MEASURES OF SEDIMENT IN MINNESOTA

Greg Johnson, Hydrologist
Minnesota Pollution Control Agency
520 Lafayette Road
St. Paul, MN 55155
651-757-2471
gregory.johnson@state.mn.us
Bill Thompson, Research Scientist
Minnesota Pollution Control Agency
18 Wood Lake Drive SE
Rochester, MN 55904
507-206-2627
bill.thompson@state.mn.us

Abstract: Sediment is one of the most significant pollutants to lakes and streams in Minnesota. Various measures have been used to represent sediment as an impairment of water quality. The Minnesota Pollution Control Agency and its partners have completed many Total Maximum Daily Loads for turbidity given the numeric criteria for turbidity in Minnesota's water quality standards (WQS). Much effort was expended in dealing with the variability in the measurement of turbidity and the development of total suspended solids (TSS) surrogates for the turbidity standards. The MPCA has recently adopted regional TSS water quality standards to replace the turbidity water quality standards to lessen the uncertainty present in the measurement of turbidity. TSS criteria were developed given the extensive dataset present for TSS even though we know that TSS is an incomplete measure of sediment in streams and rivers. A partnership with United States Geological Survey (USGS) has given Minnesota resource agencies the opportunity to evaluate the relationships between TSS and suspended sediment concentrations as well as to explore the use of surrogate technologies for SSC, conduct bedload monitoring, and evaluate dimensionless sediment rating curves in stream geomorphology assessments. While these evaluations have provided a more robust approach, on-going efforts will be required to fully characterize sediment in Minnesota's rivers and streams.

INTRODUCTION

Various parameters have been used to describe sediment suspended in water. The MPCA has traditionally used total suspended solids as a measure of the sediment suspended in water. It has also used turbidity and Secchi tube depths as measures of sediment in water. The USGS typically uses SSC as their measure of suspended sediment. The following text describes how the four parameters are being used in Minnesota.

TURBIDITY

Minnesota was one of only a few states that adopted numeric criteria for turbidity in its water quality standards. The turbidity WQS for warm and cold water streams were 25 and 10 NTU, respectively. The basis for the numeric criteria is not clear based on a review of the primary documents used in the development of early state water quality standards (Appendix B, MPCA,

2007). The lack of clarity in the development of the standard along with changes in the technology used to measure turbidity over time and variable responses of material in water to light passage made for many uncertainties in the application of the turbidity water quality standard (WQS) in assessing streams for impairment and completing TMDLs.

Sadar (1998) describes the development of turbidity measurement technologies with their similarities and differences. For a period of time around the development of the WQ criteria guidelines, various turbidity units, including JTU, ppm, NTU and even 'turbidity units' or no units, were used in the literature. Federal Water Pollution Control Administration (1968) and U.S. Environmental Protection Agency (1976) contained references to many of these units. The resulting documentation for Minnesota's numeric criteria for turbidity was silent on the method and units used in establishing the criteria.

As MPCA staff began evaluating data for TMDLs, differences in the data became evident. An initial comparison of turbidity measurements grew out of overlapping temporal data sets obtained from Hach 2100A and Hach 2100P meters in two monitoring programs at sites near Lock and Dam #3 on the Mississippi River. Definite differences in the data were apparent over similar monitoring periods (Figure 1) even though the sampling was not completed on the same days. A second comparison of turbidity data came from turbidity measurements made by two laboratories on split samples for a river remote sensing project in 2004. Samples were collected at several sites spread across the southern half of Minnesota. A plot of the data (Figure 2) shows the difference between NTU and NTRU values as measured by Hach 2100A and Hach 2100AN meters, respectively. Based on a regression analysis of the data, a surrogate value for the water quality standard for turbidity of 25 NTU was estimated to be 39 NTRU. The variability in turbidity data lead to extended discussions about the appropriate measure of turbidity to apply to the numeric criteria, differences in turbidity data resulting from the use of different meters, and differences in the relationships of turbidity and suspended solids across Minnesota.

TOTAL SUSPENDED SOLIDS

As the state water quality agency, the MPCA has traditionally used total suspended solids as its measure of sediment suspended in water. The development of this use is likely the result of the focus of the USEPA and state water quality agencies on point source pollution and wastewater treatment. Gray et al. (2000) presents information from various editions of standard laboratory methods published by the American Public Health Association, American Water Works Association, and Water Pollution Control Federation (1946, 1971, 1976, and 1985) that describes the application of TSS through the years with the transition to its application to natural waters in the 1976 edition.

TSS is a water quality parameter that is widely used as a measure of the suspended particles in rivers. It is often used as a measure of the amount of inorganic sediment suspended in water, although it also includes the organic suspended material present in water. As a measure of suspended sediment, TSS concentrations provide an indication of water quality condition for use in evaluating aquatic life use support. The TSS methods in Minnesota most often involve a simple grab sample from the stream, followed by lab analysis where a subsample is used to determine a concentration.

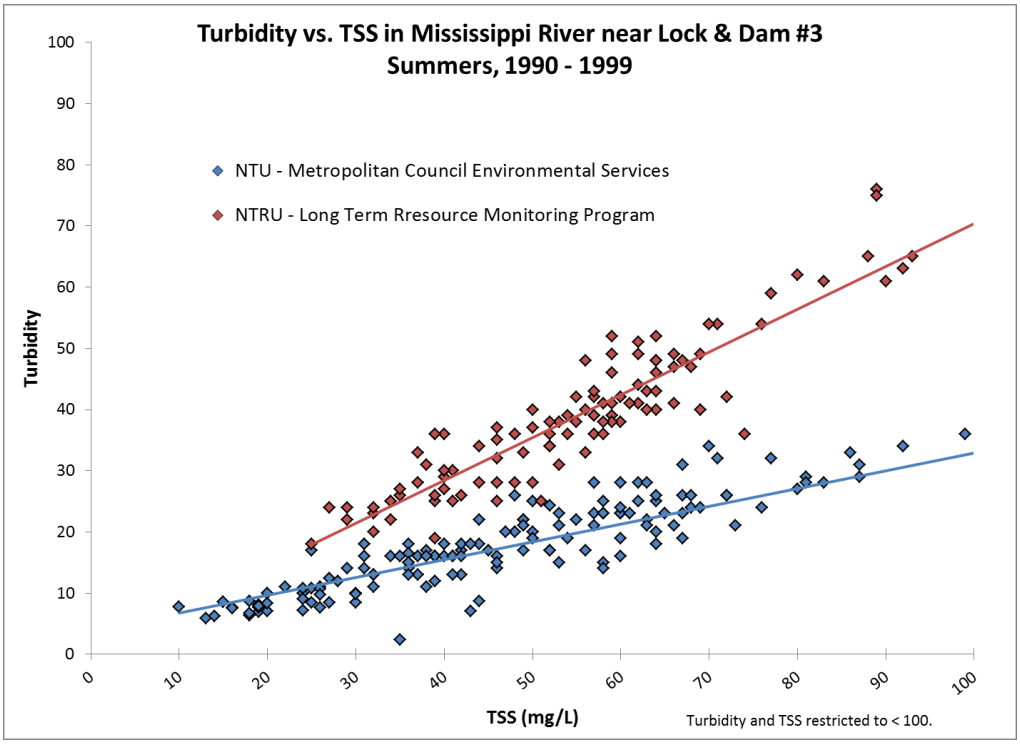

Figure 1 Comparison of turbidity data from different meters versus TSS concentrations.

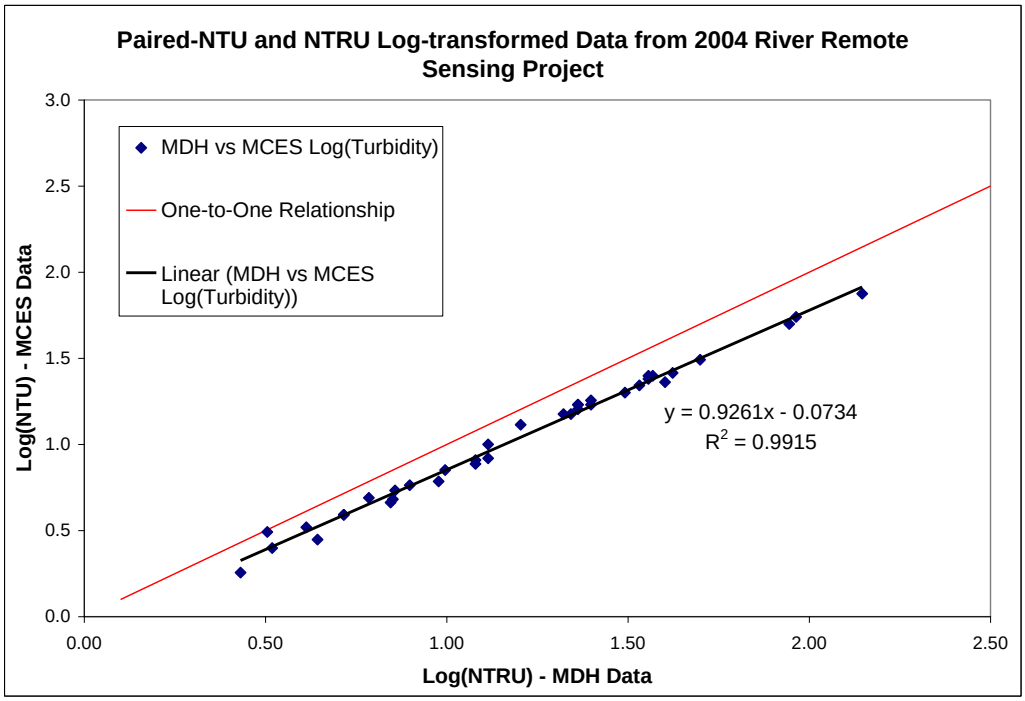

Figure 2 Relationship between paired turbidity data from different meters.

The use of TSS relative to water quality standards and TMDLs in Minnesota developed with the need to complete TMDLs for the turbidity WQS. Given that turbidity is not a measure of mass in a volume of water (concentration), a concentration surrogate had to be established in order to calculate loads for TMDLs. The use of TSS as the state's measure of particulates suspended in water and the correlation of TSS to turbidity lead to the primary use of TSS in turbidity TMDLs (MPCA 2007). The TMDL protocol (MPCA 2007) provided guidance for the development of the surrogate concentrations using simple linear regression. It noted that individual relationships should be developed for each impaired stream reach unless data analysis demonstrated that a whole stream, watershed, or region provided an equivalent result.

As the recognition of the variability in turbidity measurements and the factors causing that variability grew, the MPCA began evaluating the potential for replacing the turbidity WQS. Using two data analysis efforts, the MPCA developed proposed amendments to Minnesota water quality standards (Minn. Rule 7050) that included regional and time components for TSS (MPCA 2014). Relationships between fish and macroinvertebrate data and TSS concentrations were evaluated using quantile regression and changepoint analysis. The statistical methods are relatively new tools being used to identify threshold concentrations and establish numeric criteria to protect aquatic life. The second analysis effort involved the development of TSS frequency curves for "reference" or "least-impacted" streams in the state (Markus 2011).

Proposed TSS criteria were developed for three regions of the state for warm water aquatic life use based on a combination of major watershed and aquatic ecoregions and statewide for cold water aquatic life use. The criteria also provide temporal considerations of elevated TSS concentrations during snowmelt and storm events by indicating that the standards are not to be exceeded more than 10 percent of the water samples collected in the period, April through September. In addition, site specific water quality standards were developed for the mainstems of the Red and lower Mississippi Rivers. The statement of need and reasonableness (SONAR) required in Minnesota's rulemaking process noted that the TSS criteria would provide a transition from a statewide turbidity standard to regional standards, better connection of the water quality variable to biotic response, and more direct TMDL load calculations (MPCA 2014a). The TSS criteria were adopted following the state's rulemaking process in June 2014; however, final review and approval by EPA is still pending as of mid-January 2015.

The MPCA established the Watershed Pollutant Load Monitoring Network (WPLMN) to provide a long-term network of monitoring sites across the state to obtain spatial and temporal pollutant load information from Minnesota's rivers and streams. The WPLMN uses TSS as its measure of the sediment suspended in water. Annual and average pollutant loads, yields, and flow weighted mean concentrations are computed for each site using FLUX32 software (MPCA 2014b). Figure 3 shows the flow weighted mean concentrations for TSS for the major watershed sites in Minnesota from 2007 – 2011.

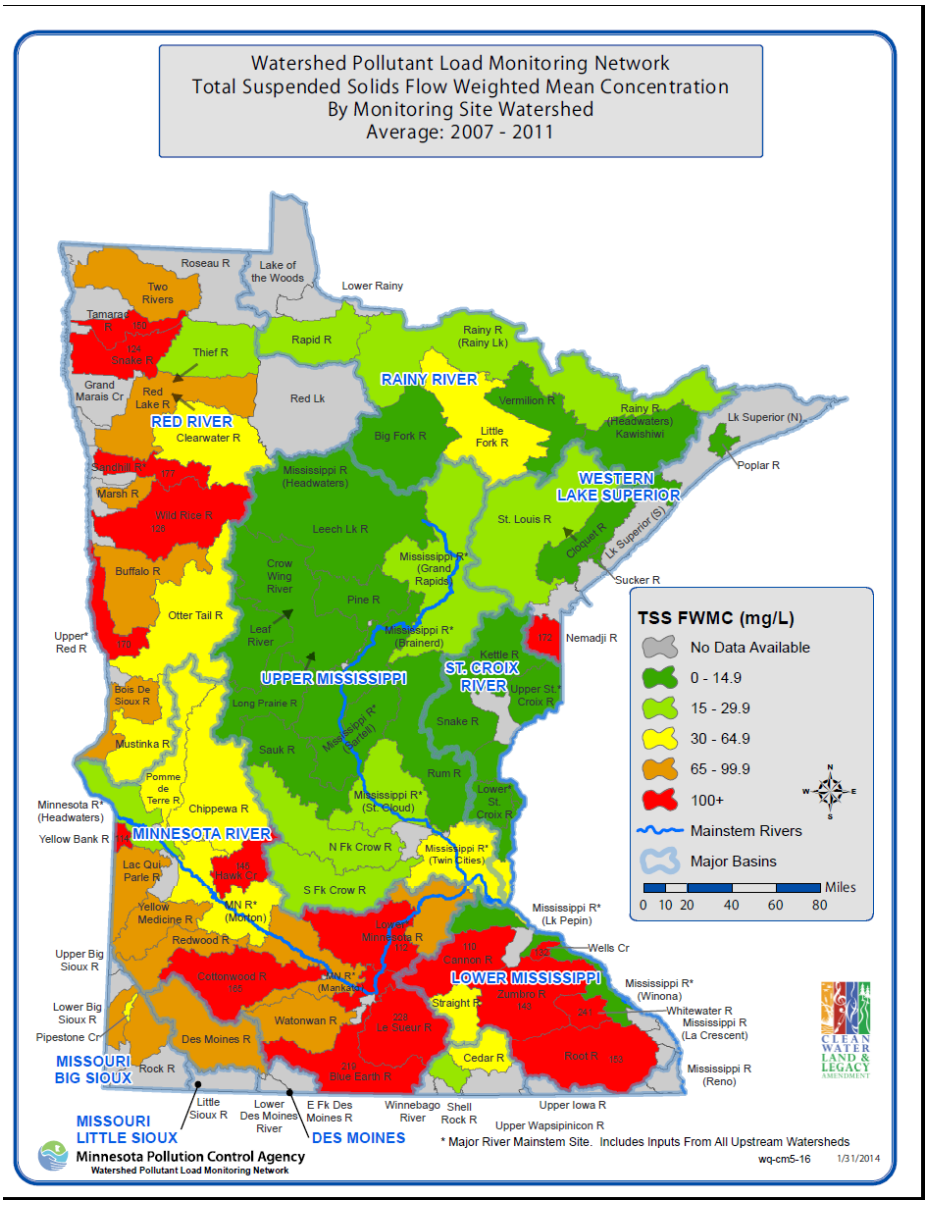

Figure 3 Flow-weighted mean concentrations of TSS by major watershed in Minnesota.

SUSPENDED SEDIMENT CONCENTRATION

Suspended sediment has been sampled by USGS at various times and locations in Minnesota. The first SSC data in Minnesota dates back to the late 1800s. Suspended-sediment concentration (SSC) samples were collected at several sites in the 1970s and 1980s as part of a focus on developing a national dataset for use in evaluating suspended sediment. Tornes (1986) compiled and analyzed the suspended sediment data in Minnesota from 1960 to 1981. SSC sampling decreased in Minnesota after the 1980s paralleling decreases at a national level. With a few exceptions, SSC monitoring was reduced to a single daily sediment station on the Minnesota River at Mankato.

A cooperative effort between the MPCA and USGS renewed a SSC monitoring effort in 2007. The monitoring network was designed to improve the understanding of fluvial sediment transport relations through systematic sampling of SSC, TSS, and turbidity in selected Minnesota rivers. SSC monitoring was deemed important given that TSS concentrations have often been found to be significantly different from corresponding SSC (Gray et al. 2000). With these differences and the great influence of sediment on water quality impairments, MPCA staff believed that it was important to characterize differences between TSS and SSC in identifying the sediment processes affecting aquatic life.

The establishment of the sediment monitoring network provided the opportunity to continue the state's progress in addressing sediment-related impairments. Although the MPCA has moved toward establishing a water quality standard for TSS, a more complete understanding of the whole amount of sediment moving in streams and rivers is needed. The results of the current study through 2011 showed that the average TSS concentration was significantly different from the corresponding SSC for each of the seven rivers sampled (Figure 4). The overall average for the seven sites combined indicated a 50 percent difference in concentration (Ellison et al. 2014). Characterization of the differences between TSS and SSC is needed to provide estimates of the total suspended sediment being transported in Minnesota's rivers in addition to the total suspended solids load provided through the use of TSS in the MPCA's statewide load monitoring program. The data and relationships established will allow better calibration of the sediment component of the HSPF watershed models being completed for each 8-digit HUC watershed in Minnesota, improved identification and characterization of the sediment stressors affecting fish and macroinvertebrates in the MPCA's stressor identification process, the incorporation of the unmeasured sediment component in TSS in sediment transport studies, and identification of best management practices needed to control excess sediment. SSC and bedload data have also been collected in a related project to evaluate the use of dimensionless sediment rating curves in stream geomorphology assessments.

The current monitoring effort has transitioned from evaluating the differences between TSS and SSC to developing hydroacoustic techniques for continuous SSC following the work of USGS and others. The use of hydroacoutics as a surrogate for SSC present an opportunity to provide sediment data that is more accurate and less costly than traditional sampling and analysis techniques (Landers 2010). The study will work to incorporate the latest developments by USGS and others in the work to develop standard procedures for the use of hydroacoustic technology.

SECCHI TUBE

Secchi tube measurements through Minnesota's volunteer stream monitoring program provide a fourth measure of sediment in water. It is an indirect measure of the amount of dissolved and suspended material in water. The Secchi tube forms the foundation of the MPCA Citizen Stream-Monitoring Program (CSMP). The CSMP is part of the volunteer water-monitoring program in Minnesota. The CSMP began in 1998 with the goal to provide individuals an opportunity to get involved in a simple, yet meaningful stream monitoring program. The Secchi tube is a modified transparency tube that is designed to function like a traditional Secchi disk used in lake monitoring (MPCA 2011). 358 CSMP volunteers monitored almost 500 sites in 2013. The transparency data are entered into the MPCA's water quality database and is used in conjunction

with turbidity and TSS data in assessing the water quality condition of Minnesota's streams (MPCA 2013).

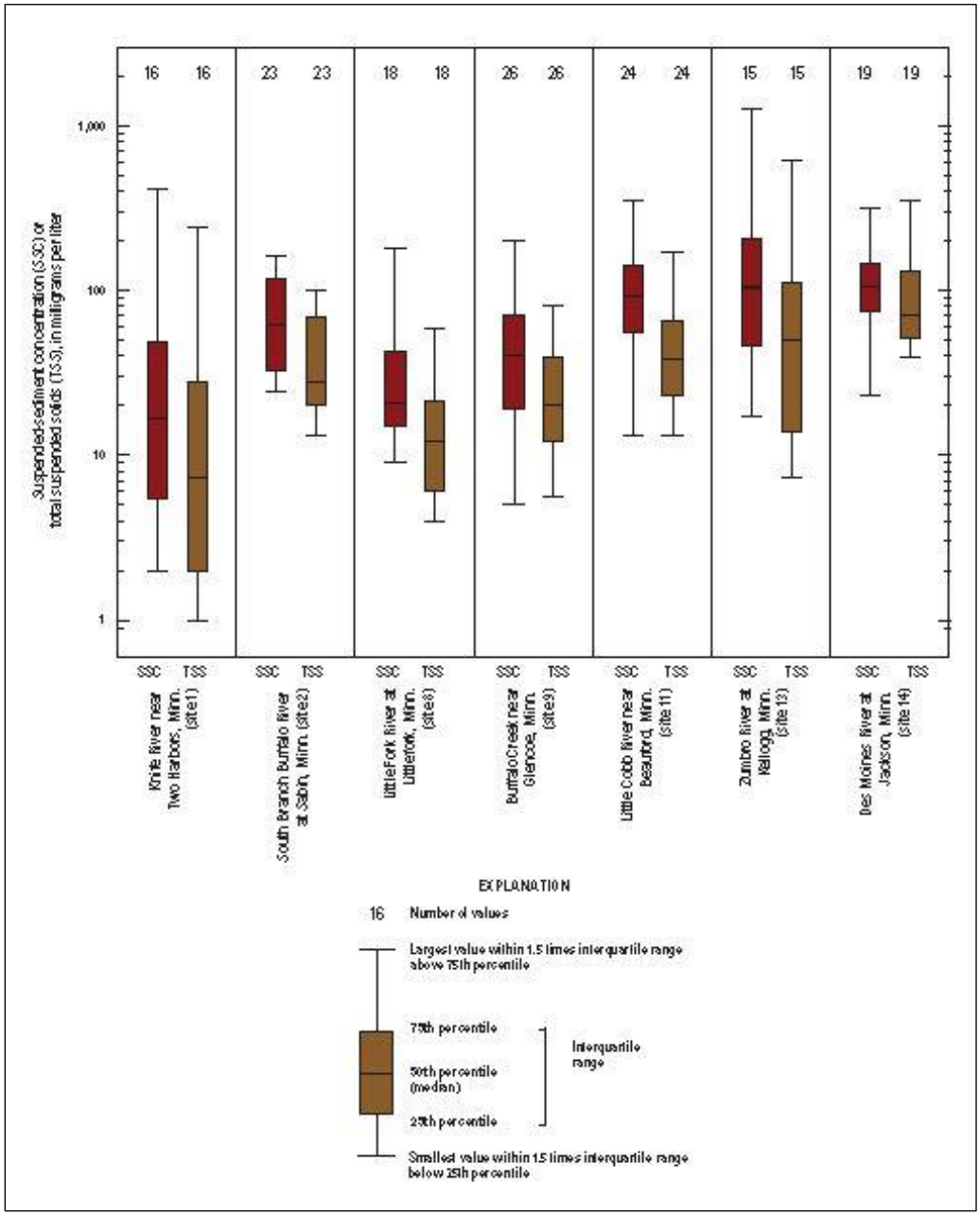

Figure 4 Suspended-sediment concentrations and total suspended solids for selected sites in Minnesota, 2007 through 2011 (from Ellison et al. 2014).

DATA APPLICATIONS

Various measures of sediment have been used in Minnesota. The use of each has its own positive and negative aspects. The use of turbidity will switch from being a numeric water quality standard to more of a surrogate for sediment issues. TSS will provide an improvement to

Minnesota's water quality standards by providing a parameter with units of concentration and mass, incorporating an explicit exceedance interval, and shifting to a direct measure of sediment. Watershed models are being developed for each major watershed in Minnesota using the Hydrological Simulation Program – FORTRAN (HSPF) computer model. The models will simulate the surface hydrology and water quality of Minnesota's 81 major watersheds. Calibration of the model requires the use of available water quality data. The model calibration for sediment relies primarily on TSS data. HSPF predicts sediment output as concentrations of clay, silt, and sand. Calibration requires that assumptions be made regarding the particle sizes of the sediment in the water and that sampled by TSS.

Sediment budgets provide an accounting method for sediment entering, leaving, and stored in a landscape unit, accounting for the sediment sources and disposition (Phillips, 1986; Reid and Dunne, 1996). Sediment budgets have been developed using various types and amounts of data. Early sediment budgets were completed by Beach (1994) and NRCS (1994, 1996, and 1997). Barr Engineering Company (2004) completed a project for the MPCA evaluating the sediment data available for the Lower Mississippi River Basin in Minnesota. Wilcock (2010) describes the most recent sediment budget work done to identify and quantify the sources of fine sediment in the Minnesota River Basin. An integrated sediment budget for the Le Sueur River Basin was completed as part of this work (Gran et al. 2011). A similar project for the Greater Blue Earth River Basin is scheduled for completion in 2015. With the exception of limited SSC and bedload data, the sediment budgets have had to rely on TSS data.

The addition of SSC and bedload monitoring through the cooperative agreement with USGS provides the opportunity to provide a more direct calibration of the watershed models, complete more comprehensive sediment budgets, and identify specific stressors affecting aquatic life. The best approach, which to date has not been fully implemented, would be to utilize a sediment budget approach incorporating improved monitoring techniques for suspended and bedload materials and to concurrently assess both stream geomorphology and the biotic community. Such an effort cannot be done for every watershed in the State, but it would be beneficial to have it in selected watersheds. Knowledge about the sand-sized particles along with the fines in suspended sediment is especially important in making connections between impaired aquatic life, habitat, and sediment sources and transport processes.

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