Project	Mustinka/Bois de Sioux HSPF model	**Date**	10/15/2014
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Regarding	Sediment parameterization and calibration		

Introduction

This memo documents the parameterization and calibration for sediment in the Mustinka/Bois de Sioux watersheds (MBdS) as per Objective 1, Task B of the project workplan.

The sediment parameterization and calibration efforts were primarily directed according to procedures outlined in EPA BASINS Technical Note 8: Sediment Parameter and Calibration Guidance for HSPF (TN#8; Donigian and Bicknell, 2006) and the MPCA Modeling Guidance for BASINS/HSPF Applications Under the MPCA One Water Program (MPCA Guidance Doc; Aqua Terra, 2013). In addition, initial and calibrated parameterizations utilized values from previous HSPF models completed in Minnesota, as available in the HSPFparmV2 MS Access database, particularly, the HSPF models for the Chippewa and Pomme de Terre watersheds which possess fairly similar climate, topography and soil characteristics as the MBdS watersheds. The efforts also incorporated information and data from work detailed in the memo sent 12/11/2012 entitled *Objective 1, Task A: Sediment Source Apportionment – Mustinka/Bois de Sioux Watersheds.*

Approach

The sediment parameterization and calibration approach followed the methodology documented in TN#8 and summarized below. This memo will discuss the efforts and results from each step.

1. Estimating target (or expected) sediment loading rates from the landscape, often as a function of topography, land use, and management practices

2. Calibrating the model loading rates to the target rates

3. Adjusting scour, deposition and transport parameters for the stream channel to mimic expected behavior of the streams/waterbodies

4. Analyzing sediment bed behavior (i.e. bed depths) and transport in each channel reach as compared to field observations

5. Analyzing overall sediment budgets for the land and stream contributions, along with stream aggrading and degrading behavior throughout the stream network

6. Calibration: Comparing simulated and observed sediment concentrations, including particle size distribution information, and load information where available

1. Estimating target (or expected) sediment loading rates from the landscape, often as a function of topography, land use, and management practices

Establishing target rates for HSPF Pervious Land Segment (PLS) field erosion (rain detachment plus surface runoff transport to streams) is necessary because HSPF does not have a physically or empirically constrained erosion algorithm (e.g., USLE). It requires target erosion rates calculated through other means to provide constraints for the HSPF detachment and washoff processes. These coupled processes can be generalized as follows: HSPF simulates what mass of soil is detached by rainfall events and stored on the surface as sediment. A certain fraction of this stored sediment – and that detached and stored previously – is then transported via surface runoff – from current and/or future rainfall or snowmelt events – to the nearest channel. Coefficients and exponents for HSPF equations associated with these processes are adjusted until HSPF erosion delivered to the channel matches the target rates.

Estimated target erosion rates (expressed as tons/ac/year for row-crops) were established after considering several lines of evidence: (1) a calibrated SWAT model constructed by B. Kurz at the Energy & Environmental Research Center (EERC) in 2008 to serve the MBdS turbidity TMDL and related BMP planning and implementation efforts (in MPCA, 2010), (2) results of an AnnAGNPS model constructed for the South Branch of the Buffalo River by Lauer et al. (2006), (3) a SWAT model constructed by EOR specifically for estimation of field erosion and sediment yields in the MBdS; the model was roughly calibrated based on total runoff volume and surface/sub-surface runoff fractions resulting from the HSPF hydrologic calibration phase, (4) analysis of observed TSS and suspended sediment (SS; derived by removing the organic, volatile fraction of TSS) loads at the Mustinka outlet (USGS 0540900) which helped constrain lower bound field erosion estimates, A summary of these target rates is presented below in Table 1.

Table 1. Row-crop target sediment yield rates (field erosion and delivery to channels) for the MBdS according to multiples sources.

Source	Sim./Calib. Periods	Est. Sed. Yld (tons/ac/yr) BdS	Est. Sed. Yld (tons/ac/yr) Mustinka
MBdS SWAT model: EERC/MPCA, 2006	1970-2007 1990-2007	0.20	0.16
S.Br. Buffalo River AnnAGNPS model: Lauer et al, 2006	2002-2005 1978	0.9*	0.9*
MBdS SWAT model: EOR, 2014	2003-2006 2003-2006	0.11	0.06
Mustinka outlet TSS/SS loading analysis: EOR, 2014	2001-2006 NA	NA	0.04**

* Area weighted estimates applied to MBdS watersheds based on rates simulated for S. Br. Buffalo R. watershed Agassiz lake plain and glacial moraine landscape types

** Represents sediment yield at the outlet after presumed stream and lake deposition – used to define lower bound on sediment yield estimates

Table 1 shows that predicted rates vary significantly amongst studies, periods and models used. Ultimately, EOR's SWAT model was used to establish target rates primarily because the EERC SWAT model results reflect a mean response over a much longer simulation period than the HSPF simulation period specifically chosen for use in EOR's SWAT model; it was assumed that both models would yield similar results over the same periods but the EOR model would apply directly to the climate conditions present during the HSPF simulation period. Both models' estimates are consistent with the TSS/SS total loading analysis when some degree of lake and stream deposition between the field sources and the outlet are taken into account.

Before field erosion rates could be calibrated, detached sediment storages associated with agricultural practices had to be applied to the model. The DETS parameter (the daily detached sediment storage on fields available for washoff) was adjusted for four scheduled practices: spring plowing (April 25), planting (May 1), row cultivation (June 15) and harvest (Oct 15); values were set to 2.0, 1.5, 1.0 and 0.7 tons/ac, respectively, based on past HSPF models constructed in the MN river basin, and EOR's review of tillage practices in the MBdS suggesting a high proportion of farmers use mulch tillage. The DETS parameter adjustments were made using the SPEC-ACTIONS block in the HSPF UCI. Lastly, the AFFIX parameter was adjusted so a very gradual reduction in DETS was observed between scheduled SPEC-ACTIONS DETS adjustments.

2. Calibrating the model loading rates to the target rates

Once target rates were established, HSPF parameters KSER and JSER (coefficient and exponent for the washoff relationship) were adjusted for *non-depressional* row-crop PLS's until predicted erosion matched the target rates. This is because the SWAT erosion rates (EOR and EERC) did not take into account depressional storage. Once the target rates were matched the resulting values were applied to the depressional row-crop PLS's. While the washoff parameters were fixed regardless of depressional/non-depressional, PLS's with significant depressional storage still yielded less sediment due to the reduced surface runoff potential – an effect and process that is physically realistic. Note: the detachment parameters KRER and JRER were held fixed. KRER was held at 0.24 – the area-weighted average USLE K factor for both AB and CD soils in the watersheds calculated from SSURGO soils data; JRER was kept at the default value of 2.0.

The erosion parameterization approach was influenced by the enhanced segmentation conducted as part of the hydrologic calibration phase, principally the extent of depressional storage calculated using LiDAR terrain analysis. Simulated net surface runoff (i.e., surface runoff that reaches the channel network) was shown to be very sensitive to the depressional storage depth parameterization (expressed as an increase in upper-zone-storage-nominal: UZSN) per meteorological segment, pervious land segment (PLS) and subbasin. Because surface runoff is the primary factor in sediment delivery and it was parameterized to a high degree of spatial explicitness, the assertion was that the sediment washoff parameterization (i.e., primarily params KSER and JSER) could be kept consistent across PLS's avoiding unneeded parameter complexity.

The last task in this step was to partition the field sediment entering the stream into size fractions of sand, silt and clay. This was accomplished by adding a two series of lines to the MASS-LINK block for AB and CD soils using sand/silt/clay ratios of 18/49/33 and 13/47/40, respectively (i.e., CD soils were composed of more fines and less sand than AB soils). Ratios for AB and CD soils were calculated using area-weighted averages from SSURGO soil data.

3. Adjusting scour, deposition and transport parameters for the stream channel to mimic expected behavior of the streams/waterbodies

4. Analyzing sediment bed behavior (i.e. bed depths) and transport in each channel reach as compared to field observations

5. Analyzing overall sediment budgets for the land and stream contributions, along with stream aggrading and degrading behavior throughout the stream network

After predictions of field sediment entering the stream network are judged reasonable, stream sediment transport calibration was undertaken. The approach for the MBdS relied heavily on general assertions as to geomorphic nature of the stream network. The work of Lauer et al., (2006), experience and professional judgment of Dr. Chris Lenhart (EOR, U of MN) in the region, and EOR's geomorphic assessment of 22 stream sites in the MBdS concluded two key findings relevant to constraint of stream sediment transport processes. First, unlike many watersheds in the adjacent MN river basin, MBdS stream sediment is thought to be predominantly field-based vs. near-channel based (i.e., banks and bluff). Second, aside from deposition presumably occurring in lakes and extremely low gradient ditch networks, MBdS channels don't appear to be in a state of pronounced systemic aggradation or degradation.

In light of these conclusions, stream scour and deposition were constrained in the following ways:

(1) No channel erosion targets were set to represent near-channel sediment export in the overall sediment budget at the calibration gauge sites.
(2) Lake reaches were set with scour/deposition thresholds (parameters KSAND, TAUCD, TAUCS, M) ensuring that almost all sediment entering each lake was settled and none scoured. As suggested in TN#8, these parameters values were adjusted 2 to 3 orders of magnitude from *typical* values and simulations were reviewed and repeated to ensure desired behavior.
(3) Beyond those in lakes, scour/deposition parameters were not adjusted on a per reach basis unless pronounced aggradation or degradation was simulated to be occurring.

These constraints and calibration methodology resulted in net deposition occurring in lake reaches and low gradient non-lake reaches over the calibration period and a rough balance between slight aggradation and degradation in the remaining channels.

6. Calibration: Comparing simulated and observed sediment concentrations, including particle size distribution information, and load information where available.

Observed sediment data
Total suspended solids (TSS) and flow paired grab samples were available for the Mustinka (0540900 near Wheaton, MN, 2001-2006), Bois de Sioux (5051300 near Doran, MN: 2001-2006) and Rabbit (54017001 near Campbell) sampling stations. (Note: No observed suspended particle size distributions were available.) These samples pre-processed for use with HSPF according to the methodology outlined below.

<u>Conversion of TSS to suspended sediment (SS) data</u>. Most MN watersheds contain a significant fraction of organics in their suspended load. HSPF does not model an organic fraction in its sediment simulations so TSS had to be converted to suspended sediment (SS). TSS data were first analyzed to determine the relationship between TSS, total volatile solids (TVS; many but not all TSS samples included TVS) and flow.   It was determined that MBdS suspended sediment averaged ~25% organics (both Mustinka and BdS – Doran). Further, the Mustinka showed a relationship with flow: 33% organics for flows <= 50 cfs, 20% for flows > 50 cfs. These organic proportions were subtracted from the sediment samples to create the SS datasets. Observed data for the Rabbit did not contain TVS samples so the TVS/TSS relationship for BdS –Doran was used for calculating Rabbit SS concentrations.

Conversion of TSS-SS to SSC. A recent USGS publication (Ellison et al., 2014) determined that SS was frequently under-estimated in TSS due to current TSS lab methods excluding the suspended sand that may settle out in samples. The publication compares SS samples across a subset of MN rivers with those analyzed using the more rigorous SSC (suspended sediment concentration) technique. The Buffalo river watershed was among those included in the study and is similar to the MBdS in its composition of glacial lake plain and moraine geologies. The study showed Buffalo river SS samples under-estimated SSC by 60%. Therefore, because the validity of the observed sediment data has an enormous impact on model parameterization and calibration, it was decided to use a 60% (1.6) conversion factor to all SS samples estimated to contain suspended sand. Without a more thorough analysis of particle size distribution vs. flow, it was assumed that significant sand was present in the top 50% of flows -- those greater or equal to approximately 50 cfs in Mustinka, BdS and Rabbit.

Conversion of grab samples to continuous time-series. Once the TSS grab samples were converted to SSC concentrations, they were extended into continuous time-series using statistical software and methods (similar to those employed in FLUX and LOADEST programs) based in their relationships to daily flow.

Generally, higher flows in the MBdS result in higher SSC concentrations making high flow periods the most important sediment loading events. However, quantifying statistically significant trends between flow and SSC is problematic due to the wide variability in SSC grab sample measurements at all flow ranges. To determine trends, linear and non-linear regression were tested first; if significant trends were determined to exist (using ~90% confidence or professional judgment) the daily flows were used in the regression equation to calculate a daily SSC. Mustinka linear regression analysis resulted in three seasonal relationships with flow (March-May, June-September, October-February).

However, BdS analysis revealed weak flow vs. SSC regression relationships which forced use of a flow-weighted mean concentration (FWMC) approach. This approach entailed dividing the sum of the total sediment load (SSC x daily flow volume) by the sum of the flow volume for discrete flow ranges defined by where SSC's were visually observed to cluster. Because the Rabbit had relatively few grab samples (and even fewer at middle and higher flows), the continuous daily SSC record for BdS was adapted and used instead. The continuous time series methodologies for all three sites are presented in Table 2.

Table 2. Regression and flow-weighted mean concentration (FWMC) analyses for generation of daily observed SSC time-series. Mustinka utilized seasonal flow vs. SSC regression relationships while Bois de Sioux and Rabbit used a FWMC approach because of variability of observed data.

Calibration Station	Regression #1 (Mar-May): Min/Max/Median mg/l	Regression #2 (Jun-Sep): Min/Max/Median mg/l	Regression #3 (Oct-Feb): Min/Max/Median mg/l		
Mustinka	50/235/81	19/263/60	19/191/33		
Calibration Station	**Flow ng #1: FWMC mg/l**	**Flow Range #2: FWMC mg/l**	**Flow Range #3: FWMC mg/l**	**Flow Range #4: FWMC mg/l**	**Flow Range #5: FWMC mg/l**
Bois de Sioux	< 25 cfs: 17	26-50 cfs: 35	51-110 cfs: 55	110-750 cfs: 126	>750 cfs: 89
Rabbit	< 25 cfs: 17	26-50 cfs: 35	51-110 cfs: 55	110-750 cfs: 126	>750 cfs: 89

Point Source Data

Eight point sources discharge into the MBdS watersheds (seven in Mustinka, one in Rabbit) where they collectively contribute ~350 tons of sediment annually. This annual load constitutes a very small proportion of the suspended sediment load (<2%). Sediment (silt and clay) discharges from point sources were input into the model via the EXTERNAL SOURCES block. Details about Mustinka point sources may be found in MPCA, 2010, pages 14-15.

Calibration Procedure

Sediment was calibrated at the Mustinka (Wheaton), Bois de Sioux (Doran) and Rabbit (Campbell) flow and water quality (WQ) sampling stations. However, unlike the hydrology calibration, validation was not conducted for 1995-2000 and 1998-2000 in the BdS and Rabbit, respectively, because (1) no TSS grab samples were available prior to 2001 at any calibration station and, (2) model support for the 2001-2006 (and more recent) period is the focus for supporting TMDLs.

The Mustinka calibration period, because of limited observed flow data, was similar to that for the hydrologic calibration (2003-2006); however, periods of valid flow data from 2001-2002 were considered in the sediment calibration in an effort to stretch the calibration period as much as possible. Bois de Sioux and Rabbit used the period 2001-2006 although for the Rabbit, only growing season flow data were available.

The calibration approach used model performance evaluation and performance criteria estimated from TN#8 and the MPCA Guidance doc as well as more arbitrary graphical evaluation. This information is summarized in Table 3. The calibration procedure was based on a weight-of-evidence approach consisting of the following components:

(1) Numerical performance statistics (i.e., goodness-of-fit [GOF]) of observed vs. simulated continuous time series *loads*
(2) Visual comparison of continuous observed vs simulated *loads* using load duration curves and monthly and annual time series

(3) Visual comparison of observed grab sample *concentrations* graphed with simulated time series

Because of the spatial and temporal complexity of landscape and stream sediment processes as well as uncertainties in observed data, simulated sediment is generally judged by lower GOF standards and at longer temporal scales (monthly and annually vs. daily) than flow. Statistics and performance criteria for sediment calibration were not specified in the model guidance documentation discussed above except in the case of evaluation of percent difference; however, by comparing thresholds (*very good, good, fair, poor*) between these criteria for flow vs. sediment, criteria for NSE and R^2 were estimated.

Table 3. Model Performance Evaluation Methodology

Site	Calibration Period	Performance Evaluation Statistics	Performance Ratings and Criteria	Graphical Evaluation
Mustinka	2003-2006	(1) Monthly NSE* of average daily load (2) Monthly R^2 of average daily load (3) Percent diff. in simulated vs. observed total load for entire period	<u>NSE, R^2</u> Very Good: > 0.65 Good: 0.55 - 0.65 Fair: 0.45 – 0.55 <u>Percent Difference</u> Very good: <20% Good: 20-30% Fair: 30-45%	(1) Monthly/annual simulated vs. observed loads (2) Daily simulated time-series vs. observed grab sample concentrations (3) Simulated vs. observed load duration curves
Bois de Sioux	2001-2006			
Rabbit	2001-2006			

* Nash-Sutcliffe Efficiency coefficient: index of cumulative error between daily observed and simulated values. Range: -∞ to 1.0 (1.0 indicates perfect agreement between observed and simulated)

Calibration statistics and graphs were calculated using a custom HSPF framework programmed by EOR in the open source R statistical software platform (R Core Team, 2014). This framework allows very flexible and efficient data processing, statistics calculation and graph generation in support of HSPF projects.

Calibration Results and Discussion

An important component of the calibration at all stations was parameterization of a groundwater contribution of clay to the stream channel. MBdS low flow SS concentrations are at a minimum ~ 20 mg/l (recall this concentration excludes organics) and it was not possible to simulate this concentration without an additional input. Following the work of TetraTech in the MN River HSPF models, 25 mg/l of groundwater clay concentration was added via the MASS-LINK block. It is not known what source or process -- groundwater entrainment vs. low flow channel/bank erosion vs. lake release of suspended sediment -- is actually responsible for the high low flow SSC. Therefore, this representation is somewhat implicit but was necessary for calibrating the models with a reasonable level of certainty for both sediment and phosphorus.

Model performance results are presented in Table 4. See Figures 1-9 for graphical results.

Performance statistics varied widely with the Mustinka showing *poor* to *fair* monthly GOF (NSE/R^2) statistics but a *very good* percent difference indicating over time that modeled suspended sediment transported out of the watershed is very close to that observed but that shorter-term high flow/sediment periods are either significantly over- or under-predicted. These large errors are disproportionally expressed in the GOF statistics. Review of the load duration curve however shows the model predicts most all loads very well but is under-predicting the highest ~2% of loading days. Concentrations appear to be reasonable as well allowing one to conclude that despite the relatively low GOF statistics, sediment prediction is adequate for Mustinka watershed.

Bois de Sioux monthly NSE/R^2 statistics were *good* to *very good* indicating modeled timing and magnitude of high flow/sediment periods agreed well with the observed, but showing an under-prediction bias overall as percent difference was 28% (rated *good*). As noted previously (and evidenced in graphical results), BdS simulations show the largest deviations from observed during high flow/sediment loading periods but an adequate balance between under- and over-prediction for these events (i.e., sometimes over-predicting, sometimes under-predicting but no clear evidence of bias). Comparison of load duration curves expresses that – unlike monthly/yearly loads – that simulated daily loads do not conform well except at the highest loading days. However, daily concentrations appear reasonably well calibrated.

Rabbit monthly NSE/R^2 statistics showed *poor* to *very good* demonstrating a *fair* GOF overall. Graphical results indicate the model generally over-predicts the largest peak loads and shows a cumulative load bias of ~30%. The load duration curves compared reasonably well, showing the same trends per flow regime as the downstream BdS but with much less error. Daily concentrations are in fair agreement but are difficult to assess because of the lack of sample data during the higher flow events during 2004-2006.

Table 4. Calibration model performance statistics and ratings

Site	Monthly NSE	Monthly R^2	Percent Difference
Mustinka	0.19 (Poor)	0.47 (Fair)	+3% (Very Good)
Bois de Sioux	0.62 (Good)	0.69 (Very Good)	-28% (Good)
Rabbit	0.36 (Poor)	0.73 (Very Good)	+29% (Good)

The hydrologic and sediment modeling issues with the Bois de Sioux River stem from three factors involving its upstream sources: (1) it receives flow/WQ from a HUC-8 (Mustinka) via large reservoirs which heavily influence flow and WQ by means beyond the scope of this project to attempt to model, (2) it receives flow from the Rabbit River which is an extremely flashy system in terms of flow/WQ and is challenging to model successfully in its own right and (3) it receives tributary and overland flow from North and South Dakota watersheds that are less studied in terms of available landscape and channel data and, most importantly, not monitored for flow or WQ. It's this context that makes the entire MBdS system fairly unique in comparison to others in MN and more challenging to model accurately.

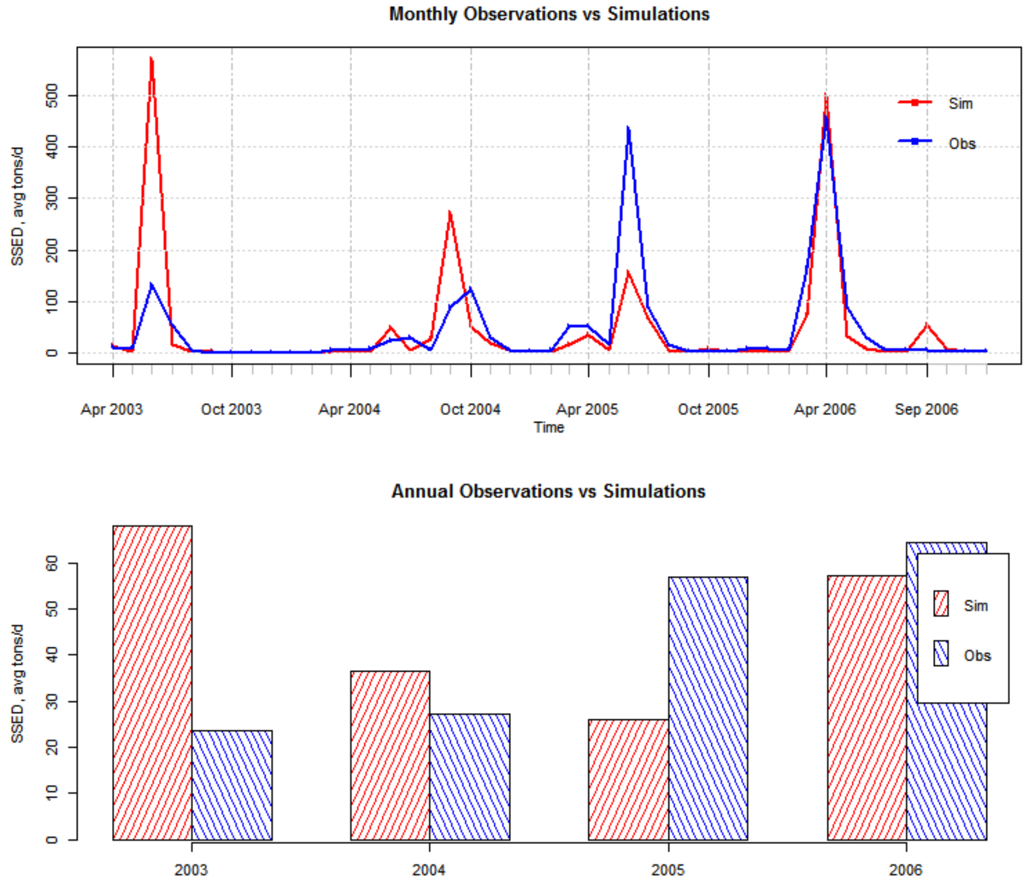


Figure 1. Mustinka monthly and yearly simulated vs observed sediment loading

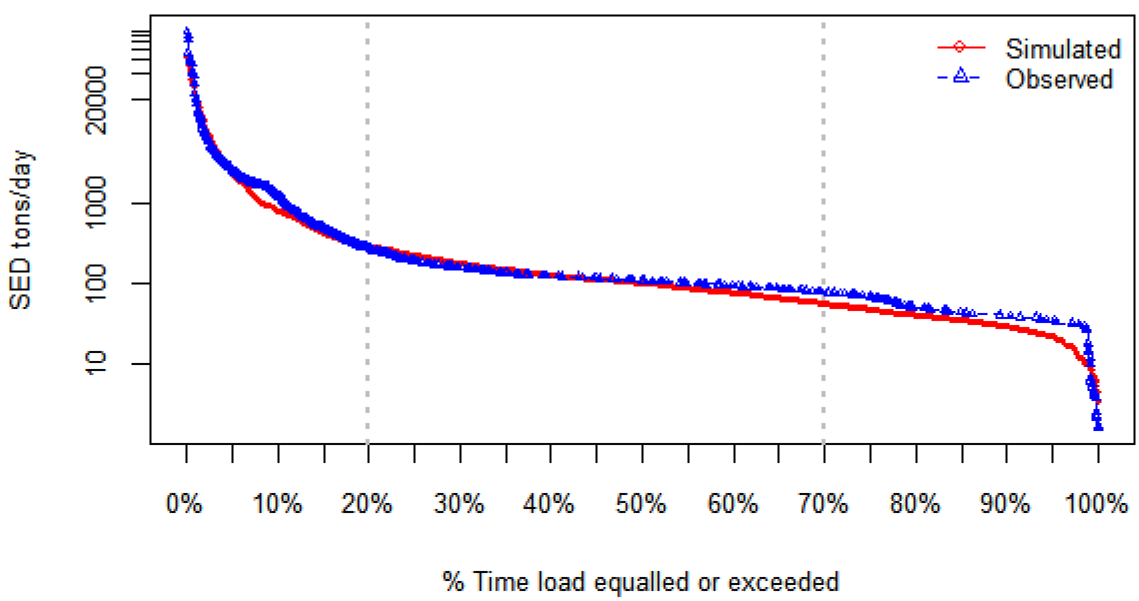


Figure 2. Mustinka simulated vs observed daily SSC load duration curves

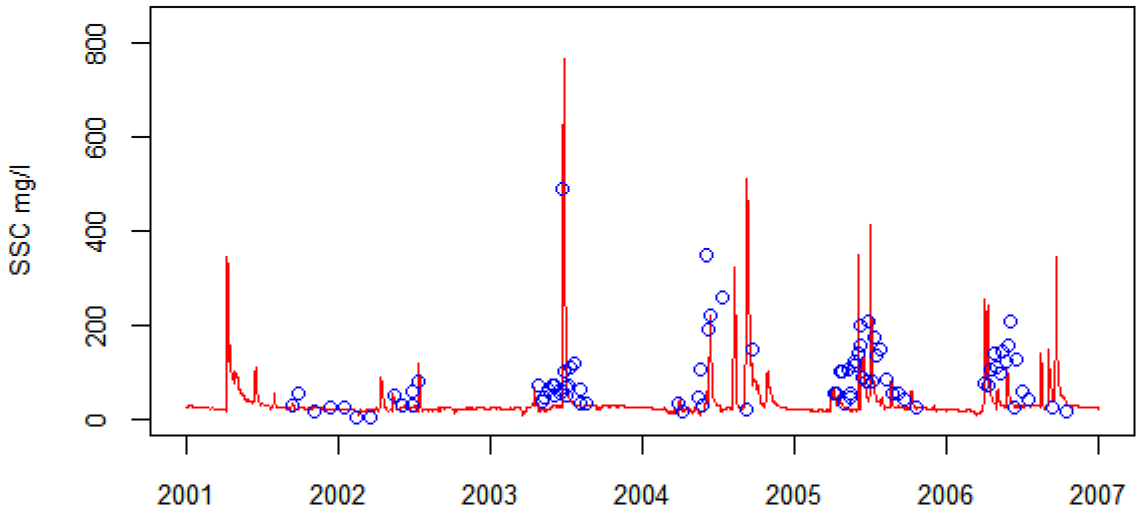
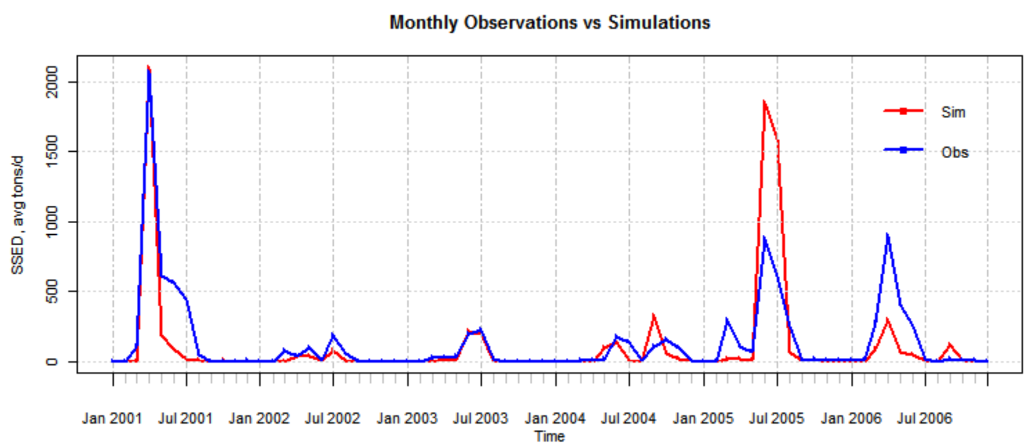


Figure 3. Mustinka simulated vs. observed daily SSC concentrations



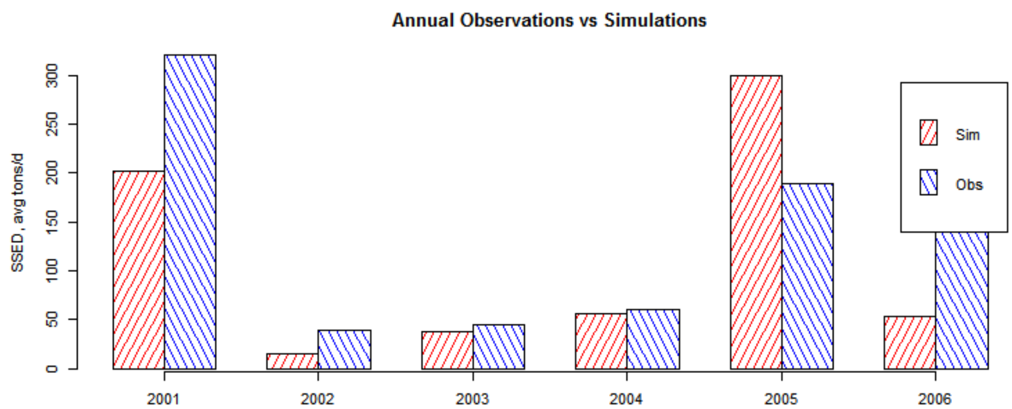


Figure 4. Bois de Sioux monthly and yearly simulated vs observed sediment loading

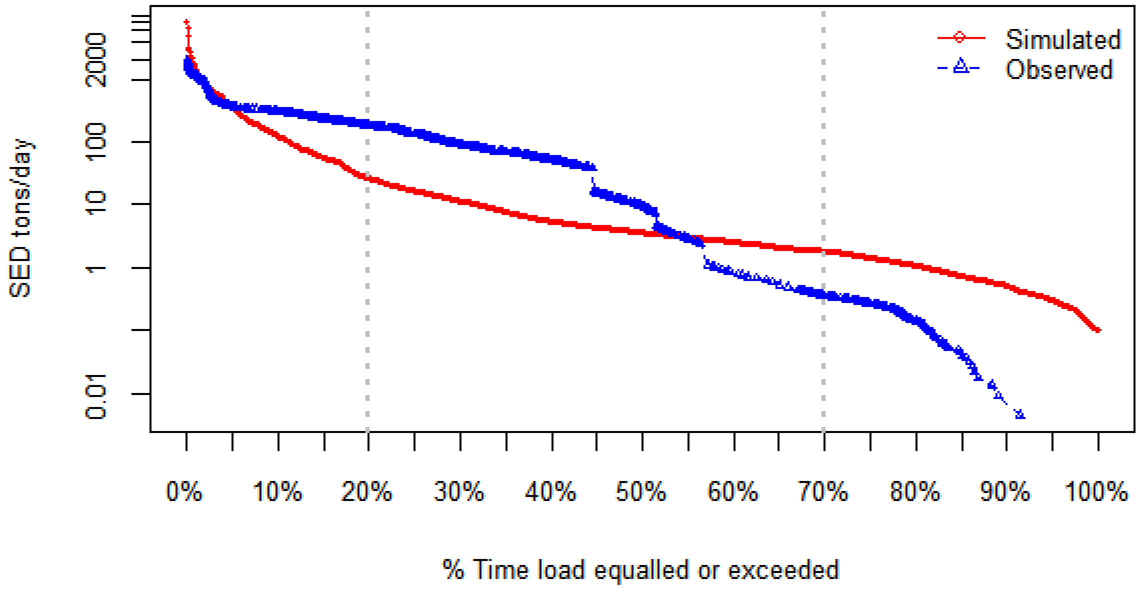


Figure 5. Bois de Sioux simulated vs observed daily SSC load duration curves

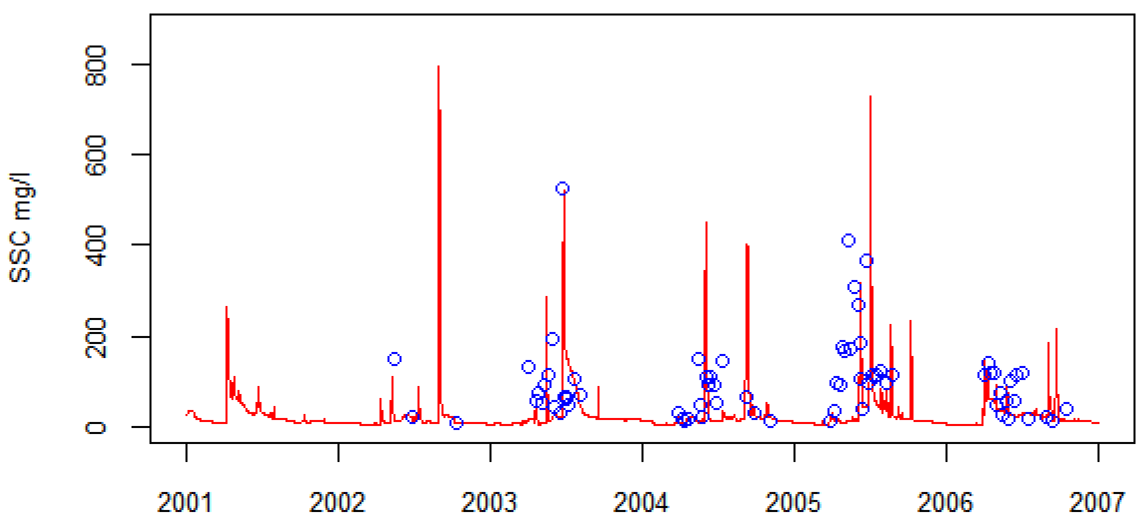


Figure 6. Bois de Sioux simulated vs. observed daily SSC concentrations

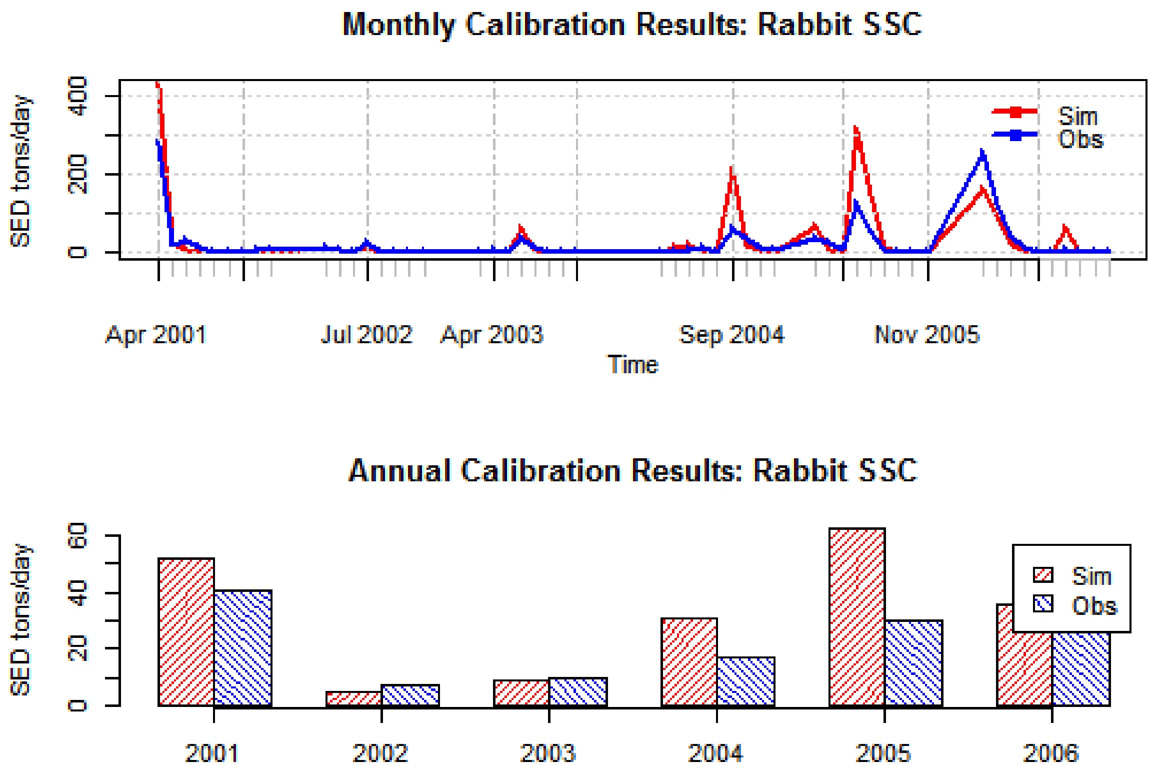


Figure 7. Rabbit monthly and yearly simulated vs observed sediment loading

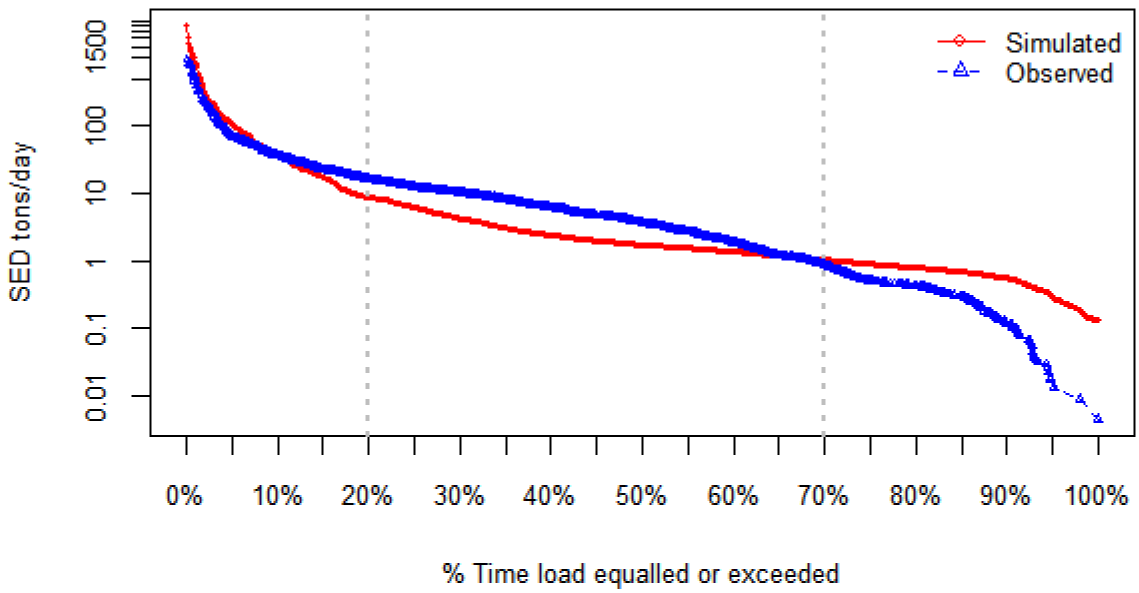


Figure 8. Bois de Sioux simulated vs observed daily SSC load duration curves

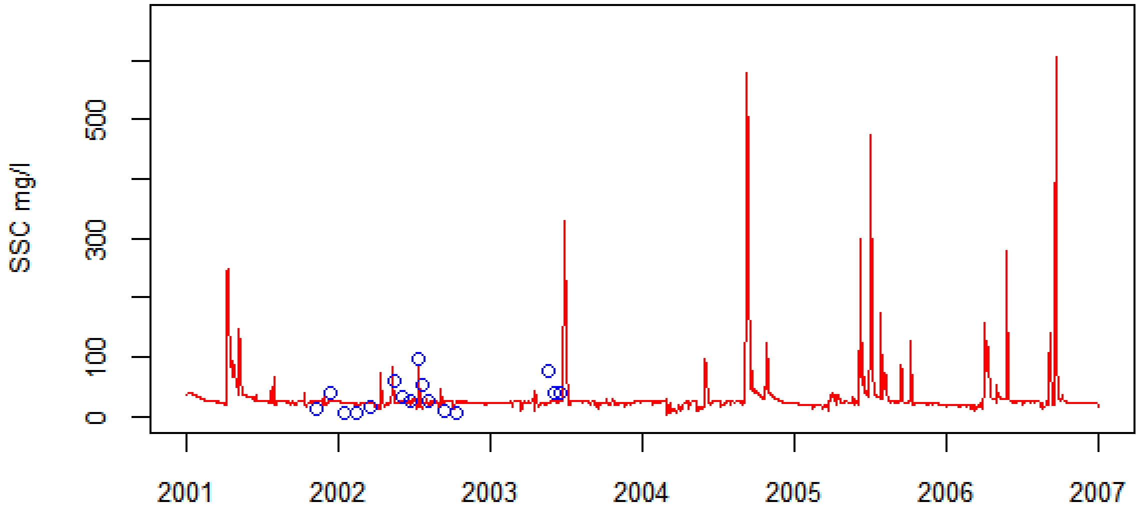


Figure 9. Rabbit simulated vs. observed daily SSC concentrations

References

Aqua Terra Consultants. 2013. Modeling Guidance for BASINS/HSPF Applications Under the MPCA One Water Program.

Ellison, C.A., B.E. Savage and G.D. Johnson. 2014. Suspended-Sediment Concentrations, Loads, Total Suspended Solids, Turbidity, and Particle-Size Fractions for Selected Rivers in Minnesota, 2007 through 2011. Scientific Investigations Report 2013-5205. U.S. Geological Survey, Reston, VA.

Lauer, W., Wong, M. and Mohseni, O. 2006. Sediment Production Model for the South Branch of the Buffalo River Watershed. Project Report No. 473. University of Minnesota, St. Anthony Falls Laboratory. Minneapolis, Minnesota.

MPCA, 2010. Mustinka River Turbidity Total Maximum Daily Load Report. Prepared for USEPA.

R Core Team. 2014. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing}, Vienna, Austria, http://www.R-project.org

Tetra Tech. 2009. Minnesota River Basin Turbidity TMDL and Lake Pepin Excessive Nutrient TMDL Model Calibration and Validation Report.

USEPA. 2000. EPA BASINS Technical Note 8: Sediment Parameter and Calibration Guidance for HSPF. USEPA Office of Water. EPA-823-R00-012.