Project	Mustinka River (09020102) & Bois de Sioux River (09020101) HSPF Model	**Date**	March 10, 2014
To	Mike Vavricka	**Contact Info**	MPCA
Cc	Cecilio Olivier	**Contact Info**	EOR
From	Jason Ulrich	**Contact Info**	EOR
Regarding	Revised Final Parameterization and Hydrologic Calibration/Validation per Task 6 of the Mustinka River (09020102) & Bois de Sioux River (09020101) HSPF Model Work Plan		

Introduction

This memo represents the revised parameterization and hydrologic calibration and validation of the Mustinka/Bois de Sioux watershed (MBdS). Calibration sites are Mustinka and Bois de Sioux River Watersheds at USGS Stations 05049000 (Mustinka River), 54017001 (Rabbit River), and 05050000 & 05051300 (Bois de Sioux River) per Task 6 of the work plan. Efforts undertaken for this phase include:

1. Parameterization changes in response to the AquaTerra model review memo dated January 15, 2013
2. Segmentation changes to improve model's use in supporting TMDL development and implementation efforts
3. Revised calibration results and discussion

1. Parameterization changes in response to the AquaTerra model review memo dated January 15, 2013

AquaTerra (ATC) recommended many changes to the previous calibration of the MBdS HSPF model. General recommendations are discussed below. See Appendix for an item-by-item report documenting all of ATC's recommendations and EOR's responses/actions.

Integrated UCI for all watersheds and Performance Statistics

Because of HSPEXP ("expert system statistics") program limitations, it was necessary to split the combined UCI for the Mustinka, Bois de Sioux and Rabbit watersheds into three separate files during the previous calibration. ATC pointed out this resulted in a more cumbersome model configuration and some parameter inconsistencies between UCI versions. A more functional and full-featured HSPEXP program was made available by ATC allowing a single UCI file to be used for the entire MBdS watershed. The program also enabled EOR to generate for the first time, expert system statistics at the two Bois de Sioux calibration sites and water balance statistics (as recommended by ATC) for all calibration sites. Further, one integrated UCI eliminated any parameter inconsistency problems.

Snow depth calibration

Snow depth was calibrated for the current version of the model; see *Revised Calibration Results and Discussion* section for a detailed summary.

Reasonable parameter values

AquaTerra provided feedback on parameters that were near to or exceeding reasonable limits based on AquaTerra experience and guidelines set forth in Technote#6 (TN6; USEPA, 2000), or when the relative difference between parameters of different pervious land segments (PLS's) did not make intuitive sense (e.g., higher interflow on developed land than forest). All ATC comments were taken in account and resulted in either parameter changes or justification of current values. The HSPFparmV2 database was consulted to help set realistic parameters based on the multitude of HSPF models completed in Minnesota.

Extension of Mustinka calibration period

AquaTerra placed a high priority on extending the calibration of all models but particularly the Mustinka by adding observed flow and meteorological data for 2007-2009. However, there are numerous meteorological stations near and within the two HUC-8 domain of the MBdS model and substantial pre-processing was required to ready the existing data for HSPF (e.g., filling missing data, outlier pcp event analysis; daily-to-hourly precipitation disaggregation, PET calculations, station aggregation for certain met-segments). As a result, it was determined that remaining activities would instead focus of improvement of segmentation and parameterization.

Enhanced Documentation

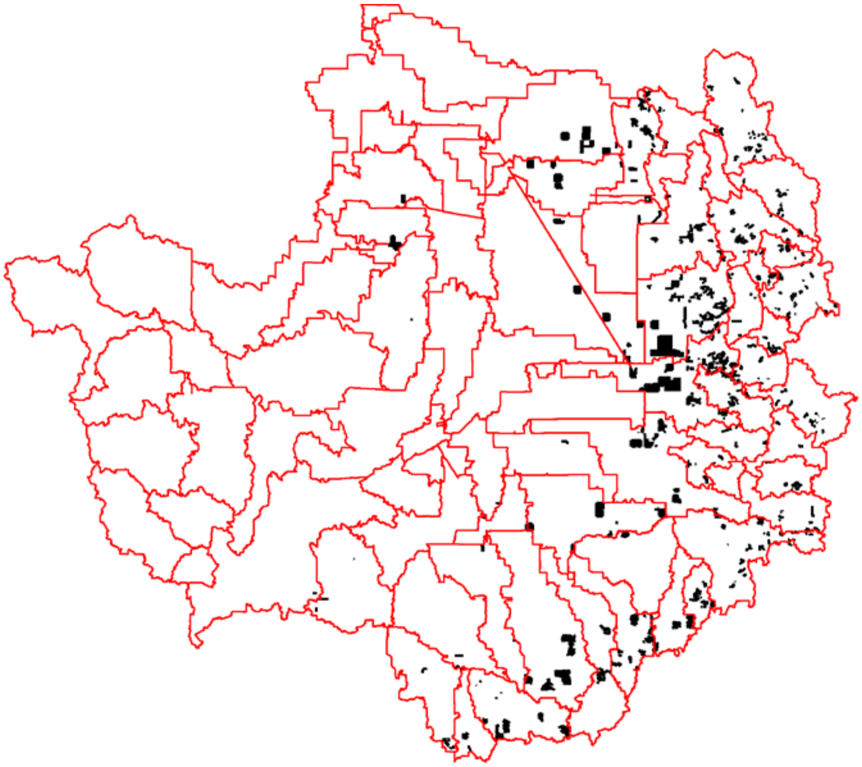
Efforts were undertaken in this document to better document the revised parameterization and calibration. In addition, ATC requested adding many new comment lines in the HSPF UCI file.

2. Segmentation changes to improve model's use in supporting TMDL development and implementation efforts.

In reviewing the previously calibrated MBdS model with EOR's TMDL team, questions emerged about the model's ability to differentiate between the watersheds' diverse landscape types (e.g., depressional vs. glacial lake plain soils and topography, drain tile locations and density, high- vs low runoff soils) at the HUC-12/reach scale of current impairments. The answer from EOR modeling staff at the time was, "relatively poorly". The previous model, like many of those completed in MN (as reported in HSPFparmV2, from BASINS 4.1 2013 installation) did not explicitly factor in these conditions beyond use of coarse resolution STATSGO soil dataset for AB, CD segmentation. While not in the work plan, it was decided to increase the complexity of segmentation to represent the spatial distribution of different hydrologic and water quality responses. It was believed this extra effort would greatly increase the model's utility in supporting TMDLs.

Location and extent of drain tile

It is widely understood that sub-surface drainage is a major driver of hydrology and water quality in many parts of Minnesota. The MBdS watershed is unique in that it has a tile permitting system started in 1999 that stores GIS information on the location and length of tile installations year to year. From this data (See Figure 1), the MBdS appears to be in a phase of widespread tile development with a significant amount added since 2006. While the tile density is relatively small during the modeling periods (1990s-2006), it was thought important to add it as a PLS for future model use (Crop-Drained) if the model is updated with more recent flow and meteorological data. The spatial extent of tile in the model for all periods (calibration/validation: 1995-2006) was set based on the total cumulative tile permitted from 1999-2006 (See Figure 1 map). Since North/South Dakota tile data was not available, and aerial photographs suggest significantly less surface drainage development in both states in comparison to Minnesota, it assumed that North/South Dakota had no drain tile during the modeling period.



Year	Tile (mi)
1999	2.9
2000	65.3
2001	59.4
2002	97.4
2003	49.2
2004	100.0
2005	162.1
2006	281.5
2007	374.7
2008	390.6
2009	740.9
2010	599.3
2011	1,612.9
2012	3,023.9
2013*	2,844.5
Total	10,404.7

Figure 1. Map of HSPF subbasins and Mustinka/Bois de Sioux (Minnesota only) pattern-tile installations during the model period 1999-2006. Table showing length of tile permitted per year from 1999-2013. From MN Bois de Sioux Watershed District.

Location and extent of depressional storage and designation as pervious land segments

The MBdS landscape can be generalized into two types: areas dominated by depressional wetlands, ponds and lakes (i.e., prairie pothole geology) that are found in the glacial moraine topography along the eastern (MN) and western (SD) sides of the watershed, and areas dominated by glacial lake plain. Although much channelization appears to have occurred in the depressional areas of the watershed, considerable hydrologic storage was analyzed to remain. In contrast, the lake plain areas were determined to have little storage, owing to flat topography and occurrences of high-density ditch networks. Differentiating between the hydrologic and water quality responses of these two landscape types was considered an important update to the previous HSPF segmentation in order to improve calibration and support TMDL development and implementation efforts. Hydrologically, depressional landscapes would be expected on average to exhibit smaller flow peaks and higher inter- and base flow as well as higher ET (resulting in lower total flow volume). Reduction of all major pollutants (i.e., nitrate, TP, DRP and TSS) would also be expected to varying degrees as a result of the hydrologic attenuation.

Wetland and open water bodies are explicitly represented in the model via land use segmentation but the drainage areas of these features are not. Cropland comprises the majority of these drainage areas. Therefore, to capture the hydrologic and water quality effects of cropland draining to depressions, a second segment for each cropland PLS (Crop-AB soils, Crop-CD soils, Crop-Drained) named "–depressional" was created.

Thus, conceptually, depressional storage is defined here as the cumulative effect of in-field ephemeral depressions, edge-of-field ponds/wetlands and open- and closed-basin lakes that receive non-channelized surface runoff from croplands. Quantitatively, storage is a depth calculated from depressional volume divided by total depressional drainage area.

Depressional storage was determined using the ArcGIS Archydro toolset and available 3 meter LiDAR dataset. A conservative approach was taken as to not over-estimate storage. The GIS layers used to constrain the depressional analysis are listed below.

- National Hydrography Dataset (NHD) Waterbody
- MN-DNR 24K lakes/ponds (generally, more consistent with aerial photographs than NHD Waterbody)
- NHD Flowline (significant less drainage density than photos and LiDAR hillshade suggest)
- Wetland/water landuse from NLCD 2006
- County roads (MN, ND, SD)

A map of potential depressions and drainage areas was created using the Archydro *Depression Evaluation* tool. The analysis also calculated volume for each depression. Depressions were excluded if they were obvious road bank impoundments, often a result of the DEM not having culverts "burned-in". Depressions intersected by NHD stream networks were also excluded unless they had visible open water – evidence that a significant amount of storage (with relatively high residence time) exists in the waterbody. Finally, depressions representing lakes being modeled explicitly by HSPF (as RCHRES) were excluded

Once all spurious depressions had been eliminated, remaining depressional drainage areas were intersected with cropland type (AB, CD, Drained) to determine applicable cropland-depressional segment area for each HSPF subbasin. Depressional volumes and drainage areas were area-weighted and aggregated by cropland type and meteorological segment to calculate storage depths for each HSPF depressional crop PLS.

Storage was expressed in HSPF by adjusting the UZSN (upper zone storage nominal) parameter for each depressional crop PLS. In HSPF, UZSN is used to simulate the effects of surface detention storage including that of depressions. Since only a portion of total depressional storage (as defined previously) actually occurs on the cropland itself (i.e., vs. adjacent, down slope depressional features), representation by cropland UZSN is somewhat implicit. However, this parameterization was much more straight-forward to implement than alternatives (e.g., creating an aggregate depressional RCHRES feature for each subbasin, determining FTABLE parameterizations and differentially routing certain PLS to each one).

Results of depressional analyses show significant storage in certain met-segments, with UZSN depths increased 0.1 to 3.6 inches over non-depressional parameter values (See Figure 2). Segments with significant storage were simulated in HSPF to have a pronounced decrease in surface runoff to channels and increases in inter- and base flow, a response hydrologically reasonable for depressional landscapes.

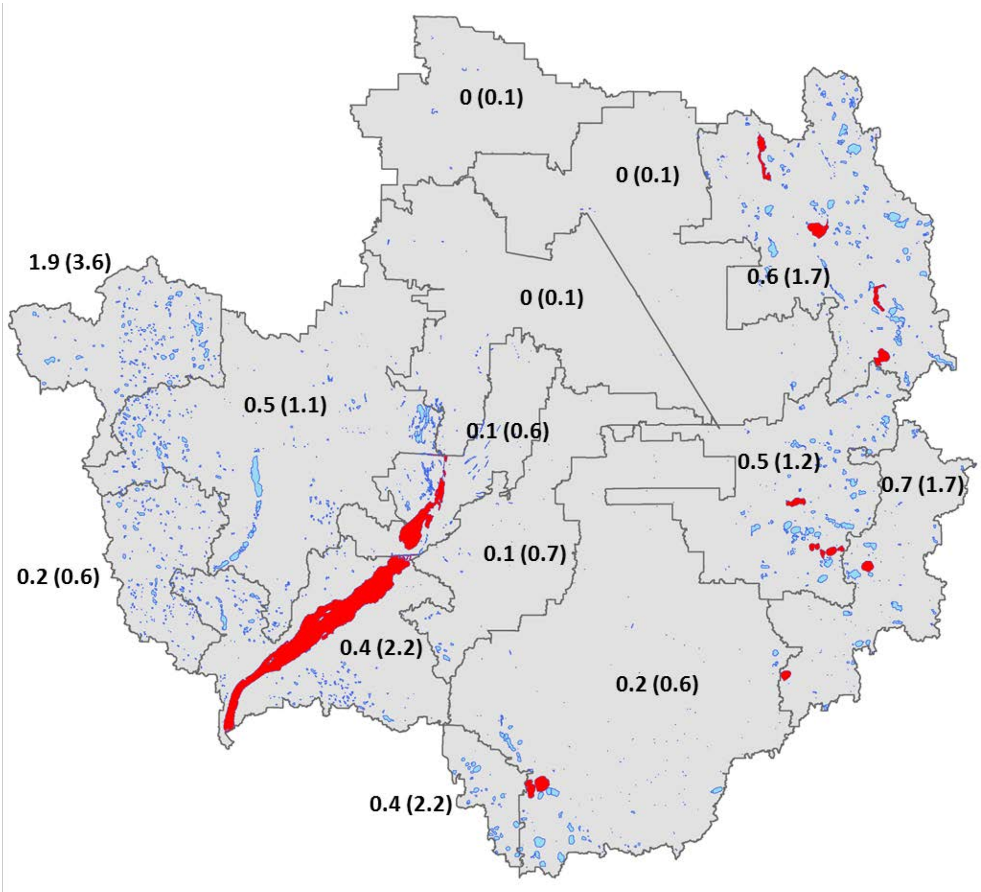


Figure 2. Depressional storage (inches) per HSPF meteorological segment (expressed in HSPF as additional UZSN). First number is total crop PLS depressional storage depth averaged over the entire meteorological segment area (a measure the total effect of depressional storage within the met-segment); number in parentheses is the max crop PLS depressional storage depth for that segment. Blue polygons are surface water bodies (utilized with other GIS data to analyze depressional storage). Red polygons are lakes modeled explicitly in HSPF (and not included as depressional storage).

Incorporation of high-resolution soils

Soil segmentation for croplands was revised using SSURGO data (vs. STATSGO) and resulted in greatly increased subbasin accuracy of cropland AB and CD soil distributions. This revision was consistent with other efforts to increase spatial accuracy of pollutant sources for TMDL development and implementation efforts. SSURGO increases soils resolution to a scale at or smaller than HSPF subbasins while STATSGO resolution is scaled to that of met-segments or larger.

Elimination of pervious land segments that added unneeded complexity

Incorporation of depressional segments added three additional PLS's per met-segment. To keep .UCI re-segmentation as simple as possible, existing PLS's were re-evaluated and after review of the MPCA Guidance doc, three PLS's (per met-segment) were eliminated keeping the total PLS number constant between versions (before/after depressional segmentation; See Table 1). Those eliminated were slope and soil variations of the Grass PLS because both landuse types comprised a considerably smaller area than row-crops, the variations were considered unnecessary. Also, slope variations of cropland were eliminated as it was observed that most crops were planted on relatively flat terrain and that the *amount* of runoff (a function of AB vs CD vs tile-drained) rather than slope was the primary determinant for field erosion.

Table 1. Previous and revised segmentation comparison

	Previous		Revised	
PLS#[1]	**PLS name**	**Description**	**PLS name**	**Description**
1	CropAB0to2	AB soils: 0-2% slopes	CropAB	AB soils: All slopes
2	Developed	All soils/slopes	Developed	*Unchanged*
3	Forest	All soils/slopes	Forest	*Unchanged*
4	GrassAB0to6	AB soils: 0-6% slopes	Grass	All soils/slopes
5	GrassCD	CD soils: All slopes	CropTile	All soils/slopes
6	CropAB2plus	AB soils: 2+% slopes	CropABdep	AB soils: All slopes: Depressional
7	CropCD0to2	CD soils: 0-2% slopes	CropCD	CD soils: All slopes
8	CropCD2plus	CD soils: 2+% slopes	CropCDdep	CD soils: All slopes: Depressional
10	Wetland	All soils/slopes	Wetland	*Unchanged*
16	GrassAB6plus	AB soils: 6+% slopes	CropTiledep	All soils/slopes: Depressional

[1] Number added to each PLS series 50,100, 150, 200, 250, 300, 350, 400, 450, 500, 550, 600, 650

Quantification and spatial distribution of deep aquifer recharge

The ATC review memo called into question the assumption that deep aquifer recharge was effectively zero. A study from Lorenz and Delin (2007) resulted in spatially distributed estimates of average annual deep recharge across all soil/geologic zones of Minnesota. These GIS based results were intersected with the HSPF met-segments to provide area weighted average parameterization values (DEEPFR; see Figure 3). MN results were extrapolated to North/South Dakota segments using soil and topographic characteristics (hydrologic soil group and depressional/non-depressional, respectively).

The resulting recharges are a significant component of the HSPF water balance (see Table 5). DEEPFR values were adjusted during calibration to roughly conform to the area-weighted means for each calibration gage watershed computed from the Lorenz and Delin data.

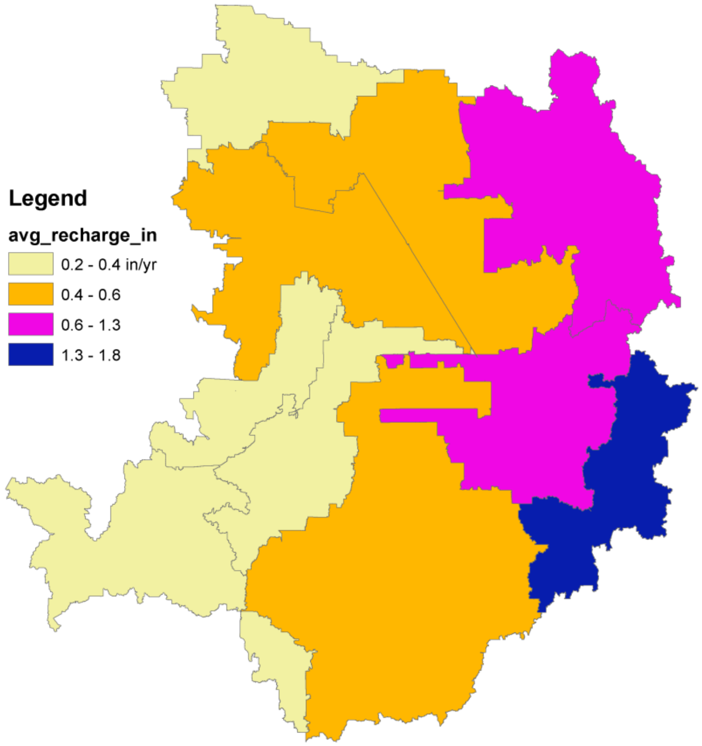


Figure 3. Area weighted average deep recharge for HSPF meteorological segments in Minnesota (in/yr). Results were extrapolated to North/South Dakota segments using soil and topographic characteristics (hydrologic soil group and depressional/non-depressional, respectively)

3. Revised calibration results and discussion

Snow Calibration

The previous calibration did not include snow depth and had issues with timing of snow melt. ATC noted that snow parameters were pushed beyond the *possible* limits outlined in TN6 in an effort to delay snowmelt as long as possible. The current calibration started with calibrating snow depth while setting snow parameters back to *typical* ranges as outlined in TN6.

It was clear the previous calibration had somewhat over-predicted snow depth. However, even after snow depth calibration and numerous iterations of parameter settings, snow melt was occurring too early and having a substantial effect on spring and summer flow errors. As a last resort, the snow-melt method was switched from the physically based energy balance approach (method 1; recommended by the MPCA HSPF guidance doc [Aqua Terra, 2013]) to the more empirically based degree-day approach (method 2). The results were much superior to method 1 with minimal calibration; thus, method 2 was adopted for the final calibration. Switching to method 2 also resolved several of AquaTerra's concerns with the method 1 parameter values from the previous calibration. See Figures 4-6 for snow calibration graphs for all 13 PLS series.

Much of the snow depth data at stations in or near the MBdS is incomplete therefore snow depth was calibrated to the nearest station with a complete record. Because of this data limitation, two stations -- located in the south central and south eastern regions of the MBdS, respectively – were used to calibration snow depth in all met-segments.

Parameters TSNOW and SNOWCF were modified for snow depth calibration. The resulting calibrations matched the general trends well and were judged adequate for re-calibrating hydrology. Obvious over-predictions in winters 2004-2005 and 2005-2006 could not be corrected for as TSNOW and SNOWCF could not be adjusted past their possible minimums.

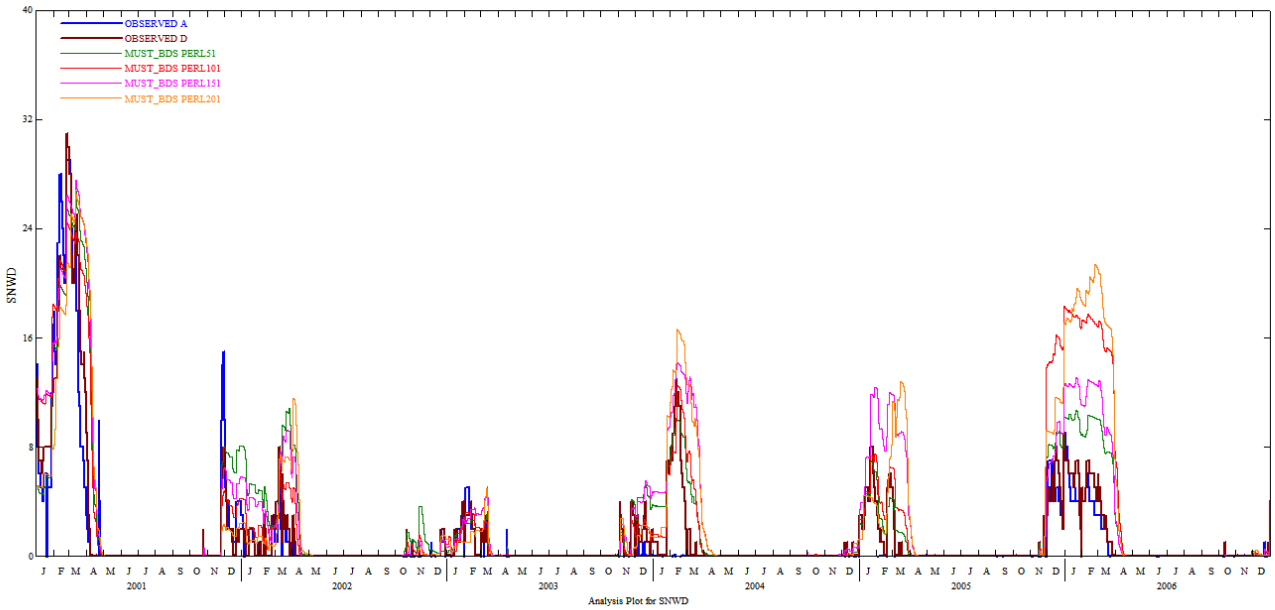


Figure 4. Snow depth calibration 2001-2006 (1 of 3) for PERLND series 50, 100, 150, 200

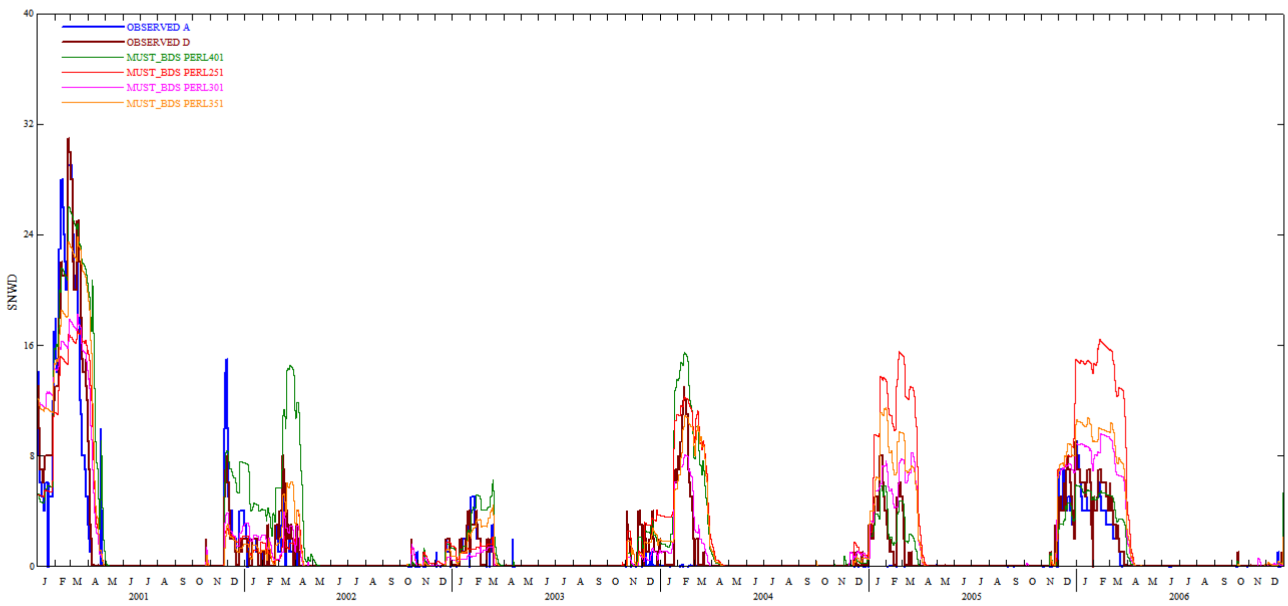


Figure 5. Snow depth calibration 2001-2006 (2 of 3) for PERLND series 250, 300, 350, 400

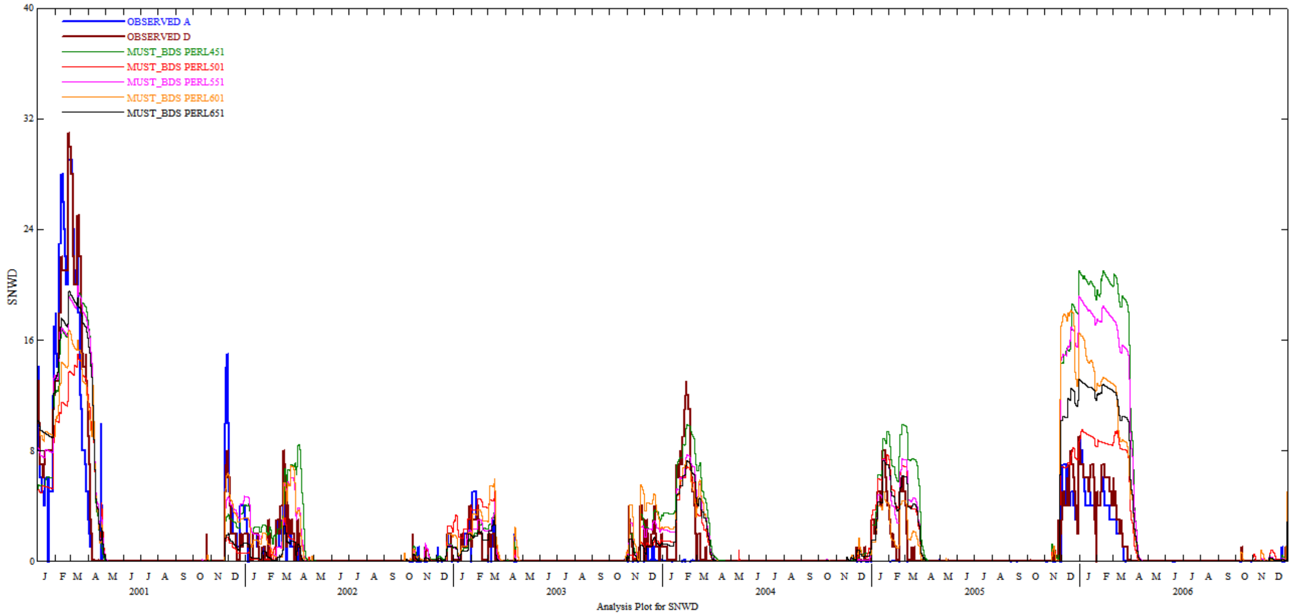


Figure 6. Snow depth calibration 2001-2006 (3 of 3) for PERLND series 450, 500, 550, 600, 650

Hydrologic Calibration Methods

Because of the re-segmentation and snow calibration activities, parameterization and calibration were completely re-done. The three most sensitive parameters (in order of greatest hydrologic effect: LZSN, INFILT and UZSN) were reset as per guidelines in several HSPF sources including TN6, HSPFparmV2, MPCA HSPF guidance doc, ARM User's Manual (USEPA, 1978) and Donigian, 1983.

The calibration approach was similar to the previous effort: calibrate the Mustinka watershed (05049000) to a high level of certainty and force the resulting parameterization (with relatively small and defensible adjustments) on the Bois de Sioux watersheds (54017001, Rabbit River; 05050000 & 05051300, Bois de Sioux River; See Figure 7). This approach is some ways compensates for the relative lack of calibration/validation for the Mustinka by essentially validating it using downstream and adjacent watersheds.

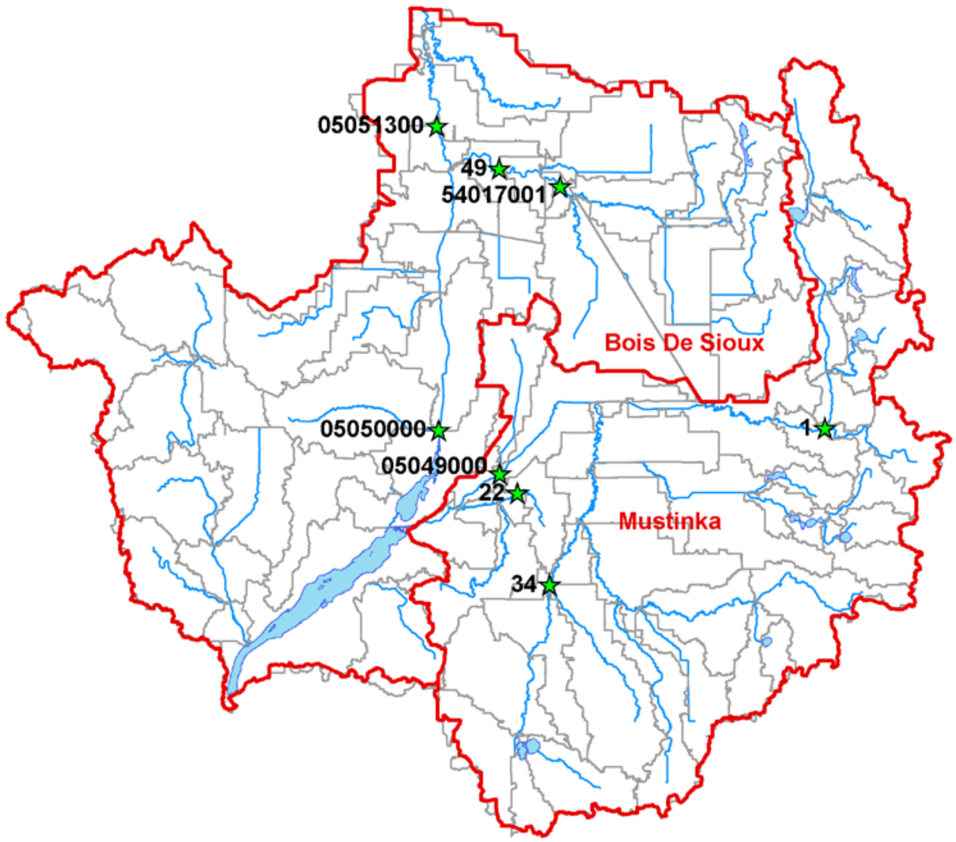


Figure 7. Calibration and validation stations used in study. Also shown are HSPF reaches, subbasins and explicitly modeled lakes.

The calibration focus on the Mustinka is justifiable given the current impairments there, the amount of North/South Dakota area in the BdS and its relatively uncertain hydrology (i.e., no gages above the Traverse and Mud Lake reservoirs), and the effect of the reservoirs (i.e., regulated outflow uncertainties) on the two downstream BdS calibration sites. However, this approach also results in a less certain calibration for the BdS sites as they are not calibrated directly.

The principal challenge of the calibration was the need to keep infiltration (INFILT) low enough to match high storm peaks during wet periods but also keep UZSN high enough to provide needed abstraction during other periods. As a result, INFILT is set relatively low when compared to TN6's *typical* ranges as well as ATC's review comments, and UZSN's are somewhat high (excluding high depressional segment values). However, review of the HSPFparmV2 database (included with BASIN 4.1 2013 installation) reveals that lower INFILT's are the rule rather than the exception in HSPF models completed in Minnesota. In addition, existing MN HSPF models make little or no distinction between Low and High Till INFILT values (presumably representing AB and CD soils, respectively; see Table 2).

Table 2. INFILT parameter value statistics for HSPF models completed in Minnesota; from HSPFparmV2 database.

Crop PLS	Avg	CV[1]	Min.	Max.	Total No. of PLS
Low Till Crop	0.1	0	0.1	0.1	31
High Till Crop	0.1	0	0.1	0.1	50
LOW TILL CROPLAND	0.04	0.47	0.016	0.12	82
HIGH TILL CROPLAND	0.04	0.47	0.016	0.12	82

[1]Coefficient of variation (standard deviation/average)

In the MBdS HSPF model, crop INFILT values were constrained such that resulting calibrated values had a 1.5:1 ratio between AB and CD soils. This resulted in an average surface runoff ratio of 1:1.5 between AB and CD soils (i.e., hydrology responded with an equivalent ratio to the INFILT ratio) for non-depressional crop segments, respectively. Therefore, CD PLS's yielded 50% more surface runoff than AB PLS's. Average surface runoff from Mustinka AB and CD PLS's were ranked as follows:

CropCD > CropCDdep ≈ CropAB > CropABdep (1.8>1.3≈1.25>0.6 inches avg annual surface runoff).

In other words, CropCD yielded the most surface runoff, CropAB-depressional the least, with CropCD-depressional and CropAB PLS's roughly equivalent. These runoff relationships between different soil and topography combinations demonstrate the utility of enhanced segmentation for supporting the determination of TMDL non-point source load allocation (especially sediment and phosphorus), and for prioritizing and simulating BMP implementations.

Results and Discussion

Calibration results are presented in Tables 3-5 and Figures 8-25. Performance of models was judged based on (1) meeting observed vs. predicted error criteria for as many error terms as possible (see Table 3) and (2) evaluation of daily and monthly goodness-of-fit statistics (GoF's; see Table 4); mainly, coefficient of determination (r^2) and Nash-Sutcliffe efficiency coefficient (NSE) using numerical standards outlined in the MPCA Guidance doc. Graphs presented in the document include hydrographs and flow duration curves for each calibration and validation.

The Mustinka calibration had the most effort allocated to it and as a result, showed the best model performance. It met virtually all the error term criteria and had good daily and monthly GoF's (daily: r^2=0.79 NSE=0.77; monthly: r^2=0.87 NSE=0.85). Comparison of flow duration curves demonstrates good agreement at all flows. However, validating the Mustinka model was difficult given the dearth of observed data at the 05409000 gage. An informal validation was conducted using three upstream gages in the Mustinka administered by BdSWD and judging performance by visual comparison of hydrographs.

Gage 1 drains approximately 25% of the Mustinka watershed; its drainage area is dominated by depressional features such as wetlands, ponds and lakes. Comparison of grab-sampled flows at this gage with model results at the nearest subbasin outlet is presented in Figure 10. The model is clearly under-predicting peak flows during three large June-July events in 2001-2003 but performed well during a very large snow melt event in 2001 and showed good agreement during the 2004-2006 calibration period.

Gage 34 drains approximately 20% of the Mustinka watershed. Comparison with model results in shown in Figure 11. There is general agreement between observed and modeled but more so when suspect flows in factored out: high base flows in 2003, late fall 2004 and 2005 are possibly gage errors as the flow rate roughly equals the base flow rate at the Mustinka gage (draining a much larger area). Removing the high base flow would better align summer storm flows in 2003 and 2005.

Gage 22 drains a single headwater subbasin in the Mustinka. See Figure 12 for model comparison. There is fair agreement between observed vs simulated but a significant amount of peak flow under-prediction is present. HSPF may be under-representing the flashiness of this 1st order stream.

Overall, the visual comparisons at upstream gages exhibit good enough agreement to judge the Mustinka model adequate for subsequent phases.

Proper evaluation of the Rabbit calibration/validation was problematic because no data was collected during the winter. The missing periods greatly skewed the results of the Expert System Statistics program, forcing flow volume error and GoF computations to be done manually using MS Excel. Generally, given the drainage area at the calibration gage is less than 25% of either the BdS or Mustinka HUC-8 watersheds, the overall calibration performance (as implied in the MPCA guidance doc) could be considered fair/adequate with most error criteria met and GoF statistics of 0.55 and 0.56 for daily r^2 and NSE, respectively, and good monthly GoF performance of 0.89 and 0.88 for r^2 and NSE. However, validation was very poor, probably owing to the short validation period exacerbated by missing spring/early summer data in 1998 and probable gauging errors during periods of 1998 (late fall), 1999 (late summer and fall), and 2000 (summer).

Calibration and validation performance at the two BdS gages (05050000 & 05051300) was mixed with pronounced problems with over-prediction of low flows in all seasons skewing model performance statistics. The presumed issue with these sites is the inadequate parameterization of the upstream reservoirs and their regulated dam discharges, and to a lesser degree the lack of flow data to calibrate North/South Dakota flows into the reservoirs and BdS River.

Calibration at gage 05050000 (at White Rock Dam) shows acceptable error term performance for the top 50% of flows but poor GoF owing to the issues with low flow. Daily r^2 and NSE were 0.42 and 0.32, respectively; monthly r^2 and NSE were both 0.59. Validation showed a 27% over-prediction of flow volume and GoF statistics similar (but slightly lower) to those from the calibration.

Calibration at gage 0505130 (near Doran; furthest downstream gage in the BdS) has the same low flows issues as 05050000 but exhibits worse error term performance (upper 50% where under-predicted in addition to the low flow over-prediction) but profoundly better GoF's: 0.70 for daily r^2 and NSE; 0.84 and 0.80 for monthly r^2 and NSE, respectively. Similar to 0505000, validation predicted a 24% over-prediction of flow volume. Daily GoF's were poor; monthly were fair.

Overall, despite some issues with the BdS sites, the model appears adequate to proceed with water quality calibration. Hydrologic calibration will most likely be re-visited and tweaked as the water quality calibration progresses. In terms of the model serving the needs of MBdS TMDLs, model error is the primary determinant as to whether the model will provide reasonably accurate flows at un-gaged impaired reaches; in this capacity, the model appears adequate overall but not exceptional. As far as supporting other TMDL phases, given the model's detailed segmentation it should be a very helpful tool for supporting TMDL non-point source apportionment and prioritization/implementation activities.

Table 3. Summary of observed vs. simulated error terms, acceptance criteria and model performance for all calibration and validation sites. Numbers in red indicate percent error not meeting error criteria. NA indicates computations skewed by missing winter flow data.

		Mustinka Wheaton 540900	Rabbit Campbell CR4 54017001		Bois de Sioux W. Rock Dam 5050000		Bois de Sioux Doran 5051300	
		2003-06	2001-06	1998-00	2001-06	1995-00	2001-06	1995-00
Error Terms	**Criteria**	**Calib.**	**Calib.**	**Valid.**	**Calib.**	**Valid.**	**Calib.**	**Valid.**
	+/-	**%**	**%**	**%**	**%**	**%**	**%**	**%**
Error in total volume (%)	10	9.6	5.2[1]	-11.5[1]	-1.4	26.9	-5.2	24
Error in 10% highest flows (%)	15	-1.7	6.2	11.5	-6.8	11.5	-16.9	4.7
Error in 25% highest flows (%)	10	2.5	11.4	13.8	-9.5	13.8	-19	7.1
Error in 50% highest flows (%	10	8	14.8	22	-6.5	22	-12.2	16.1
Error in 50% lowest flows (%)	10	22.3	NA	NA	361	551	528	1159
Error in 25% lowest flows (%)	15	6.7	NA	NA	326	110	2189	1732
Error in 10% lowest flows (%)	20	-3.2	NA	NA	4075	261	68815	4685
Error in low-flow recession	0.01	0.021	0.007	0.026	0.019	0.03	0.008	0.023
Error in storm volumes (%)	15	0.8	6.1	-19.3	-16.3	-19.3	-19.9	-8.2
Seasonal volume error (%)	10	-3.8	NA	NA	-123.2	-32.4	-178	-122
Error in average storm peak (%)	15	7.9	-6.8	0.3	-6.8	0.3	-19.7	-8.1
Summer volume error (%)	20	9.3	2.7	162	11.6	162	-1.3	120
Winter volume error (%)	15	13.1	NA	NA	135	194	177	242
Summer storm volume error (%)	15	4.5	-6.9	119	5.5	119	-11.7	55

[1] indicates volumes calculated outside of expert system stats program because missing winter data.

Table 4. Model goodness-of-fit (GoF) statistics for all calibration and validation sites. NC indicates statistics not computed because of missing winter flow data.

	Mustinka Wheaton 540900	Rabbit Campbell CR4 54017001		Bois de Sioux W. Rock Dam 5050000		Bois de Sioux Doran 5051300	
	2003-06	2001-06	1998-00	2001-06	1995-00	2001-06	1995-00
Daily GoF	**Calib.**	**Calib.**	**Valid.**	**Calib.**	**Valid.**	**Calib.**	**Valid.**
Correlation Coefficient	0.89	0.75	0.43	0.65	0.61	0.84	0.69
Coefficient of Determination (r^2)	0.79	0.56	0.19	0.42	0.37	0.70	0.48
Mean Error	13.0	NC	NC	-3.3	63	-20.7	86
Mean Absolute Error	60	NC	NC	185	238	234	302
RMS Error	162	NC	NC	373	527	465	699
Nash-Sutcliffe (NSE)	0.77	0.55	NC	0.32	0.27	0.70	0.41
Monthly GoF							
Correlation Coefficient	0.93	0.94	0.41	0.77	0.72	0.92	0.88
Coefficient of Determination (r^2)	0.87	0.89	0.17	0.59	0.52	0.84	0.78
Mean Error	18.9	NC	NC	-2.4	63	-20	86
Mean Absolute Error	48	NC	NC	157	207	184	227
RMS Error	79	NC	NC	250	372	318	385
Nash-Sutcliffe (NSE)	0.85	0.88	NC	0.59	0.49	0.80	0.77

Table 5. Simulated water balance components for all calibration and validation sites. All units in inches.

		Mustinka Wheaton 540900	Rabbit Campbell CR4 54017001		Bois de Sioux W. Rock Dam 5050000		Bois de Sioux Doran 5051300	
		2003-06	**2001-06**	**1998-00**	**2001-06**	**1995-00**	**2001-06**	**1995-00**
Water Balance		**Calib.**	**Calib.**	**Valid.**	**Calib.**	**Valid.**	**Calib.**	**Valid.**
Influx								
	Rainfall	27.2	27.4	24.6	26.5	24.6	26.9	25.7
Runoff								
	Surface-PER	1.1	1.2	0.4	0.9	0.4	1.1	1.0
	Surface-IMP	0.0	0.1	0.0	0.0	0.0	0.0	0.0
	Interflow	0.8	0.8	0.3	0.7	0.3	0.8	1.1
	Baseflow	1.2	1.2	0.9	1.2	0.9	1.2	1.5
	Total	3.2	3.2	1.7	2.9	1.7	3.1	3.7
GW	Inflow							
	Deep	0.7	0.7	0.4	0.5	0.4	0.5	0.6
	Active	1.3	1.4	0.8	1.6	0.8	1.5	1.7
Evaporation								
	Potential	40.1	39.0	43.9	39.0	43.9	39.0	36.0
	Intercep	6.2	6.1	6.1	5.9	6.1	5.9	5.7
	Upper Zone	6.1	6.4	5.4	5.9	5.4	6.2	5.1
	Lower Zone	11.2	11.1	11.7	11.2	11.7	11.1	10.7
	Grnd Water	0.29	0.29	0.20	0.47	0.2	0.36	0.31
	Baseflow	0.04	0.04	0.05	0.04	0.0	0.04	0.04
	Impervious	0.02	0.02	0.02	0.01	0.0	0.01	0.01
	Total	23.9	23.9	23.5	23.5	23.5	23.7	21.9

`

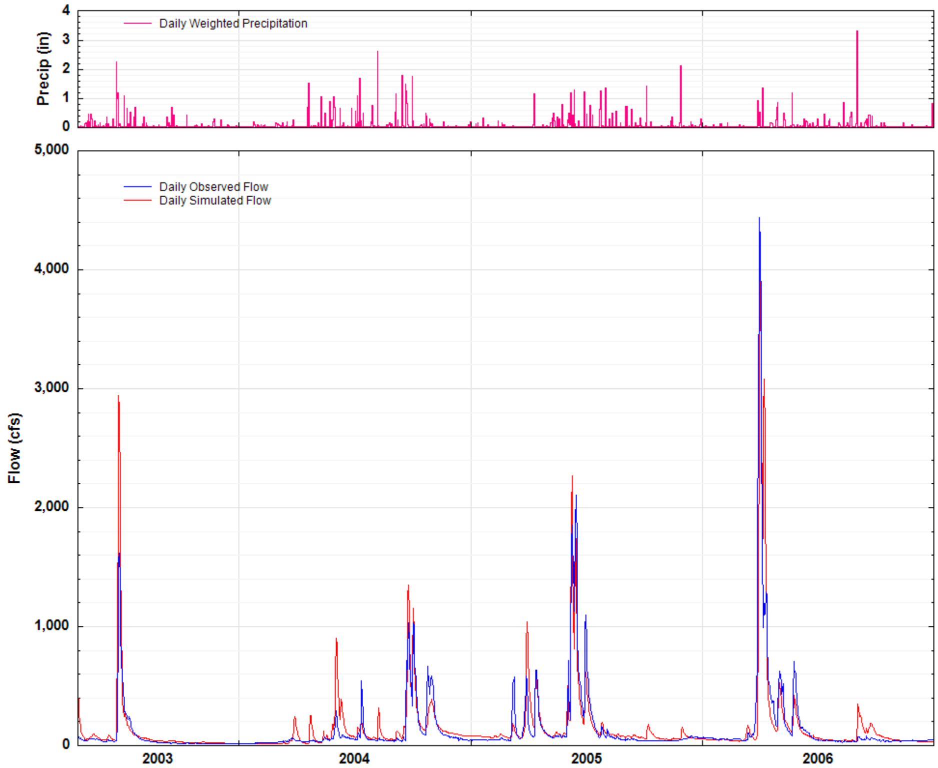


Figure 8. Calibration results for Mustinka 05049000, 2003-2006.

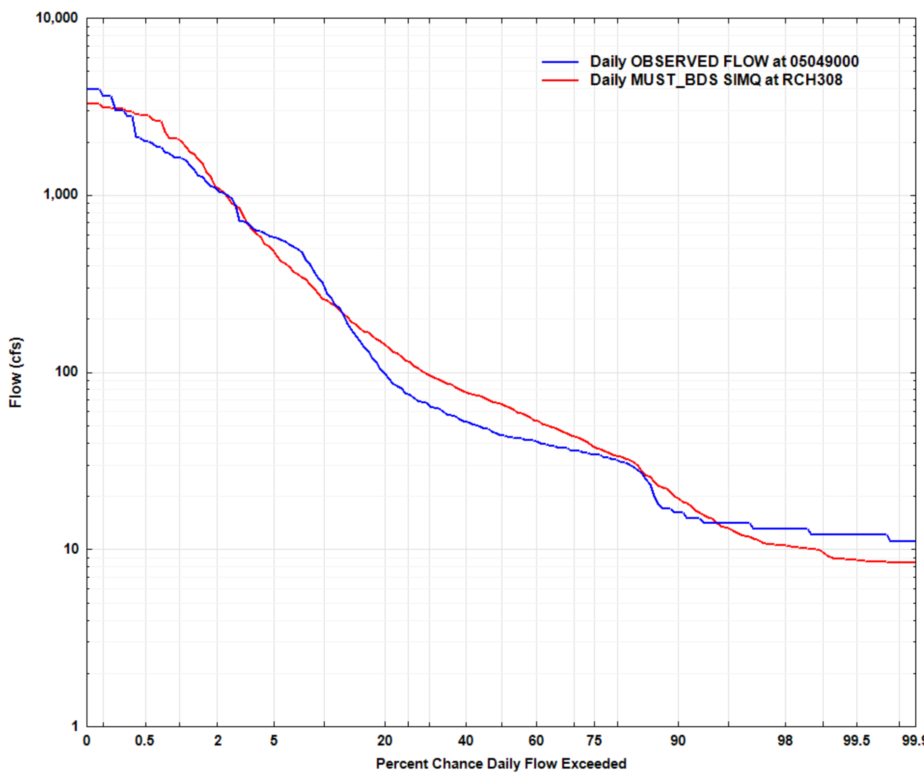


Figure 9. Calibration flow duration curves for Mustinka 05049000, 2003-2006.

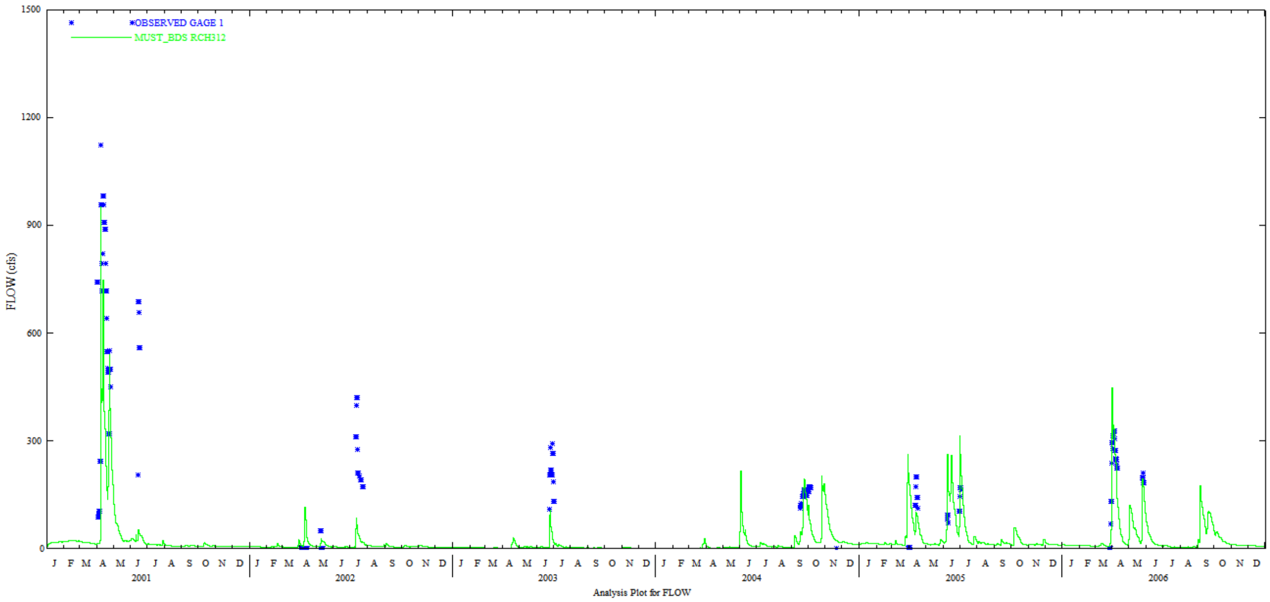


Figure 10. Validation results for Mustinka model at Gage 1, 2001-2006.

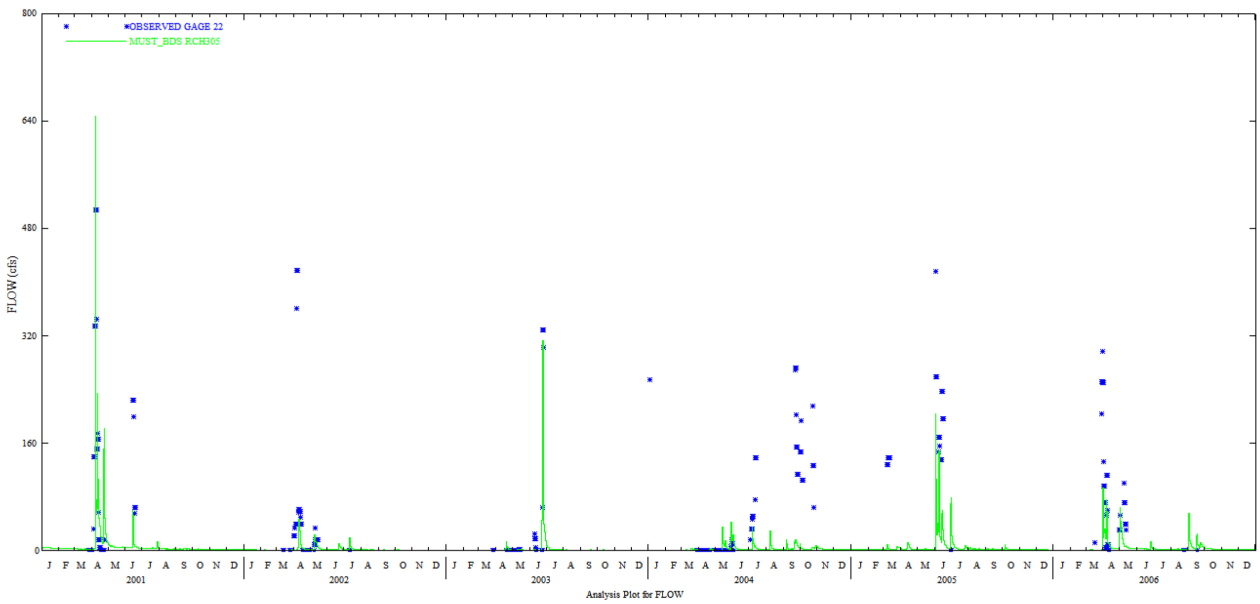


Figure 11. Validation results for Mustinka model at Gage 22, 2001-2006.

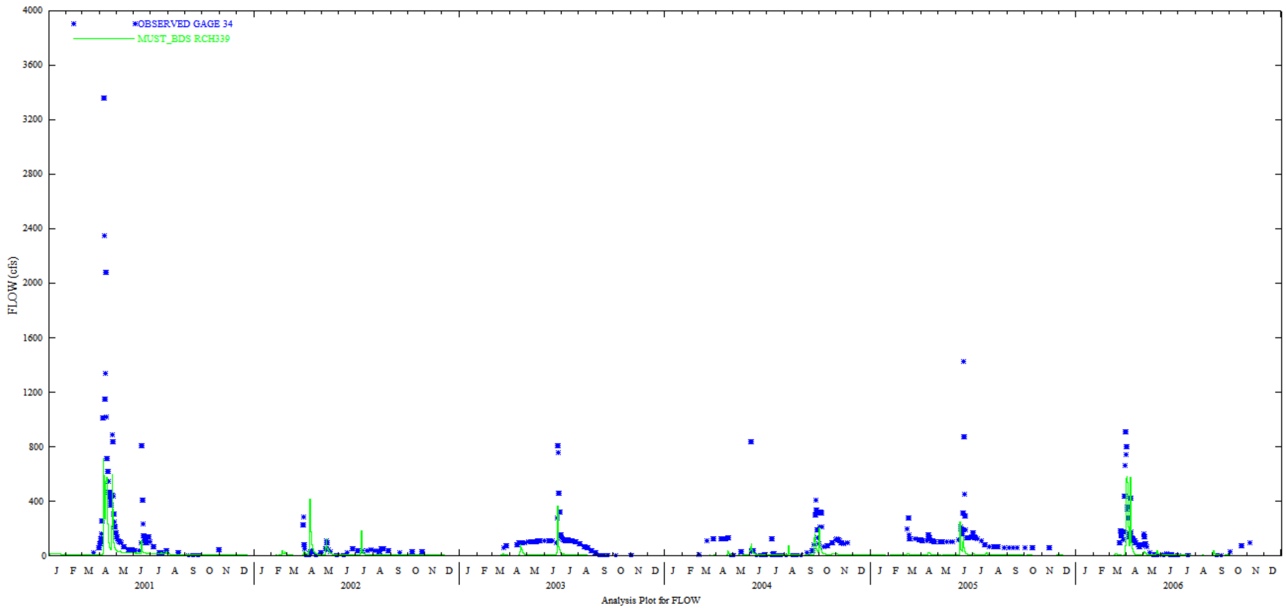


Figure 12. Validation results for Mustinka model at Gage 24, 2001-2006.

Figure 13. Calibration results for Rabbit 54017001, 2001-2006.

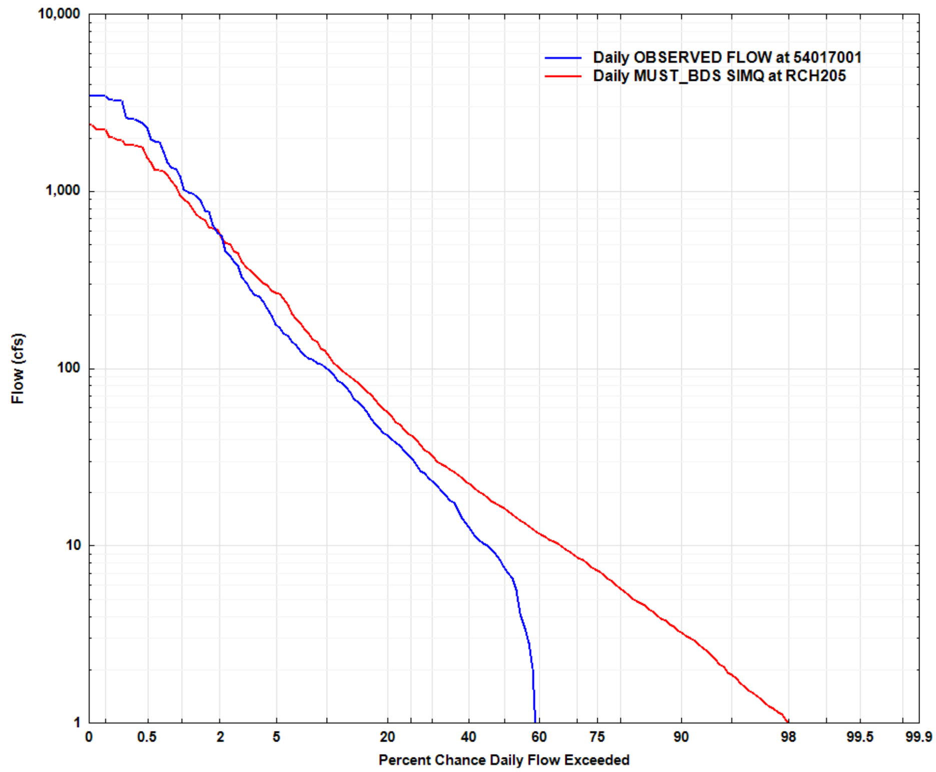


Figure 14. Calibration flow duration curves for Rabbit 54017001, 2001-2006

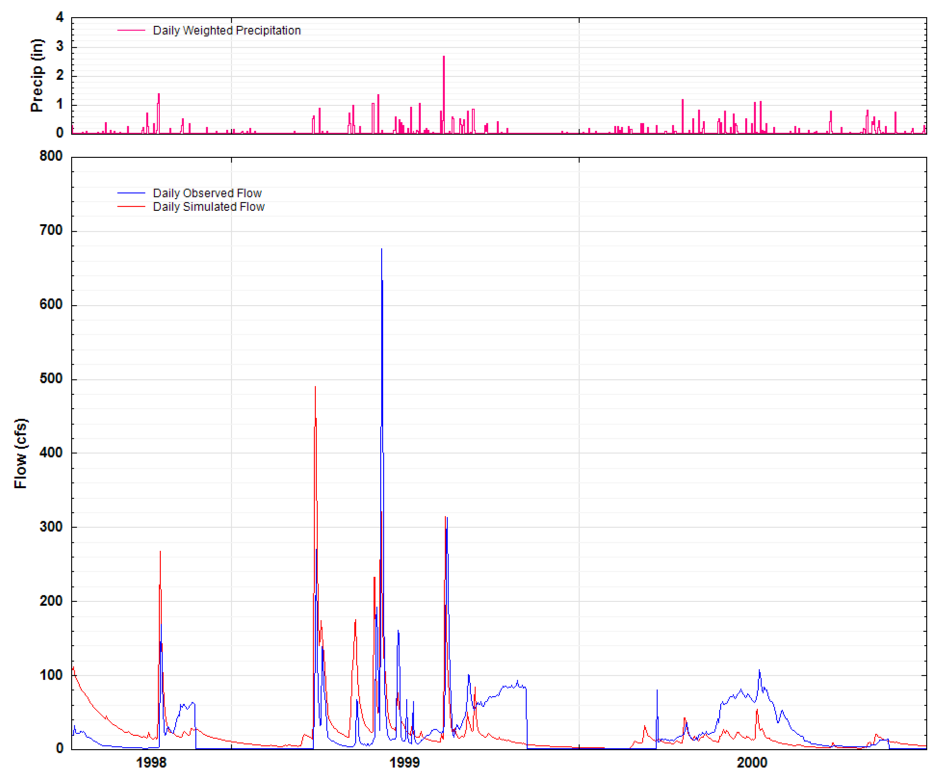


Figure 15. Validation results for Rabbit 54017001, 1998-2000

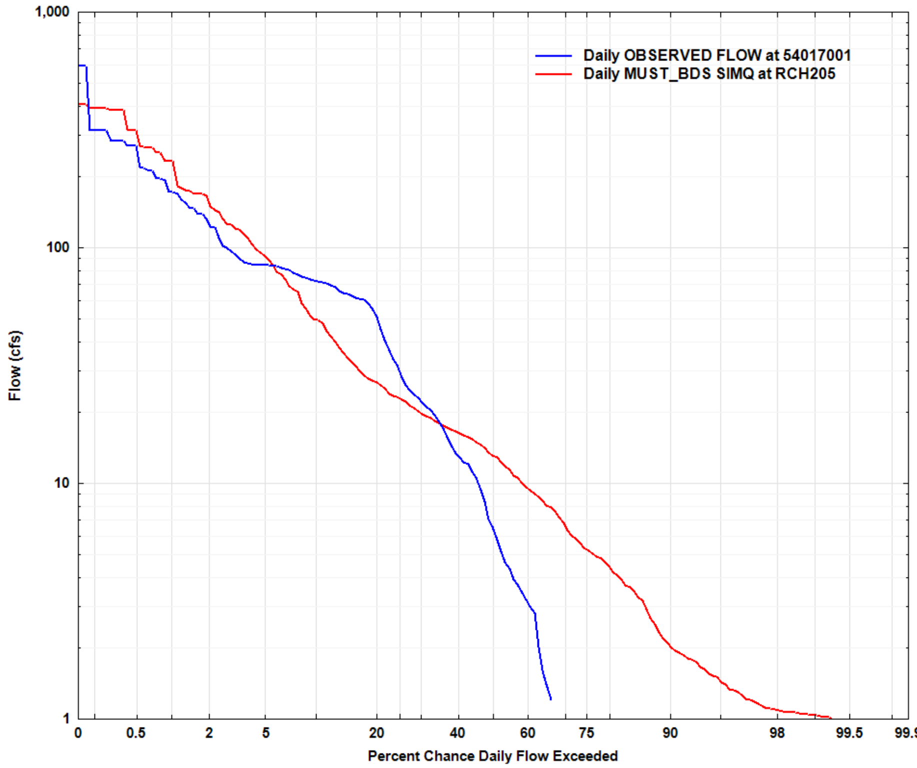


Figure 16. Validation flow duration curves for Rabbit 54017001, 1998-2000

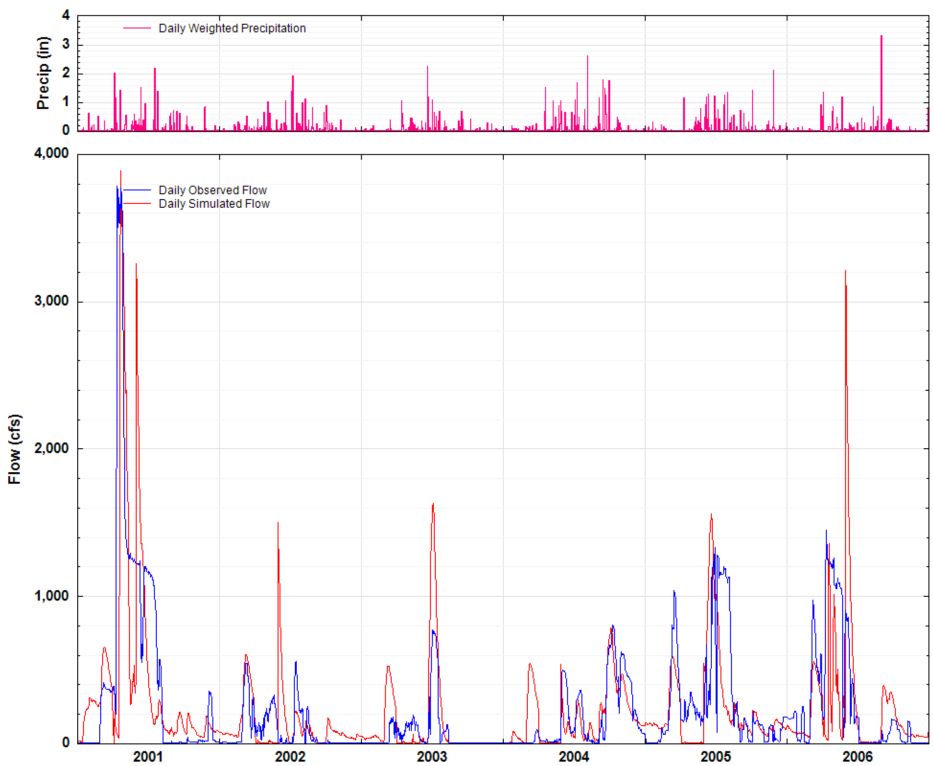


Figure 17. Calibration results for Bois de Sioux 05050000, 2001-2006

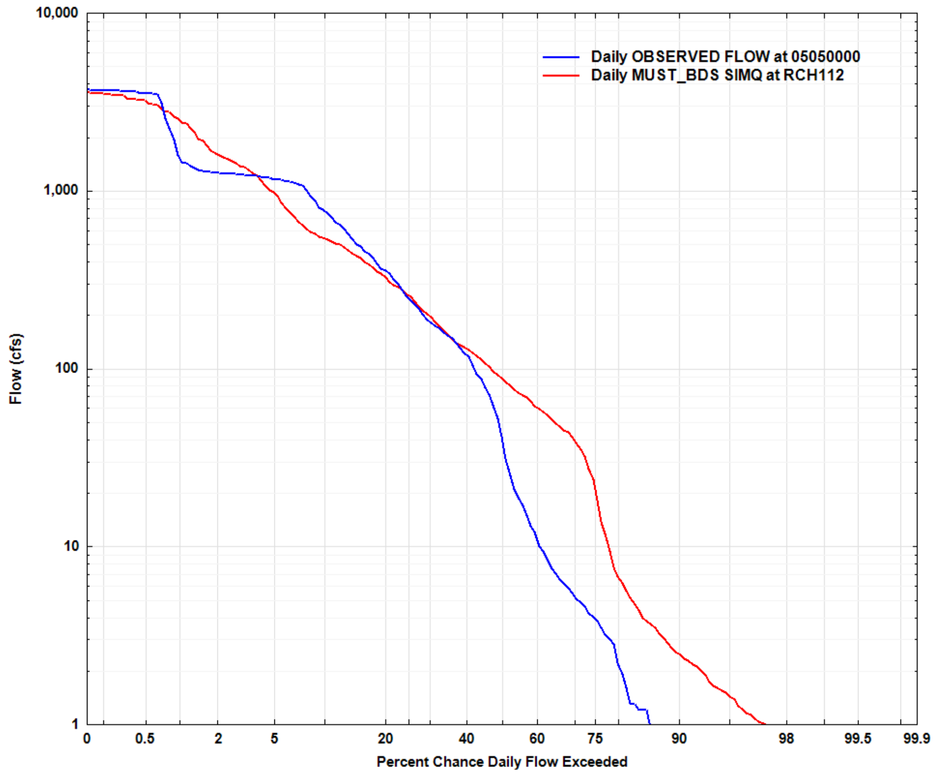


Figure 18. Calibration flow duration curves for Bois de Sioux 05050000, 2001-2006

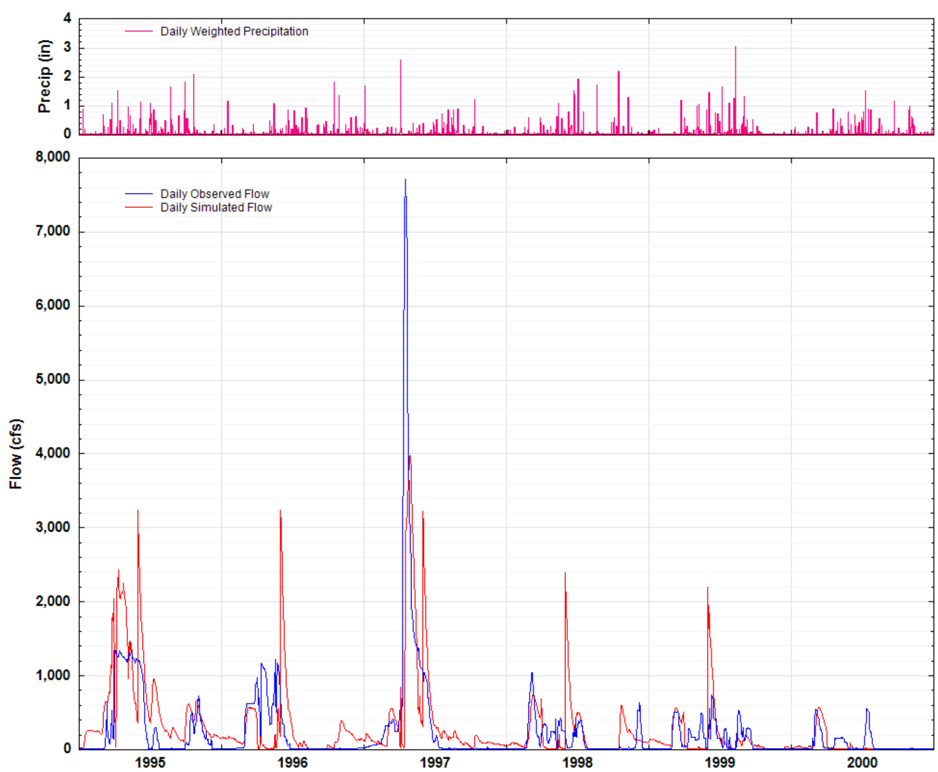


Figure 19. Validation results for Bois de Sioux 05050000, 1995-2000

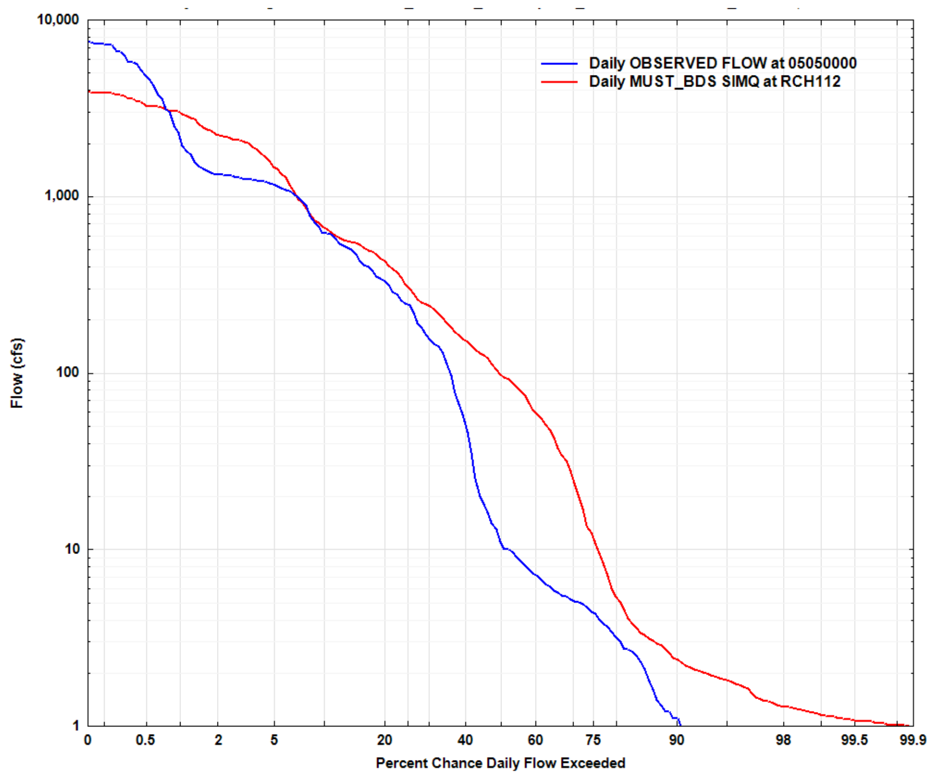


Figure 20. Validation flow duration curves for Bois de Sioux 05050000, 1995-2000

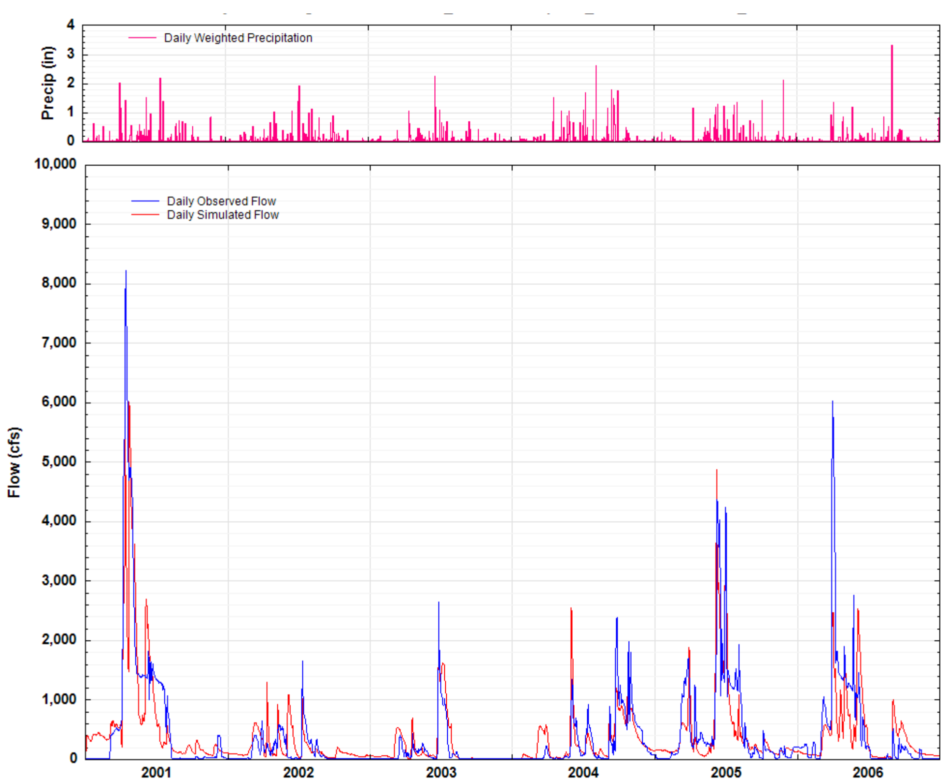


Figure 21. Calibration results for Bois de Sioux 05051300, 2001-2006

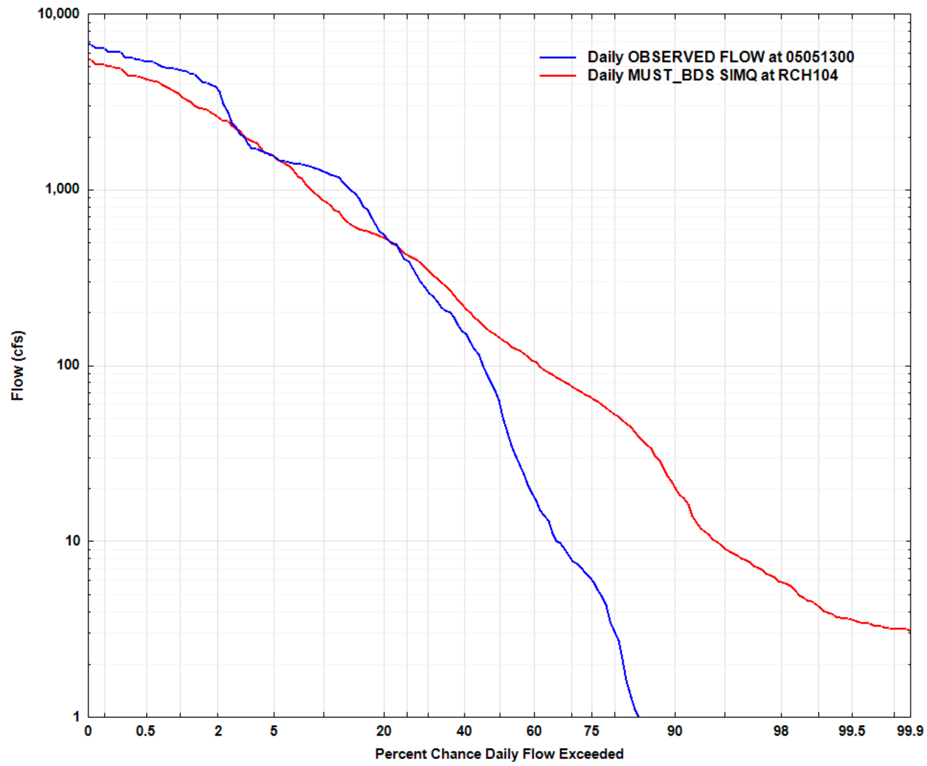


Figure 22. Calibration flow duration curves for Bois de Sioux 05051300, 2001-2006

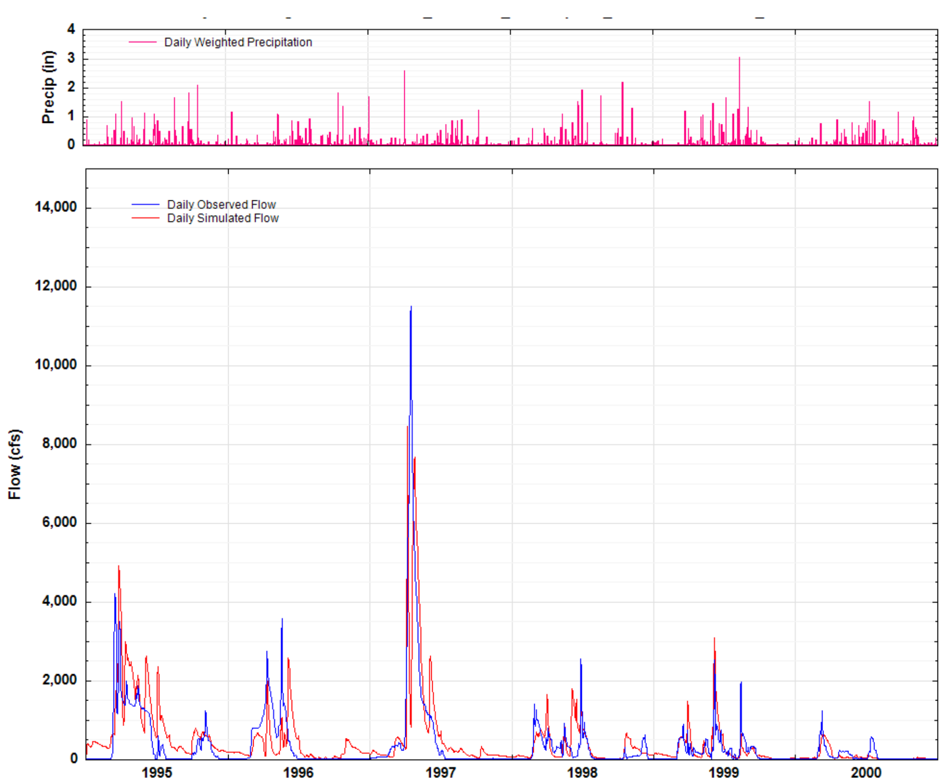


Figure 23. Validation results for Bois de Sioux 05051300, 1995-2000

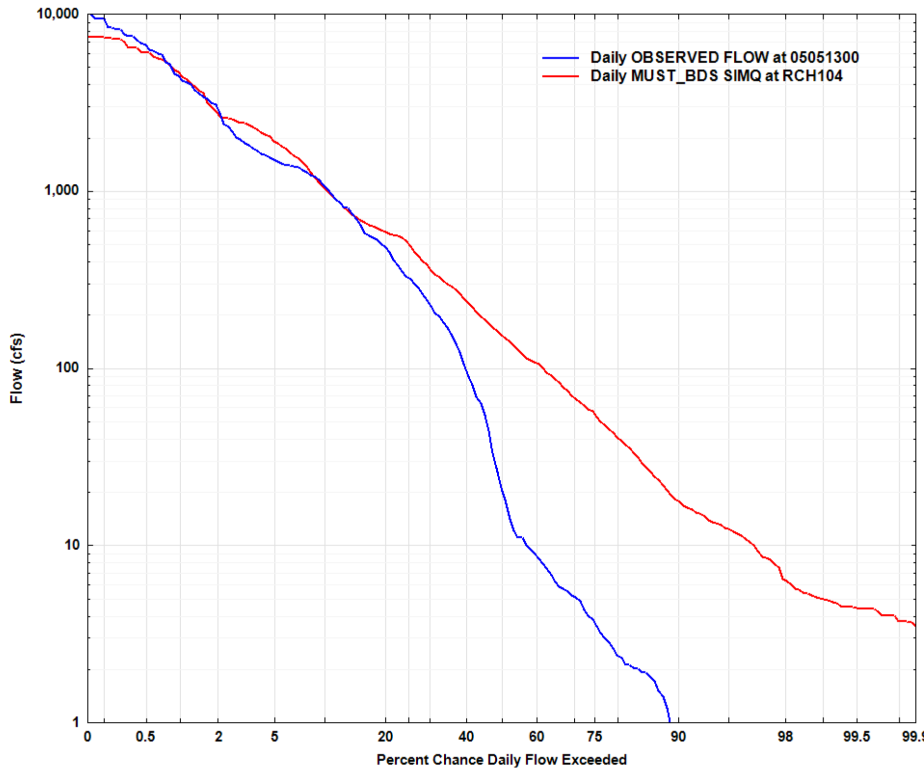


Figure 24. Validation flow duration curves for Bois de Sioux 05051300, 1995-2000

Figure 21. Validation results for Bois de Sioux 05051300, 1995-2000

References

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

Aqua Terra Consultants. BASINS/HSPF Training Handbook. St. Paul, MN. August 9-13, 2010. Sponsored by the United States Environmental Protection Agency, Office of Water/OST, Washington, DC.

Donigian, A.S., Baker, J.L., Haith, D.A., Walter, M.F. 1983. HSPF parameter adjustments to evaluate the effects of agricultural best management practices. Prepared for the Environmental Research Laboratory Office of Research and Development, United States Environmental Protection Agency, Athens, Georgia.

Lorenz, D.L.and G.N. Delin. 2007. A regression model to estimate regional ground water recharge. Groundwater. Mar-Apr 45(2): 196-208.

USEPA. 1978. User's manual for agricultural runoff management (ARM) model. EPA400/3-78-080.

USEPA. 2000. EPA BASINS Technical Note 6: Estimating Hydrology and Hydraulic Parameters for HSPF. USEPA Office of Water. EPA-823-R00-012.

APPENDIX: Responses to AquaTerra Model Review memo dated January 15, 2013.

General Comments

a) A single uci file for the two watersheds or two uci files (one for Mustinka and one for Bois de Sioux) would have been preferred. Fewer uci's would ensure consistency in parameters. Since the combined uci file treats inter basin transfer of water differently than the individual uci files, calibration on combined uci would have eliminated any inconsistency that might have arisen because of it.

All UCI files have been combined and parameters made consistent. See *Integrated UCI for all watersheds and Performance Statistics* section in main body of this document.

b) In the calibration approach memo, eight stations are listed as possible calibration locations, but detailed calibration was performed at only two stations (Mustinka River and Rabbit River). At two Bois de Sioux stations, only calibration and validation graphs were shown.

Available data is sparse at the BdSWD stations and were not used for calibration. However, calibration/validation has now been performed at all four USGS gauging stations.

c) A number of snow and hydrologic parameters are outside expected ranges, possibly because no snow depth comparisons (model vs. data) are shown in the calibration/validation memo report (dated 28 June 2012). These model-data comparisons are an important requirement for demonstrating a valid calibration in MN and substantiation of the snow parameters calibrated.

Snow calibration has been completed as recommended. Because of problems calibrating snow melt and spring flows, snow melt method 1 was replaced with method 2 which does not use the same parameters; therefore parameter ranges are no longer an issue. See *Snow Calibration* section in main body of this document.

d) There should be a high priority on extending the calibration through 2009 (BASINS met data currently available) so that additional calibration can be performed and the model results/agreement can be improved.

See section *Extension of Mustinka calibration period* in main document

e) Model documentation is scattered throughout numerous memos and subsequent revisions, making our review difficult (and time-consuming); the model documentation should be consolidated into a single comprehensive modeling report when the model is finalized.

This will be done at completion of water quality calibration.

f) **As part of the recommended model documentation, some discussion of the model calibration and validation is needed to address the adequacy of the model for subsequent water quality modeling and TMDL development purposes. Possibly the contractors were awaiting this review before discussing the model results, but it would have helped to have that discussion included in this review. In its current state, these models do not appear to be adequate for the planned uses without further refinements and improvements as recommended herein.**

Calibration discussion has been included in this document.

Comments for MUST.uci – Note that many of these comments also apply to the other UCIs, and will not be repeated in the subsequent discussions.

1. **The total area of the watersheds is about 550,000 acres, and the area of land uses is about 554,000 acres (this value is represented in the uci file), a difference of less than 1%.**

Probably a factor of the segmentation process (overlaying slopes, land covers, and soils). No change anticipated.

2. **The ordering and numbering of land uses is somewhat inconsistent, this makes it difficult to compare parameters among different land uses. For example, we recommend numbering all cropland landuses sequentially, and similarly for other categories, making it easier to confirm the use of the same (or similar) parameter values within a group of model land use segments.**

This was discussed in follow-up discussion with Chuck Regan and ATC 02/19/13. The numbering system was judged to be adequate. Note: New PLS's have been created and others omitted. See section *Elimination of pervious land segments that added unneeded complexity* and Table 2.

3. **Since about 80% of this watershed is cropland, in corn, soybeans, and spring wheat, it might be appropriate to allow or consider segmentation by crop types, especially since nonpoint loads might vary by the cropping type. We did not see any discussion of this in the documentation, but it might have been covered in conference calls.**

Corn and soybeans dominate croplands with a relatively small amount of sugar beets. Further segmentation was not undertaken in favor of enhanced SSURGO AB, CD soil and crop-depressional segmentation.

4. **The values of SHADE (fraction of area that is shielded from solar radiation) are very high with values of up to 0.84 for Forest, 0.63 and 0.74 for grassland in the SNOW section. No justification was provided for such high SHADE values, since this reduces the impact of solar radiation on the melt process.**

Shade parameters were changed to match values per PLS in HSPFparmV2 for Minnesota watersheds. See *Snow Calibration* section in main body of this document.

5. **The SNOWCF value of 1.5 is somewhat high, but not unrealistic. It would be helpful to know if the precip gages have snow shields which would imply a better catch and lower SNOWCF values. In *discussions with Ms. Nancy-Jeanne LeFevre, we learned that they***

had discussed this issue with the local meteorological agency and decided that higher SNOWCF values were reasonable.

SNOWCF was used as a calibration parameter for snow depth. Most met-segments had calibrated SNOWCF parameters=1; two had SNOWCF=1.5. See *Snow Calibration* section in main body of this document.

6. The values of CCFACT are about two orders of magnitude lower than typical. Both the SHADE and CCFACT values demonstrate that the modelers were attempting to delay the snow melt, and this resulted in parameter values beyond expected, and possibly, reasonable limits. Our experience, when parameters are pushed beyond reasonable limits, is that there may be other issues in the model setup or operation that may be causing the problem, which in this case is snow melting too early. This makes comparison with snow depth data doubly important in resolving this situation. The snow depth data can be downloaded from http://climate.umn.edu/doc/historical.htm

Snow depth has been calibrated. Values of CCFACT are irrelevant in the current version given snow melt method was changed from 1 to 2. See *Snow Calibration* section in main body of this document.

7. The MWATER value of 0.1 is greater than the value of 0.03, but it is less than the maximum possible value noted in U.S. EPA BASINS Tech Note #6.

MWATER is set to 0.1 in every Minnesota HSPF model present in HSPFparmV2

8. The high water table option was turned on for the Wetlands land category. This routine should be turned on only if additional data about the potentiometric, and/or water surface levels is available, for calibration. We recommend turning it off. This additional complexity is not needed, especially since wetlands are only about 5% of the area.

High water table option has been turned off.

9. IFFCFG is set to 1, so that infiltration is a function of ice content of the snow pack, which is a common and accepted approach for this region.

Noted.

10. INFILT values are very low, in the range of 0.017 to 0.037, except for Wetlands which have a value of 0.5. There is no discussion of how or if it was adjusted in calibration (unless we missed it).

PLS INFILT parameters in current model version are 0.02 Developed and Crop-CD, 0.03 for Crop-AB and Crop-Drained, 0.045 for Grass and Forest, and 0.5 for wetlands. This values are all within the *typical* range of Technote#6 and consistent with values for Minnesota HSPF models in HSPF parmV2. See *Calibration Results* section in main body of this document.

11. KVARY values are relatively high for Developed areas, some Grass land uses, some Cropland areas, and Wetlands. KVARY is most commonly assessed at a watershed, or subwatershed, scale, and is more a function of subsurface hydrogeologic conditions, not

land use categories, i.e., we don't normally change KVARY by land use. The only exception is for wetlands where groundwater levels are close to the land surface, and would be expected to have a more direct impact on recession rates. We recommend following the guidance in U.S. EPA BASINS Tech Note #6.

KVARY was set to 0.2 for all PLS's in current version.

12. The maximum SLSUR value is about 1.5%. This seems pretty low, but may be entirely possible for this watershed.

Maximum SLSUR is actually about 15%

13. The parameter DEEPFR, which assigns a fraction of the GW inflows to deep recharge is set to 0.0 for all land areas, as per the instructions in the MPCA Work Order. We feel this is not realistic for all watersheds, especially for the extremely flat landscapes common to much of MN, since it effectively represents the watershed as a 'bathtub'. However, DEEPFR should not be used as a calibration parameter without providing justification for the non-zero values that may be reasonable in many situations. Consequently, we recommend that the evaluation of DEEPFR be left to the individual contractors/modelers for their watersheds, with the stipulation that they provide some hydrogeologic evidence (or support) for any non-zero values applied to their watersheds, and a demonstration that the resulting deep recharge (as part of the required water balance display) is reasonable and appropriate. The basis for deciding what range of values of DEEPFR is 'reasonable and appropriate' will be the valueranges shown in BASINS Tech Note #6. Non-zero values of DEEPFR might improve some of the low flow simulation results, as shown in the flow duration curves for Bois de Sioux gage 5051300.

DEEPFR was set based on existing research of deep aquifer recharge in the current model version. See *Quantification and spatial distribution of deep aquifer recharge* section in main body.

14. BASETP is low for all land uses and even for Wetland areas.

Riparian vegetation is not expected to be a large player in evapotranspiration. ATC concurred that the values were appropriate in 02/19/2013 discussion.

15. INTFW values in the Forest areas are lower than most other land uses. It is difficult to rationalize this physically, and actually just the opposite is normally expected, i.e., Forests should have the higher INTFW values (unless tile drainage is significant).

This has been corrected in current version: Forest and Grass INTFW are set to 3.0; Developed INFTW is set to 1.0.

16. PWAT-PARM 6 and 7 tables should be deleted after turning off the high water table option for Wetland areas.

Completed.

17. Lower UZSN values on Croplands than on Developed Land, and essentially identical values for Forests and Developed lands, are generally not appropriate, and should be corrected or justified.

This has been corrected in current version. Annual UZSN and average MON-UZSN values follow this relationship: Wetland>Forest=Grass>CropAB=Crop-Drained>CropCD>Developed. Note: High Wetland UZSN is common and consistent practice (as exhibited in HSPFparmV2) to characterize storage capacity of wetlands. Further, in some PLS within this model, Crop-depressional UZSN's exceed those of Wetlands. See section: *Location and extent of depressional storage and designation as pervious land segments.*

18. Some Cropland areas have similar INTFW values to Developed Land areas. We would recommend modelers to revisit the table PWAT-PARM1 and ensure that only the PERLNDs that are supposed to have monthly varying values are shown in the monthly tables. This will avoid confusion and reduce potential mistakes as noted above.

This has been corrected.

19. Forest should have greater LZETP than Developed Land areas.

This has been corrected.

20. All Urban land use was assigned to a single category; in the HSPF Model Guidance document, it was recommended that three (3) Urban categories be included: Developed/Open, Developed/Low Intensity, Developed/Med-High Intensity. The NLCD coverage provides these other categories, and including these three categories allows the model to be more useful for assessing impacts of future conditions.

Developed land uses make up approximately 5.0% of the watershed area. 'Developed, Open Space' makes up 89% of the developed land uses, followed by 'Developed, Low Intensity'. There are no MS4s. No change was made.

21. The report says that the PET time series was generated using the Penman Pan method and the MFactor will remain 1.0 (Nancy-Jeanne LeFevre noted that this was a typo). However, the MFactor used in the model is 0.7.

A value of 0.75 was used in current version of model.

22. The calibration statistics at Mustinka River gage are acceptable, but we expect that some recalibration will be required after addressing the comments.

Mustinka calibration has been revised.

<u>**Comments for RAB.uci**</u>

1. The RAB.uci ends on 12/11/2000. It was changed to end on 12/31/2000, for ease of calculating statistics.

Noted.

2. In MUST.uci and MUST_BDS.uci, CropAB0to2 and CropAB2plus were modeled with monthly-varying INTFW values, but in RAB.uci they were not modeled with monthly values.

As noted, the current version of the model has been combined into one UCI thus these inconsistencies have been corrected.

3. KVARY values are significantly higher in RAB.uci and AGWRC is lower than in MUST.uci.

As per above, item#2.

4. LZETP values are greater in RAB.uci than MUST.uci. These should be the same for each land use category, representing vegetation characteristics, so the same values should be applied in each UCI.

As per above, items#2-3

5. After addressing the comments above, RAB.uci may need further calibration. Calibration statistics at Rabbit River are fair, and the validation statistics for RAB.uci are not acceptable.

Rabbit River calibration has been revised.

6. Most of the comments to MUST.uci apply to RAB.uci as well.

Noted.

7. See comments for MUST_BDS.uci related to interbasin transfers and point sources.

Noted.

Comments for MUST_BDS.uci

1. MUST_BDS.uci is a uci for the entire watershed. We believe that the Contractors should have constructed and/or submitted only one or possibly two uci files.

As previously noted, the current version of the model consists of one combined UCI

2. MUST_BDS.uci takes most of its parameters from MUST.uci and RAB.uci, so many of the comments on those uci files apply to this one.

Noted.

3. The modelers did not calculate the HSPF Expert System statistics at the two USGS gages on the Bois de Sioux River; we recommend that the modelers calculate those statistics.

Expert statistics have been calculated for the two Bois de Sioux river gages. See *Integrated UCI for all watersheds and Performance Statistics*

4. In the absence of EXS files for the Bois de Sioux gages, AQUA TERRA did not calculate HSPEXP Expert System statistics and did not produce flow comparison graphs for gages on the Bois de Sioux river.

See above, item#3

5. **There are three transfers from the Mustinka mainstem (RCHs 308 and 309) to the Rabbit (RCHs 206 and 213). These transfers are based on the flow level in the Mustinka reaches; the FTABLEs for RCHs 308 and 309 have additional outflow curves that determine these transfers. In the MUST.uci and RAB.uci, these transfers were accomplished using daily WDM datasets. In the unified uci file the transfers are direct. We recommend better documentation of these transfers in the uci file through the use of comments.**

Comments in this UCI section (and others) are over-written when parameters are changed and saved using WinHSPF. Need for better UCI documentation is noted and will be added in the latter stages of water quality calibration.

6. **There are eight point source discharges in the watershed. They should be documented in the uci file using comment lines.**

See above, item#5

7. **The outflow rates from Lake Traverse (RCH 114) and Mud Lake (RCH 112) on the Red River are determined using multiple discharge curves that are used at different times of the year based on user-specified timeseries (COLIND), which determine which of the FTABLE discharge columns to use. The approach seems to be correctly implemented. The only issue is that these two reaches have three outflow exits/gates as specified in table HYDR-PARM1, but only the first exit is being used. It is possible the modeler originally intended to use three separate exits, and then changed the approach. We recommend reducing the number of exits to one. Also, we recommend better documentation of the multiple discharge curves using comment lines in the uci file.**

See above, items#5-6