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TETRA TECH

Memorandum

To:	Dr. Chuck Regan, Tim Larson (MPCA)	**Date:**	03/17/2016 (Revised)
From:	J. Wyss, H.I.T; J. Butcher, Ph.D., P.H.	**Subject:**	**Minnesota River Basin HSPF Model Sediment Recalibration**
Cc:	Jennifer Olson	**Includes:**	Electronic supplement

1 Introduction

The Minnesota River basin HSPF models have a long history. Models for six of the 8-digit Hydrologic Unit Code (HUC8) basins were originally developed by MPCA in the 1990s and subsequently expanded and calibrated to include the entire basin from Lac qui Parle to Jordan, MN by Tetra Tech in 2002. Those models were used to support the development of a nutrient/dissolved oxygen TMDL and associated wasteload allocations. Tetra Tech (2008) subsequently refined these models for sediment simulation. These models were discretized at approximately the HUC10 scale. Tetra Tech later developed finer-resolution (HUC12-scale) models of the Chippewa and Hawk-Yellow Medicine HUC8 sub-models. MPCA then contracted with RESPEC to develop HUC12-scale models of the entire basin downstream of Lac qui Parle, as well as to extend the models in time through 2012. That effort was completed in 2014.

In 2015, MPCA contracted with Tetra Tech to refine the hydrologic and sediment calibrations for the Basin. The initial review of the RESPEC models provided to MPCA by Tetra Tech suggested that hydrology was fit reasonably well; however, sediment source attribution did not match up well with the evidence available from radiometric data (e.g., Schottler et al., 2010). Subsequent analysis revealed other aspects of the hydrologic calibration that potentially affect sediment calibration. Accordingly, MPCA requested review and revisions to the hydrologic calibration as part of the sediment recalibration effort. Tetra Tech completed the hydrology recalibration in November, 2015 and then used those models to complete the sediment recalibration.

The hydrologic recalibration is summarized in *Minnesota River Basin HSPF Model Hydrology Recalibration*, submitted to MPCA on November 3, 2015. This memorandum, along with accompanying electronic files, specifically documents the sediment recalibration and validation of the Minnesota River Basin HSPF modeling system, including linked models for the following HUC8 watersheds:

- Hawk-Yellow Medicine (07020004)
- Chippewa (07020005)
- Redwood (07020006)

- Middle Minnesota (07020007)
- Cottonwood (07020008)
- Blue Earth (07020009)
- Watonwan (07020010)
- Le Sueur (07020011)
- Lower Minnesota (07020012).

2 Approach

2.1 GOALS AND OBJECTIVES FOR RECALIBRATION

The goal of this effort is to update the sediment calibration of the Minnesota River HSPF models using all relevant available sources of information including evidence on source attribution. Model performance was adjusted at all calibration gages in the watershed to meet the following objectives:

- **Formulation of sediment source attribution targets**. The MPCA was responsible for generating the first set of sediment apportionment calibration targets for Minnesota River HSPF models. The greatest amount of data is available from the detailed sediment budget study of the Le Sueur River, where estimates have been developed for sediment load deriving from upland sheet and rill erosion, ravines, channel degradation, and bluff collapse. Sediment apportionment calibration targets in the Le Sueur are based on flow and sediment measurements above and below the nick zones of active headcuts in the Le Sueur mainstem, Big Cobb River, and Maple River. Radiometric information aided in the partitioning of the field derived and channel derived sediment contributions based primarily on analysis of cores from depositional “integrator sites” (Schottler et al., 2010 plus additional ongoing work to further refine the interpretation by Schottler, as presented to Chuck Regan of MPCA, with additional information from the Le Sueur and Greater Blue Earth sediment mass balance studies of Gran et al., 2011 and Bevis, 2015).. Information from the Le Sueur Sediment Budget and other on-going work in the Greater Blue Earth watershed (Greater Blue Earth Sediment Budget) and throughout the Minnesota Basin are used to partition sediment contributions among fields, ravines, bluff, and channel incision sources. The sediment apportionment target information is summarized below in Table 1, showing the range of attributed upland loads from all sources and the current best estimate for this source.
- **Implementation of the sediment apportionment calibration targets.** The 2014 Minnesota River Basin HSPF models parameters were modified so that the amount of sediment coming from the four source categories were consistent with the calibration targets formulated in the previous task. The models were adjusted as needed to maintain acceptable levels of calibration for sediment transport.
- **Tabulation of the simulated sediment source apportionment.** For each watershed, Excel™ workbooks were created that tabulate the simulated sediment source apportionment. Each workbook is currently set up to supply simulated sediment source apportionment at instream calibration and validation stations for each watershed. They have been created in such a way that the workbooks can easily be modified to provide simulated sediment source apportionment at any pour point in each model. Each workbook uses standard model output from the HBN file so the

structure of the 2014 Minnesota River Basin HSPF models did not need to be modified to generate these results.

- **Assess the per-acre sediment loading rates for all of the pervious and impervious land classes in each model.** The 2014 Minnesota River Basin HSPF models generated per-acre upland sediment loading rates that are inconsistent with current constraining information. The models were adjusted as needed to make the sediment loading rates consistent with current constraining information.
- **Maintain acceptable fit between observed and simulated loads and concentrations** as recommended by MPCA's modeling guidance (AQUA TERRA, 2012). The existing calibration for sediment in the 2014 models appears to provide a decent fit to observations of suspended sediment concentrations, but the source apportionment is not consistent with available evidence and statistical analysis of model fit was not presented in RESPEC (2014). The objective of this work is to develop models that conform to constraining information on sediment source apportionment and annual loads while maintaining a high quality fit to instream observations of suspended sediment concentrations. The multi-objective calibration helps ensure a robust model; however, assuring an appropriate fit to source attribution information does appear to make it more difficult to match instream observations.

Table 1. Sediment Apportionment Calibration Targets

HUC8	Upland Best Estimate	Upland Range	Ravine	Bluff	Stream
Chippewa	31%	30-31%	ND	ND	ND
Redwood	23%	21-25%	ND	ND	ND
Yellow Medicine	ND	ND	ND	ND	ND
Cottonwood	21%	21-41%	ND	ND	ND
Watonwan	27%	27-41%	7%	43%	21%
Le Sueur	27%	12-27%	9%	57%	8%
Blue Earth	26%	19-28%	5%	55%	18%
Middle	27%	16-27%	ND	ND	ND
Lower/Metro	23%	14-31%	ND	ND	ND

2.2 SEDIMENT PERFORMANCE METRICS

Sediment is one of the more difficult water quality constituents to represent accurately in watershed and stream models. Important aspects of sediment behavior within a watershed system include loading and erosion sources, delivery of these eroded sediment sources to streams, drains and other pathways, and subsequent instream transport, scour and deposition processes (USEPA, 2006).

Sediment calibration for watershed models involves numerous steps in estimating model parameters and determining appropriate adjustments needed to insure a reasonable simulation of the sediment sources on the watershed, delivery to the waterbody, and transport behavior within the channel system. Rarely is there sufficient observed local data at sufficient spatial detail to obtain a unique calibration for all parameters for all land uses and each stream and waterbody reach. Consequently, model users focus the calibration on sites with observed data and review simulations in all parts of the watershed to ensure that the model results are consistent with field observations, historical reports, and expected behavior from past experience (Donigian and Love, 2003, AQUA TERRA, 2012).

The level of performance and overall quality of sediment calibration is evaluated in a weight of evidence approach that includes both visual comparisons and quantitative statistical measures. For this effort, the models were already stated to be calibrated for sediment, but did not match evidence on source attribution. Therefore, the primary focus of the model re-calibration was on approximating the source attribution evidence. We also adopted a philosophy, consistent with the RESPEC model representation, of using a parsimonious parameter set in which the parameter KSER, which controls washoff of upland sediment, were generally held constant for a given land use within a HUC8 basin. Similarly, the instream critical shear stresses for scour and deposition were held to narrow and consistent ranges. This approach leads to a robust model that is not over-fit to uncertain data and the fine-scale factors that may skew observations at individual stations; however, it also can reduce the apparent quality of fit in comparing model predictions to observations at individual stations.

The standard approach to sediment calibration focuses on the comparison of model predictions and observed total suspended solids or suspended sediment concentration data. Given the inherent errors in input and observed data and the approximate nature of model formulations, absolute criteria for watershed model performance are not generally considered appropriate by most modeling professionals. Yet, most decision makers want definitive answers to the questions—"How accurate is the model?" and "Is the model good enough for this evaluation?" Consequently, the current state of the art for model evaluation is to express model results in terms of ranges that correspond to "very good", "good", "fair", or "poor" quality of simulation fit to observed behavior. These characterizations inform appropriate uses of the model: for example, where a model achieves a good to very good fit, decision-makers often have greater confidence in having the model assume a strong role in evaluating management options. Conversely, where a model achieves only a fair or poor fit, decision makers may assign a less prominent role for the model results in the overall weight-of-evidence evaluation of management options.

For HSPF and similar watershed models, a variety of performance targets for comparison to observed suspended sediment concentrations have been documented in the literature, including Donigian et al. (1984), Lumb et al. (1994), Donigian (2000), and Moriasi et al. (2007). Based on these references and past experience, HSPF performance targets for sediment are summarized in Table 2.

Table 2. Performance Targets for HSPF Suspended Sediment Simulation (Magnitude of Annual and Seasonal Relative Mean Error (*RE)*; daily and monthly NSE)

Model Component	Very Good	Good	Fair	Poor
Sediment	≤ 20%	20 - 30%	30 - 45%	> 45%

It is important to clarify that the tolerance ranges are intended to be applied to mean values, and that individual events or observations may show larger differences and still be acceptable (Donigian, 2000).

Where model fit to observations is rated less than "good" this can be due to deficiencies in the model simulation of sediment, deficiencies in the model simulation of hydrology, deficiencies in the flow gage and water quality monitoring records, or a combination of the three. Model calibration typically assumes that the observed records are "correct" and maximizes the fit of the model to those records. It is clear in some cases, however, that uncertainty in the monitoring record itself is a major contributor to poor predictability. This is most likely to be true for stations that have short periods of record, locations that are impacted by backwater effects, and sites with unstable channels at which rating curve adjustments (which are essential to the simulation of shear stress and sediment scour and deposition) have not been frequently revised. In addition, most of the observed data consist of grab samples that represent a specific point in space and time. These are compared to model predictions that represent a daily average over a whole model reach (typically several miles in length) that is assumed to be completely mixed. An instantaneous grab sample may not be representative of an average concentration over the course of a day, and small errors in the timing of storm flows will propagate into apparent error in the fit to suspended sediment concentration. Further, observations at a specific spatial location may be affected by local conditions, such as bridge scour, that deviate from the average over the whole reach. As a result, calibration is an inexact science that must proceed by a weight-of-evidence approach.

2.3 CALIBRATION AND VALIDATION/CORROBORATION

Traditional model validation is intended to provide a test of the robustness of calibrated parameters through application to a second time period. In watershed models, this is, in practice, usually an iterative process in which evaluation of model application to a validation period leads to further adjustments in the calibration. A second, and perhaps more useful constraint on model specification and performance is a spatial calibration/corroboration approach in which the model is tested at multiple gages on the stream network to ensure that the model is not over parameterized to fit any one gage or collection of gages. In particular, obtaining model fit to numerous gages at multiple spatial scales from individual headwater streams to downstream stations that integrate across the entire Minnesota River basin helps to ensure that the model calibration is robust. This is especially appropriate for the present model recalibration effort in which the full set of available data has already been used to develop the initial model calibration.

The overall model application period is 1/1/1995 – 12/31/2012. Typical sediment sampling frequencies range from once a week to once a month, but often cover only a subset of years within the overall application period. All of the sediment samples at a gage were used as a full record for that gage and no split sample calibration/validation periods were adopted. Instead a spatial distribution of calibration and validation stations was selected in which initial efforts focused on the “calibration” stations, followed by additional testing and refinement using the corroboration stations. Generally, headwater and upstream gages are considered corroboration stations, which ensures that a corroboration station is not downstream of a calibration station and thus represents a semi-independent test of the model parameterization. Note, however, that model fit to observations is likely to decline for stations with smaller drainage areas because these stations are likely to have flashier responses that amplify the potential discrepancy between grab sample observations and model daily average predictions.

2.4 COMPONENTS NOT ADJUSTED

The adjustments to the sediment calibration are conditional on accepting several aspects of the RESPEC model development (RESPEC, 2014). Most of these were discussed in the hydrology recalibration memo:

- Development and assignment of meteorological forcing time series, including the calculation of potential evapotranspiration, was not adjusted. The models are forced by rainfall gauge records, which have in many instances have been shown not to be representative of areal average precipitation totals during large convective summer storm events.
- Point source discharges are accepted as specified by RESPEC.
- The RESPEC models use a degree-day method for the simulation of snow melt in which melt is estimated solely as a function of air temperature. This provided a good fit to the overall water balance at most stations, but is less adept at simulating rapid changes in the snow balance and does not account for sublimation from the snow pack.

- Hydraulic functional tables (FTables) are not altered from the RESPEC models. Lake simulation is also as set up by RESPEC. Most of the stream reach FTables appear to be specified based on regional hydraulic geometry information and do not incorporate measured channel cross section data[1]. This can bias simulation of channel shear stresses, especially during large storm events.

Also significant to the sediment recalibration are the following:

- The RESPEC models represent sediment contributions from tile drains with surface inlets through the use of GENER statements. The methodology used to generate tile drain sediment loads in this application is unchanged; however, the area factors associated with the GENER statements were updated to properly represent the modifications made to separate agricultural lands by hydrologic soil group (HSG), as described in Section 4. Examination of the approach to simulating tile drain sediment in these models indicates a much more rapid response and quick recession of sediment loads compared to those represented through Special Actions in the Tetra Tech (2008) models.
- The setup of which land uses contribute mass scour (ravine erosion) from the uplands was unchanged. The RESPEC models assign ravine erosion to agricultural lands and to the special bluff and ravine land uses. With the exception of the bluff and ravine land uses (where scour rates were increased to generate considerably more sediment from the land), the setup for ravine erosion is unchanged from what RESPEC provided; however, the results will differ due to the revisions to model hydrology.
- The partitioning from upland total sediment yield to instream sand, silt, and clay fraction loads is not modified from what RESPEC provided.
- Initial stream bed composition of sand, silt, and clay is not modified from what RESPEC provided.
- The Chippewa model received from RESPEC and adapted from the earlier Tetra Tech model is set up with an additional general quality constituent simulating sediment load independent of sheet and rill or gully erosion. This was done because suspended solids concentrations at the upstream station on the Chippewa River at Cyrus have an atypical relationship to flow. That is, high concentrations of TSS often occur at relatively low flows, while the concentration tends to decrease for higher flows. This suggests the presence of an approximately constant load of solids that is independent of flow, such as could occur from extensive animal activity in the stream or sand mining operations. This approach was not modified for the sediment recalibration.

3 Calibration Gage Sites

A total of 63 in-stream water quality stations were used for the Minnesota River Basin HSPF model sediment recalibration. All selected in-stream stations have at least 100 TSS samples during the simulation period. Additionally, with the exception of Watonwan (Watonwan has only one station with more than 100 samples) at least three stations were included for each HUC8. As previously discussed the stations were split into calibration (31 stations) and corroboration (32 stations) based on spatial

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[1] The RESPEC memoranda say that for reaches where Tetra Tech previously calculated FTables using results of HEC-RAS models, those FTables “will be scaled by reach length and applied to corresponding reaches in order to maximize the use of the best available data.” For reaches that did not have HEC-RAS models, the documentation implies that cross-sectional measurements at USGS gage sites will be used, and, when field information on a gage is not available, “The USGS maximum width, depth, and area data will be used to calculate cross-sections assuming a trapezoidal channel and a bank slope of 1/3.”

information. The in-stream water quality stations used for sediment calibration and corroboration are listed in Table 3.

Table 3. Sediment Calibration and Corroboration Stations

Site	HUC_8	HYDSTRA ID	STORET ID	Period of Record	Type
Chippewa R at 140th St, 7 mi N of Cyrus	7020005	276033	S002-190	5/1999 - 9/2012	Calibration
Chippewa R at CSAH-22, 1 mi E of Clontarf	7020005	276036	S002-193	5/1998 - 9/2012	Calibration
Shakopee Ck, at Unn Twnshp Rd, 1 mi W Mn-29, 8 mi*	7020005	276043	S002-201	5/1998 - 9/2012	Calibration
Chippewa R, at MN-40, 5.5 mi E of Milan	7020005	276045	S002-203	5/1998 - 12/2012	Calibration
Dry Weather Creek, at 85th Ave NW, 4 mi NE of Wat*	7020005	276046	S002-204	5/1998 - 9/2012	Corroboration
Shakopee Ck S Andrew Rd at Lk Andrew Otl 4.5 mi W*	7020005	276051	S002-209	6/1996 - 10/2007	Corroboration
Little Chippewa R at MN-28, 4 mi W of Starbuck	7020005	276146	S004-705	3/2007 - 9/2009	Corroboration
Chippewa R, EB, at 15th Ave Ne, 2.5 mi N of Benson	7020005	276156	S005-364	5/1998 - 9/2012	Corroboration
W Fk Beaver Ck at CSAH-4 6.5 mi S of Olivia	7020004	275971	S000-405	6/1999 - 9/2009	Corroboration
Beaver Ck at CSAH-2 2.5 mi NE of North Redwood	7020004	275976	S000-666	6/1999 - 9/2012	Calibration
Sacred Heart Ck at CSAH-15 Br, 5 mi NW of Delhi, *	7020004	275988	S001-341	4/1999 - 9/2012	Corroboration
Hawk Ck at Cr 52 Br, 6.5 mi SE of Granite Falls	7020004	276009	S002-012	6/1999 - 12/2012	Calibration
Palmer Ck at 15th Ave Se, 2 mi NW of Granite Falls	7020004	276010	S002-136	4/1999 - 9/2012	Corroboration
Hawk Ck, at Cr-116, 1.25 mi S of MN-40, 4.2 mi SW*	7020004	276014	S002-140	6/1999 - 9/2012	Corroboration
Hawk Ck, at MN-23, 2.2 mi SW of Maynard	7020004	276022	S002-148	6/1999 - 9/2012	Calibration
Chetomba Ck, at Unnamed Twp Rd, 5 mi SE of Maynard	7020004	276026	S002-152	6/1999 - 9/2012	Corroboration
Yellow Med R, 1 1/3 mi No CSAH-18, 5 1/4 mi NE Ha*	7020004	276068	S002-316	4/2001 - 10/2012	Calibration
So Br Yellow Medicine R On CSAH-26, 4 mi N Minneo*	7020004	276071	S002-320	4/2001 - 8/2012	Corroboration
Cd-119 at CSAH-15, 5.6 mi S of Sacred Heart, Minn*	7020004	276116	S003-866	4/2005 - 8/2012	Corroboration
Timms Ck at CSAH-15, 2.8 mi NNE of Delhi, Minneso*	7020004	276117	S003-867	4/2005 - 8/2012	Corroboration
MM R 500 Ft S CSAH-13 near USGS Gage House Dwnst *	7020004	276123	S004-649	3/2007 - 12/2012	Calibration
Minnesota R, Ethanol Facility Water Supply Intake*	7020004	276349	S007-748	2/2007 - 1/2008	Calibration
Redwood R at CSAH-15 In Russell	7020006	272519	S000-696	5/2001 - 9/2012	Calibration
Redwood R at CSAH-17, 3 miles SW of Redwood Falls	7020006	272872	S001-679	3/1996 - 9/2012	Calibration
Clear Ck Cr-56, 1/3 mi upst conflu Redwd R, NE Ed*	7020006	272541	S002-311	3/1996 - 9/2012	Corroboration
Three mile Ck at Cr-67, 1 mi No of Green Valley	7020006	273019	S002-313	3/1996 - 10/2011	Corroboration
Plum Creek at CSAH 10 Br, 4.75 mi NE of Walnut Gr*	7020008	273015	S001-913	4/1997 - 7/2012	Corroboration
Cottonwood R near MN-68 And Cottonwood St In New *	7020008	273017	S001-918	4/1997 - 10/2011	Calibration
Sleepy Eye Cr at CSAH 8 Br, 2.2 mi N of Leavenwor*	7020008	272478	S001-919	4/1997 - 9/2012	Corroboration
Cottonwood R at CSAH 8 Br, 0.4 mi N of Leavenwort*	7020008	272479	S001-920	4/1997 - 9/2012	Calibration
Cottonwood R at Us-14 Brg, 1 mi NE of Lamberton	7020008	272532	S002-247	5/2000 - 9/2012	Calibration
Watonwan R Br On CSAH-13, 1 mi W of Garden City	7020010	272526	S000-163	10/1996 - 3/2012	Calibration
Le Sueur R MN-66 1.5 mi NE of Rapidan	7020011	272867	S000-340	1/2005 - 7/2012	Calibration
Unn Trib To Big Cobb R, Sh22 0.5 mi N Beauford	7020011	273013	S001-210	1/2005 - 9/2012	Corroboration
Maple R at CSAH 35 5.2 mi S of Mankato, MN	7020011	272950	S002-427	4/2003 - 8/2012	Calibration
Cobb R at CSAH-16, 4.4 mi NE of Good Thunder, MN	7020011	272629	S003-446	3/2006 - 9/2011	Calibration
Le Sueur R at CSAH 28 in Saint Clair, MN	7020011	273029	S003-448	3/2007 - 6/2012	Corroboration
Little Cobb near CSAH-16, 6.3 mi W of Pemberton, *	7020011	272962	S003-574	1/2005 - 9/2012	Corroboration
Le Sueur R at CSAH-8, 5.1 mi SSE of Mankato, MN	7020011	272617	S003-860	3/2006 - 9/2011	Calibration
Maple R at CSAH-18, 2 miles North of Sterling Cen*	7020011	272627	S004-101	4/2006 - 9/2012	Corroboration
Blue Earth River 150 Ft dwst of Rapidan Dam	7020009	272948	S001-231	1/2005 - 3/2012	Calibration
Dutch Creek at 100th St, 0.5 miles W of Fairmont	7020009	272881	S003-000	4/2000 - 10/2008	Corroboration
Center Creek at 315th Avenue - 1 mi S of Huntley	7020009	272608	S003-024	2/2002 - 10/2008	Corroboration
Elm Creek at 290th Ave - 4.5 mi NE of Granada	7020009	272609	S003-025	2/2002 - 10/2008	Calibration
Minnesota River at Mankato, MN	7020007	273053	5325000	3/1996 - 8/2007	Calibration
Minnesota R Bridge On Us-71 And MN-19 at Morton	7020007	272517	S000-145	10/2000 - 10/2011	Calibration
Minnesota R at CSAH 42 at Judson	7020007	272509	S001-759	1/2005 - 2/2012	Calibration
Sevenmile Ck dwst of MN-99, 6 mi SW of St. Peter	7020007	272646	S002-934	4/1996 - 8/2011	Corroboration
Cty Dtch 46A dwst of CSAH-13, 6 mi SW of St. Peter	7020007	272880	S002-936	4/2000 - 9/2011	Corroboration
Sevenmile Ck in Sevenmile Ck Cty Pk, 5.5 mi SW of*	7020007	273028	S002-937	4/1996 - 9/2011	Calibration
Minnesota R at MN-99 in St. Peter, MN	7020007	273031	S004-130	1/2005 - 2/2012	Calibration
Little Cottonwood R at Apple Rd, 1.6 mi S of Courtland	7020007	273033	S004-609	4/1996 - 6/2010	Corroboration
High Island Cr., CSAH-6 By Henderson	7020012	272518	S000-676	6/1998 - 9/2012	Calibration

Site	HUC_8	HYDSTRA ID	STORET ID	Period of Record	Type
Rush River, Sh-93 By Henderson	7020012	272599	S000-822	6/1998 - 9/2012	Calibration
Bevens Cr.,CSAH-41 By East Union	7020012	272871	S000-825	2/1998 - 9/2011	Calibration
Silver Cr.,CSAH-41 By East Union	7020012	272600	S000-843	6/2000 - 8/2011	Corroboration
Buffalo Ck, at 270th St, 1.5 mi NW of Henderson	7020012	272468	S001-807	5/2000 - 9/2012	Corroboration
High Island Ck at CSAH 9, 1 mi NW of Arlington	7020012	272482	S001-891	5/2000 - 9/2012	Corroboration
Carver Ck at Us-212, 2.5 mi E of Cologne, MN	7020012	273022	S002-489	5/1997 - 9/2011	Corroboration
Carver Ck at Cr-140, 2.3 mi NE of Benton, MN	7020012	272489	S002-490	5/1997 - 9/2011	Corroboration
Bevens Ck at 321st Ave, 3 mi SE of Hamburg, MN	7020012	272503	S002-516	11/1999 - 9/2011	Corroboration
Bevens Ck at Rice Ave, 3.9 mi SE of Norwood Yng America	7020012	272470	S002-539	5/1997 - 9/2011	Corroboration
W Chaska Ck, 250' W of Cty Rd 10, behind VFW, in *	7020012	272472	S002-548	4/1998 - 9/2011	Calibration

* Name truncated in RESPEC database

4 Model Updates

4.1 MODEL STRUCTURAL RECONFIGURATION

After consultation with MPCA, a number of changes were made in the structure of the 2014 models. These included subdivision of agricultural land to separate hydrologic soil group (HSG) classes and separation of cropland areas receiving manure applications – both of which may be useful for development of model scenarios. The reconfiguration of the models is described below.

- **Separation of cropland into two classes based on HSG.** Most of the agricultural land in the watershed incorporates tile drainage to improve spring water balance, with intensity of tile drainage generally being greatest in the lacustrine soils of the Le Sueur watershed and adjacent parts of the Blue Earth and Middle Minnesota 8-digit HUCs. The RESPEC (2014) models (exclusive of the Chippewa and Hawk-Yellow Medicine models developed by Tetra Tech) lumped all cropland into two conventional and conservation tillage groups regardless of soil type, which precludes identification of critical areas with marginal soil characteristics. This was rectified by reprocessing the land use information and generating four cropland classes representing Cropland – Conservation Till (HSG A,B), Cropland – Conservation Till (HSG C,D), Cropland – Conventional Till (HSG A,B), and Cropland – Conventional Till (HSG C,D), where the HSG class for cropland is the designation "with drainage" for dual classification soils (i.e., B/D soils are soils that have B characteristics when drained) under the assumption that tile drainage is ubiquitous where it is necessary to improve production performance in the corn belt. This change was implemented before the completion of the hydrology recalibration but not discussed in the November 2015 memo.
- **Representation of manured lands.** For all models except Chippewa and Hawk Yellow Medicine, land receiving manure application was not explicitly represented in the RESPEC (2014) models. The models were set up with a land use called "Cropland – Reserved" for this purpose, but this land use was assigned no area in the 2014 models. The Cropland – Reserved category was changed to "Manure Application (conventional A,B)" and area from Cropland – Conventional Till (HSG A,B) was changed to the Manure Application land use to reflect the estimated acreage that receives manure application. We assumed that manure would primarily be applied to land with better drainage, as the (A,B) grouping (with drainage) is also the dominant component of the overall cropland area, and also that regular manure application is not generally consistent with conservation tillage maintenance of residue cover. The decision by MPCA to incorporate this change in the model structure occurred after the hydrology recalibration and most of the sediment recalibration was complete. To have no net impact on the hydrology and

sediment recalibrations, the manured land was reassigned solely from Cropland – Conventional Till (HSG A,B) and the hydrologic and sediment parameters for manured land were set equal to those for Cropland – Conventional Till (HSG A,B). This was the approach that used in the 2008 TMDL model as well.

- **Separation of Lower Minnesota model into two models.** The increase in the number of model pervious upland land units (PERLNDs) due to the cropland and manured area modifications increased the number of operations in the Lower Minnesota model beyond the upper limit for the current version of the HSPF model. The 2014 Lower Minnesota model was split into two separate linked models: a revised Lower Minnesota model incorporating all sub-basins upstream of and including reach 310 and a new “Metro” Minnesota that incorporates the portion of the original Lower Minnesota model downstream of reach 310.
- **Representation of bluff land area.** The RESPEC (2014) models include the land area in bluffs (as shown on a spatial coverage of bluff area developed in 2011-2012 and provided by MPCA) for all the models except for Chippewa and Hawk Yellow Medicine. There is newer work in progress to better delineate bluffs from LiDAR elevation data; however, those coverages are not yet suitable for use as they identify many small features, such as ditch banks, as bluffs, which is not consistent with the characterization of bluff areas in the model. Similarly, ravine land use has been identified as a separate coverage in the Le Sueur watershed, but work is not complete in other basins (although ravine loading is simulated as a part of the general crop land simulation). Both the bluff and ravine coverages should be updated when this ongoing work is completed. For the present round of models, bluff land use area (as shown on the 2011-12 bluff coverage) was incorporated into the Chippewa and Hawk Yellow Medicine models.
- **Representation of bluff collapse.** The RESPEC (2014) models removed the earlier models’ pseudo-random process of contribution from bluff collapse that was implemented via SPECIAL ACTIONS. The old approach, where the process of bluff collapse is simulated as an increase in the bed sediment that is available for transport in stream segments, was reincorporated in the updated models. Table 5-2 (*Bluff Erosion Contribution Rates to Available Stream Bed Sediment*) from Tetra Tech (2008) was used as a starting point along with information from the Le Sueur and Greater Blue Earth sediment mass balance studies (Gran et al., 2011; Bevis, 2015). The watershed-specific estimated total bluff loads were split by area-weighting the bluff contribution based on each individual sub-watershed bluff area for each of the watersheds and then that load was supplied as a constant replenishment to the bed via SPECIAL ACTIONS. This approach maintains the watershed-specific bluff contribution loads at the mouth of each model but proportionally modifies the amount of sediment load applied to a reach containing a bluff land use by the area of bluff contributing to the reach. In the Tetra Tech (2008) report, bluff loading was not represented in the Middle Minnesota and Lower Minnesota models and no specific information on bluff loading rates has been obtained. However, there is bluff land use area in those two models. To implement the SPECIAL ACTIONS in the Middle and Lower Minnesota models, the Le Sueur bluff contribution loads were used as a proxy at the recommendation of the MPCA project manager. First, the Le Sueur bluff loading rate was converted to a yield in tons/ac relative to the specified bluff acreage. Second, the converted Le Sueur rate was applied to the bluff area in the Middle, Lower, and Metro models to develop the bluff erosion contribution rates to available stream bed sediment.
- **Creation of PLTGEN outputs for models not having those outputs.** Most of the RESPEC (2014) models provided model output at instream monitoring locations by writing to PLTGEN’s. PLTGEN output was added to the Chippewa, Hawk-Yellow Medicine, Middle Minnesota, Lower Minnesota, and Metro Minnesota models. This allowed for a consistent set of tools to compare simulated and observed instream concentrations and load summaries.

4.2 UPLAND SEDIMENT SIMULATION

The RESPEC (2014) Minnesota River Basin HSPF models in most cases had upland sediment parameters similar to those calibrated in Tetra Tech (2008) and thus produce consistent loading rate estimates. This was not the case for the impervious land simulation, where the use of a high value of the washoff parameter (KEIM) resulting in extremely high loading rates from urban land, apparently accidentally set at ten times the previously calibrated value, resulted in urban impervious land generating about 1 ton per acre per year of solids and dominating total sediment load in some watersheds. Municipal Separate Storm Sewer System (MS4) monitoring results summarized by MPCA suggest that the sediment rate for urban developed land should, on average, be less than 0.1 ton/ac/yr.

The main parameters controlling upland sediment generation and transport to the stream are:

- KRER coefficient in the soil detachment equation for pervious land
- KSER coefficient in the detached sediment washoff equation for pervious land
- KEIM coefficient in the solids washoff equation for impervious land

The above parameters were the main PERLND and IMPLND parameters modified to bring consistency with the current constraining information and the simulated per acre sediment loading rates. There are other parameters that have a major influence specifically the exponential terms (JRER, JSER, and JEIM), although those were not modified from what RESPEC previously used because reasonable per acre sediment loading rates were obtained without modifying them. However, almost all sediment parameters were modified for Bluffs and Ravines. Since these land uses have small area and are large contributors of the overall sediment load in the stream, all of the parameters were set up so that the land areas have high loading rates.

Table 4 through Table 6 show the range of values used for each land use and each model for the three main parameters modified for the upland sediment simulation. KRER was calculated using the land use coverage and soils coverage and then area weighted to a value for each land use and weather station zone and was not further modified during calibration. KSER was the main parameter adjusted to control the sediment washoff and delivery. KEIM was the only parameter adjusted to control solids washoff and delivery. Table 7 provides the typical monthly erosion-related cover used for all models to provide some context to the calibrated values of KRER and KSER.

Table 4. KRER Values Used for Updated Models

Land Use	Redwood	Cottonwood	Watonwan	Le Sueur	Blue Earth	Middle	Lower	Metro
Urban	0.241 - 0.287	0.233 - 0.27	0.233 - 0.266	0.237 - 0.278	0.239 - 0.289	0.228 - 0.268	0.229 - 0.271	0.207 - 0.281
Forest	0.24 - 0.281	0.234 - 0.273	0.211 - 0.253	0.209 - 0.287	0.24 - 0.292	0.165 - 0.269	0.2 - 0.274	0.177 - 0.261
Cropland - Conservation Till (HSG A,B)	0.243 - 0.277	0.233 - 0.27	0.232 - 0.265	0.225 - 0.272	0.217 - 0.284	0.23 - 0.251	0.217 - 0.256	0.04 - 0.305
Cropland - Conservation Till (HSG C,D)	0.314 - 0.363	0.312 - 0.362	0.127 - 0.331	0.106 - 0.286	0.15 - 0.336	0.192 - 0.339	0.219 - 0.357	0.02 - 0.313
Cropland - Conventional Till (HSG A,B)	0.243 - 0.277	0.233 - 0.27	0.232 - 0.265	0.225 - 0.272	0.217 - 0.284	0.23 - 0.251	0.217 - 0.256	0.04 - 0.305
Cropland - Conventional Till (HSG C,D)	0.314 - 0.363	0.312 - 0.362	0.127 - 0.331	0.106 - 0.286	0.15 - 0.336	0.192 - 0.339	0.219 - 0.357	0.02 - 0.313
Cropland - Manure Application (conv A,B)	0.243 - 0.277	0.233 - 0.27	0.232 - 0.265	0.225 - 0.272	0.217 - 0.284	0.23 - 0.251	0.217 - 0.256	0.04 - 0.305
Grassland	0.249 - 0.28	0.212 - 0.277	0.217 - 0.287	0.209 - 0.264	0.214 - 0.274	0.204 - 0265	0.21 - 0.275	0.171 - 0.276
Pasture	0.211 - 0.288	0.22 - 0.284	0.211 0.261	0.192 - 0.282	0.227 - 0.279	0.208 - 0.27	0.217 - 0.268	0.113 - 0.274
Wetland	0.254 - 0.313	0.227 - 0.278	0.155 - 0.244	0.042 - 0.249	0.104 - 0.276	0.066 - 0.311	0.072 - 0.264	0.049 - 0.236
Feedlot	0.25	0.25	0.25	0.23 - 0.27	0.246	0.245	0.244	0.244
Bluff	0.24	0.24	0.24	0.23 - 0.27	0.243	0.243	0.174	0.174
Ravine	0.28	0.28	0.28	0.23	0.278	0.278	0.278	0.278

Notes: KRER estimates are derived from soil survey data on the Universal Soil Loss Equation erodibility (K) factor. Values for Chippewa and Hawk Yellow Medicine not presented here due to different PERLND configurations. Refer to their UCI files for their parameterization

Table 5. KSER Values Used for Updated Models

Land Use	Redwood	Cottonwood	Watonwan	Le Sueur	Blue Earth	Middle	Lower	Metro
Urban	0.08	0.08	0.07	0.08	0.08	0.08	0.08	0.08
Forest	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Cropland - Conservation Till (HSG A,B)	0.2	0.3	0.08	0.2 & 0.05	0.25	0.3	0.15	0.15
Cropland - Conservation Till (HSG C,D)	0.15	0.3	0.08	0.2 & 0.05	0.1	0.3	0.15	0.15
Cropland - Conventional Till (HSG A,B)	0.25	0.4	0.11	0.3 & 0.1	0.3	0.4	0.2	0.2
Cropland - Conventional Till (HSG C,D)	0.2	0.4	0.11	0.3 & 0.1	0.15	0.4	0.2	0.2
Cropland - Manure Application (conv A,B)	0.25	0.4	0.09	0.3 & 0.1	0.3	0.4	0.2	0.2
Grassland	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Pasture	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Wetland	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Feedlot	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
Bluff	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Ravine	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

Note: Values for Chippewa and Hawk Yellow Medicine not presented here due to different PERLND configurations. Refer to their UCI files for their parameterization

Table 6. KEIM Values Used for Updated Models

Land Use	Chippewa	HYM	Redwood	Cottonwood	Watonwan	Le Sueur	Blue Earth	Middle	Lower	Metro
Urban Impervious	0.03	0.02	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015

Table 7. Typical Monthly Cover Values Used for Updated Models

Land Use	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Urban	0.85	0.85	0.85	0.88	0.88	0.88	0.88	0.88	0.88	0.86	0.85	0.85
Forest	0.85	0.85	0.85	0.9	0.95	0.95	0.95	0.95	0.95	0.95	0.85	0.85
Cropland - Conservation Till A,B	0.2	0.2	0.2	0.35	0.35	0.3	0.4	0.85	0.85	0.7	0.55	0.35
Cropland - Conservation Till C,D	0.2	0.2	0.2	0.35	0.35	0.3	0.4	0.85	0.85	0.7	0.55	0.35
Cropland - Conventional Till A,B	0.05	0.05	0.05	0.15	0.15	0.2	0.4	0.85	0.85	0.6	0.4	0.15
Cropland - Conventional Till C,D	0.05	0.05	0.05	0.15	0.15	0.2	0.4	0.85	0.85	0.6	0.4	0.15
Cropland - Manure Application (conv A,B)	0.05	0.05	0.05	0.15	0.15	0.2	0.4	0.85	0.85	0.6	0.4	0.15
Grassland	0.75	0.75	0.75	0.8	0.85	0.9	0.9	0.9	0.9	0.9	0.85	0.8
Pasture	0.75	0.75	0.75	0.8	0.85	0.9	0.9	0.9	0.9	0.9	0.85	0.8
Wetland	0.9	0.9	0.9	0.92	0.97	0.97	0.97	0.97	0.97	0.97	0.92	0.9
Feedlot	0.1	0.1	0.1	0.03	0.03	0.1	0.6	0.85	0.85	0.7	0.2	0.15
Bluff	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Ravine	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

4.3 INSTREAM SEDIMENT SIMULATION

As previously discussed the 2014 Minnesota River Basin HSPF models had sediment source apportionment results that were inconsistent with the current constraining information. For example, the 2014 models of the Blue Earth and Le Sueur watersheds attributed over 70 percent of the total sediment load to upland sources compared to less than 30 percent based on radiometric analysis (see Table 1 above). This fact, along with the updated hydrology calibration, required adjustment of the instream simulation of sediment.

There are two types and three classes of sediment simulated in HSPF non-cohesive (sand) and cohesive (silt and clay). The three sediment classes are simulated independently of one another in the stream. Load delivered from the land surface is simulated as total sediment and partitioned into sand, silt, and clay factions at the stream edge. As previously stated, the upland to instream partitioning of sediment was not modified from what was provided by RESPEC.

In HSPF, sand can be simulated by one of three approaches: 1) Toffaletti equation, 2) Colby method, or 3) power function of velocity. For the Minnesota River Basin HSPF the selected sand method is 3) power function of velocity. This was the method that RESPEC used and was unmodified for the recalibration.

The main parameters controlling the cohesive instream sediment simulation are listed below. These values are contained in the SILT-CLAY-PM block of the UCI and the data block is repeated twice. The first set in the UCI pertains to silt and the second set in the UCI pertains to clay.

• D	effective diameter of the particles
• W	particle fall velocity in still water
• RHO	particle density
• TAUCD	critical bed shear stress for deposition
• TAUCS	critical bed shear stress for scour
• M	erodibility coefficient of the sediment

D, W, and RHO were parameterized with values in range with those outlined in US EPA (2006) and following the approach laid out for MPCA One Water projects by AQUA TERRA (2012). Values for TAUCD, TAUCS, and M were calibrated by first outputting the hourly TAU (bed shear stress) for the simulation period. Second, the percentile ranges of TAU for each simulated reach were tabulated. Third, initial values TAUCD, TAUCS, were input by selecting a percentile used in previous model calibrations and finding each reaches TAU value corresponding to that percentile. Lastly, after the upland simulation was completed, TAUCD, TAUCS, and M were adjusted through an iterative process until an acceptable match was achieved between observed instream concentrations and loads and simulated concentrations and loads, and sediment source apportionment (percent and estimated load where available) were consistent with the current constraining information.

As noted above, the representation of sediment load associated with mass wasting of bluffs was reverted to the prior approach (Tetra Tech, 2008) where the process of bluff collapse is simulated as an increase in the bed sediment that is available for transport in stream segments. Table 8 shows the bluff erosion contribution rates to available stream bed sediment as a total rate above each models pour point or end point. The watershed-specific bluff contribution loads were split among identified bluff land uses based on the bluff area by sub-basin. That load was then supplied as a constant replenishment rate to the bed for the reaches containing upland bluff area via SPECIAL ACTIONS. The added sediment was then mobilized when higher flows occur (i.e., TAU values greater than TAUCS). The bluff reaches had higher values of the erodibility coefficient M specified to maintain proper stream bed balance.

Table 8. Total Sediment Loading to Stream Bed Storage from Bluff Mass Wasting Processes

Watershed	Bluff Contribution (tons/hr)
Blue Earth River	28
Chippewa River	0.1
Cottonwood River	2.1
Hawk Creek	0.97
Le Sueur River	11.2
Lower Minnesota River	0.05
Middle Minnesota River	0.13
Redwood River	1.6
Watonwan River	2.1
Yellow Medicine River	1.5

In the initial calibration the simulated TSS concentrations were generally lower than those observed at base flow conditions. To improve the baseflow simulation, a clay load associated with groundwater was supplied as a surrogate for a combination of fine material in actual groundwater discharges, and activity of fish, animals, and humans in the streams. The added clay load equated to 5 mg/L for all models except Hawk-Yellow Medicine, and Chippewa, which were assigned 1 mg/L.

Table 9 provides the range of values used in the SILT- and CLAY-PM blocks. Values for D, W, RHO, and M in this table are the actual values input into the UCI, while entries for TAUCD and TAUCS provide the percentile range of simulated TAU. Since each reach has its own model derived value for TAU providing the percentile range of TAU provides much more insight into the parameterization of TAUCD and TAUCS. For each basin, parameters other than the critical shear stresses were specified separately for stream, lake, and bluff-area reaches but otherwise held constant or varied only slightly (in the case of M) across the basin. The erodibility and critical shear stress parameters were varied within relatively constrained ranges to improve the calibration fit.

Table 9. SILT-CLAY-PM Block Values Used for Updated Models

Constituent	RCHRES Type	Parameter	Chippewa	HYM	Redwood	Cottonwood	Watonwan	Le Sueur	Blue Earth	Middle	Lower	Metro
Silt	Stream	D	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006
		W	0.0039	0.0039	0.0039	0.0039	0.0039	0.0039	0.0039	0.0039	0.0039	0.0039
		RHO	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
		TAUCD*	1-50	4-7	1-18	4-6	1-10	4-10	1-13	1-18	1-13	1-16
		TAUCS*	80-85	80-81	75-76	75-76	66-78	65-92	65-80	73-91	74-78	68-80
		M	0.004	0.004	0.015	0.015-0.025	0.01	0.006-0.03	0.025	0.01	0.02	0.02
	Bluff	D	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006
		W	0.0039	0.0039	0.0039	0.0039	0.0039	0.0039	0.0039	0.0039	0.0039	0.0039
		RHO	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
		TAUCD*	6	5-6	6	5-6	5-6	4-11	5-6	5-6	5-6	5-6
		TAUCS*	80-81	81	76	75-76	66-78	65-92	65-75	85-86	75-76	75-76
		M	0.01	0.07	0.1	0.05-0.1	0.03-0.05	0.008-0.07	0.1	0.1	0.1	0.1
	Lake	D	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006
		W	0.0039	0.0039	0.0039	0.0039	0.0039	0.0039	0.0039	0.0039	0.0039	0.0039
		RHO	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
		TAUCD*	97-99.9	97-98	97-99.9	97-99.9	98-99	97-99	95-99	97-99	97-99	97-99
		TAUCS*	99-99.9	99	99-99.9	97-99.9	99-99.9	99-99.9	96-99.9	99-99.9	99-99.9	99-99.9
		M	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Clay	Stream	D	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
		W	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001
		RHO	2	2	2	2	2	2	2	2	2	2
		TAUCD*	1-47	3-4	1-18	3-4	1-10	1-9	1-13	1-16	1-12	1-13
		TAUCS*	75-85	75-76	70-71	70-72	60-73	60-87	65-80	60-89	68-75	64-73
		M	0.004	0.004	0.015	0.015-0.025	0.01	0.006-0.03	0.025	0.01	0.02	0.02
	Bluff	D	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
		W	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001
		RHO	2	2	2	2	2	2	2	2	2	2
		TAUCD*	3-4	3-4	3-4	3-4	3-4	1-5	3-4	3-4	3-4	3-4
		TAUCS*	76	75-76	70	70-71	60-73	60-87	60-70	80-81	70-71	70-71
		M	0.01	0.07	0.1	0.05-0.1	0.03-0.05	0.008-0.07	0.1	0.1	0.1	0.1
	Lake	D	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
		W	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001
		RHO	2	2	2	2	2	2	2	2	2	2
		TAUCD*	97-99.9	97-98	97-99.9	97-99.9	98-99	97-99	95-99	97-99	97-99	97-99
		TAUCS*	99-99.9	99	99-99.9	97-99.9	99-99.9	99-99.9	96-99.9	99-99.9	99-99.9	99-99.9
		M	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005

* Value in table provided as a percentile of the hourly simulated TAU range

4.4 SEDIMENT SOURCE APPORTIONMENT

Sediment source data is primarily based on interpretation of radiometric data (^{210}Pb and ^{137}Cs) that provides an estimate of the fraction of sediment that has recently been in contact with the atmosphere (Schottler et al., 2010). To a first approximation, the percentage of "new" sediment is interpreted as the fraction of stream sediment load that derives from upland surface erosion, as opposed to load from channel erosion, ravine erosion, or bluffs. That interpretation is not exact, however, as each source contains some mixture of older, buried soil and exposed surface sediment. Another problem for interpretation is that upland sediment load may be temporarily stored and then re-scoured from the stream bed, so model output of channel scour does not necessarily represent only "old" sediment. A unique set of upland loading rates, bed erosion rates, and downstream sediment transport measures is thus not readily interpretable from the model output and the ratio of old to new sediment is not directly extractable from the model because individual sediment particles are not tracked as they move in and out of bed storage.

This issue was explored in some detail in Tetra Tech (2008), from which the following text is summarized:

Consider a case in which there is an external (upland) sediment load of *X* and a bank and bluff erosion load of *B*. The processes can be conceptually represented by a simple box model (Figure 1).

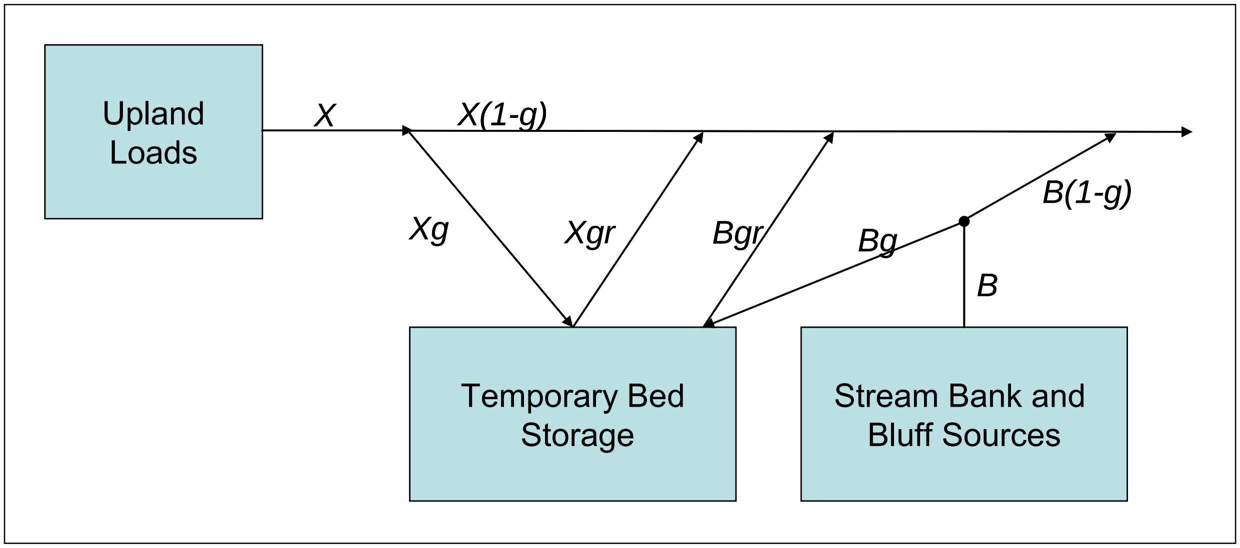


Figure 1. Conceptual Representation of Stream Sediment Processing

For an external sediment load *X*, a fraction *g* goes into temporary bed or floodplain storage. A fraction of this (*r*) is in turn resuspended and transported downstream as *Xgr*. Similarly, erosion of established stream banks and bluffs yields a total load *B*. This is assumed to be subject to the same physical processes as the upland load, *X*: A fraction *g* goes into temporary storage, of which a further fraction *r* is transported downstream. (The factor *r* may be thought of as a recycle rate. The total sediment load transported downstream, *Y*, is then:

$$Y = (X + B)(1 - g + gr).$$

The model output provides information on both gross bed scour (*GS*, resuspension flux only) and net bed scour (*NS*, balance of scour and deposition). Two additional equations can be written for *GS* and *NS* based on the simple box model:

$$GS = Xgr + B + Bgr$$
$$NS = X\,(gr - g) + B(1 + gr - g).$$

Given X, this appears to yield three equations in three unknowns. However, the system of equations is indeterminate, as the output, Y, is simply equal to the net scour (NS) + X. Therefore, there is not a unique solution unless additional constraints are imposed regarding the recycle rate, r.

Tetra Tech (2008) explored this issue further and concluded that the net effect of scour plus deposition was that the true upland-derived fraction at the outlet was likely to be about 95% of the simulated upland load divided by the downstream output load. Conducting the analysis is, however, difficult because the gross scour and net scour components need to be separated based on analysis of hourly simulation results and the results, in the end, remain uncertain because a value for *r* must be assumed.

To address these issues, a new approximate methodology was developed to generate simulated source apportionments in an efficient manner. For this purpose, Excel™ "Sediment Sources" workbooks were created with live equations that tabulate the simulated sediment source apportionment. The workbooks are provided for further investigation. The following discusses how to update the workbooks and the calculations that are being performed in the workbooks.

To use/update the workbook for any of the watershed models in the Minnesota River Basin HSPF the user must first generate yearly reach.HBN and wshd.HBN files for sediment. To do this the user must specify a flag of 5 for SED, SLD, and SED in the BINARY-INFO blocks for PERLND, IMPLND, and RCHRES respectively and then run the model. The needed HBN files can be found in the PLTGEN folder for the model that you are working with. Data for certain constituents contained in the reach.HBN and wshd.HBN are used to update the reachHBN and wshdHBN tabs in the EXCEL workbook. To access the data the user must open the reach.HBN and wshd.HBN files with the SARA Timeseries Utility. The reach.HBN file is populated with ISED-TOT (inflow of total sediment to each RCHRES by year), ROSED-TOT (outflow of total sediment from each RCHRES by year), and RSED-BED-TOT (average bed storage mass of sediment for each RCHRES by year). The wshd.HBN is populated with WSSD (washoff of detached sediment for each PERLND by year), SCRSD (scour of matrix soil for each PERLND by year), and SOSLD (washoff of solids for surface for each IMPLND per year). The user must select each constituent individually and also be sure to select the location attribute otherwise the workbook will not function properly. Copy/Paste the created list from SARA to the appropriate location in the attribution workbook and the pertinent information should be updated.

The All_Reach_Summary worksheet performs a series of tabulations that calculate the necessary information to determine the source apportionment. The workbook has comments associate with cells A4:A21 to provide the user with information about what is actually being calculated. The calculations use the information in the reachHBN and wshdHBN along with information in the SchemPLS_All, SchemPLS_RAV, SchemPLS_BLF, SchemPLS_OTH, SchemILS, and SchemRch tabs. All of the tabs listed in this paragraph contain live equations so please be very cautious about inserting, deleting, or modifying anything in all of the listed tabs.

The results of the All_Reach_Summary are then used to populate the Source_Attribution tab. For each workbook the Source_Attribution tab varies in the number of locations where source attributions are currently calculated, and the number of upstream reaches that are used to develop the source attribution. Basically, the source attribution is calculated by using the full 18 year simulation for all reaches upstream and including the reach pour point of interest. For each reach the sediment load of WSSD and SCOUR for Ravine, Bluff, and all other PERLND's are found in the All_Reach_Summary tab. Also found for each reach is the amount of sediment coming from IMPLND's as well as the deposition (positive value) or scour (negative value) from the instream simulation. Upland, Ravine, Bluff, and Stream mass are then approximated using the following calculations:

- Upland = Sum of WSSD Other, SCRSD Other, and SOSLD

- Ravine = Sum of WSSD Ravine and SCRSD Ravine
- Bluff = Sum of WSSD Bluff , SCRSD Bluff, and (-1* Deposition/Scour from Bluff Reaches)
- Stream = Sum of -1* Deposition/Scour from Non-Bluff Reaches (as scour is negative in the output).

Sediment source apportionments from upstream models are copy/pasted into the downstream model workbooks. For instance, for the Blue Earth at the mouth the workbook is theoretically only calculating the input from the Blue Earth model itself (the local drainage); however, when the Watonwan and Le Sueur source apportionment results are incorporated you can calculate the source apportionment at the mouth for the entire drainage basin. Additionally, the Chippewa model accounts for the Watson Sag Diversion to the Lac Qui Parle. The source apportionment calculations do not explicitly account for the sediment lost due to the diversion. Instead the apportionment is calculated on a percentage basis as though the diversion did not exist and then the calculated source fractions are applied to the Chippewa ROSED value at the mouth to calculate the source apportionment going into the Hawk Yellow Medicine model. That same source apportionment is applied to the Lac qui Parle input to the Hawk-Yellow Medicine model as simulation model results are not yet available for Lac qui Parle and its upstream watershed.

Based on comparison to a detailed (hourly) analysis of the Le Sueur River basin, this method, which includes only annual totals of scour and/or deposition, provides a close approximation to a more complex analysis using hourly data. However, as noted above, complete attribution of surface sediment sources would require correction for net storage/resuspension within the stream network, which would be expected to result in a small reduction in the estimated surface-derived fraction.

5 Results

5.1 UPLAND UNIT AREA LOADS

As described above, some of the existing (2014) models provided unrealistic results for the amount of sediment being generated from upland sources, especially from developed land. Table 10 displays the simulated upland sediment loading rates by basin and land use for the revised model. HSPF simulates urban pervious and impervious lands separately, so a combination result for 25 percent impervious (and 75 percent developed pervious) land is shown for comparison with MS4 loading rates. These results were calculated by taking the wshd.HBN outputs of WSSD, SCRSD, and SOSLD (discussed in section 4.4) and 1) calculating the average annual sediment load for each PERLND/IMPLND (combination of weather station zone and land use) and 2) averaging the PERLND/IMPLND average annual sediment load across all weather station zones to find the average annual sediment load for each land use. Note, the loads are not area weighted but are simply a tabulation of unit area load as provided by the wshd.HBN output.

Excel™ workbooks for each watershed model were created and are provided as a supplement to this memorandum to allow for further investigation.

Le Sueur, Blue Earth, and Watonwan watersheds had much more constraining information for the apportionment of sediment mass and percent contribution due to the Le Sueur sediment budget and Greater Blue Earth sediment budget efforts (Gran et al., 2011; Bevis, 2015). That information along with results of Schottler et al. (2010) as further updated in presentations by the investigators to MPCA (personal communication from Chuck Regan, MPCA) was used to constrain the upland sediment source apportionment.

A goal for the upland sediment simulation was to supply largely homogeneous parameterization throughout the entire suite of Minnesota River Basin HSPF. Simulated upland unit area loading rates are in general roughly consistent between basins, but differ according to the local meteorological forcing, soil characteristics, and hydrologic simulation. Some deviations between basins are intentional: Specifically, for the Watonwan basin, the unit area loadings were reduced to obtain a better match between simulated and observed upland source mass as provided in the Greater Blue Earth sediment budget (Bevis, 2015). Additionally, for the Blue Earth the unit area loading was increased to get a better match between simulated upland source mass and observed upland source mass provided in the Greater Blue Earth sediment budget. It is also worth noting that the Hawk-Yellow Medicine model shows less distinction between HSG A,B and C,D soils for agriculture. This basin contains primarily B and B/D (B when drained) soils so the difference is not of great practical importance for total load simulation. The similarity between loading rates for different soil groups appears to be due to the hydrology set up of the model, which specifies only a small difference in infiltration rates between the different HSG classes.

Table 10. Revised Annual Average Unit Area Sediment Loads, 1995-2012 pound/acre/year

Land Use	Chippewa	HawkYM	Redwood	Cottonwood	Watonwan	Le Sueur	Blue Earth	Middle	Lower	Metro
Urban Pervious	31.3	129.6	72.1	86.1	89.6	195.7	147.2	46.1	38.4	70.5
Urban Impervious	325.7	285.3	292.9	304.9	338.1	364.4	361.0	318.5	318.9	349.9
Urban Combo (75% Pervious 25% Impervious)	104.9	168.5	127.3	140.8	151.7	238.9	200.7	114.2	108.5	140.4
Forest	0.6	7.5	6.0	6.8	14.2	13.6	16.5	4.4	3.7	7.0
Cropland - Conservation Till (HSG A,B)	61.3	47.5	36.8	55.6	31.0	85.3	77.4	107.0	45.3	81.4
Cropland - Conservation Till (HSG C,D)	126.4	52.5	247.1	375.8	198.1	350.0	266.1	244.3	283.4	347.7
Cropland - Conventional Till (HSG A,B)	63.5	71.2	51.0	79.2	48.2	138.9	104.4	150.8	67.4	115.5
Cropland - Conventional Till (HSG C,D)	160.3	77.4	312.6	497.7	260.5	512.1	359.0	301.1	355.2	426.9
Cropland - Manure Application (conv A,B)	148.3	77.1	51.0	79.1	48.2	138.4	104.4	150.3	67.4	114.5
Grassland	1.6	13.7	8.7	8.7	22.3	26.1	25.7	3.4	1.1	2.3
Pasture	28.2	NA	16.5	17.2	36.4	47.5	39.4	6.1	2.3	4.8
Wetland	0.6	0.0	0.5	0.3	2.9	1.5	1.2	0.6	0.5	0.9
Feedlot	NA	NA	233.5	294.8	367.5	570.8	563.7	167.7	129.7	239.4
Bluff	271	25	2,276	3,124	5,696	6,262	10,550	1,202	516	1,053
Ravine	NA	NA	7,827	16,369	95,117	31,237	393,722	8,996	1,097	2,198

Note: For Chippewa, results shown for Forest, Grass, and Pasture are for D soils. For Hawk-Yellow Medicine, results shown for Forest, Grass, and Pasture are for D soils on low slopes. Feedlot and Ravine land uses are not specified separately in the Chippewa and Hawk-Yellow Medicine models.

5.2 INSTREAM CALIBRATION AND VALIDATION

As previously discussed, separate calibration and validation tests were conducted based on a spatial and temporal distribution of stations (Table 3). These are summarized in electronic spreadsheets provided as a supplement to this memorandum. The statistical results below are reported according to the two groups of gages (calibration and validation) in the next two sub-sections. A representative station was selected for each group and graphical results are provided for those stations for example purposes. Comprehensive graphics for each gage are provided in the electronic files.

The summary statistics include concentration average error, concentration median error, load average error and load median error. All of the statistics are performed on paired comparisons of simulated daily average and observed instream instantaneous grab measurements. Also provided is the number of paired comparisons for each station.

5.2.1 Calibration Stations

Table 11 (in five parts) shows the statistical results for the calibration gages. The calibration strategy focused foremost on sediment source attribution and used harmonized parameter estimates instead of over-fitting individual gages, resulting in some relatively large errors, especially at some of the stations where there are limited data for accurate hydrologic calibration. The quality of fit for suspended sediment is generally in the good to very good range for concentration and load median errors. The quality of fit ranges from very good to poor for concentration and load average errors. Average errors are more susceptible to large deviations because they can be heavily influenced by extreme events and slight shifts in timing. Additionally, the stations that show large differences in the average error have a much more favorable comparison when looking at the graphical comparisons. It is advised to look at both the statistical comparison and graphical comparison when assessing the overall model fit to instream monitoring data.

Graphical examples of the calibration for Le Sueur River at MN-66 1.5 miles NE of Rapidan are provided in Figure 2 through Figure 6. Results for all other calibration gages are contained in the electronic files.

Table 11. Summary Statistics for Calibration Stations

Site	Chippewa R at 140th St, 7 mi N of Cyrus	Chippewa R at CSAH-22, 1 mi E Of Clontarf	Shakopee Ck, at Unn Twnshp Rd, 1 mi W MN-29	Chippewa R, at MN-40, 5.5 mi E of Milan	Beaver Ck at CSAH-2 2.5 mi NE of North Redwood	Hawk Ck at CR 52 Br, 6.5 mi SE off Granite Falls	Hawk Ck, at MN-23, 2.2 mi SW of Maynard
STORET Code	S002-190	S002-193	S002-201	S002-203	S000-666	S002-012	S002-148
Count	243	322	314	367	374	408	375
Conc Ave Error	68.7%	-129.9%	-33.9%	-141.7%	-428.6%	-76.6%	-3.89074
Conc Median Error	1.6%	-26.3%	-52.5%	-26.9%	20.0%	14.1%	-1.0%
Load Ave Error	340.3%	39.1%	-62.1%	-23.3%	3.8%	62.0%	44.6%
Load Median Error	5.9%	-14.4%	-33.9%	-10.2%	0.2%	0.5%	-0.4%

(Table 11. Continued)

Site	**Yellow Med R, 1 1/3 mi N CSAH-18**	**MN R 500 Ft S CSAH-13 near USGS Gage**	**Minnesota R, Ethanol Facility WS Intake***	**Redwood R at CSAH-15 in Russell**	**Redwood R at CSAH-17, 3 Miles SW of Redwood Falls**	**Cottonwood R near MN-68 In New Ulm**	**Cottonwood R at CSAH 8 Br, 0.4 mi N Leavenworth**
STORET Code	S002-316	S004-649	S007-748	S000-696	S001-679	S001-918	S001-920
Count	-7.7%	-59.8%	61.1%	47.1%	-21.0%	-37.8%	-18.7%
Conc Ave Error	7.7%	22.7%	8.7%	3.1%	-6.9%	0.2%	-1.6%
Conc Median Error	136.5%	-2.3%	-27.5%	-35.3%	76.2%	-3.2%	62.8%
Load Ave Error	0.4%	5.2%	1.7%	0.1%	-1.5%	0.0%	-0.1%
Load Median Error	-7.7%	-59.8%	61.1%	47.1%	-21.0%	-37.8%	-18.7%

(Table 11. Continued)

Site	**Cottonwood R at US-14 Brg, 1 mi NE Lamberton**	**Watonwan R Br on CSH-13, 1 mi W of Garden City**	**Le Sueur R Mn-66 1.5 mi NE of Rapidan**	**Maple R At CSAH 35 5.2 mi S of Mankato**	**Cobb R at CSAH-16, 4.4 mi NE of Good Thunder**	**Le Sueur R at CSAH-8, 5.1 mi SSE of Mankato**	**Blue Earth R 150 Ft dnst of Rapidan Dam**
STORET Code	S002-247	S000-163	S000-340	S002-427	S003-446	S003-860	S001-231
Count	210	502	251	378	210	205	240
Conc Ave Error	17.5%	-423.8%	39.2%	14.6%	-162.7%	164.7%	-18.9%
Conc Median Error	5.7%	-13.5%	11.5%	-0.2%	51.0%	2.9%	4.9%
Load Ave Error	123.3%	15.6%	12.2%	19.0%	161.7%	-25.1%	-4.3%
Load Median Error	0.1%	-1.3%	0.6%	0.1%	15.3%	0.0%	0.7%

(Table 11. Continued)

Site	**Elm Creek at 290th Ave - 4.5 mi NE of Granada**	**Minnesota River at Mankato**	**Minnesota R Bridge on US-71 and MN-19 at Morton**	**Minnesota R at CSAH 42 at Judson**	**Sevenmile Ck In Sevenmile Ck Cty Pk**	**Minnesota R at MN-99 in St. Peter**	**High Island Cr., CSAH-6, Henderson**
STORET Code	213	45	165	199	261	239	297
Count	213	45	165	199	261	239	297
Conc Ave Error	-31.7%	77.6%	-43.1%	-58.8%	-710.8%	-39.3%	16.6%
Conc Median Error	-3.5%	9.6%	-1.5%	5.7%	2.5%	6.4%	1.3%
Load Ave Error	126.7%	34.7%	92.3%	66.8%	-43.5%	42.6%	-55.6%
Load Median Error	0.5%	0.6%	-0.5%	0.3%	0.0%	1.8%	-0.1%

(Table 11. Continued)

Site	Rush River, SH-93 by Henderson	Bevens Cr.,CSAH-41 by East Union	W Chaska Ck, 250' W of Cty Rd 10
STORET Code	S000-822	S000-825	S002-548
Count	266	135	129
Conc Ave Error	1.1%	27.1%	-4.4%
Conc Median Error	-7.2%	-14.0%	3.0%
Load Ave Error	-81.5%	-34.4%	-56.0%
Load Median Error	-2.3%	-3.5%	0.2%

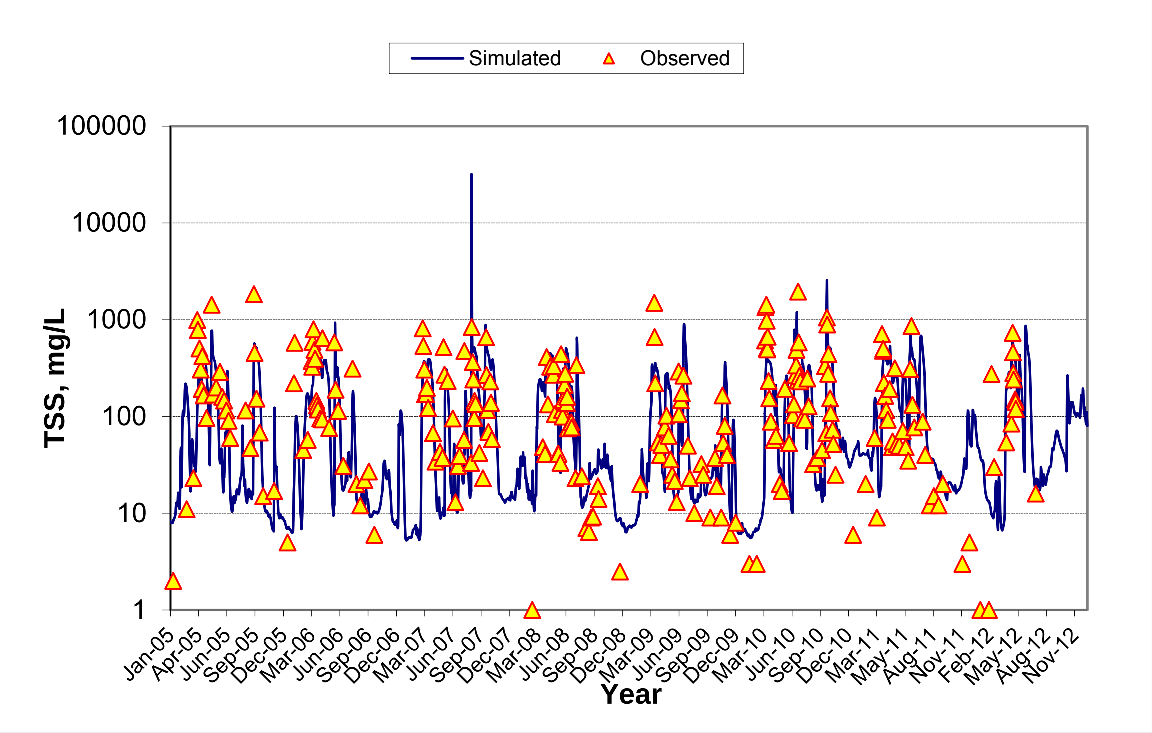


Figure 2. Timeseries Plot of Simulated and Observed TSS Concentration for Le Sueur River at MN-66 1.5 miles NE of Rapidan for 2005-2012

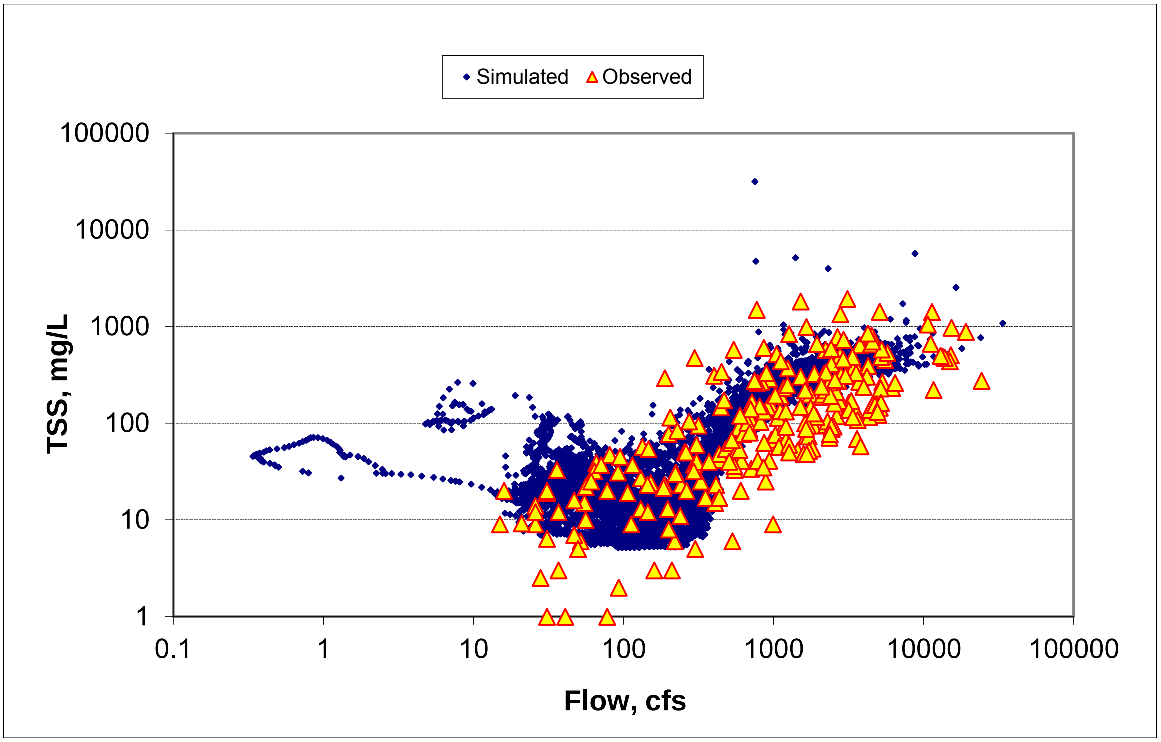


Figure 3. Concentration vs Flow Plot of Simulated and Observed TSS Concentration for Le Sueur River at MN-66 1.5 miles NE of Rapidan for 2005-2012

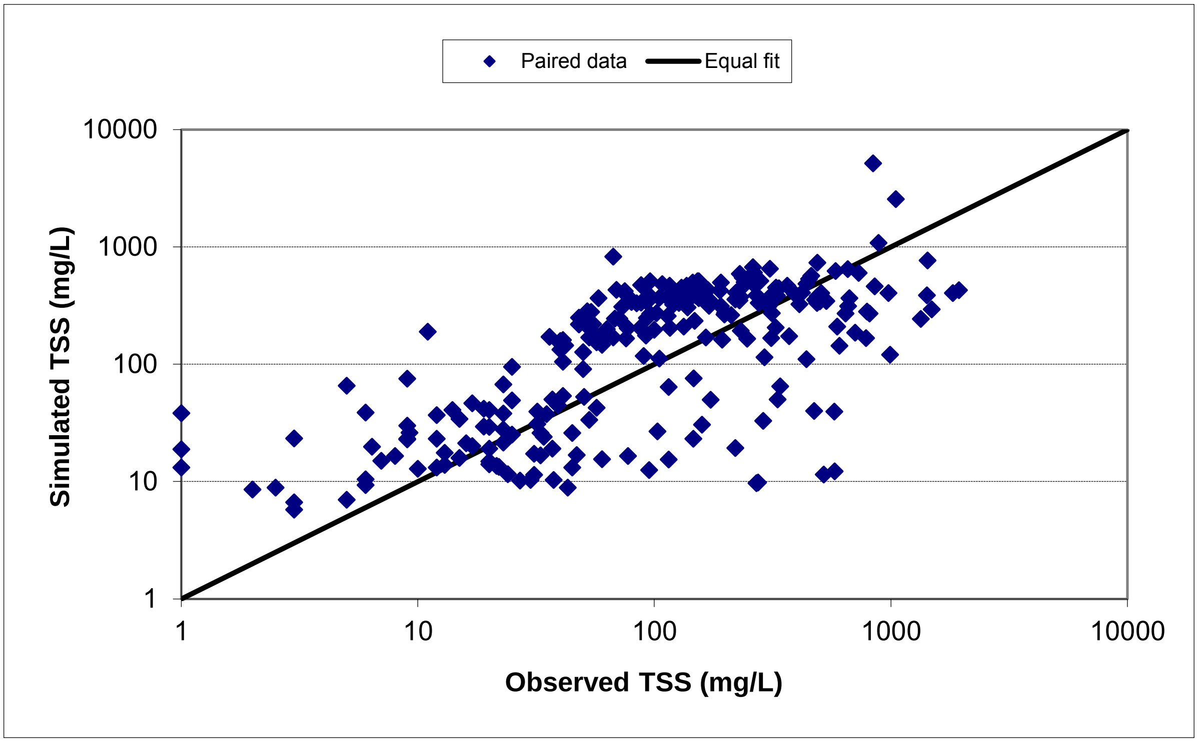


Figure 4. Simulated and Observed TSS Concentration Paired Regression Plot for Le Sueur River at MN-66 1.5 miles NE of Rapidan for 2005-2012

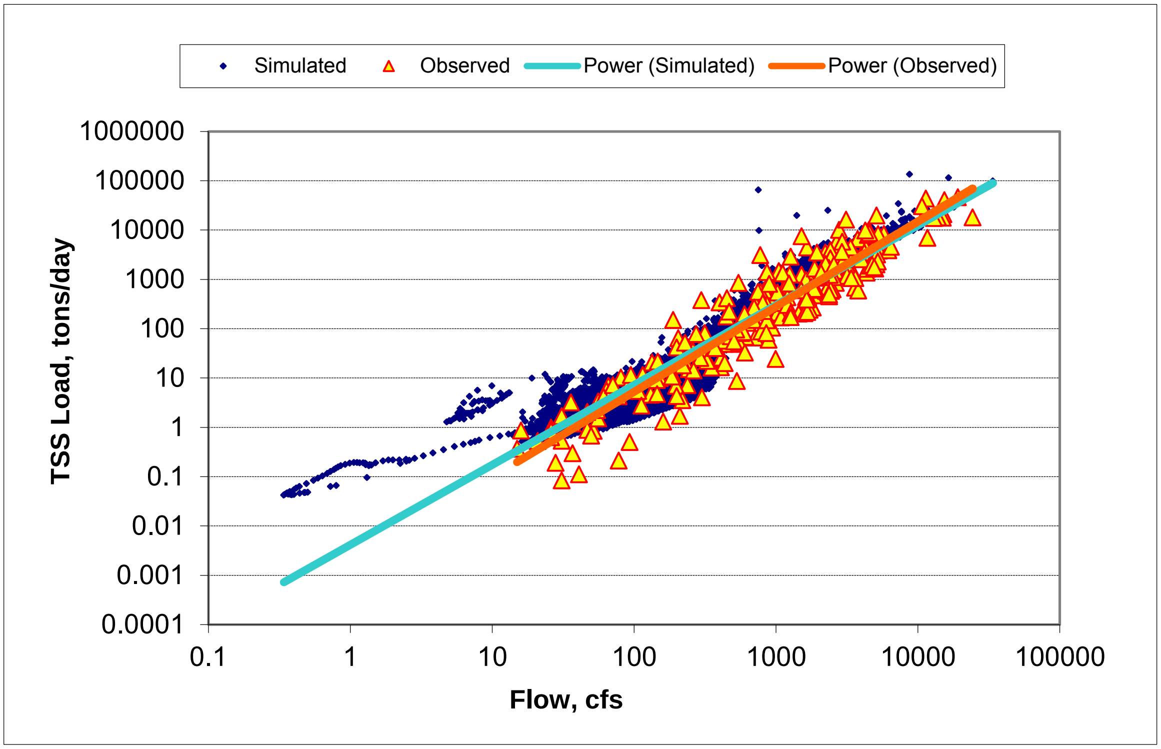


Figure 5. Load vs Flow Plot of Simulated and Observed TSS Load for Le Sueur River at MN-66 1.5 miles NE of Rapidan for 2005-2012

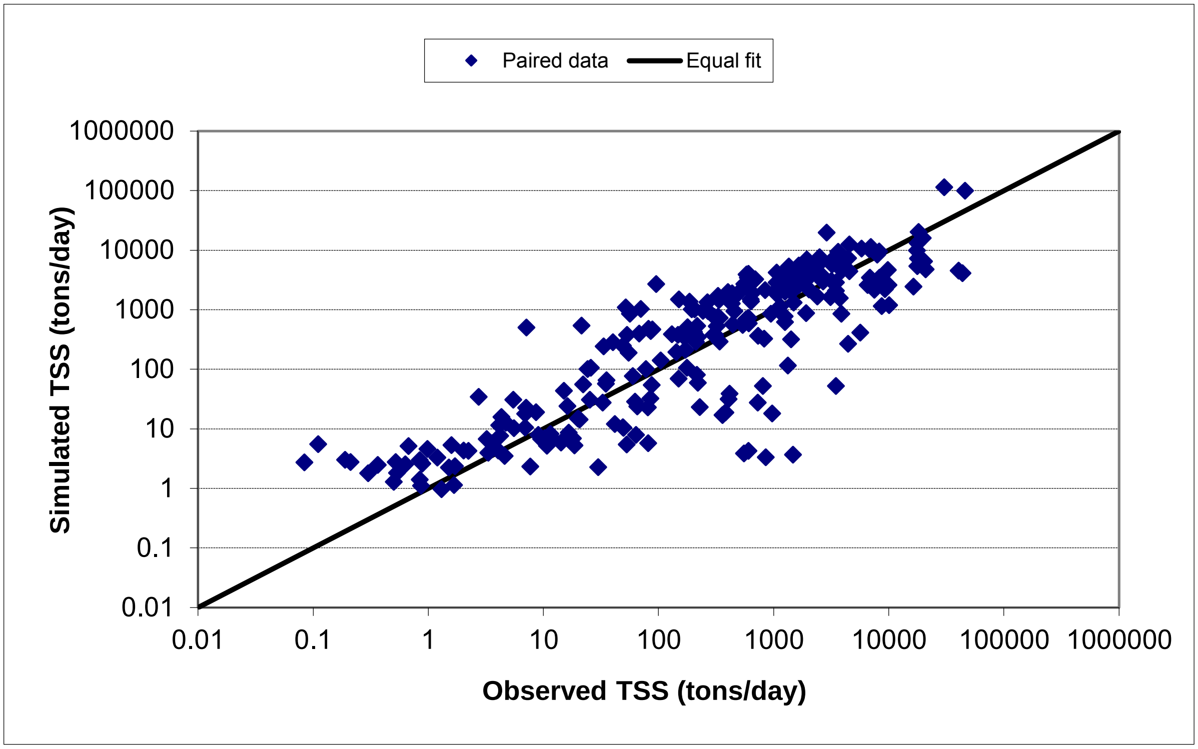


Figure 6. Simulated and Observed TSS Load Paired Regression Plot for Le Sueur River at MN-66 1.5 miles NE of Rapidan for 2005-2012

5.2.2 Validation Stations

The parameters developed during calibration were applied without modification to the validation stations. Table 12 (in five parts) shows the statistical results for the validation gages. Similar to the calibration stations the quality of fit is generally in the good to very good range for concentration and load median errors but from very good to poor for concentration and load average errors. There are a few validation stations that have poor fit for both averages and medians (e.g., Shakopee Creek S002-209 and High Island Creek S001-891). Model performance could likely be improved at individual stations; however, the parameters were not modified due to the desire to maintain spatial homogeneity across all models in the upland parameters and maintain reach homogeneity within each individual model.

Graphical examples of the calibration for Little Cottonwood River at Apple Road are provided in Figure 7 through Figure 11. While fit is reasonable at this station, the model appears to under-estimate suspended sediment concentrations observed at high flows Results for all other validation gages are contained in the electronic files.

Table 12. Summary Statistics for Validation Stations

Site	**Dry Weather Creek, at 85th Ave NW, 4 mi NE of Watson**	**Shakopee Ck ,S Andrew Rd at Lk Andrew Otl**	**Little Chippewa R at Mn-28, 4 mi W of Starbuck**	**Chippewa R, EB, at 15th Ave NE, 2.5 mi N of Benson**	**W Fk Beaver Ck at CSAH-4 6.5 mi S of Olivia**	**Sacred Heart Ck at CSAH-15 Br, 5 mi NW of Delhi**	**Palmer Ck at 15th Ave SE, 2 mi NW of Granite Falls**
STORET Code	S002-204	S002-209	S004-705	S005-364	S000-405	S001-341	S002-136
Count	322	116	64	307	234	131	126
Conc Ave Error	17.8%	715.2%	-96.4%	-4.0%	-189.5%	-321.7%	107.9%
Conc Median Error	-2.5%	258.1%	37.9%	1.0%	-14.9%	19.5%	6.9%
Load Ave Error	-63.0%	474.3%	-21.0%	25.2%	418.1%	-52.1%	-25.5%
Load Median Error	0.0%	182.3%	8.7%	0.3%	0.5%	0.4%	0.4%

(Table 12. Continued)

Site	**Hawk Ck, at CR-116, 1.25 mi S of MN-40**	**Chetomba Ck, 5 mi SE of Maynard**	**S Br Yellow Medicine R on CSAH-26**	**CD-119 at CSAG-15, 5.6 mi S of Sacred Heart**	**Timms Ck at CSAG-15, 2.8 mi NNE of Delhi**	**Clear Ck Cr, 1/3 mi upst confl Redwd R**	**Three Mile Ck at CR-67, 1 mi N Green Valley**
STORET Code	S002-140	S002-152	S002-320	S003-866	S003-867	S002-311	S002-313
Count	368	374	105	96	124	208	209
Conc Ave Error	-141.1%	35.7%	89.6%	33.2%	34.6%	-7.9%	-47.9%
Conc Median Error	-8.7%	17.0%	20.6%	8.2%	7.9%	-6.5%	-14.4%
Load Ave Error	60.7%	61.4%	36.8%	-69.3%	-62.6%	150.3%	-18.3%
Load Median Error	-2.1%	0.2%	0.8%	0.4%	0.1%	-0.1%	-0.4%

(Table 12. Continued)

Site	Plum Creek At CSAH 10 Br	Sleepy Eye Cr at CSAH 8 Br, 2.2 mi N of Leavenworth	Unn Trib To Big Cobb R, 0.5 mi N Beauford	Le Sueur R at CSAH 28 In Saint Clair	Little Cobb nr CSAH-16, 6.3 mi W of Pemberton	Maple R at CSAH-18, 2 mi N of Sterling Center	Dutch Creek at 100th St, 0.5 mi W of Fairmont
STORET Code	S001-913	S001-919	S001-210	S003-448	S003-574	S004-101	S003-000
Count	193	221	201	181	250	232	202
Conc Ave Error	-993.4%	-84.9%	-22.3%	-97.4%	-223.6%	-118.1%	-367.7%
Conc Median Error	-1.6%	1.5%	-1.2%	-5.2%	-19.4%	-11.6%	6.1%
Load Ave Error	-10.4%	20.4%	102.4%	84.1%	210.4%	280.2%	23.5%
Load Median Error	0.0%	0.1%	-0.1%	-0.3%	-0.8%	-0.5%	0.1%

(Table 12. Continued)

Site	Center Creek at 315th Avenue - 1 mi S of Huntley	Sevenmile Ck dwst of MN-99, 6 mi SW of St. Peter	CD 46A dwst of CSAH-13, 6 mi SW of St. Peter	Little Cottonwood R at Apple Rd, 1.6 mi S of Courtland*	Silver Cr.,CSAH-41 by East Union	Buffalo Ck, at 270th St, 1.5 mi NW of Henderson	High Island Ck at CSAH 9, 1 mi NW of Arlington
STORET Code	S003-024	S002-934	S002-936	S004-609	S000-843	S001-807	S001-891
Count	220	197	188	212	113	276	274
Conc Ave Error	-39.4%	118.0%	474.9%	35.5%	17.0%	24.6%	987.1%
Conc Median Error	-15.2%	27.7%	5.7%	-0.6%	2.3%	3.0%	131.7%
Load Ave Error	28.0%	288.3%	15.3%	-9.9%	-15.0%	-91.1%	551.2%
Load Median Error	-1.1%	3.8%	0.1%	0.0%	0.3%	0.0%	75.3%

(Table 12. Continued)

Site	Carver Ck at US-212, 2.5 mi E of Cologne	Carver Ck at Cr-140, 2.3 mi NE of Benton	Bevens Ck at 321st Ave, 3 mi SE of Hamburg	Bevens Ck at Rice Ave, 3.9 mi SE of Norwood Yng America
STORET Code	S002-489	S002-490	S002-516	S002-539
Count	165	164	116	153
Conc Ave Error	-40.1%	-98.3%	41.2%	-73.0%
Conc Median Error	-16.2%	153.4%	3.2%	-5.4%
Load Ave Error	-47.8%	499.4%	-42.9%	3.3%
Load Median Error	-4.7%	42.0%	0.5%	-0.6%

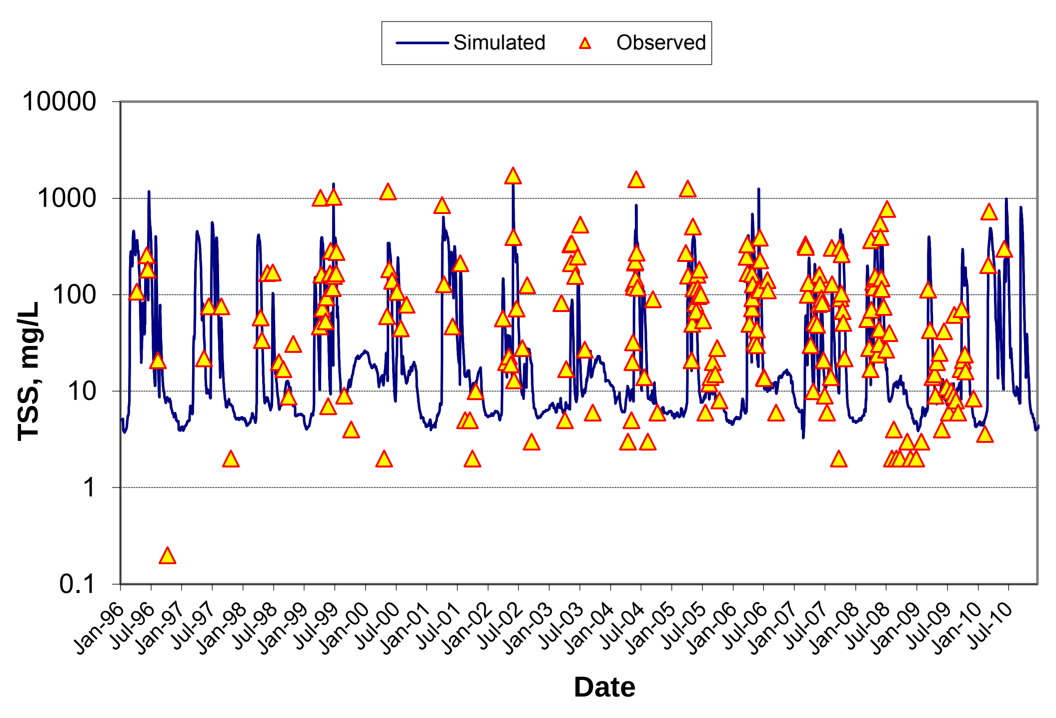


Figure 7. Timeseries Plot of Simulated and Observed TSS Concentration for Little Cottonwood River at Apple Road for 1996-2010

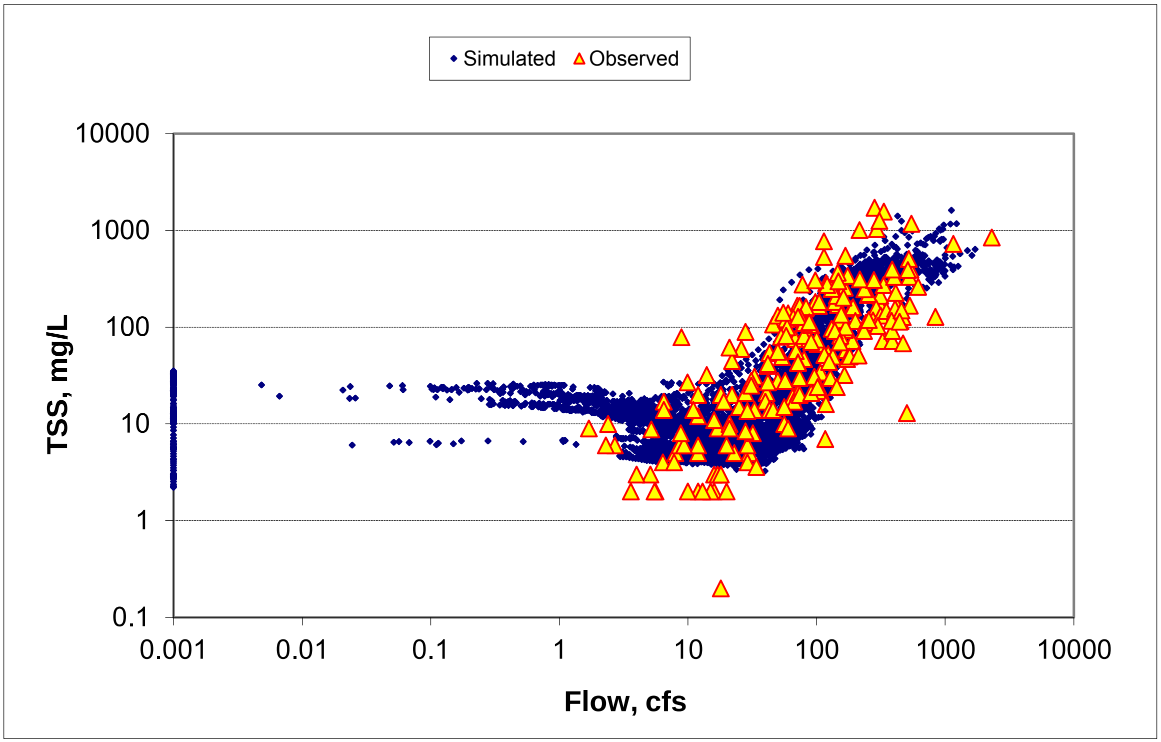


Figure 8. Concentration vs Flow Plot of Simulated and Observed TSS Concentration for Little Cottonwood River at Apple Road for 1996-2010

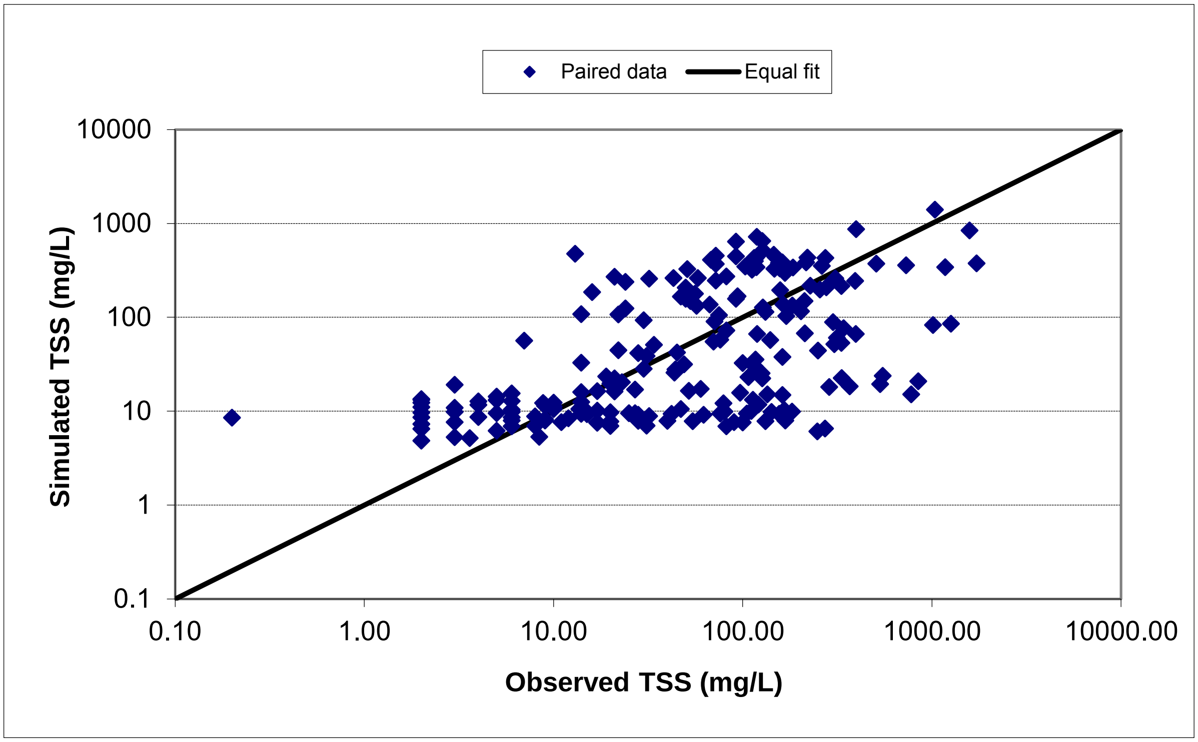


Figure 9. Simulated and Observed TSS Concentration Paired Regression Plot for Little Cottonwood River at Apple Road for 1996-2010

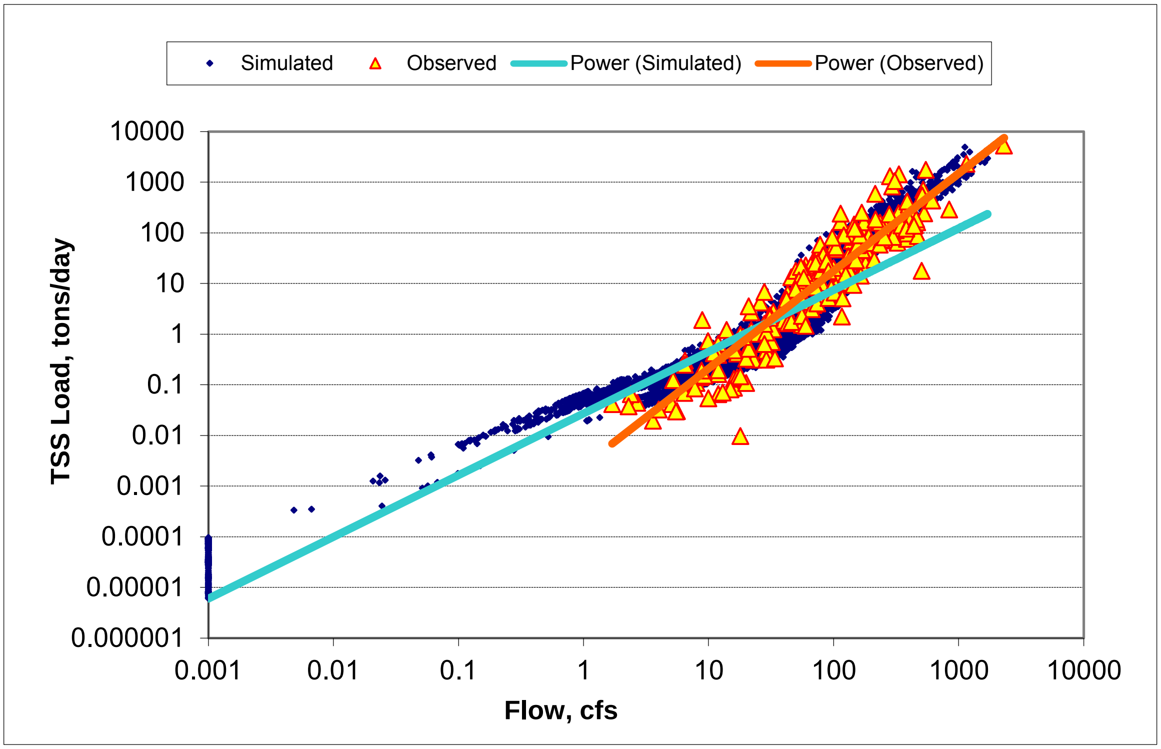


Figure 10. Load vs Flow Plot of Simulated and Observed TSS Load for Little Cottonwood River at Apple Road for 1996-2010

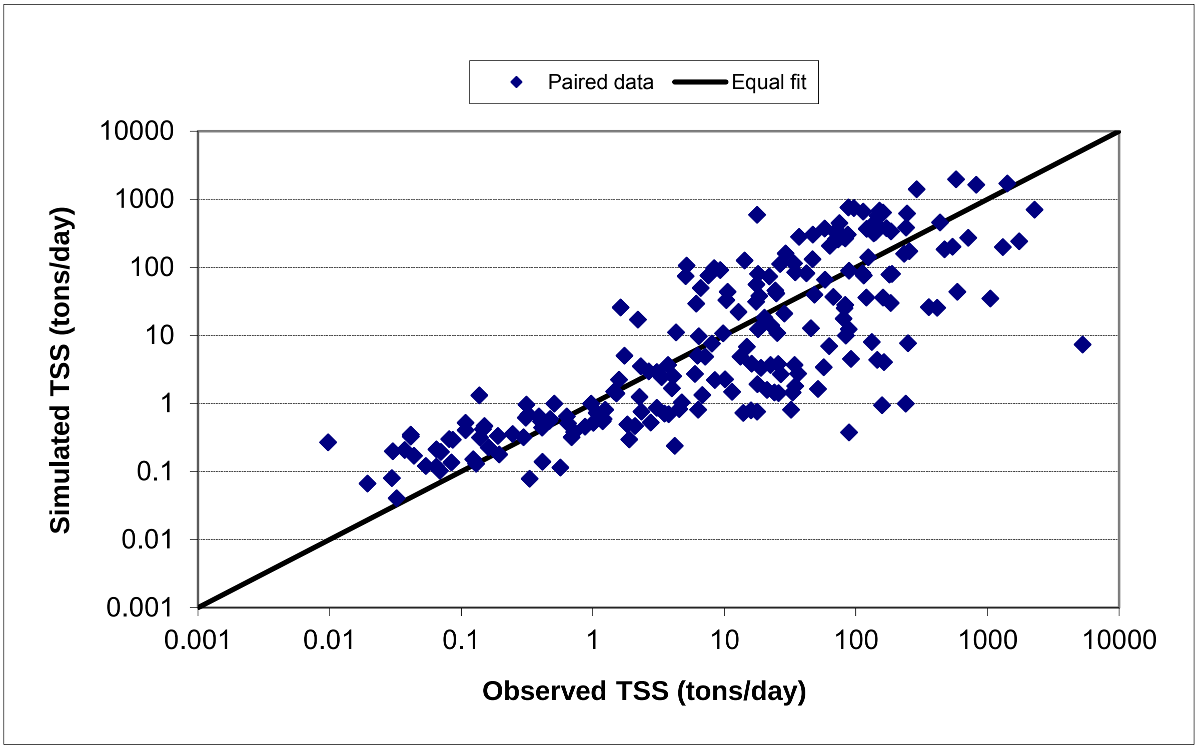


Figure 11. Simulated and Observed TSS Load Paired Regression Plot for Little Cottonwood River at Apple Road for 1996-2010

5.3 COMPARISON TO FLUX LOADS

MPCA's Watershed Pollutant Load Monitoring Network (WPLMN) is designed to obtain spatial and temporal pollutant load information from Minnesota's rivers and streams and track water quality trends. As part of this program, MPCA releases estimates of annual pollutant loads for each 8-digit hydrologic unit code basin. These "observed" monthly loads are estimated using the USACE FLUX32 program (a Windows-based update of the FLUX program developed by Walker, 1996; available at https://www.pca.state.mn.us/water/watershed-pollutant-load-monitoring-network#flux32-8f1620f5), and are themselves subject to significant uncertainty.

MPCA estimates at the downstream gage station on each of the HUC-8 watersheds within the Minnesota River basin are currently available for calendar years 2007 – 2011. The model and FLUX estimates are compared in Figure 12. While the fit is generally close, there are some discrepancies at individual stations during 2011 and 2012 where FLUX estimates are higher than loads produced by the model.

Figure 12. Comparison of Model and FLUX TSS Load Estimates, Calendar Years 2007 - 2011

5.4 SEDIMENT SOURCE APPORTIONMENT

Provided below are results for simulated source apportionment at the mouth of each 8-digit (HUC). Results at the mouth include the influence of upstream model(s) if one or more exist. As previously stated each model had its own unique processing workbook created and those are provided in electronic format as a supplement to this memorandum. Each electronic workbook contains source apportionment at additional locations in each watershed. Also include are the incremental or local drainage area contributions for those locations that receive influence of upstream model(s). Specifically for Le Sueur, the between stations (between upper and lower stations) source apportionment has been calculated. This allows you to see the proportion and amount of sediment generated in the nick zone area for each drainage basin. Table 13 provides the average annual sediment load and source percentage at the mouth of each model.

Figure 13 (in two parts) shows the source percentage as pie charts which are similar to how source apportionment was shown in the Le Sueur and Greater Blue Earth sediment budgets. The Le Sueur and greater Blue Earth produce sediment source apportionment (mass and percentage) that are consistent with the full sediment budgets, while the other basins approximately replicate the upland source fraction attribution provided in Table 1 (see Figure 13). An exact match is not expected because the model results are for 1995 – 2012, while the radiometric source data are primarily depositional sediment cores collected in 2007 and 2008 that integrate over an uncertain time period.

Also provided in Table 14 and Figure 15 is an apportionment of the annual average sediment load at the mouth of the Metro model for each HUC8 watershed contributing to that point. Note, the Lac Qui Parle is not explicitly modeled as part of the Minnesota River Basin HSPF model suite but it is represented like a point source input to the Hawk Yellow Medicine model.

Table 13. Summary of Source Apportionment at the Mouth of each HUC8

HUC8	Metric	Upland	Ravine	Bluff	Stream	Total
Chippewa	Mass (ton/year)	4,309	66	2,107	5,518	12,000
	Source Percentage	36%	1%	18%	46%	100%
Redwood	Mass (ton/year)	11,438	937	17,180	12,572	42,127
	Source Percentage	27%	2%	41%	30%	100%
Hawk Yellow Medicine	Mass (ton/year)	71,513	2,564	64,997	67,262	206,336
	Source Percentage	35%	1%	32%	33%	100%
Cottonwood	Mass (ton/year)	31,846	1,492	75,227	50,067	158,633
	Source Percentage	20%	1%	47%	32%	100%
Watonwan	Mass (ton/year)	12,602	2,283	21,451	8,483	44,819
	Source Percentage	28%	5%	48%	19%	100%
Le Sueur	Mass (ton/year)	59,352	32,103	135,185	18,837	245,477
	Source Percentage	24%	13%	55%	8%	100%
Blue Earth	Mass (ton/year)	127,406	40,968	284,940	93,384	546,698
	Source Percentage	23%	7%	52%	17%	100%
Middle	Mass (ton/year)	289,417	48,976	482,842	297,839	1,119,074
	Source Percentage	26%	4%	43%	27%	100%
Lower/Metro	Mass (ton/year)	331,411	53,414	624,074	354,566	1,363,464
	Source Percentage	24%	4%	46%	26%	100%

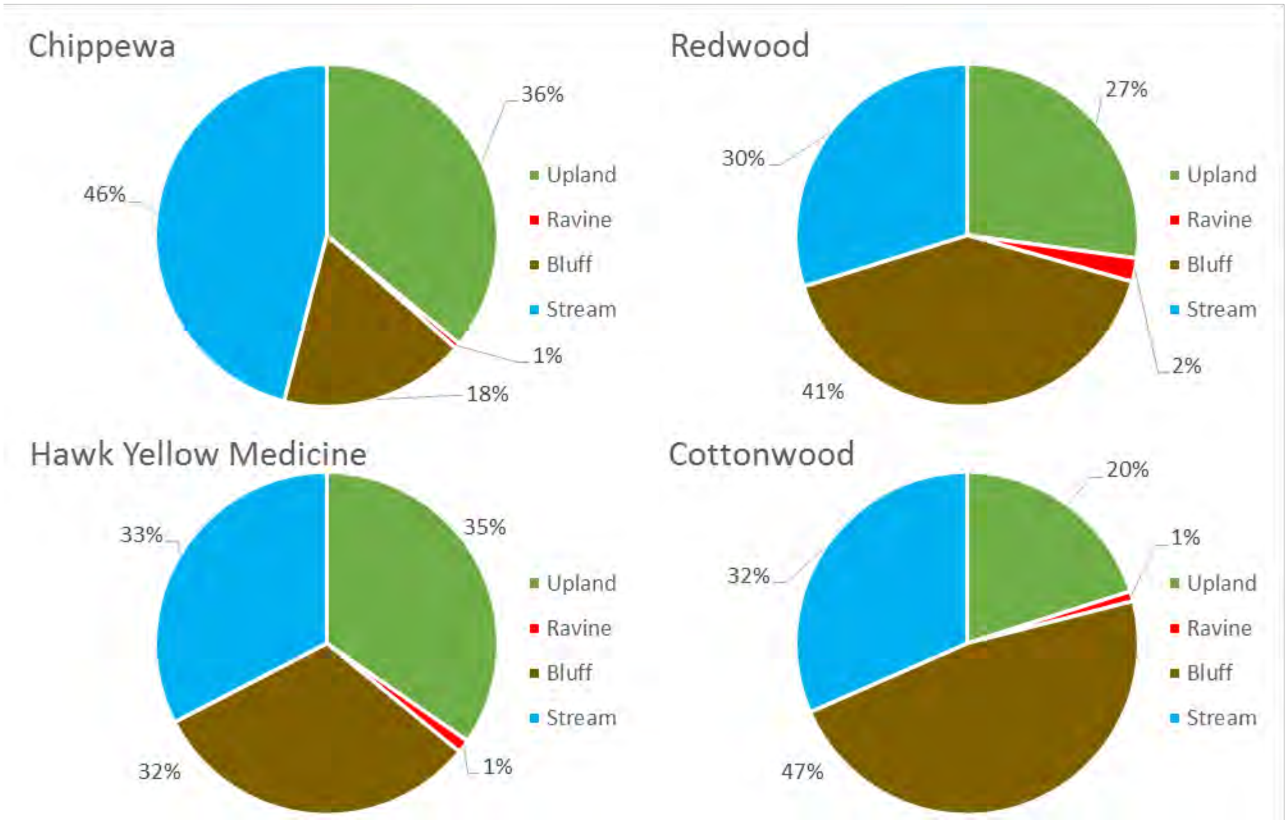
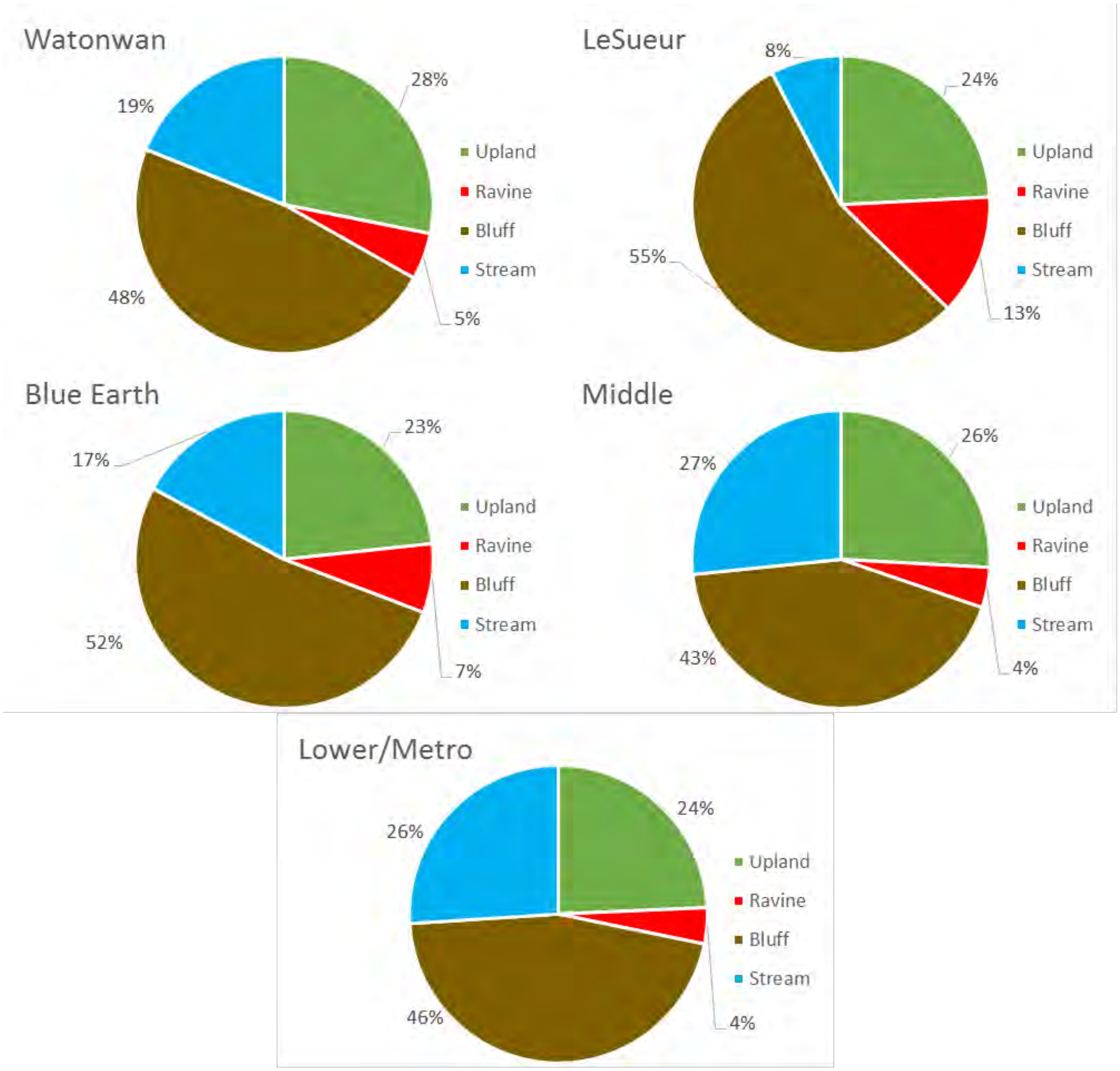


Figure 13. Instream Sediment Source Apportionment at HUC8 Outlets



(Figure 13 Continued, Instream Sediment Source Apportionment at HUC8 Outlets)

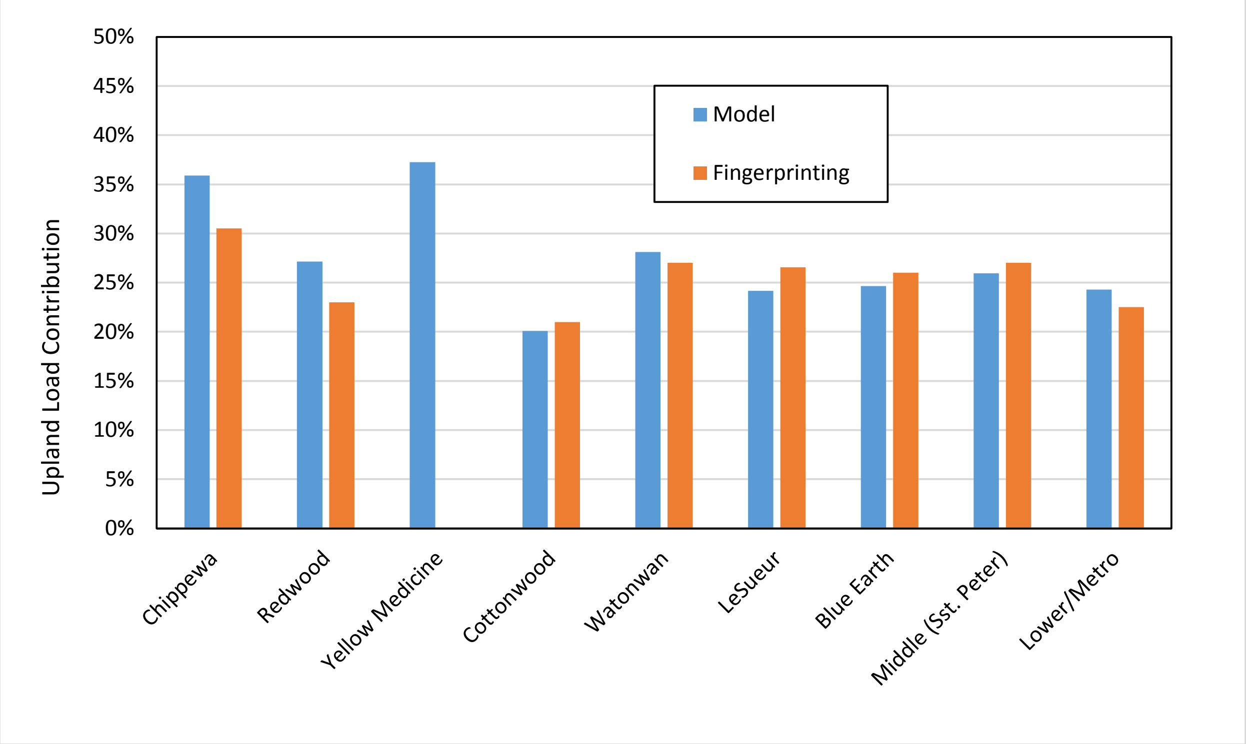


Figure 14. Comparison of Simulated Surface Washoff Loading to Surface Source Fraction from Sediment Fingerprinting Analysis

Note: Refer to Table 1 for sediment source attribution targets.

Table 14. HUC8 Contributions to Sediment Load at the Mouth of the Metro Model

Watershed	Sediment Ton/year	Percent of Total
Chippewa	12,000	0.9%
Redwood	42,127	3.1%
Hawk Yellow Medicine	104,604	7.7%
Lac Qui Parle	54,269	4.0%
Cottonwood	158,633	11.6%
Watonwan	44,819	3.3%
LeSueur	245,477	18.0%
Blue Earth	256,370	18.8%
Middle	200,776	14.7%
Lower	127,446	9.3%
Metro	116,948	8.6%
Total at Metro Mouth	1,363,464	100.0%

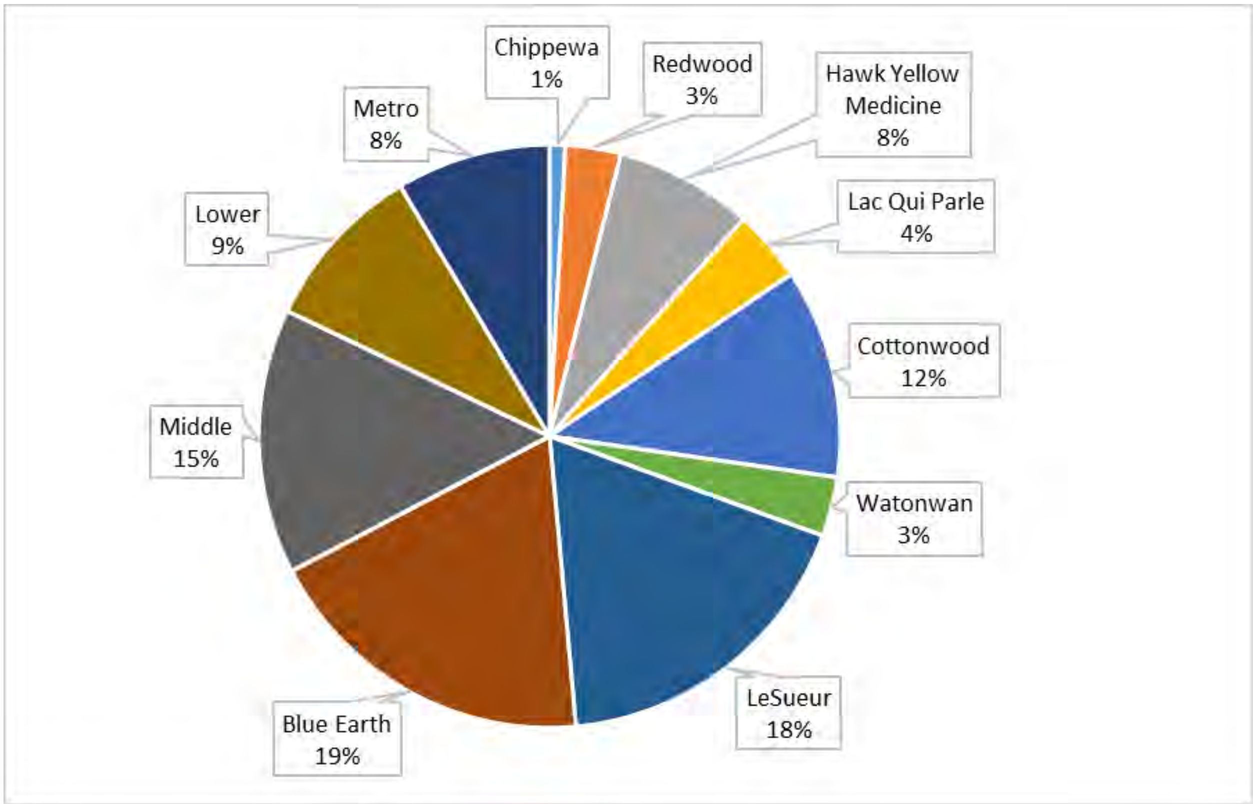


Figure 15. HUC8 Contributions to Sediment Load at the Mouth of the Metro Model

6 Summary and Potential Enhancements

The primary motivation for the sediment recalibration for the Minnesota River Basin was to better represent the source attribution information available from radiometric data and the detailed sediment source budgets for the Greater Blue Earth basin. Adjustments to the calibration to better simulate observed suspended sediment concentration data was also pursued, but under a constraint to use a relatively parsimonious parameter set that kept sediment parameters that are not based on observed soils and geological data at values that are generally constant across a basin for a given land use or waterbody type. Better fits to observed data could likely be obtained at many observation sites if more site-specific calibration with local parameter adjustments was pursued. While such an approach is likely to provide better model fit statistics it also raises the danger of over-calibration. Before taking such an approach it would be wise to consider several other factors that may be contributing to model uncertainty and potential enhancements that might improve overall model performance. Among other issues, the following items should be considered if the models are further developed:

1. **Meteorological Data**: The current model refinements make use of the meteorological time series developed by RESPEC (2014). These are based on point rainfall measurements and are often derived from volunteer daily total observations that have been disaggregated based on nearest available hourly station templates. We have seen through previous model applications that point gauges can be un-representative of the areal average precipitation depth over a model sub-basin, especially during summer convective storms, which often have local variability. The switch back to point gauge measurements appears to have resulted in a significant decline in hydrologic calibration performance in the model Chippewa basin, which has strong precipitation gradients but rather limited precipitation gauging. Further, temporal disaggregation to a template station that is some distance away can incorporate significant biases in the timing of major rainfall events, which in turn translates into apparent mismatches between model simulation and observed sediment concentrations. The newest generation of PRISM gridded precipitation products (which incorporate gage data, NEXRAD radar precipitation intensity information, and regressions against topographic characteristics) provide a potentially stronger approach to estimate the average precipitation characteristics on a reach. Downscaling to an hourly scale in the absence of nearby hourly template stations may be better achieved by using a fractal simulation approach to assign random intra-day intensities rather than assuming timing is synchronized with the template station. Potential evapotranspiration time series construction is also an issue as the energy inputs (e.g., solar radiation, dew point, wind) are often not available for rural areas and are translated from distant airport stations. The gridded NLDAS evapotranspiration estimates may provide a better means of estimation for areas far from first-order airport meteorological stations. Improvements in the representation of storm hydrology would lead directly to improvements in the simulation of sediment washoff and channel erosion during large storm events, which typically move the majority of sediment in a given year.
2. **Hydraulics**: The current models incorporate only limited information on channel hydraulics. RESPEC (2014) created much finer-scale models than the earlier Tetra Tech (2008) models. This required the development of new hydraulic functional tables (FTables), expressing the relationship between reach storage volume, outflow, surface area, and depth. These calculations in turn determine the shear stress exerted on the channel. As channel erosion has been identified as a major contributor to the total sediment load in the basin this component of the model is critical. The RESPEC memoranda say that for reaches where Tetra Tech previously calculated FTables using results of HEC-RAS models, those FTables “will be scaled by reach length and applied to corresponding reaches in order to maximize the use of the best available data.” For reaches that did not have HEC-RAS models, the documentation implies that cross-sectional measurements at USGS gage sites will be used, and, when field information on a gage is not

available, "the USGS maximum width, depth, and area data will be used to calculate cross-sections assuming a trapezoidal channel and a bank slope of 1/3." Exact details of how FTables were developed for individual reaches are not provided. It is clear, however, that a scaling approach related to gage data can introduce problems because gage rating curves are often developed at constrictions, such as bridge crossings. Similarly, FTables derived from HEC models should be re-calculated based on new reach lengths (not scaled relative to coarser determinations) to incorporate the information available in the HEC models. Re-evaluation of HEC model output plus analysis of measured cross-sections would likely improve the hydraulic performance – and thus the channel sediment scour performance – of the models. Related to this topic, we noted that the 2014 models omit representation of Rapidan Dam on the Blue Earth River. While the pool behind Rapidan Dam is largely silted up, the dam does have an effect on hydraulics and sediment transport in the lower Blue Earth, which is a major source of sediment load to the lower Minnesota River. Therefore it should be important to incorporate the effects of this structure into the models.

3. **Ravine and Bluff Areas**: At the start of this work assignment it was anticipated that new information on the extent of ravine and bluff land use areas would be provided for each HUC8 watershed. Those coverages have not been finalized (and the current bluff coverage based on LiDAR appears to delineate features such as ditch banks as "bluffs," which is not particularly useful to basin-scale modeling). When these delineation efforts are completed the models should be updated to incorporate the information.
4. **Parameters for Manured Land**: It required a considerable amount of time to reach an agreement with MPCA on the appropriate approach to determine the land area that received manure applications. Manure applications have impacts on nutrient loading, but also change the soil structure in somewhat subtle ways that can change runoff and sediment loading impacts. Due to the delay in resolving the manured land area representation, the definition of manured area was not finalized until after the hydrologic recalibration had been completed. To avoid disturbing the hydrologic calibration, the manure application areas were specified (and area shifted from) as equal to existing conventional tillage on A/B soils. In fact, evidence (summarized in Tetra Tech, 2008) suggests that land receiving manure application should have somewhat greater upper zone storage capacity (UZSN), which in turn affects runoff sediment transport capacity. This refinement should be incorporated into any revised models.
5. **Tile Drain Sediment**: RESPEC (2014) adopted a modified approach to the simulation of sediment transport through surface tile inlets that was much simpler and more efficient than the SPECIAL ACTIONS approach implemented by Tetra Tech (2008). The revised approach gives a similar estimate of total sediment load transported by this pathway, but the pollutograph is very different, with the load transmitted to the stream much more quickly. At this point it is not clear which representation is correct, although the approach earlier use by Tetra Tech did result in a good match between observed and simulated sediment concentrations. This topic appears worthy of further investigation.

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