SEDIMENT BUDGET DEVELOPMENT FOR THE GREAT LAKES REGION

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Abstract The U.S. Army Corps of Engineers (USACE) is responsible for the operation and management of a number of harbors in the Great Lakes region. Under section 516(e) of the Water Resources Development Act, the USACE has authorization to develop sediment transport models and tools for federal harbors to facilitate the reduction of sedimentation from watershed sources and harbor dredging expenses. Many of these harbors are also impaired by excessive sediment and/or contaminated sediments and have been listed as federal Great Lakes Areas of Concern (AOC) (similar to impaired waters under of the United States TMDL program). Using 15 years of results from numerous harbor and river studies, along with extensive literature review, the USACE is in the process of publishing a Sediment Budget Guidance Document for Great Lakes Tributary watersheds. This document outlines a standard approach to developing sediment budgets, typical challenges faced when developing a sediment budget, and an example application that illustrates and compares the sediment budget results from numerous empirical methods, field studies, and the development of a watershed and river sediment transport and yield model. Alternative methods for the development of sediment budgets for Great Lakes watersheds are presented including examples of methods, application, and results from previous studies. Likely sediment sources and sinks to a Great Lakes fluvial system and a discussion of how these data sets are used to construct a sediment budget are presented. Obtainment of sediment budget data is discussed with emphasis on existing data sources, data use, and data clearinghouses.

INTRODUCTION

Background In accordance with the U.S.-Canada Great Lakes Water Quality Agreement of 1987, severely degraded bays and harbors in the Great Lakes have been identified as Great Lakes Areas of Concern. These areas fail to meet the general or specific objectives of the agreement, resulting in the impairment of beneficial use and/or the area's ability to support aquatic life (EPA, 2008). The U.S. and Canadian governments have identified 43 such areas; 26 in U.S. waters, 17 in Canadian waters (five that are shared between U.S. and Canada on connecting river systems) (Figure 1). The United States and Canada must act cooperatively with state and provincial governments to develop and implement Remedial Action Plans (RAP) for each AOC with the goal of remediation and removal of impaired status declaration. Many of the AOCs include federal harbors and fall under jurisdiction of the USACE, with the impairing pollutant being excessive sediment and related constituents (nutrients, contaminants, etc.).

Excessive sedimentation is one of the leading stressors responsible for the listing of AOCs in the Great Lakes region and has significant impacts on the environment and economy. These include loss and degradation of farming land, increased fertilizer use and agricultural expenses, loss of aquatic habitats, reduction in water quality and aquatic ecosystem integrity, road and highway structural damage due to streambank erosion, sedimentation of impoundments and navigation channels, and increased dredging costs. These sediments can also be sources of a wide array of environmental pollutants including nutrients, residual agricultural chemicals, and sediments contaminated with toxic or hazardous substances which threaten aquatic species (USACE, 2005). The cumulative effects of sediment and pollutant loadings to harbors and the Great Lakes also have significant economic impacts, with one example being decreased home values in close proximity to contaminated areas (Braden, et al., 2006).

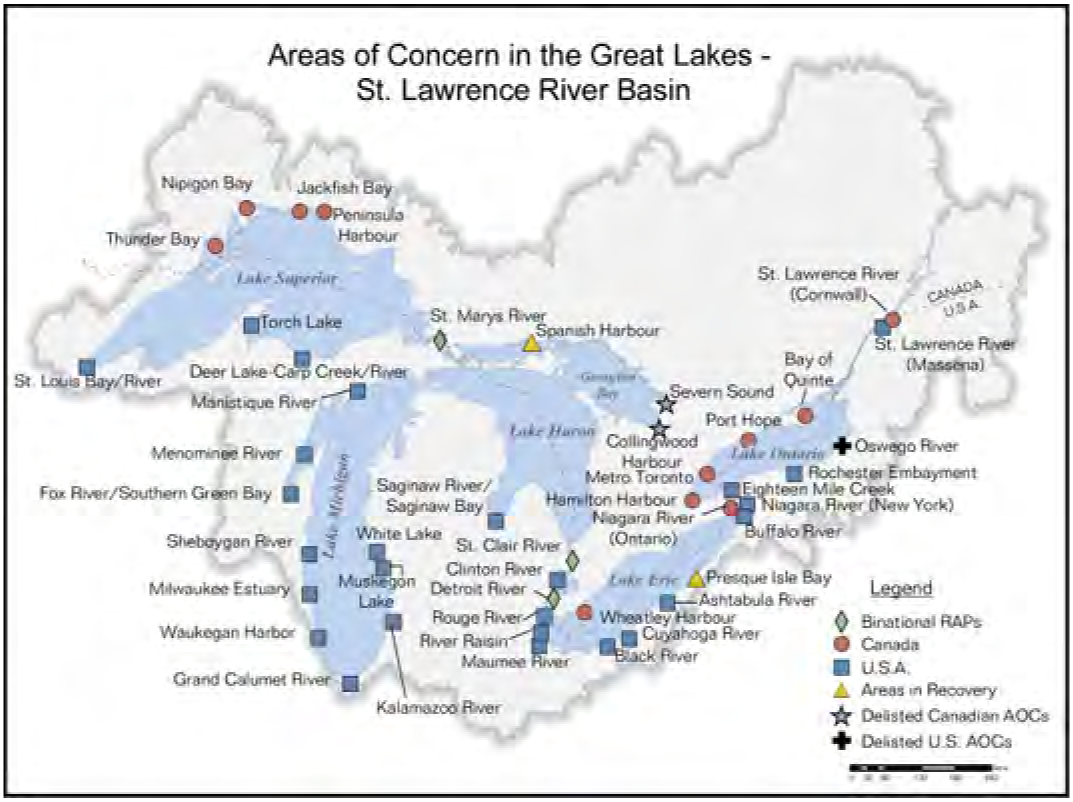

Figure 1 Great Lakes Areas of Concern (source: U.S. EPA).

Under section 516(e) of the Water Resources Development Act, the Great Lakes Tributary Sediment Modeling Program (http://www.glc.org/tributary/), the USACE of Engineers is directed to develop sediment transport models for tributaries to the Great Lakes that discharge to federal navigation channels or AOCs (USACE, 2005). These models are being developed to assist state and local resource agencies in evaluating alternatives for soil conservation and non-point source (NPS) pollution prevention in the tributary watersheds. The ultimate goal is to support state and local measures that will reduce the loading of sediments to navigation channels and AOCs, and thereby reduce the costs for navigation maintenance and sediment remediation. This also facilitates the removal of federal AOCs from being listed as impaired (EPA, 2001). One of the main goals of the 516(e) program is to facilitate the identification of sediment sources, transport mechanisms, and fate – the components of sediment budgets. Figure 2 shows the various 516(e) program watersheds throughout the Great Lakes region and their status. For completed 516(e) watersheds, the Great Lakes Tributary Sediment Modeling Program has led to the production of numerous watershed sediment transport modeling projects (Figure 3, Table 1).

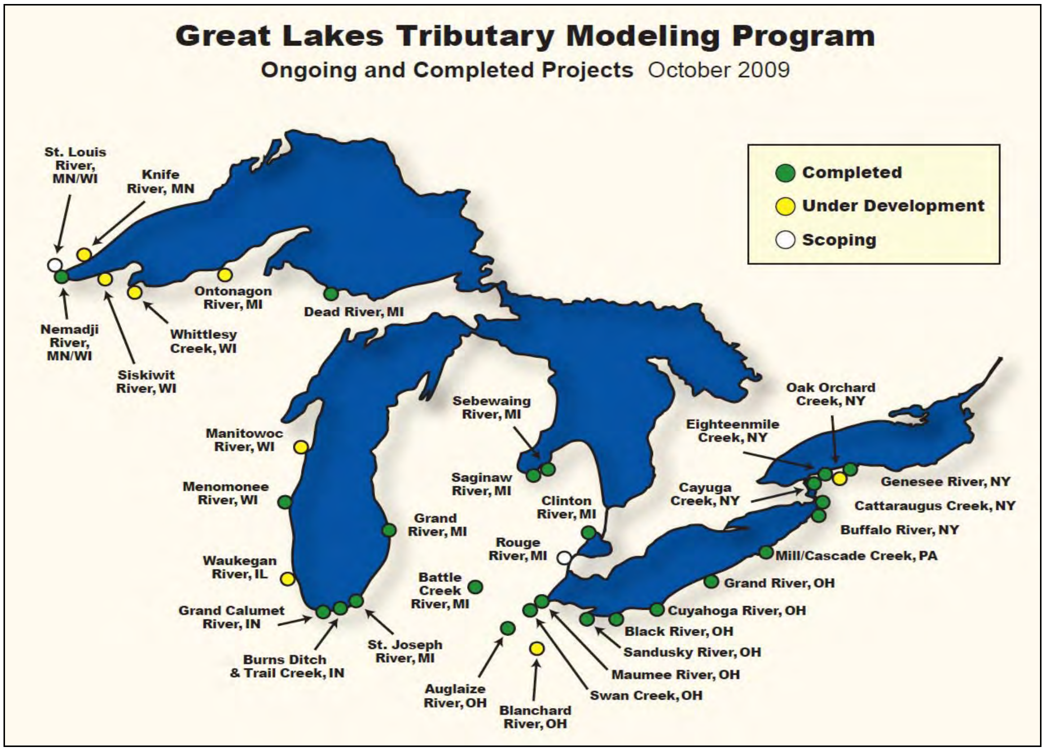

Figure 2 Status of 516(e) program watersheds in the Great Lakes region (source: USACE).

Figure 3 Locations of Great Lakes 516(e) studies conducted through 2009 by the USACE Detroit and Buffalo Districts.

Table 1 Completed 516(e) Studies with Sediment Budgets.

Study River	Area (mi^2)
Saginaw River (MI)	8,730
St. Joseph River (MI)	4,840
Sandusky River (OH)	1,270
Clinton River (MI)	770
Black River (OH)	470
Nemadji River (MN/WI)	440
Buffalo River (NY)	424
Maumee Upper Auglaize River (OH)	335
Battle Creek River (MI)	240
Menomonee River (WI)	136
Sebewaing River (MI)	103
Mill Creek (PA)	14
Cascade Creek (PA)	7

As a result of completion of these studies, the USACE is in the process of publishing a Coastal and Hydraulic Engineering Technical Note (CHETN) titled “Sediment Budget Development for the Great Lakes Region” (Figure 4). The purposes of this document include:

- to facilitate broader dissemination of these studies;
- to provide a “Status of our Knowledge” from the previous 15 years;
- to provide a central reference that summarizes pertinent literature;
- to share data sources, tool, and lessons learned from these studies, and;
- to provide a standard framework for developing sediment budgets.

The first version of the CHETN will be published through the USACE Engineering Research and Development Center (ERDC). It is anticipated this document, as with other CHETN reports, will be periodically updated to include new data, methodologies, and expansion of existing material. The CHETN will be available online in Section VII: River Engineering and Sedimentation, at the ERDC CHETN clearinghouse (http://chl.erdc.usace.army.mil/chetn).

Great Lakes Setting The quaternary glacial geologic history of the Great Lakes region is very unique and of particular importance because glacial land forming mechanisms have produced vast deposits of lacustrine clay and clay dominated tills throughout this region. It is common for Great Lakes tributary watersheds to have anywhere from 50% to over 75% of their soils dominated by these clays (data from Soller and Packard, 1998; Figure 5). The quaternary clays are predominantly Montmorillonite, Smectite Clays, with high shrink-swell capacity, high cohesive strength, high porosity, and low permeability. Under natural land cover, these soils are very resistant to erosion and provide resilient stream channels (Riedel, et al., 2005; NRCS, 1998). However, watershed disturbing activities that expose these soils, disturb riparian areas and stream banks, and increase runoff can greatly destabilize channels and cause widespread and dramatic fluvial erosion (Riedel, et al., 2005; Fitzpatrick, et al., 1999).

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Great Lakes Tributary Modeling Program (516(e))

Sediment Budget Development for the Great Lakes Region

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Deer Creek, a tributary to the Nemadji River and one of the first 516(e) projects, at bankfull discharge (photo courtesy of the U.S. Forest Service Northern Research Station).

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Figure 4 Cover from draft CHETN. Anticipated publication is in late 2010.

Figure 5 Distribution of Clay Soils and Surface Geology Associated with Quaternary Glaciation (data from Soller and Packard, 1998).

The high shrink-swell capacity also makes these particularly vulnerable to cracking under drought conditions and prone to slope failure and gully erosion in river valleys (Mengel and Brown, 1979). The combined effects of human disturbance and base level change due to differential glacial rebound have resulted in numerous areas where excessive watershed and fluvial erosion of these clays have produced problematic sedimentation in the Great Lakes (USACE 2007; Riedel, et al., 2005; Fitzpatrick, et al., 1999; Kingston, et al., 1987; Kemp, et al., 1978; Stortz, et al., 1976).

SEDIMENT BUDGET DEVELOPMENT FOR THE GREAT LAKES REGION

This CHETN provides “how-to” guidance for the development of sediment budgets in the Great Lakes region with emphasis on applications and lessons learned from past 516(e) projects. The methods section is broken into four major subsections that provide the reader a step-by-step approach to developing a sediment budget. It also includes case study examples from completed 516(e) studies as well as a number of literature and digital data sources.

These steps are presented within the context of an example application to the Battle Creek River Watershed (BCRW) and other 516(e) projects. The BCRW 516(e) project is one of the most recently completed by the USACE, Detroit District (USACE, 2008). The main goal of this project was to develop a number of sediment budget/yield estimates using a wide variety of methods, compare the results, and document the potential range in magnitude of estimates. The BCRW provides an example of the development, application, and challenges faced when creating a sediment budget for a Great Lakes watershed.

Methods This section describes data sources and standard methods for the development of sediment budgets in the Great Lakes region. An example application of sediment budget methods to the BCRW, Michigan is presented.

Step 1 Sediment Budget Discharge Point This step walks the reader through the process of identifying and selecting a sediment budget discharge point. This elementary step is critical to the successful development of a sediment budget that will meet the goals and objectives of the reader. Sources of data and convenient locations are discussed to best facilitate completion of the remaining steps. For example, the reader may be faced with choosing either a dam or a USGS gauge location as their point of interest. There are potential advantages and disadvantages to both, depending on what type of data are available.

Step 2 Literature and Data Review The second step is to conduct a comprehensive literature and data review. This step provides guidance to the reader on what types of site specific data sources exist, how the data may be obtained and used. A number of general data sources and helpful references are cited with explanations of how they may be used. The CHETN provides nearly 100 cited references and illustrates how they may specifically used to assist with the development of sediment budgets. In addition, interviews with various stakeholders, regulators, and other personnel resources are recommended along with examples of the types of data they might provide. This includes references to a number of soil conservation resources and programs that may be a potential source of unpublished data. A number of web addresses for sources of data from the internet are also provided. These sources are described and their potential use is explained for the reader.

Perhaps of most value to the reader, this step includes a review of past 516(e) studies for all of the Great Lakes watersheds listed in Table 1. The sediment yield results from these watersheds are presented along with a regional relationship to predict Great Lakes tributary sediment yield based upon the watershed sizes of the 516(e) study watersheds. The results from the past 516(e) studies provide a strong relationship of sediment yield with watershed area and give the reader a very good start to estimating total sediment yield from a watershed.

Step 3 Sediment Budget Components This section provides an overview of typical components of sediment budgets for Great Lakes tributary watersheds. A number of references and examples are provided to assist the reader with addressing various components of a sediment budget. The major components discussed include:

- Soil erosion,
- Fluvial Sediments,
    - Bank Erosion
    - Bed Material Load
- Mass Wasting

The total contribution of all sediment sources to the watershed outlet represent sediment yield (or discharge), the most important part of a sediment budget because it represents the sediment budget end member. This value represents the sediment exported from the watershed and is the net sum of all sediment sources and sinks; it is typically represented as a long-term average annual yield (mass/area/time) or sediment discharge value (mass/time). Sediment yield (or discharge), as the total sediment budget “end member” is discussed. While there are a variety of methods with which to estimate sediment yield, the following four methods are presented within the context of application to the BCRW, in central Michigan:

1. Denudation rate,
2. Regional sediment yield data,
3. Sediment surveys in receiving water bodies, and
4. Regional sediment yield relationships.

For each of these methods, a number of references and example applications are provided. At a minimum, these allow the reader to develop preliminary sediment yield estimates using a variety of methods. This is a beneficial process because the results can illustrate the potential for great deviation in sediment budget estimates depending on which method is selected. However, the reader may not be able to quantify some individual components of the sediment budget.

The final step, watershed hydrology and sedimentation modeling is presented as an option because the development, testing, and application of such models can be resource intensive and beyond the reader's capabilities. The methods from Steps 1 – 3 will allow the reader to develop a preliminary total sediment yield estimate. For cases where available data and the above methods are insufficient to develop a watershed sediment budget, the reader is directed to the fourth optional step, watershed hydrology and sedimentation modeling

Step 4 Watershed Hydrology and Sedimentation Modeling This step provides guidance to potentially launch the reader into the process of developing and calibrating a watershed hydrology and sedimentation model. Step 4 first addresses the question as to whether or not a modeling approach is really necessary, what it will likely entail, and what the anticipated results might be. A number of models are presented to the reader with associated references to completed 516(e) studies that document the implementation and use of the models. The models include the full suite of capabilities from simple applications of Universal Soil Loss Equation with routing, to multi-dimensional, spatially explicit GIS-based models. The various models address all aspects of hydrologic and sediment transport processes including watershed hydrology, fluvial processes, sediment transport, and deposition. A partial listing of the models includes:

- HEC-HMS, HSPF, MIKE-NAM, AGNPS, SWAT, AVSWAT, ARCSWAT, WCS, GSSHA, HEC-RAS, HEC6, MIKE11, BRANCH1D, MIKE21, RMA2, EFDC, and MISED.

The 516(e) study reports often include a walk-through or case-study/example application that provides modeling guidance and instruction to the reader. The purpose of this step is not to repeat what is already published; rather it serves as a clearinghouse for the reader by gathering together sources that may not be readily available elsewhere.

Results and Discussion This section presents the results of the sediment budget example application. These are discussed within the context of sediment budgets for the Great Lakes region, common challenges, and potential solutions for the development of sediment budgets. A summary of the development of a sediment budget for the BCRW is presented along with a table of results using the methods presented in Step 3 (Table 2). This provides the reader an opportunity to check computations against the published methods and compare the results for all the methods against the published results for 516(e) watersheds.

Table 2 Sediment Yield Estimates for the Battle Creek River Watershed.

Source	Sediment Yield	
	t/mi^2/yr	t/ha/yr
U.S. Water Resources Council, 1968	10-800	0.35
Leopold et al, 1995; Corbel, 1959	131	0.46
Brune, 1951	1514	5.30
Dendy and Bolton, 1976	685	2.40
Syed, Bennett, & Rachol, 2004	22	0.08
Ouyang, Bartholic, & Selegean, 2005	25-49	0.09–0.17
Past 516(e) studies	114	0.44
SWAT model	240	0.84

The results of comprehensive watershed sediment yield modeling for the BCRW are also provided for the reader. This includes development and testing of the model, as well as comparing the model results to those in Table 2. Output from the BCRW modeling illustrates sediment yield from soil erosion (Figure 6) and channel processes, (Figure 7) yet also highlights the challenges of working in a watershed where potentially significant sources of sediment, such as bank erosion, may be undocumented. The reader is provided with recommendations for future activities that may help to resolve sediment budget data gaps.

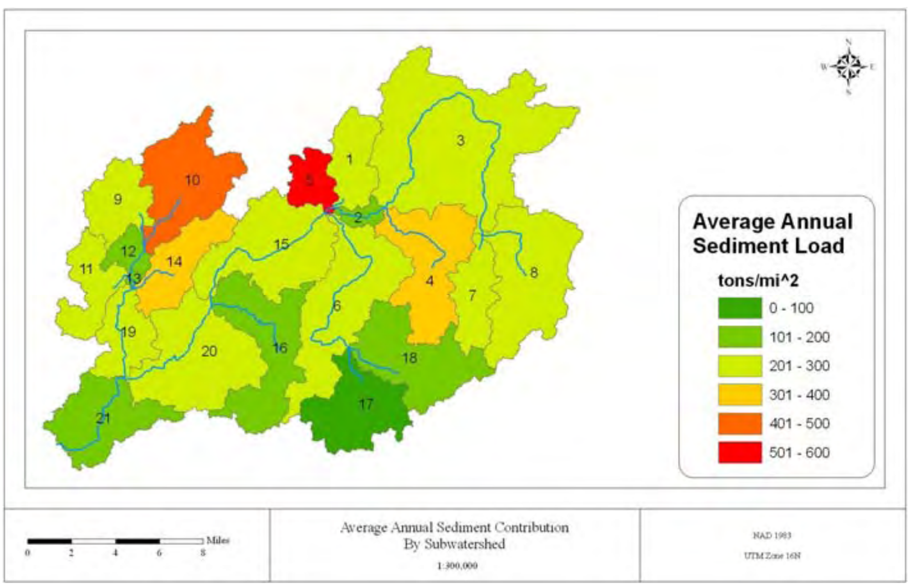

Figure 6 Predicted Sub-watershed Sediment Yield from Soil Erosion.

SUMMARY

Sediment, and sediment bound contaminants and nutrients, are the leading causes of impairment for AOC in the Great Lakes. In collaboration with the Great Lakes Commission, the USACE has undertaken a number of studies on Great Lakes tributary watersheds to develop sediment transport models and tools that may be used to reduce sediment loading to AOCs and facilitate restoration of their impaired uses. The 516(e) tributary modeling program has resulted in a wealth of information that may be of benefit to stakeholders and local resource managers throughout the region. This paper summarizes the upcoming USACE CHETN report, "Sediment Budget Development for the Great Lakes Region" which will serve as a clearinghouse of 516(e) study methods and results.

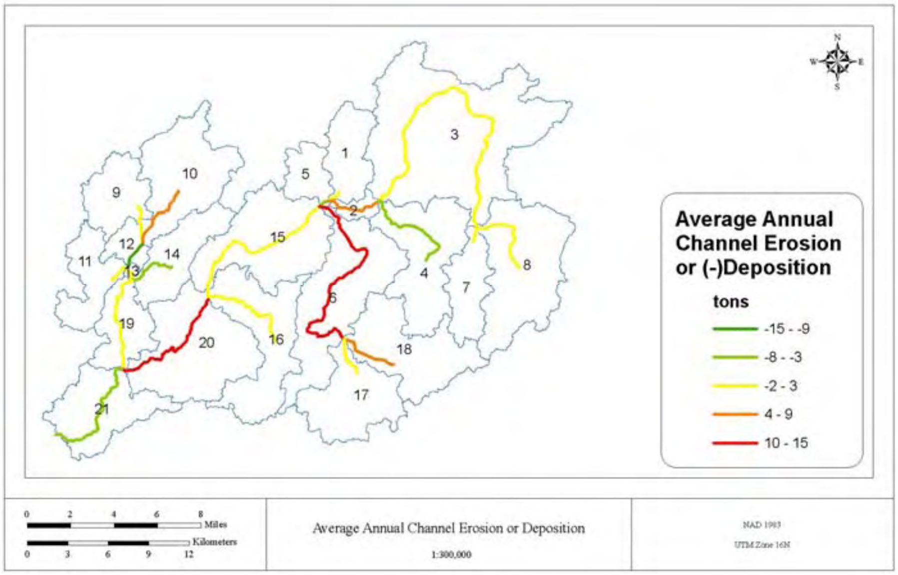

Figure 7 Predicted Bed Material Erosion and Deposition in the BCRW.

The development and application of sediment budgets is crucial to properly identifying the sediment sources, pathways, and sinks in fluvial systems. Once this process is complete for a given watershed, the important steps of watershed remediation and sediment control/reduction measures can begin. Through 2007, the Great Lakes Commission program for soil erosion and sediment control has protected over 129,000 acres of land against soil loss and prevented the discharge of over 1.6 million tons of sediment to surface waters (Great Lakes Commission, 2007). Clearly, efforts to reduce sedimentation from Great Lakes tributaries since the early 90's have been successful. The continued dedication and support of stakeholders, local, state, regional, and federal governments will provide even greater reductions in the future.

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