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MEMORANDUM

To: Cory Netland (Hawk Creek Watershed Project)
Hafiz Munir, Darrell Schindler (MPCA)

Date: June 25, 2011

From: Jonathan Butcher

Project: Hawk Creek

Subject: Hawk Creek/Yellow Medicine River Detailed Model

This memorandum transmits and describes the development and calibration of a 12-digit HUC-scale HSPF model of Hawk Creek, Yellow Medicine River, and other minor tributaries of the Minnesota River contained within the 8-digit HUC 07020004 (Figure 1). The detailed model does not simulate the portion of the Minnesota River that runs through the center of this HUC8; however, it could readily be linked to the larger-scale model of the Minnesota River.

The model exists in two forms, currently labeled as HawkYM24.uci and HawkYM24-FullSA.uci. The latter version contains HSPF Special Actions implemented to account for sediment transport through tile drains (in addition to those that represent tillage and bluff collapse). These Special Actions for tile sediment transport are complex and time-consuming to run, increasing run time from about 15 minutes to 6 hours for a 10-year simulation, and must be applied to a large number of HRU combinations. Experiments with the model show that these Special Actions have no effect on hydrology and contribute a change in average pollutant concentration of less than 2 percent at all analyzed locations in the Hawk/Yellow Medicine basins. Therefore, it is recommended that the version without Special Actions for tile drain transport of sediment is adequate for most analysis purposes in these basins.

The model uci files may be edited using a text editor (we suggest the shareware TextPad program) or using the WinHSPF program. Each has advantages for different situations. The model may be run using WinHSPFLt or WinHSPF. Please note the following:

- The WinHSPF engine should be updated by copying the September 2009 version of hass_ent.dll (previously provided) into the Windows\System32 directory. This allows for a greater number of operations.
- The uci files cannot be run with the DOS version of HSPF due to number of operations.

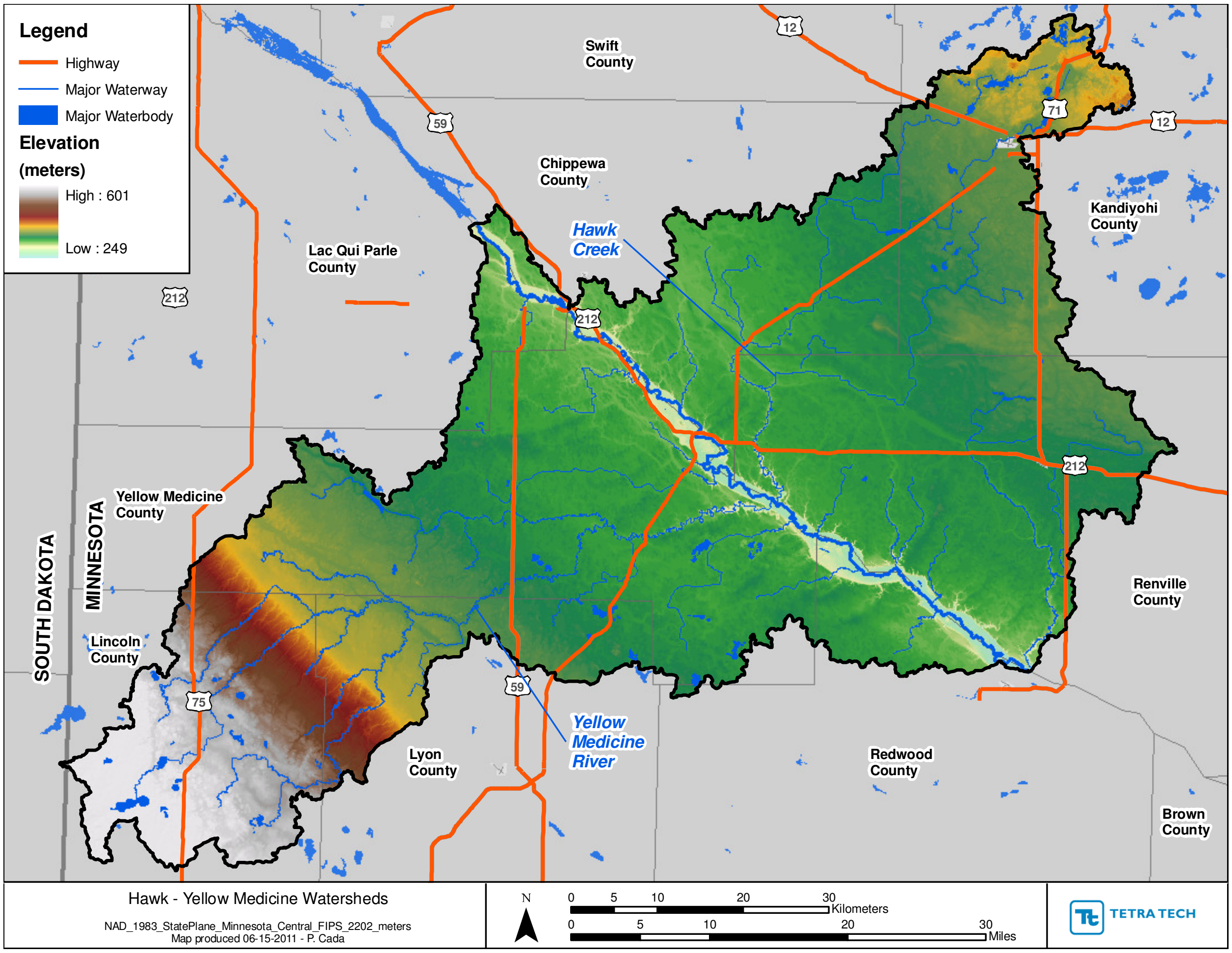

Figure 1. The Yellow Medicine River/Hawk Creek Basin

1 Model Setup

The model is set up on a hydrologic response unit (HRU) basis, which takes into account land use, hydrologic soil group (HSG), and slope – along with weather station assignment. Each PERLND (and IMPLND) has a three digit numeric code. There are 14 weather stations used in the model, and 37 potential land use/hydrologic soil group (HSG) combinations (although not all are used). The three digit code identifying an HRU is calculated as (*hru* – 1)*14 + *wst*. Where *hru* is the base code for the land use/HSG combination and *wst* is the precipitation station assignment. This enables the PERLNDs to be grouped consecutively by HRUs, which is useful for parameter entry.

Land use/land cover was developed from multiple data sources. NLCD 2001 GIS grid-based data products were used to represent the spatial distribution of developed, agricultural, and undeveloped land in the watersheds (Figure 2). Because NLCD lacks detailed information about types of crops and tillage practices, county-level agricultural statistical data were used to refine the agricultural land classification, as discussed below under *Processing Steps*.

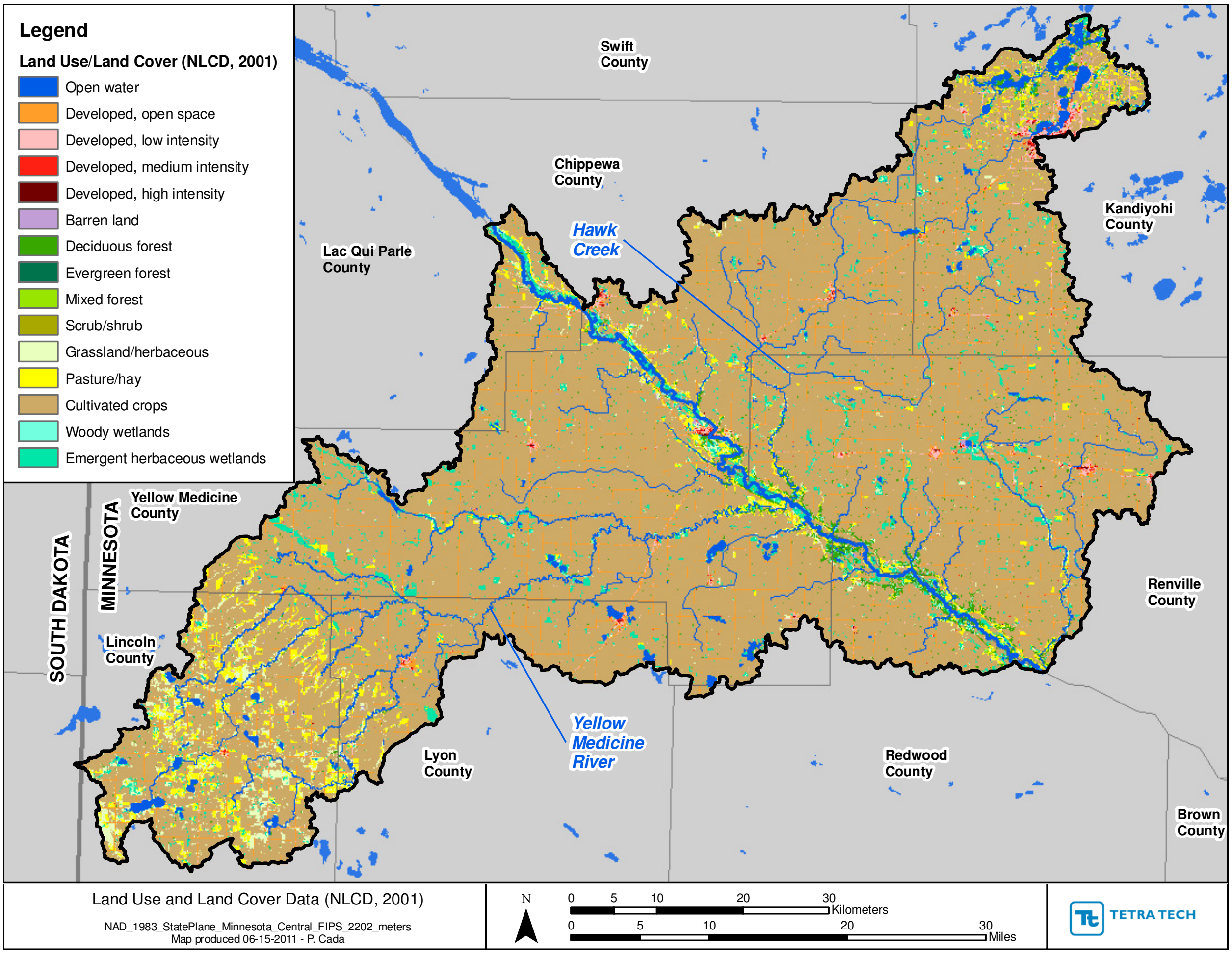

Figure 2. Land Use/Land Cover in the Yellow Medicine/Hawk Creek Basin

NLCD provides four developed classes representing degrees of development from rural to high intensity. The HSPF model, on the other hand, was configured to separate developed pervious and impervious surfaces. The NLCD impervious area grid was used to estimate representative percent impervious values for each of the developed NLCD classes. The analysis yielded the following percent impervious values:

- Rural/open space (NLCD 21): 6.12%
- Low intensity (NLCD 22): 27.65%
- Medium intensity (NLCD 23): 58.65%
- High intensity (NLCD 24): 86.36%

Soil HSG was developed by combining county-level SSURGO GIS data into a unified coverage for the entire study area (Figure 3). HSG A soils were found to be rare in the watershed, and were combined with B soils to reduce the number of HRUs and simplify the HSPF model. The study area also had a high proportion of soils with a dual designation (e.g., “B/D”). The two designators represent performance under drained and undrained conditions. During HRU processing, the first (drained) designator was used for cropland and the second (undrained) designator was used for all other land uses.

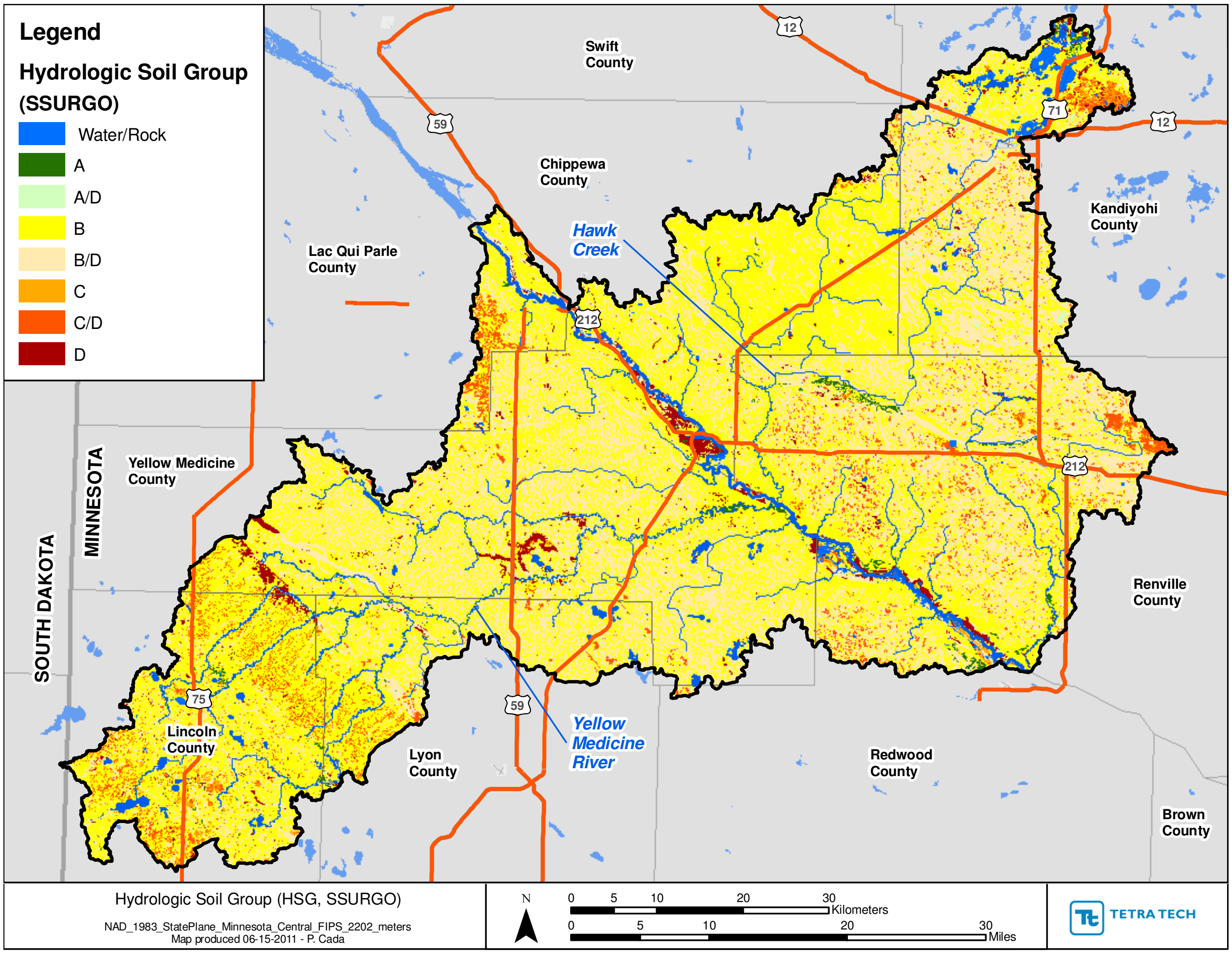

Figure 3. Hydrologic Soil Groups

Slope was calculated from a 30 meter DEM in ArcGIS. Thirty meter grid cells were ideal for this project because the cell size matched the NLCD grids, and smaller DEM cells would have yielded micro-variations in slope that would not be consistent with the purpose of the slope classification. The slope grid was reclassified into two categories – Low (less than 1 percent), and High (greater than 1 percent). This was done to distinguish between areas that are likely to have surface tile inlets (lower slopes) versus those that are not likely to have such inlets. Sediment transport through tile drains is simulated only for the lower slope areas. Low and High slope categories were applied only to tilled land and grassland/pasture.

Processing Steps

NLCD land use, soil HSG, and the Low/High slope grid were combined in ArcGIS to produce a grid with unique values for each combination of NLCD land cover, HSG, and slope.

The resulting grid was simplified as follows, according to NLCD land cover classes:

- The three forest types (deciduous, evergreen, and mixed) and shrubland were lumped into one category representing forest. Shrubland made up a fraction of a percent of land area in the study area and is not simulated separately.
- Woody and herbaceous wetlands were lumped into a single wetland category.
- Grassland and Pasture/Hay were lumped into a single grass/pasture category.
- HSG classes
- A soils were lumped with B soils.
- For untilled land, C soils were found to be rare, and were lumped with the A-B category.
- For tilled land, D soils were relatively rare, and were lumped with C soils.
- Water and wetland categories were assumed to behave like D soils with poor infiltration, so all HSGs were lumped for these two categories.
- Barren land was a tiny fraction of the watershed (about 0.1 percent), so its HSG classes were lumped into a single category.
- Slope classes were eliminated for all land except tilled land and grass/pasture.

The simplified grid was processed in BASINS4, splitting the developed NLCD classes into pervious and impervious area. Developed pervious land retained the HSG subcategories. The overall result of the BASINS4 operation provided a land use/land cover table with each HRU and weather station assignment, as well as model subbasin. Data were imported into the Land Use Processing spreadsheet, and the processed developed lands were lumped in the *RawLU* worksheet.

The tabulated tilled land was post-processed to further categorize by tillage practice and manure application. The conservation tillage and manured tillage land use classes were assigned based on county-level agricultural statistics and information on CRP/CREP/RIM acres as shown in the Land Use Processing spreadsheet. As such, there is no explicit spatial location for the types of agricultural land use. Rather, they should be viewed as approximate proportions within each subbasin.

To avoid double counting, the NLCD water land use area was corrected for the surface area of lakes that were explicitly simulated as reaches in the Land Use Processing spreadsheet

The HRU numbering scheme is summarized in Table 1. Setup of the HRUs is controlled by the HRU and Land Use Processing.xlsx spreadsheet.

Table 1. HRU Numbering Scheme

Land Use	HSG	Slope	Base Code
Water	all	all	01
Barren	all	all	02
Wetland	all	all	03
Forest	A,B,C	all	04
Forest	D	all	06
Grass/Pasture	A,B,C	L	10
Grass/Pasture	A,B,C	H	11
Grass/Pasture	D	L	14
Grass/Pasture	D	H	15
Conventional Tillage	A,B	L	16
Conventional Tillage	A,B	H	17
Conventional Tillage	C,D	L	18
Conventional Tillage	C,D	H	19
Conservation Tillage	A,B	L	22
Conservation Tillage	A,B	H	23
Conservation Tillage	C,D	L	24
Conservation Tillage	C,D	H	25
Manured Tillage	A,B	L	28
Manured Tillage	A,B	H	29
Manured Tillage	C,D	L	30
Manured Tillage	C,D	H	31
Developed Pervious	A,B,C	all	34
Developed Pervious	D	all	36
Impervious	all	all	37

The precipitation stations are assigned to model subbasins based on proximity. The stations are identified in Table 2. The last eight stations are NLCD stations, and the model uses disaggregated hourly time series previously created by Tetra Tech for the Minnesota River Turbidity TMDL project (through 2006), with augmented data through 2009. The first six, "SWCD" stations are additional SOD stations obtained and processed by MPCA.

Table 2. Precipitation Stations

Met Station	WST#	Name
SWCD1	1	253879-4947441
SWCD2	2	270561-4962989
SWCD3	3	297650-4952225
SWCD4	4	302088-4940775
SWCD5	5	329702-4946407
SWCD6	6	341200-4980208
MN213311	7	Granite Falls
MN215204	8	Marshall
MN215482	9	Minneota
MN215563	10	Montevideo 1 SW
MN216152	11	Olivia 1 SE
MN218429	12	Tyler
MN219004	13	Willmar RTC
SD390422	14	Astoria, SD 4S

The model contains 75 subbasins and 76 stream reaches (RCHRES 100, representing Yellow Medicine River from the USGS gage to the mouth, is a routing reach only, with no assigned direct drainage). The subbasins and reaches have the same numbering. The reaches and associated precipitation station assignments are shown in Table 3, while the spatial distribution of subbasins is shown in Figure 4.

Table 3. Reaches, Subbasins, and Weather Station Assignments

Reach Number	Name	WST #
100	Yellow Medicine River mouth	3
101	Yellow Medicine River at Gage	3
102	Unnamed Trib 3 to Yellow Medicine River	3
103	Unnamed Trib 4 to Yellow Medicine River	8
104	Yellow Medicine River	8
105	Unnamed Trib 2 to Yellow Medicine River	9
106	South Branch Yellow Medicine River	9
107	South Branch Yellow Medicine River	9
108	Unnamed Trib 1 to South Branch Yellow Medicine River	12

Reach Number	Name	WST #
109	South Branch Yellow Medicine River	12
110	Unnamed Trib 2 to South Branch Yellow Medicine River	9
111	Yellow Medicine River	1
112	Unnamed Trib 1 to Yellow Medicine River	9
113	Yellow Medicine River	1
114	Yellow Medicine River	14
115	Shaokotan Lake	14
116	North Branch Yellow Medicine River	1
117	North Branch Yellow Medicine River	14
118	Mud Creek	1
119	Spring Creek	2
120	Unnamed Trib 3 to Spring Creek	2
121	Spring Creek	2
122	Unnamed Trib 2 to Spring Creek	1
123	Spring Creek	1
124	Unnamed Trib 1 to Spring Creek	1
130	Rice Creek	5
140	Boiling Spring Creek	4
150	Wood Lake Creek	3
151	Unnamed Trib 1 to Wood Lake Creek	4
152	Unnamed Trib 2 to Wood Lake Creek	4
153	Wood Lake	3
160	Hazel Creek	3
161	Hazel Creek	2
170	Unnamed Trib 2 to Minnesota River	7

Reach Number	Name	WST #
180	Stony Run Creek	10
190	Unnamed Trib 1 to Minnesota River	10
201	Hawk Creek	7
202	Hawk Creek	7
203	County Ditch 11	7
204	Unnamed Trib 2 to Hawk Creek	7
205	Hawk Creek	7
206	Hawk Creek	7
207	Unnamed Trib 1 to Hawk Creek	13
208	Saint Johns Lake	13
209	West Solomon Lake	13
210	Long Lake	13
211	Hawk Creek	6
212	Hawk Creek	13
213	Hawk Creek	13
214	Foot Lake	13
215	Eagle Lake	13
216	Judicial Ditch 2	6
217	Chetomba Creek	7
218	Judicial Ditch 1	7
219	Chetomba Creek	6
220	Chetomba Creek	6
221	County Ditch 8	6
230	Beaver Creek	5
231	West Fork Beaver Creek	5

Reach Number	Name	WST #
232	West Fork Beaver Creek	6
233	County Ditch 59	11
234	East Fork Beaver Creek	11
235	East Fork Beaver Creek	11
240	Timms Creek	5
250	Sacred Heart Creek, East Branch	5
260	Sacred Heart Creek	5
270	Unnamed Trib 3 to Minnesota River	7
280	Palmer Creek	7
301	Minnesota River direct drainage 301	5
302	Minnesota River direct drainage 302	5
303	Minnesota River direct drainage 303	5
304	Minnesota River direct drainage 304	5
305	Minnesota River direct drainage 305	7
306	Minnesota River direct drainage 306	7
307	Minnesota River direct drainage 307	10
308	Minnesota River direct drainage 308	10

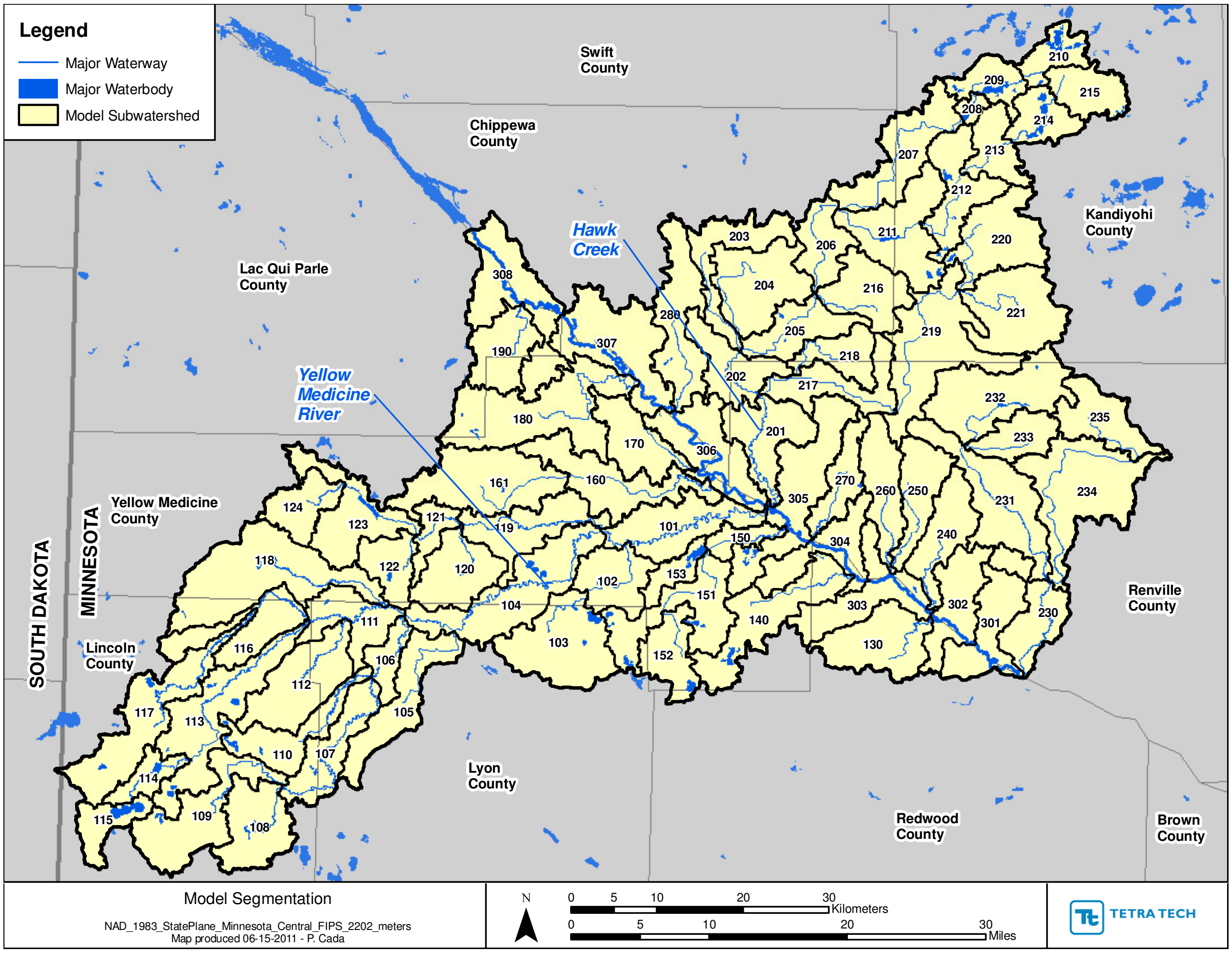

Figure 4. **Model Segmentation**

Hydraulic FTables for the reaches were developed from Lyon County HEC-RAS models where available (Yellow Medicine reaches 100, 101, 104, and 111). HEC-RAS models apparently exist for Beaver Creek and lower Hawk Creek, but MDNR was not able to provide these. Flowing reaches not covered by HEC-RAS models have the default FTables generated by BASINS4. Lakes are particularly important in the Hawk Creek headwaters. Thirteen lakes are explicitly represented in the model (Ringo, Long, Solomon, West Solomon, Lindgren, Saint Johns, Eagle, Swan, Willmar, Foot, Shaokotan, Wood, and Mud Lakes) and separate FTables have been created for these lakes (or sets of connected lakes) based on available information about storage and discharge characteristics.

As noted above, the Land Use Processing spreadsheet reassigns agricultural land in conventional tillage, conservation tillage, and manured land categories, and also removes the water area represented by explicitly simulated lakes. This spreadsheet is also set up with functionality to represent a variety of management measures, using the same procedures as for the Minnesota River model. This is set up on the Scenario tab, but no scenario adjustments are implemented at this time.

Point sources and atmospheric deposition of nitrogen are included in the model based on information developed for the Minnesota River model and supplemented through 2009 for this project. Explicitly simulated major point source locations are shown in Figure 5. In addition, minor discharges from stabilization ponds are represented in the model using the generic, aggregated approach employed in the Minnesota River basin model. These are summarized in Table 4.

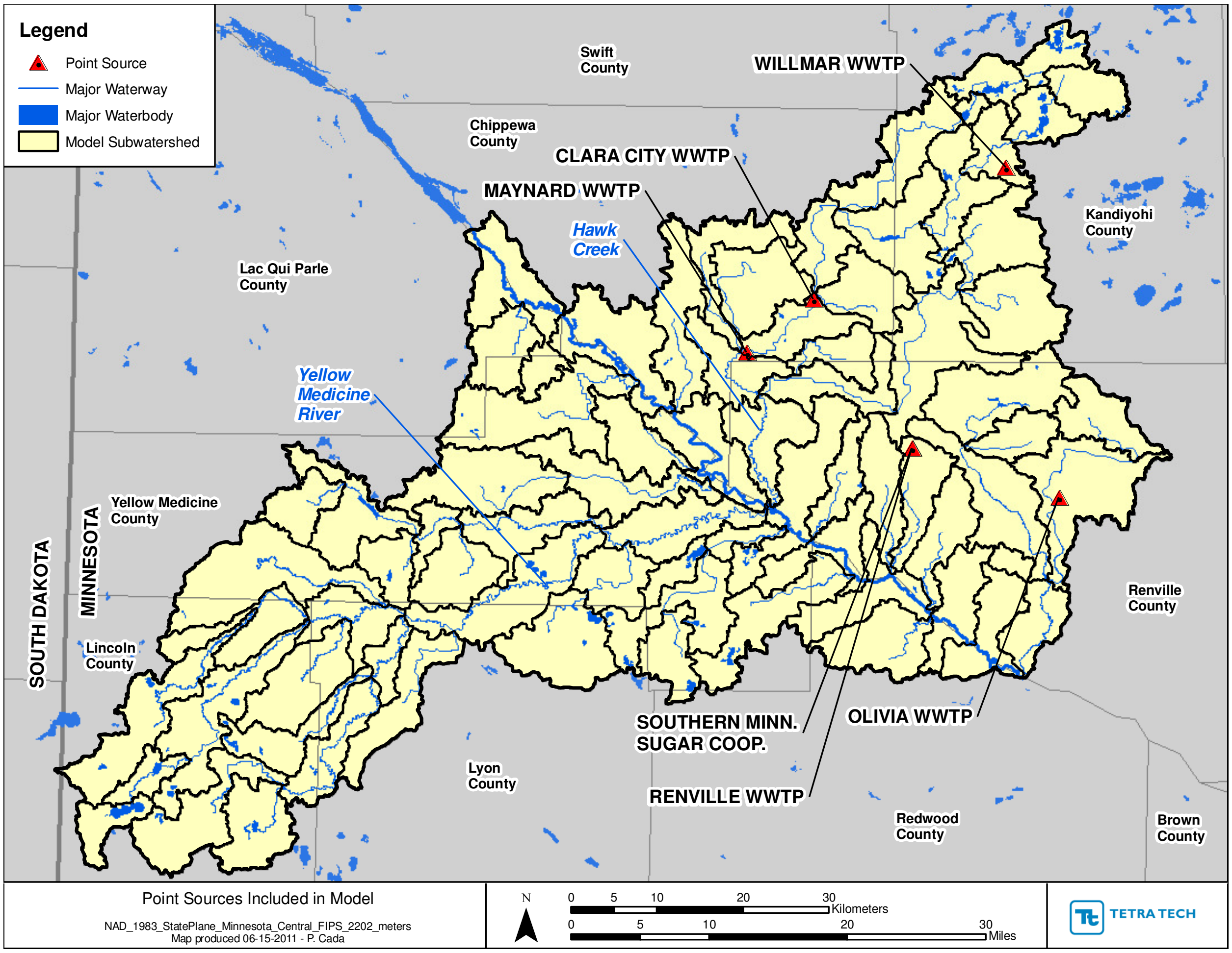

Figure 5. Explicitly Simulated Point Sources

Table 4. Stabilization Ponds in the Model

Permit No.	Name	Receiving Water	Model Subbasin
MNG580122	Hanley Falls WWTP	Yellow Medicine	101
MNG580010	Cottonwood WWTP	JD #10	103
MNG580033	Minneota WWTP	SB Yellow Medicine	106
MNG580090	Taunton WWTP	unnamed to YMR	112
MNG580103	Ivanhoe WWTP	Yellow Medicine	113
MNG580128	Porter WWTP	Mud Cr	118
MN0024775	St Leo WWTP	unnamed to YMR	123
MNG580003	Belview WWTP	CD #12	130
MNG580059	Echo WWTP	Boiling Springs Ck	140
MNG580107	Wood Lake WWTP	JD #10	152
MNG580093	Clarkfield WWTP	CD #9	161
MNG580104	Pennock WWTP	trib to Hawk Cr, ds St. Johns lake	207
MN0045446	Raymond WWTP	Hawk Cr	211
MNG580057	Danube WWTP	WF Beaver Ck	231
MN0022829	Bird Island WWTP	CD #66	234

The model also accounts for straight pipe discharges to tile drain systems. Incorporated communities with direct discharges (“unsewered communities”) are explicitly represented on a population basis (Blomkest and Prinsburg in the Hawk Creek basin, Hazel Run and Delhi in the Yellow Medicine basin). Both Prinsburg and Hazel Run shifted to stabilization ponds prior to 2007, but this is not yet represented in the model. For unincorporated areas the model assumes a regional rate of direct-to-tile individual sewage treatment systems (ISTS), using the methodology described in Tetra Tech’s 2002 *Minnesota River Basin Model, Model Calibration and Validation Report*, in which pollutant loads are estimated on a per capita basis. These assumptions should be reviewed before using the model for bacteria simulations, particularly in regard to areas in which larger concentrations of direct discharging systems have been identified (e.g., Svea, Roseland, Gluek, Bunde).

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2 Hydrologic Calibration

There is only one USGS gage with a long period of record in the basin – Yellow Medicine River near Granite Falls – and previous work with the Minnesota River basin model revealed this as a difficult gage to calibrate, which apparently has a somewhat difference rainfall-runoff response over the last decade than was seen in the 1980s and early to mid-1990s. Since 1999 additional gaging has been conducted at multiple locations in the Hawk and Beaver Creek watersheds by the Hawk Creek Watershed Project (Figure 6). These gages, however, operate only on a seasonal basis (generally April through September), which means that a large portion of the spring runoff may be missed, complicating efforts to fit an overall water balance. In addition, there have been concerns with rating curves at some of these gage locations (for instance, the Chetomba Creek results for 2000 yielded flows that are significantly higher than those at the downstream Hawk Creek at mouth gage, later determined to be a result of deficiencies in the rating curve), and the frequency at which rating curves have been field measured and adjusted is apparently less than the USGS standard.

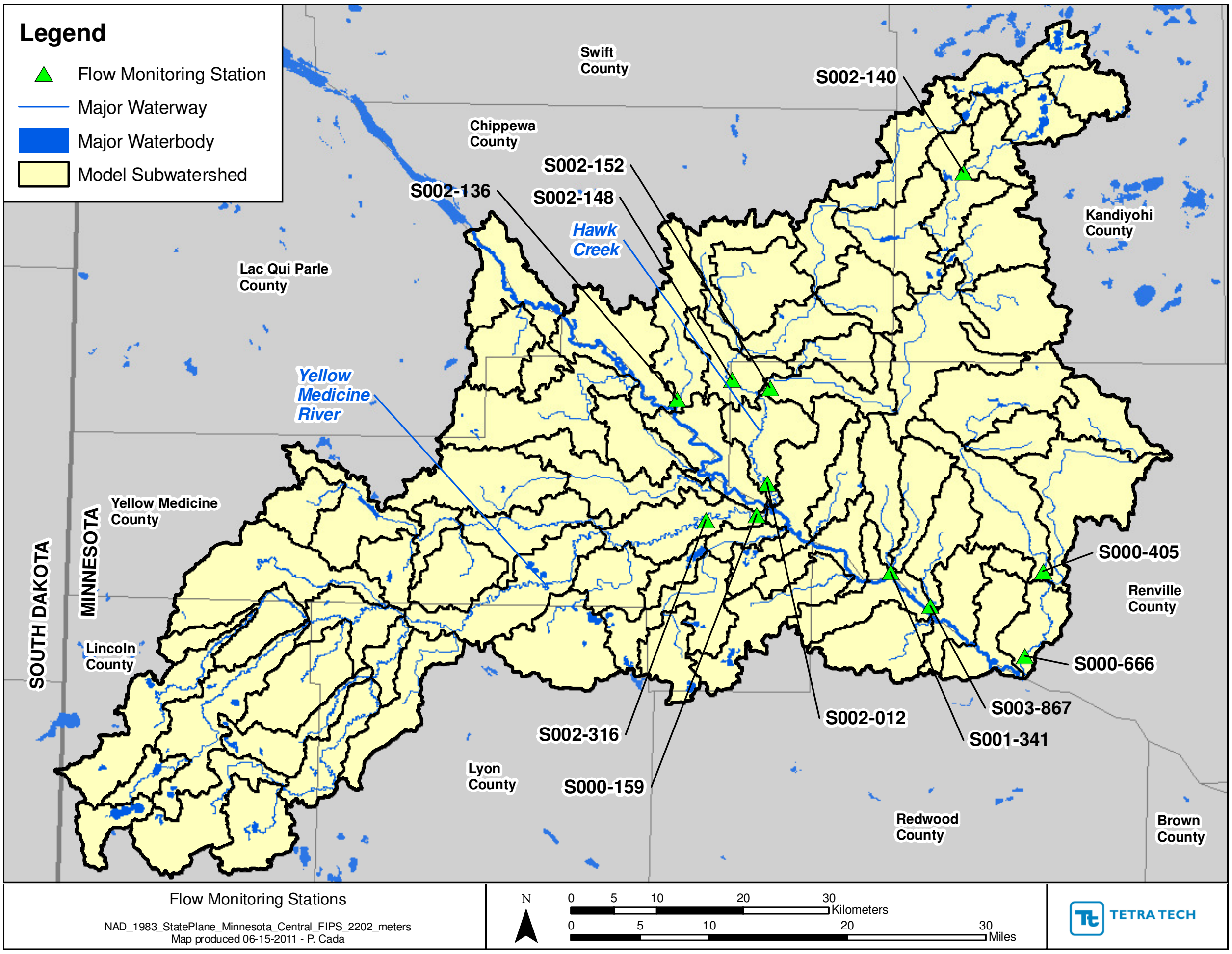

Figure 6. Stream Gaging and Water Quality Monitoring Locations

The general strategy for hydrologic calibration was to focus first on the Yellow Medicine gage for 2001-2009. Parameters derived for that gage were then extended to the various Hawk Creek and Beaver Creek gages as a spatial corroboration or validation test, with some iterative adjustments to the unified parameter set. Finally, model performance on the earlier gage records for Yellow Medicine was examined as an additional corroboration test.

The starting point for hydrologic parameters was provided by the Hawk/Yellow Medicine section of the existing Minnesota River Basin model and refined to reflect the more detailed representation of HRUs. The primary calibration adjustments were to the lower zone nominal soil moisture storage (LZSN, varied by land use) and the infiltration parameter (INFILT, assigned according to soil hydrologic group). Various other parameters were also adjusted to (1) reflect lessons learned in the development of the LeSueur River detailed model, and (2) to better conform to recommendations contained in BASINS Technical Note 6.

One important change from the prior model was that snowmelt was shifted from an energy balance method to a degree day method (SNOP=1), depending only on air temperature. This was done because the degree day method appears to yield better results for the simulation of spring snowmelt. In theory, the energy balance method (also taking into account solar radiation, wind, relative humidity, cloud cover) should be superior; however, it can be very sensitive to uncertainty in the meteorological inputs. In addition, the energy balance method implemented in HSPF provides little user control over the time course of snow albedo, which is a major factor in the uptake of heat by the snowpack.

Only one spatial adjustment was required to achieve acceptable fit. This was in the exerted PET, for which a somewhat lower factor was required for portions of the Hawk Creek (exclusive of Chetomba Creek) and East Fork Beaver Creek. This likely reflects uncertainties in extrapolation of Penman Pan Evaporation estimates from a limited number of stations with wind and temperature measurements.

Detailed results of the hydrologic calibration are provided in Attachment 1. A good fit is obtained to all aspects of flow at the Yellow Medicine gage for 2001-2009. Fit to observed flows at the various Hawk and Beaver Creek gages also appears good, except that there is considerable uncertainty regarding the lowest flows. For these stations, the daily Nash-Sutcliffe coefficients (NSE) tend to be fair, while the monthly NSE values are excellent (around 0.9). This likely reflects the fact that the model is driven mostly by daily precipitation that has been disaggregated, not by true hourly precipitation.

As was noted in earlier model applications, flows at the Yellow Medicine gage for 1994 to 2000 tend to be consistently underestimated – in all seasons and for both high and low flows, although the NSE values are good. The reasons for this discrepancy are not fully understood.

3 Water Quality Calibration

The model is set up consistent with the Minnesota River Basin model to provide a full range of water quality simulation, including sediment, temperature, BOD/DO, nutrients, and bacteria. However, full calibration has been pursued only for sediment, inorganic N, total N, inorganic P, and total P at this time.

Sediment calibration is the most time-consuming part of model development, and was conducted consistent with BASINS Technical Note 8. Upland sediment erodibility rates were set based on SSURGO USLE K factors. As with the Minnesota River Basin model, critical shear stresses for scour and deposition of cohesive sediment in channels are set equal to percentiles of the simulated distribution. Silt was set to deposit below the 20th percentile and scour above the 95th percentile daily shear stress, while clay was set to deposit below the 15th and scour above the 90th percentile. An example of the shear stress distribution is shown in Figure 7.

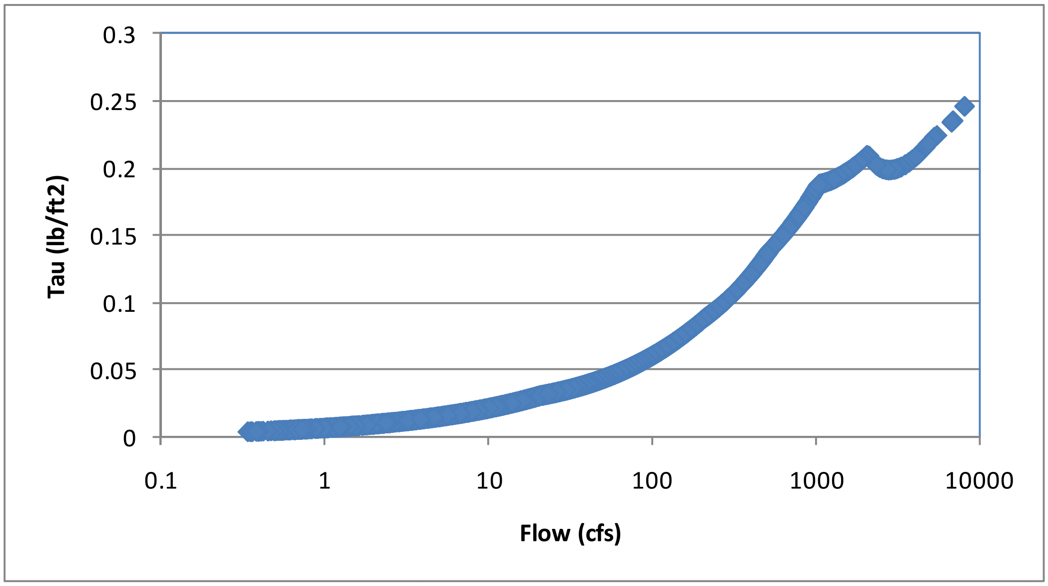

Figure 7. Simulated Shear Stress (Tau) Distribution for Yellow Medicine Reach 101 (Yellow Medicine at USGS Gage near Granite Falls)

Bluff loads were assigned consistent with the Minnesota River model using Special Actions to replenish the sediment available in the bed. These loads consisted of 1.2 tons/hr in the lowermost reach of Yellow Medicine (100) and 0.97 tons/hr in the lowermost reach of Hawk Creek (201). A reach-by-reach mass balance analysis of channel sediment was conducted to ensure reasonable sediment accumulation/loss behavior and approximately stable bed composition. The final simulation shows slow rates of channel degradation over the course of the 17-year simulation (Figure 8), with the exception of net accumulation in the bluff reaches (100 and 201), and in the lake reaches (111, 115, 153, 208-210, 214-215). The large gain represented in the bluff reaches is a temporary phenomenon, reflecting accumulation during 2008 and 2009 after large events reduced bed storages in preceding years. Net trapping efficiency (depth/scour as a fraction of influent sediment, exclusive of bluff loads) had a median of -11 percent, with positive trapping (> 80 percent) for the lake segments, consistent with observations that a significant portion of the total load in this basin arises from channel processes (Figure 9).

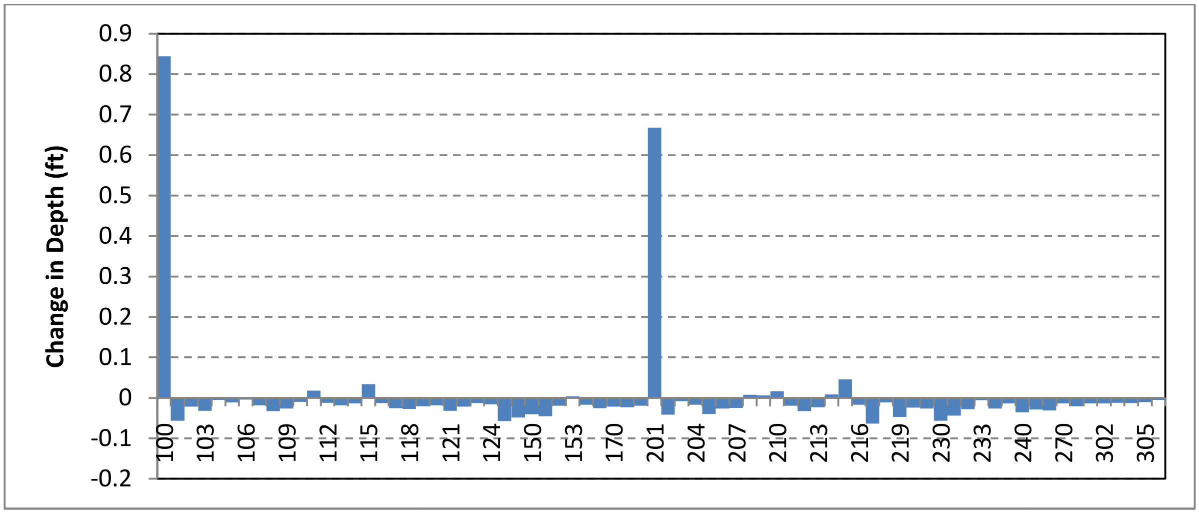

Figure 8. Simulated Change in Sediment Bed Depth over 1996-2009 Simulation

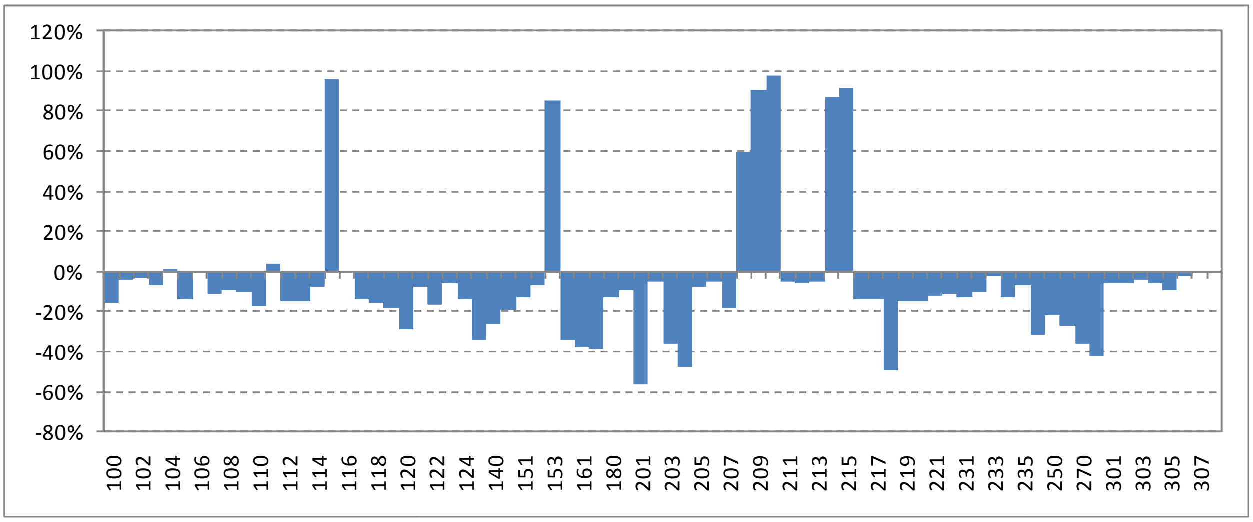

Figure 9. Net Sediment Trapping Efficiency by Reach

The nutrient simulation follows the same approach used in the Minnesota River Basin models. Ammonia, nitrate nitrogen, orthophosphate, and generalized organic matter are simulated on the land surface, with the first two being represented by buildup-washoff processes and the second two simulated as sediment-associated with potency factors. The Mass-Link table is used to apportion generalized organic matter to organic carbon, organic nitrogen, organic phosphorus, and BOD at entry to the stream.

The Hawk Creek Watershed Project has collected a wealth of data useful for water quality calibration. Given the limits of the schedule for this effort, the calibration focused on six stations with long periods of record and a variety of conditions: Chetomba Creek (S002-152), Hawk Creek at Maynard (S002-148), Hawk Creek at Mouth (S002-012), West Fork Beaver Creek (S000-405), Yellow Medicine River at Gage (S002-316), and Yellow Medicine River at Mouth (S000-159). Only the last of these stations was used for calibration in the previous Minnesota River modeling effort.

The initial calibration focused on Chetomba Creek and Yellow Medicine River at Mouth as these are not strongly impacted by point sources (there are no major point sources on Chetomba Creek, although there are some direct discharging systems in Prinsburg, Svea, Blomkest, and Roseland; Yellow Medicine River has a number of stabilization pond systems but no major discharges). Intensive monitoring for the 2006-

2009 period was used as the main basis for calibration, with earlier monitoring providing a corroboration test.

Calibration for nutrients is complicated by a number of factors, including the presence of large point sources at Willmar (discharging to Hawk Creek) and Southern Minnesota Beet Sugar (discharged to County Ditch 37 to West Fork Beaver Creek through August 2004, subsequently to County Ditch 45 to Sacred Heart Creek). Pollutant concentrations are generally reported only monthly, leading to considerable uncertainty in actual loading time series. In addition, ammonia is the only form of nitrogen regularly monitored in the discharges, requiring use of approximate assumptions to specify concentrations of nitrate and organic nitrogen. Not surprisingly, this leads to considerable uncertainty in the prediction of nutrient concentrations downstream of these sources. In Hawk Creek it appears that the total N loading from Willmar is over-estimated during the period around 2005, leading to over-estimation of instream N concentrations, but is much better represented in more recent data.

Another factor complicating the nutrient simulation is evident strong interactions between nutrients and algae/macrophytes. HSPF represents planktonic algae and periphyton, but does not have a routine to explicitly represent uptake and release of nutrients by macrophytes. In addition, the HSPF model code shuts down the simulation of a variety of nutrient and algal processes when stream depth falls below 3 inches (to prevent numeric instability). In addition to preventing algal uptake of nutrients, this can result in “stranding” of pollutant mass until depth again increases above the threshold. These factors tend to cause consistent over-prediction of nutrient concentrations at very low flows, particularly for stations on smaller streams. The model occasionally predicts very high concentration values (but low net loads) during low flow conditions due to the stranding phenomenon. This biases statistics based on average concentration, but does not affect median error statistics.

Parameter updates to improve nutrient fit generally required only small modifications to the previous setup of the Minnesota River model. One particular area of improvement was in the specification of interflow N concentrations associated with tile drainage. Model fit was greatly improved by assigning two seasonal patterns, with higher concentrations associated with the areas nearer the Minnesota River (areas associated with weather stations 3 – 7, and 10 – 11) and lower concentrations associated with the upland moraine areas that appear to be characterized by more wetlands and ponds (areas associated with weather stations 1 – 2, 8 – 9, and 12 – 14; see Table 3). The geochemical reasons for this apparent difference need further investigation and confirmation.

The full set of water quality simulation results is provided in Attachment 2. The quality of model fit ranges from fair to excellent, according to parameter and location, and is consistent with other applications of HSPF in the Minnesota River Basin. The largest discrepancies between model and data appear to be associated with point source nutrient loads and the simulation of nutrients under very low flow conditions. Overall, the model is appropriately calibrated to support scenario evaluation for sediment and nutrients. As mentioned above, the model has not been fully calibrated for dissolved oxygen and bacteria at this time.

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4 Model Scenarios

This task order included a limited amount of budget and calendar time to support scenario analysis. Two specific scenarios were requested by the Hawk Creek Watershed Project. Scenario 1 evaluates the potential impacts of the recent upgrades to the Willmar wastewater treatment plant, which was a major source of pollutant load to Hawk Creek. Scenario 2 investigates the potential impact of widespread acceptance of stream buffers in agricultural lands.

4.1 SCENARIO 1: WILLMAR TREATMENT PLANT UPGRADES

The City of Willmar recently undertook a major upgrade to their wastewater treatment plant. This scenario is designed to evaluate the potential water quality benefits of the plant upgrade.

The upgrade included phosphorus removal and nitrification, resulting in order of magnitude decreases in total phosphorus and ammonia nitrogen load. Nitrogen is not removed, however; rather it is mostly converted to nitrate form. There has also been a significant decrease in biochemical oxygen demand (BOD).

As part of the upgrade, Willmar also moved its discharge point. However, the new discharge location still falls within the same model segment (213).

Specifications for post-upgrade water quality in the Willmar effluent were provided by the Hawk Creek Watershed Project after consultation with the wastewater treatment plant superintendent. The following assumptions are used:

Total Phosphorus	0.661 mg/L
Ammonia-N	0.20 mg/L
Nitrate-N	17 mg/L
Organic N	1.6 mg/L
TSS	5.857 mg/L
Fecal Coliform	59 #/100 ml
BOD5	2 mg/L

The projected average flow for the new plant is 4.73 MGD, whereas the average flow in the model for 1996-2009 is 3.55 MGD. Because effluent flow is correlated to weather conditions the scenario was constructed by using the historic weather and effluent flow time series, scaling up the effluent flow by a factor 1.214. Pollutant loads are then added based on the concentration assumptions provided above.

4.2 SCENARIO 2: AGRICULTURAL BUFFER IMPLEMENTATION

This scenario is a bounding scenario, designed to investigate the maximum impact of applying 50-foot stream buffers to all cropland within the Hawk Creek watershed. Partial implementation would approximate a linear scaling between current conditions and full implementation.

The buffers are assumed to be applied to all NHD streamlines in the watershed. Further, the average stream density characteristics of the entire watershed are assumed to apply to croplands within each subbasin of the Hawk Creek watershed. A GIS analysis indicates that land area within 50 feet of NHD streamlines accounts for 1.57 percent of the total area in the watershed. (A cursory examination suggests that the NHD represents the majority, but not the entirety of public drainage ditches within the watershed.

Thus, the impact of instituting buffers based on the NHD may be slightly less than could be obtained by instituting buffers on all public drainage ditches.)

Buffers are assumed to be maintained as vegetative filter strips (VFSs) with perennial grass cover. Thus, the first effect of the scenario is a shift in land use with 1.57% of cropland converting to grass.

The representation of pollutant removal by buffers in HSPF presents challenges because HSPF is a lumped model. That is, land use areas within a subbasin do not have a specific position relative to streams, as would be the case in a gridded model, so it is difficult to assess how buffers affect total pollutant loading. Similar problems are present in SWAT, also a lumped model. In the recent release of SWAT2009 an approach was developed to address this issue, and the same approach is adopted for the HSPF representation of this scenario.

The SWAT2009 approach (M.J. White and J.G. Arnold, 2009, Development of a simplistic vegetative filter strip model for sediment and nutrient retention at the field scale, *Hydrological Processes*, 23: 1602-1616) develops a method based on empirical analyses of field studies and application of the vegetative filter strip model (VFSMOD) to create an approximation of treatment by buffers and filter strips that can be incorporated into lumped models. The approach contains two major components: a conceptualization of the flow paths and their impacts on BMP efficiency in an agricultural setting, and regression equations that estimate pollutant removal rates conditional on flow path. The approach also replaces the traditional reliance on buffer width with an alternate measure, the ratio of contributing area to buffer area, which is more appropriate to the varied and uncertain geometry of lumped models.

The best buffer pollutant removal performance is obtained when all flow is directed to the buffer as sheet flow and evenly distributed across the length of the buffer. In contrast, flow that becomes fully channelized is able to punch through the buffer with little or no pollutant removal. White and Arnold’s approach recognizes that most real-world applications of buffers occur in situations where a majority of the field runoff is directed to a relatively small portion of the buffer. It thus divides the flow from the upland area into three categories: general loading to the buffer without concentrated flow, the fraction of (non-channelized) concentrated flow that is directed to the most heavily loaded 10 percent of the filter strip, and fully channelized flow that is subject to minimal pollutant removal.

Pollutant removal relationships depend on the magnitude of flow and the magnitude of sediment loading in the regression models developed by White and Arnold. This is inconvenient to implement in HSPF without changes to the underlying FORTRAN code; however, at the ranges of surface runoff flow and surface sediment loading expected in the Hawk Creek watershed, the impacts on removal rates are relatively small – and also well within the range of uncertainty in the regression models. It is thus appropriate to adopt a static representation of treatment efficiency for incorporation into HSPF.

A key factor in applying the White and Arnold approach is the determination of the different flow fractions – especially the fraction of surface runoff that is expected to be fully channelized. It is generally believed that it is difficult to maintain dispersed sheet flow over a distance of more than 300 feet from the buffer – which, with a buffer width of 50 feet, would result in a ratio of contributing area to buffer area of 6. The GIS analysis indicates that ratio of contributing area to buffer area is 62.6. This suggests that 90 percent of the flow reaching the buffer will be concentrated; however, this may fall within the 10 percent focus area and may not all be fully channelized. We assume that 50% of the flow directed to the concentrated area is fully channelized, and that the remaining 50% receives some treatment (although less effective than in the portion of the buffer that receives sheet flow).

As mentioned above, the treatment efficiency of buffers varies with flow loading rate. For small flows, most of the volume may be infiltrated in the buffer, stranding any particulate pollutants. However, these stranded pollutants may be remobilized and transported to the streams during subsequent events. Further, soils in streamside buffer areas are often saturated during wet weather events, reducing or eliminating infiltration. Therefore, it is reasonable to settle on fixed (rather than flow-dependent) removal rates.

In the relatively flat and permeable Hawk Creek watershed rates of generation of overland flow and overland sediment transport are quite low, with much of the flow proceeding through ground water and tile drainage, and much of the sediment being generated from scour associated with tile drain outlets and channel erosion during high flow events. We undertook a modeling analysis of the predicted pollutant removal rates using the equations of White and Arnold under a variety of flows ranging from the median overland surface flow to the 99th percentile overland surface flow. While removal rates are predicted to be greater at lower flow depths, the range is generally small (due in part to the assumptions regarding fully channelized or bypass flow). Further, the majority of pollutant loads move during a few large events. Therefore, the removal rates calculated at the 95th percentile overland surface flow appear appropriate for the analysis. The resulting removal rates relative to the total upland field load generation, calculated consistent with the approach employed in SWAT2009, are shown in Table 5.

Table 5. Pollutant Removal Rates for Agricultural Buffer Scenario

Constituent	Range of Net Removal Rates (50th to 99th percentile overland flow)	Selected Removal Rate (95th percentile overland flow)
Sediment	48 – 55 %	51 %
Organic N	38 – 47 %	42 %
Inorganic N	34 – 54 %	43 %
Sorbed and Organic P	43 – 50 %	46 %
Dissolved P	27 – 44 %	35 %

Note that these rates apply only to sheet and rill erosion; loads generated through ravine/gully erosion are assumed to not be treated by buffers.

In sum, the approach for implementing this scenario is as follows:

1. Shift 1.57 % of cropland to the grass land use category (in the corresponding slope and hydrologic soil group class.)
2. Modify the MASS-LINK table to incorporate the reduction rates for pollutant loads associated with surface runoff (excluding ravine sediment load) as shown in the table above.

This should provide a realistic first-cut estimate of the potential benefits associated with streamside buffers in reducing upland pollutant loads. It should be noted, however, that the analysis will not account for any additional benefits that might accrue from increasing streambank stability through the use of buffers.

4.3 SCENARIO RESULTS

Results of the scenarios are analyzed by comparing pollutant loads and concentrations at the mouth of Hawk Creek. Scenario 2 results are also shown at the mouth of Beaver Creek (Scenario 1 does not affect Beaver Creek). Concentrations are compared on the basis of medians, as the averages are potentially biased by the model difficulties in simulating concentrations at very low flows.

Scenario results are summarized in Table 6 and Table 7. In general, the upgrade of the Willmar Wastewater Treatment Plant is predicted to result in large decreases in both median concentrations and loads of total P and total N – although the median concentration of nitrate-N is not predicted to change.

The buffer scenario results in a predicted 11 percent decrease in TSS load in Hawk Creek and a 15 percent decrease in Beaver Creek, with smaller fractional losses of N and P. The net effect of the buffers is reduced at the watershed scale due to the assumptions regarding the fraction of flow that can be effectively treated in non-concentrated form, as well as the fact that subsurface loads (including tile drainage) are not mitigated by the buffers. The buffers have little impact on median concentrations because they primarily address surface loading during high flow events.

Table 6. Scenario Results, Hawk Creek Mouth (1996-2009 Simulation)

	Baseline	Scenario 1	Scenario 2
TSS median concentration (mg/L)	10.80	10.10	10.10
TSS mass (tons/yr)	8927	8921	7901
NOx median concentration (mg/L)	6.30	6.30	6.20
Total N median concentration (mg/L)	13.40	7.20	13.10
Total N mass (tons/yr)	2025	1123	1965
Total P concentration (mg/L)	1.00	0.49	0.96
Total P Mass (tons/yr)	59.9	36.3	58.8

Table 7. Scenario Results, Beaver Creek Mouth (1996-2009 Simulation)

	Baseline	Scenario 2
TSS median concentration (mg/L)	9.40	8.70
TSS mass (tons/yr)	4203	3571
NOx median concentration (mg/L)	3.40	3.30
Total N median concentration (mg/L)	6.20	6.10
Total N mass (tons/yr)	413	385
Total P concentration (mg/L)	0.45	0.45
Total P Mass (tons/yr)	14.2	13.5