingo (Lancaster County, PA)	0.4 t/ft/yr	LandStudies, 2005	From a table of “problem area” erosion rates in the LandStudies report. The reference for the original study is provided in the report, but couldn’t be located based on a quick Google search.
Spencer Run (Blair County, PA)	0.2 t/ft/yr	LandStudies, 2005	From a table of “problem area” erosion rates in the LandStudies report. The reference for the original study is provided in the report, but couldn’t be located based on a quick Google search.
Stony Run (Maryland)	0.7 t/ft/yr	LandStudies, 2005	From a table of “problem area” erosion rates in the LandStudies report. The reference for the original study is provided in the report, but couldn’t be located based on a quick Google search.
Trout Run (Chester County, PA)	0.4 t/ft/yr	LandStudies, 2005	From a table of “problem area” erosion rates in the LandStudies report. The reference for the original study is provided in the report, but couldn’t be located based on a quick Google search.

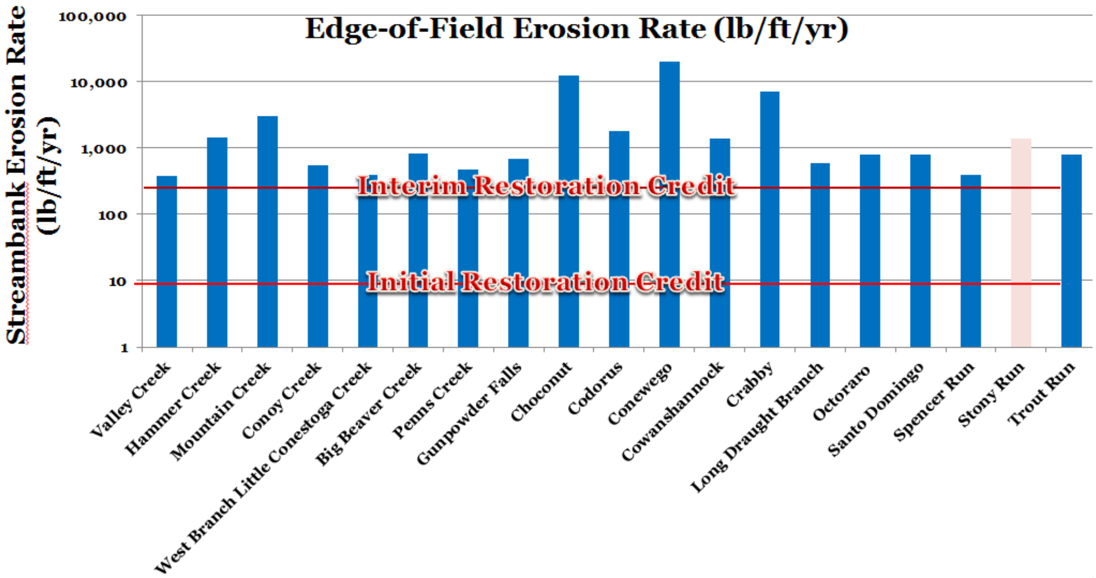

Figure 1. Streambank erosion rates plotted from the research summarized in Table 1. The initial restoration credit is the original Chesapeake Bay Program approved rate for urban stream restoration. The Interim restoration credit is the new rate approved in 2012.

3.2 Urban Streambank Loadings

Several urban stream loading studies are presented below to further help define sediment and nutrient loadings from headwater streams.

- Trimble (1997) conducted a 10 year study of San Diego Creek in southern California and determined that stream channel erosion was responsible for two-thirds of the total sediment yield in Newport Bay. Measurements were made from 196 monumented cross sections installed in 1983, 108 of which remained in 1993. Sediment erosion was exacerbated by increased urbanization and impervious surfaces. Average erosion rates show few signs of declining and new development may locally accelerate channel erosion.

- During the development of the Wissahickon Creek TMDL in Pennsylvania [USEPA, 2006], sediment loads coming from bank and upland sources were estimated using the Generalized Watershed Loading Function (GWLF) watershed model. Based on information from two subwatersheds in the study, the average streambank contribution to sediment load was 20%, but ranged from 10% to 38%.

- HSPF modeling in the Anacostia watershed (Maryland and Washington DC) for the development of a sediment TMDL used mass balance approach where land surface loads and other point sources were estimated based on land use and subtracted from monitored loads to estimate stream bank and bed contributions. The resulting estimate was that approximately 75% of the sediment load is coming from in-stream movement (bed & bank erosion and legacy sediment) in the Northwest Branch and the Northeast Branch [MDE, 2013a]. This point was made in the point source memo portion of the TMDL and was expanded to say estimates may be refined with increased monitoring. Over the entire watershed, this number was reduced to 73%.

- Devereux (2006) conducted a sediment fingerprinting analysis of sediment sources for eight storms in the Anacostia River Watershed between October 2005 and June 2006. On average, the channel banks (58 percent) were the most important source of sediment, followed by uplands (30 percent), and street residue (13 percent). Seasonal differences were found to be significant, with the banks contributing the most sediment during the fall and spring and the upland areas contributing the most in winter. Devereux also found that, “In the headwaters there was evidence of erosion while the mid-reaches of the streams showed erosion and sediment storage. The downstream reaches of the streams showed erosion but little storage. This means that the sediment being eroded from the headwaters is not the same that passes through the gauge station on the Northeast Branch. Rather, it is sediment eroded from the mid-reaches that continues downstream because of a lack of sediment storage.”

3.3 Agricultural Streambank Loadings

Several agricultural stream loading studies are presented below:

- The USDA NRCS developed three showcase watershed projects beginning in 2010 that are designed to demonstrate water quality improvements in a confined geographic area through expanded producer outreach efforts, use of innovative conservation practices, and intensive conservation planning, implementation, and monitoring. The three showcase watersheds are the 23,000-acre Upper Chester River Watershed in Maryland’s Eastern Shore; the 34,000-acre Conewago Creek Watershed in Central Pennsylvania, where Merrigan announced the showcase watersheds; and the 67,000-acre Smith Creek Watershed in Virginia’s Shenandoah Valley. These watershed projects contain a long-term monitoring approach that includes the installation of new stream gauges. Conewago and Smith Creeks have incorporated stream sediment sampling to identify sediment sources. The studies are still in progress, but it may be possible to obtain preliminary results. One objective of Smith Creek in particular is to relate the in-stream sediment to landscape sediment sources (streambanks, floodplain, pasture, forested, etc.) (Hyer, 2012). http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/programs/farmbill/initiatives/?cid=stelprdb1044442

- A study by Gellis and Landwehr (2006), “Identifying Sources of Fine-Grained Suspended Sediment for the Pocomoke River, an Eastern Shore Tributary to the Chesapeake Bay,” found that the channel corridor (channel and ditch banks, and ditch beds) were significant sources, averaging 76.5% of the total sediment sources for seven storm events sampled. Cropland was an important source of sediment for the two storms with the highest peak flow which occurred in the late summer and fall when harvesting began and vegetative cover was low. Ditch beds, which contributed an average of 46.1 % of sediment for the seven storms, were important sources of sediment over a range of peak flows and may also be important when crop areas have mature leaf cover. Infrequent periods of overland flow in the Pocomoke River limit upland areas (cropland and forest) as significant sources of sediment, except under periods of high rainfall intensity or under saturated-soil conditions when overland flow may occur. During periods when cropland is devoid of vegetation, such as before planting and after harvesting (late August to May), cropland is an important sediment source. When crop cover is mature, the ditch beds are an important sediment source.

- Belmont et al. (2011) used geochemical fingerprinting and sediment mass balance of Lake Pepin, a natural lake on the Mississippi River and found that the dominant source of sediment has shifted from agricultural soil erosion to accelerated erosion of stream banks and bluffs, driven by increased river discharge. This study found that between the years 2000-2010, 70% of sedimentation of the Le Sueur River came from the channel network (bluffs, banks, ravines, and channel incision). The authors believed that larger and more frequent storms (caused by climate change) and the use of subsurface drain tiles in agricultural land contributed to the higher erosion rates of streams and channels.

- Work done by [Simon et al., 2003] on a 114 km2 watershed in Mississippi estimated 70% of the sediment load leaving the mouth of the stream was due to bed and bank erosion between 1970 and 2002. Though this is a relatively large watershed compared to a 1st order stream (maybe 0.5 km2), the authors state that due to scour in the main channel, tributary outlet elevations dropped. The dropping elevations at the tributary outlets increased slopes and caused those tributaries to “reincise” to compensate for changes in the trunk stream. This may lead to increased tributary slope as rebalancing occurs.

Mark Dubin, the Agricultural Technical Coordinator at CBP, is currently working with USDA and NRCS to develop an agriculture modeling support group to assist with agricultural BMP panels in providing sediment delivery analysis data. This could be another source of modeling data later this year for the agricultural contribution to EoF and EoS.

3.4 Mixed Land Use Streambank Loadings

- In the agricultural and urbanizing Little Conestoga Creek Watershed, a Piedmont watershed, sources of sediment using the “sediment-fingerprinting” approach showed that cropland was the most important source (77 percent), followed by streambanks (23 percent) (Gellis et al., 2008).

- In the mixed land use (forested, agricultural, and urbanizing) Mattawoman Creek Watershed, a Coastal Plain watershed, sources of sediment using the sediment-fingerprinting approach were distributed as follows: streambanks (31 percent), forest (29 percent), construction (23 percent), and cropland (17 percent). Mattawoman Creek Watershed drains a rapidly developing region with 182 hectares (approximately 1.26 percent of the watershed) under construction. Sediment from construction sites was determined as a source of sediment in the Mattawoman Creek Watershed (Gellis et al., 2008).

4.0 Monitoring Databases

To better elucidate the role that stream channel and bank erosion contributes to the total sediment load, a literature search was conducted for sources of sediment and streamflow monitoring data that include watershed and in-stream stations. Data analysis was not conducted, but a discussion of how this data could be utilized is provided in Section 5 – Potential Methods to Estimate Streambank Loading. The databases consist of federal, state, and local sources and are described below.

National Stormwater Quality Database v. 3

Name	**National Stormwater Quality Database v.3**
Source	Pitt et al. (2004)
Period of Record	1992-2002
Parameters	TSS concentration, precipitation, runoff
Contact	Robert Pitt Cudworth Professor of Urban Water Systems, Department of Civil, Construction, and Environmental Engineering, and Director of Environmental Engineering Programs, University of

	Alabama (205) 348-2684 rpitt@eng.ua.edu

The National Stormwater Quality Database version 3 (NSQD) contains selected water quality information from the monitoring carried out as part of the U.S. EPA's National Pollutant Discharge Elimination System (NPDES) Phase 1 stormwater permit applications and subsequent permits. Monitoring data was compiled by Pitt et al (2004) over nearly a ten-year period from 1992-2002 from more than 200 municipalities throughout the country. Version 3 contains data from more than 8,500 events from about 100 municipalities throughout the country, representing several land uses. For each site, data includes the percentage of each land use in the catchment, the total area, the percentage of impervious cover, the geographic location, and the season. Information about the characteristics of each event is also included. Total precipitation, precipitation intensity, total runoff and antecedent dry period are also included, if collected. The database only contains information for samples collected at drainage system outfalls; in-stream samples (which were a component of some state programs) were not included in the database, although some outfalls were located in open channel conveyances. Because only outfall data is included, these data would most likely represent the data from upland sources and not the stream system.

There are approximately 243 monitoring stations in the Chesapeake Bay watershed. The database distinguishes the type of conveyance as curb and gutter or grass swale. There are also many sites with no type of conveyance listed (i.e, "blank"). A summary of the monitoring stations by jurisdiction is provided in Table 2 below. There appears to be some duplication between stations in the NSQD and the MD MS4 database described below. When conducting data analysis, it will be important to identify these sites to avoid redundancy.

Table 2. NSQD Monitoring Stations within the Chesapeake Bay Watershed

	Type of Conveyance			
Jurisdiction	**Curb and Gutter**	**Grass Channel**	**Blank**	**Total**
Arlington			8	8
Baltimore City			13	13
Centreville			2	2
Chantilly			3	3
Charlottesville			10	10
Chesapeake	7	1	7	15
Chesterfield			2	2
Clinton			2	2
Hampton	6		7	13
Leesburg			1	1
Mays Chapel			1	1
Newport News	6	3	5	14
Norfolk	7		9	16
Portsmouth	6		6	12
Virginia Beach	5		9	14
Washington DC			6	6
Albemarle			10	10
Anne Arundel County	6		1	7
Baltimore County			7	7
Carroll County	1	4	1	6
Charles County	3	1	2	6

Chesterfield County	5	2	4	11
Fairfax County	11		3	14
Frederick County			1	1
Hampton Roads			2	2
Harford County			7	7
Henrico County	6			6
Howard County	4		6	10
Loudoun			1	1
Montgomery County	5		3	8
Prince George's County	5	1	5	11
Queen Anne's County			2	2
State Highway		1	1	2
Total	**83**	**13**	**147**	**243**

Maryland MS4 Monitoring Database

Name	**Maryland MS4 Monitoring Database**
Source	MDE (2013b)
Period of Record	1996-2011
Parameters	TSS concentration
Contact	Ray Bahr and Andrew Tagoe Maryland Department of the Environment atagoe@mde.state.md.us rbahr@mde.state.md.us

The MDE Stormwater division maintains the MS4 chemical monitoring database that contains monitoring data for Maryland jurisdictions for stormflow up to 2011 and baseflow up to 2009. Some data fields are missing, particularly in the monitoring site/land use document. This is mainly due to issues with getting the counties to submit their data on record (as well as equipment failure, measurement error, etc.). Though flow data are not available, concentration data, along with assumptions about upland contributions based on land use, could be used to estimate stream bank/bed contributions. The table below shows the number of outfall and in-stream monitoring stations for MD counties.

Table 3. MD MS4 Monitoring Stations

County	**Station Type**	**# Stations**
Baltimore	Outfall	1
	In-Stream	1
Baltimore City	Outfall	18
	In-Stream	357
Carroll	Outfall	4
	In-Stream	4
Frederick	Outfall	1
	In-Stream	1
Howard	Outfall	3
	In-Stream	8
Harford	Outfall	2
	In-Stream	3

Montgomery	Outfall	15
	In-Stream	45
Prince George's	Outfall	3
	In-Stream	56
Anne Arundel	Outfall	1
	In-Stream	1
MDSHA	Outfall	3
	In-Stream	3

USGS Water Quality Databases

Name	**U.S. Geological Survey Water Quality Databases**
Source	United States Geological Survey
Period of Record	Unknown - present
Parameters	TSS, flow
Contact	http://nwis.waterdata.usgs.gov/nwis/qw http://cbrim.er.usgs.gov/

The USGS collects and stores a large amount of water quality data. National USGS water quality data are available from the National Water Information System (NWISweb) at http://nwis.waterdata.usgs.gov/nwis/qw. Granato (2009) describes five computer programs that were developed for obtaining and analyzing streamflow data from the NWISweb, including downloading and reformatting the data, creating charts and graphs, and statistically analyzing the data.

Data specific to the Chesapeake Bay watershed are available at: http://cbrim.er.usgs.gov/ - "Water Quality Loads and Trends at Nontidal Monitoring Stations in the Chesapeake Bay Watershed." The objectives of the Chesapeake Bay nontidal monitoring program are to quantify sediment and nutrient loads in the nontidal rivers of the Chesapeake Bay watershed and to estimate trends in sediment and nutrient concentrations that are related to the implementation of Best Management Practices or other anthropogenic factors. The data utilized for these analyses are collected by numerous agencies through the nontidal monitoring partnership for a network of approximately 120 water quality monitoring stations.

USEPA STORET Data Warehouse

Name	**U.S. EPA STORET Data Warehouse**
Source	United States Environmental Protection Agency
Period of Record	Unknown - present
Parameters	Chemical parameters
Contact	www.epa.gov/storet/index.html

EPA's STORET Data Warehouse is a repository of water quality monitoring data collected by water resource management groups across the country, available at: www.epa.gov/storet/index.html. This data warehouse contains information on biological, physical, chemical, and habitat parameters.

VA DEQ Non-Tidal Chesapeake Bay Monitoring Program

Name	VA DEQ Non-Tidal Chesapeake Bay Monitoring Program
Source	Virginia Department of Environmental Quality
Period of Record	2008-2013
Parameters	unknown
Contact	Roger Stuart VA DEQ

VA DEQ has limited data over the past 5 years from non-tidal Chesapeake Bay sites where they have done storm event monitoring. The non-tidal Chesapeake Bay monitoring program includes a total of 37 sites. Data was provided to us that list the sites, but additional data will need to be obtained from VA DEQ on the actual monitoring results.

VA DEQ Volunteer Monitoring Data

Name	VA DEQ Volunteer Monitoring Data
Source	Virginia Department of Environmental Quality
Period of Record	unknown
Parameters	TSS, flow
Contact	www.deq.virginia.gov/easi/

Water quality information collected by volunteer monitoring programs in Virginia is posted to on the Virginia Department of Environmental Quality website (http://www.deq.virginia.gov/easi/). Though the information collected at each monitoring site is not, necessarily, consistent, information is available for viewing. There is the option to do a “data dump” for some of the locations listed, which is useful for pulling out trends and relationships at a given site. From a quick review, few sites have information about sediment and fewer still have sediment and flow, which would be needed for estimating loads. Sifting through this information to pull out representative streams with appropriate monitoring data may take some time, but may add a level of validation to any methods developed for estimating stream bed/bank erosion contributions to sediment loads in small streams.

Susquehanna River Basin Commission Monitoring Data

Name	Susquehanna River Basin Commission Monitoring Data
Source	SRBC (2012)
Period of Record	2010-present
Parameters	turbidity, flow
Contact	http://mdw.srbc.net/remotewaterquality/

The Susquehanna River Basin Commission also collects water quality data through a remote water quality monitoring network [SRBC, 2012]. The network is comprised of 51 monitoring stations for smaller rivers and streams in areas of concern for natural gas drilling in northern Pennsylvania and southern New York. Continuous monitoring is conducted for temperature, pH, dissolved oxygen, conductance, and turbidity. The stations range from 30-60 square miles and select stations also include streamflow measurements. This flow data can be aligned with the turbidity data to obtain an estimate of sediment load.

5.0 Potential Methods to Estimate Streambank Loading

Although data analysis was not conducted as part of the research for this technical memo, pertinent information can be used from the review to inform subsequent phases of this research. For example, pertinent information obtained from the monitoring databases could include stream flow and suspended sediment concentration, which when multiplied together provide the stream suspended sediment load. Concentration data, along with assumptions about upland contributions based on land use, could be used to estimate stream bank/bed contributions. The following section provides potential methods for using the available data sources summarized in this technical memo to estimate streambank loading.

5.1 Relationship between Stream Classification and In-Stream Erosion

There may be some opportunities to draw a relationship between stream classification and contribution of in-stream erosion to total sediment load. For example, Fangmeier et al. [2006] suggest narrow deep streams that are entrenched (G classification based on the Rosgen method) tend to have high erosion rates with substantial downward cutting resulting in high bedloads and suspended sediment. Wide shallow streams that are entrenched (F classification) tend to have large sediment loads due to bank erosion. If studies producing estimates of stream bank/bed contributions to total sediment load can be classified, a trend may become apparent between classification and in-stream erosion contributions. A relationship like this would use stream classification as a proxy for watershed land use (and sediment delivery). An assumption that the current condition of a stream is in reaction to watershed conditions would be needed.

5.2 Conservational Channel Evolution and Pollutant Transport System Model

The portion of bank contribution to sediment load could be estimated using the Conservational Channel Evolution and Pollutant Transport System (CONCEPTS) model [Langendoen, 2000]. A range of model scenarios could be run to span the various situations in the Bay (urban conditions, various drainage areas, weak stream bank material, etc), which may allow for some generalities to be made for different region and watershed characteristics. The newest version of the Hydrologic Engineering Center River Analysis System (HEC-RAS) (version 4.1) [USACE, 2013] also includes a sediment transport process that may be implemented in a similar fashion to CONCEPTS.

5.3 Couple Water Quality Data with Flow Data

There may be opportunities for coupling water quality data – turbidity/secchi depth from long-term or continuous monitoring programs (Eyes on the Bay - http://mddnr.chesapeakebay.net/eyesonthebay/index.cfm) with flow data from USGS. Additional assumptions about the relationship between turbidity and sediment concentrations would be needed to estimate loads.

5.4 USGS ESTIMATOR Model

A mass balance approach could be implemented using land surface sediment loads and total sediment loads from the USGS ESTIMATOR computer model. Similar to the Wissahickon Creen TMDL, stream bed and bank sediment contribution would be the difference between ESTIMATOR results and land surface loads (multiplied by an appropriate sediment delivery ratio). A standalone ESTIMATOR analysis was done for the Northwest and Northeast Branches of the Anacostia watershed during the development of the sediment TMDL [MDE, 2013] (Appendix A).

Exploring the modeling work done in the Anacostia shows a wide range of estimated stream bank contributions:

Table 4. Estimated Stream Bank Sediment Contribution in the Anacostia Watershed

Segment	Average Annual Monthly Flow (cfs)	Average Annual AVGWLF Streambank Erosion (tons/yr)	Fraction of Total Watershed Load
10	73.8	1,686	0.18
20	93.2	1,648	0.17
30	43.1	242	0.03
40	129.2	5,871	0.61
50	38.9	306	0.02
60	63.9	934	0.07
70	99.5	2,240	0.16
80	62.2	377	0.03
90	60.6	490	0.04
100	181.2	9,337	0.68
120	50.3	429	0.36
130	35	182	0.15
140	70.7	587	0.49
150	28.6	116	1
210	30.8	155	0.02
270	24	78	0.01

5.5 Relationship between Impervious Cover and Streambank Erosion

Work in Baltimore County, MD as part of the Upper Gwynns Falls Small Watershed Action Plan completed in 2011 [BCOMD, 2013], highlighted an equation estimating stream bank erosion based on the amount of impervious area in a watershed. The original estimate relationship was provided by MDE and based on the CBP P5 urban sediment load edge-of-field target values.

$$\%E = \frac{I * L_I}{I * L_I + (1 - I) * L_P}$$

Where:
%E = Percent erosional sediment resultant from streambank erosion
I = Percent impervious
LI = Impervious urban land use edge-of-field load
LP = Pervious urban land use edge-of-field load

This is graphically represented in the report by Figure 2 below.

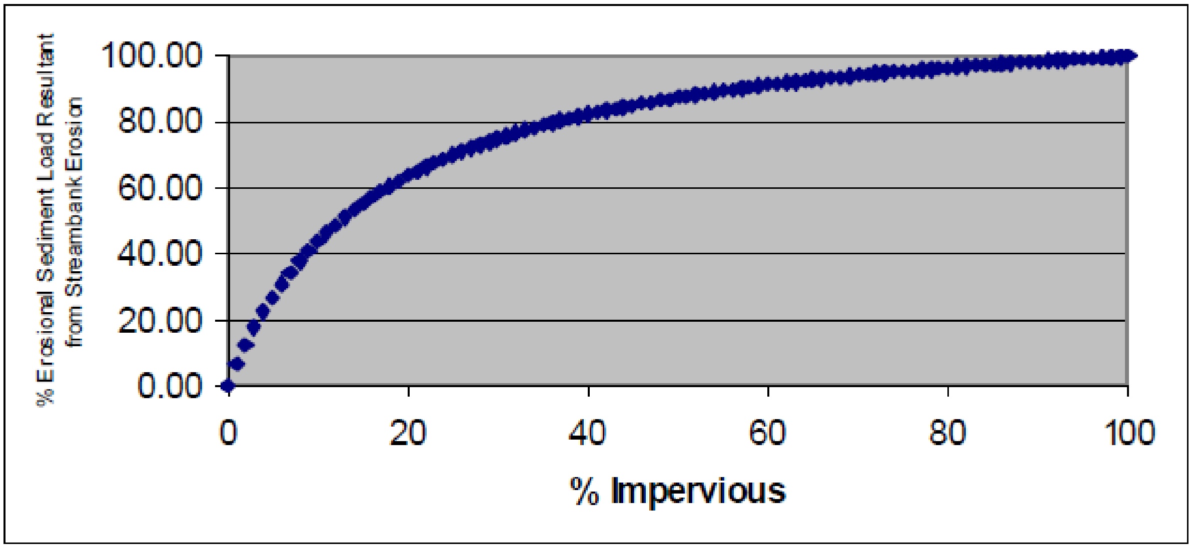

Figure 2. Percent Impervious vs. Percent Erosional Sediment Load Resultant from Streambank Erosion

This Small Watershed Action Plan applies the above equation to the Anacostia watershed, which is 23% impervious and results in 68% sediment load from stream banks (roughly corresponds to the 73% estimated in the Anacostia sediment TMDL [MDE, 2013]). Applying this to the Gwynn Falls watershed, which is 33% impervious, an estimated 77% of the sediment load would come from streambank erosion.

By combining a relationship presented in Figure 1 of the Recommendations of the Expert Panel to Define Removal Rates for Individual Stream Restoration Projects (Draft Decision submitted to the Urban Stormwater Work Group in December 2012), which was credited to [Langland and Cronin, 2003], with the above equation from BCOMD [BCOMD, 2013], a direct load from streambank erosion can be estimated. The figure in the Expert Panel Recommendations provides a relationship between percent impervious and sediment load at edge of stream (sediment load at edge-of-stream (lb/ac/yr) = 6.0178 * %Impervious + 98.386).

Figure 3 and the resulting relationship uses impervious urban and pervious urban edge-of-field loads presented in the Gwynn Falls Small Watershed Action Plan:

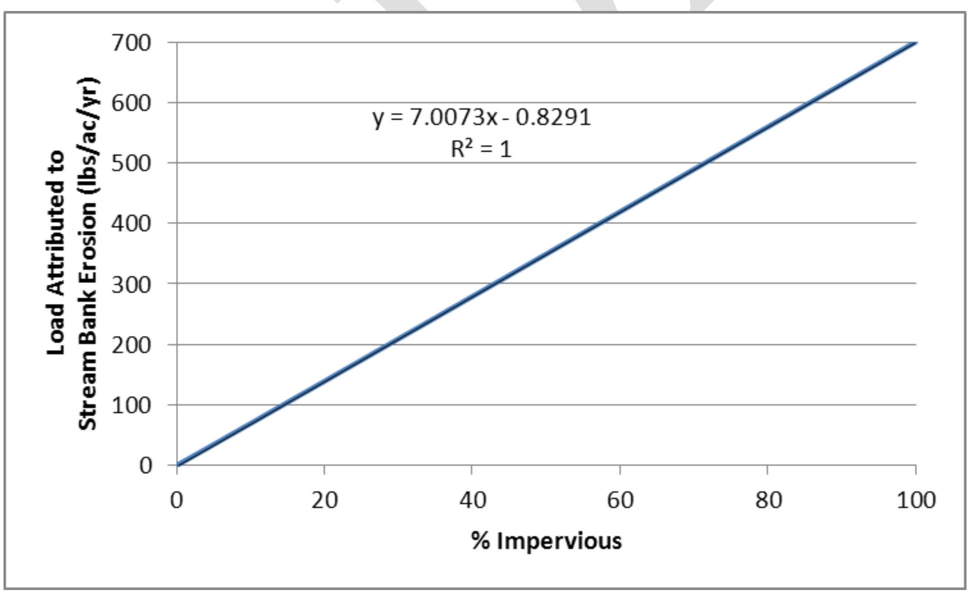

Figure 3. Relationship between impervious cover and load attributed to streambank erosion.

6.0 Discussion of Findings and Next Steps

The technical memo identifies data sources to help quantify in-stream sediment loadings to assist the development of the CBWM. The studies included in this technical memo document that in-stream erosion in both urban and agricultural areas is a significant (if not the most significant) component of the total watershed sediment load. Measurements of in-stream erosion included modeling, sediment fingerprinting, and geomorphic measurements (i.e., monumented cross sections). From the studies, in-stream erosion in urban watersheds ranged from 20% to 75%, and in agricultural watersheds ranged from 70% to 75%. Mixed land use watersheds (i.e., urbanizing agricultural watersheds) had much lower percentages of 23% and 31%, which may be accounted for by higher sediment loading from construction activities.

The second phase of this research is a synthesis document that involves analysis of the available databases. There are numerous water quality monitoring databases presented that may be useful for estimating the contribution of in-stream erosion to watershed sediment load. Water quality data, coupled with flow data would provide an estimate of sediment loading. When possible, the data will be parsed out by landcover (urban vs agricultural) and stream order as part of the analysis. However, navigating the data, narrowing the databases down to the pertinent information, and analyzing the results for statistical significance could prove to be labor-intensive.

Additional methods that may prove useful for estimating in-stream erosion are documented in this memo and include relating stream classification and/or impervious cover to erosion, as well as modeling through the use of CONCEPTS or the USGS ESTIMATOR model. Further investigation into these methods should be considered to determine their ability to provide reliable estimates of in-stream erosion.

Whichever method(s) is eventually selected, it is important to consider the unique conditions found within watersheds across the Bay watershed, as well as the methods used for data collection. For instance, Gellis et al. (2008) and Gellis and Landwehr (2006) documented the influence of crop harvesting season on the percentage of sediment contributed from upland vs in-stream sediment sources. In addition, how and where the monitoring data are collected are important. Devereux (2006) found that the sediment recorded at a particular stream gauge was only representative of one particular reach in the watershed because the in-stream erosion from headwater reaches was deposited before it reached the gauge.

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