12-Mile Creek Dissolved Oxygen Total Maximum Daily Load Report

North Fork Crow River Major Watershed

Minnesota Pollution Control Agency

October 2015

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12-Mile Creek TMDL Report - Draft
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Acronyms

ac-ft/yr	acre feet per year
AUID	Assessment Unit ID
BMP	Best Management Practice
CAFO	Concentrated Animal Feeding Operation
CBOD	Carbonaceous biochemical oxygen demand
Chl-*a*	Chlorophyll-*a*
CROW	Crow River Organization of Water
DMR	Discharge Monitoring Reports
DNR	Minnesota Department of Natural Resources
DO	dissolved oxygen
EPA	Environmental Protection Agency
EQuIS	Environmental Quality Information System
FWMC	Flow weighted mean concentration
GIS	geographic information systems
GW	Groundwater
HSPF	Hydrologic Simulation Program-Fortran
HUC	Hydrologic unit code
km^2	square kilometer
LA	Load Allocation
Lb	pound
lb/day	pounds per day
lb/yr	pounds per year
m	meter
mg/L	milligrams per liter
mg/m^2-day	milligram per square meter per day
mL	milliliter
MOS	Margin of Safety
MPCA	Minnesota Pollution Control Agency
MS4	Municipal Separate Storm Sewer Systems
NBOD	Nitrogenous biochemical oxygen demand

NCHF	North Central Hardwood Forest
NPDES	National Pollutant Discharge Elimination System
ON	Organic Nitrogen
RA	reasonable assurance
SOD	Sediment oxygen demand
SONAR	Statement of Need and Reasonableness
SSTS	Subsurface Sewage Treatment Systems
SWCD	Soil and Water Conservation Districts
SWPPP	Stormwater Pollution Prevention Plan
TAG	Technical Advisory Group
TDLC	Total Daily Loading Capacity
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TP	Total phosphorus
TSS	total suspended solids
UAL	Unit-area Load
µg/L	microgram per liter
VSS	volatile suspended solids
WLA	Waste Load Allocation
WRAPS	Watershed Restoration and Protection Strategies

Executive Summary

This Total Maximum Daily Load (TMDL) study was completed for 12 Mile Creek (AUID 07010204-681), which is a tributary reach in the North Fork Crow 8 digit Hydrologic Unit (HUC) located in the Upper Mississippi River Basin in Minnesota. The study addresses one dissolved oxygen (DO) impairment. The 12-Mile Creek DO impaired reach watershed covers approximately 61 square miles in Wright County, Minnesota. The predominant land cover types throughout the watershed are corn/soybeans (46%), hay and pasture (23%) and wetlands and open water areas (14%). The goal of this TMDL is to quantify the oxygen demanding pollutant load reductions needed to meet State water quality standards for DO in the impaired reach.

DO is an important water quality parameter for the protection and management of aquatic life. All higher life forms, including fish and aquatic macroinvertebrates, are dependent on minimum levels of oxygen for critical life cycle functions such as growth, maintenance, and reproduction. Problems with low DO in river and stream systems are often the result of excessive loadings of carbonaceous biochemical oxygen demand (CBOD) and nitrogenous biochemical oxygen demand (NBOD), particularly in combination with high temperatures and low flow conditions. The breakdown of organic compounds in the water column and/or sediment consumes water column DO. Organic matter loading to streams can come from both natural (plant, leaf and periphyton debris, in-situ primary production) and anthropogenic (wastewater effluent, agricultural animal feces) sources. The amount of oxygen that a given volume of water can hold is a function of atmospheric pressure, water temperature, and the amount of other substances dissolved in the water.

The 12-Mile Creek DO TMDL was based on meeting the DO standard of 5.0 mg/L as a daily minimum. Historic DO monitoring indicates that summer low-flow is the critical condition for DO in the impaired reach. Thus, the TMDL was established using an EPA supported model referred to as the Hydrological Simulation Program – Fortran (HSPF) model. To set the TMDL, HSPF model scenarios were established whereby headwater DO conditions and/or CBOD, NBOD and sediment oxygen demand (SOD) were adjusted until the impaired reach exhibited a minimum DO greater than 5.0 mg/L. The final (TMDL) model scenario was then used to calculate the wasteload allocation (WLA), load allocation (LA) and margin of safety (MOS) for the impaired reach.

In order to meet Minnesota's DO standard, this TMDL requires CBOD and SOD reductions of 4.9 kg-O_2/day and 20.6 kg-O_2/day, respectively. To achieve the CBOD reduction, water quality in Little Waverly Lake (headwaters of the 12-Mile Creek impaired reach) will need to be restored to meet state water quality standards. A nutrient (phosphorus) TMDL study for Little Waverly Lake was completed in 2014. This study identified crop and manure management, upland erosion, loading from upstream lakes, and internal (sediment) phosphorus release as the primary sources of phosphorus and eutrophication in Little Waverly Lake. SOD will also need to be decreased within 12-Mile Creek in order to meet the DO TMDL. There are currently two over-widened, flow-through wetland reaches within the DO impaired reach that were identified as high potential SOD areas. One way to decrease SOD and improve DO in these areas is to concentrate flow by engineering low-flow channels that increase velocity and reaeration.

1. Project Overview

1.1 Purpose

This TMDL study addresses one DO impairment in the North Fork Crow River Watershed. The 12-Mile Creek DO impaired reach is located in the west central portion of the North Fork Crow River Watershed as shown in Figure 1-1. The goal of this TMDL is to quantify the pollutant reductions needed to meet State water quality standards for DO. This TMDL is established in accordance with Section 303(d) of the Clean Water Act and provides WLAs and LAs for the 12-Mile Creek DO impairment.

1.2 Identification of Waterbodies

The 12-Mile Creek DO impaired reach was placed on the State of Minnesota's 303(d) list of impaired waters in 2010 as detailed in Table 1-1. The impaired reach addressed in this TMDL is a Class 2B (warm water) water for which aquatic life is the protected beneficial use.

Table 1-1. Impairment addressed in this report.

Listed Water body Name	AUID#	Class	Listed Pollutant	Impaired Use	Year Placed in Impairment Inventory	303(d) List Scheduled Start & Completion Dates
12-Mile Creek	07010204-681	2B	Low oxygen	Aquatic Life	2010	2010//2015

1.3 Priority Ranking

The Minnesota Pollution Control Agency's (MPCA) projected schedule for TMDL completions, as indicated on the 303(d) impaired waters list, implicitly reflects Minnesota's priority ranking of this TMDL. Ranking criteria for scheduling TMDL projects include, but are not limited to the following items:

- Impairment impacts on public health and aquatic life
- Public value of the impaired water resource
- Likelihood of completing the TMDL in an expedient manner, including a strong base of existing data and restorability of the waterbody
- Technical capability and willingness locally to assist with the TMDL
- Appropriate sequencing of TMDLs within a watershed or basin

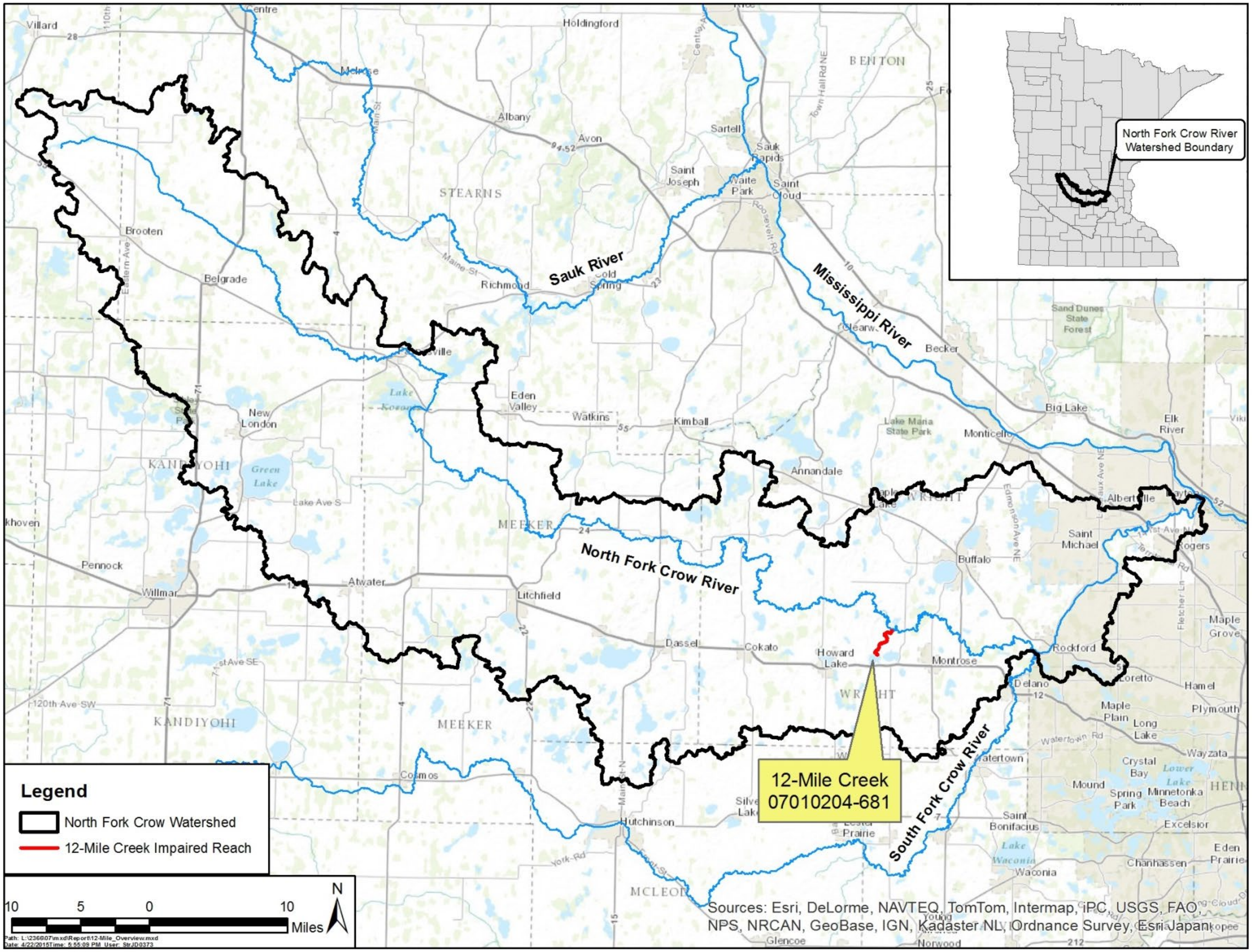

Figure 1-1. 12-Mile Creek DO impaired reach.

2. Applicable Water Quality Standards and Numeric Water Quality Targets

Minnesota's standard for DO in Class 2B waters is a daily minimum of 5.0 mg/L, as set forth in Minn. R. 7050.0222 (4). This DO standard requires compliance with the standard 50%of the days at which the flow of the receiving water is equal to the 7-day, 10 year low-flow condition ($7Q_{10}$). The criteria used for determining stream reach impairments are outlined in the MPCA document Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment – 305(b) Report and 303(d) List, January 2010. The applicable water body classifications and water quality standards are specified in Minn. R. ch. 7050. Minn. R. ch. 7050.0407 lists water body classifications and Minn. R ch. 7050.2222 (5) lists applicable water quality standards for the impaired reaches.

The 12-Mile Creek DO impaired reach was designated as impaired under the listing standards in place prior to the 2010 assessment cycle, in which a water body was considered impaired for DO if it met the following criteria:

- There are at least 10 observations in the most recent 10 years, of which at least 5 observations are in the most recent 5 years, or
- At least 10 observations in the most recent 5 years, and evidence of action in the watershed sufficient to change impairment status, and
- In either case, more than 10% of observations are below the minimum DO water quality standard.

3. Watershed and Waterbody Characterization

3.1 Reach and Watershed Description

The 12-Mile Creek DO impaired reach is contained entirely by Wright County and is approximately 3.4 miles in length. The reach covers 12-Mile Creek from the outlet of Little Waverly Lake to the creek's confluence with the North Fork Crow River north of Waverly, Minnesota. Little Waverly Lake is a nutrient impaired lake with an approved TMDL that was addressed in the North Fork Crow River TMDL (Wenck Associates 2014). The watershed of the 12-Mile Creek DO impaired reach, including land upstream of Little Waverly Lake, covers approximately 38,952 acres in Wright County (Table 3-1 and Figure 3-1). The area draining directly to the impaired reach downstream of Little Waverly Lake is approximately 655 acres. The predominant land cover types throughout the watershed are corn/soybeans (46%), hay and pasture (23%) and wetlands and open water areas (14%). There are currently two registered feedlots and 175 animal units (primarily cows) in the 12-Mile Creek DO impaired reach direct watershed (Figure 3-2). There are also three feedlots and 642 animal units located in close proximity to the impaired reach watershed.

Table 3-1. Land cover in the 12-Mile Creek Watershed.

[1]Landuse Type	12-Mile Creek Direct Watershed	12-Mile Creek Watershed - All
Total area (acres)	*655*	*38,952*
Corn/Soybeans	36%	46%
Hay and Pasture	29%	23%
Wetlands and Open Water	3%	14%
Forest and Shrubland	20%	8%
Urban/Roads	6%	6%
Grains and other Crops	6%	3%

The 12-Mile Creek impaired reach has three distinct sections as it flows from Little Waverly Lake to its confluence with the North Fork Crow River. The stream is forested with a wide buffer as it leaves Little Waverly Lake (Figure 3-2). The creek eventually flows out of the forested area into a stretch characterized by floodplain wetlands prior to reaching the primary monitoring point at 40th Street Southwest. Riparian wetland stretches tend to have high sediment oxygen demand (SOD) due to the high organic content of wetland peat deposits. The final stretch of the reach also flows through a rather large riparian wetland prior to discharging to the North Fork Crow River (Figure 3-2).

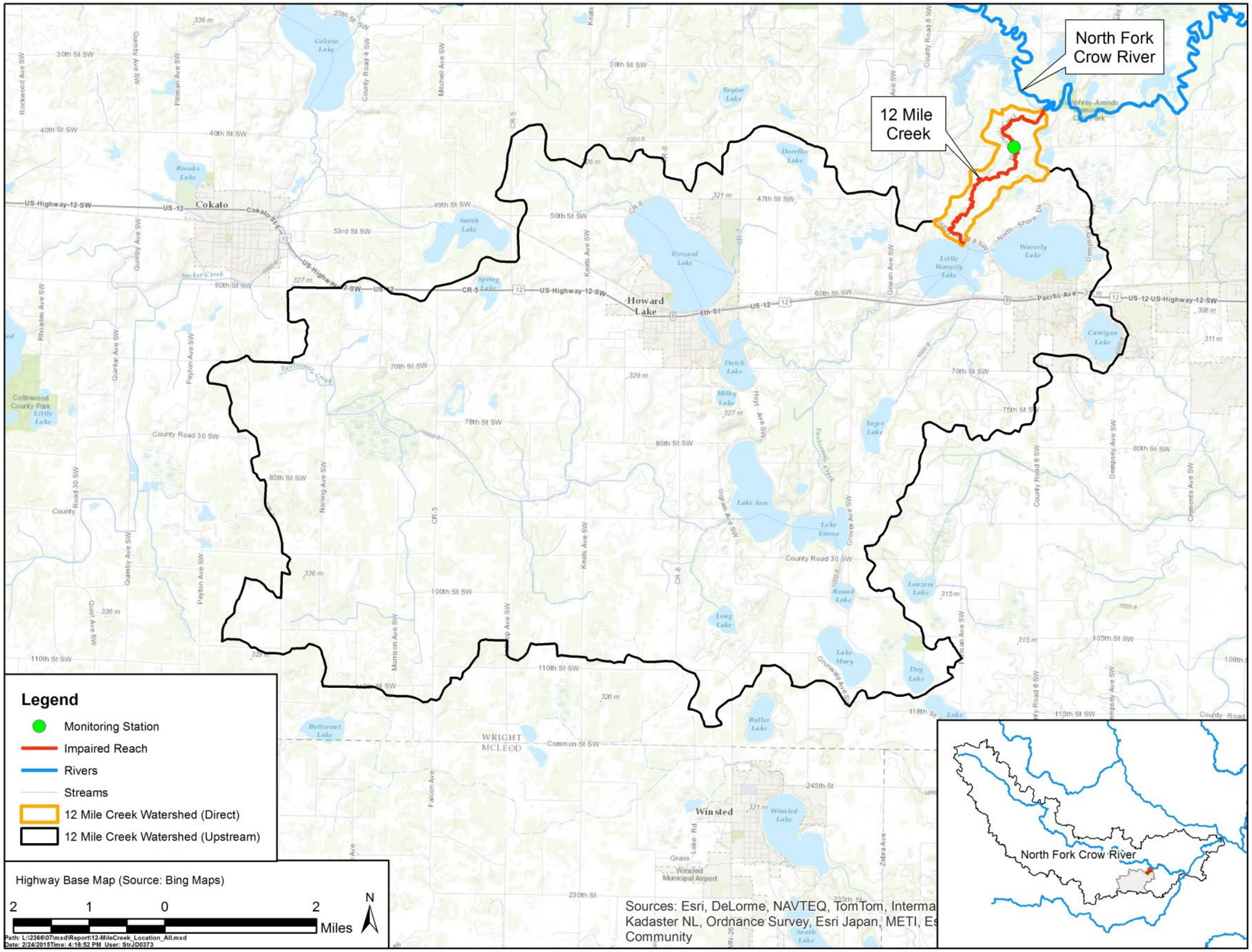

Figure 3-1. 12-Mile Creek impaired reach watershed

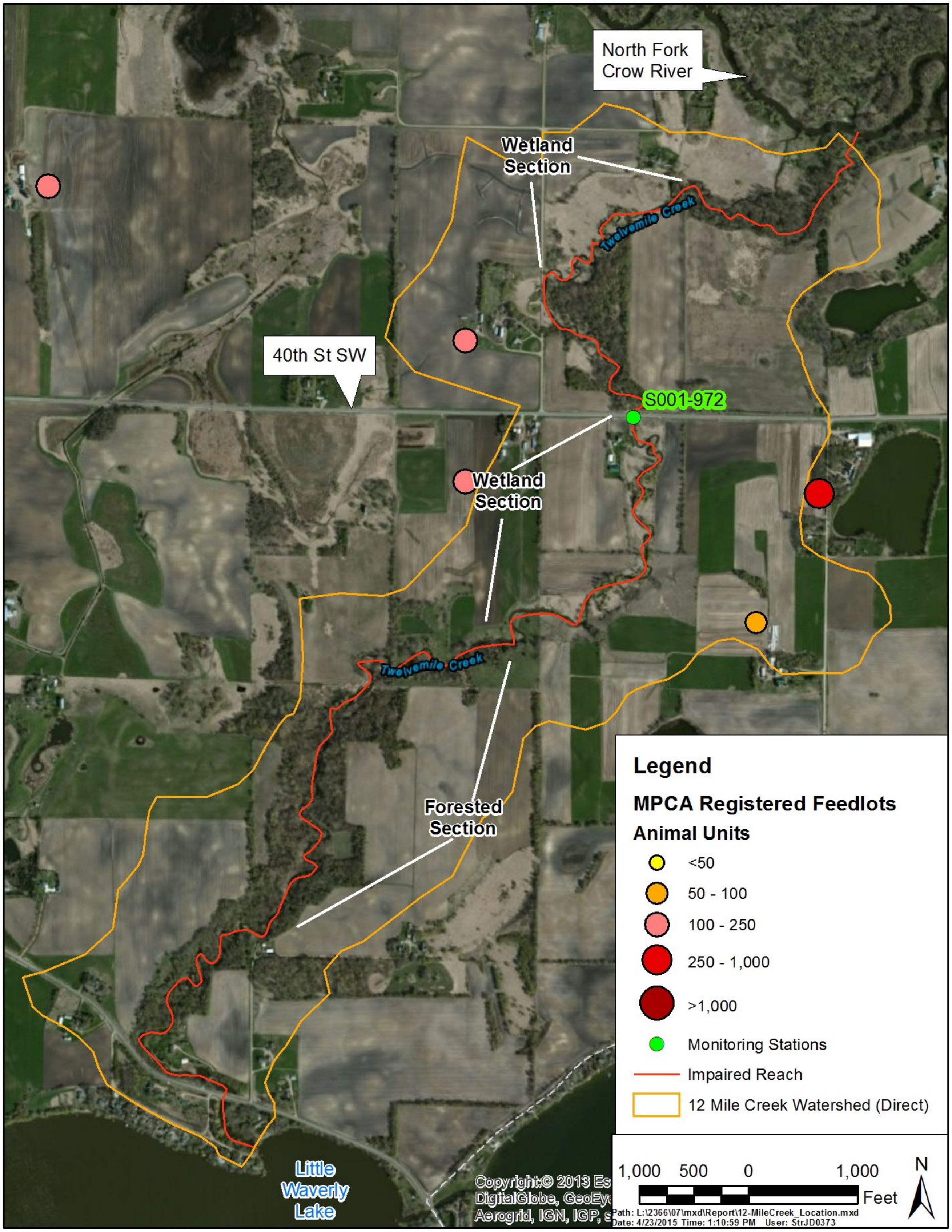

Figure 3-2. 12-Mile Creek impaired reach direct watershed, flow pattern and feedlot animal units.

3.2 Current/Historic DO Data

The MPCA and the Crow River Organization of Water (CROW) staff have collected DO and other water quality parameters at one station (S001-972) on the 12-Mile Creek DO impaired reach since 2001 (Figure 3-2). There is no continuous stream flow available for this reach, therefore simulated daily flow data for 12-Mile Creek from the North Fork Crow River Hydrological Simulation Program – Fortran (HSPF) model was used to develop the flow duration analysis for this TMDL (Section 4.1 and Appendix A).

3.2.1 DO Grabs and Field Measurements

The 12-Mile Creek impaired reach is designated by state statute as a beneficial-use Class 2B warm water stream. This designation states that DO concentrations shall not fall below 5.0 mg/L as a daily minimum in order to support the aquatic life and recreation of the system. Approximately 25% of the May-September DO observations collected at the S001-972 station were below the 5.0 mg/L DO standard (Table 3-2 and Figure 3-3). Plotting DO by time of day indicates only 5 of the 36 DO measurements were collected prior to 9:00 am (Figure 3-4). It should be noted that time of day records are unavailable for a few of the samples. The MPCA now recognizes measurements taken after 9:00 am do not represent daily minimums, and thus measurements greater than 5.0 mg/L DO later in the day are no longer considered to be indications that a stream is meeting state standards. None of the samples collected before 9:00 am were below the DO standard. By comparison, 9 of the 31 (29%) measurements recorded after 9:00 am were in violation of the DO standard, suggesting DO violations are common throughout the impaired reach regardless of the time of day. Monthly plots (Figure 3-5) show a majority of the violations were recorded during the warmer summer months (June through August).

Table 3-2. 12-Mile Creek May through September DO data.

EQuIS ID	Location	River Mile	DO Observations	DO Violations (<5 mg/L)	Years
S001-972	12-Mile Creek at 40th St SW	1.1	36	9	2001-2009

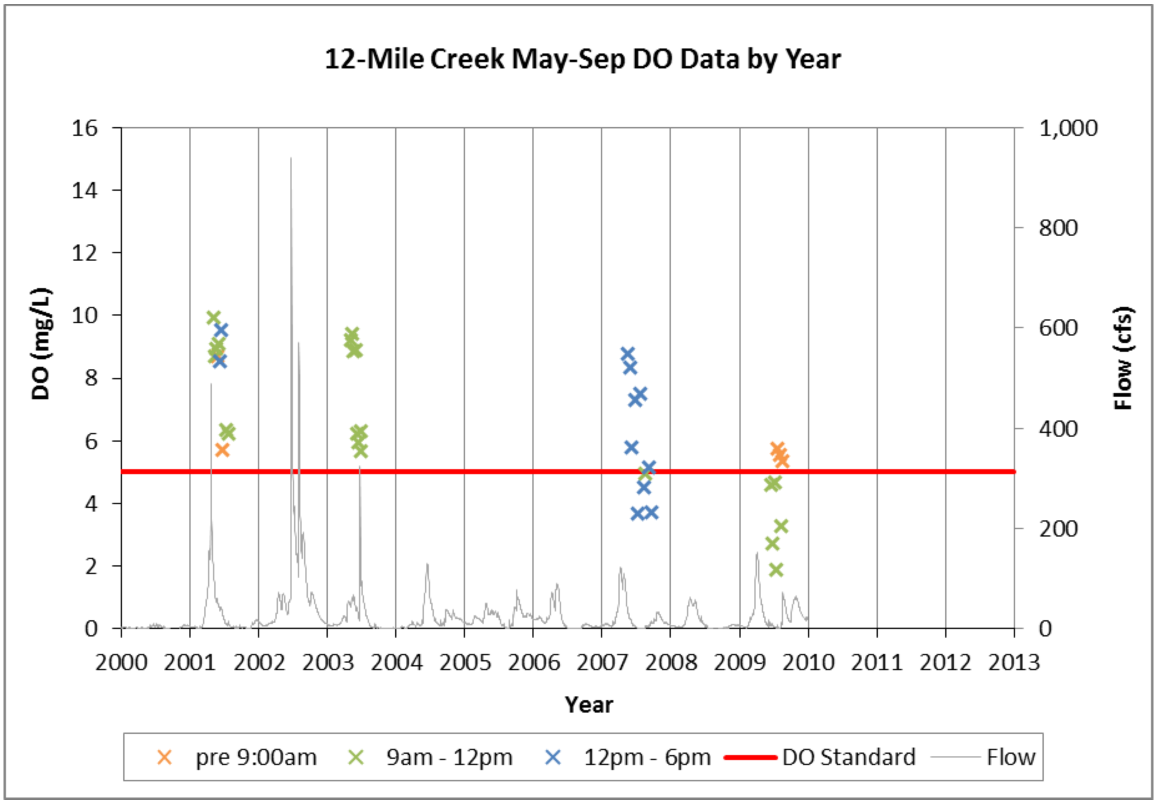

Figure 3-3. DO data (May-Sep) and modeled flow (HSPF) for the 12-Mile Creek impaired reach. Data is organized by year and color coded by time of day.

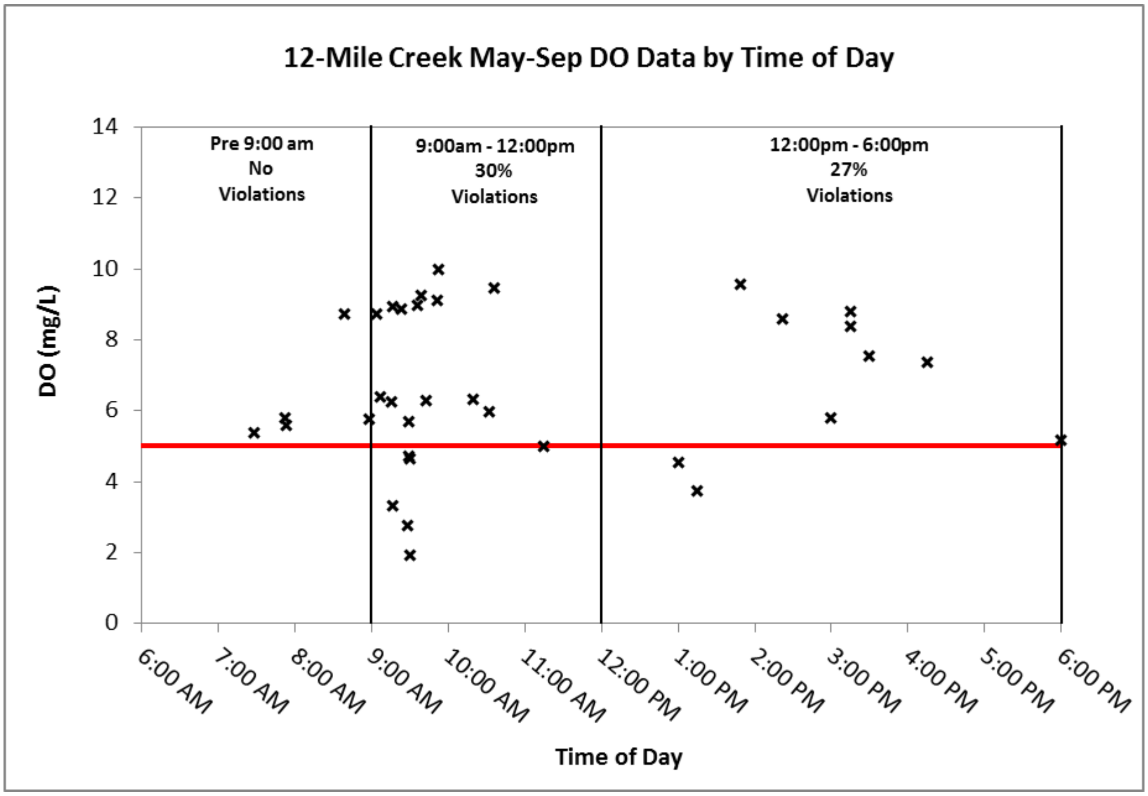

Figure 3-4. 12-Mile Creek DO data (May-Sep) by time of day.

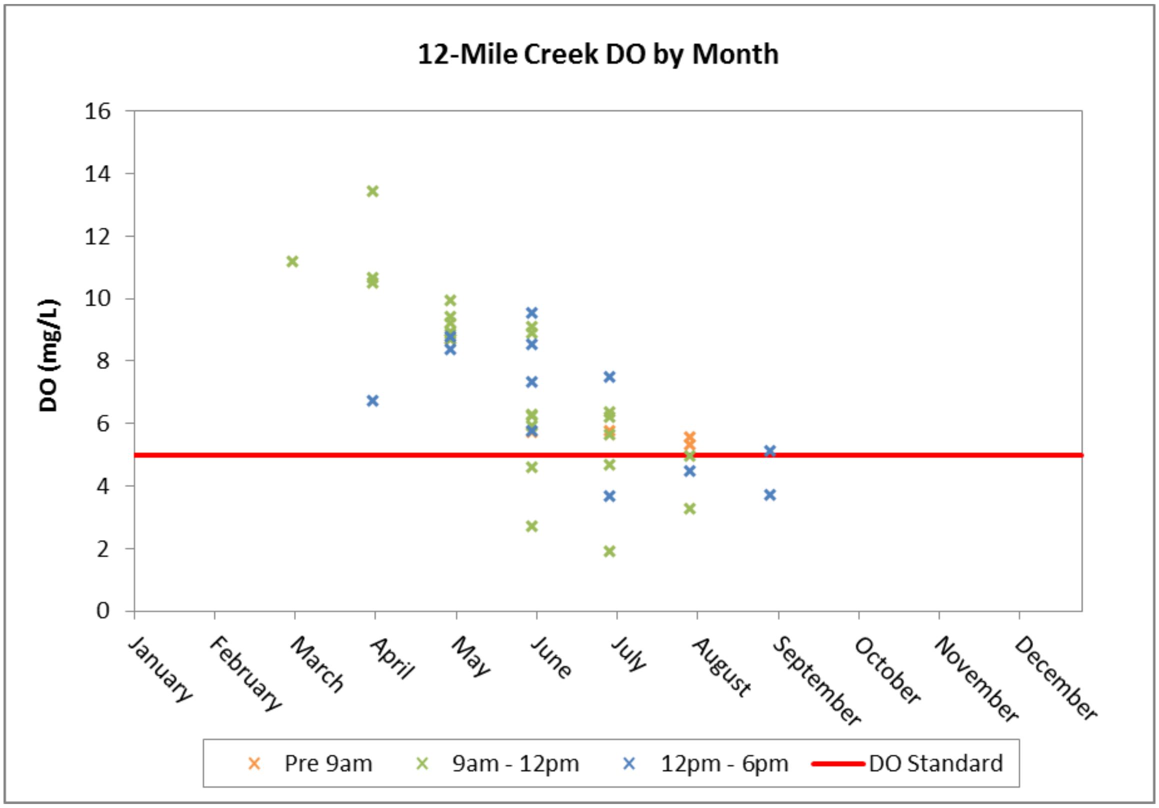

Figure 3-5. 12-Mile Creek DO data by month.

3.2.2 DO Relation to Flow

Average daily flow for 12-Mile Creek from the North Fork Crow River HSPF model was compared to 12-Mile Creek DO measurements. Representing DO measurements on flow duration plots show all DO violations occur under mid and low-flow conditions (Figure 3-6). These results, combined with the DO monthly plots, suggest DO violations have only been observed in 12-Mile Creek during the summer low-flow period. This reach, which is controlled by outflow from Little Waverly Lake, has been observed to stop flowing during late summer/fall drought conditions (MPCA, personal communication), which likely explains the lack of DO measurements during “very low” conditions.

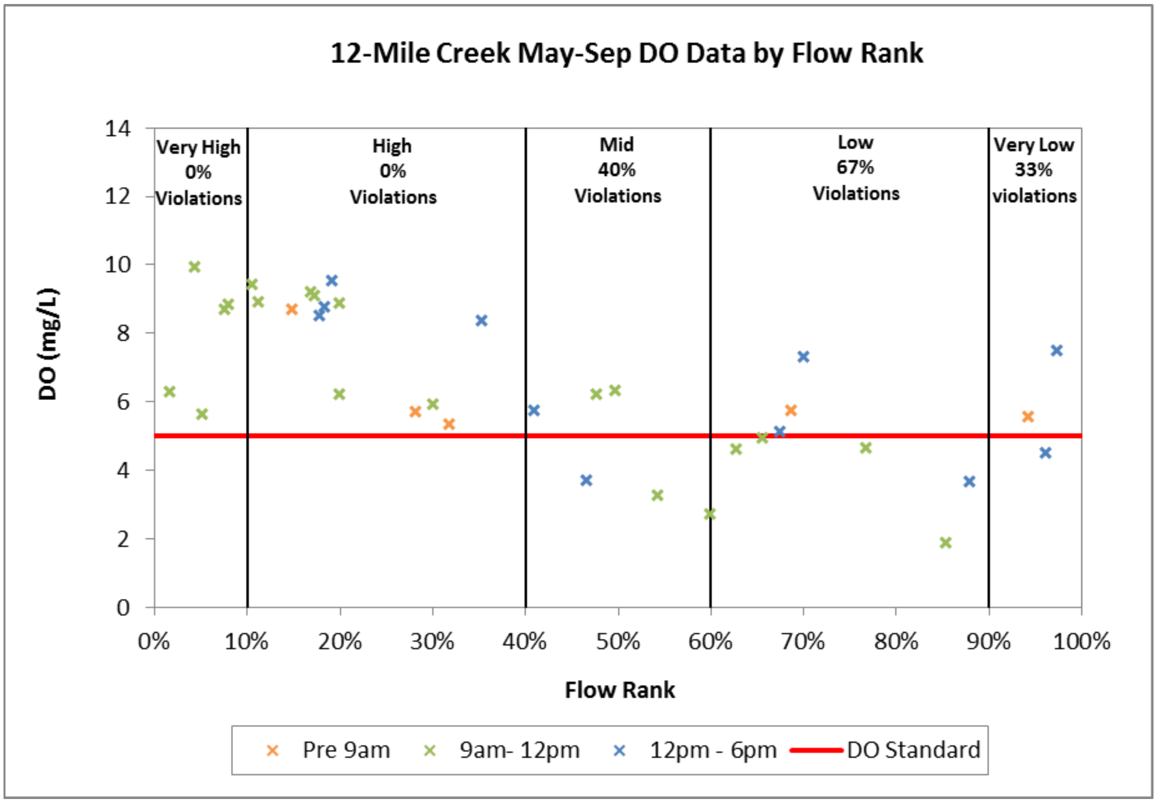

Figure 3-6. 12-Mile Creek DO by flow condition. Flow duration was constructed using model predicted average daily flow data for 12-Mile Creek from the North Fork Crow River HSPF model.

3.3 Low DO Source Summary

DO is required by most aquatic organisms for survival. If the DO drops below acceptable levels, fish and other aquatic organisms may die or be harmed. DO concentrations go through a daily cycle in most rivers and streams with concentrations reaching their daily maximum levels in late afternoon when photosynthesis by aquatic plants is highest. Minimum DO concentrations typically occur early in the morning around sunrise when respiration rates exceed photosynthesis and oxygen is being consumed by aquatic organisms faster than it is replaced. Stream DO is also affected by water column and/or sediment oxygen consumption that occurs through the breakdown of organic compounds. Loading of organic matter to streams can come from both natural (plant and leaf debris, in-situ primary production) and anthropogenic (wastewater effluent, animal feces) sources. Critical conditions for stream DO usually occur during late summer when flows are low and water temperatures and stream metabolism is high. This section provides an analysis of the main processes that may be affecting DO conditions in the 12-Mile Creek impaired reach.

3.3.1 Breakdown of Organic Matter

Oxygen depletion in streams commonly occurs from loading and subsequent breakdown of organic matter within the system. Loading of biochemical oxygen demanding (BOD) substances can be traced to both natural and anthropogenic sources. The most common human-related inputs are associated with effluent from wastewater treatment plants. There are currently no WWTPs in the 12-Mile Creek Watershed, however there are several nonpoint source factors that may be causing oxygen depletion and the low DO levels observed throughout the system. As discussed in section 3.1, there are currently five feedlots and 817 animal units located within and near the DO impaired reach watershed. Manure produced by the animals in the watershed is typically deposited on pasture lands and/or applied to fields for fertilizer as well as general manure management. Manure is typically high in phosphorus, nitrogen, and BOD, and when it is applied to fields during sensitive portions of the year has the ability to move easily into surface waters.

Total BOD is comprised of two components: NBOD and CBOD. CBOD is the reduction of organic carbon to carbon dioxide through the metabolic action of microorganisms. NBOD is the term for the oxygen required for nitrification, which is the biologic oxidation of ammonia to nitrate. NBOD is typically calculated by subtracting CBOD from total BOD. Carbonaceous demand is usually exerted first, normally as a result of a lag in the growth of the nitrifying bacteria necessary for oxidation of the nitrogen forms. High ammonia levels are typically associated with elevated NBOD as it indicates organic matter is decomposing rapidly within the system and/or there are significant inputs of human/animal waste.

To date, there have been no BOD samples collected in the 12-Mile Creek impaired reach. Total Kjeldahl Nitrogen (TKN) and ammonia+ammonium ($NH3 + NH4^+$-N) data have been collected in 12-Mile Creek since 2001. TKN measurements can be used as an indicator of NBOD in a stream as it represents the total amount of reduced nitrogen in a sample and is the sum of organic nitrogen (ON) and $NH3+NH4^+$-N. Of the nitrogen components, $NH3+NH4^+$-N break down quickly in natural systems and are rapidly converted to nitrate by nitrifying bacteria, a process which consumes oxygen. 12-Mile Creek $NH3+NH4^+$-N sampling results indicate ammonia levels from 0.01 – 0.88 mg/L and, on average, accounts for approximately 10% of the TKN in the system. Thus, a majority of the reduced nitrogen in 12-Mile Creek is organic nitrogen. Both ammonia and TKN samples are likely driven by outflow from Little Waverly Lake and tend to be higher during the low-flow summer months (Figures 3-7 and 3-8).

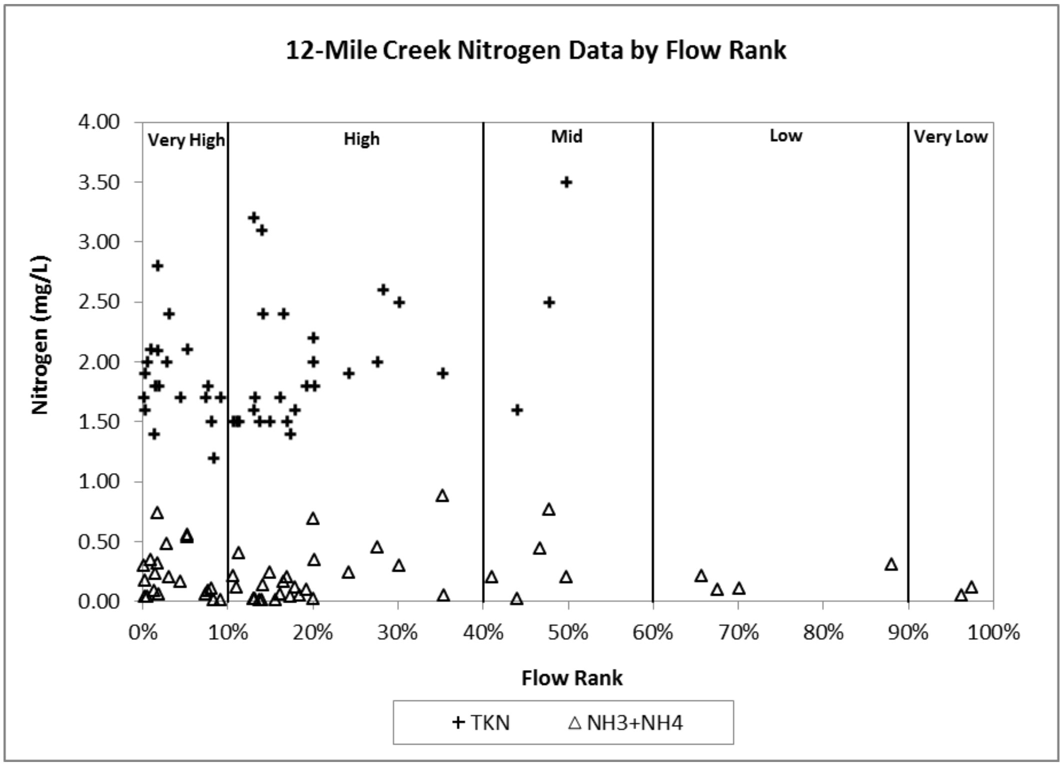

Figure 3-7. 12-Mile Creek TKN and ammonia+ammonium-N data by flow condition.

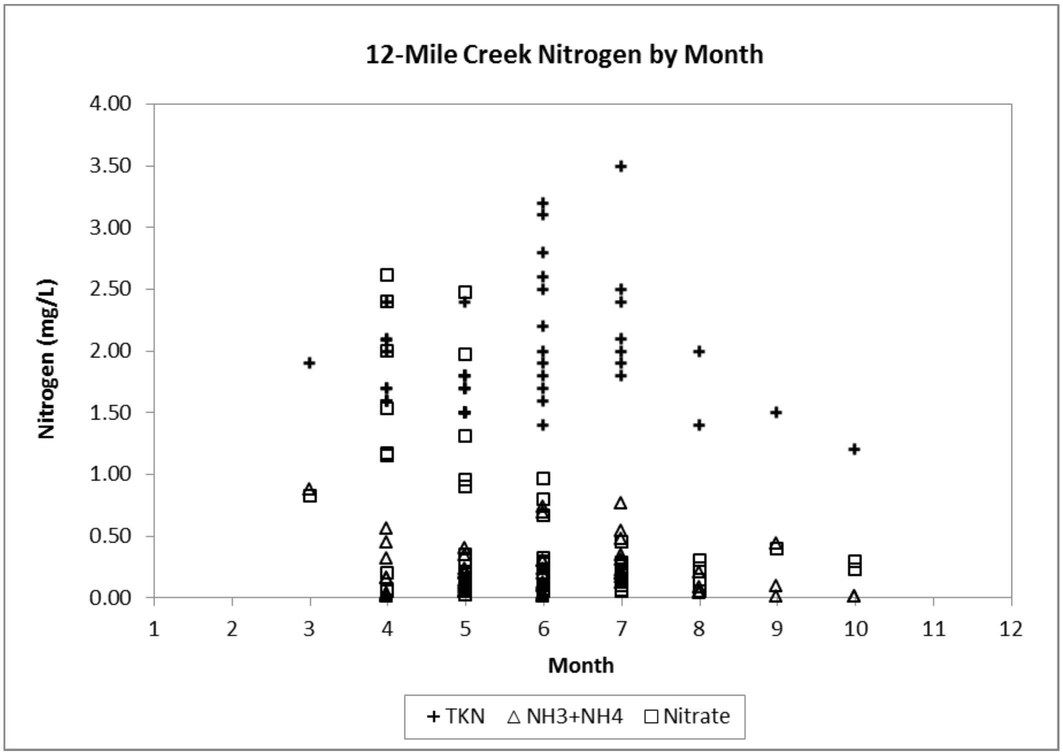

Figure 3-8. 12-Mile Creek TKN and ammonia+ammonium-N data by month.

3.3.2 Sediment Oxygen Demand (SOD)

Another factor that influences DO concentrations in streams is SOD. SOD is the aerobic decay of organic materials that settle to the bottom of the stream. In natural, free-flowing streams, SOD is usually considered negligible because frequent scouring during storm events prevents long-term accumulation of organic materials. However, it is apparent the 12-Mile Creek impaired reach has been ditched, straightened and over-widened in areas and has a few sections that contain flow-through wetlands (Figure 3-2). These stream modifications have likely lowered average velocity in 12-Mile Creek resulting in accumulation of organic matter and fine sediment particles.

SOD is difficult and expensive to measure and typically expresses a high level of variability in natural systems. Because of these difficulties, SOD is often estimated using modeling tools. For this TMDL, SOD was calculated for each reach using the HSPF model (Appendix A). Within the model, moderately high SOD was prescribed to the 12-Mile Creek impaired reach in order to calibrate model predicted DO to observed conditions. These SOD conditions represent the accumulation of organic matter in the channel from over-widened conditions and additional organic substrates from Little Waverly Lake and the impaired reach's direct watershed.

3.3.3 Nutrients and Eutrophication

High in-stream nutrient concentrations, particularly phosphorus, can accelerate primary production allowing for increases in biological activities. When plants and algae die, bacteria decomposing the plant tissue consume DO while at the same time releasing nutrients into the water column. Total phosphorus (TP) was measured in 12-Mile Creek from 2001-2007. Additionally, TP sampling was conducted in Little Waverly Lake from 2002-2010. TP concentrations in both 12-Mile Creek and Little Waverly Lake ranged from 90-690 µg/L and 48-1,150 µg/L, respectively. These concentration ranges are extremely high for natural systems and exceed the proposed central region river/stream eutrophication standard (100 µg/L; MPCA 2013) and the eutrophication standard for shallow lakes in the North Central Hardwood Forest (NCHF) Ecoregion (60 µg/L). Ortho-phosphorus concentrations in 12-Mile Creek were also high and accounted for, on average, about 50% of the TP in the stream. TP and ortho-phosphorus concentrations were highest during summer low-flow conditions and are likely driven by algae export from Little Waverly Lake and internal phosphorus release from the lake's sediments and/or the stream channel itself (Figures 3-9 and 3-10).

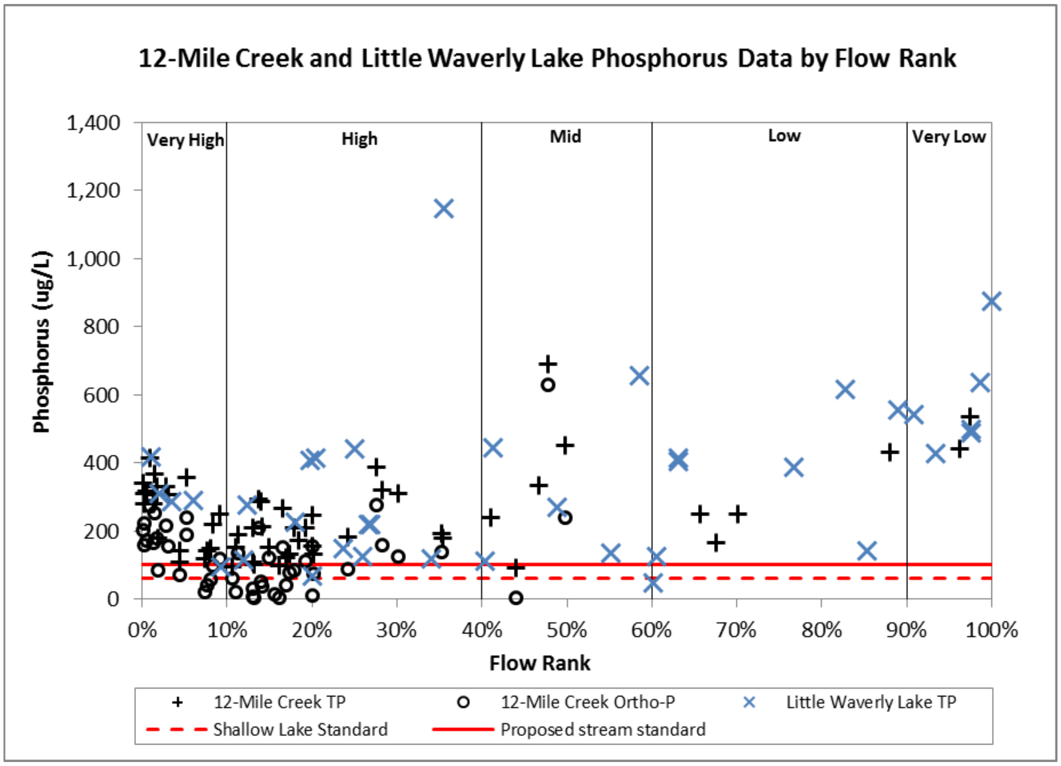

Figure 3-9. 12-Mile Creek and Little Waverly Lake TP and ortho-P data by flow condition.

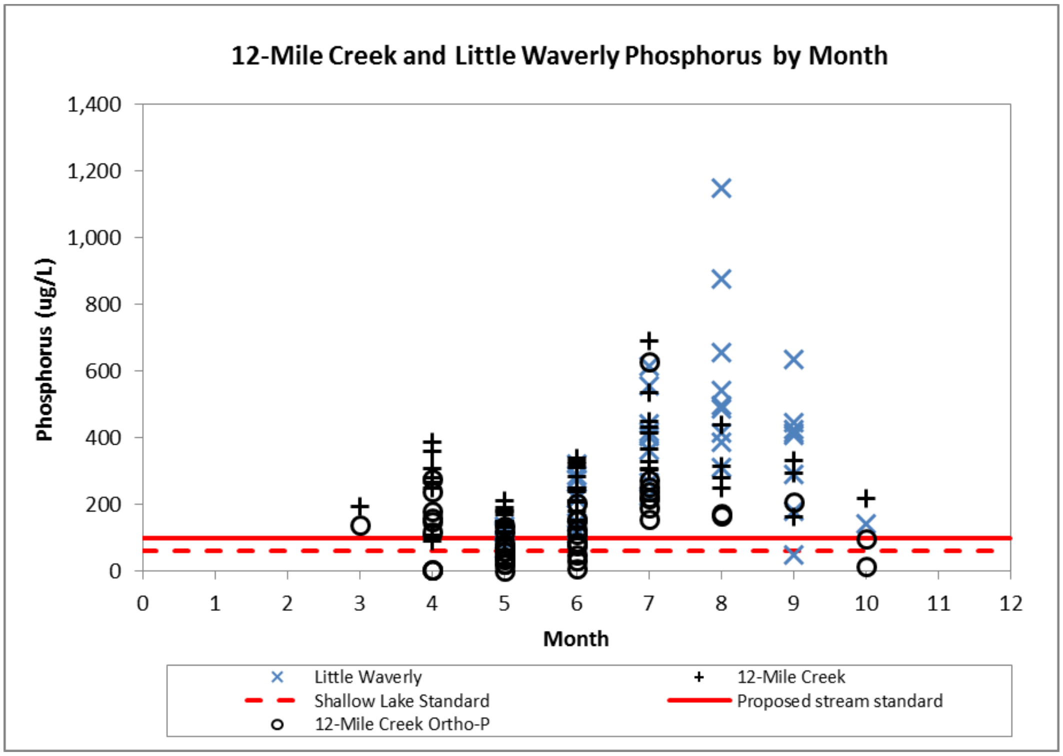

Figure 3-10. 12- Mile Creek and Little Waverly Lake TP and ortho-P data by month.

Chlorophyll-a (Chl-*a*) is the primary pigment in aquatic algae and has been shown to have a direct correlation with algal biomass. Since Chl-a is a simple measurement, it is often used to evaluate algal abundance rather than expensive cell counts. Chl-a measurements are often paired with TP and transparency to assess trophic status in lakes and streams. To date, there have been no Chl-a samples collected in the 12-Mile Creek impaired reach. Chl-a samples from Little Waverly Lake were analyzed to assess potential algae loading to the 12-Mile Creek impaired reach. Similar to phosphorus, Chl-a levels in Little Waverly Lake are extremely high and occasionally reach concentrations more than 10 times the proposed central region river/stream (18 µg/L) and shallow lake eutrophication standards (20 µg/L) (Figures 3-11 and 3-12). These Chl-a levels indicate extreme eutrophication during the summer months and suggest high algae loading to 12-Mile Creek. It is unclear if, or how much of the algae discharged from Little Waverly Lake are able to survive and remain suspended once it enters 12-Mile Creek. Typically, lake phytoplankton do not survive well in stream and river environments. Summer total suspended solids (TSS) (5-91 mg/L) and volatile suspended solids (VSS) (2-23 mg/L) concentrations at S001-972 are moderately high, suggesting at least some algae survives and remains in-suspension (Figure3-13).

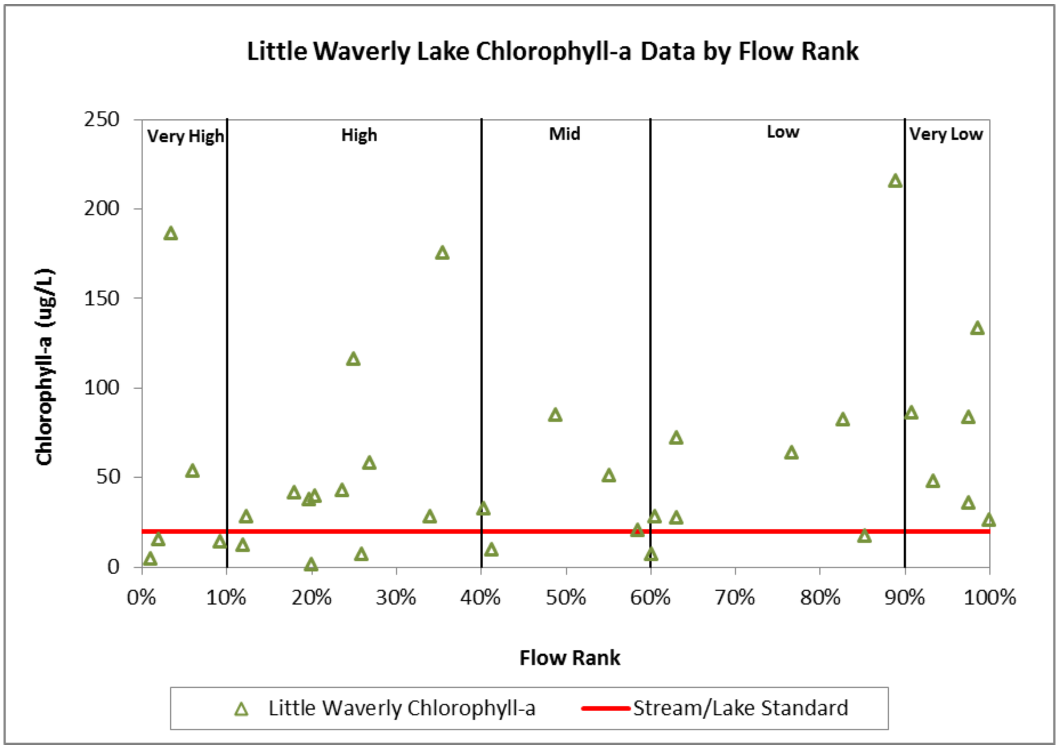

Figure 3-11. Little Waverly Lake chlorophyll-a data by flow condition.

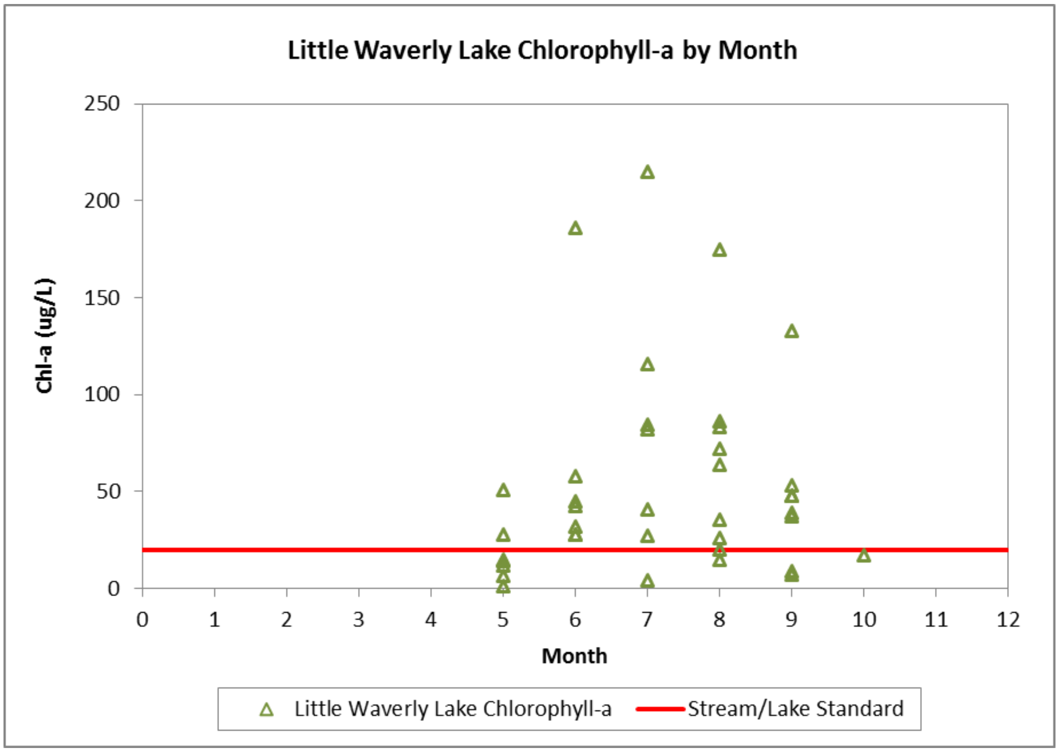

Figure 3-12. Little Waverly Lake chlorophyll-a data by month.

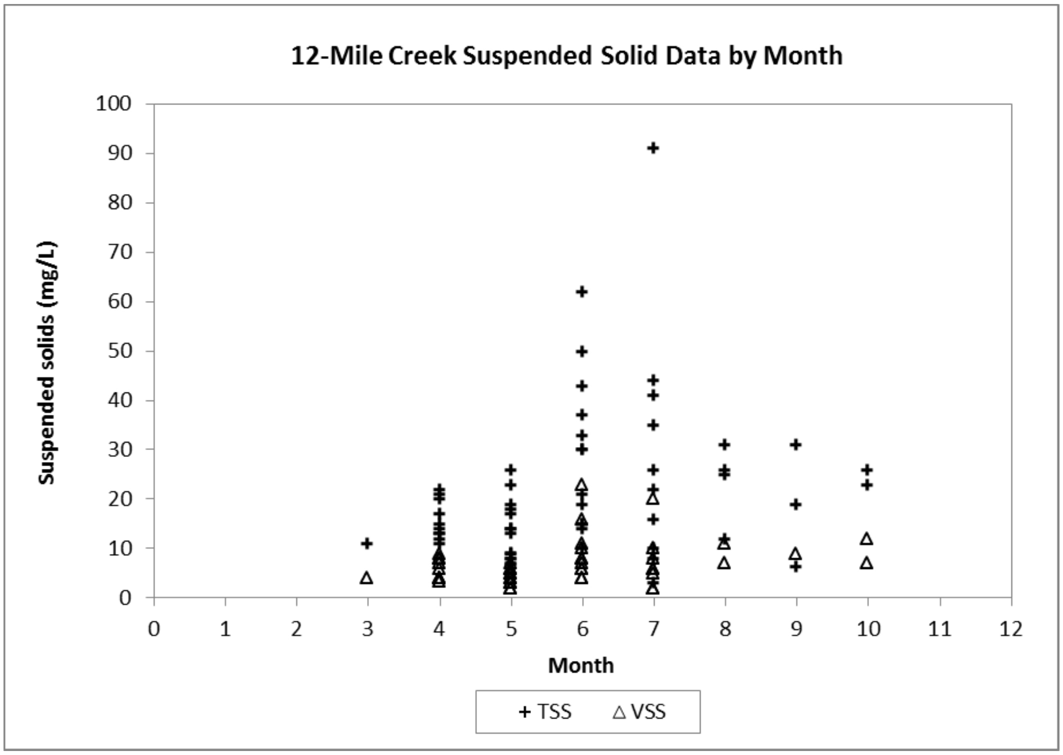

Figure 3-13. 12-Mile Creek TSS and VSS data by month.

3.3.4 Canopy Cover and Water Temperature

Canopy coverage may also have a significant effect on stream DO concentrations. Decreased shading leads to more light penetration which has the potential to increase primary production and raise mean water temperatures, which in turn decreases the solubility of oxygen in water. DO solubility in water is temperature-dependent in that cold water holds more DO than warmer water. Summer water temperatures for the 12-Mile Creek impaired reach are above the upper end of typical NCHF Ecoregion streams (2-21°C; Figure 3-14). Canopy coverage for the 12-Mile Creek impaired reach is quite variable as it flows through both forested areas (high canopy coverage) and wetland sections (low canopy coverage). Since it is such a short reach, temperatures in the 12-Mile Creek impaired reach are likely more affected by headwater temperatures in Little Waverly Lake than canopy coverage and shading in the impaired reach. A longitudinal survey conducted along 12-Mile Creek in late July 2013 did not show any temperature change between the outlet of Little Waverly Lake and the long term monitoring station at 40th Street Southwest (S001-972).

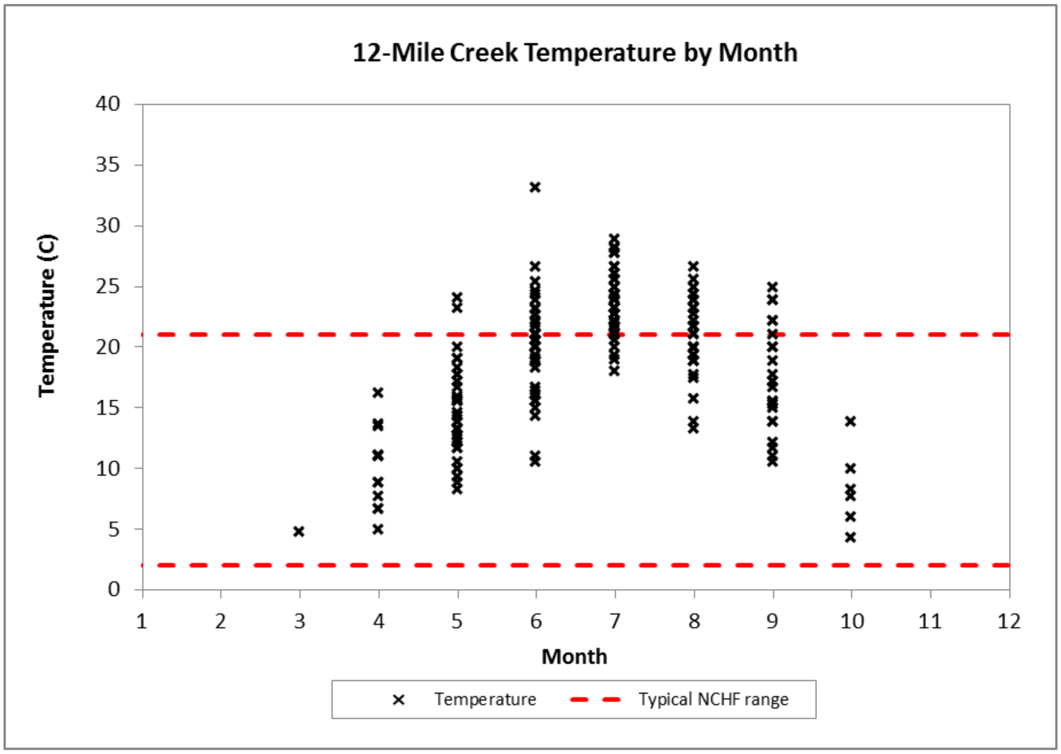

Figure 3-14. 12-Mile Creek temperature data by month.

3.3.5 Low DO Source Summary Conclusions

12-Mile Creek DO measurements indicate violations only occur during summer (June-September) low-flow conditions, when primary production in Little Waverly Lake (headwaters) is highest. Further analysis of the water quality parameters that affect DO suggest eutrophication in Little Waverly Lake and the subsequent phosphorus and algae loading to the 12-Mile Creek impaired reach are likely the main drivers of low DO during summer low-flow conditions.

Water quality data for the 12-Mile Creek impaired reach and Little Waverly Lake support the following conclusions:

1. Headwater conditions in Little Waverly Lake likely play a large role in the DO dynamics in 12-Mile Creek. Little Waverly is hypereutrophic and discharges high concentrations of phosphorus and Chl-a .

2. No Chl-a data have been collected in 12-Mile Creek, so it is difficult to determine the role of algae in stream DO dynamics. Algae discharged from the lake may or may not survive in the stream; however phosphorus levels are high and suggest that high algae growth could be supported. It is also possible that the algae discharged from Little Waverly Lake rapidly breaks down and/or settles out in the creek, thus contributing to low-DO through BOD and SOD processes.

3. SOD is likely high throughout the middle and lower reaches due to the large riparian wetlands in these reaches.

4. Intermittent flow likely plays a role in the DO dynamics of the stream as it often stops flowing during dry periods. Some of the data collected may have been during stagnant periods when no reaeration occurs.

5. Ammonia appears to be relatively high at times suggesting that nitrification consumes oxygen from the stream when ammonia is available. The source of the ammonia is unclear but is likely a result of breakdown of the peat deposits in the wetlands. Other potential sources include Little Waverly Lake and manure runoff from the watershed. There are approximately five feedlots and 817 animal units located within, or close to the impaired reach direct watershed (Figure 3-2).

6. BOD has not been measured in either Little Waverly Lake or 12-Mile Creek making the estimation of oxygen demand from the breakdown of carbonaceous and nitrogenous material problematic.

4 TMDL Development

4.1 Modeling Approach

The computational framework, or model, chosen for determining the DO TMDL for the 12 Mile Creek impaired reach was the HSPF model. The HSPF is a comprehensive package for simulating watershed hydrology and water quality for both conventional and toxic organic pollutants. The HSPF is capable of simulating the hydrologic and associated water-quality processes on pervious and impervious land surfaces, in streams, and in well-mixed impoundments. The HSPF is generally used to assess the effects of land-use change, reservoir operations, point-source or nonpoint-source treatment alternatives, and flow diversions. The model contains hundreds of process algorithms developed from theory, laboratory experiments, and empirical relations from instrumented watersheds. The model simulates processes such as evapotranspiration; interception of precipitation; snow accumulation and melt; surface runoff; interflow; base flow; soil moisture storage; groundwater (GW) recharge; nutrient speciation; BOD; heat transfer; sediment (sand, silt, and clay) detachment and transport; sediment routing by particle size; channel and reservoir routing; algae growth and die-off; bacterial die-off and decay; and build-up, wash-off, routing, and first-order decay of water-quality constituents.

The HSPF model for the 12-Mile Creek DO impaired reach was initially included as part of a larger scale 8-digit Hydrologic Unit Code (HUC) HSPF model for the Crow River/North Fork Crow River (RESPEC 2012). DO dynamics for Crow River/North Fork Crow River HSPF model included temperature (using HTRCH), organic and inorganic nitrogen, total ammonia, organic and inorganic phosphorus (using NUTRX), DO and biochemical oxygen demand (using OXRX), and algae (using PLANK). Overall sources considered for BOD and DO in the model included point sources such as water treatment facilities, nonpoint sources from the watershed, interflow and active GW flow. The model application also addressed BOD accumulation, storage, decay rates, benthic algae oxygen demand, settling rates, and reaeration rates, as well as respiration, growth, settling rates, density, and nutrient requirements of algae and phytoplankton (Appendix A).

Calibration and validation of the Crow River/North Fork Crow River HSPF model was evaluated at six primary monitoring stations along the main stem of the Crow River (Appendix B). The calibration for sediment, TP, nitrogen and DO at the six main stem stations was considered “good” (Appendix B). Since the original Crow River/North Fork Crow River HSPF model was calibrated at a relatively large scale, additional calibration adjustments for the 12-Mile Creek impaired reach portion of the model were executed to better reflect the monitoring data discussed in section 3.2. A complete discussion of the 12-Mile Creek calibration adjustments and results are presented in Appendix C.

4.2 Critical Conditions

Minn. R. 7050.0222, subp. 4, state compliance of the 5.0 mg/L class 2B DO standard is required 50% of the days at which the flow of the receiving water is equal to the $7Q_{10}$ flow condition. No continuous flow data has been collected for 12-Mile Creek, however the calibrated 12-Mile Creek HSPF model does provide flow simulation for the 5 years (2005-2009) the model was setup and calibrated. Since it is not possible to calculate a $7Q_{10}$ with only 5 years of flow data, a 7-day, 5 year low-flow condition ($7Q_5$) was established for 12-Mile Creek using HSPF modeled flow. The observed DO data suggests summer low-flows are the critical conditions for DO in 12-Mile Creek since all recorded violations occurred between June – September when flow was below 11.8 cfs (Figure 3-6). During these conditions, stream temperatures are typically at their maximum resulting in minimal holding capacity for stream DO. Stream velocities are also low, therefore reducing reaeration of the stream. Thus, all allocations and reductions presented in this TMDL were set using the 12-Mile Creek impaired reach HSPF modeled summer $7Q_5$ flow condition (approximately 1.3 cfs).

4.3 TMDL Allocation Methodology

Headwater conditions (Little Waverly Lake), diffuse sources (tributary and GW), and in-stream sources (SOD) were identified as the major contributors of flow and oxygen demanding pollutant loads to the 12-Mile Creek impaired reach. The numerical TMDL is the sum of the WLA, LA, and the MOS. The 12-Mile Creek HSPF model was run at $7Q_5$ flow conditions to solve the TMDL equation for a numeric DO target of 5.0 mg/L (daily minimum). Section 4.3.7 describes the stream condition and necessary load reduction scenarios required for 12-Mile Creek to meet DO water quality standards.

4.3.1 Oxygen Deficit Terms

DO is consumed both in the water column and at the sediment interface. For water quality samples, oxygen demand is typically expressed as a concentration in terms of the mass of oxygen consumed per liter of water (mg-O_2/L). For this TMDL, oxygen demand will be expressed throughout the entire impaired reach/stream as mass of oxygen-demanding substances available per day.

The CBOD represents the oxygen equivalent (amount of oxygen that microorganisms require to breakdown and convert organic carbon to CO_2) of the carbonaceous organic matter in a sample. A second source is NBOD. A wide variety of micro-organisms rapidly transform ON to ammonia nitrogen (NH_3-N). Bacteria then transform NH_3-N to nitrate through an oxygen consuming process called nitrification. Finally, SOD is the aerobic decay of organic materials in stream bed sediments and in peat soils in wetlands. SOD rates are defined in units of oxygen used per surface area per day (g-O_2/m^2/day). In HSPF, SOD rates are prescribed by the modeler and are typically assigned based on literature rates.

4.3.2 Load Capacity

For DO TMDLs, the loading capacity is the maximum allowable oxygen demand (CBOD+NBOD+SOD) the stream can withstand and still meet water quality standards. To determine this number, SOD rates and pollutant loading from headwaters and/or tributary/diffuse sources were adjusted until it was clear model-predicted minimum daily DO in the impaired reach never dropped below the 5.0 mg/L standard.

4.3.3 Load Allocations

The LA is oxygen demand from non-point sources such as headwater, tributary and GW sources and from the sediments. Water quality and flow data from the 12-Mile Creek HSPF model were used to calculate or project the CBOD and NBOD loads for headwater, GW and tributary inputs. The current loads were calculated within the HSPF model by integrating model-predicted oxygen consumption rates across the wetted area of the impaired reach. SOD TMDL loads were calculated the same way using the SOD reductions necessary to meet the TMDL.

4.3.4 Wasteload Allocation Methodology

TMDL WLAs are typically divided into three categories: National Pollutant Discharge Elimination System (NPDES) point source dischargers, permitted Municipal Separate Storm Sewer Systems (MS4s), and construction and industrial stormwater. The following sections describe how each of these WLAs was estimated.

4.3.4.1 NPDES Point Source Dischargers

There are no NPDES point source dischargers in the 12-Mile Creek impaired reach watershed.

4.3.4.2 Permitted MS4s

There are currently no permitted MS4s located in the 12-Mile Creek Watershed.

4.3.4.3 Construction and Industrial Stormwater

A permit review by the MPCA showed there are currently no construction or industrial stormwater permits in the direct watershed of the DO impaired reach. To account for potential growth in the watershed, 1% of the tributary/GW LA was assigned to the WLA for future construction and industrial stormwater permits.

4.3.5 Margin of Safety

The purpose of the MOS is to account for uncertainty that the load reductions will result in the desired improvement to water quality. The MOS may be implicit, that is, incorporated into the TMDL through conservative assumptions in the analysis. The MOS may also be explicit and expressed in the TMDL as a set aside load. For DO TMDLs, the MOS are typically applied to the oxygen deficit terms that require a measurable reduction to achieve the standard. The 12-Mile Creek TMDL requires significant reductions to CBOD and SOD, therefore an explicit MOS of 10% were applied to these LAs in the TMDL equation. CBOD and SOD for this TMDL were not measured directly as they were calculated using model predicted rates and variables. Thus, a 10% MOS accounts for the uncertainty in model predicted SOD loads and the uncertainty in how the stream may respond to changes in CBOD and SOD loading. It is also important to note that the TMDL model scenarios were set to predict the stream meeting the DO standard 100% of the time at the low flow condition whereas the standard only requires meeting the DO standard 50% of the time at the low flow condition. Consequently, the current modeling also provides an implicit MOS.

4.3.6 Seasonal Variation

Seasonal variation is accounted for by establishing the TMDL for the critical summer low flow condition. By selecting the most sensitive conditions for the stream, DO concentrations in all seasons will be protected.

4.3.7 TMDL Baseline

This TMDL is based on HSPF modeling results from the five year period 2005-2009. Any activities implemented during or after the mid-point of that time period, specifically 2007, which lead to a reduction in oxygen demand in 12-Mile Creek, may be considered as progress towards meeting a WLA or LA.

4.3.8 TMDL Summary

Summer (June through September) water quality sampling for Little Waverly Lake does not currently meet the Chl-a or TP standards for shallow lakes in the NCHF Ecoregion (Figures 3-11 and 3-12). Thus, the first 12-Mile Creek model scenario was setup to evaluate the stream's DO response if Little Waverly Lake were to meet the 20 µg/L Chl-a and 60 µg/L TP standards. Under this scenario, decreasing algae production and biomass (represented by Chl-a) in Little Waverly Lake reduced CBOD loading to 12-Mile Creek from 6.7 kg/L to 1.8 kg/day. This scenario greatly improved minimum DO throughout 12-Mile Creek during low flow conditions; however not enough to meet the minimum DO standard 100% of the time throughout the reach. A second scenario was run whereby SOD was systematically reduced throughout the impaired reach until the 5.0 mg/L DO standard was achieved. Under this scenario, SOD will need to be reduced by approximately 68% (20.6 kg/day) in order for the impaired reach to meet the DO standard 100% of the time. Final TMDL allocations for 12-Mile Creek are presented in Table 4-1. The following rounding conversions were used in Table 4-1:

- Values ≥0.1 reported in kg/day have been rounded to the nearest tenth of a kilogram
- Values <0.1 reported in kg/day have been rounded to enough significant digits so that the value is greater than zero and a number is displayed in the table
- While some of the numbers in the tables show multiple digits, they are not intended to imply great precision; this is done primarily to make the arithmetic accurate.

Table 4-1. 12-Mile Creek total maximum daily oxygen demand to meet DO standards.

Source	Oxygen Demand (kg/day) from:						Total Oxygen Demand (kg/day)	
	CBOD		NBOD		SOD			
	Current	TMDL	Current	TMDL	Current	TMDL	Current	TMDL
WLA								
Construction & Industrial Stormwater	0.01	0.01	0.003	0.003	--	--	0.01	0.01
LA								
Little Waverly Lake Headwaters[1]	6.7	1.8	0.8	0.8	--	--	7.5	2.6
Tribs/Groundwater	1.4	1.4	0.3	0.3	--	--	1.7	1.7
Sediment Fluxes	--	--	0.4	0.4	30.2	9.6	30.6	10.0
MOS[2]	--	0.3	--	--	--	1.0	--	1.3
Total	8.1	3.5	1.5	1.5	30.2	10.6	39.8	15.6

[1] Assumes Little Waverly Lake will meet NCHF shallow lake standards under TMDL conditions

[2] MOS was determined to be 10% for all sources requiring load reductions

5 Future Growth/Reserve Capacity

The following applies for determining the impact of growth and reserve capacity on allocations for the 12-Mile Creek impaired reach.

5.1 New or Expanding Permitted MS4 WLA Transfer Process

Future transfer of watershed runoff loads in this TMDL may be necessary if any of the following scenarios occur within the project watershed boundaries:

1. New development occurs within a regulated MS4. Newly developed areas that are not already included in the WLA must be transferred from the LA to the WLA to account for the growth.
2. One regulated MS4 acquires land from another regulated MS4. Examples include annexation or highway expansions. In these cases, the transfer is WLA to WLA.
3. One or more non-regulated MS4s become regulated. If this has not been accounted for in the WLA, then a transfer must occur from the LA.
4. Expansion of a United States Census Bureau Urban Area encompasses new regulated areas for existing permittees. An example is existing state highways that were outside an Urban Area at the time the TMDL was completed, but are now inside a newly expanded Urban Area. This will require either a WLA to WLA transfer or a LA to WLA transfer.
5. A new MS4 or other stormwater-related point source is identified and is covered under a NPDES Permit. In this situation, a transfer must occur from the LA.

Load transfers will be based on methods consistent with the area weighted methodology used in setting the allocations in this TMDL. In cases where WLA is transferred from or to a permitted MS4, the permittees will be notified of the transfer and have an opportunity to comment.

5.2 New or Expanding Wastewater

The MPCA, in coordination with the EPA Region 5, has developed a streamlined process for setting or revising WLAs for new or expanding wastewater discharges to waterbodies with an EPA approved TMDL (MPCA 2012). This procedure will be used to update WLAs in approved TMDLs for new or expanding wastewater dischargers whose permitted effluent limits are at or below the in-stream target and will ensure that the effluent concentrations will not exceed applicable water quality standards or surrogate measures. The process for modifying any and all WLAs will be handled by the MPCA, with input and involvement by the EPA, once a permit request or reissuance is submitted. The overall process will use the permitting public notice process to allow for the public and EPA to comment on the permit changes based on the proposed WLA modification(s). Once any comments or concerns are addressed, and the MPCA determines that the new or expanded wastewater discharge is consistent with the applicable water quality standards, the permit will be issued and any updates to the TMDL WLA(s) will be made. For more information on the overall process visit the MPCA's TMDL Policy and Guidance webpage.

6 Reasonable Assurance

Reasonable assurance (RA) activities are programs that are in place to assist in attaining the TMDL allocations and applicable water quality standards. The RA evaluation provides documentation that the TMDL's WLAs and LAs are properly calibrated and the TMDL loads will ultimately meet the applicable water quality targets. Without such calibration, a TMDL's ability to serve as an effective guidepost of water quality improvement is significantly diminished. The development of a rigorous RA demonstration includes both state and local regulatory oversight, funding, implementation strategies, follow-up monitoring, progress tracking and adaptive management. (Note: Some of these elements are described in Sections 7.0 and 8.0.)

When establishing a TMDL, RAs must be provided demonstrating the ability to reach and maintain water quality endpoints. Several factors control RA, including a thorough knowledge of the ability to implement BMPs as well as the overall effectiveness of the BMPs. This TMDL establishes aggressive goals for reducing oxygen demand in the 12-Mile Creek DO impaired reach.

Many of the goals outlined in this TMDL study are consistent with objectives outlined in the Wright County Local Water Management Plan (http://www.wrightswcd.org/docs/WaterPlan.pdf). This plan has the same objective of developing and implementing strategies to bring impaired waters into compliance with appropriate water quality standards and thereby establish the basis for removing those impaired waters from the 303(d) Impaired Waters List. This plan provides the watershed management framework for addressing water quality issues. In addition, the stakeholder processes associated with this TMDL effort as well as the broader planning efforts mentioned previously have generated commitment and support from the local government units affected by this TMDL and will help ensure that this TMDL project is carried successfully through implementation.

Various sources of technical assistance and funding will be used to execute measures detailed in the North Fork Crow WRAPS. Funding resources include a mixture of state and federal programs, including (but not limited to) the following:

- Federal Section 319 Grants for watershed improvements
- Funds ear-marked to support TMDL implementation from the Clean Water, Land, and Legacy constitutional amendment, approved by the state's citizens in November 2008.
- Watershed District cost-share funds
- Local government funds
- Soil and Water Conservation Districts (SWCD) cost-share funds
- NRCS cost-share funds
- Local Lake Association funds

Finally, it is a reasonable expectation that existing regulatory programs will continue to be administered to control discharges from industrial, municipal, and construction sources as well as large animal feedlots that meet the thresholds identified in those regulations.

6.1 Regulatory Approaches

There are currently no permitted MS4s located in the 12-Mile Creek Watershed. The NPDES Phase II MS4 Stormwater Permits are in place if any existing MS4 were to expand its boundary into the 12-Mile Creek Watershed. Under the stormwater program, permit holders are required to develop and implement a Stormwater Pollution Prevention Plan (SWPPP; MPCA 2004). The SWPPP must cover six minimum control measures:

- Public education and outreach;
- Public participation/involvement;
- Illicit discharge, detection and elimination;
- Construction site runoff control;
- Post-construction site runoff controls;
- Pollution prevention/good housekeeping

The permit holder must identify BMPs and measurable goals associated with each minimum control measure.

The MPCA's MS4 General Permit requires MS4 permittees to provide RAs that progress is being made toward achieving all WLAs in TMDL's approved by EPA prior to the effective date of the permit. In doing so, they must determine if they are currently meeting their WLA(s). If the WLA is not being achieved at the time of application, a compliance schedule is required that includes interim milestones, expressed as best management practices (BMPs), that will be implemented over the current five-year permit term to reduce loading of the pollutant of concern in the TMDL. Additionally, a long-term implementation strategy and target date for fully meeting the WLA must be included.

6.2 Crow River Organization of Water

Portions of 10 counties in Central Minnesota make up the Crow River Watershed, which includes both the North Fork and South Fork Crow Rivers. From the perspective of the Upper Mississippi River Basin, the Crow River is one of its major tributaries to the Mississippi River. The effects of rapid urban growth, new and expanding wastewater facilities and erosion from agricultural lands have been common concerns of many citizens, local, state and regional governments in Central Minnesota. As a result, many groups began meeting in 1998 to discuss management of the Crow River basin consisting of the North

Fork and South Fork. The CROW was formed in 1999 as a result of heightened interest in the Crow River. A Joint Powers Agreement has been signed between all 10 of the Counties with land in the Crow River Watershed. The CROW Joint Powers Board is made up of one representative from each of the County Boards who signed the agreement. The Counties involved in the CROW Joint Powers include Carver, Hennepin, Kandiyohi, McLeod, Meeker, Pope, Renville, Sibley, Stearns and Wright. The CROW currently focuses on identifying and promoting the following:

- Protecting water quality and quantity
- Protecting and enhancing fish and wildlife habitat and water recreation facilities
- Public education & awareness
- BMP implementation

In summer of 2007, the CROW began working with the MPCAs new Major Watershed Restoration and Protection Project (MWRPP) approach in the North Fork Crow River Watershed. The idea behind the watershed approach is to provide a more complete assessment of water quality and facilitate data collection for the development of TMDLs and protection strategies. In the watershed approach, the streams and lakes within a major watershed are intensively monitored to determine the overall health of the water resources, identify impaired waters, and identify those waters in need of additional protection efforts to prevent impairments. This process is different from the past approach because previously, monitoring efforts were concentrated in a defined area (a lake or stream reach) to address one impairment. Under the WRAPS approach, all impairments are addressed at the same time. This process provides a communication tool that can inform stakeholders, engage volunteers, and help coordinate local/state/federal monitoring efforts so the data necessary for effective water resources planning is available, citizens and stakeholders are engaged in the process, and citizens and governments across Minnesota can evaluate the progress.

6.3 County Soil and Water Conservation Districts

The purpose of the County SWCDs is to plan and execute policies, programs, and projects which conserve the soil and water resources within its jurisdictions. They are particularly concerned with erosion of soil due to wind and water. The Wright County SWCD is heavily involved in the implementation of practices that effectively reduce or prevent erosion, sedimentation, siltation, and agricultural-related pollution in order to preserve water and soil as resources. The SWCD frequently acts as a local sponsor for various projects, including grassed waterways, on-farm terracing, erosion control structures, and flow control structures. The CROW has established close working relationships with the Wright County SWCD on a variety of projects. One example is the conservation buffer strip cash incentives program that provides cash incentives to create permanent grass buffer strips adjacent to water bodies and water courses on land in agricultural use.

7 Monitoring Plan

Two types of monitoring are necessary to track progress toward achieving the load reduction required in the TMDL and the attainment of water quality standards. The first type of monitoring is tracking implementation of BMPs on the ground. The CROW and the Wright County SWCD will track the implementation of these projects annually in eLINK. The second type of monitoring is physical and chemical monitoring of the resource. The CROW plans to monitor 12-Mile Creek on a 10 year cycle in conjunction with the North Fork Crow River WRAPS process.

This type of effectiveness monitoring is critical in the adaptive management approach (refer to Figure 8-2). Results of the monitoring identify progress toward benchmarks as well as shape the next course of action for implementation. Adaptive management combined with obtainable benchmark goals and monitoring is the best approach for implementing this TMDL.

8 Implementation Strategy Summary

8.1 Implementation Framework

As the CROW coordinates with its stakeholders on the details of this TMDL, some of the following BMPs may be selected to achieve the 12-Mile Creek DO TMDL. These actions are further developed in the North Fork Crow WRAPS Report. The following provides an overview of implementation options to be considered.

8.2 Strategies

The following is a description of potential actions for controlling headwater CBOD loading and SOD in the 12-Mile Creek DO impaired reach. It is not possible to accurately estimate the cost of implementing any of these or other strategies without more study, but the cost is likely in the range of $1,000,000 to $2,500,000.

8.2.1 Little Waverly Lake Restoration and Nutrient Reduction

The HSPF model indicates Little Waverly Lake is the primary source of water column TP, algae and CBOD to 12-Mile Creek. The model also suggests DO in 12-Mile Creek is sensitive to eutrophication loading from the lake and DO in the impaired reach would improve if Little Waverly Lake is able to meet Minnesota's 60 µg/L TP standard, and 20 µg/L chlorophyll-a standard for shallow lakes. Therefore, restoration of Little Waverly Lake should be considered a primary strategy for improving DO in the 12-Mile Creek impaired reach. A TMDL study was completed on Little Waverly Lake in 2014 that outlines allocations and a reduction strategy to reduce TP and algae growth to meet state water quality standards (Wenck Associates 2014). This report identified crop and manure management, upland erosion, loading from upstream lakes, and internal (sediment) phosphorus release as the primary sources of phosphorus and eutrophication in Little Waverly Lake. Strategies to address these sources are presented in the North Fork Crow WRAPS Report (CROW and MPCA 2014). Restoration of Little Waverly Lake to meet state water quality standards will likely cost between $200,000 and $1,000,000.

8.2.2 Little Waverly Lake Outlet Reaeration

At this time, there has been no monitoring data collected at the outlet of Little Waverly Lake to determine if, or how often headwater DO conditions are below the 5.0 mg/L standard. The HSPF model suggests the water discharged from Little Waverly Lake is occasionally below than the 5.0 mg/L standard. More monitoring data will need to be collected to verify these conditions. If monitoring results indicate Little Waverly Lake is a source of low DO to 12-Mile Creek, the hope is that the phosphorus load reductions set forth in the Little Waverly Lake TMDL to improve in-lake water quality conditions will also improve DO conditions in 12 Mile Creek. If not, other options may need to be explored such as mechanical reaeration and/or modifications to the lake's outlet structure. Mechanical reaeration typically costs between $15,000 and $25,000.

8.2.3 Channel Morphology Alteration

The TMDL model scenario indicated SOD will need to be reduced in 12-Mile Creek in order for the impaired reach to meet DO standards. Perhaps the most effective way to do this is by creating a low-flow channel (Figure 8-1) through over-widened sections of the impaired reach where channel sediments may be exerting significant oxygen demand (e.g. wetland reaches). The newly engineered low-flow channel would be thinner and deeper than the pre-existing channel, thus reducing SOD. Restoring the stream channel using a low-flow design standard would require excavation and channel alteration. The estimated cost of stream morphology alteration and stream restoration is $1,000,000 per mile, depending on whether the restoration is retrofitting an in-place channel or is making significant channel modifications. The wetland reaches within the 12-Mile Creek impaired reach are approximately 1.2 miles in length. Total estimated cost to restore these sections would be approximately $1,200,000.

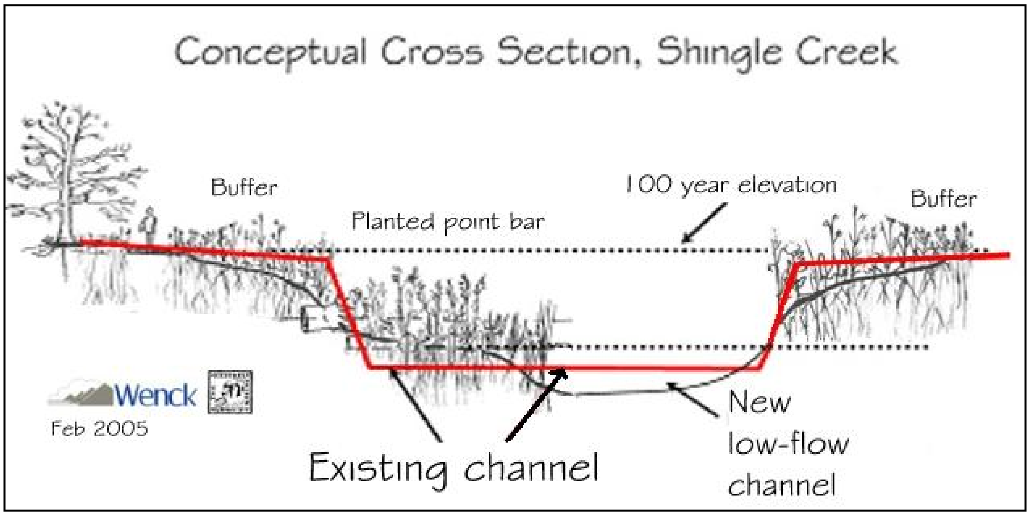

Figure 8-1. Desirable stream cross section with enhanced habitat and low-flow channel.
Source: Shingle Creek Watershed Management Commission, 2006.

8.3 Adaptive Management

Implementation strategies in the North Fork Crow River WRAPS report focused on adaptive management (Figure 8-2). Continued monitoring and "course corrections" responding to monitoring results are the most appropriate strategy for attaining the water quality goals established in this TMDL. Management activities will be changed or refined to efficiently meet the TMDL and lay the groundwork for de-listing the impaired water bodies.

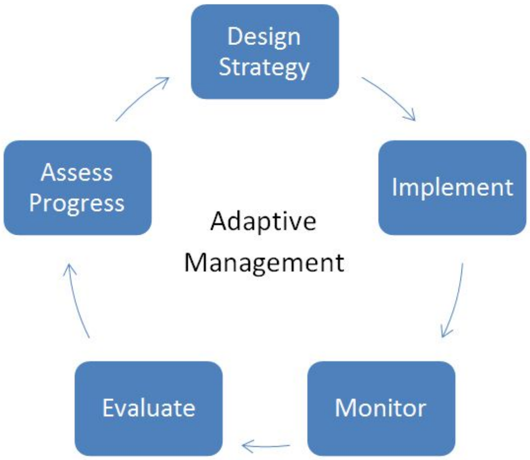

Figure 8-2. Adaptive Management.

9 Public Participation

CROW and local partners increased education awareness of water quality efforts and impacts throughout the watershed. Considerable emphasis on public awareness and engagement ensure success and longevity of our water quality.

2013 - CROW collaborated with the local counties, SWCD's, Middle Fork Crow River Watershed District, North Fork Crow River Watershed District, state agencies, and consultants to produce the North Fork Crow River WRAPS Report. Technical assistance and recommendations from these entities along with stakeholders (lake association members, agricultural community members and cities) developed watershed protection and restoration strategies. Members regularly attended meetings to track and evaluate the projects progress and review DO, nutrients, bacteria and turbidity TMDL information. CROW worked with the MPCA on developing a pilot online web application called, "North Fork Crow River Story Map" in ArcGIS. The North Fork story map is an interactive map that highlights implementation projects, educational efforts and resource concerns in the watershed. The map provides pictures from the watershed and links to local partners for additional information. The North Fork story map is another tool to help connect with citizens throughout the area for them to learn about the work that is being done to protect and restore our water quality.

2014 – Local partners group met to review project data, develop implementation actions and measureable goals, and identified protection and restoration areas in the North Fork Crow River Watershed. The group developed and submitted the North Fork WRAP to the MPCA for routing and notification of public comment. Informational public meetings were held on June 18 in Buffalo and June 24 in Spicer to engage stakeholders and review the North Fork WRAP results, TMDLs, and document. A total of 19 stakeholders provided comments and recommendations for the WRAP.

2015 – CROW and local partners were chosen to participate in the state's 1W1P pilot project. The 1W1P project will align planning on major watershed boundaries with prioritized, targeted, and measurable watershed plans that will be developed and implemented locally. Pilot plans will build on existing efforts, using current local water plans, state and local knowledge and a systematic, science-based approach to watershed management. The resulting plans will address the largest threats that provide the greatest environmental benefits to each watershed. The pilot program will involve a broad range of stakeholders, including local governments, state agencies, and community members as true partners in the planning process. Local partners determined the North Fork WRAP and 1W1P projects would help integrate plans and develop a cohesive opportunity to implement strategies, track progress through effectiveness monitoring and evaluate progress in the watershed.

The public notice dates were July 27, to August 26, 2015.

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Appendices

Appendix A

RESPEC
WATER & NATURAL RESOURCES

RSI(RCO)-1953/6-11/32

July 12, 2011

Mr. Charles Regan
Minnesota Pollution Control Agency
520 Lafayette Road North
St. Paul, MN 55155

Dear Mr. Regan:

RE: Proposed Approcah for Modeling Water Quality in the Sauk, North Crow, and South Crow Hydrological Simiulation Program – FORTRAN (HSPF) Watershed Models

Please review the following proposed approach for water-quality calibration and validation in the Sauk, North Crow, and South Crow **Hydrological Simiulation Program – FORTRAN (HSPF)** Watershed model applications.

Impairments in the Sauk Watershed include dissolved oxygen (DO), turbidity, E. *coli*, fecal coliform, polychlorinated biphenyls (PCB) in fish, and fish and invertebrate bioassessments. Similarly, impairments in the Crow Watersheds (North and South) include chloride, DO, ammonia, turbidity, E. *coli*, fecal coliform, and fish and invertebrate bioassessments. The Sauk and Crow Watersheds also have nutrient impairments in multiple lakes and the North Fork Crow Watershed has one plant-bioassessment lake impairment. The project parameters to be modeled include turbidity (total suspended solids (TSS)), temperature, DO/ biochemical oxygen command (BOD) dynamics, and nutrients (including ammonia).

The following methods will give RESPEC the ability to estimate turbidity, temperature, DO, and nutrient loads and the watershed allocations; calculate contributions from point, nonpoint, and atmospheric sources where necessary; and provide a means of evaluating impacts of alternative management strategies to reduce these loads and improve water-quality conditions. The model applications will apply empirical washoff functions and will focus on agricultural, urban, and rural sources of pollutants. As discussed in Love [2011], separate user control inputs (UCIs) were created to represent land use changes: one UCI represents 1995 through 2003 using National Land Cover Data (NLCD) 2001 land use data and the other represents 2004 through 2009 using NLCD 2006 land use data. The primary calibration period will be 2004 to 2009 (based on NLCD 2006 land use data), and the validation period will be from 1996 to 2003 (based on NLCD 2001 land use data). Once the model applications have been calibrated and validated for the two time periods with alternate land use configurations, a single application will be developed to simulate dynamic land use change within a single execution. This full-time period application will be used for long-term scenario simulations. Note that much of the proposed approach builds off historical **HSPF** applications (e.g., Minnesota River application); however, the proposed approach can be adapted based on the specifications document, contingent on the timing of its development and reasonableness for this application.

TURBIDITY APPROACH

Turbidity impairments exist in the Sauk and Crow Watersheds. A regression analysis, which will be part of the next project work order, will be completed to determine the relationship of total suspended solids (TSS) and turbidity in the Sauk and Crow Watersheds. This is a similar approach to that used in the Minnesota River Model application, for which TSS was used as a surrogate for turbidity based on a strong observed correlation between the two. The approach for modeling suspended sediment will be similar to the Minnesota River Model application, and initial calibration parameters and/or methods will be estimated from it where deemed appropriate. The model application will be capable of identifying sources of sediment and the processes that drive sediment erosion, delivery, and transport in the watersheds as well as point source sediment contribution. The model application will represent municipal separate storm sewer system (MS4) areas for future Total Maximum Daily Load (TMDL) development. In areas drained by tile drains, sand, silt, and clay concentrations in interflow from open tile intakes will be represented using the SPECIAL ACTION approach used in the Minnesota River application or a comparable approach will be developed.

Before completing sediment calibration, RESPEC will review the following documents that will be used to determine calibration targets for each identified sediment source within the watershed:

- Sediment fingerprinting by the St. Croix Watershed Research Station.
- Le Sueur River Watershed Sediment budget by the National Center for Earth-surface Dynamics.
- Minnesota River Basin turbidity model calibration and validation report (Section 5) by TetraTech.

Sediment parameter estimation and calibration will be performed according to guidance from U.S. Environmental Protection Agency (EPA) **BASINS** Technical Note 8 [U.S. Environmental Protection Agency, 2006]. Steps for sediment calibration include estimation of model parameters, adjustment of parameters to represent estimated landscape erosion loading rates and delivery to the stream, adjustment of parameters to represent in-stream transport and bed behavior, and analysis of sediment budgets for landscape and in-stream contributions. Observed local data are rarely sufficient to accurately calibrate all parameters for all land uses for each stream and waterbody reach. Therefore, the majority of the calibration is based on those sites with observed data. Simulation in all parts of the watershed must be reviewed to ensure that the model results are consistent with congruent analysis, field observations, historical reports, and expected behavior from past experience. This is especially critical for sediment modeling because of the extreme dynamic behavior of sediment erosion and transport processes [U.S. Environmental Protection Agency, 2006].

Sediment erosion and delivery and in-stream sediment transport will be represented in the sediment model application. Parameters predicting sediment erosion from the landscape and delivery to the stream will be estimated and compared with results from the Revised Universal Soil Loss Equation (RUSLE), which will be a part of the next work order. The RUSLE gives an estimate of the average soil loss in tons per acre based on numerical factors developed from spatial soil and land use characterization data, slope, and rainfall and runoff intensity estimates. A detailed procedure for the RUSLE analysis is described in EPA Technical Note 8 [U.S. Environmental Protection Agency, 2006]. A sediment delivery ratio (SDR), likely based on watershed area and slope, will be applied to the average soil loss because the RUSLE provides gross erosional estimates that are greater than the sediment load that is actually delivered to the stream. HSPF landscape loading rates represent the predicted sediment load delivered to the stream from the landscape. Annual sediment load per acre predicted by the model on a subwatershed scale will be compared to the RUSLE loading rates adjusted with the SDR using appropriate parameterization. Model sediment loading rates will also be compared to typical ranges of expected erosion rates from literature for applicable land use categories, shown in Table 1, and to surficial geology and soils maps for information on particle size distribution. The SPECIAL ACTIONS Block may be used to represent agricultural practices such as planting, cultivation, and harvest. In addition to the landscape sediment budgets estimated by RUSLE and typical expected erosion rates, model results will be compared to LOADEST load estimations. Sediment loads in LOADEST are estimated using flow. During the rise of the hydrograph, there is typically much more sediment being transported than on the recession of a storm hydrograph–LOADEST does not account for this. Therefore, two LOADEST models could potentially be used for comparison to simulated loads at calibration sites, one for the upslope and one for the downslope of storm hydrograph which, when summed, would provide the overall annual load.

Table 1. Typical Ranges of Expected Erosion Rates [U.S. Environmental Protection Agency, 2006]

Land Use	Tons/Acre
Forest	0.05–0.4 dashes
Pasture	0.3–1.5
Conventional Tillage	1.0–7.0
Conservation Tillage	0.5–4.0
Hay	0.3–1.8
Urban	0.2–1.0
Highly Erodible Land	> ~ 15.0

The primary calibration parameters involved in landscape erosion simulation are the coefficients and exponents from three equations representing different soil detachment and removal processes. KRER and JRER are the coefficient and exponent, respectively, from the soil detachment from rainfall impact equation; KSER and JSER are the coefficient and exponent from the soil washoff or transport equation; and KGER and JGER are the coefficient and exponent from the matrix soil equation which simulates gully erosion. KRER will be estimated as the soil erodibility coefficient from the RUSLE equation which can be estimated from the Soil Survey Geographic (SSURGO) spatial soils database. Landscape fractionation of sand, silt, and clay will also be represented using data from the SSURGO spatial soils database. The remaining parameters will be initially given the recommended initial values from EPA **BASINS** Technical Note 8 [U.S. Environmental Protection Agency, 2006] or the Minnesota River model application. Row crops and other temporally varying land segments will be represented using monthly values.

After landscape sediment erosion rates are adjusted to provide the expected loading to the stream channel, calibration will continue with adjustment of parameters governing the processes of deposition, scour, and transport of sediment within the stream. Calibration will be performed on a reach-by-reach basis from upstream to downstream because of the influence of upstream parameter adjustments on downstream reaches. Bed behavior and sediment budgets are analyzed at each reach to ensure that results are consistent with field observations, historical reports, and expected behavior from past experience. Initial composition of the channel beds will be estimated using any available particle size distribution data. Calibration focus will be at locations where TSS concentration data are available, with TSS being used as a surrogate for turbidity. TSS concentration data are widely available within the Minnesota Pollution Control Agency (MPCA) dataset, while suspended sediment concentrations (SSC) are very limited with only two sites in the three watersheds having greater than three samples during the modeling period.

The primary parameters that will be involved in the calibration of in-stream sediment transport and bed behavior include critical shear stresses for deposition and scour for cohesive sediment (silt and clay) and the coefficient and exponent in the non-cohesive (sand) transport power function. TAUCD and TAUCS are the critical deposition and scour shear stress parameters, respectively. They will be initially estimated as the 25th percentile of the simulated bed shear stress for TAUCD and 75th percentile for TAUCS. Cohesive sediment is being transported when the bed shear stress is higher than TAUCD and settles and deposits when the bed shear stress is lower than TAUCD. Sediment is being scoured from the bed when the shear stress is greater than TAUCS. The erodibility parameter (M) for silt and clay determines the intensity of scour when scour is occurring. KSAND and EXPSAND are the coefficient and exponent of the sand transport power function.

TEMPERATURE/DO/BOD DYNAMICS/NUTRIENT APPROACH

The proposed approach for modeling temperature, DO/BOD dynamics, and nutrients will be similar to that of the Minnesota River Model Application. The model application will simulate temperature (using HTRCH), organic and inorganic nitrogen, total ammonia, organic and inorganic phosphorus (using NUTRX), dissolved oxygen and biochemical oxygen demand (using OXRX), and algae (using PLANK). Adsorption/desorption of total ammonia and orthophosphate to sediment will also be simulated The modeled output will support MPCA activities for Total Maximum Daily Load (TMDL) development, in-stream nutrient criteria compliance testing, and future support for municipal separate storm sewer system (MS4) permitting and point source permitting. Initial calibration parameters will be estimated from the Minnesota River model application.

Overall sources considered for nutrients include point sources such as water treatment facilities and nonpoint sources from the watershed, atmospheric deposition (nitrate and ammonia), subsurface flow, and soil-bed contributions. Major point source facility contributions and MS4 areas will be explicitly modeled for future permitting purposes. Nonpoint sources will be calculated by considering accumulation and depletion/removal and a first-order washoff rate from overland flow. Quantities of nutrients applied to land as fertilizer will be estimated using crop type and suggested crop application rates and/or available data. Atmospheric deposition of nitrogen and ammonia will be applied to all of the land areas and will provide a contribution to the nonpoint source load through the buildup/washoff process. Atmospheric deposition onto water surfaces will be represented in the model as a direct input to the lakes and river systems. Subsurface flow concentrations will be estimated on a monthly basis for calibration and will also represent concentrations from tile drainage. This will include particulate phosphorus and potentially ammonia from sediment in interflow (tile drains) and from sediment derived from PERLNDs as well as dissolved phosphorus, ammonia, and nitrogen in interflow and active groundwater.

Biochemical reactions that affect DO will be represented in the model application. Overall sources considered for BOD and DO include point sources such as water treatment facilities, nonpoint sources from the watershed, interflow, and active groundwater flow. The Minnesota River model application represented BOD through tile drainage. The model application will address BOD accumulation, storage, decay rates, benthic algal oxygen demand, settling rates, and reaeration rates. The model will also represent respiration, growth, settling rates, density, and nutrient requirements of algae and phytoplankton.

OVERVIEW OF WATERSHED MODEL DATA NEEDS

A watershed model application representing nutrients, oxygen/BOD dynamics, and primary production requires observed values of temperature, DO, BOD, Nitrogen species (nitrate/nitrite, ammonia, and organic nitrogen), Phosphorus species (organic and inorganic phosphorus), organic carbon, and chlorophyll a (representing phytoplankton) throughout the watershed for comparison to simulated results.

Water temperature and DO measurements are available throughout the watershed in ambient water-quality monitoring data and the point source data. BOD is a measure of the amount of oxygen required to stabilize organic matter. As such, BOD is an equivalent indicator rather than a true physical or chemical substance. BOD measurements are available at multiple ambient water-quality monitoring sites as well as within point source data. Because all organic matter, no matter how complex, are composed of carbon, which is available at multiple ambient water-quality monitoring sites, TOC can be converted to BOD if necessary.

Ammonia-nitrogen, inorganic nitrogen (nitrate plus nitrite), and Kjeldahl nitrogen (organic nitrogen plus ammonia) are available at ambient water-quality monitoring sites throughout the watersheds. Total nitrogen was available but limited, but can be calculated using the sum of concurrent samples of inorganic nitrogen and Kjeldahl nitrogen. Similarly, organic nitrogen can be calculated using the difference between concurrent samples of Kjeldahl nitrogen and ammonia-nitrogen. For the most part, ammonia is the only nitrogen species available in the major and minor point source data. Some sites have less than five samples of nitrate plus nitrite and Kjeldahl nitrogen. With limited amount of observed data a method must be chosen to develop a continuous time series of these parameters. Relevant options include using the mean of available values and applying it as a continuous steady concentration. Another option would be to estimate a ratio between concurrent ammonia samples and apply the ratio to the ammonia time series to develop continuous time series for the missing nitrogen species. Orthophosphate-phosphorus and total phosphorus are available at ambient water-quality monitoring sites throughout the watershed. Organic phosphorous can be calculated using the difference in concurrent samples of total phosphorous and orthophosphate-phosphorous. Total phosphorus is available in the point source data but no other phosphorus species are available in the point source data. Methods for estimation of other phosphorus species from point sources can be derived from methods similar to those used in the Minnesota River model application. Chlorophyll a is typically used as an estimate of algal biomass and is available at multiple sites throughout the watersheds.

Observed ambient water-quality data are available throughout the watershed. These data were obtained from MPCA as well as the U.S. Geological Survey (USGS). Table 2 lists 46 MPCA gages and 31 USGS gages from which data can be used for calibration and validation. These gages are also shown in Figure 1. All available data to be used for model inputs and for comparison to simulated data have been uploaded into the project Watershed Data Management file and the observed data Excel file.

Atmospheric Deposition Data Available

Atmospheric deposition of nitrate and ammonia will be explicitly accounted for in the Sauk and Crow Watershed models by input of separate wet and dry deposition fluxes. Wet atmospheric deposition data were downloaded from the National Atmospheric Deposition Program (NADP). The nearest NADP sites to the Sauk, North Fork Crow, and South Fork Crow Watersheds were located within Minnesota and include MN27 in Redwood County, MN23 in Morrison County, and MN01 in Anoka County. MN01 data do not exist for the entire modeling period, as operation of this site began December 31, 1996. Theissen polygons were created for wet deposition sites, which were used to assign data to hydrozones, and data from MN23 were used to fill site MN01 for 1995 and 1996 (based on proximity). The atmospheric deposition sites and the wet deposition Thiessen polygons are shown in Figure 2. Wet deposition includes the deposition of pollutants from the atmosphere that occur during precipitation events. Thus nitrate and ammonia wet deposition was applied to the watersheds in the model application as concentrations (milligrams per liter (mg/L)) to observed precipitation.

Dry atmospheric deposition data were downloaded from the EPA's Clean Air Status and Trends Network (CASTNet). CASTNet sites, shown in Figure 3, nearest to the Sauk, North Fork Crow, and South Fork Crow Watersheds, include MN32/VOY413 in northern Minnesota, WI35/PRK134 in west-central Wisconsin, IL18/STK138 in northwestern Illinois, and SD99/SAN189 on the border of South Dakota and Nebraska. Theissen polygons were not created for the dry deposition sites because ambient concentration trends were reviewed which show that data trends from the South Dakota/Nebraska border site and the west-central Wisconsin site are far more representative of central Minnesota than the northern Minnesota site and the northwestern Illinois site. Figure 3 shows nitrate and ammonia trends from 2007 through 2009. Trends of most atmospheric deposition parameters were similar to those shown in Figure 3. Dry deposition data from the west-central Wisconsin site (WI35) was chosen to represent the three watersheds because the South Dakota/Nebraska border site was not active until mid-2006. Site WI35 is also referred to as PRK134. Because dry deposition is not

Table 2. Minnesota Pollution Control Agency and U.S. Geological Survey Ambient Water-Quality Sites in the Crow and Sauk Watersheds (Page 1 of 5)

MPCA Site	USGS Site	Description	Period of Record*	Watershed	Number Of Samples													
					BOD	Chlorophyll-a	DO	NH3	NO2	NO3	Total NO2+NO3	Total Kjeldahl Nitrogen	Dissolved Ortho-Phosphate	Total Phosphorus	Water Temperature	Suspended Solids Concentration	Total Suspended Solids	Turbidity
S000-017	N/A	Sauk River Downstream of Br On Csah-1 At Sauk Rapids	1995–2009	Sauk	15	32	227	166			207	125		179	212		172	232
S000-444	N/A	Mill Creek at MN-23 in Rockville	2003–2009	Sauk	25	16												
S000-497	N/A	Stony Creek at County Road near Spring Hill	1999–2009	Sauk	2		91	151			59	56		236	92		183	7
S000-517	N/A	Sauk River at CSAH-12 bridge near Richmond	1995–2009	Sauk			83	151			65	82		218	84		166	1
S002-649	N/A	Sauk River at CSAH 37 East Side Lake, OSAKIS NE OF OSAKIS	1995–2009	Sauk			86	134			48	45		210	84		146	1
S003-286	N/A	Sauk River at CSAH 2, 0.4 mile south of Cold Springs, MN	1995–2009	Sauk		21	90	147			52	86		205	92		167	1
S003-289	N/A	Getchel Creek at CSAH 176, 3.1 miles SENEW Munich, MN	1995–2009	Sauk	2	2	79	139			73	74		224	79		179	9
S003-523	N/A	Hoboken Creek at CR-72, 1 mile northwest of Sauk Centre, MN	2000–2004	Sauk				22			12						50	
N/A	5270500	Sauk River near St. Cloud, MN	1995–2001	Sauk			11		2	14		2	7	4	14	1		
N/A	5270380	Sauk River at Richmond, MN	1995	Sauk			2								1			
N/A	5270195	Sauk River above Melrose WWTP at Melrose, MN	2009	Sauk					2	2						1		
N/A	5270197	Sauk River below Melrose WWTP at Melrose, MN	2009	Sauk					2	2						1		

Table 2. Minnesota Pollution Control Agency and U.S. Geological Survey Ambient Water-Quality Sites in the Crow and Sauk Watersheds (Page 2 of 5)

MPCA Site	USGS Site	Description	Period of Record*	Watershed	Number Of Samples													
					BOD	Chlorophyll-a	DO	NH3	NO2	NO3	Total NO2+NO3	Total Kjeldahl Nitrogen	Dissolved Ortho-Phosphate	Total Phosphorus	Water Temperature	Suspended Solids Concentration	Total Suspended Solids	Turbidity
N/A	5270183	Sauk River below Sauk Centre WWTP at Sauk Centre, MN	2009	Sauk					2	2						1		
N/A	5270181	Sauk River above Sauk Centre WWTP A at T Sauk Centre, MN	2009	Sauk					2	2						1		
N/A	5270103	Sauk River below Lake Osakis near Osakis, MN	2007	Sauk					4	4						1		
S000-004	N/A	Crow River at bridge ON CSAH-36 AT DAYTON	1995–2009	North Crow	42	44	118	77			91	26	3	82	93		84	96
S000-847	N/A	Grove Creek A At T CSAH-3 7.5 Miles Northeast Of Grove City	2001–2009	North Crow	16	23												
S001-255	N/A	South Fork Crow River, BR at BRIDGE Ave. in Delano	1998–2009	North Crow	34	25		74			133	133	42				140	158
S001-257	N/A	Crow River at BR at Bridge Street in Rockford, MN	1998–2007	North Crow	5	6		5			5	5	2				6	7
S001-502	N/A	Jewett Creek near 300th Street BRG, 4 miles north of Litchfield	2000–2009	North Crow	15	23		77			66		37					59
S001-517	N/A	North Fork Crow River at CSAH-4 BRG, 1.5 miles west of Albright	2001–2009	North Crow	19	22							39					
S001-972	N/A	Twelvemile Creek at CSAH 7, 2 miles northwest of Waverly, MN	2001–2009	North Crow									36					

Table 2. Minnesota Pollution Control Agency and U.S. Geological Survey Ambient Water-Quality Sites in the Crow and Sauk Watersheds (Page 3 of 5)

MPCA Site	USGS Site	Description	Period of Record*	Watershed	Number Of Samples													
					BOD	Chlorophyll-a	DO	NH3	NO2	NO3	Total NO2+NO3	Total Kjeldahl Nitrogen	Dissolved Ortho-Phosphate	Total Phosphorus	Water Temperature	Suspended Solids Concentration	Total Suspended Solids	Turbidity
S002-018	N/A	Mill Creek on CSAH-12, 3½ miles southwest of Buffalo	2001–2009	North Crow	15	24							40					
S002-020	N/A	CO. DT 31 ON MN-25,NO OF US-12, 4 miles northwest of Delano	2001–2009	North Crow	23	15												
S002-295	N/A	Crow River Middle Fork Inlet to Nest Lake, 3 miles north northwest of Spicer, MN	2000–2009	North Crow				12			7	85					130	13
S002-384	N/A	Sedan Break and Ironside Road, 3.5 miles northeast of Brooten, MN	2000–2009	North Crow				3			3						57	18
S002-387	N/A	Crow River, North Fork, at CSAH 30 BRG, east Side Manannah, MN	2001–2009	North Crow				3			3							
S002-391	N/A	JD1 near Dam at South Grove Lake Street, 4 miles northeast of Sedan, MN	1997–2009	North Crow				1				23		88			84	15
S002-403	N/A	Crow River, North Fork, Rice Lake Inlet, 3 miles east of PAYNESVILLE	1997–2001	North Crow										33			33	
N/A	5276005	North Fork Crow River above Paynesville, MN	1995–1998	North Crow			72		70	70		35	70	35	36	35		
N/A	5276000	North Fork Crow River near Regal, MN	1995	North Crow			2			2				4	6			

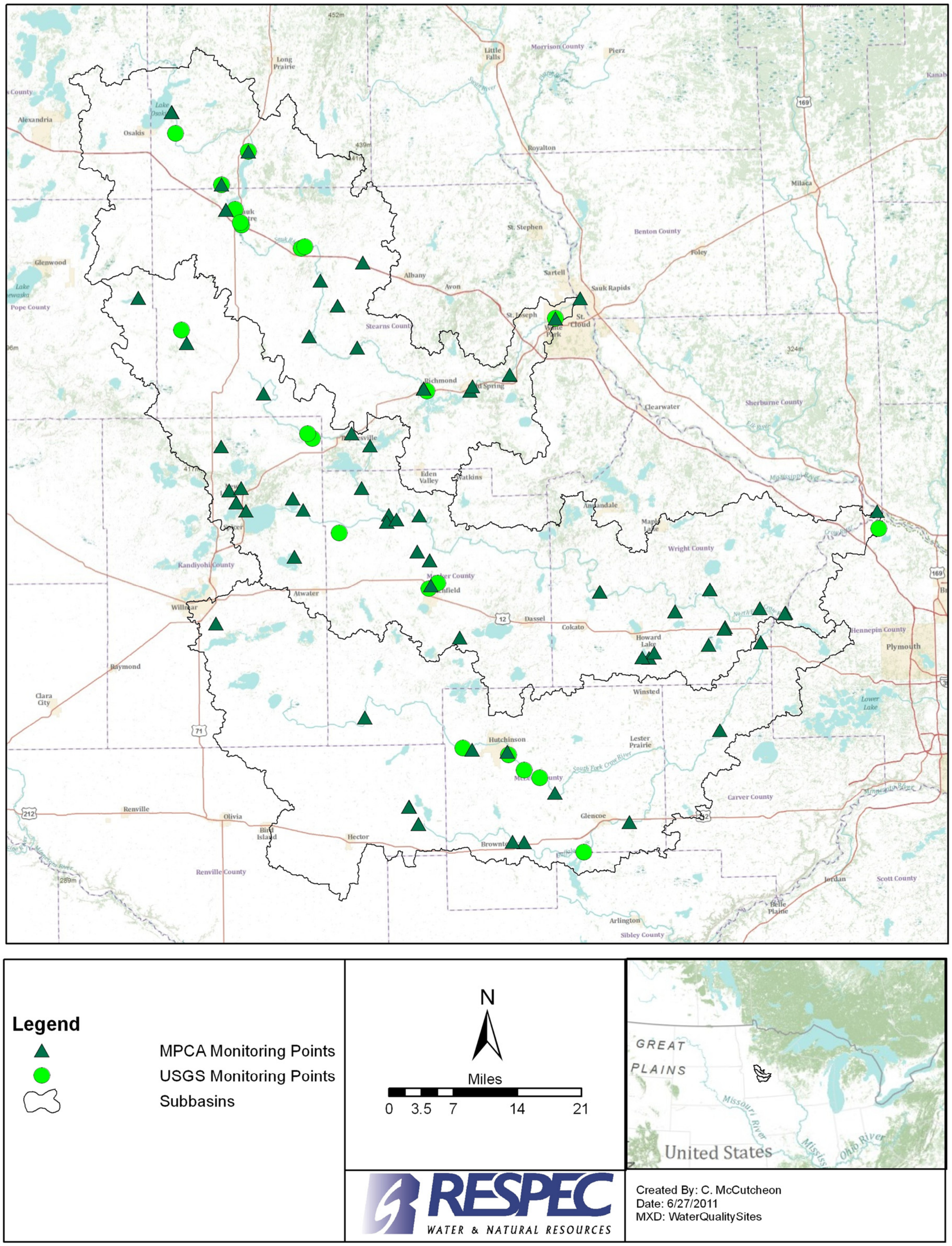
Table 2. Minnesota Pollution Control Agency and U.S. Geological Survey Ambient Water-Quality Sites in the Crow and Sauk Watersheds (Page 4 of 5)

MPCA Site	USGS Site	Description	Period of Record*	Watershed	Number Of Samples													
					BOD	Chlorophyll-a	DO	NH3	NO2	NO3	Total NO2+NO3	Total Kjeldahl Nitrogen	Dissolved Ortho-Phosphate	Total Phosphorus	Water Temperature	Suspended Solids Concentration	Total Suspended Solids	Turbidity
N/A	5278080	Jewitts Creek at U.S. Highway 12 in Litchfield, MN	2009	North Crow					2	2						1		
N/A	5278083	Jewitts Creek Near Litchfield, MN	2009	North Crow					2	2						1		
N/A	5278020	Middle Fork Crow River at Crow River, MN	2007	North Crow					6	6						2		
N/A	5280400	Crow River Below State Highway 101 at Dayton, MN	1995–2001	North Crow			8								4			
N/A	5275960	North Fork Crow River near Brooten, MN	2007	North Crow					2	2								
S000-460	N/A	Buffalo Creek AT N/S RD IN S28 0.5 MI E OF BROWNTON	2001–2009	South Crow	49	30							39					
S002-014	N/A	South Fork Crow River on CR-59, 3 miles west of Hutchinson	2001–2009	South Crow	30	13							41					
S002-016	N/A	JD #15, 2 miles west CSAH-20, 3½ miles northeast of Buffalo Lake	2001–2009	South Crow	48	29												
S002-017	N/A	Buffalo Creek on CSAH-24, 4 miles northeast of Buffalo Lake	2002–2009	South Crow	44	30												
N/A	5278880	Buffalo Creek Near New Auburn, MN	1997	South Crow			2		2	2		1	2	1	1	1		1
N/A	5278590	South Fork Crow River at Highway 22 near Biscay, MN	1995–2007	South Crow			14		6	6		1	6	4	8	1		3

Table 2. Minnesota Pollution Control Agency and U.S. Geological Survey Ambient Water-Quality Sites in the Crow and Sauk Watersheds (Page 5 of 5)

MPCA Site	USGS Site	Description	Period of Record*	Watershed	Number Of Samples													
					BOD	Chlorophyll-a	DO	NH3	NO2	NO3	Total NO2+NO3	Total Kjeldahl Nitrogen	Dissolved Ortho-Phosphate	Total Phosphorus	Water Temperature	Suspended Solids Concentration	Total Suspended Solids	Turbidity
N/A	5278580	South Fork Crow River below Hutchinson, MN	2007–2009	South Crow					6	6						1		
N/A	5278570	South Fork Crow River above wastewater treatment plant (WWTP) at Hutchinson, MN	2009	South Crow					2	2						1		
N/A	5278560	South Fork Crow River above Otter Lake near Hutchinson	2007	South Crow					4	4								

Note: The period of record shows only years within the Crow/Sauk modeling period (1995–2009).



Created By: C. McCutcheon
Date: 6/27/2011
MXD: WaterQualitySites

Figure 1. Ambient Water-Quality Monitoring Sites Within the Sauk and Crow Watersheds.

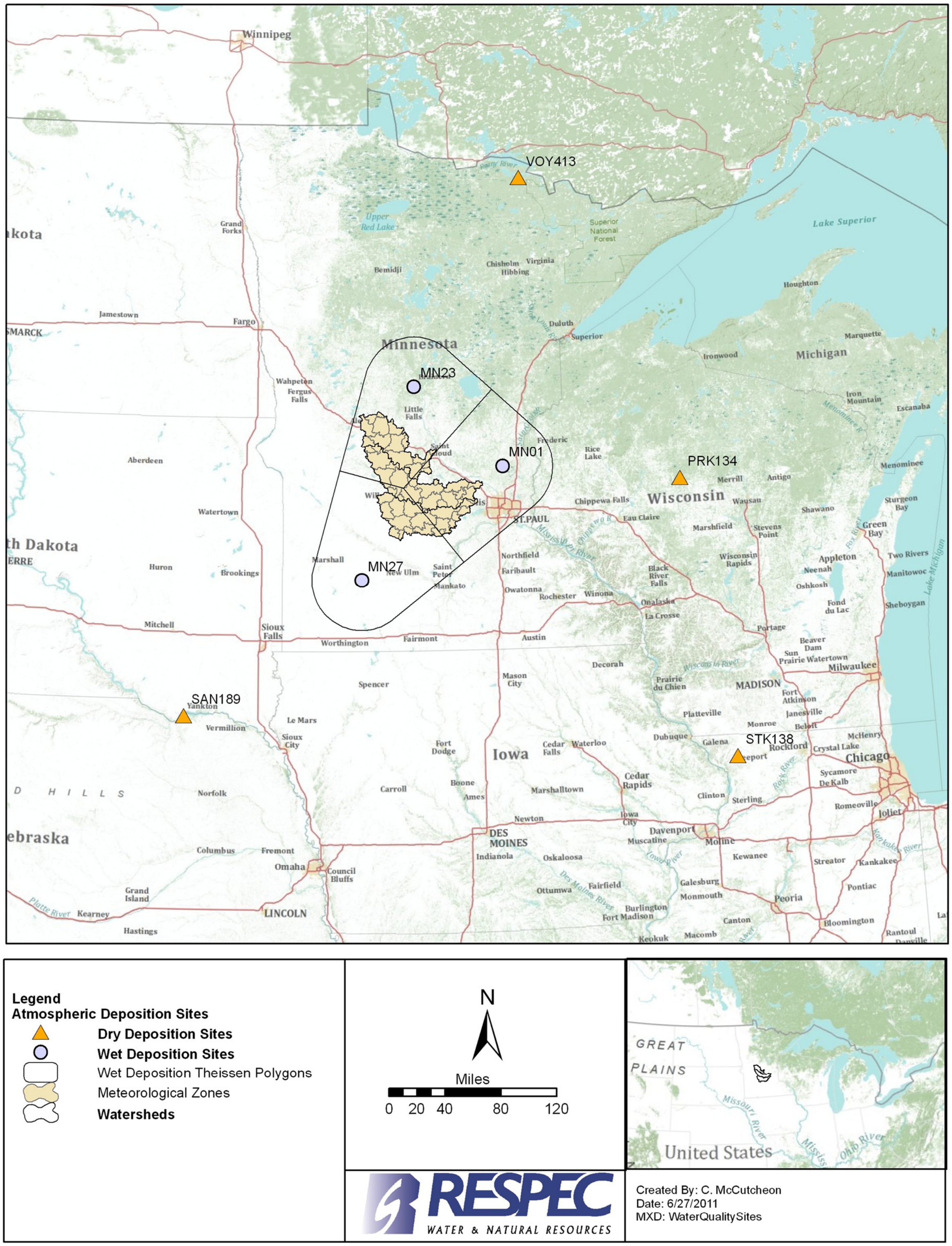
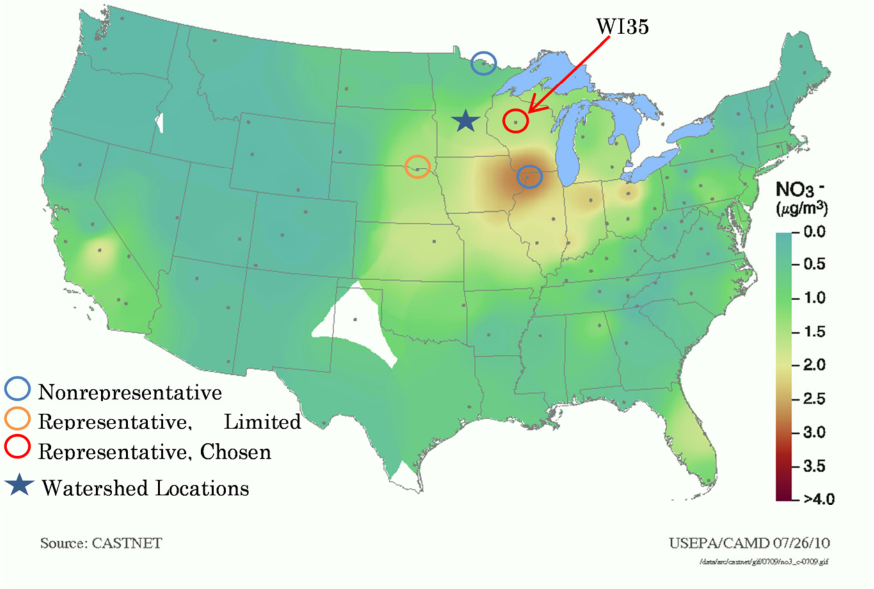


Figure 2. Atmospheric Deposition Sites and Wet Deposition Site Thiessen Polygons.



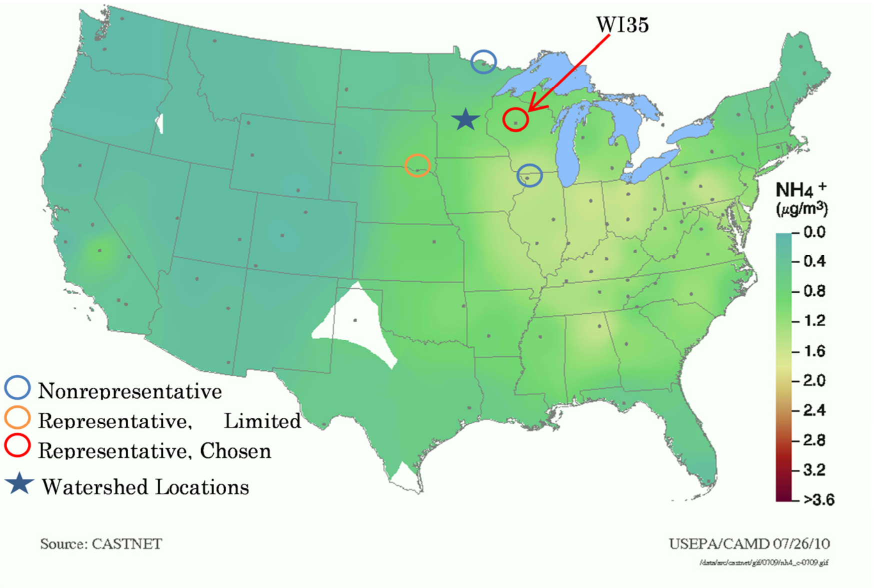


Figure 3. Particulate Nitrate (Top) and Ammonia (Bottom) Concentrations for 2007–2009 [CASTNet, 2011].

dependent on precipitation, nitrate and ammonia dry deposition data (originally in kg/ha) was applied in the model application using a pound-per-acre approach. Phosphorus data were not available from CASTNet or NADP and will not be represented.

Original dry deposition data were weekly and were in kg/ha. Because this is a mass per area and data were being transformed to daily time-series data, it had to be divided by the number of days in the sampling period. Similarly, the wet deposition was weekly but plus or minus multiple days. Because wet deposition was a concentration, it did not need to be divided by the number of days in the sampling period. Instead, the concentration was assigned to each day of the sampling period. Once transformed to daily time-series data, missing dry and wet deposition data were patched using interpolation between the previous and later dates when less than 7 days occurred between values (rare with this dataset) and using monthly mean values when greater than 7 days occurred between values (likely scenario).

Point Source Data Available

Major point sources were represented using the MPCA-provided daily discharge point source data for major wastewater treatment plant facilities in the Sauk, North Fork Crow, and South Fork Crow Watersheds. For each facility, the period of record and completeness were assessed. Both major and minor point sources are shown in Figure 4.

A challenge in the major point source data is the lack of effluent flow data available. Table 3 shows the number of influent and effluent flow available for each major site. A Mann-Whitney test, which compares the equality of two population medians, was performed on all paired influent and effluent data from the Sauk and Crow Watersheds (available at Cold Spring, Delano, Hutchinson, and Rogers). When completed on influent and effluent data of all sites combined, this test concluded that there is insufficient evidence to support a difference between the population medians. Because a better alternative does not readily exist for estimating effluent data, and because the Mann-Whitney test of influent and effluent data for all sites combined showed equal medians, effluent flow was assumed to be equal to influent flow when effluent flow data were not available.

Minor point sources include controlled ponds and mechanical sites. Controlled ponds generally discharge intermittently for variable lengths of time, while mechanical sites discharge more continuously. Discharge data for minor controlled pond sites were provided as a combination of monthly volumes and monthly average flow. Because controlled ponds release effluent intermittently, if a controlled pond was missing monthly discharge, it was assumed that the pond did not release effluent to surface water during that month. Minor discharge data for mechanical sites was also provided as a combination of monthly volumes and monthly average flow. However, because mechanical sites release effluent more continuously, if a mechanical site was missing monthly discharge data, it was assumed that the site was releasing effluent to surface water, and any missing months were filled using monthly averages.

Effluent water-quality parameters available at all point source sites which will be included in the model application include carbonaceous 5-day biological oxygen demand ($CBOD_5$), total suspended solids (TSS), phosphorus (P), dissolved oxygen (DO), ammonia (NH3), and

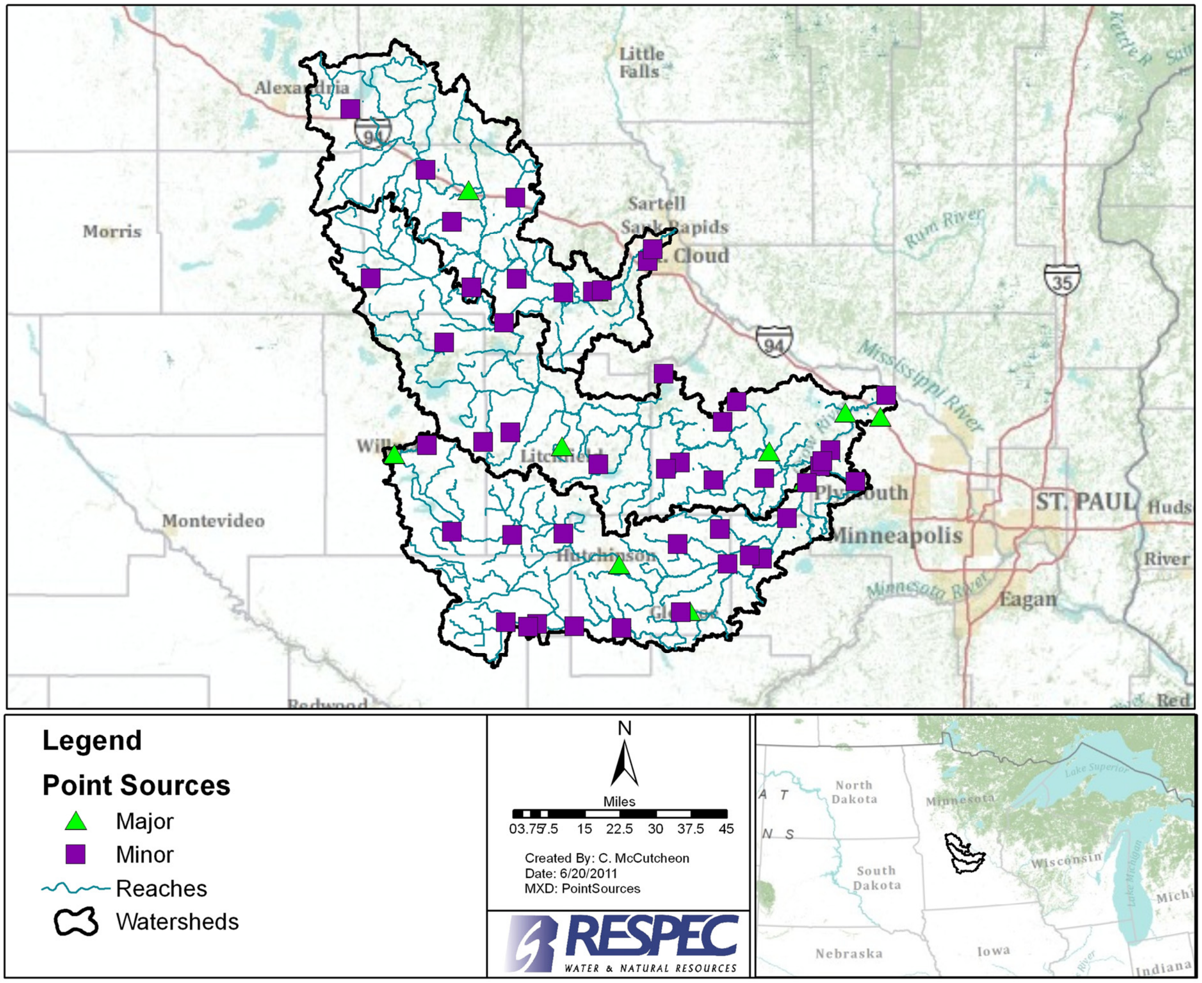


Figure 4. Major and Minor Point Sources in the Sauk, North Fork Crow, and South Fork Crow Watersheds.

Table 3. Number of Influent and Effluent Flow Samples at Major Point Source Sites

Number of Flow Samples									
Major Point Sources	**Sauk**		**North Fork Crow**				**South Fork Crow**		
	Cold Spring (1995–2009)	**Melrose** (1995–2009)	**Buffalo** (1995–2009)	**Litchfield** (1995–2009)	**Rogers** (1995–2009)	**St. Michael** (10/1998–2009)	**Hutchinson** (1995–2009)	**Delano** (1995–2009)	**Glencoe** (1995–2009)
Influent Flow (MGD)	4,018	5,477	5,478	3,259	5,478	2,100	5,479	5,479	3,708
Effluent Flow (MGD)	5,054			2,158	92	3,379	4,018	31	

temperature. Water-quality data at point sources were filled using interpolation between the previous and later dates when less than 7 days occurred between values and using monthly mean values when greater than 7 days occurred between values. Table 4 shows parameter availability for each site, with “x” representing the ability to fill daily load time series, “~” representing sites with minimal available samples (generally less than 5) for which a constant time series can be calculated using ratios and/or means, and blanks representing when no data are available. Major point sources are shown in bold font.

Nutrient data besides NH3 and total P are very limited, and methods similar to those in the Minnesota River Model will be used to estimate missing nutrient loadings. The External Sources Block currently contains estimates where data were unavailable which will be subject to change during the next work order. An example of the Minnesota River External Sources, which was used to derive current estimates, is shown in Appendix A.

Besides temperature, concentrations of all available constituents, including BOD as $CBOD_U$ (which was converted from $CBOD_5$ using Equation 1 [Chapra, 1997]) were converted from mg/L to loads in pounds per day (concentration × flow × conversion factor, conversion factor = 8.34). Temperature was converted from °F to a heat load in BTU per day (temperature × flow × conversion factor, conversion factor = 8,339,145).

$$L_0 = \frac{y_5}{1 - e^{-k_1(5)}} \tag{1}$$

where:

$L_0 = CBOD_u$

$y_5 = CBOD_5$

$k_1 = 0.10,$ minimum value after primary treatment.

Estimated daily time series were then imported into the binary watershed data management (wdm) files, and loads were applied to the corresponding stream in the External Sources Block.

REFERENCES

Chapra, S.C., 1997. *Surface Water Quality Modeling.* McGraw-Hill Companies, United States of America, pages 357-358.

CASTNet, 2011. Retrieved June 1, 2011, from the Worldwide Web at *http://java.epa.gov/castnet/maps.do?mapType=MAPCON*

Love, J. T., 2011. *Pervious (PERLND) and Impervious Land (IMPLND) Category Development*, Revision 1, RSI(RCO)-1953/4-11/5, external memorandum from J. T. Love, RESPEC, Rapid City, SD, to C. Reagan, Minnesota Pollution Control Agency, St. Paul, MN, April 7.

Table 4. Parameter Availability at Major and Minor Point Sources (Page 1 of 2)

Watershed	Site	Description	Period of Record	Period of Operation	Type	CBOD5 (mg/L)	DO (mg/L)	Ammonia (mg/L)	Inorganic Nitrogen (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Total Phosphorus (mg/L)	TSS (mg/L)	Water Tempurature (F)
Sauk	**MN0023094**	**Cold Spring**	**1995–2009**	**1995–2009**	**Major**	**x**	**x**	**x**			**x**	**x**	
Sauk	**MN0020290**	**Melrose**	**1995–2009**	**1995–2009**	**Major**	**x**	**x**	**x**			**x**	**x**	
Sauk	MN0045721	Bel Clare Estates Wastewater Treatment Plant (WWTP)	1996–2009	Unknown–2009	Minor	x	x				x	x	
Sauk	MN0055221	Cold Spring Brewing Company	2001–2009	Unknown–2009	Minor						~		x
Sauk	MNG580019/MN0030333	Freeport WWTP	1995–2009	1995–2009	Minor	x	x				x	x	
Sauk	MNG580205/MN0056863	GEM Sanitary District	1995–2009	1995–2009	Minor	x	x				x	x	
Sauk	MN0047261	Gold'n Plump Poultry–Cold Spring	1995–2009	1995–2009	Minor	x		x			x	x	
Sauk	MN0020885	Lake Henry Wastewater Treatment Plant	1995–2009	1995–2009	Minor	x	x				x	x	
Sauk	MN0004031	Martin Marietta Materials Inc	1995–2009	1995–2009	Minor		~					x	
Sauk	MN0020028	Osakis WWTP	1995–2009	1995–2009	Minor	x	x				x	x	
Sauk	MN0024597	Richmond WWTP	1995–2009	1995–2009	Minor	x	x				x	x	
Sauk	MN0024821	Sauk Centre WWTP	1995–2009	1995–2009	Minor	x	x	x	~	~	x	x	
Sauk	MN0024783	St Martin WWTP	1995–2009	1995–2009	Minor	x	x				x	x	
South Fork Crow	**MN0051250**	**Delano**	**1995–2009**	**1995–2009**	**Major**	**x**	**x**	**x**		**~**	**x**	**x**	**x**
South Fork Crow	**MN0022233**	**Glencoe**	**1995–2009**	**1995–2009**	**Major**	**x**	**x**	**x**			**x**	**x**	
South Fork Crow	**MN0055832**	**Hutchinson**	**1996–2009**	**1995–2009**	**Major**	**x**	**x**	**x**			**x**	**x**	**x**
South Fork Crow	MN0022951	Brownton WWTP	1995–2009	1995–2009	Minor	x	x	x			x	x	
South Fork Crow	MN0050211	Buffalo Lake WWTP	1995–2009	1995–2009	Minor	x	x				x	x	
South Fork Crow	MN0066605	Cedar Mills WWTP	2004–2009	Unknown–2009	Minor	x	x	~	~	~	x	x	
South Fork Crow	MNG580056/MN0038792	Cosmos WWTP	1995–2009	1995–2009	Minor	x	x				x	x	
South Fork Crow	MN0025445	Hector WWTP	1995–2009	1995–2009	Minor	x	x		~	~	x	x	
South Fork Crow	MN0023841	Kandiyohi WWTP	1995–2009	1995–2009	Minor	x	x		~	~	x	x	
South Fork Crow	MN0021954	Lake Lillian WWTP	1995–2009	1995–2009	Minor	x	x		~	~	x	x	
South Fork Crow	MN0023957	Lester Prairie WWTP	1995–2009	1995–2009	Minor	x	x	x			x	x	
South Fork Crow	MN0023990	Loretto WWTP	1996–2009	Unknown–2009	Minor	x	x				x	x	
South Fork Crow	MN0021202	Mayer WWTP	1995–2009	1995–2009	Minor	x	x	x			x	x	
South Fork Crow	MN0063151	Minnesota Energy	1996–2009	Unknown–2009	Minor	x						x	
South Fork Crow	MN0024295	New Germany WWTP	1995–2009	1995–2009	Minor	x	x				x	x	
South Fork Crow	MN0001236	Seneca Foods Corp - Glencoe	1996–2009	1995–2009	Minor	x						x	x

Table 4. Parameter Availability at Major and Minor Point Sources (Page 2 of 2)

Watershed	Site	Description	Period of Record*	Period of Operation*	Type	CBOD5 (mg/L)	DO (mg/L)	Ammonia (mg/L)	Inorganic Nitrogen (mg/L)	Total Kjeldahl Nitrogen (mg/L)	Total Phosphorus (mg/L)	TSS (mg/L)	Water Tempurature (F)
South Fork Crow	MNG580164/MN0024902	Silver Lake WWTP	1995–2009	1995–2009	Minor	x	x				x	x	
South Fork Crow	MNG580077/MN0053210	Stewart WWTP	1995–2009	1995–2009	Minor	x	x				x	x	
South Fork Crow	MN0020940	Watertown WWTP	1995–2009	1995–2009	Minor	x	x	x	~	~	x	x	
South Fork Crow	MN0021571	Winsted WWTP	1995–2009	1995–2009	Minor	x	x				x	x	
North Fork Crow	**MN0040649**	**Buffalo**	**1995–2009**	**1995–2009**	**Major**	**x**	**x**	**x**			**x**	**x**	
North Fork Crow	**MN0023973**	**Litchfield**	**1995–2009**	**1995–2009**	**Major**	**x**	**x**	**x**	**~**		**x**	**x**	
North Fork Crow	**MN0029629**	**Rogers**	**1995–2009**	**1995–2009**	**Major**	**x**	**x**	**x**			**x**	**x**	
North Fork Crow	**MN0020222**	**St. Michael**	**1998–2009**	**1995–2009**	**Major**	**x**	**x**	**x**	**~**		**x**	**x**	**x**
North Fork Crow	MN0066966	Annandale/Maple Lake WWTP	Unknown–2009	Unknown–2009	Minor	x	x	x	~	~			
North Fork Crow	MN0022659	Atwater WWTP	1995–2009	1995–2009	Minor								
North Fork Crow	MN0025909	Brooten WWTP	1995–2009	1995–2009	Minor	x	x	~	~	~	x	x	
North Fork Crow	MN0049204	Cokato WWTP	1995–2009	1995–2009	Minor	x	x	x	~	~	x	x	
North Fork Crow	MNG580150/MN0023159	Darwin WWTP	1995–2009	1995–2009	Minor	x	x				x	x	
North Fork Crow	MN0030635	Faribault Foods - Cokato	1995–2009	1995–2009	Minor	x					x	x	x
North Fork Crow	MN0052752	Green Lake SSWD WWTP	1998–2009	1998–2009	Minor	x	x	x			x	x	
North Fork Crow	MN0063762	Greenfield WWTP	2002–2009	Unknown–2009	Minor	x	x				x	x	
North Fork Crow	MN0023574	Grove City WWTP	1995–2009	1995–2009	Minor	x	x				x	x	
North Fork Crow	MN0051926	Howard Lake WWTP	1995–2009	1995–2009	Minor	x	x				x	x	
North Fork Crow	MN0024082	Maple Lake WWTP	1995–2009	1995–2009	Minor	x	x				x	x	
North Fork Crow	MN0066753	Meadows of Whisper Creek WWTP	2007–2009	Unknown–2009	Minor	x	x	x			x	x	
North Fork Crow	MN0024228	Montrose WWTP	1995–2009	1995–2009	Minor	x	x				x	x	
North Fork Crow	MN0064190	Otsego East WWTP	2000–2009	Unknown–2009	Minor	x	x	x			x	x	
North Fork Crow	MN0020168	Paynesville WWTP	1995–2009	1995–2009	Minor	x	x				x	x	
North Fork Crow	MN0024627	Rockford WWTP	1995–2009	1995–2009	Minor	X	x	x			x	x	

Note: Period of record and period of operation show only years within the Crow/Sauk modeling period (1995–2009). Most sites were in operation before and after the modeling period unless specified.

x = Daily load time series can be calculated using interpolation and monthly averages.

~ = Average concentration can be used to calculate a constant load time series

We would be happy to discuss these methods with you and hear any feedback you may have regarding the water-quality calibration and validation of the Sauk, North Crow, and South Crow **HSPF** Watershed Models applications.

Sincerely,

JASON LOVE

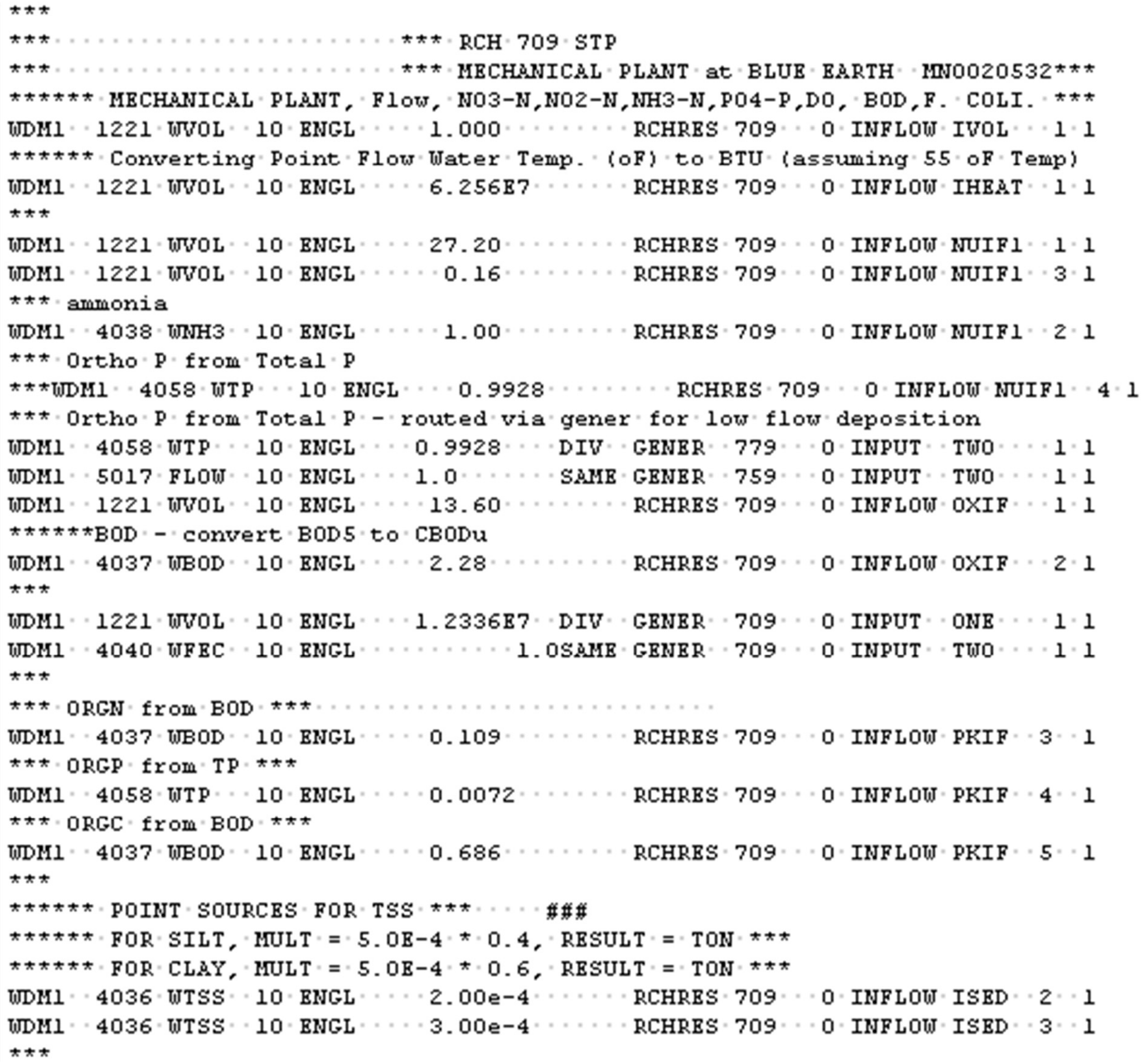
Jason T. Love
Vice President, Water & Natural Resources

JTL:llf

cc: Project Central File 1953 — Category A

APPENDIX A. MINNESOTA RIVER EXTERNAL SOURCE BLOCK

The following is a section of the external source block used in the Minnesota River Watershed model application. It represents the heat, nitrate, nitrite, ammonia, phosphate, dissolved oxygen, biochemical oxygen demand, and fecal coliform.



```
***
***                        *** RCH 709 STP
***                        *** MECHANICAL PLANT at BLUE EARTH  MN0020532***
****** MECHANICAL PLANT, Flow, NO3-N,NO2-N,NH3-N,PO4-P,DO, BOD,F. COLI. ***
WDM1  1221 WVOL  10 ENGL     1.000         RCHRES 709   0 INFLOW IVOL   1 1
****** Converting Point Flow Water Temp. (oF) to BTU (assuming 55 oF Temp)
WDM1  1221 WVOL  10 ENGL     6.256E7       RCHRES 709   0 INFLOW IHEAT  1 1
***
WDM1  1221 WVOL  10 ENGL     27.20         RCHRES 709   0 INFLOW NUIF1  1 1
WDM1  1221 WVOL  10 ENGL      0.16         RCHRES 709   0 INFLOW NUIF1  3 1
*** ammonia
WDM1  4038 WNH3  10 ENGL      1.00         RCHRES 709   0 INFLOW NUIF1  2 1
*** Ortho P from Total P
***WDM1  4058 WTP   10 ENGL    0.9928         RCHRES 709   0 INFLOW NUIF1  4 1
*** Ortho P from Total P - routed via gener for low flow deposition
WDM1  4058 WTP   10 ENGL    0.9928    DIV  GENER  779   0 INPUT  TWO    1 1
WDM1  5017 FLOW  10 ENGL    1.0       SAME GENER  759   0 INPUT  TWO    1 1
WDM1  1221 WVOL  10 ENGL     13.60         RCHRES 709   0 INFLOW OXIF   1 1
******BOD - convert BOD5 to CBODu
WDM1  4037 WBOD  10 ENGL     2.28          RCHRES 709   0 INFLOW OXIF   2 1
***
WDM1  1221 WVOL  10 ENGL    1.2336E7  DIV  GENER  709   0 INPUT  ONE    1 1
WDM1  4040 WFEC  10 ENGL           1.0SAME GENER  709   0 INPUT  TWO    1 1
***
*** ORGN from BOD ***
WDM1  4037 WBOD  10 ENGL     0.109         RCHRES 709   0 INFLOW PKIF  3  1
*** ORGP from TP ***
WDM1  4058 WTP   10 ENGL     0.0072        RCHRES 709   0 INFLOW PKIF  4  1
*** ORGC from BOD ***
WDM1  4037 WBOD  10 ENGL     0.686         RCHRES 709   0 INFLOW PKIF  5  1
***
****** POINT SOURCES FOR TSS ***     ###
****** FOR SILT, MULT = 5.0E-4 * 0.4, RESULT = TON ***
****** FOR CLAY, MULT = 5.0E-4 * 0.6, RESULT = TON ***
WDM1  4036 WTSS  10 ENGL     2.00e-4       RCHRES 709   0 INFLOW ISED  2  1
WDM1  4036 WTSS  10 ENGL     3.00e-4       RCHRES 709   0 INFLOW ISED  3  1
***
```

Appendix B

HSPF MODELING OF THE SAUK RIVER, CROW RIVER, AND SOUTH FORK CROW RIVER

Topical Report RSI-2292

prepared for

Minnesota Pollution Control Agency
520 Lafayette Road
St. Paul, Minnesota 55155

July 2012

RESPEC
CONSULTING & SERVICES

HSPF MODELING OF THE SAUK RIVER, CROW RIVER, AND SOUTH FORK CROW RIVER

Topical Report RSI-2292

by

Daniel L. Reisinger
Jason T. Love

RESPEC
P.O. Box 725
Rapid City, South Dakota 57709

prepared for

Minnesota Pollution Control Agency
520 Lafayette Road
St. Paul, Minnesota 55155

July 2012

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1.0 INTRODUCTION

1.1 PURPOSE AND OBJECTIVES

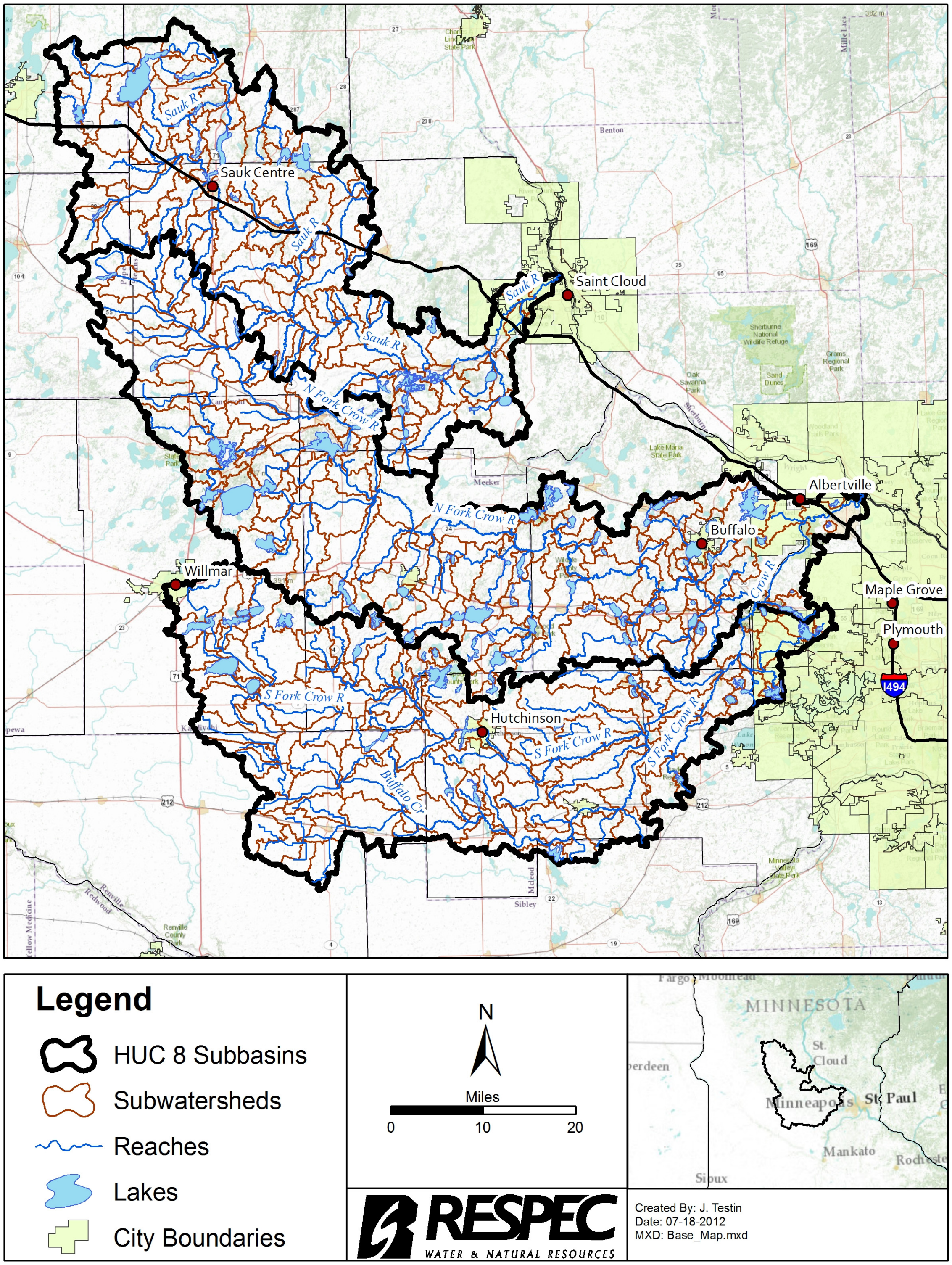
The U.S. Environmental Protection Agency (EPA) requires the Minnesota Pollution Control Agency (MPCA) to execute the Total Maximum Daily Load (TMDL) Program in the state of Minnesota. Minnesota has an abundance of lakes and river reaches, many of which will require a TMDL assessment. In an effort to expedite the completion of TMDL projects, the MPCA decided to construct watershed models. These models have the potential to support the simultaneous development of TMDL assessments for multiple listings within a cataloging unit or 8-digit Hydrologic Unit Code (HUC) watershed. This report documents the modeling of three 8-digit HUC watersheds: Crow River/North Fork Crow River (07010204), South Fork Crow River (07010205), and the Sauk River (07010202).

The objective of this project is the successful calibration and validation of **HSPF** model applications for the three watersheds. These fully functioning, calibrated, and validated executable models simulate the following at a management unit level:

- hydrology
- sediment
- temperature
- phosphorus
- nitrogen
- dissolved oxygen
- oxygen demand
- chlorophyll.

1.2 WATERSHED DESCRIPTION

The three 8-digit HUC watersheds are located in the west-central portion of Minnesota, as shown in Figure 1-1. The South Fork Crow River (South Crow) flows into the Crow River near Rockford, Minnesota. The watershed upstream of the confluence is referred to as the North Fork Crow River (North Crow), while areas downstream are referred to as the Crow River (Crow). Note the term “Crow Watershed” is used in this report to represent the entire watershed, including the North Crow and South Crow Watersheds. All three rivers flow from the west to the east. The outlet of the Sauk River (Sauk) is located on the western side of the St. Cloud metropolitan area.



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Date: 07-18-2012
MXD: Base_Map.mxd

Figure 1-1. Crow and Sauk River Watersheds.

The watersheds are largely agricultural, mostly corn/soybean and dairy operations. There are 122 communities interspersed throughout the watersheds. Larger communities include Buffalo, Corcoran, Dayton, Glencoe, Hutchinson, Independence City, Le Sauk, Litchfield, Loretto, Maple Plain, Medina, Minnetrista, Monticello, Otsego, Sartell, St. Cloud, St. Joseph, St. Michael, Waite Park, and Willmar, Minnesota. The watersheds include all or part of the following counties: Carver, Douglas, Hennepin, Kandiyohi, McLeod, Pope, Renville, Sibley, Stearns, Todd, and Wright.

The watersheds are found in two ecological providences. The western and southern portions of the watersheds are in the Northern Glaciated Plains, while the eastern portions are in the Northern Hardwood forests. The Northern Hardwood forests areas are characterized by deep lakes that can trap substantial sediment and nutrients. While this trapping may reduce the nutrient concentrations further downstream, it can impair water quality in the lakes. The Northern Glaciated Plains tend to have shallower lakes that can also have water-quality issues.

Soils have a strong influence on hydrology and land management. Soils in the Sauk Watershed generally have a higher sand content than those in the Crow Watershed. Irrigation is used in some portions of the Sauk Watershed but is rare in the Crow Watershed. The soils in the Crow Watershed are generally less permeable (more silt and clay). Tile drainage is used in all three watersheds. However, the Crow Watershed has a higher density of tile drainage, with the highest in the South Crow Watershed.

Impairments in the Sauk Watershed include dissolved oxygen (DO), turbidity, *E. coli*, fecal coliform, polychlorinated biphenyls (PCB) in fish, and fish and invertebrate bioassessments. Similarly, impairments in the Crow Watersheds (North and South) include chloride, DO, ammonia, turbidity, *E. coli*, fecal coliform, and fish and invertebrate bioassessments. The Sauk and Crow Watersheds also have nutrient impairments in multiple lakes and the North Fork Crow Watershed has one plant-bioassessment lake impairment. Figure 1-2 shows the TMDL waterbodies in the watersheds.

HSPF uses this information, measured data, and established hydrologic and water-quality relationships to represent the watersheds. This report documents the formulation, calibration, validation, and execution of the model applications. The models are documented in this report as well as in previous separate memorandums.

1.3 WORK ORDER TASKS

The contents of this report were developed over the Fiscal Years 2011 and 2012. Four work orders were issued to build the model, calibrate/validate, and run scenarios. The objectives of these work orders are presented below.

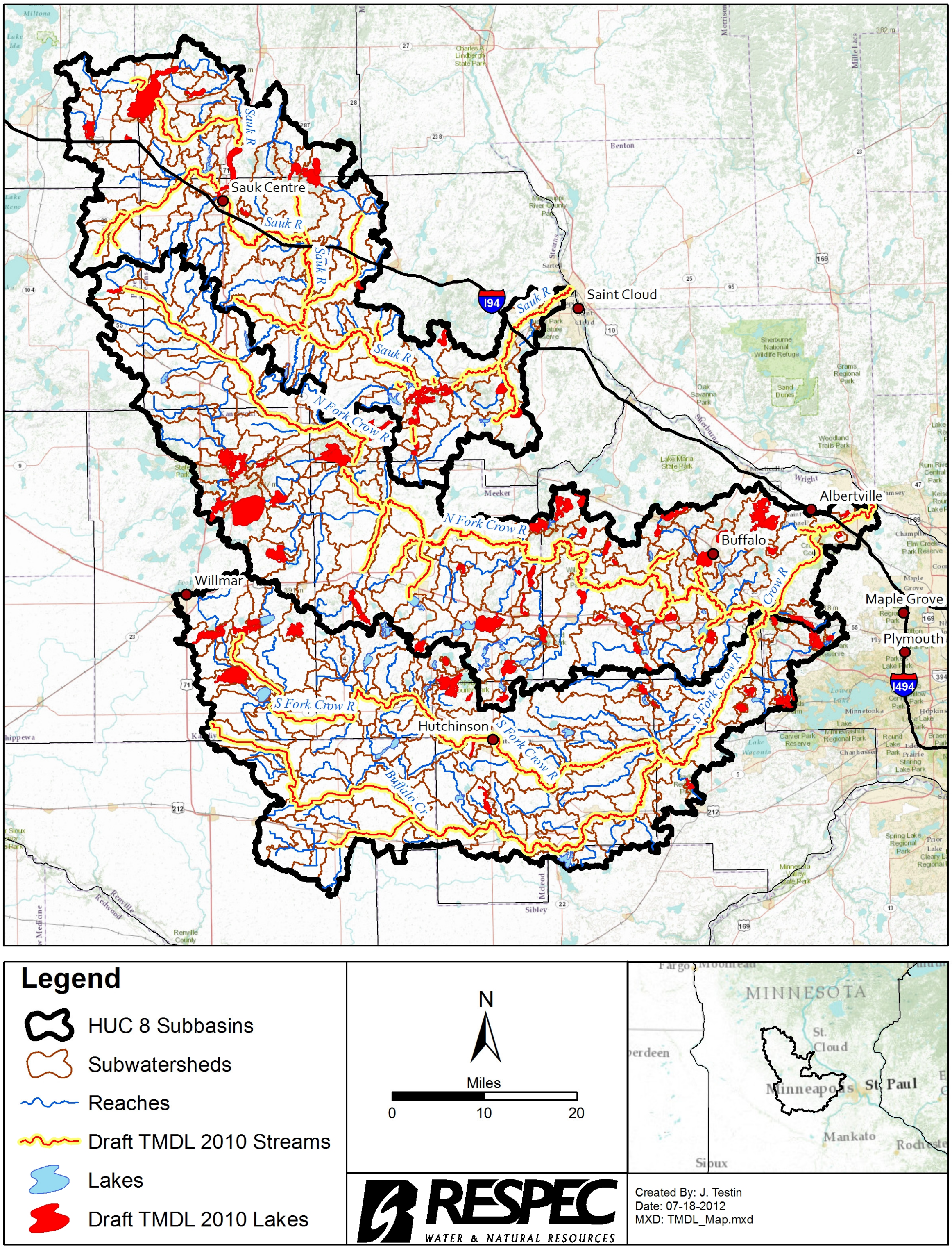

Figure 1-2. Impaired Streams and Lakes in the Crow and Sauk River Watersheds.

1. Compile both the geographic and time-series data required to construct the model framework.
2. Develop representation of watershed area and drainage network.
   - *Lake Selection for Sauk, North Crow, and South Crow Watersheds* [Love, 2011a]
   - *Primary Reach Selection, Reach/Subwatershed Numbering Scheme Development, and F-Table Development for Sauk, North Crow, and South Crow Watersheds* [Love, 2011b]
   - *Pervious (PERLND) and Impervious Land (IMPLND) Category Development* [Love, 2011c]
3. Develop and implement a strategy for the representation of point sources within the **HSPF** model domain.
   - *Time-Series Development for Sauk, North Fork Crow, and South Fork Crow Watersheds* [Love, 2011d]
4. Formulate time series from observed flow and water-quality monitoring to be used for watershed model calibration and validation.
5. Perform the hydrologic calibration, conduct hydrologic validation, and provide water balance.
   - *Hydrology Calibration and Validation of Sauk, North Crow, and South Crow HSPF Watershed Models* [Love, 2011e]
6. Define the sources of sediment within the watershed and conduct sediment calibration and validation tests.
   - *Proposed Approach for Modeling Water Quality in the Sauk, North Crow, and South Crow* ***Hydrological Simulation Program – FORTRAN (HSPF)*** *Watershed Models* [Love, 2011f]
7. Conduct water-quality calibration, validation, and model evaluation.
8. Incorporate internally generated phosphorus loadings for explicitly modeled lakes.
9. Develop and execute implementation scenarios.
10. Create **GenScn** projects containing output from the Sauk and Crow Rivers (including both North and South Forks).

The memorandums, result figures, **GenScn** projects, **HSPF** model files, and Geographic Information System (GIS) data were provided separately in the 2012 deliverable package [Love, 2012]. Result figures have been included for all primary calibration stations for hydrology and all water-quality parameters. The **GenScn** projects have been formulated for the Sauk and Crow (i.e., Crow River, North Fork Crow River, and South Fork Crow River) and incorporate both the base models and the implementation scenarios.

2.0 MODEL SETUP AND APPROACH

The **HSPF** model applications from the South Crow, North Crow, and Sauk Rivers represent connected watershed and in-stream processes. The general workflow for modeling is presented in Figure 2-1. Model setup focuses on incorporating major sources of flow and water-quality loads into the model applications. The calibration/validation process focuses on adjusting parameters that cannot be reasonably estimated by characteristics of the watershed to obtain acceptable results. The results are presented and discussed in Chapter 3.0 and Chapter 5.0. The following section provides an overview of the model and its calibration.

2.1 SUMMARY OF HSPF

"**HSPF** simulates for extended periods of time the hydrologic and associated water quality, processes on pervious and impervious land surfaces and in streams and well-mixed impoundments [U.S. Geological Survey, 2012]." **HSPF** is a continuous simulation that typically produces output on a daily basis using an hourly time step. The model incorporates nonpoint or watershed flow and water-quality loads. Pervious areas are simulated using the PERLND module and impervious areas are simulated using the IMPLND module. In-stream hydraulics and stream/lake water-quality processes are simulated with the RCHRES module, using inputs from the other modules. Meteorological, point source, and other data are incorporated through time series stored in a binary Watershed Data Management (WDM) file.

2.2 MODEL SETUP

The model applications represent agricultural, urban, and rural sources of pollutants. This section summarizes the source assessment and generation phase of the modeling processes.

2.2.1 Meteorological Data

Forty-three separate meteorological zones (referred to as hydrozones) were used in the Crow and Sauk model applications. The hydrozones were based on available precipitation stations, as shown in Figure 2-2. The extensive meteorological zones were developed using stations from the U.S. Environmental Protection Agency's (EPA) **BASINS** database and supplemental data from the **High Spatial Density, Daily Operations (HIDEN)** database. The meteorological parameters used to represent precipitation, potential evaporation and snow processes include:

- precipitation
- air temperature
- solar radiation

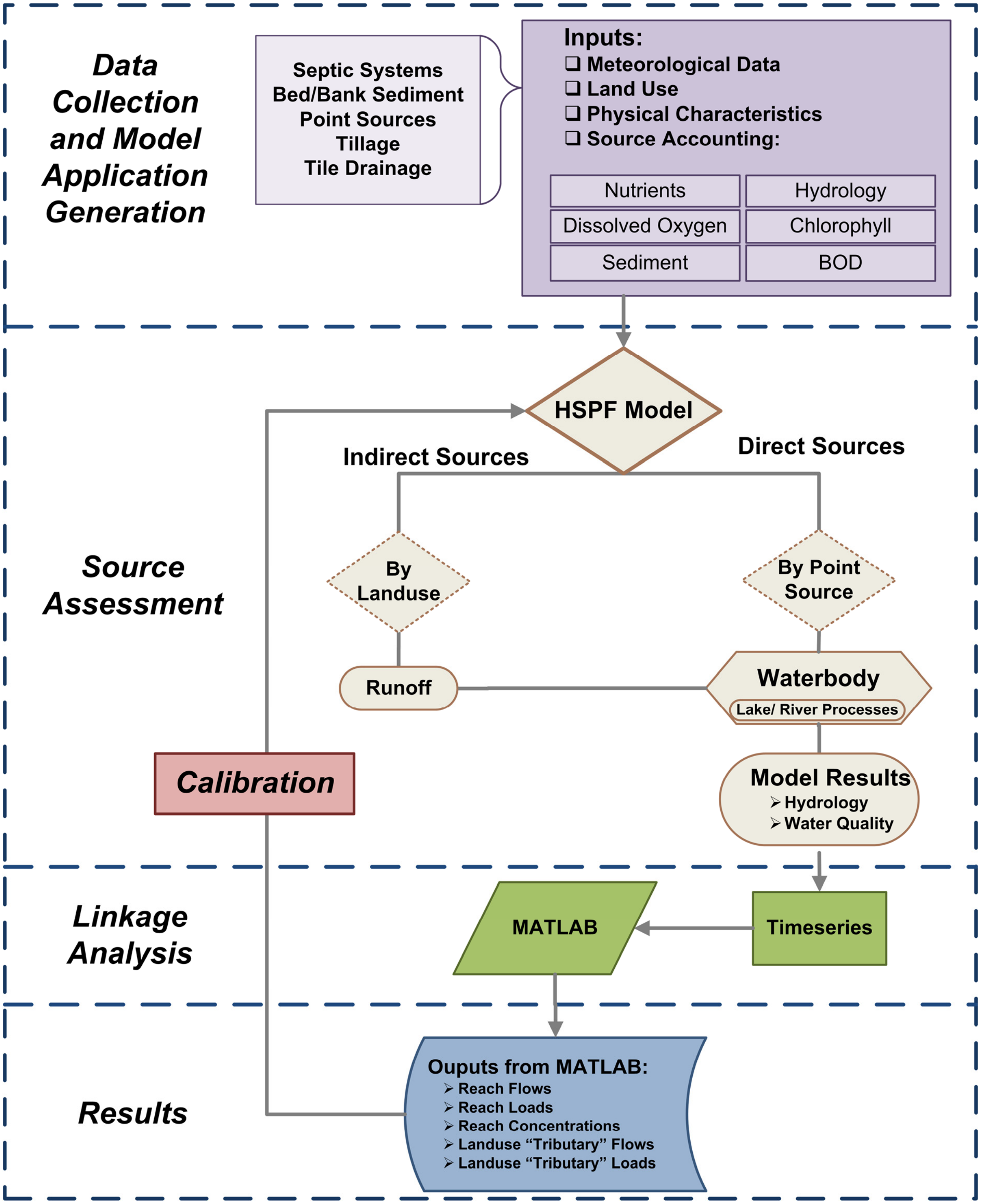

Figure 2-1. HSPF Model Application General Work Flow Diagram.

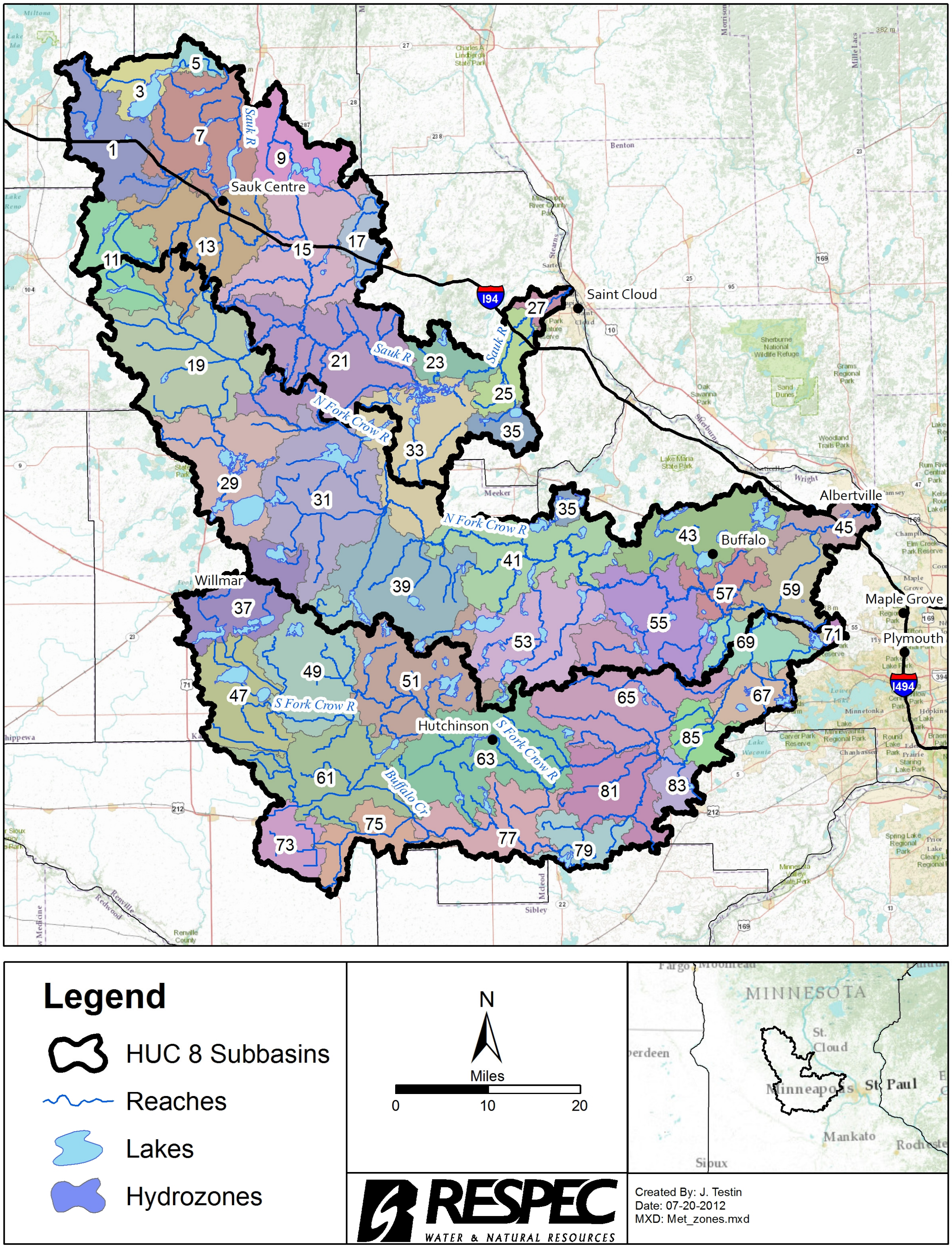

Figure 2-2. Hydrozones Included in HSPF Model Applications.

- wind speed
- dewpoint
- cloud cover.

For each meteorological parameter, a continuous time series was developed for the period of January 1, 1995, through December 31, 2009. Stations with incomplete data for the modeling period were extended or filled with available data from the closest station.

2.2.2 Land Use

The **HSPF** model applications from the South Crow, North Crow, and Sauk Rivers simulate watershed processes for six broad land uses. To better model the existing conditions and to aid in evaluating alternative management strategies, these land uses were further categorized into 13 land uses, as presented in Figure 2-3. Additionally, the model applications were formulated to track the watershed flow and load from municipal separate storm sewer systems (MS4s). The 13 land uses were represented in each of the 43 meteorological zones resulting in a total of 559 unique land uses.

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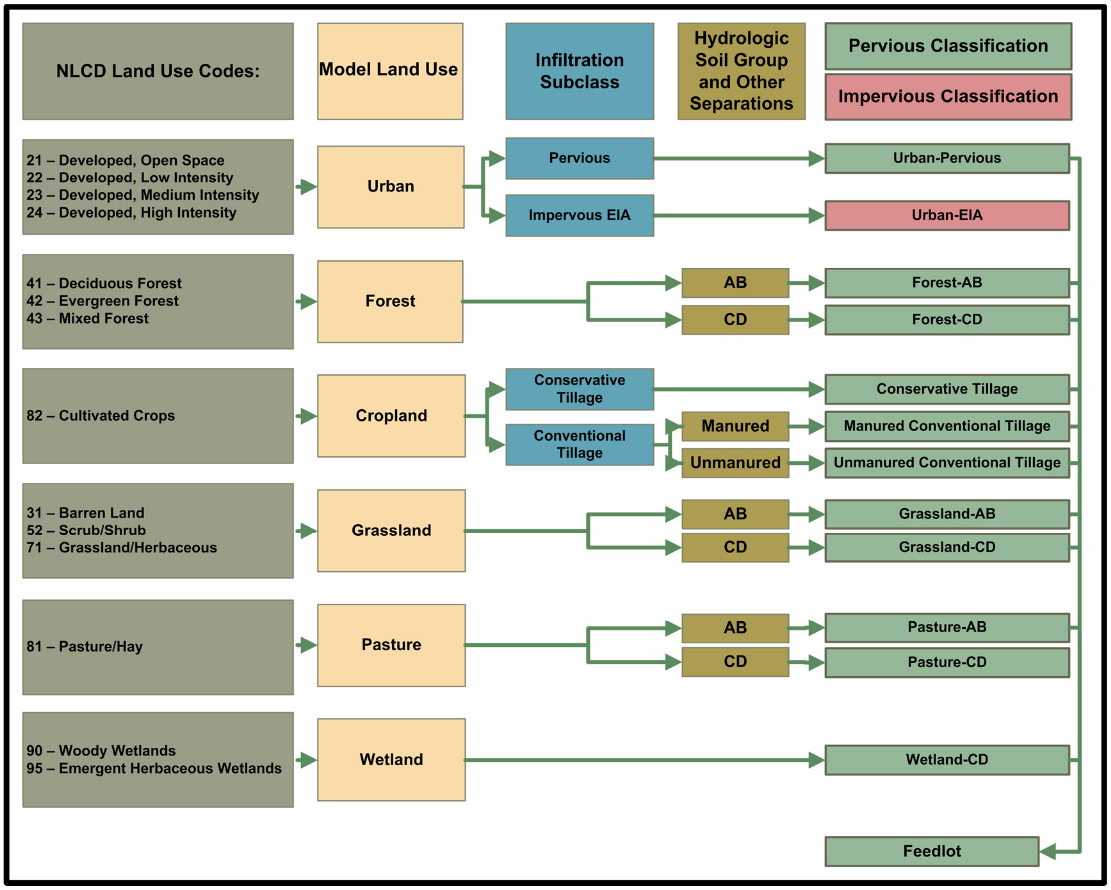

Figure 2-3. Classification for the Crow and Sauk Watershed Model Applications.

As the major land use in the watersheds, agricultural activities were categorized into six separate pasture and cropland pervious land uses (e.g., conservation tillage, manured conventional tillage, unmanured conventional tillage, pasture AB, pasture CD, and feedlot). In previous submittals, the cropland land use was categorized by artificial drainage and hydrologic soil group, rather than tillage. The current tillage classification was considered preferable when developing Best Management Practices (BMPs) and management scenarios.

A key assumption for the proposed classification is that farmers are working to maintain ideal soil moisture conditions on cropland through irrigation (when available) and through tile drainage, tillage, and manure application. Thus the hydrologic soil group may not provide a good representation of field conditions. Hydrologic soil groups (AB and CD soils) will still be represented on forest, grassland, and pastureland as soil moisture conditions are not likely to be as highly regulated on the majority of these lands. While drainage was removed as a land use, sediment loading through surface inlets was explicitly incorporated into each reach. Further, the effect of artificial drainage was implicitly represented in the hydrology parameterization.

2.2.2.1 Estimating Conservation and Conventional Tillage Areas

Minnesota Tillage Transect Survey Data Center data were available by county (*http://mrbdc.mnsu.edu/minnesota-tillage-transect-survey-data-center*). These tillage surveys included total acres farmed, total conservation tillage acres, and total conventional tillage acres in 1995 through 1998, 2000, 2002, 2004, and 2007. Conservation tillage was categorized by greater than 30 percent of residue remaining on the field and includes no-till, ridge-till, and mulch-till practices. Conventional tillage was categorized by 30 percent or less residue remaining on the field and included reduced-till and intensive-till practices. Residue on the fields can increase the upper zone storage capacity, which in turn, can decrease runoff, impacting sediment and water-quality processes.

ArcGIS was used with these data to estimate weighted-area fractions of conservation tillage versus conventional tillage for each subwatershed. The validation model applications (based upon National Land Cover Data [NLCD] 2001 version 2 land use), 1995 through 2003, used an average of the 1995 through 1998, 2000, and 2002 transect surveys. The calibration model applications (based upon NLCD 2006 land use was used to represent 2004 through 2009), 2004 through 2009, an average of the 2004 and 2007 transect surveys. In both cases, conventional tillage was used in at least 60 percent of surveyed fields, except Reach 535 of the South Crow (49 percent).

2.2.2.2 Estimating Feedlots and Manure Application Areas

An estimated 1,664, 1,133, and 824 animal feedlot operations are located in the Sauk, North Crow, and South Crow River Watersheds, respectively. Feedlot operations are required to adhere to health, safety, and environmental laws. Feedlots with 1,000 or greater animal units are required to have no surface discharge. Manure generated at these operations is used throughout the watersheds as a fertilizer and to increase water retention in the soil. Manure, as well as inorganic fertilizers, may contribute to impaired water quality in waterbodies.

There was substantial uncertainty in spatial distribution of manure application. Therefore, a single conventional tillage land use was used to represent both chemical and organic fertilizer applications. This land use was calibrated throughout the watersheds to implicitly represent differences in fertilizer use, including manure. The manured conventional tillage land use was reserved to aid in developing future scenarios (no area has been allocated to the land use in the base models), if necessary. The representation of the feedlot land use class, which was retained, was further discussed in Love [2011c].

2.2.3 Physical Characteristics

An extensive network of reaches represents the river, streams, and lakes of the watersheds. Consistent with local planning activities, the model reach watersheds were based on the Crow and Sauk Management Units. These management units are typically of similar or smaller size than the U.S. Geological Survey (USGS) HUC 12 watersheds. Cross-sectional and hydrologic information was used to generate representation of the reach geometry. Explicitly simulated lakes were selected based the availability of bathymetry data, potential impacts on downstream reaches, and need for future evaluation (i.e., TMDL evaluations, and point-source permits). Additional details on the formulation of reaches and the use of physical characteristics in representing the watershed loading can be found in Love [2011a; 2011b].

2.2.4 Source Accounting

Flow and water-quality loads from key sources were determined based on discussions with MPCA, watershed district staff, and RESPEC experience from model development and calibration. **HSPF** represents the majority of these sources as part of the land use (e.g., tillage and tile drainage) or in-stream water-quality processes (e.g., bed/bank erosion and internal lake phosphorus loading). To better represent field conditions after tillage, additional detached sediment was added to cropland fields in April, May, June, and October. Internal phosphorus loading to lakes was also modeled, which is described in more detail in Chapter 4.0. Point sources and septic tanks, or individual treatment systems (ISTS), were also incorporated using well-established methods.

Effluent water-quality parameters used in the model application include carbonaceous 5-day biological oxygen demand (CBOD5), total suspended solids (TSS), total phosphorus (TP), DO, total ammonia (NH3+NH4), and water temperature. Time series of flow and water-quality load were used when data were available. Periods of missing data were filled generally by interpolation or as a constant concentration when no data were available, as described in Love [2011d].

The approach to estimating the discharge to stabilization ponds was updated from what is described in Love [2011d]. Controlled ponds generally discharge intermittently for variable lengths of time, while mechanical sites discharge more continuously. Discharge data for minor controlled pond sites were provided as a combination of monthly volumes and monthly average flow. Because controlled ponds release effluent intermittently, if a controlled pond was missing monthly discharge, it was assumed that the pond did not release effluent to surface water during that month. Minor discharge data for mechanical sites were also provided as a combination of monthly volumes and monthly average flow. However, because mechanical sites release effluent more continuously, if a mechanical site was missing monthly discharge data, it was assumed that the site was releasing effluent to surface water, and any missing months were filled using monthly averages. An estimate of number of discharge days was supplied by MPCA and was incorporated using the following logic supplied by Henningsgaard [2012]:

1. If there are only a few discharge days followed by a month with only a few discharge days, or if the first month has only a couple of days and the next month has up to 10 discharge days, the days should be placed at the end and beginning of the 2 months.
2. If there are over 6 discharge days in a month, but less than about 18 days, the days can be placed anywhere consecutively.
3. If there are over 18 discharge days, half of the days should be placed in the first half of the month and half of the days in the second half of the month.

The loading from ISTS were included in the models based on Minnesota Pollution Control Agency [2004]. The numbers of residence with ISTS were allocated evenly across the county and watershed. Loads per septic system were incorporated into the model with the same parameters as point sources. ISTS loading was on a per-person basis. Systems were given 50 gallons per day (gpd) flow and constant concentration of 53 milligrams per liter (mg/L) nitrogen, 10 mg/L phosphate, and 175 mg/L CBODs.

2.3 CALIBRATION AND VALIDATION

Calibration was a critical process in the development of parameters for the **HSPF** hydrologic model applications. Calibration was required for parameters that cannot be reasonably estimated by characteristics of the watershed. The calibration of the **HSPF** model applications was a cyclical process of making parameter changes, running the model, producing graphical and statistical comparisons of simulated and observed values, and interpreting the results. Observed data for hydrologic calibration involved continuous stream flow collected at gaging stations from reputable sources. Calibration was typically evaluated with visual and statistical performance criteria. A validation of model performance was conducted separately from the calibration effort.

The period of record used for the calibration and validation of the model application was based on the available meteorological data (1995–2009). The calibration period was defined as

January 1, 2003, through December 31, 2009. The validation period was defined as January 1, 1996, through December 31, 2003. The year 1995 was excluded from statistical analyses because of the sensitivity of some model outputs to the initial modeling conditions. The validation period in the Crow Watershed was limited by the available records for the actively managed New London dam. The validation in the Crow Watershed was restricted to January 1, 2000, through December 31, 2003. To maximize the use of available water-quality data, the entire period of record was used in the calibration/validation of the water quality in the Crow and Sauk model applications.

3.0 HYDROLOGY

Hydrology provides the basis of the model application and includes streamflow and lake levels. Water-quality simulations are highly dependent on the hydrology process. Therefore, water-quality calibration could not begin until the hydrology calibration was considered acceptable. This section provides a summary of the final hydrology results. Additional details can be found in the technical memorandum referenced in Love [2011e].

3.1 MODEL PERFORMANCE CRITERIA FOR HYDROLOGY

Model performance was evaluated using a weight-of-evidence approach described in Donigian [2002]. This type of approach used both visual and statistical methods to best define the performance of the model. The process was performed at each flow gage by adjusting parameters for land segments upstream. Moreover, greater weight was applied to the performance of the model at gages where there is more contributing area and a longer period of record. It was also desired to maintain comparable parameter values and intra-parameter variations for each land segment category throughout the watershed.

The graphical plots were visually evaluated to objectively assess the model performance while the statistics were compared to objective criteria developed from 20 years of experience with **HSPF** applications. Graphical plots of streamflow included annual, monthly, and daily time series, as well as flow duration plots. Because of the high number of lakes occurring in these watersheds, lake level was considered. Lake levels were graphically evaluated based on daily time-series and scatter plots of paired measured and simulated data.

Statistical objectives in Table 3-1 were used to evaluate the percent error statistics. The correlation coefficient (r) and coefficient of determination (r^2) were also compared with the criteria in Figure 3-1 to evaluate the performance of the daily and monthly flows.

Table 3-1. General Calibration/Validation Targets or Tolerances for HSPF Applications

	Difference Between Simulated and Recorded Values (%)		
	Fair	**Good**	**Very Good**
Hydrology/Flow	15–25	10–15	<10

Caveats: Relevant to monthly and annual values; storm peaks may differ more.
Quality and detail of input and calibration data.
Purpose of model application.
Availability of alternative assessment procedures.
Resource availability (i.e., time, money, personnel).

Source: Donigian [2000].

R	← 0.75 — 0.80 — 0.85 — 0.90 — 0.95 →
R^2	← 0.6 — 0.7 — 0.8 — 0.9 →
Daily Flows	Poor Fair Good Very Good
Monthly Flows	Poor | Fair | Good | Very Good

Figure 3-1. General Calibration/Validation *R* and R^2 Targets for HSPF Applications.

3.2 HYDROLOGY RESULTS

The final calibration was performed using the primary downstream gages for the Sauk and Crow Watershed model applications. Secondary gages upstream and on tributaries were used to help calibrate parameters for less influential land segment categories but are not reported here. A map of the primary discharge gages from initial calibration results is shown in Figure 3-2. Tables 3-2 and 3-3 display the calibration statistics for the Sauk and Crow model applications, respectively, and Tables 3-4 and 3-5 display the validation statistics for the Sauk and Crow model applications, respectively. The “weighted overall” statistic represents a drainage area weighted average. Table 3-6 summarizes the weighted water balance components at the outlets of the Sauk and Crow Watershed model applications. Additional results for the primary gages can be found in Love [2012].

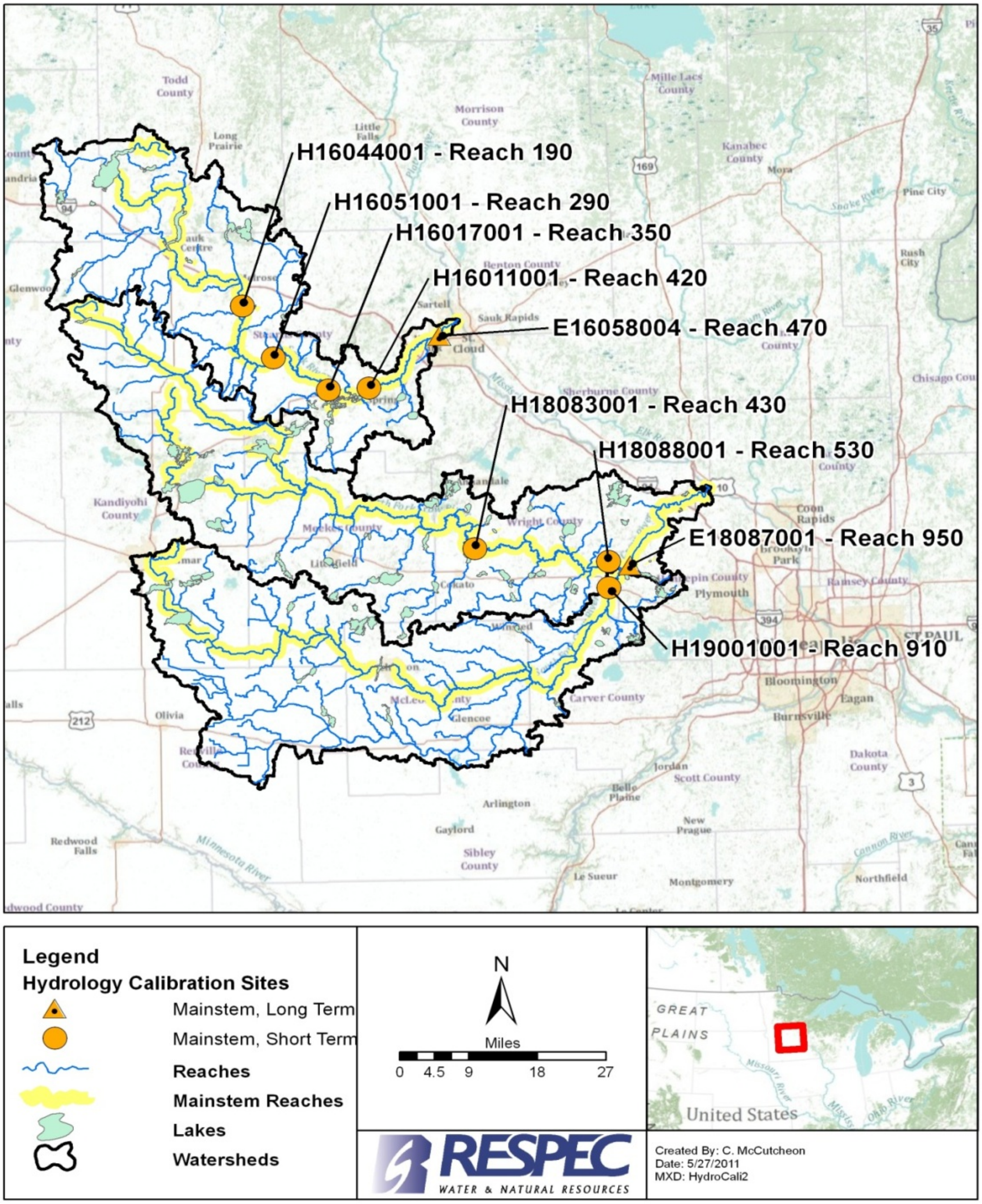

Figure 3-2. Map of Primary Gages for Calibration.

Table 3-2. Summary Statistics for Primary Calibration Gages in the Sauk Watershed

Observed Flow Gage	HSPF Reach I.D.	Total Runoff Volume			Monthly			Daily			Storm % Error	
		Obs (in)	Sim (in)	% Δ	*R*	R^2	MFE	*R*	R^2	MFE	Volume	Peak
H16044001	190	3.91	4.07	4	0.95	0.91	0.88	0.92	0.85	0.76	9	8
H16051001	290	3.31	3.37	1.9	0.95	0.91	0.90	0.88	0.78	0.70	4.1	-5.2
H16017001	350	4.16	4.02	–3.5	0.97	0.94	0.91	0.93	0.87	0.86	–5.8	–7.2
H16011001	420	4.22	4.16	–1.7	0.98	0.96	0.96	0.94	0.89	0.88	0.5	14.6
E16058004	470	4.97	4.87	–2	0.96	0.91	0.90	0.91	0.83	0.78	2.1	15.3
Weighted Overall		**4.2**	**4.1**	**–1.9**	**0.96**	**0.92**	**0.9**	**0.89**	**0.8**	**0.73**	**3.15**	**14.7**

Table 3-3. Summary Statistics for Primary Calibration Gages in the Crow Watershed

Observed Flow Gage	HSPF Reach I.D.	Total Runoff Volume			Monthly			Daily			Storm % Error	
		Obs (in)	Sim (in)	% Δ	*R*	R^2	MFE	*R*	R^2	MFE	Volume	Peak
H18083001	430	3.35	4.5	33.7	0.86	0.73	0.70	0.77	0.59	0.47	–6.6	1.9
H18088001	530	3.60	3.45	–4.20	0.91	0.84	0.83	0.91	0.84	0.83	–7.9	–7.5
H19001001	910	4.23	4.36	3.0	0.89	0.80	0.79	0.86	0.73	0.71	–1.4	0.1
E18087001	950	5.00	4.99	–0.3	0.93	0.86	0.86	0.91	0.83	0.82	–3.2	–6.4
Weighted Overall		**4.28**	**4.46**	**5.01**	**0.91**	**0.82**	**0.81**	**0.88**	**0.77**	**0.74**	**–4.35**	**–3.95**

Table 3-4. Summary Statistics for Primary Validation Gages in the Sauk Watershed

Observed Flow Gage	HSPF Reach I.D.	Total Runoff Volume			Monthly			Daily			Storm % Error	
		Obs (in)	Sim (in)	% Δ	*R*	R^2	MFE	*R*	R^2	MFE	Volume	Peak
E16058004	470	5.78	5.45	–5.7	0.87	0.76	0.71	0.80	0.64	0.52	–1.5	12.1

Table 3-5. Summary Statistics for Primary Validation Gages in the Crow Watershed

Observed Flow Gage	HSPF Reach I.D.	Total Runoff Volume			Monthly			Daily			Storm % Error	
		Obs (in)	Sim (in)	% Δ	*R*	R^2	MFE	*R*	R^2	MFE	Volume	Peak
H18083001	430	2.94	2.87	–2.3	0.90	0.80	0.78	0.84	0.71	0.71	–3.7	–22.7
H18088001	530	4.92	4.80	–2.5	0.86	0.75	0.72	0.84	0.71	0.62	–17.3	14.0
H19001001	910	4.87	4.82	–1.1	0.90	0.80	0.76	0.79	0.63	0.55	–10.8	9.7
E18087001	950	6.12	5.76	–5.9	0.92	0.85	0.83	0.89	0.79	0.78	–10.1	2.7
Weighted Overall		**5.10**	**4.90**	**–3.61**	**0.90**	**0.81**	**0.78**	**0.85**	**0.73**	**0.69**	**–10.73**	**2.46**

Table 3-6. Summary of Water Balance Component Volumes

Water Balance Component	Water Balance Component Description	Sauk Watershed Weighted Volume (in)	Crow Watershed Weighted Volume (in)
SUPY	Water supply to soil surface	28.12	27.38
SURO	Surface outflow	0.27	0.19
IFWO	Interflow outflow	1.82	1.48
AGWO	Active groundwater outflow	3.59	3.57
PERO	Total outflow from pervious land	5.64	5.22
IGWI	Inflow to inactive groundwater	0.23	0.51
AGWI	Active groundwater inflow	3.95	4.22
PET	Potential evapotranspiration	38.04	37.43
CEPE	Evaporation from interception storage	5.5	5.23
UZET	Evapotranspiration from upper zone	7.13	6.13
LZET	Evapotranspiration from lower zone	9.15	9.39
AGWET	Evapotranspiration from active groundwater storage	0.09	0.06
BASET	Evapotranspiration from active groundwater outflow (baseflow)	0.24	0.59
TAET	Total simulated evapotranspiration	22.1	21.4

4.0 INTERNAL LAKE PHOSPHORUS LOADING

Internal lake phosphorus loads can be caused by anoxic conditions, wind mixing, biota die-off (i.e., curly-leaf pondweed), bioturbation, or other factors. The explicit representation of these loads when developing load allocations at a HUC 8 scale is not imperative; however, it is important to include phosphorus loads from internal lake processes to support allocation development at a finer scale. This chapter focuses on internal loading from anoxic conditions, which is common in deep lakes in Minnesota.

The base package of **HSPF** does not explicitly represent this seasonal type of internal loading. Therefore, a new approach was developed to incorporate internal lake phosphorus loads.

4.1 SUMMARY OF LITERATURE REVIEW FINDINGS

It has been well documented that deep lakes in Minnesota typically thermally stratify in both the winter and summer. Lakes with this cycle of thermal stratification are referred to as dimictic lakes. Thermal stratification occurs when a lake develops layers of water with different temperatures. In the summer, the upper layer of water will heat, while the bottom layer of the lakes remains cool. The level of stratification will change through the year and from year to year. These layers can have substantially different water quality. The lower layer (hypolimnion) can become anoxic. Dimictic refers to a lake that mixes twice a year. In the fall, these layers will mix as the top layer becomes colder than the bottom layer. In the spring, the lack of stratification allows wind to mix the lake.

This stratification often leads to the formation of anoxic conditions in the deeper and littoral portions of the lake. Under anoxic conditions, elemental phosphorus will not be bound to hydroxide complexes, and thus, become geochemically mobile. The phosphorus release from complexes within the lake sediments will result in an increase in phosphorus concentration in the anoxic portions of the lake. As the lake “turns over” or becomes well mixed, because of the disappearance of the redoxcline, the internally generated phosphorus load will be redistributed throughout the water column of the lake. Ultimately, the internally generated phosphorus becomes available for biological uptake either within the lake or in other lake or river reaches downstream of the lake.

Studies to define empirical relationships for lakes, including implicit internal loading, were reviewed [Reckhow, 1979; Canfield and Bachmann, 1981; Panuska, and J. C. Kreider, 2003; and Walker, 1985]. Additionally, Chapra and Canale [1991] and Nürnberg [1984] studies looked in depth at anoxic internal loading on specific lakes. The two most commonly applied methods are the Canfield-Bachmann method [1981] and the Bathtub model [Walker, 1985].

More recent in-depth studies of specific lakes conducted for the TMDL program highlight the importance of internal loading to lakes. For example, Eagle Lake in the South Crow Watershed was found to have 70 percent of the total annual load from internal loading [Carver County Land and Water Services, 2010]. These studies have also documented strong annual variability in internal loading.

Based on previous studies, a multiple-step process was created to calculate the internal phosphorus loading in lakes:

1. Determine if a lake thermally stratifies.
2. Verify anoxic conditions in measured data.
3. Determine the average summer TP concentration, including internal loading.
4. Determine the internal TP load for each stratified lake.

Each of these steps is discussed in the following section.

4.2 DETERMINATION OF THERMAL LAKE STRATIFICATION

Lakes were considered likely stratified if they met the criteria of having a maximum depth greater than 7 meters (approximately 23 feet). However, mixing from substantial inflows may reduce or eliminate stratification. Therefore, it was initially assumed that all lakes with overflow (Outflow/Surface Area) rates greater than 50 meters per year would not stratify. This criterion was removed based on the evaluation of anoxic conditions (Step 2), which showed this criterion does not hold true for several lakes in the watershed. The results of the lake stratification analysis for the Sauk, South Crow, and North Crow are presented in Tables 4-1, 4-2, and 4-3 , respectively.

4.3 VERIFICATION OF ANOXIC CONDITIONS FROM MEASURED DATA

Measured data were used to verify if lakes underwent periods with anoxic conditions, when available. Anoxic conditions were determined based on comparing the overall lake TP concentration with the TP concentrations in the hypolimnion. The literature did not provide a firm rule on what difference in TP concentration was typical for anoxic conditions. A review of the data found that hypolimnion concentrations at least five times the overall lake average were not uncommon. Ultimately, summer hypolimnion TP concentrations that were double the average lake concentrations were considered to be subjected to internal loading. Tables 4-4, 4-5, and 4-6 present the results of the evaluation of anoxic conditions for selected lakes in Sauk, South Crow, and North Crow, respectively.

Table 4-1. Summary of Lake Stratification in the Sauk River Watershed

Reach	Lake I.D.	Lake Name	Average Depth (m)	Overflow Rate (m/yr)	Likely Stratified
2	21-0016-00	Smith	8	8	Yes
14	77-0181-00	Maple	7	5	No
20	77-0215-00	Osakis	21	3	Yes
22	21-0003-00	Clifford	11	30	Yes
24	77-0195-00	faille	2	122	No
52	77-0164-00	Little Sauk	8	139	No
54	77-0163-00	Juergens	5	357	No
72	61-0029-00	Westport	11	25	Yes
100	77-0150-01	Sauk	18	47	No
124	73-0273-00	McCormic	11	1	Yes
162	77-0084-01	Big Birch	24	4	Yes
164	77-0089-00	Little Birch	26	24	Yes
184	73-0208-00	Uhlenkolts	5	4	No
202	73-0215-00	Maria	13	3	Yes
242	73-0199-00	Sand	3	0	No
264	NA	Henry	10	0	Yes
374	73-0159-00	Big	12	4	Yes
386	73-0151-00	Vails	6	58	Yes
388	73-0150-00	Eden	21	38	Yes
392	73-0147-00	North Brown's	11	34	Yes
394	73-0139-00	Long	9	28	Yes
400	Multiple	Chain of Lakes	16	743	Yes
420	73-0082-00	Schneider	4	396	Yes
432	73-0037-00	Pearl	4	8	No
434	73-0055-00	Grand	10	3	Yes

Table 4-2. Summary of Lake Stratification in the South Fork Crow River Watershed

Reach	Lake I.D.	Lake Name	Average Depth (m)	Overflow Rate (m/yr)	Likely Stratified
528	34-0072-00	Lillian	1	0.0013	No
532	34-0086-00	Big Kandiyohi	4	0.0105	No
536	34-0169-03	Wakanda (Main Basin)	4	6.7	No
542	34-0076-00	Minnetaga	2	4.5	No
544	34-0105-00	Kasota	11	2.4	Yes
546	34-0096-00	Little Kandiyohi	11	1.8	Yes
558	34-0022-02	Elizabeth (Main)	2	4.2	No
618	47-0129-00	Star	4	0.1	No
622	NA	NA	11	8.3	Yes
632	43-0104-00	Stahl's	2	0.6	No
634	47-0062-00	Greenleaf	5	0.7	No
636	47-0061-00	Willie	5	16.0	No
638	47-0106-00	Hoff	2	47.1	No
646	65-0013-00	Boon	11	1.5	Yes
660	43-0085-01	Otter (Main Basin)	0.2	3,938	No
718	43-0034-00	Silver	0.3	0.0	No
738	43-0014-00	South	11	1.3	Yes
742	43-0012-00	Winsted	3	18.0	No
744	10-0127-00	Campbell	10	0.0	Yes
772	65-0006-00	Allie	3	1.9	No
774	65-0002-00	Preston	3	1.8	No
796	43-0084-00	Marion	3	2.8	No
806	72-0049-00	Schilling	11	1.0	Yes
842	10-0121-00	Eagle	4	2.5	No
892	10-0095-00	Swede	3	0.2	No
894	10-0093-00	Oak	3	0.5	No
896	27-0184-01	Whaletail (N. Bay)	8	0.7	Yes
898	27-0149-00	Spurzem	12	13.5	Yes
902	27-0176-00	Independence	17	3.6	Yes
922	27-0192-00	Rebecca	9	1.2	Yes

Table 4-3. Summary of Lake Stratification in the North Fork Crow River Watershed (Page 1 of 2)

Reach	Lake I.D.	Lake Name	Average Depth (m)	Overflow Rate (m/yr)	Likely Stratified
2	61-0023-00	Grove	9	7.9	Yes
120	73-0196-00	Rice	11	47.8	Yes
140	73-0200-01	Koronis	39	23.2	Yes
172	34-0066-00	Long	13	2.6	Yes
180	34-0158-01	Monongalia Lake (Mud)	5	11.4	No
220	34-0142-00	Nest	12	41.6	Yes
240	34-0079-00	Green	33	6.2	Yes
242	34-0062-00	Calhoun	3	4.1	No
282	34-0044-00	Diamond	8	3.0	Yes
322	47-0183-00	Hope	3	8.3	No
324	47-0177-00	Long	1	149.4	No
342	47-0134-02	Ripley	6	20.9	No
344	47-0134-02	Ripley	5	5.9	No
352	86-0279-00	West Lake Sylvia	25	0.0	Yes
354	47-0002-00	Francis	5	0.1	No
356	47-0119-00	Minnie-Belle	14	0.2	Yes
362	47-0068-00	Stella	22	11.8	Yes
364	47-0046-00	Washington	5	2.5	No
366	47-0088-00	Richardson	14	75.9	Yes
368	47-0082-00	Dunns	5	65.2	No
374	43-0073-00	Hook	5	2.5	No
376	47-0015-00	Jennie	4	2.9	No
378	47-0032-00	Spring	8	1.3	Yes
382	86-0293-00	Collinwood	8	17.8	Yes
384	47-0038-00	Big Swan	8	36.0	Yes
402	86-0273-00	French	15	6.3	Yes
422	86-0217-00	Granite	10	1.8	Yes

Table 4-3. Summary of Lake Stratification in the North Fork Crow River Watershed (Page 2 of 2)

Reach	Lake I.D.	Lake Name	Average Depth (m)	Overflow Rate (m/yr)	Likely Stratified
442	86-0250-00	Smith	1	0.6	No
444	86-0263-00	Cokato	14	31.4	Yes
446	86-0221-00	Camp	16	1.0	Yes
462	86-0182-00	Rock	11	1.4	Yes
472	86-0190-00	Ann	4	27.6	No
474	86-0199-00	Howard	12	2.6	Yes
476	86-0184-00	Dutch	6	17.4	No
482	86-0114-00	Waverly	21	1.5	Yes
484	86-0106-00	Little Waverly	3	60.3	No
492	86-0120-00	Ramsey	24	8.3	Yes
496	86-0122-00	Light Foot	6	107.0	No
498	86-0090-00	Buffalo	9	7.7	Yes
502	86-0107-00	Deer	8	71.0	Yes
508	86-0112-00	Malardi	11	3.8	Yes
516	S005-837	Woodland	11	19.5	Yes
522	86-0086-00	Fountain	11	0.6	Yes
942	27-0191-01	Sarah	17	2.7	Yes
962	27-0199-00	Hafften	13	1.4	Yes
982	86-0031-00	Pelican	3	0.4	No
984	86-0023-00	Beebe	8	0.1	Yes
986	27-0169-00	Cowley	11	2.5	Yes
988	86-0001-00	Foster	3	9.1	No

Table 4-4. Evidence of Anoxic Conditions in the Sauk River Lakes

Lake	Reach	TP Summer Median (mg/L)	Number of Samples	TP Summer Hypolimnion Median (mg/L)	Number of Hypolmnion Samples	Evidence of Anoxic Conditions
Little Long	896	0.060	245	0.082	18	No
Hennepin	898	0.155	151	1.383	26	Yes
Independence	902	0.065	259	0.299	102	Yes
Rebecca	922	0.099	139	0.467	25	Yes

Table 4-5. Evidence of Anoxic Conditions in the South Fork Crow River Lakes

Lake	Reach	TP Summer Median (mg/L)	Number of Samples	TP Summer Hypolimnion Median (mg/L)	Number of Hypolmnion Samples	Evidence of Anoxic Conditions
Little Long	896	0.060	245	0.082	18	No
Hennepin	898	0.155	151	1.383	26	Yes
Independence	902	0.065	259	0.299	102	Yes
Rebecca	922	0.099	139	0.467	25	Yes

Table 4-6. Evidence of Anoxic Conditions in the North Fork Crow River Lakes

Lake	Reach	TP Summer Median (mg/L)	Number of Samples	TP Summer Hypolimnion Median (mg/L)	Number of Hypolmnion Samples	Evidence of Anoxic Conditions
Waverly	482	0.0395	77	0.36	12	Yes
Richardson	366	0.1045	53	0.77	15	Yes
Diamond	282	0.072	203	0.047	21	No
Hafften	962	0.07	111	0.39	25	Yes
Minnie-belle	356	0.024	101	0.076	43	Yes
Sarah	942	0.114	289	0.6308	71	Yes

4.4 DETERMINATION OF THE AVERAGE SUMMER TOTAL PHOSPHORUS CONCENTRATION, INCLUDING INTERNAL LOADING

The average summer TP concentration was determined using the natural lake model developed by Canfield and Bachmann [1981] or by measured data if sufficiently present. This model is used to predict seasonal to annual TP concentrations and is based on the Vollenweider equation (Equation 4-1), with a TP settling rate specific to natural lakes. The TP settling rate (Equation 4-2) was calibrated based on data from 290 lakes.

$$\text{TP Concentration} = \frac{\text{External TP Load}}{\text{Depth (TP Settling Rate + Annual Flushing Rate)}} \tag{4-1}$$

where:

$$\text{Annual Flushing Rate}\left(\frac{1}{\text{yr}}\right)=\frac{\text{Lake Outflow}}{\text{Lake Volume}}$$

$$\text{Depth (m)} = \text{Average Annual Depth}$$

$$\text{External TP Load}\left(\frac{\text{mg}}{\text{yr m}^2}\right)=\text{Average Annual TP Load.}$$

$$\text{TP Settling Rate} = 0.162\left(\frac{\text{External TP (Load)}}{\text{Depth}}\right)^{0.458} \qquad (4\text{-}2)$$

The **HSPF** watershed application was used to generate the inputs needed to predict the TP concentrations using the above equations. The results of this approach were unable to consistently predict the measured average summer TP concentration in lakes where data were available. The concentrations were typically lower than the observed summer values. Further investigation indicated the **HSPF** model applications generated relatively low phosphorus loads when compared to what would be required to predict in-lake TP concentrations using the Canfield-Bachmann method.

These lower concentrations may be the result of an internal load of lakes exceeding the amount of internal load implicitly included in the Canfield-Bachmann method. Alternatively, the **HSPF** applications generate consistently lower external TP loads than the values used when developing the Canfield-Bachmann method. However, these same **HSPF** watershed loads provided a well-calibrated **HSPF** model application at multiple points throughout the watershed.

Because the models use different approaches to modeling lakes, it is unclear which model is more appropriate. Therefore, the observed concentrations were used instead of the Canfield-Bachmann-predicted concentrations. Specifically, the average summer concentration was calculated from the available data. A threshold of at least 12 TP samples was set to ensure the calculated summer average was representative of the actual conditions. This threshold is consistent with MPCA's data requirement to list a lake as "impaired" [Minnesota Pollution Control Agency, 2007].

4.5 DETERMINATION OF THE INTERNAL TOTAL PHOSPHORUS LOAD FOR EACH STRATIFIED LAKE

Initially, the internal TP loading was determined using the methods from Nürnberg [1984]. The general equation to represent the TP concentration in a lake is presentated in Equation 4-3, where both internal and external loading are included. This equation can be rearranged to solve for internal TP loading. The resulting internal TP loads were generated on an annual basis.

$$\text{TP Concentration} = \left(\frac{\text{External TP Load}}{\text{Overflow Rate}}\right)\left(1-\text{TP Retention Time}\right)+\frac{\text{Internal Loading}}{\text{Overflow Rate}} \qquad (4\text{-}3)$$

The results of the internal loading calculation were added as input into the **HSPF** applications. Annual internal loads were loaded into the **HSPF** model, as phosphate (PO4), during likely periods of mixing (the first week of May and the third week of October). These loads produced several orders of magnitude higher in-lake TP concentrations in the **HSPF** model than expected. Therefore, an alternative internal load method was used.

Consistent with recent TMDL approaches in the South Crow Watershed [Carver County Land and Water Services 2010], a lake-specific internal loading rate was included into the **HSPF** application. Internal loading was included in two ways. First, a benthic Biochemical Oxygen Demand (BOD) load is included as part of the in-stream processes in the **HSPF** applications. This type of loading was increased in lakes beyond the typical levels found in streams. The increased BOD loading, which was a constant daily value, was applied to all lakes and was the sole method used to improve the calibration in nonstratified lakes. The BOD included organic phosphorus, nitrogen, and carbon. As the BOD decays, inorganic phosphorus and nitrogen are released and DO is depleted. This process was not consistent with the release of phosphorus under anoxic conditions; therefore, a separate internal PO4 load was included in stratified lakes. These loads mimicked the internal loads applied from the Nürnberg method but were substantially lower in magnitude. In both cases, **HSPF** was found to be very sensitive to the magnitude of the internal load.

While improving many lakes, this methodology was not sufficient for all lakes. Additional detailed evaluations of loading, external to **HSPF**, may aid in improving the calibration.

4.6 CONCLUSIONS AND RECOMMENDATIONS

The **HSPF** watershed applications of the Sauk River and Crow River Watersheds benefit from the inclusion of internal phosphorus loading. Lake-specific internal loading was successfully included into the applications to improve the model calibration. Annual and seasonal methods for predicting in-lake TP concentrations and internal loads were not able to be used directly with **HSPF**, likely because of different approaches between these steady-state models and the dynamic **HSPF** applications.

RESPEC recommends that future **HSPF** applications representing lakes also include lake-specific internal loading. The combined BOD and anoxic loading during periods of mixing was able to improve the calibration. For select lakes, incorporating internal loads that vary annually or seasonally may help improve the calibration. Because of the time commitment needed for this type of calibration, it is not recommended for widescale application. Additional methods should be developed for lakes with complex internal loading (e.g., wind mixing, curly-leaf pond weed, and complex shapes).

5.0 WATER QUALITY

The Crow and Sauk River model applications simulate the following specific parameters at a management unit level:

- hydrology
- sediment (sand, silt, and clay)
- temperature
- phosphorus (TP, orthophosphate, and organic phosphorus)
- nitrogen (total nitrogen, nitrate and nitrite, ammonia, and organic nitrogen)
- DO
- BOD
- Chlorophyll-a.

In the model application, these parameters interact, and in many cases, are interdependent. For example, Chlorophyll-a (Plankton) growth is in part a function of water temperature, orthophosphate concentrations, and inorganic nitrogen (ammonia and nitrate) concentrations. The concentration of organic matter (Chlorphyll-a and BOD) is used in computing the TP and total nitrogen (TN). Therefore, the results of the model must be looked at holistically. A priority was placed on TP, TSS, and DO, as those parameters are driving the majority of impairments in the watersheds.

The key results for each model application are presented in this section along with a discussion of the results. The results at each calibration/validation station are provided in Love [2012].

5.1 SAUK RIVER

The Sauk River calibration for water quality represents the measured data well throughout the watershed. The main calibration/validation stations evaluated for the model are shown in Figure 5-1. The presence of large in-stream lakes had a substantial impact on the water quality in the Sauk River. These lakes include Lake Osakis at Reach 20, Sauk Lake at Reach 100, and the Chain of Lakes (Reaches 400 and 420).

This section presents results at the Sauk River outlet for four parameters: TSS, TP, TN, and DO. The results for other parameters and stations are provided in Love [2012]. The Chain of Lakes has a direct impact on the results at the Sauk River Outlet (Reach 490). The summer growing season (May through September) was considered the priority period when calibrating these lakes In some cases, such as a river outlet, a lake can restrict the ability to calibrate

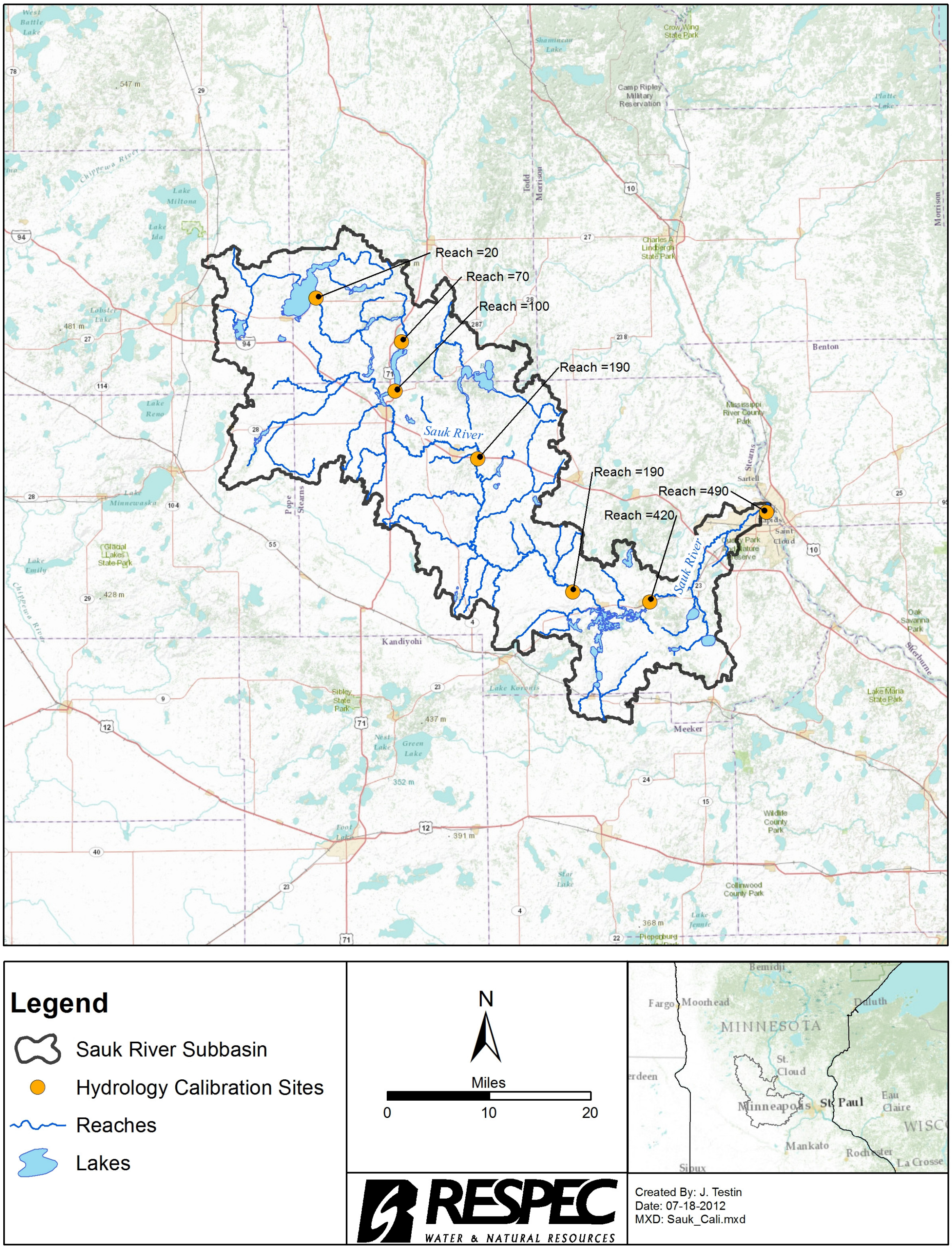

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Figure 5-1. Primary Calibration Reaches for the Sauk River Model Application.

a downstream reach, particularly when evaluating at less than a seasonal timestep. In these cases, the stream calibration was considered a priority over the lake calibration.

The sediment simulation in the Sauk considered the in-stream concentration results and the apportionment of loading from overland sources versus the stream bed, bank, and gullies. A review of available information did not yield source apportionment testing in the Sauk. Source apportionment testing was performed extensively in the Minnesota River to the south and several samples were taken in the South Crow. While the soils in the Sauk have a greater traction of sand than these areas (potentially less loading from the watershed), the testing established that a substantial portion of sediment can occur from stream bed, bank, and gully sources (45 percent in the South Crow). Discussion with local watershed district staff indicated that bank erosion was an issue in several sections of the Sauk River. Therefore, an apportionment goal of 55 percent from stream bed, bank, and gully was set for the Sauk River Watershed. The model results showed 57 percent of the sediment load occurring from stream bed, bank, and gully sources.

The sediment results at the Sauk River outlet are presented in Figure 5-2. The calibration for sediment is considered fair. It should be noted, challenges in representing the sediment mechanisms in the very complex Horseshoe Chain of Lakes propagate downstream and affect the results at this station.

The results at the Sauk River outlet are presented for TP in Figure 5-3 and for TN in Figure 5-4. The calibration for nutrients is considered good. Croplands contributed the greatest nutrient load to the watershed. DO results are highly influenced by plankton growth and BOD decay. The results for DO, which were considered good, are presented in Figure 5-5. The results for other parameters and the nutrient speciations are provided in Love [2012]**.**

5.2 SOUTH FORK CROW RIVER

The South Crow calibration for water quality represents the measured data well throughout the watershed. The main calibration/validation stations evaluated for the model are shown in Figure 5-6. Nutrient concentrations are in the South Crow are relatively higher than those in the Sauk and North Crow.

This section presents results at the South Crow outlet for four parameters: TSS, TP, TN, and DO. A good calibration was achieved throughout the South Crow. There are fewer lakes in the South Crow, and therefore, they have a lower impact on overall calibration.

The sediment simulation in the South Crow watershed considered the in-stream concentration results and the apportionment of loading from overland sources versus the stream bed, bank, and gully. A review of available information found that source apportionment tests were conducted and found that an average of 45 percent of the sediment was from stream bed, bank,

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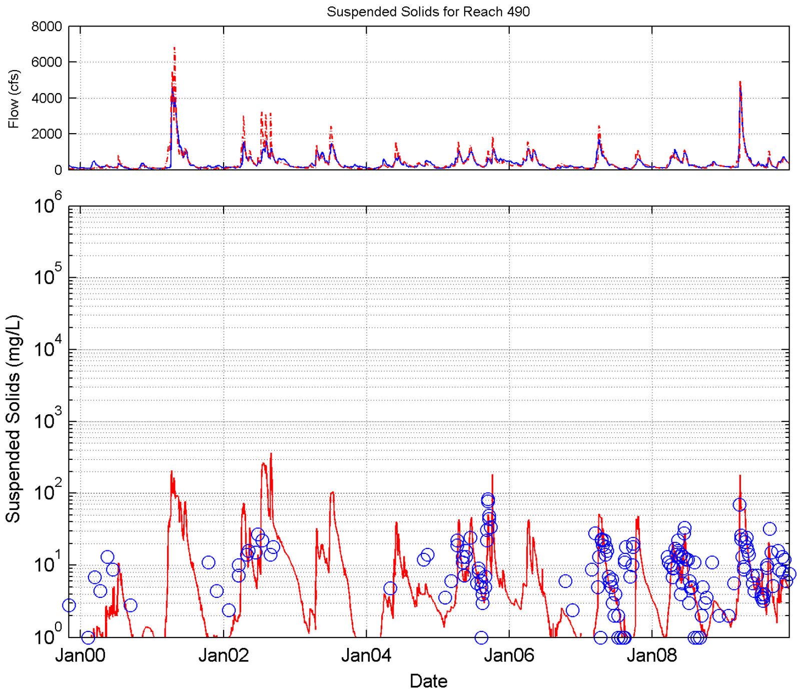

Figure 5-2. Total Suspended Solids at the Sauk River Outlet, Reach 490.

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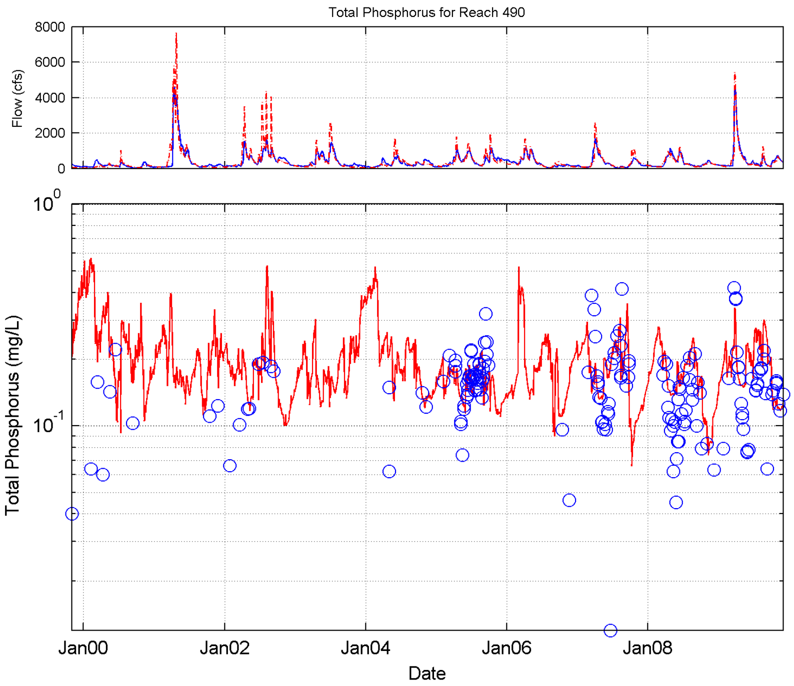

Figure 5-3. Total Phosphorus at the Sauk River Outlet, Reach 490.

RSI-1953-12-060

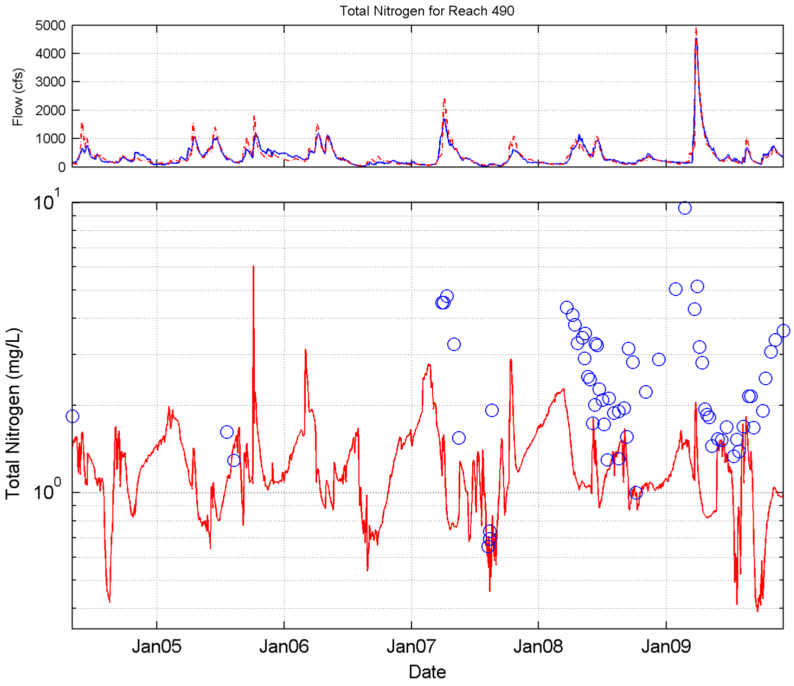

Figure 5-4. Total Nitrogen at the Sauk River Outlet, Reach 490.

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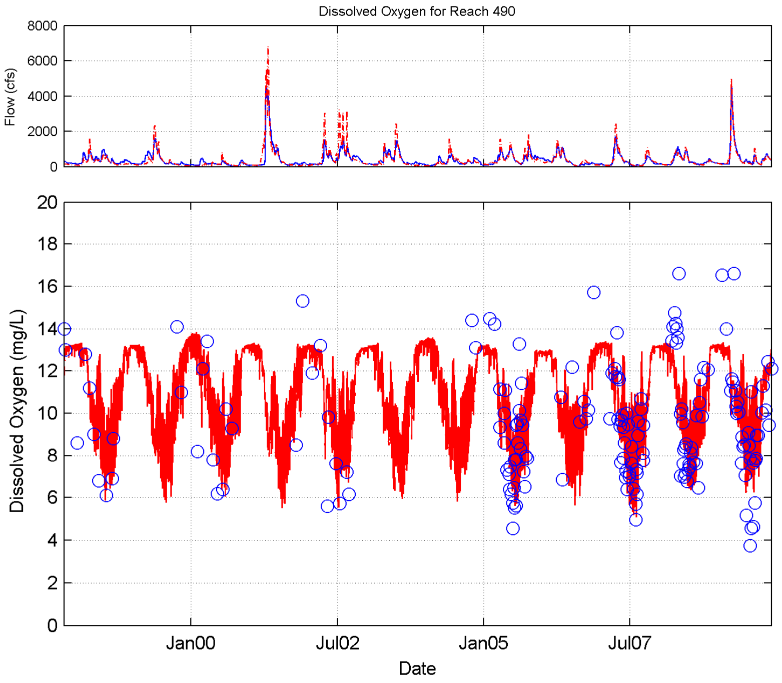

Figure 5-5. Dissovled Oxygen at the Sauk River Outlet, Reach 490.

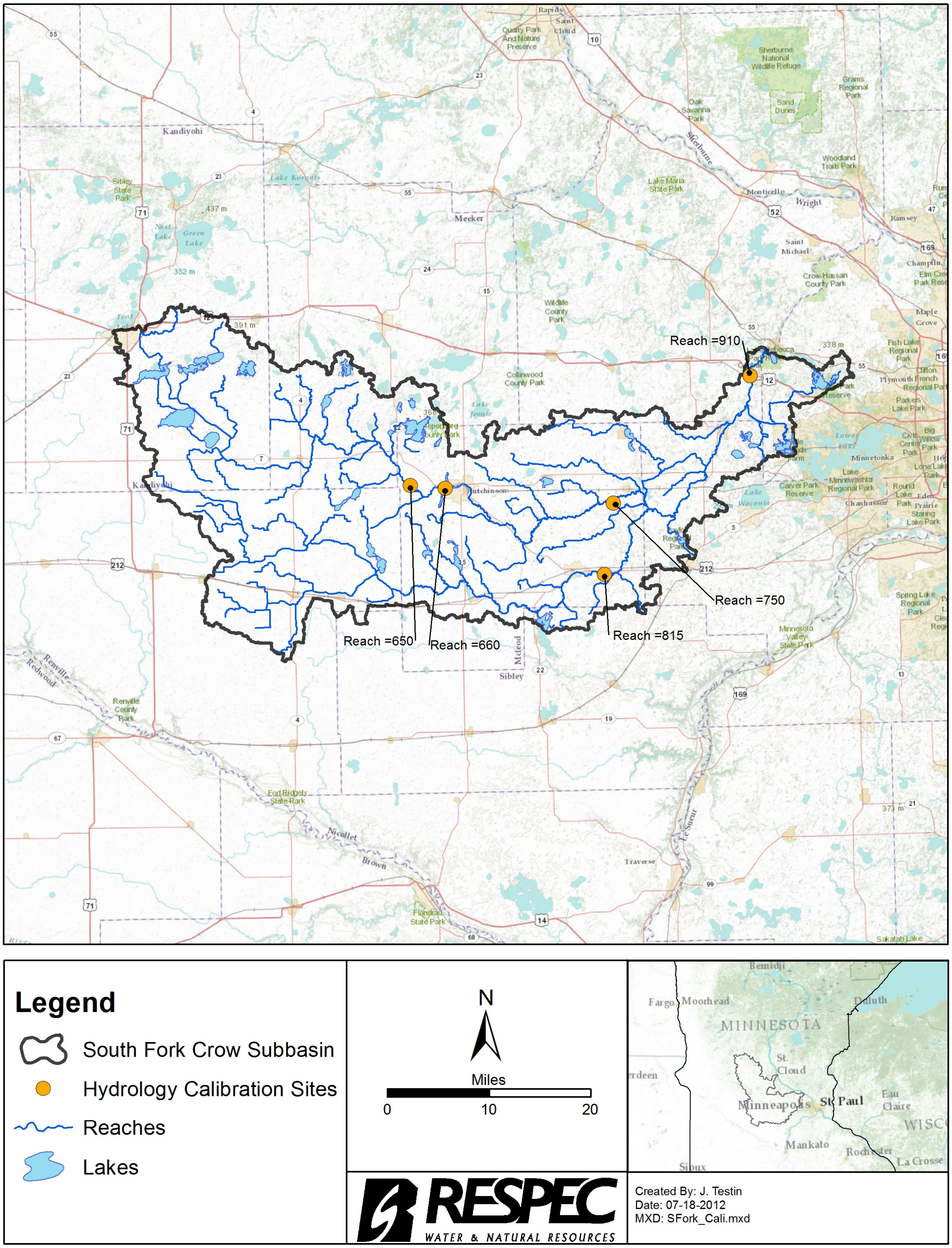

Figure 5-6. Primary Calibration Reaches for the South Fork Crow River Model Application.

and gully sources. The model results showed 47 percent of the sediment load occurring from stream bed, bank, and gully sources.

The sediment results at the South Crow outlet are presented in Figure 5-7. The calibration for sediment is considered good. The results at the South Crow outlet are presented for TP in Figure 5-8 and for TN in Figure 5-9. The calibration for nutrients is considered good. Croplands contributed the greatest nutrient load to the watershed. DO results are highly influenced by plankton growth and BOD decay. The results for DO, which were considered good, are presented in Figure 5-10. The results for other parameters and the nutrient speciation's are provided in Love [2012].

5.3 CROW RIVER

The Crow calibration for water quality represents the measured data well throughout the watershed. The main calibration/validations stations evaluated for the model are shown in Figure 5-11. This section presents the results for the North Fork Crow River outlet (Reach 530).

This section presents results at the Crow and North Fork outlets for four parameters: TSS, TP, TN, and DO. Lake Koronis is the North Crow's only in-stream lake; however, there are numerous lakes on its tributaries. These lakes play an important role in the overall calibration of the watershed, but do not limit calibration to the same extent as the Sauk River model calibration.

The sediment simulation in the Crow considered the in-stream concentration results and the apportionment of loading from overland sources versus stream bed, bank, and gully. As previously stated, an average of 45 percent of the sediment was from stream bed, bank, and gully sources used in the South Crow. Soils in North Crow are coarser (higher silt and sand fraction) than South Crow; therefore, an apportionment goal of 55 percent was set for the North Crow. The model results showed 60 percent of the sediment load occurring from stream bed, bank, and gully sources. No source apportionment goal was set for the Crow River outlet because the vast majority of the watershed was considered under the North Crow and South Crow calibrations.

The sediment results at the North Crow outlet are presented in Figure 5-12. The calibration for sediment is considered good. The results at the North Crow outlet are presented for TP in Figure 5-13 and for TN in Figure 5-14. The calibration for nutrients is considered good. Croplands contributed the greatest nutrient load to the watershed. The results at the Crow River outlet were considered fair. It is important to consider that the models performed well

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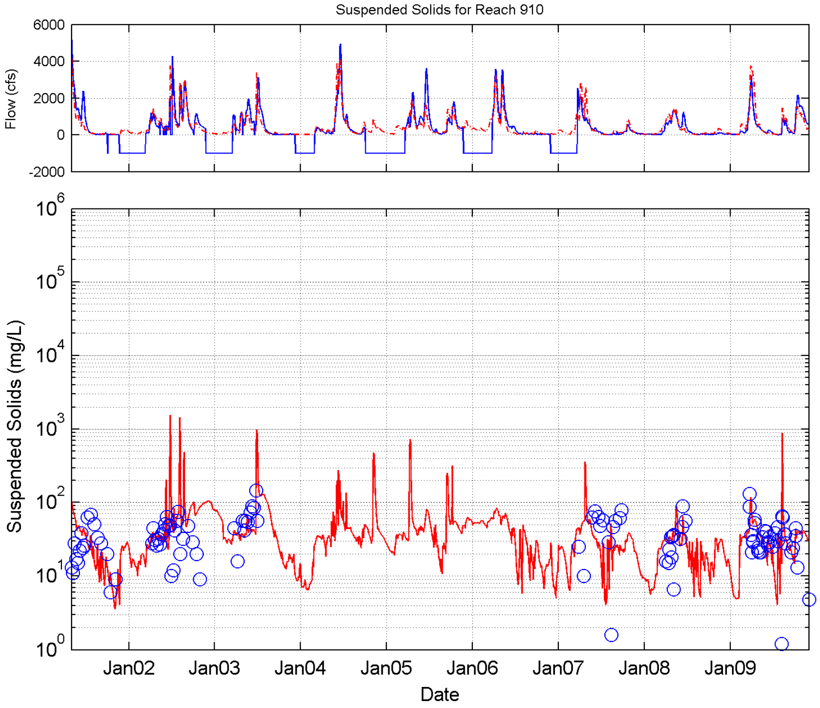

Figure 5-7. Suspended Solids at the South Fork Crow River Outlet, Reach 910.

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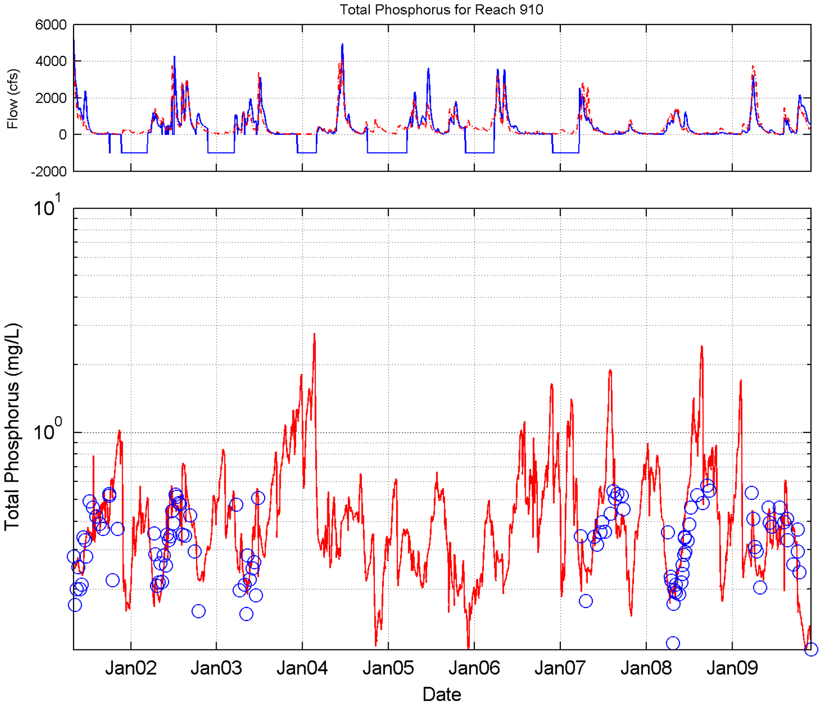

Figure 5-8. Total Phosphorus at the South Fork Crow River Outlet, Reach 910.

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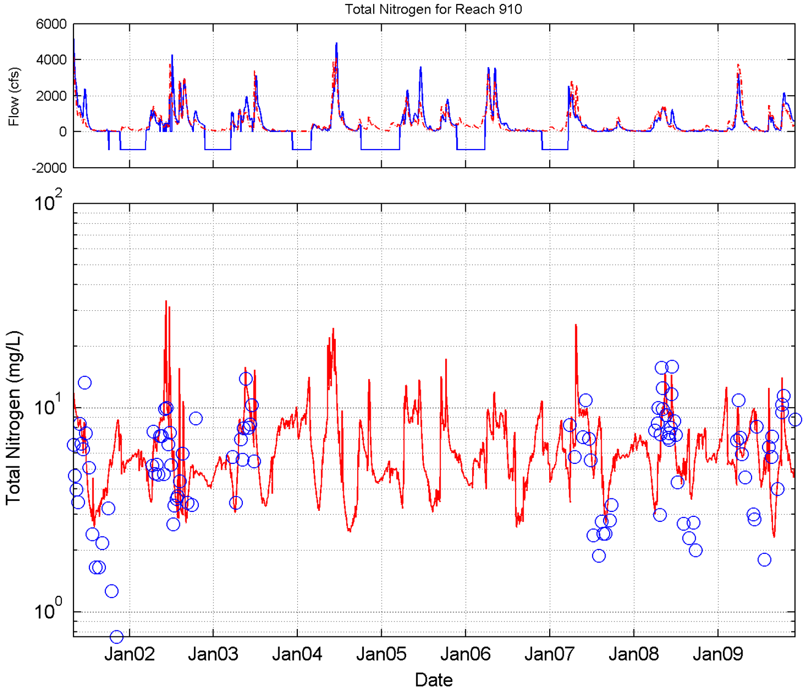

Figure 5-9. Total Nitrogen at the South Fork Crow River Outlet, Reach 910.

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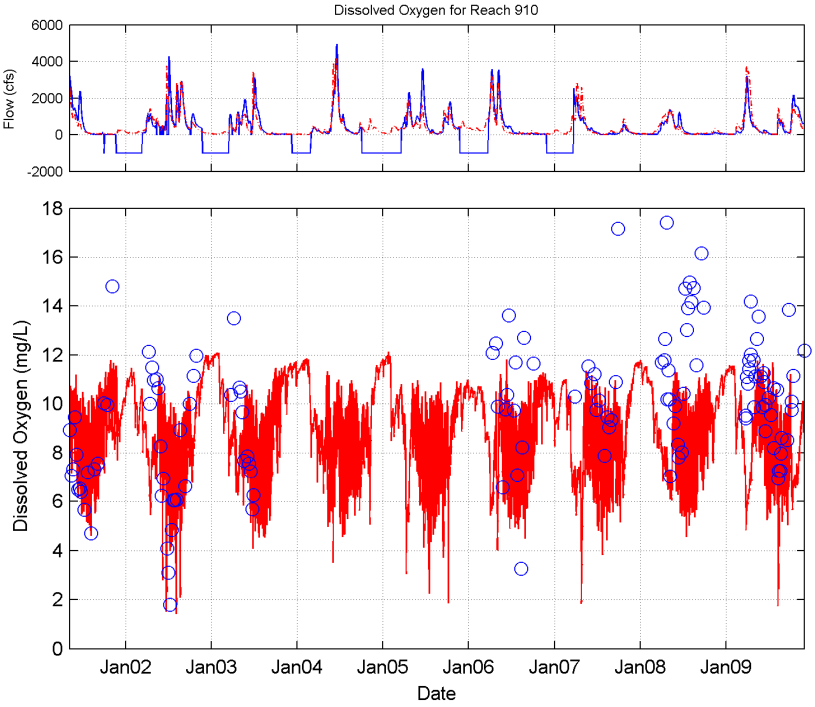

Figure 5-10. Dissolved Oxygen at the South Fork Crow River Outlet, Reach 910.

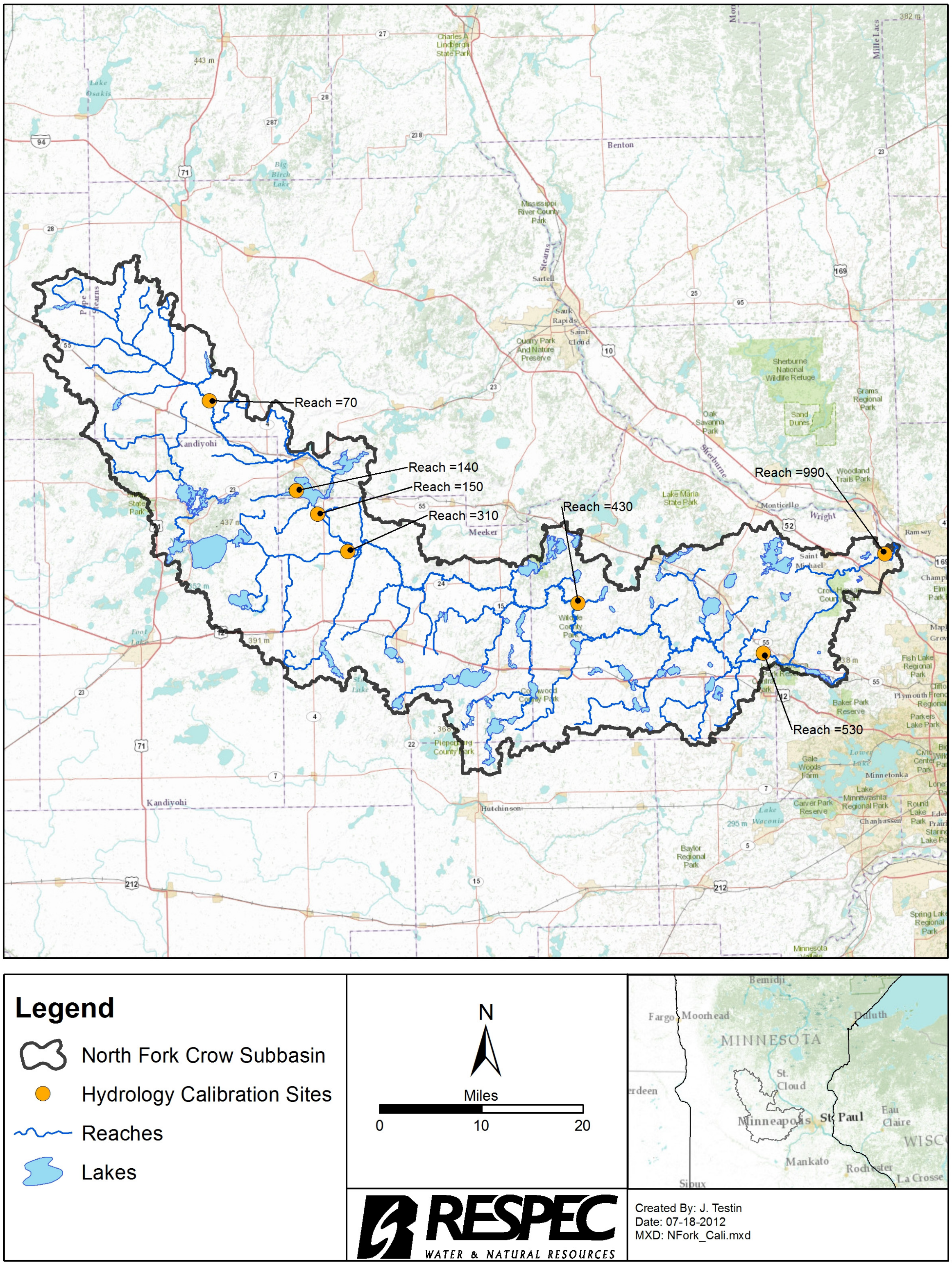

Figure 5-11. Primary Calibration Reaches for the Crow River Model Application.

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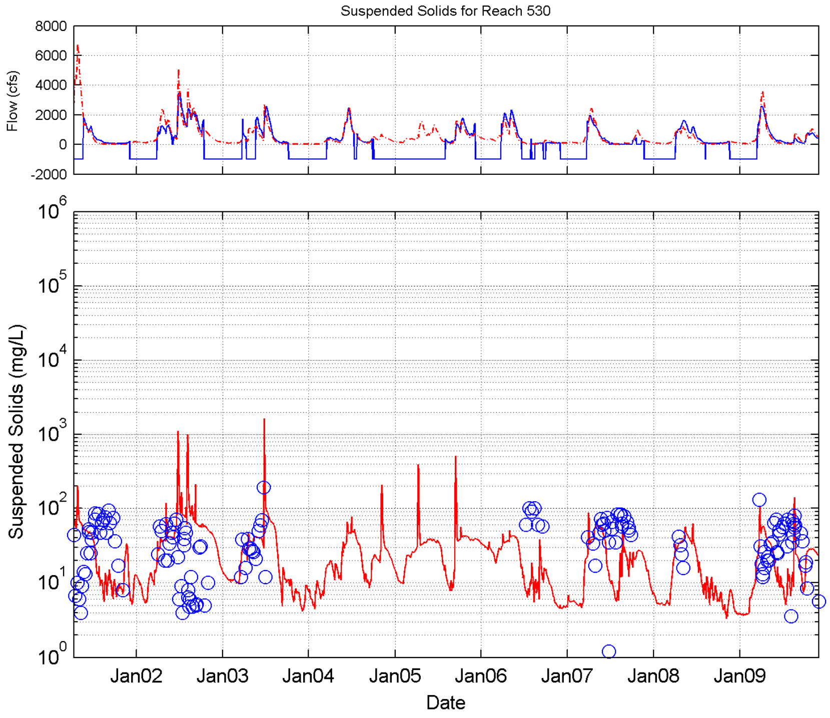

Figure 5-12. Suspended Solids at the North Fork Crow River Outlet, Reach 530.

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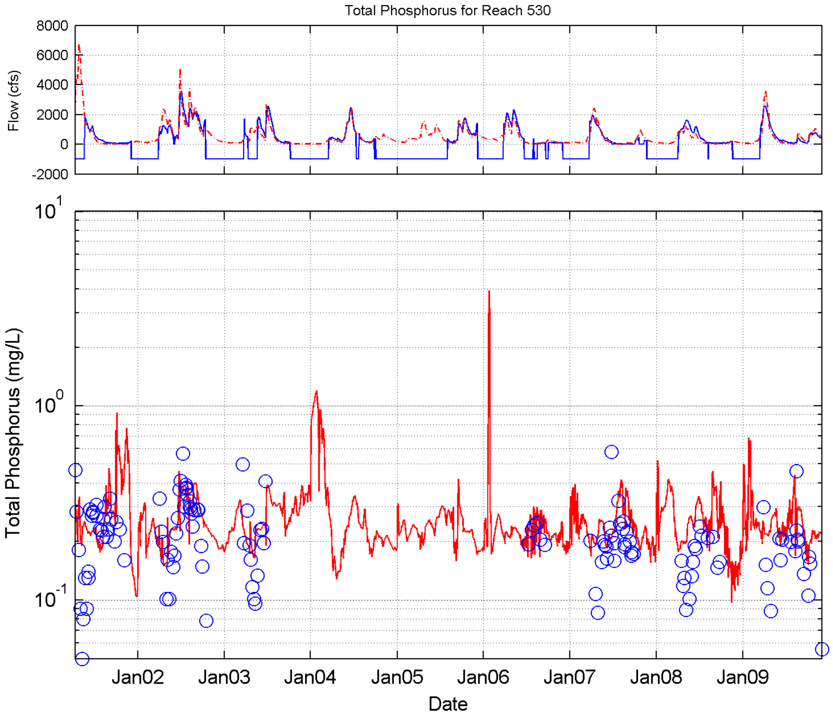

Figure 5-13. Total Phosphorus at the North Fork Crow River Outlet, Reach 530.

throughout the North Fork and South Fork. Additionally, there are three major point sources in the Crow, which may contribute to the fair calibration. The results for DO, which were considered good, are presented in Figure 5-15. The results for other parameters and the nutrient speciation's are provided in Love [2012].

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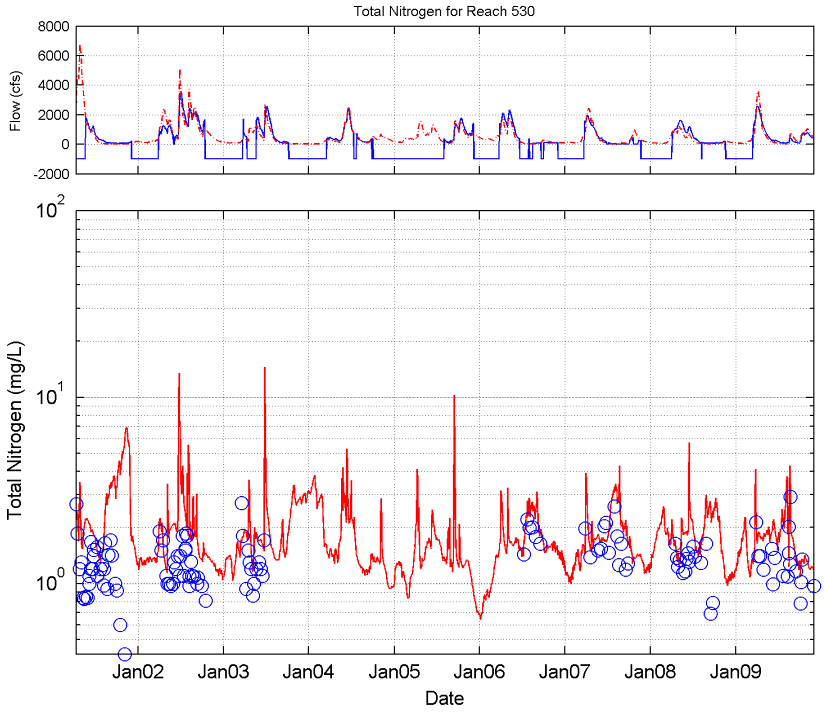

Figure 5-14. Total Nitrogen at the North Fork Crow River Outlet, Reach 530.

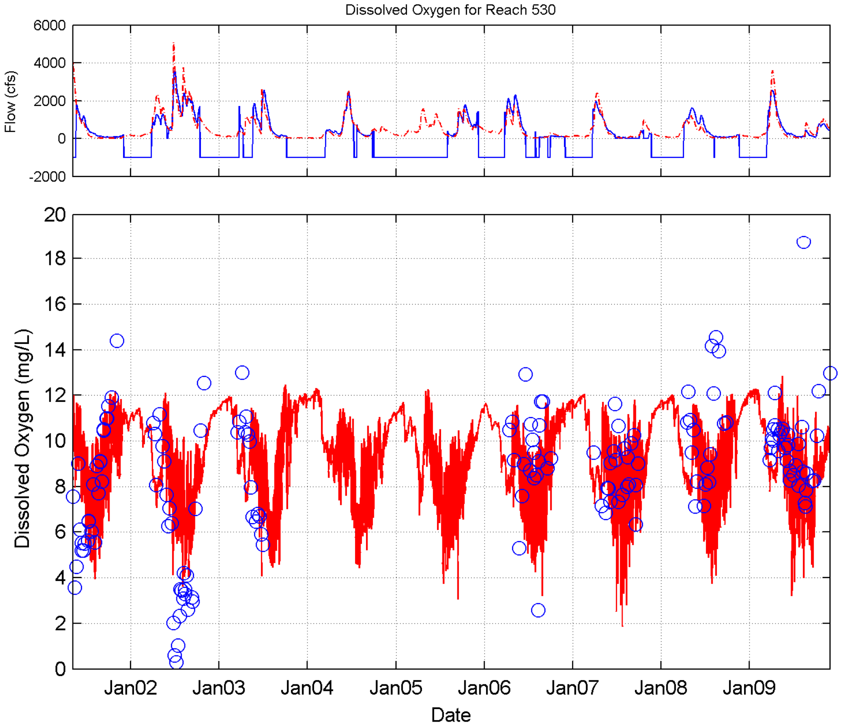

Figure 5-15. Dissolved Oxygen at the North Fork Crow River Outlet, Reach 530.

6.0 SCENARIOS

Three scenarios were evaluated for the Crow and Sauk Watersheds: (1) the “accelerating change” scenario from the Minnesota River Basin Turbidity TMDL Scenario Report [TetraTech, 2009], (2) removal of all point sources, and (3) all point sources at permitted capacity. A description of the scenario and the modeling approach used are presented in Table 6-1. The “accelerating change” scenario includes eight separate actions. Based on the Minnesota River work, all of the actions were determined to be necessary to meet the studies objectives. Consistent with that work, a single scenario was used in the Crow and Sauk Watersheds. However, each of the eight actions could be run as separate scenarios if requested.

The results of the three scenarios are presented in Tables 6-2, 6-3, and 6-4. Scenario 1, “accelerating change,” results in decreased nutrient concentrations. The reduction of fertilizer and manure to agronomic levels was found to have the largest impact. Sediment results are largely driven by changes in hydrology and related bed/bank erosion. The **HSPF** model uses a coarse representation of the river channel; therefore, a more detailed study of in-stream sediment loading should be conducted if further refinement of this scenario is required. Conservation Reserve Program (CRP) lands and conversion to conservation tillage decreased sediment load and concentrations. Scenario 2, eliminating point-source discharges, substantially decreases nutrient concentrations. The results of Scenario 3 were not intuitive because of changes in point-source discharges over time. Results of Scenario 3 should be evaluated for each point source rather than the effect on the basin as a whole.

The results of the scenarios have been included in the **GENSCN** project provided with the Final Sauk, North Crow, and South Crow **HSPF** watershed model applications. The **GENSCN** includes the scenario results at the HUC10 level for flow, TSS, TP, TN, and DO. Providing results at the HUC10 level will allow further detailed analysis than provided in Tables 6-2 through 6-4, where results are summarized at the outlets of the three HUC 8s.

Table 6-1. Summary of Scenarios for the HSPF Watershed Model Applications (Page 1 of 2)

Scenario	Type	Name	Description	Approach
1—Accelerating Change	Point	TP in Wastewater Discharges	Constant discharge concentration of 1 mg/L TP for major point sources without an existing limit at or below that concentration	Only the Glencoe Plant in the South Fork of the Crow River was required to decreased TP concentrations. All other major point sources have an existing TP limit of 1 mg/L.
1—Accelerating Change	Nonpoint	Conventional Tillage to Pasture/Hay on High Slopes	CRP lands to 20% of cropland/pasture	CRP land was represented as grassland. The area needed to achieve 20 percent CRP was calculated based on the amount of cropland and pasture land uses. The new CRP lands were removed from conventional tillage cropland and added to grassland. Existing grasslands were assumed to be CRP for these calculations. Changes were applied to the schematic.
1—Accelerating Change	Nonpoint	From MN River Scenario 4—Cropping System–Conventional to Conservation Tillage on High Slopes	75% conservation tillage on slopes greater than 3%	The area of cropland with greater than 3 percent slope was calculated for each reach. The amount of conservation tillage on these lands was increased to 75 percent (conventional tillage was reduced to 25 percent). This conversion from conventional to conservation tillage was done after the shift to 20 percent CRP. Changes were applied to the schematic.
1—Accelerating Change	Nonpoint	From MN River Scenario 4—Cropping System–Tile Surface Inlet Removal	Eliminate all tiling surface inlets	The elimination of tile surface inlets were represented by a 0.25 decrease in INTFW and the removal of sediment loading from cropland to interflow.
1—Accelerating Change	Nonpoint	From MN River Scenario 4—Cropping System–Nutrient Management	Reduce fertilizer (commercial and manure) on cropland to agronomic rates	Mulla et al. [2001] reported that south-central Minnesota overapplies nitrogen by 44 percent and phosphorus by 186 percent, based on the recommended rates. The mass-link was changed to reduce TN and TP to the recommended rates.
1—Accelerating Change	Nonpoint	From MN River Scenario 4—Cropping System	30 percent reduction in sediment from ravines from drop structures	The multiplicative factor on ravine transport (KGER) was reduced by 30%.

Table 6-1. Summary of Scenarios for the HSPF Watershed Model Applications (Page 2 of 2)

Scenario	Type	Name	Description	Approach
1—Accelerating Change	Nonpoint	From MN River Scenario 4—Upland Drainage Management	Controlled drainage on cropland with <1% slope, two-stage ditch design, store 1-inch runoff for at least 24 hours	Cropland was adjusted based on the parameterization for the Minnesota River Scenario Report [TetraTech, 2009]. LSUR was increased to 2,350 for cropland land. INTFW reduced to the value for non-drained cropland during summer months on lands with <1% slope. For same lands, IRC was increased to a constant 0.95. Sediment transport capacity was unlinked from hydrology (SDOP option was turned off).
1—Accelerating Change	Nonpoint	From MN River Scenario 4—Urban Stormwater	Treat the first inch of runoff from both impervious urban surfaces	Urban BMPs were included based on the methods described in Tetra Tech [2009]. BMPs were only added to urban areas in MS4s. Up to 1 inch of urban runoff was treated by a pond-type BMP. It was assumed that TSS and PO4 are reduced to regional groundwater concentrations of 5 and 0.06 mg/L, respectively. TN concentrations were reduced by 50%. All organic matter was removed.
2—No Point Sources	Point	No Point Sources	Eliminate all point-source contributions	Removed all point sources from the external sources block, including flow.
3—Point Sources at Permitted Capacity	Point	Point Sources at Permitted Discharge Rates	All point sources at permitted limits	Calculated a representative concentration and flow-peaking factor to estimate permitted constituents.

Table 6-2. Scenario 1 Percent Change in Flow or Concentration From Accelerating Change as a Percent Difference From Baseline

Scenario	Flow (%)	Suspended Solids (%)	Total Phosphorus (%)	Total Nitrogen (%)	Dissolved Oxygen (%)
Sauk	1.0%	–4.3%	–4.6%	–6.1%	0.3%
South Crow	–0.3	–12.6	–23.5	–4.8	2.1
North Crow	3.1	–14.3	–16.8	2.8	–0.8
Crow	1.6	8.4	–10.9	–0.1	–0.1

Table 6-3. Scenario 2 Percent Change in Flow or Concentration From Eliminating Point-Source Discharges as a Percent Difference From Baseline

Scenario	Flow (%)	Suspended Solids (%)	Total Phosphorus (%)	Total Nitrogen (%)	Dissolved Oxygen (%)
Sauk	–2.1	–1.0	–48.0	–36.1	–7.0
South Crow	–0.8	–1.0	–58.2	–13.8	–1.9
North Crow	–1.1	–1.0	–38.0	–35.3	–5.1
Crow	–0.6	–0.3	–18.4	–13.9	–0.5

Table 6-4. Scenario 3 Percent Change in Flow or Concentration From Point-Source Discharges as a Permitted Capacity as a Percent Difference From Baseline

Scenario	Flow (%)	Suspended Solids (%)	Total Phosphorus (%)	Total Nitrogen (%)	Dissolved Oxygen (%)
Sauk	2.0	2.0	98.8	11.8	11.1
South Crow	3.4	4.5	–30.7	–10.8	5.2
North Crow	2.0	5.9	–25.7	39.2	3.6
Crow	2.0	3.4	–2.6	10.6	3.4

7.0 RECOMMENDATIONS

The Crow/Sauk **HSPF** applications provided good results for a wide range of parameters and at multiple locations throughout the watershed. Recommendations for future modeling were created based on “lessons learned” in the process of formulating, calibrating, and executing the models. These recommendations are provided below.

- The Crow/Sauk models are well calibrated and can be used for future evaluations and studies.
- Internal loading should be incorporated into lake modeling in the future. However, further refinement of internal loading approach is recommended to reduce the numerous runs required for its implementation and potentially represent additional internal loading processes.
- Scenario 3—Point Sources at Permitted Levels-should be refined with input from MPCA staff. The complex, interrelated nature of **HSPF** and the changes in discharges over time make the results from this scenario not intuitive to understand. Therefore, refinements should be made to add clarify on an individual point-source level.
- The Crow and Sauk Watersheds have an abundance of flow and water-quality data. This level of data collection should be continued if possible. Additionally, sediment source apportionment data, tillage transects, septic tank studies, and other supplemental information cited in this report were very helpful for modeling and should be continued.
- To further improve the model calibration, particularly for sediment and water temperature, additional stream cross-sectional and lake outlet hydraulics information should be collected.
- Currently, the model combines the watershed loading from chemical and organic fertilizers. If required for specific management scenarios, the watershed loading should be split to represent manure specifically. Additional information and methodology would be required to implement this recommendation.

8.0 REFERENCES

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Appendix C

RESPEC

External Memorandum

To: Mr. Joe Bischoff
Wenck Associates
1800 Pioneer Creek Center
Maple Plain, MN 55359

cc: Project Central File 2418 — Category A

From: Mr. Seth Kenner
RESPEC
P.O. Box 725
Rapid City, SD 57709

Date: June 15, 2015

Subject: North Fork Crow River HSPF Model Application for Dissolved Oxygen Total Maximum Daily Load

This memorandum summarizes the HSPF model and the North Fork Crow River Model Application (NFCRM), provides an update to the calibration, describes the simulated processes driving dissolved oxygen (DO) impairments, and discusses the scenarios simulated using the model application to meet the DO standards.

HSPF MODEL SUMMARY

The HSPF watershed modeling system is a comprehensive package for simulating watershed hydrology and water quality for both conventional and toxic organic pollutants. HSPF is capable of simulating the hydrologic and associated water quality processes on pervious and impervious land surfaces, in streams, and in well-mixed impoundments. HSPF incorporates the watershed-scale Agricultural Runoff Management (ARM) and nonpoint-source models into a basin-scale analysis framework that includes fate and transport in one-dimensional stream channels. It is the only comprehensive model of watershed hydrology and water quality that allows the integrated simulation of land and soil contaminant runoff processes with in-stream hydraulic and sediment/chemical interactions. The result of this coupled simulation is a continuous record of the runoff flow rate and sediment, nutrient, and other water quality constituent concentrations at any point in a watershed [Bicknell et al., 2001][1].

The HSPF model contains hundreds of process algorithms developed from theory, laboratory experiments, and empirical relations from instrumented watersheds. The model simulates

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[1] **Bicknell, B. R.; J. C. Imhoff; J. L. Kittle Jr.; T. H. Jobes; and A. S. Donigian, Jr., 2001.** HSPF Version 12.2 User's Manual, prepared by AQUA TERRA Consultants, Mountain View, CA.

processes such as evapotranspiration; interception of precipitation; snow accumulation and melt; surface runoff; interflow; base flow; soil moisture storage; groundwater recharge; build-up and wash-off of landscape pollutants; heat transfer; sediment (sand, silt, and clay) detachment and transport; sediment routing by particle size; channel and reservoir routing; algae growth, respiration, and die-off; nitrogen and phosphorus cycles; and DO and biochemical oxygen demand (BOD) reactions. Continuous rainfall and other meteorological records are input at an hourly time-step into the model algorithms to compute streamflow, pollutant concentrations, and loading time series.

NFCRM APPLICATION SUMMARY

The initial calibration of the NFCRM was completed for the Minnesota Pollution Control Agency (MPCA) in July 2012 and was provided with a memorandum that contains a high level of detail about the development of the model application [Reisinger and Love, 2012]. This calibration represents a long term period from 2001 through 2009 with more focus on recent results. Figure 1 illustrates the model application area and primary calibration gages for the NFCRM. Figures 2 through 9 illustrate the calibrated results for flow, water temperature, nitrate and nitrite, total ammonia, total phosphorus, BOD, chlorophyll *a*, and DO, respectively, at Reach 530. The simulated results in red are plotted against observed data in blue for model Reach 530, which is just upstream of the confluence with the South Fork Crow River.

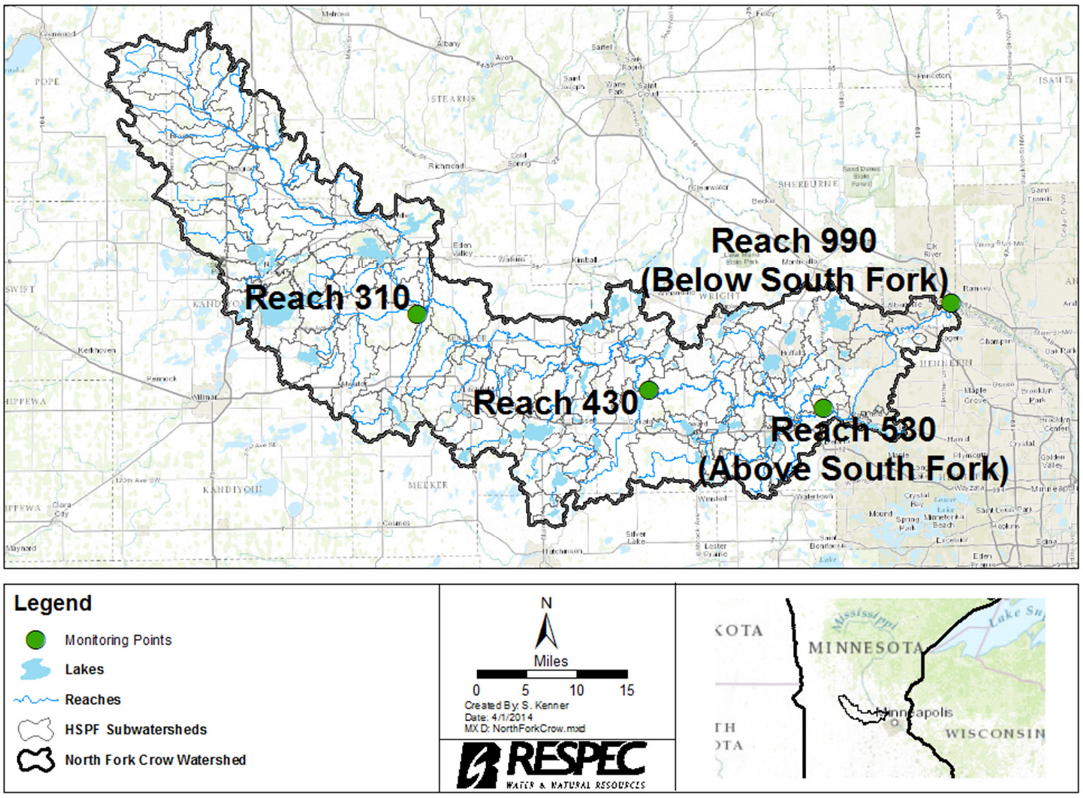

Figure 1. Map of the North Fork Crow River Model Application Area.

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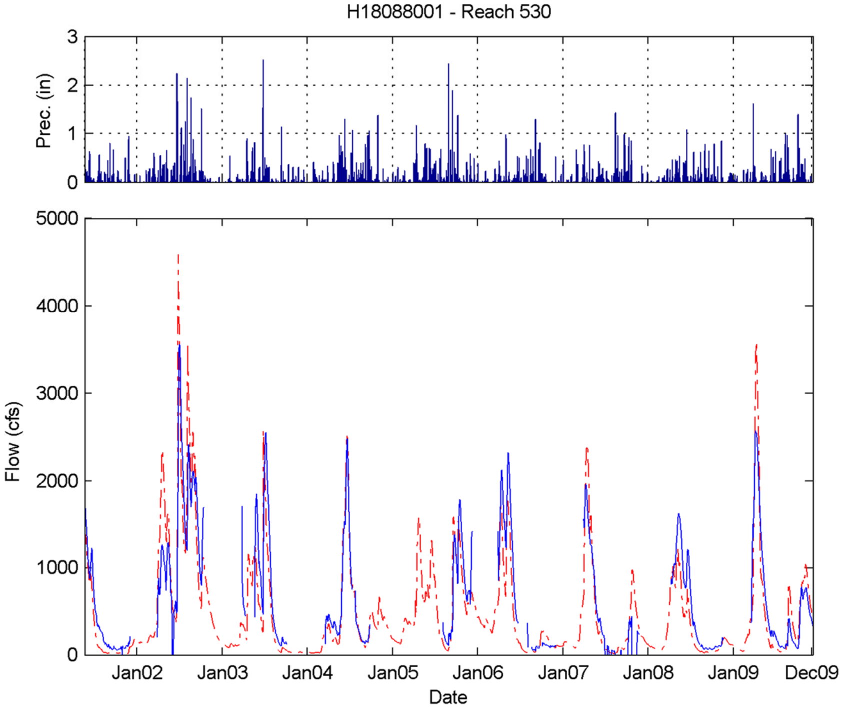

Figure 2. Simulated and Observed Flow at North Fork Crow River Reach 530.

RSI-2418-15-082

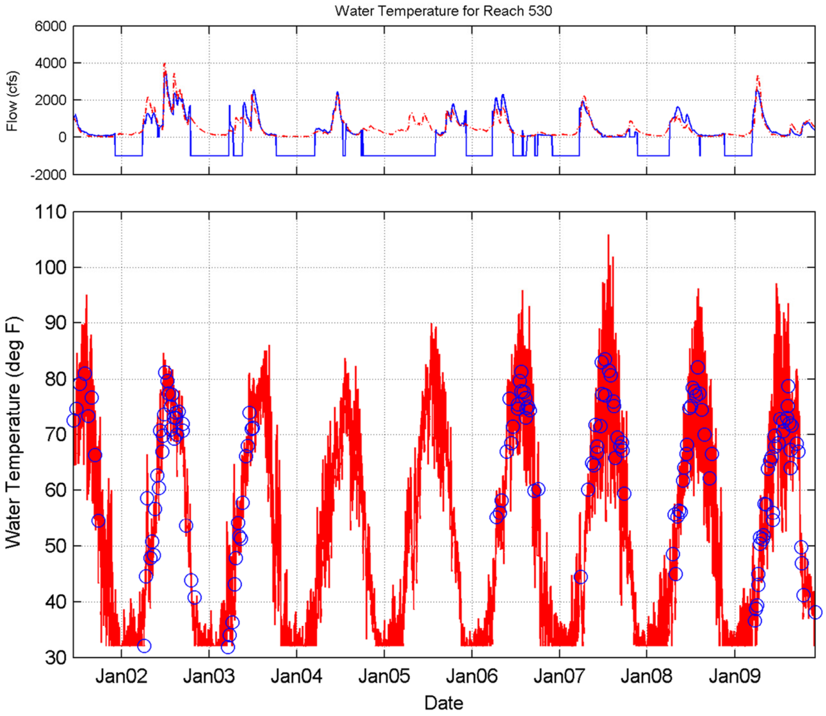

Figure 3. Simulated and Observed Water Temperature at North Fork Crow River Reach 530.

RSI-2418-15-083

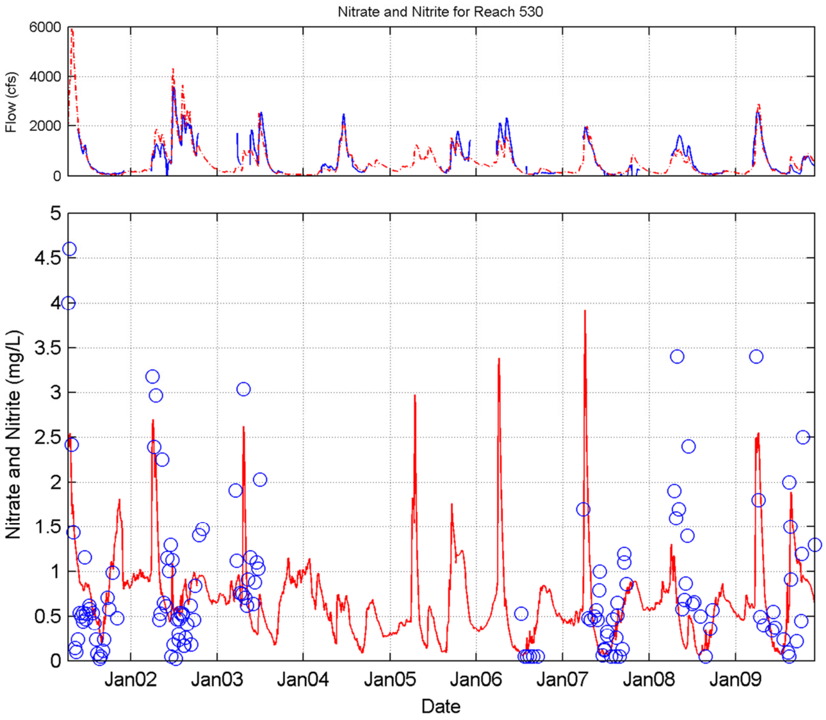

Figure 4. Simulated and Observed Nitrate and Nitrite at North Fork Crow River Reach 530.

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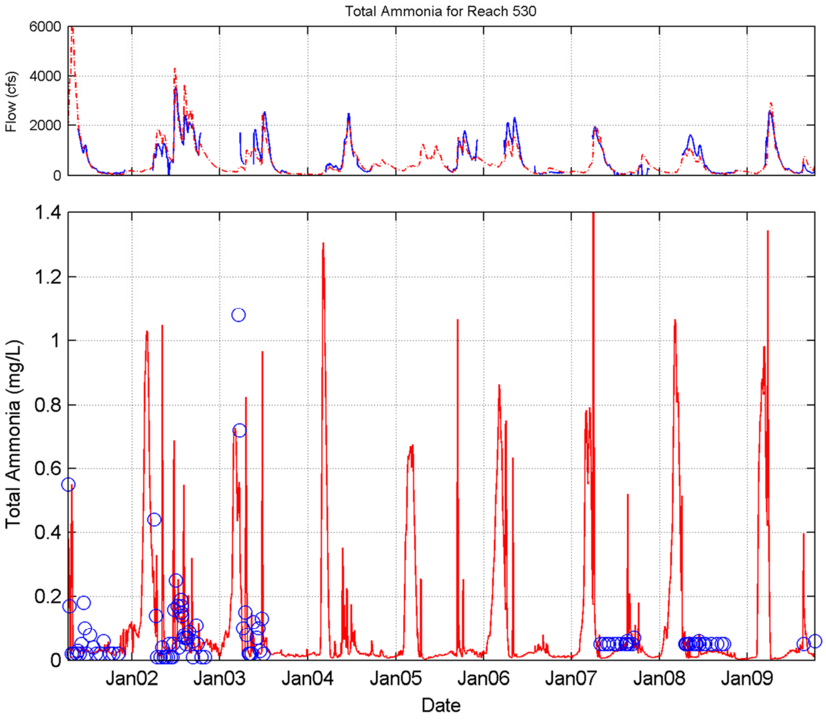

Figure 5. Simulated and Observed Total Ammonia at North Fork Crow River Reach 530.

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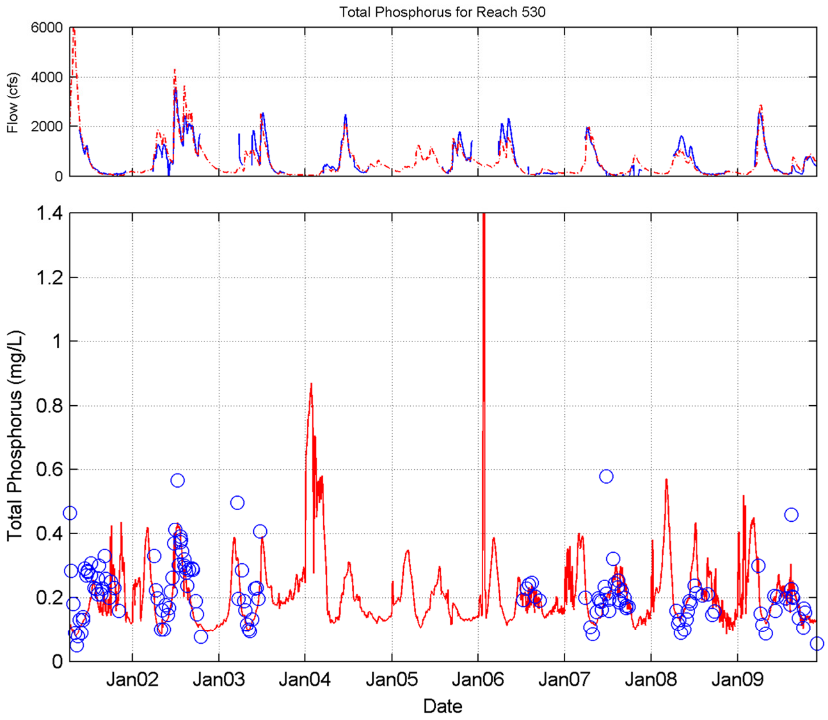

Figure 6. Simulated and Observed Total Phosphorus at North Fork Crow River Reach 530.

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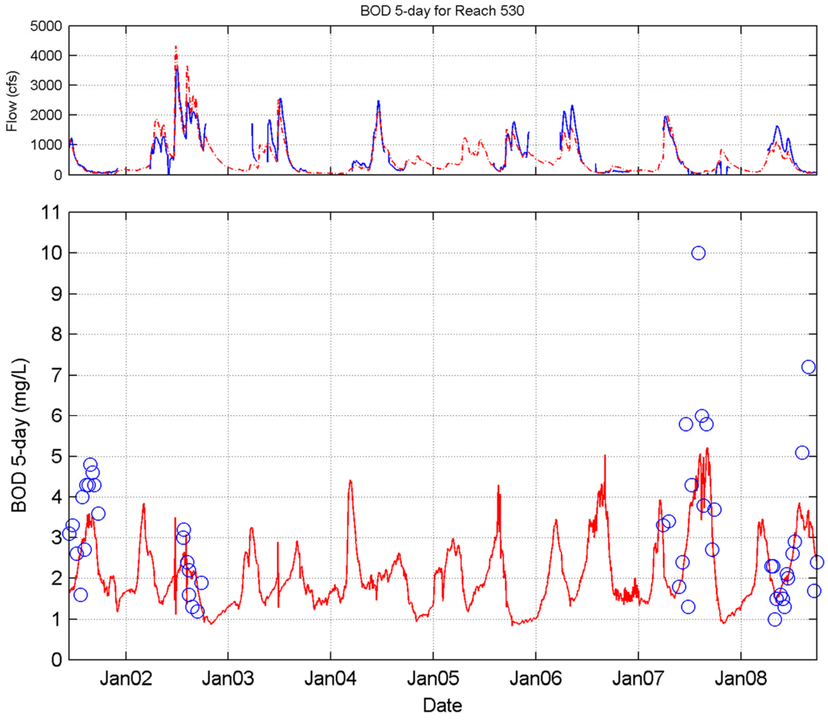

Figure 7. Simulated and Observed Biochemical Oxygen Demand at North Fork Crow River Reach 530.

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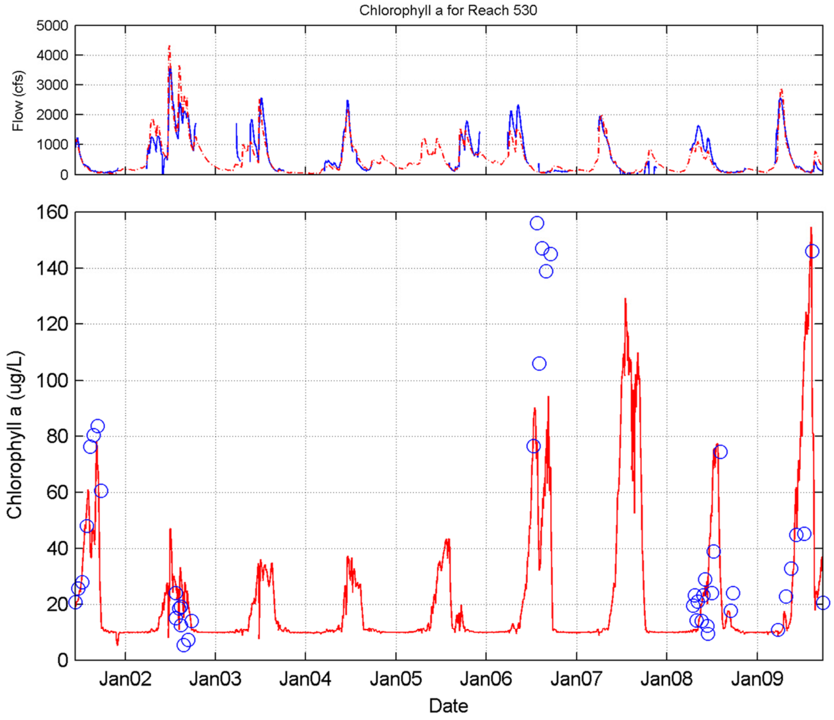

Figure 8. Simulated and Observed Chlorophyll *a* at North Fork Crow River Reach 530.

RSI-2418-15-088

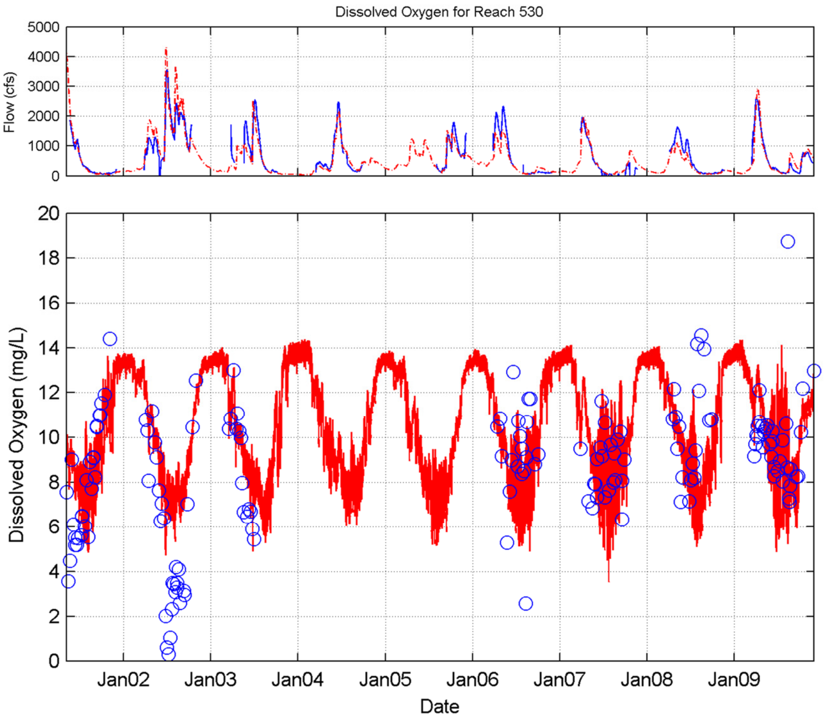

Figure 9. Simulated and Observed Dissolved Oxygen at North Fork Crow River Reach 530.

CALIBRATION UPDATES

The impairments being addressed are DO impairments on Assessment Unit Identification (AUID) numbers 07010204-502 and -503, and -681. These AUIDs correspond to model Reaches 530 and 990, respectively. A discussion of the calibration update to Reach 530 is provided here to focus on the impact from the North Fork Crow River Watershed.

The focus of the North Fork Crow River calibration update was for the year 2002 because the majority of the DO concentrations that are below 5 milligrams per liter (mg/l) occur in the year 2002 at very high flows. The original calibration shows a reasonable fit during the year 2002 for all constituents except dissolved oxygen. To identify the drivers of the low dissolved oxygen during this period, parameters were adjusted to determine which ones had the most sensitivity to the dissolved oxygen concentrations. The two most sensitive parameters were those that represent reaeration and sediment oxygen demand. The reaeration impacted all the dissolved oxygen concentrations throughout the year, which resulted in low concentrations outside of the summer months. Increasing the sediment oxygen demand created the desired fit during spring, summer, and fall months.

Figure 10 shows the updated dissolved oxygen calibration with a good fit in the year 2002 but had a poor fit in the other years that have low flows during the summer months. Research was done to determine the cause of the high sediment oxygen demand required at high flows to fit the model to the observed data. A Total Maximum Daily Load (TMDL) project in the Long Prairie Watershed reported low dissolved oxygen at higher flows and attributed the cause to sediment oxygen demand in riparian wetlands that only became inundated at higher flows [MPCA, 2004][2].

Figure 11 illustrates a stretch of the North Fork Crow River just upstream of where the observed data for Reach 530 was collected. The figure indicates a blue area that represents the primary channel and a red area that represents the floodplain where riparian wetlands typically occur. The figure shows a clear riparian wetland on the left bank just upstream of the water quality sampling location, which is shown as the green circle.

The result of the calibration update is two distinct models. Both models represent all water quality constituents well except the dissolved oxygen. The original calibrated model uses a sediment oxygen demand that represents the channel within the banks, and the updated model uses a much higher sediment oxygen demand that represents the riparian wetlands in the floodplain. The higher sediment oxygen demand is estimated to begin to have an impact at flows between 1,000 and 1,500 cubic feet per second (cfs).

DRIVERS OF DISSOLVED OXYGEN CONDITIONS

The primary driver of the low dissolved oxygen at high flows in the North Fork Crow River impaired reaches was determined to be sediment oxygen demand in riparian wetlands. Riparian wetland processes can cause higher sediment oxygen demand that can be greatly intensified by

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[2] **Minnesota Pollution Control Agency, 2004.** *Long Prairie River Watershed TMDL Project: Final Project Report*, prepared by Wenck Associates, Inc., Maple Plain, MN, and FTN Associates, LTD, Little Rock, AR, for the Minnesota Pollution Control Agency, St. Paul, MN.

increased nutrients introduced through anthropogenic sources. Another cause of the low dissolved oxygen could be the effect of lower velocity flow through riparian wetlands, which can reduce the amount of reaeration that occurs.

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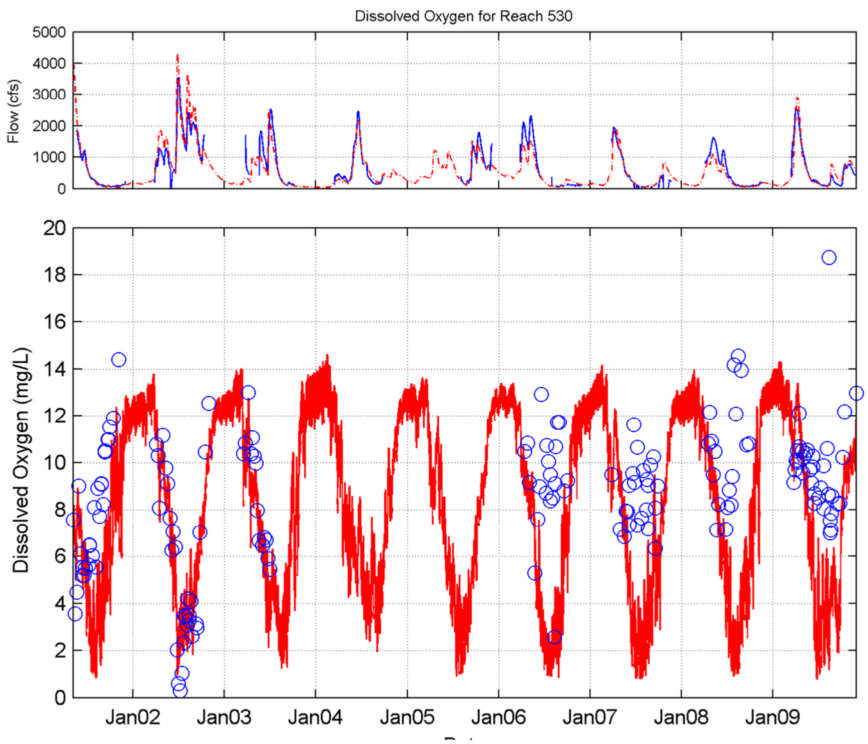

Figure 10. Simulated and Observed Dissolved Oxygen at North Fork Crow River Reach 530 for the Updated Calibration.

RECOMMENDATIONS

The application of two distinct models should be done to address the appropriate conditions. The original model should be used to address dissolved oxygen issues that occur at lower flows. The updated model based on the high flows in year 2002 should be used to address dissolved oxygen issues at higher flows that are greater than 1,000 to 1,500 cfs.

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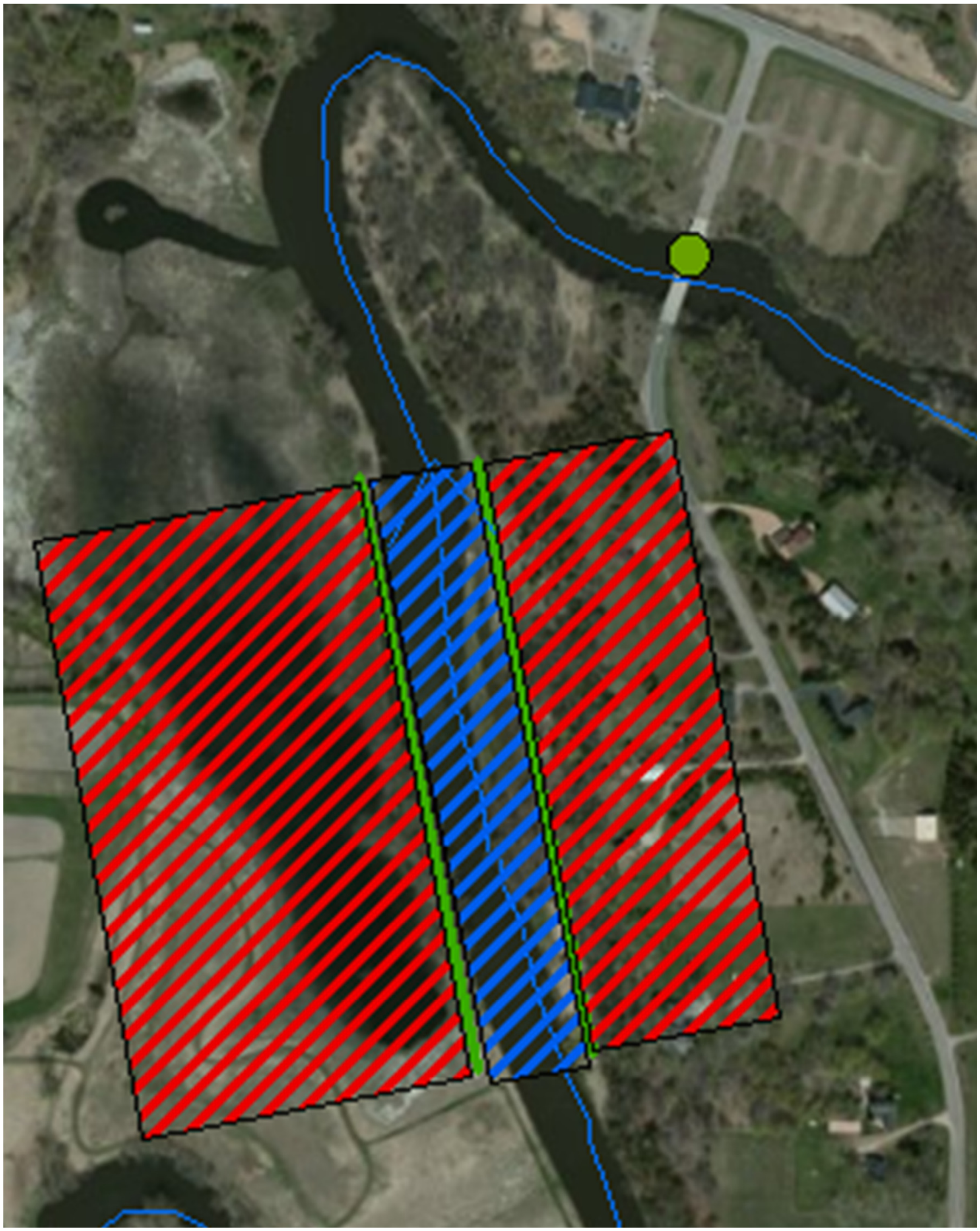

Figure 11. North Fork Crow River Reach Upstream of Reach 530 Sampling Location.

ATTACHMENT A

HSPF MODELING OF THE SAUK RIVER, CROW RIVER, AND SOUTH FORK CROW RIVER

HSPF MODELING OF THE SAUK RIVER, CROW RIVER, AND SOUTH FORK CROW RIVER

Topical Report RSI-2292

prepared for

Minnesota Pollution Control Agency
520 Lafayette Road
St. Paul, Minnesota 55155

July 2012

RESPEC
CONSULTING & SERVICES

HSPF MODELING OF THE SAUK RIVER, CROW RIVER, AND SOUTH FORK CROW RIVER

Topical Report RSI-2292

by

Daniel L. Reisinger
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July 2012

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1.0 INTRODUCTION

1.1 PURPOSE AND OBJECTIVES

The U.S. Environmental Protection Agency (EPA) requires the Minnesota Pollution Control Agency (MPCA) to execute the Total Maximum Daily Load (TMDL) Program in the state of Minnesota. Minnesota has an abundance of lakes and river reaches, many of which will require a TMDL assessment. In an effort to expedite the completion of TMDL projects, the MPCA decided to construct watershed models. These models have the potential to support the simultaneous development of TMDL assessments for multiple listings within a cataloging unit or 8-digit Hydrologic Unit Code (HUC) watershed. This report documents the modeling of three 8-digit HUC watersheds: Crow River/North Fork Crow River (07010204), South Fork Crow River (07010205), and the Sauk River (07010202).

The objective of this project is the successful calibration and validation of **HSPF** model applications for the three watersheds. These fully functioning, calibrated, and validated executable models simulate the following at a management unit level:

- hydrology
- sediment
- temperature
- phosphorus
- nitrogen
- dissolved oxygen
- oxygen demand
- chlorophyll.

1.2 WATERSHED DESCRIPTION

The three 8-digit HUC watersheds are located in the west-central portion of Minnesota, as shown in Figure 1-1. The South Fork Crow River (South Crow) flows into the Crow River near Rockford, Minnesota. The watershed upstream of the confluence is referred to as the North Fork Crow River (North Crow), while areas downstream are referred to as the Crow River (Crow). Note the term “Crow Watershed” is used in this report to represent the entire watershed, including the North Crow and South Crow Watersheds. All three rivers flow from the west to the east. The outlet of the Sauk River (Sauk) is located on the western side of the St. Cloud metropolitan area.

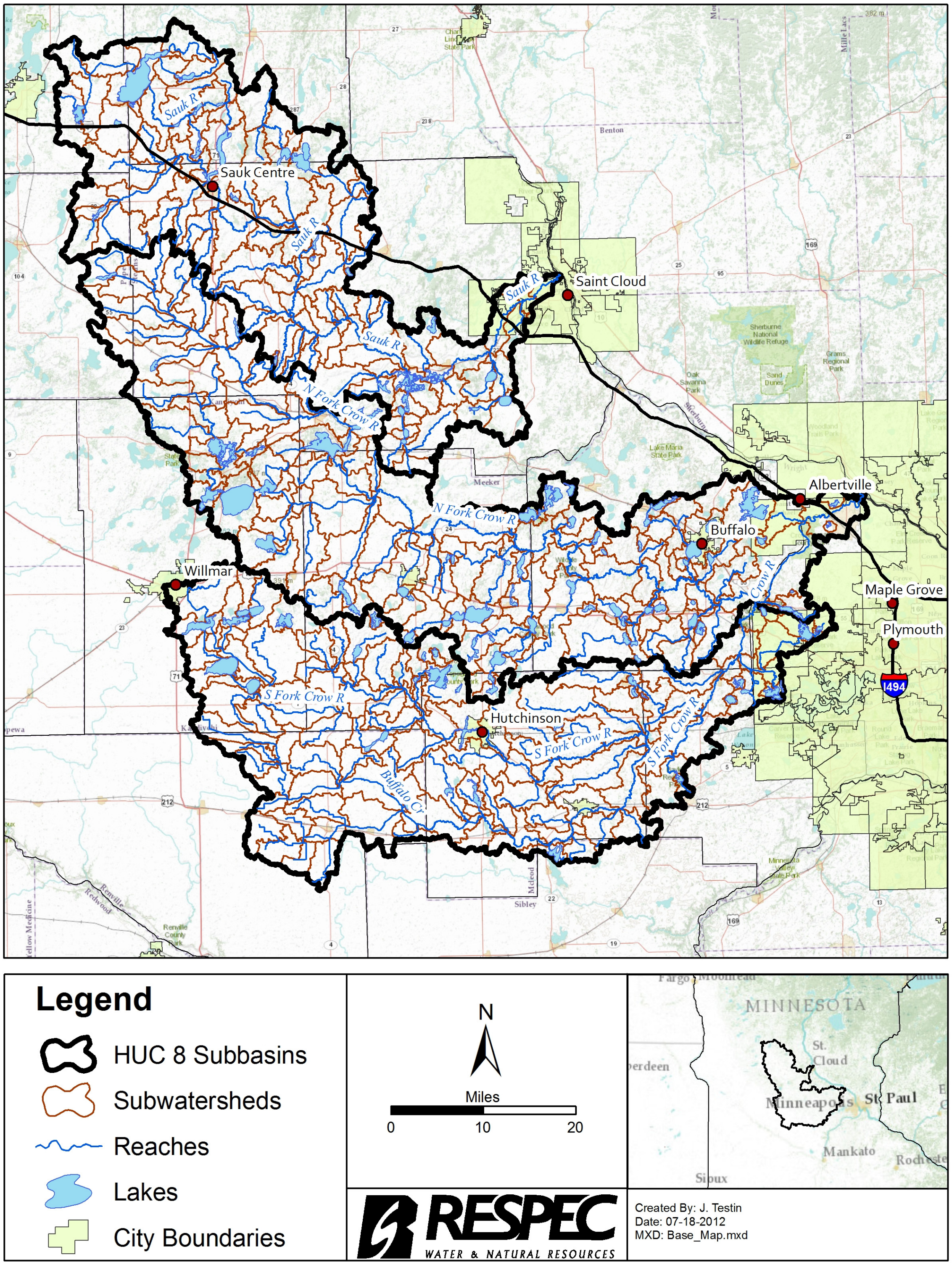

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Figure 1-1. Crow and Sauk River Watersheds.

The watersheds are largely agricultural, mostly corn/soybean and dairy operations. There are 122 communities interspersed throughout the watersheds. Larger communities include Buffalo, Corcoran, Dayton, Glencoe, Hutchinson, Independence City, Le Sauk, Litchfield, Loretto, Maple Plain, Medina, Minnetrista, Monticello, Otsego, Sartell, St. Cloud, St. Joseph, St. Michael, Waite Park, and Willmar, Minnesota. The watersheds include all or part of the following counties: Carver, Douglas, Hennepin, Kandiyohi, McLeod, Pope, Renville, Sibley, Stearns, Todd, and Wright.

The watersheds are found in two ecological providences. The western and southern portions of the watersheds are in the Northern Glaciated Plains, while the eastern portions are in the Northern Hardwood forests. The Northern Hardwood forests areas are characterized by deep lakes that can trap substantial sediment and nutrients. While this trapping may reduce the nutrient concentrations further downstream, it can impair water quality in the lakes. The Northern Glaciated Plains tend to have shallower lakes that can also have water-quality issues.

Soils have a strong influence on hydrology and land management. Soils in the Sauk Watershed generally have a higher sand content than those in the Crow Watershed. Irrigation is used in some portions of the Sauk Watershed but is rare in the Crow Watershed. The soils in the Crow Watershed are generally less permeable (more silt and clay). Tile drainage is used in all three watersheds. However, the Crow Watershed has a higher density of tile drainage, with the highest in the South Crow Watershed.

Impairments in the Sauk Watershed include dissolved oxygen (DO), turbidity, *E. coli*, fecal coliform, polychlorinated biphenyls (PCB) in fish, and fish and invertebrate bioassessments. Similarly, impairments in the Crow Watersheds (North and South) include chloride, DO, ammonia, turbidity, *E. coli*, fecal coliform, and fish and invertebrate bioassessments. The Sauk and Crow Watersheds also have nutrient impairments in multiple lakes and the North Fork Crow Watershed has one plant-bioassessment lake impairment. Figure 1-2 shows the TMDL waterbodies in the watersheds.

HSPF uses this information, measured data, and established hydrologic and water-quality relationships to represent the watersheds. This report documents the formulation, calibration, validation, and execution of the model applications. The models are documented in this report as well as in previous separate memorandums.

1.3 WORK ORDER TASKS

The contents of this report were developed over the Fiscal Years 2011 and 2012. Four work orders were issued to build the model, calibrate/validate, and run scenarios. The objectives of these work orders are presented below.

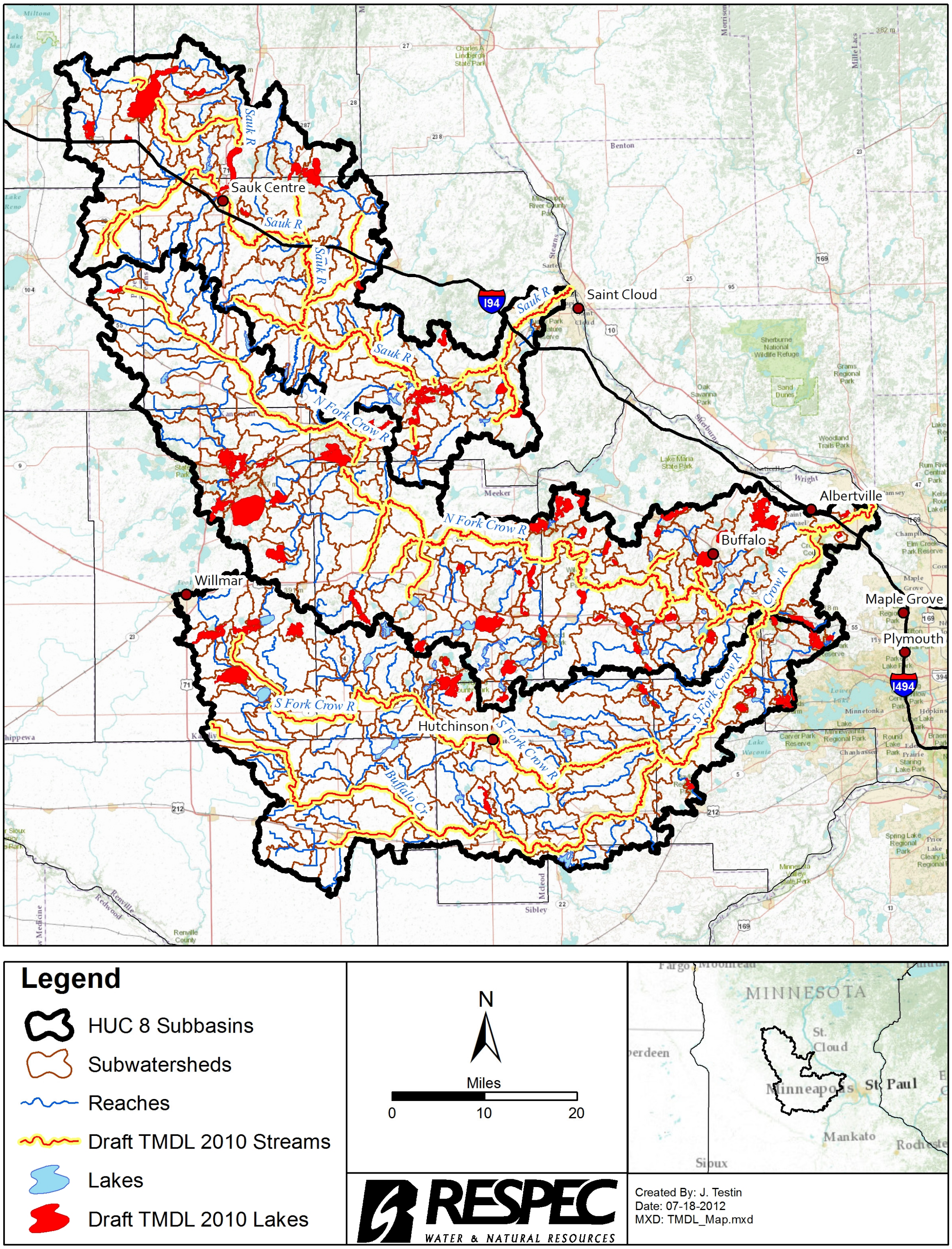

Figure 1-2. Impaired Streams and Lakes in the Crow and Sauk River Watersheds.

1. Compile both the geographic and time-series data required to construct the model framework.
2. Develop representation of watershed area and drainage network.
    - *Lake Selection for Sauk, North Crow, and South Crow Watersheds* [Love, 2011a]
    - *Primary Reach Selection, Reach/Subwatershed Numbering Scheme Development, and F-Table Development for Sauk, North Crow, and South Crow Watersheds* [Love, 2011b]
    - *Pervious (PERLND) and Impervious Land (IMPLND) Category Development* [Love, 2011c]
3. Develop and implement a strategy for the representation of point sources within the **HSPF** model domain.
    - *Time-Series Development for Sauk, North Fork Crow, and South Fork Crow Watersheds* [Love, 2011d]
4. Formulate time series from observed flow and water-quality monitoring to be used for watershed model calibration and validation.
5. Perform the hydrologic calibration, conduct hydrologic validation, and provide water balance.
    - *Hydrology Calibration and Validation of Sauk, North Crow, and South Crow HSPF Watershed Models* [Love, 2011e]
6. Define the sources of sediment within the watershed and conduct sediment calibration and validation tests.
    - *Proposed Approach for Modeling Water Quality in the Sauk, North Crow, and South Crow* ***Hydrological Simulation Program – FORTRAN (HSPF)*** *Watershed Models* [Love, 2011f]
7. Conduct water-quality calibration, validation, and model evaluation.
8. Incorporate internally generated phosphorus loadings for explicitly modeled lakes.
9. Develop and execute implementation scenarios.
10. Create **GenScn** projects containing output from the Sauk and Crow Rivers (including both North and South Forks).

The memorandums, result figures, **GenScn** projects, **HSPF** model files, and Geographic Information System (GIS) data were provided separately in the 2012 deliverable package [Love, 2012]. Result figures have been included for all primary calibration stations for hydrology and all water-quality parameters. The **GenScn** projects have been formulated for the Sauk and Crow (i.e., Crow River, North Fork Crow River, and South Fork Crow River) and incorporate both the base models and the implementation scenarios.

2.0 MODEL SETUP AND APPROACH

The **HSPF** model applications from the South Crow, North Crow, and Sauk Rivers represent connected watershed and in-stream processes. The general workflow for modeling is presented in Figure 2-1. Model setup focuses on incorporating major sources of flow and water-quality loads into the model applications. The calibration/validation process focuses on adjusting parameters that cannot be reasonably estimated by characteristics of the watershed to obtain acceptable results. The results are presented and discussed in Chapter 3.0 and Chapter 5.0. The following section provides an overview of the model and its calibration.

2.1 SUMMARY OF HSPF

"**HSPF** simulates for extended periods of time the hydrologic and associated water quality, processes on pervious and impervious land surfaces and in streams and well-mixed impoundments [U.S. Geological Survey, 2012]." **HSPF** is a continuous simulation that typically produces output on a daily basis using an hourly time step. The model incorporates nonpoint or watershed flow and water-quality loads. Pervious areas are simulated using the PERLND module and impervious areas are simulated using the IMPLND module. In-stream hydraulics and stream/lake water-quality processes are simulated with the RCHRES module, using inputs from the other modules. Meteorological, point source, and other data are incorporated through time series stored in a binary Watershed Data Management (WDM) file.

2.2 MODEL SETUP

The model applications represent agricultural, urban, and rural sources of pollutants. This section summarizes the source assessment and generation phase of the modeling processes.

2.2.1 Meteorological Data

Forty-three separate meteorological zones (referred to as hydrozones) were used in the Crow and Sauk model applications. The hydrozones were based on available precipitation stations, as shown in Figure 2-2. The extensive meteorological zones were developed using stations from the U.S. Environmental Protection Agency's (EPA) **BASINS** database and supplemental data from the **High Spatial Density, Daily Operations (HIDEN)** database. The meteorological parameters used to represent precipitation, potential evaporation and snow processes include:

- precipitation
- air temperature
- solar radiation

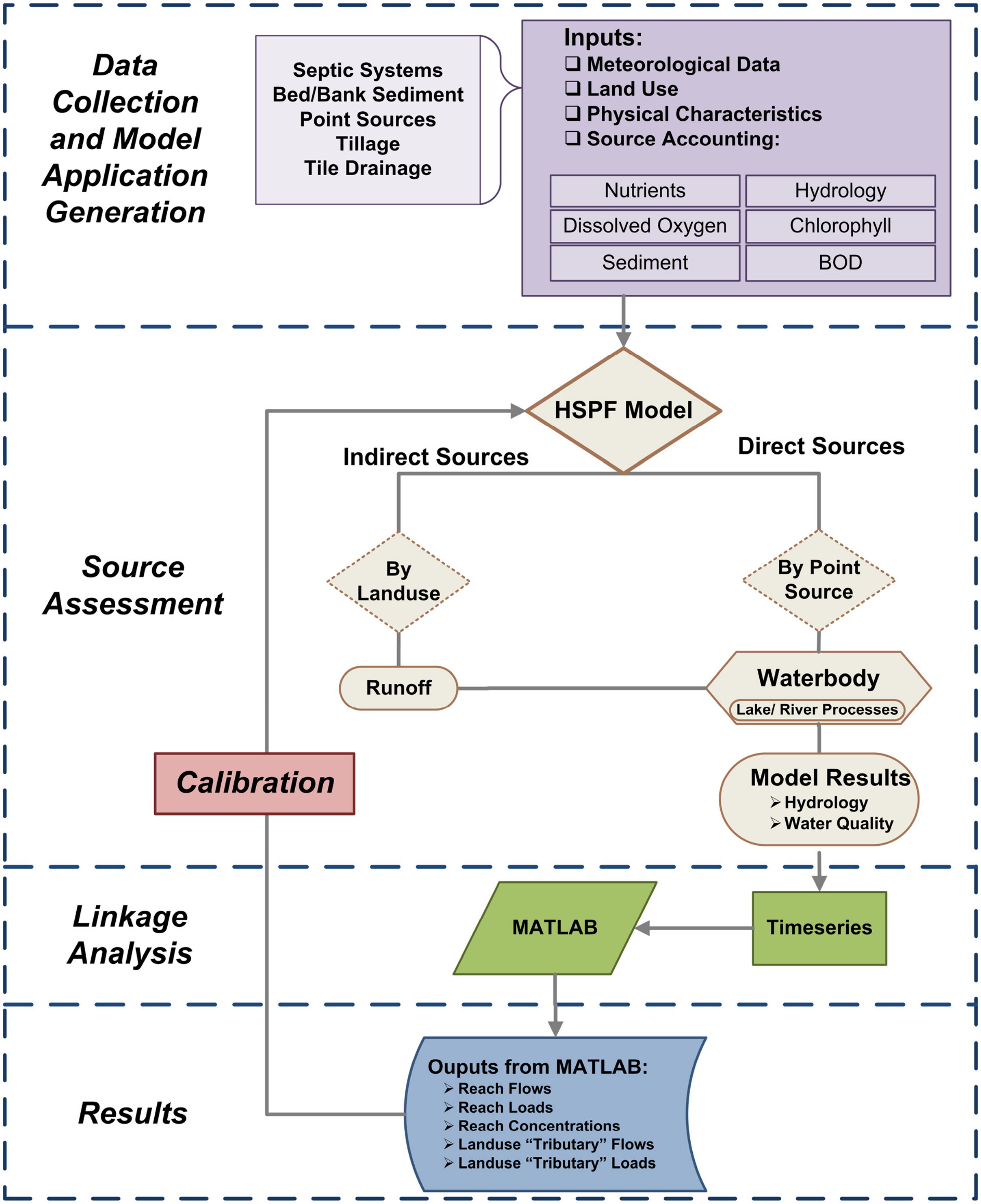

Figure 2-1. HSPF Model Application General Work Flow Diagram.

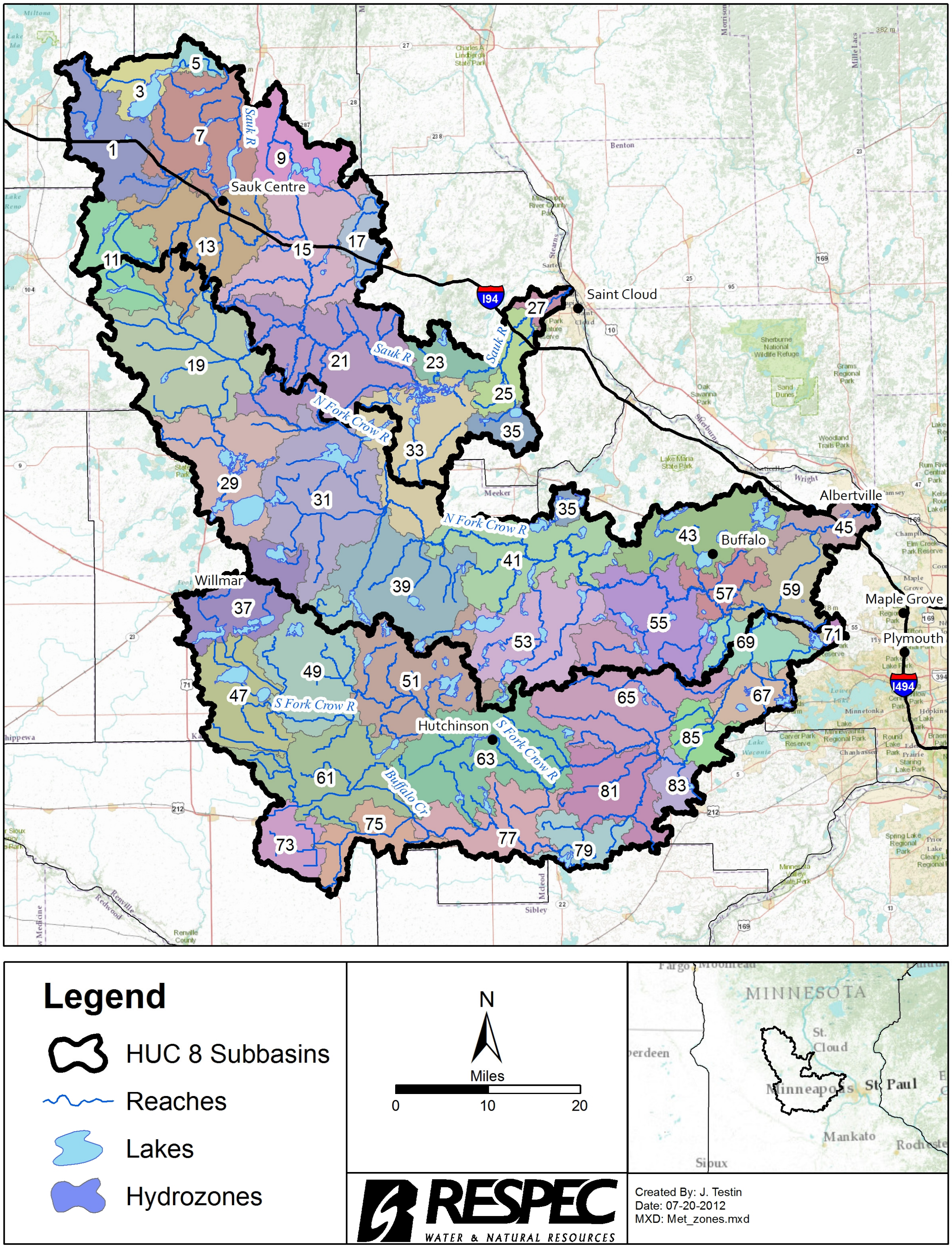

Figure 2-2. Hydrozones Included in HSPF Model Applications.

- wind speed
- dewpoint
- cloud cover.

For each meteorological parameter, a continuous time series was developed for the period of January 1, 1995, through December 31, 2009. Stations with incomplete data for the modeling period were extended or filled with available data from the closest station.

2.2.2 Land Use

The **HSPF** model applications from the South Crow, North Crow, and Sauk Rivers simulate watershed processes for six broad land uses. To better model the existing conditions and to aid in evaluating alternative management strategies, these land uses were further categorized into 13 land uses, as presented in Figure 2-3. Additionally, the model applications were formulated to track the watershed flow and load from municipal separate storm sewer systems (MS4s). The 13 land uses were represented in each of the 43 meteorological zones resulting in a total of 559 unique land uses.

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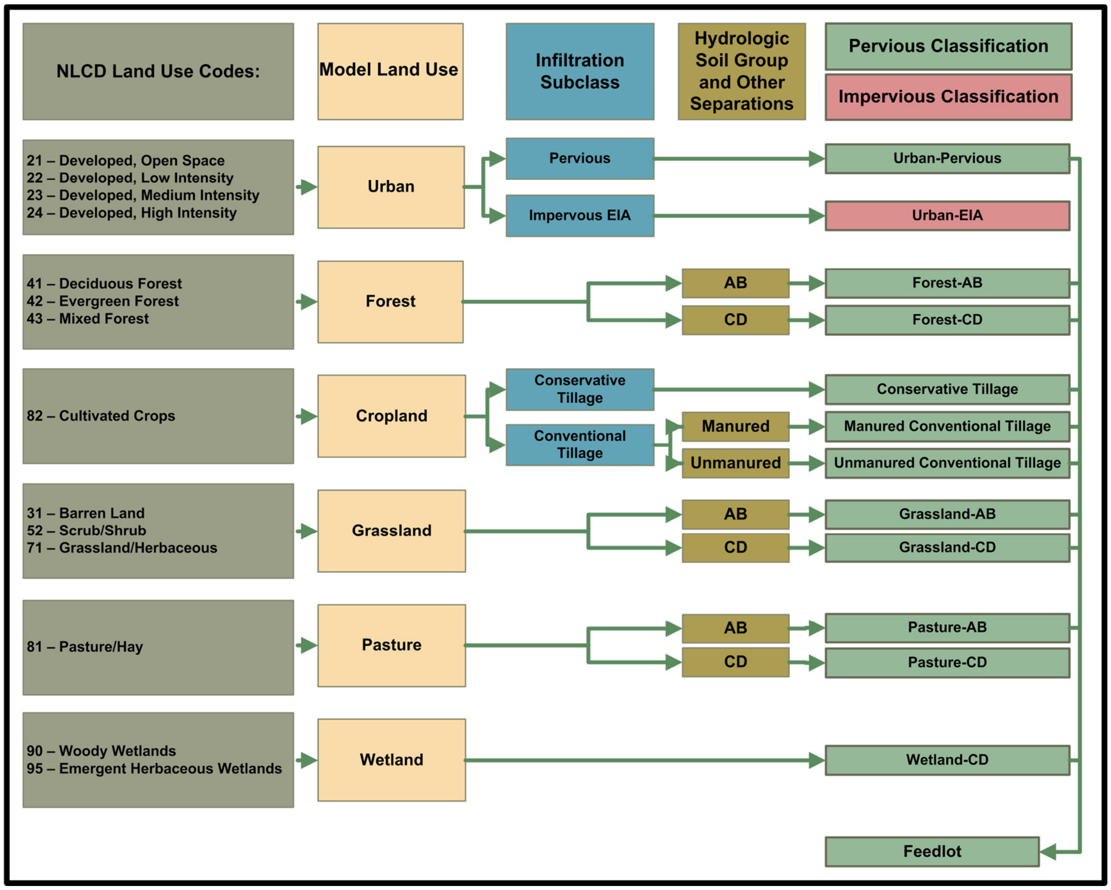

Figure 2-3. Classification for the Crow and Sauk Watershed Model Applications.

As the major land use in the watersheds, agricultural activities were categorized into six separate pasture and cropland pervious land uses (e.g., conservation tillage, manured conventional tillage, unmanured conventional tillage, pasture AB, pasture CD, and feedlot). In previous submittals, the cropland land use was categorized by artificial drainage and hydrologic soil group, rather than tillage. The current tillage classification was considered preferable when developing Best Management Practices (BMPs) and management scenarios.

A key assumption for the proposed classification is that farmers are working to maintain ideal soil moisture conditions on cropland through irrigation (when available) and through tile drainage, tillage, and manure application. Thus the hydrologic soil group may not provide a good representation of field conditions. Hydrologic soil groups (AB and CD soils) will still be represented on forest, grassland, and pastureland as soil moisture conditions are not likely to be as highly regulated on the majority of these lands. While drainage was removed as a land use, sediment loading through surface inlets was explicitly incorporated into each reach. Further, the effect of artificial drainage was implicitly represented in the hydrology parameterization.

2.2.2.1 Estimating Conservation and Conventional Tillage Areas

Minnesota Tillage Transect Survey Data Center data were available by county (*http://mrbdc.mnsu.edu/minnesota-tillage-transect-survey-data-center*). These tillage surveys included total acres farmed, total conservation tillage acres, and total conventional tillage acres in 1995 through 1998, 2000, 2002, 2004, and 2007. Conservation tillage was categorized by greater than 30 percent of residue remaining on the field and includes no-till, ridge-till, and mulch-till practices. Conventional tillage was categorized by 30 percent or less residue remaining on the field and included reduced-till and intensive-till practices. Residue on the fields can increase the upper zone storage capacity, which in turn, can decrease runoff, impacting sediment and water-quality processes.

ArcGIS was used with these data to estimate weighted-area fractions of conservation tillage versus conventional tillage for each subwatershed. The validation model applications (based upon National Land Cover Data [NLCD] 2001 version 2 land use), 1995 through 2003, used an average of the 1995 through 1998, 2000, and 2002 transect surveys. The calibration model applications (based upon NLCD 2006 land use was used to represent 2004 through 2009), 2004 through 2009, an average of the 2004 and 2007 transect surveys. In both cases, conventional tillage was used in at least 60 percent of surveyed fields, except Reach 535 of the South Crow (49 percent).

2.2.2.2 Estimating Feedlots and Manure Application Areas

An estimated 1,664, 1,133, and 824 animal feedlot operations are located in the Sauk, North Crow, and South Crow River Watersheds, respectively. Feedlot operations are required to adhere to health, safety, and environmental laws. Feedlots with 1,000 or greater animal units are required to have no surface discharge. Manure generated at these operations is used throughout the watersheds as a fertilizer and to increase water retention in the soil. Manure, as well as inorganic fertilizers, may contribute to impaired water quality in waterbodies.

There was substantial uncertainty in spatial distribution of manure application. Therefore, a single conventional tillage land use was used to represent both chemical and organic fertilizer applications. This land use was calibrated throughout the watersheds to implicitly represent differences in fertilizer use, including manure. The manured conventional tillage land use was reserved to aid in developing future scenarios (no area has been allocated to the land use in the base models), if necessary. The representation of the feedlot land use class, which was retained, was further discussed in Love [2011c].

2.2.3 Physical Characteristics

An extensive network of reaches represents the river, streams, and lakes of the watersheds. Consistent with local planning activities, the model reach watersheds were based on the Crow and Sauk Management Units. These management units are typically of similar or smaller size than the U.S. Geological Survey (USGS) HUC 12 watersheds. Cross-sectional and hydrologic information was used to generate representation of the reach geometry. Explicitly simulated lakes were selected based the availability of bathymetry data, potential impacts on downstream reaches, and need for future evaluation (i.e., TMDL evaluations, and point-source permits). Additional details on the formulation of reaches and the use of physical characteristics in representing the watershed loading can be found in Love [2011a; 2011b].

2.2.4 Source Accounting

Flow and water-quality loads from key sources were determined based on discussions with MPCA, watershed district staff, and RESPEC experience from model development and calibration. **HSPF** represents the majority of these sources as part of the land use (e.g., tillage and tile drainage) or in-stream water-quality processes (e.g., bed/bank erosion and internal lake phosphorus loading). To better represent field conditions after tillage, additional detached sediment was added to cropland fields in April, May, June, and October. Internal phosphorus loading to lakes was also modeled, which is described in more detail in Chapter 4.0. Point sources and septic tanks, or individual treatment systems (ISTS), were also incorporated using well-established methods.

Effluent water-quality parameters used in the model application include carbonaceous 5-day biological oxygen demand (CBOD5), total suspended solids (TSS), total phosphorus (TP), DO, total ammonia (NH3+NH4), and water temperature. Time series of flow and water-quality load were used when data were available. Periods of missing data were filled generally by interpolation or as a constant concentration when no data were available, as described in Love [2011d].

The approach to estimating the discharge to stabilization ponds was updated from what is described in Love [2011d]. Controlled ponds generally discharge intermittently for variable lengths of time, while mechanical sites discharge more continuously. Discharge data for minor controlled pond sites were provided as a combination of monthly volumes and monthly average flow. Because controlled ponds release effluent intermittently, if a controlled pond was missing monthly discharge, it was assumed that the pond did not release effluent to surface water during that month. Minor discharge data for mechanical sites were also provided as a combination of monthly volumes and monthly average flow. However, because mechanical sites release effluent more continuously, if a mechanical site was missing monthly discharge data, it was assumed that the site was releasing effluent to surface water, and any missing months were filled using monthly averages. An estimate of number of discharge days was supplied by MPCA and was incorporated using the following logic supplied by Henningsgaard [2012]:

1. If there are only a few discharge days followed by a month with only a few discharge days, or if the first month has only a couple of days and the next month has up to 10 discharge days, the days should be placed at the end and beginning of the 2 months.
2. If there are over 6 discharge days in a month, but less than about 18 days, the days can be placed anywhere consecutively.
3. If there are over 18 discharge days, half of the days should be placed in the first half of the month and half of the days in the second half of the month.

The loading from ISTS were included in the models based on Minnesota Pollution Control Agency [2004]. The numbers of residence with ISTS were allocated evenly across the county and watershed. Loads per septic system were incorporated into the model with the same parameters as point sources. ISTS loading was on a per-person basis. Systems were given 50 gallons per day (gpd) flow and constant concentration of 53 milligrams per liter (mg/L) nitrogen, 10 mg/L phosphate, and 175 mg/L CBODs.

2.3 CALIBRATION AND VALIDATION

Calibration was a critical process in the development of parameters for the **HSPF** hydrologic model applications. Calibration was required for parameters that cannot be reasonably estimated by characteristics of the watershed. The calibration of the **HSPF** model applications was a cyclical process of making parameter changes, running the model, producing graphical and statistical comparisons of simulated and observed values, and interpreting the results. Observed data for hydrologic calibration involved continuous stream flow collected at gaging stations from reputable sources. Calibration was typically evaluated with visual and statistical performance criteria. A validation of model performance was conducted separately from the calibration effort.

The period of record used for the calibration and validation of the model application was based on the available meteorological data (1995–2009). The calibration period was defined as

January 1, 2003, through December 31, 2009. The validation period was defined as January 1, 1996, through December 31, 2003. The year 1995 was excluded from statistical analyses because of the sensitivity of some model outputs to the initial modeling conditions. The validation period in the Crow Watershed was limited by the available records for the actively managed New London dam. The validation in the Crow Watershed was restricted to January 1, 2000, through December 31, 2003. To maximize the use of available water-quality data, the entire period of record was used in the calibration/validation of the water quality in the Crow and Sauk model applications.

3.0 HYDROLOGY

Hydrology provides the basis of the model application and includes streamflow and lake levels. Water-quality simulations are highly dependent on the hydrology process. Therefore, water-quality calibration could not begin until the hydrology calibration was considered acceptable. This section provides a summary of the final hydrology results. Additional details can be found in the technical memorandum referenced in Love [2011e].

3.1 MODEL PERFORMANCE CRITERIA FOR HYDROLOGY

Model performance was evaluated using a weight-of-evidence approach described in Donigian [2002]. This type of approach used both visual and statistical methods to best define the performance of the model. The process was performed at each flow gage by adjusting parameters for land segments upstream. Moreover, greater weight was applied to the performance of the model at gages where there is more contributing area and a longer period of record. It was also desired to maintain comparable parameter values and intra-parameter variations for each land segment category throughout the watershed.

The graphical plots were visually evaluated to objectively assess the model performance while the statistics were compared to objective criteria developed from 20 years of experience with **HSPF** applications. Graphical plots of streamflow included annual, monthly, and daily time series, as well as flow duration plots. Because of the high number of lakes occurring in these watersheds, lake level was considered. Lake levels were graphically evaluated based on daily time-series and scatter plots of paired measured and simulated data.

Statistical objectives in Table 3-1 were used to evaluate the percent error statistics. The correlation coefficient (r) and coefficient of determination (r^2) were also compared with the criteria in Figure 3-1 to evaluate the performance of the daily and monthly flows.

Table 3-1. General Calibration/Validation Targets or Tolerances for HSPF Applications

	Difference Between Simulated and Recorded Values (%)		
	Fair	**Good**	**Very Good**
Hydrology/Flow	15–25	10–15	<10

Caveats: Relevant to monthly and annual values; storm peaks may differ more.
Quality and detail of input and calibration data.
Purpose of model application.
Availability of alternative assessment procedures.
Resource availability (i.e., time, money, personnel).

Source: Donigian [2000].

R	← 0.75 ——— 0.80 ——— 0.85 ——— 0.90 ——— 0.95 ——→
R^2	←—— 0.6 ——— 0.7 ——— 0.8 ——— 0.9 ——→
Daily Flows	Poor Fair Good Very Good
Monthly Flows	Poor | Fair | Good | Very Good

Figure 3-1. General Calibration/Validation R and R^2 Targets for **HSPF** Applications.

3.2 HYDROLOGY RESULTS

The final calibration was performed using the primary downstream gages for the Sauk and Crow Watershed model applications. Secondary gages upstream and on tributaries were used to help calibrate parameters for less influential land segment categories but are not reported here. A map of the primary discharge gages from initial calibration results is shown in Figure 3-2. Tables 3-2 and 3-3 display the calibration statistics for the Sauk and Crow model applications, respectively, and Tables 3-4 and 3-5 display the validation statistics for the Sauk and Crow model applications, respectively. The “weighted overall” statistic represents a drainage area weighted average. Table 3-6 summarizes the weighted water balance components at the outlets of the Sauk and Crow Watershed model applications. Additional results for the primary gages can be found in Love [2012].

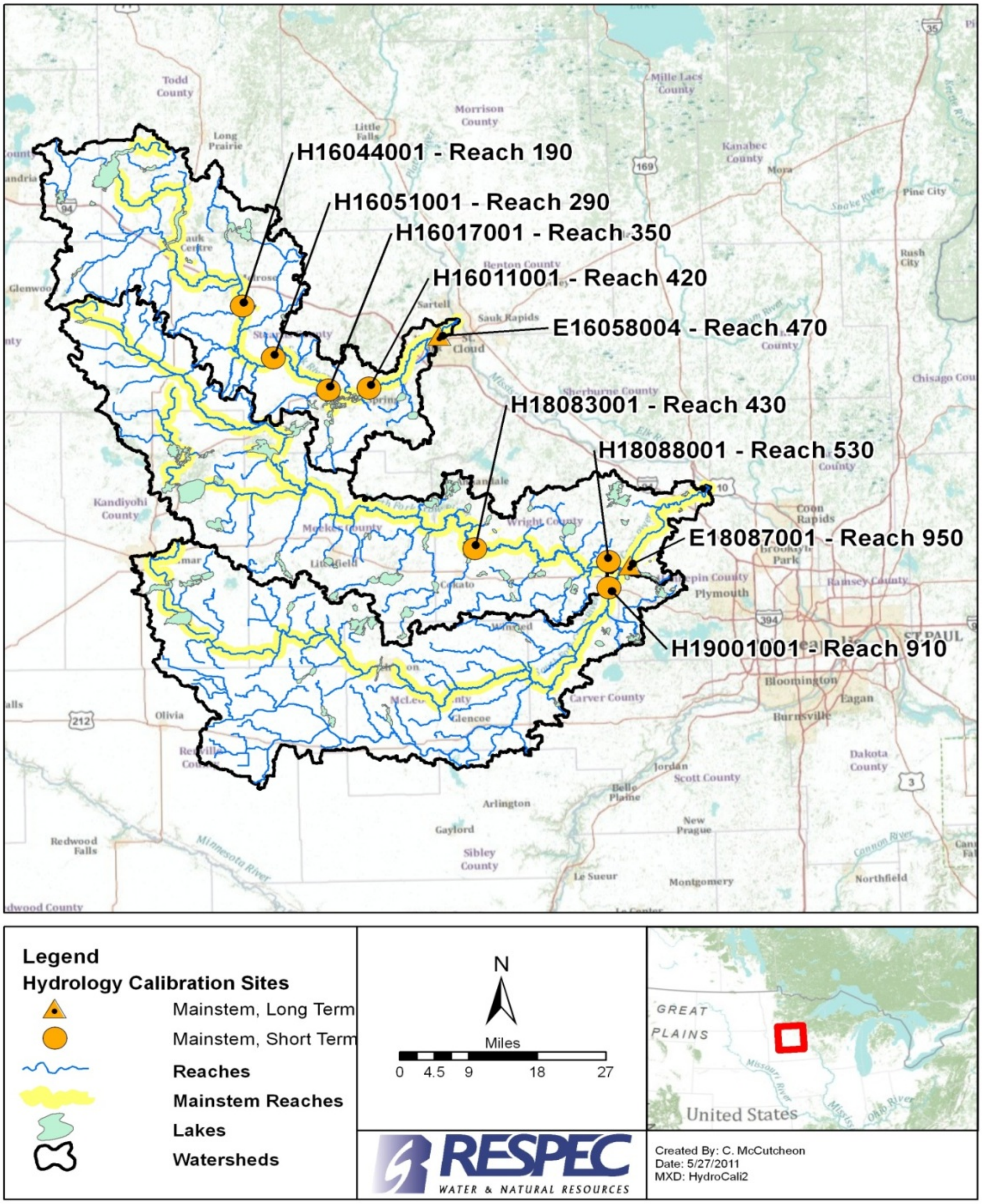

Figure 3-2. Map of Primary Gages for Calibration.

Table 3-2. Summary Statistics for Primary Calibration Gages in the Sauk Watershed

Observed Flow Gage	**HSPF Reach I.D.**	**Total Runoff Volume**			**Monthly**			**Daily**			**Storm % Error**	
		Obs (in)	**Sim (in)**	**% Δ**	***R***	**R^2**	**MFE**	***R***	**R^2**	**MFE**	**Volume**	**Peak**
H16044001	190	3.91	4.07	4	0.95	0.91	0.88	0.92	0.85	0.76	9	8
H16051001	290	3.31	3.37	1.9	0.95	0.91	0.90	0.88	0.78	0.70	4.1	-5.2
H16017001	350	4.16	4.02	–3.5	0.97	0.94	0.91	0.93	0.87	0.86	–5.8	–7.2
H16011001	420	4.22	4.16	–1.7	0.98	0.96	0.96	0.94	0.89	0.88	0.5	14.6
E16058004	470	4.97	4.87	–2	0.96	0.91	0.90	0.91	0.83	0.78	2.1	15.3
Weighted Overall		**4.2**	**4.1**	**–1.9**	**0.96**	**0.92**	**0.9**	**0.89**	**0.8**	**0.73**	**3.15**	**14.7**

Table 3-3. Summary Statistics for Primary Calibration Gages in the Crow Watershed

Observed Flow Gage	**HSPF Reach I.D.**	**Total Runoff Volume**			**Monthly**			**Daily**			**Storm % Error**	
		Obs (in)	**Sim (in)**	**% Δ**	***R***	**R^2**	**MFE**	***R***	**R^2**	**MFE**	**Volume**	**Peak**
H18083001	430	3.35	4.5	33.7	0.86	0.73	0.70	0.77	0.59	0.47	–6.6	1.9
H18088001	530	3.60	3.45	–4.20	0.91	0.84	0.83	0.91	0.84	0.83	–7.9	–7.5
H19001001	910	4.23	4.36	3.0	0.89	0.80	0.79	0.86	0.73	0.71	–1.4	0.1
E18087001	950	5.00	4.99	–0.3	0.93	0.86	0.86	0.91	0.83	0.82	–3.2	–6.4
Weighted Overall		**4.28**	**4.46**	**5.01**	**0.91**	**0.82**	**0.81**	**0.88**	**0.77**	**0.74**	**–4.35**	**–3.95**

Table 3-4. Summary Statistics for Primary Validation Gages in the Sauk Watershed

Observed Flow Gage	**HSPF Reach I.D.**	**Total Runoff Volume**			**Monthly**			**Daily**			**Storm % Error**	
		Obs (in)	**Sim (in)**	**% Δ**	***R***	**R^2**	**MFE**	***R***	**R^2**	**MFE**	**Volume**	**Peak**
E16058004	470	5.78	5.45	–5.7	0.87	0.76	0.71	0.80	0.64	0.52	–1.5	12.1

Table 3-5. Summary Statistics for Primary Validation Gages in the Crow Watershed

Observed Flow Gage	**HSPF Reach I.D.**	**Total Runoff Volume**			**Monthly**			**Daily**			**Storm % Error**	
		Obs (in)	**Sim (in)**	**% Δ**	***R***	**R^2**	**MFE**	***R***	**R^2**	**MFE**	**Volume**	**Peak**
H18083001	430	2.94	2.87	–2.3	0.90	0.80	0.78	0.84	0.71	0.71	–3.7	–22.7
H18088001	530	4.92	4.80	–2.5	0.86	0.75	0.72	0.84	0.71	0.62	–17.3	14.0
H19001001	910	4.87	4.82	–1.1	0.90	0.80	0.76	0.79	0.63	0.55	–10.8	9.7
E18087001	950	6.12	5.76	–5.9	0.92	0.85	0.83	0.89	0.79	0.78	–10.1	2.7
Weighted Overall		**5.10**	**4.90**	**–3.61**	**0.90**	**0.81**	**0.78**	**0.85**	**0.73**	**0.69**	**–10.73**	**2.46**

Table 3-6. Summary of Water Balance Component Volumes

Water Balance Component	Water Balance Component Description	Sauk Watershed Weighted Volume (in)	Crow Watershed Weighted Volume (in)
SUPY	Water supply to soil surface	28.12	27.38
SURO	Surface outflow	0.27	0.19
IFWO	Interflow outflow	1.82	1.48
AGWO	Active groundwater outflow	3.59	3.57
PERO	Total outflow from pervious land	5.64	5.22
IGWI	Inflow to inactive groundwater	0.23	0.51
AGWI	Active groundwater inflow	3.95	4.22
PET	Potential evapotranspiration	38.04	37.43
CEPE	Evaporation from interception storage	5.5	5.23
UZET	Evapotranspiration from upper zone	7.13	6.13
LZET	Evapotranspiration from lower zone	9.15	9.39
AGWET	Evapotranspiration from active groundwater storage	0.09	0.06
BASET	Evapotranspiration from active groundwater outflow (baseflow)	0.24	0.59
TAET	Total simulated evapotranspiration	22.1	21.4

4.0 INTERNAL LAKE PHOSPHORUS LOADING

Internal lake phosphorus loads can be caused by anoxic conditions, wind mixing, biota die-off (i.e., curly-leaf pondweed), bioturbation, or other factors. The explicit representation of these loads when developing load allocations at a HUC 8 scale is not imperative; however, it is important to include phosphorus loads from internal lake processes to support allocation development at a finer scale. This chapter focuses on internal loading from anoxic conditions, which is common in deep lakes in Minnesota.

The base package of **HSPF** does not explicitly represent this seasonal type of internal loading. Therefore, a new approach was developed to incorporate internal lake phosphorus loads.

4.1 SUMMARY OF LITERATURE REVIEW FINDINGS

It has been well documented that deep lakes in Minnesota typically thermally stratify in both the winter and summer. Lakes with this cycle of thermal stratification are referred to as dimictic lakes. Thermal stratification occurs when a lake develops layers of water with different temperatures. In the summer, the upper layer of water will heat, while the bottom layer of the lakes remains cool. The level of stratification will change through the year and from year to year. These layers can have substantially different water quality. The lower layer (hypolimnion) can become anoxic. Dimictic refers to a lake that mixes twice a year. In the fall, these layers will mix as the top layer becomes colder than the bottom layer. In the spring, the lack of stratification allows wind to mix the lake.

This stratification often leads to the formation of anoxic conditions in the deeper and littoral portions of the lake. Under anoxic conditions, elemental phosphorus will not be bound to hydroxide complexes, and thus, become geochemically mobile. The phosphorus release from complexes within the lake sediments will result in an increase in phosphorus concentration in the anoxic portions of the lake. As the lake “turns over” or becomes well mixed, because of the disappearance of the redoxcline, the internally generated phosphorus load will be redistributed throughout the water column of the lake. Ultimately, the internally generated phosphorus becomes available for biological uptake either within the lake or in other lake or river reaches downstream of the lake.

Studies to define empirical relationships for lakes, including implicit internal loading, were reviewed [Reckhow, 1979; Canfield and Bachmann, 1981; Panuska, and J. C. Kreider, 2003; and Walker, 1985]. Additionally, Chapra and Canale [1991] and Nürnberg [1984] studies looked in depth at anoxic internal loading on specific lakes. The two most commonly applied methods are the Canfield-Bachmann method [1981] and the Bathtub model [Walker, 1985].

More recent in-depth studies of specific lakes conducted for the TMDL program highlight the importance of internal loading to lakes. For example, Eagle Lake in the South Crow Watershed was found to have 70 percent of the total annual load from internal loading [Carver County Land and Water Services, 2010]. These studies have also documented strong annual variability in internal loading.

Based on previous studies, a multiple-step process was created to calculate the internal phosphorus loading in lakes:

1. Determine if a lake thermally stratifies.
2. Verify anoxic conditions in measured data.
3. Determine the average summer TP concentration, including internal loading.
4. Determine the internal TP load for each stratified lake.

Each of these steps is discussed in the following section.

4.2 DETERMINATION OF THERMAL LAKE STRATIFICATION

Lakes were considered likely stratified if they met the criteria of having a maximum depth greater than 7 meters (approximately 23 feet). However, mixing from substantial inflows may reduce or eliminate stratification. Therefore, it was initially assumed that all lakes with overflow (Outflow/Surface Area) rates greater than 50 meters per year would not stratify. This criterion was removed based on the evaluation of anoxic conditions (Step 2), which showed this criterion does not hold true for several lakes in the watershed. The results of the lake stratification analysis for the Sauk, South Crow, and North Crow are presented in Tables 4-1, 4-2, and 4-3 , respectively.

4.3 VERIFICATION OF ANOXIC CONDITIONS FROM MEASURED DATA

Measured data were used to verify if lakes underwent periods with anoxic conditions, when available. Anoxic conditions were determined based on comparing the overall lake TP concentration with the TP concentrations in the hypolimnion. The literature did not provide a firm rule on what difference in TP concentration was typical for anoxic conditions. A review of the data found that hypolimnion concentrations at least five times the overall lake average were not uncommon. Ultimately, summer hypolimnion TP concentrations that were double the average lake concentrations were considered to be subjected to internal loading. Tables 4-4, 4-5, and 4-6 present the results of the evaluation of anoxic conditions for selected lakes in Sauk, South Crow, and North Crow, respectively.

Table 4-1. Summary of Lake Stratification in the Sauk River Watershed

Reach	Lake I.D.	Lake Name	Average Depth (m)	Overflow Rate (m/yr)	Likely Stratified
2	21-0016-00	Smith	8	8	Yes
14	77-0181-00	Maple	7	5	No
20	77-0215-00	Osakis	21	3	Yes
22	21-0003-00	Clifford	11	30	Yes
24	77-0195-00	faille	2	122	No
52	77-0164-00	Little Sauk	8	139	No
54	77-0163-00	Juergens	5	357	No
72	61-0029-00	Westport	11	25	Yes
100	77-0150-01	Sauk	18	47	No
124	73-0273-00	McCormic	11	1	Yes
162	77-0084-01	Big Birch	24	4	Yes
164	77-0089-00	Little Birch	26	24	Yes
184	73-0208-00	Uhlenkolts	5	4	No
202	73-0215-00	Maria	13	3	Yes
242	73-0199-00	Sand	3	0	No
264	NA	Henry	10	0	Yes
374	73-0159-00	Big	12	4	Yes
386	73-0151-00	Vails	6	58	Yes
388	73-0150-00	Eden	21	38	Yes
392	73-0147-00	North Brown’s	11	34	Yes
394	73-0139-00	Long	9	28	Yes
400	Multiple	Chain of Lakes	16	743	Yes
420	73-0082-00	Schneider	4	396	Yes
432	73-0037-00	Pearl	4	8	No
434	73-0055-00	Grand	10	3	Yes

Table 4-2. Summary of Lake Stratification in the South Fork Crow River Watershed

Reach	Lake I.D.	Lake Name	Average Depth (m)	Overflow Rate (m/yr)	Likely Stratified
528	34-0072-00	Lillian	1	0.0013	No
532	34-0086-00	Big Kandiyohi	4	0.0105	No
536	34-0169-03	Wakanda (Main Basin)	4	6.7	No
542	34-0076-00	Minnetaga	2	4.5	No
544	34-0105-00	Kasota	11	2.4	Yes
546	34-0096-00	Little Kandiyohi	11	1.8	Yes
558	34-0022-02	Elizabeth (Main)	2	4.2	No
618	47-0129-00	Star	4	0.1	No
622	NA	NA	11	8.3	Yes
632	43-0104-00	Stahl's	2	0.6	No
634	47-0062-00	Greenleaf	5	0.7	No
636	47-0061-00	Willie	5	16.0	No
638	47-0106-00	Hoff	2	47.1	No
646	65-0013-00	Boon	11	1.5	Yes
660	43-0085-01	Otter (Main Basin)	0.2	3,938	No
718	43-0034-00	Silver	0.3	0.0	No
738	43-0014-00	South	11	1.3	Yes
742	43-0012-00	Winsted	3	18.0	No
744	10-0127-00	Campbell	10	0.0	Yes
772	65-0006-00	Allie	3	1.9	No
774	65-0002-00	Preston	3	1.8	No
796	43-0084-00	Marion	3	2.8	No
806	72-0049-00	Schilling	11	1.0	Yes
842	10-0121-00	Eagle	4	2.5	No
892	10-0095-00	Swede	3	0.2	No
894	10-0093-00	Oak	3	0.5	No
896	27-0184-01	Whaletail (N. Bay)	8	0.7	Yes
898	27-0149-00	Spurzem	12	13.5	Yes
902	27-0176-00	Independence	17	3.6	Yes
922	27-0192-00	Rebecca	9	1.2	Yes

Table 4-3. Summary of Lake Stratification in the North Fork Crow River Watershed (Page 1 of 2)

Reach	Lake I.D.	Lake Name	Average Depth (m)	Overflow Rate (m/yr)	Likely Stratified
2	61-0023-00	Grove	9	7.9	Yes
120	73-0196-00	Rice	11	47.8	Yes
140	73-0200-01	Koronis	39	23.2	Yes
172	34-0066-00	Long	13	2.6	Yes
180	34-0158-01	Monongalia Lake (Mud)	5	11.4	No
220	34-0142-00	Nest	12	41.6	Yes
240	34-0079-00	Green	33	6.2	Yes
242	34-0062-00	Calhoun	3	4.1	No
282	34-0044-00	Diamond	8	3.0	Yes
322	47-0183-00	Hope	3	8.3	No
324	47-0177-00	Long	1	149.4	No
342	47-0134-02	Ripley	6	20.9	No
344	47-0134-02	Ripley	5	5.9	No
352	86-0279-00	West Lake Sylvia	25	0.0	Yes
354	47-0002-00	Francis	5	0.1	No
356	47-0119-00	Minnie-Belle	14	0.2	Yes
362	47-0068-00	Stella	22	11.8	Yes
364	47-0046-00	Washington	5	2.5	No
366	47-0088-00	Richardson	14	75.9	Yes
368	47-0082-00	Dunns	5	65.2	No
374	43-0073-00	Hook	5	2.5	No
376	47-0015-00	Jennie	4	2.9	No
378	47-0032-00	Spring	8	1.3	Yes
382	86-0293-00	Collinwood	8	17.8	Yes
384	47-0038-00	Big Swan	8	36.0	Yes
402	86-0273-00	French	15	6.3	Yes
422	86-0217-00	Granite	10	1.8	Yes

Table 4-3. Summary of Lake Stratification in the North Fork Crow River Watershed (Page 2 of 2)

Reach	Lake I.D.	Lake Name	Average Depth (m)	Overflow Rate (m/yr)	Likely Stratified
442	86-0250-00	Smith	1	0.6	No
444	86-0263-00	Cokato	14	31.4	Yes
446	86-0221-00	Camp	16	1.0	Yes
462	86-0182-00	Rock	11	1.4	Yes
472	86-0190-00	Ann	4	27.6	No
474	86-0199-00	Howard	12	2.6	Yes
476	86-0184-00	Dutch	6	17.4	No
482	86-0114-00	Waverly	21	1.5	Yes
484	86-0106-00	Little Waverly	3	60.3	No
492	86-0120-00	Ramsey	24	8.3	Yes
496	86-0122-00	Light Foot	6	107.0	No
498	86-0090-00	Buffalo	9	7.7	Yes
502	86-0107-00	Deer	8	71.0	Yes
508	86-0112-00	Malardi	11	3.8	Yes
516	S005-837	Woodland	11	19.5	Yes
522	86-0086-00	Fountain	11	0.6	Yes
942	27-0191-01	Sarah	17	2.7	Yes
962	27-0199-00	Hafften	13	1.4	Yes
982	86-0031-00	Pelican	3	0.4	No
984	86-0023-00	Beebe	8	0.1	Yes
986	27-0169-00	Cowley	11	2.5	Yes
988	86-0001-00	Foster	3	9.1	No

Table 4-4. Evidence of Anoxic Conditions in the Sauk River Lakes

Lake	Reach	TP Summer Median (mg/L)	Number of Samples	TP Summer Hypolimnion Median (mg/L)	Number of Hypolmnion Samples	Evidence of Anoxic Conditions
Little Long	896	0.060	245	0.082	18	No
Hennepin	898	0.155	151	1.383	26	Yes
Independence	902	0.065	259	0.299	102	Yes
Rebecca	922	0.099	139	0.467	25	Yes

Table 4-5. Evidence of Anoxic Conditions in the South Fork Crow River Lakes

Lake	Reach	TP Summer Median (mg/L)	Number of Samples	TP Summer Hypolimnion Median (mg/L)	Number of Hypolmnion Samples	Evidence of Anoxic Conditions
Little Long	896	0.060	245	0.082	18	No
Hennepin	898	0.155	151	1.383	26	Yes
Independence	902	0.065	259	0.299	102	Yes
Rebecca	922	0.099	139	0.467	25	Yes

Table 4-6. Evidence of Anoxic Conditions in the North Fork Crow River Lakes

Lake	Reach	TP Summer Median (mg/L)	Number of Samples	TP Summer Hypolimnion Median (mg/L)	Number of Hypolmnion Samples	Evidence of Anoxic Conditions
Waverly	482	0.0395	77	0.36	12	Yes
Richardson	366	0.1045	53	0.77	15	Yes
Diamond	282	0.072	203	0.047	21	No
Hafften	962	0.07	111	0.39	25	Yes
Minnie-belle	356	0.024	101	0.076	43	Yes
Sarah	942	0.114	289	0.6308	71	Yes

4.4 DETERMINATION OF THE AVERAGE SUMMER TOTAL PHOSPHORUS CONCENTRATION, INCLUDING INTERNAL LOADING

The average summer TP concentration was determined using the natural lake model developed by Canfield and Bachmann [1981] or by measured data if sufficiently present. This model is used to predict seasonal to annual TP concentrations and is based on the Vollenweider equation (Equation 4-1), with a TP settling rate specific to natural lakes. The TP settling rate (Equation 4-2) was calibrated based on data from 290 lakes.

$$\text{TP Concentration} = \frac{\text{External TP Load}}{\text{Depth (TP Settling Rate + Annual Flushing Rate)}} \tag{4-1}$$

where:

$$\text{Annual Flushing Rate}\left(\frac{1}{\text{yr}}\right)=\frac{\text{Lake Outflow}}{\text{Lake Volume}}$$

$$\text{Depth (m)} = \text{Average Annual Depth}$$

$$\text{External TP Load}\left(\frac{\text{mg}}{\text{yr m}^2}\right)=\text{Average Annual TP Load.}$$

$$\text{TP Settling Rate} = 0.162\left(\frac{\text{External TP (Load)}}{\text{Depth}}\right)^{0.458} \qquad (4\text{-}2)$$

The **HSPF** watershed application was used to generate the inputs needed to predict the TP concentrations using the above equations. The results of this approach were unable to consistently predict the measured average summer TP concentration in lakes where data were available. The concentrations were typically lower than the observed summer values. Further investigation indicated the **HSPF** model applications generated relatively low phosphorus loads when compared to what would be required to predict in-lake TP concentrations using the Canfield-Bachmann method.

These lower concentrations may be the result of an internal load of lakes exceeding the amount of internal load implicitly included in the Canfield-Bachmann method. Alternatively, the **HSPF** applications generate consistently lower external TP loads than the values used when developing the Canfield-Bachmann method. However, these same **HSPF** watershed loads provided a well-calibrated **HSPF** model application at multiple points throughout the watershed.

Because the models use different approaches to modeling lakes, it is unclear which model is more appropriate. Therefore, the observed concentrations were used instead of the Canfield-Bachmann-predicted concentrations. Specifically, the average summer concentration was calculated from the available data. A threshold of at least 12 TP samples was set to ensure the calculated summer average was representative of the actual conditions. This threshold is consistent with MPCA's data requirement to list a lake as "impaired" [Minnesota Pollution Control Agency, 2007].

4.5 DETERMINATION OF THE INTERNAL TOTAL PHOSPHORUS LOAD FOR EACH STRATIFIED LAKE

Initially, the internal TP loading was determined using the methods from Nürnberg [1984]. The general equation to represent the TP concentration in a lake is presentated in Equation 4-3, where both internal and external loading are included. This equation can be rearranged to solve for internal TP loading. The resulting internal TP loads were generated on an annual basis.

$$\text{TP Concentration} = \left(\frac{\text{External TP Load}}{\text{Overflow Rate}}\right)\left(1-\text{TP Retention Time}\right)+\frac{\text{Internal Loading}}{\text{Overflow Rate}} \qquad (4\text{-}3)$$

The results of the internal loading calculation were added as input into the **HSPF** applications. Annual internal loads were loaded into the **HSPF** model, as phosphate (PO4), during likely periods of mixing (the first week of May and the third week of October). These loads produced several orders of magnitude higher in-lake TP concentrations in the **HSPF** model than expected. Therefore, an alternative internal load method was used.

Consistent with recent TMDL approaches in the South Crow Watershed [Carver County Land and Water Services 2010], a lake-specific internal loading rate was included into the **HSPF** application. Internal loading was included in two ways. First, a benthic Biochemical Oxygen Demand (BOD) load is included as part of the in-stream processes in the **HSPF** applications. This type of loading was increased in lakes beyond the typical levels found in streams. The increased BOD loading, which was a constant daily value, was applied to all lakes and was the sole method used to improve the calibration in nonstratified lakes. The BOD included organic phosphorus, nitrogen, and carbon. As the BOD decays, inorganic phosphorus and nitrogen are released and DO is depleted. This process was not consistent with the release of phosphorus under anoxic conditions; therefore, a separate internal PO4 load was included in stratified lakes. These loads mimicked the internal loads applied from the Nürnberg method but were substantially lower in magnitude. In both cases, **HSPF** was found to be very sensitive to the magnitude of the internal load.

While improving many lakes, this methodology was not sufficient for all lakes. Additional detailed evaluations of loading, external to **HSPF**, may aid in improving the calibration.

4.6 CONCLUSIONS AND RECOMMENDATIONS

The **HSPF** watershed applications of the Sauk River and Crow River Watersheds benefit from the inclusion of internal phosphorus loading. Lake-specific internal loading was successfully included into the applications to improve the model calibration. Annual and seasonal methods for predicting in-lake TP concentrations and internal loads were not able to be used directly with **HSPF**, likely because of different approaches between these steady-state models and the dynamic **HSPF** applications.

RESPEC recommends that future **HSPF** applications representing lakes also include lake-specific internal loading. The combined BOD and anoxic loading during periods of mixing was able to improve the calibration. For select lakes, incorporating internal loads that vary annually or seasonally may help improve the calibration. Because of the time commitment needed for this type of calibration, it is not recommended for widescale application. Additional methods should be developed for lakes with complex internal loading (e.g., wind mixing, curly-leaf pond weed, and complex shapes).

5.0 WATER QUALITY

The Crow and Sauk River model applications simulate the following specific parameters at a management unit level:

- hydrology
- sediment (sand, silt, and clay)
- temperature
- phosphorus (TP, orthophosphate, and organic phosphorus)
- nitrogen (total nitrogen, nitrate and nitrite, ammonia, and organic nitrogen)
- DO
- BOD
- Chlorophyll-a.

In the model application, these parameters interact, and in many cases, are interdependent. For example, Chlorophyll-a (Plankton) growth is in part a function of water temperature, orthophosphate concentrations, and inorganic nitrogen (ammonia and nitrate) concentrations. The concentration of organic matter (Chlorphyll-a and BOD) is used in computing the TP and total nitrogen (TN). Therefore, the results of the model must be looked at holistically. A priority was placed on TP, TSS, and DO, as those parameters are driving the majority of impairments in the watersheds.

The key results for each model application are presented in this section along with a discussion of the results. The results at each calibration/validation station are provided in Love [2012].

5.1 SAUK RIVER

The Sauk River calibration for water quality represents the measured data well throughout the watershed. The main calibration/validation stations evaluated for the model are shown in Figure 5-1. The presence of large in-stream lakes had a substantial impact on the water quality in the Sauk River. These lakes include Lake Osakis at Reach 20, Sauk Lake at Reach 100, and the Chain of Lakes (Reaches 400 and 420).

This section presents results at the Sauk River outlet for four parameters: TSS, TP, TN, and DO. The results for other parameters and stations are provided in Love [2012]. The Chain of Lakes has a direct impact on the results at the Sauk River Outlet (Reach 490). The summer growing season (May through September) was considered the priority period when calibrating these lakes In some cases, such as a river outlet, a lake can restrict the ability to calibrate

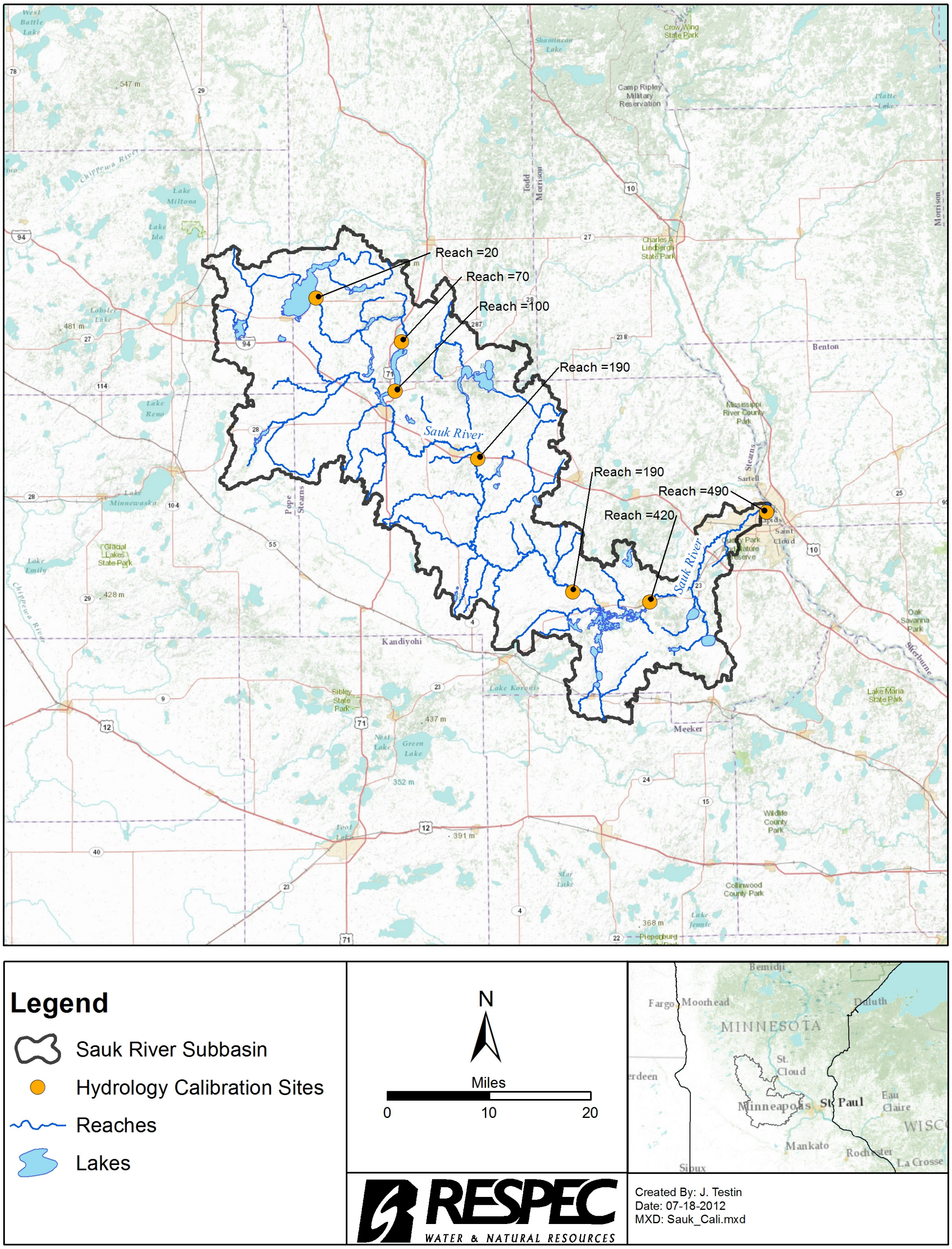

Figure 5-1. Primary Calibration Reaches for the Sauk River Model Application.

a downstream reach, particularly when evaluating at less than a seasonal timestep. In these cases, the stream calibration was considered a priority over the lake calibration.

The sediment simulation in the Sauk considered the in-stream concentration results and the apportionment of loading from overland sources versus the stream bed, bank, and gullies. A review of available information did not yield source apportionment testing in the Sauk. Source apportionment testing was performed extensively in the Minnesota River to the south and several samples were taken in the South Crow. While the soils in the Sauk have a greater traction of sand than these areas (potentially less loading from the watershed), the testing established that a substantial portion of sediment can occur from stream bed, bank, and gully sources (45 percent in the South Crow). Discussion with local watershed district staff indicated that bank erosion was an issue in several sections of the Sauk River. Therefore, an apportionment goal of 55 percent from stream bed, bank, and gully was set for the Sauk River Watershed. The model results showed 57 percent of the sediment load occurring from stream bed, bank, and gully sources.

The sediment results at the Sauk River outlet are presented in Figure 5-2. The calibration for sediment is considered fair. It should be noted, challenges in representing the sediment mechanisms in the very complex Horseshoe Chain of Lakes propagate downstream and affect the results at this station.

The results at the Sauk River outlet are presented for TP in Figure 5-3 and for TN in Figure 5-4. The calibration for nutrients is considered good. Croplands contributed the greatest nutrient load to the watershed. DO results are highly influenced by plankton growth and BOD decay. The results for DO, which were considered good, are presented in Figure 5-5. The results for other parameters and the nutrient speciations are provided in Love [2012]**.**

5.2 SOUTH FORK CROW RIVER

The South Crow calibration for water quality represents the measured data well throughout the watershed. The main calibration/validation stations evaluated for the model are shown in Figure 5-6. Nutrient concentrations are in the South Crow are relatively higher than those in the Sauk and North Crow.

This section presents results at the South Crow outlet for four parameters: TSS, TP, TN, and DO. A good calibration was achieved throughout the South Crow. There are fewer lakes in the South Crow, and therefore, they have a lower impact on overall calibration.

The sediment simulation in the South Crow watershed considered the in-stream concentration results and the apportionment of loading from overland sources versus the stream bed, bank, and gully. A review of available information found that source apportionment tests were conducted and found that an average of 45 percent of the sediment was from stream bed, bank,

RSI-1953-12-057

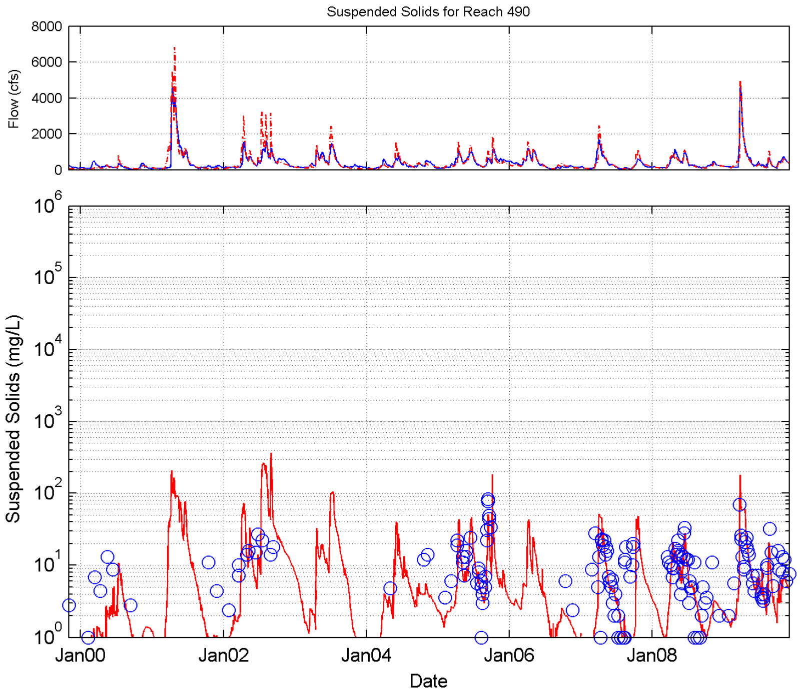

Figure 5-2. Total Suspended Solids at the Sauk River Outlet, Reach 490.

RSI-1953-12-058

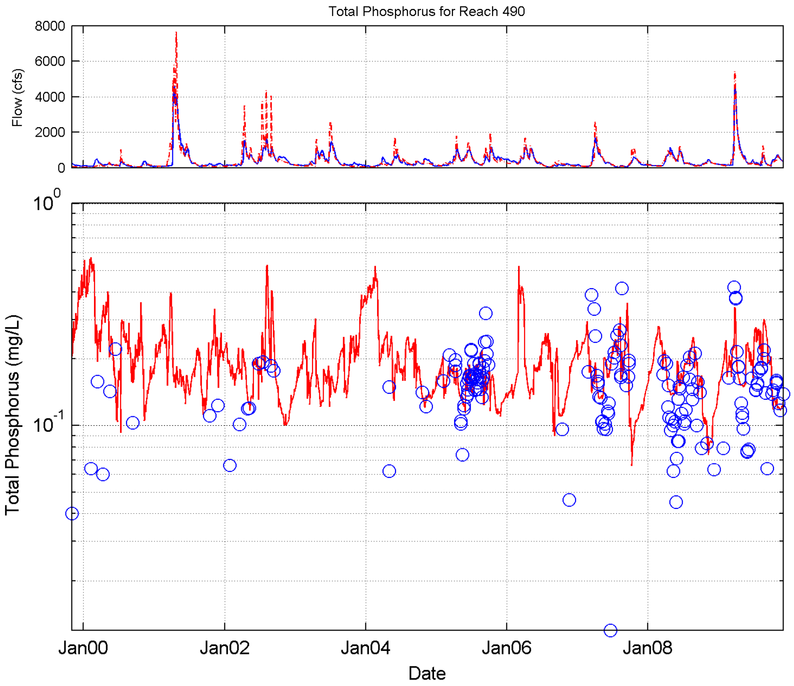

Figure 5-3. Total Phosphorus at the Sauk River Outlet, Reach 490.

RSI-1953-12-060

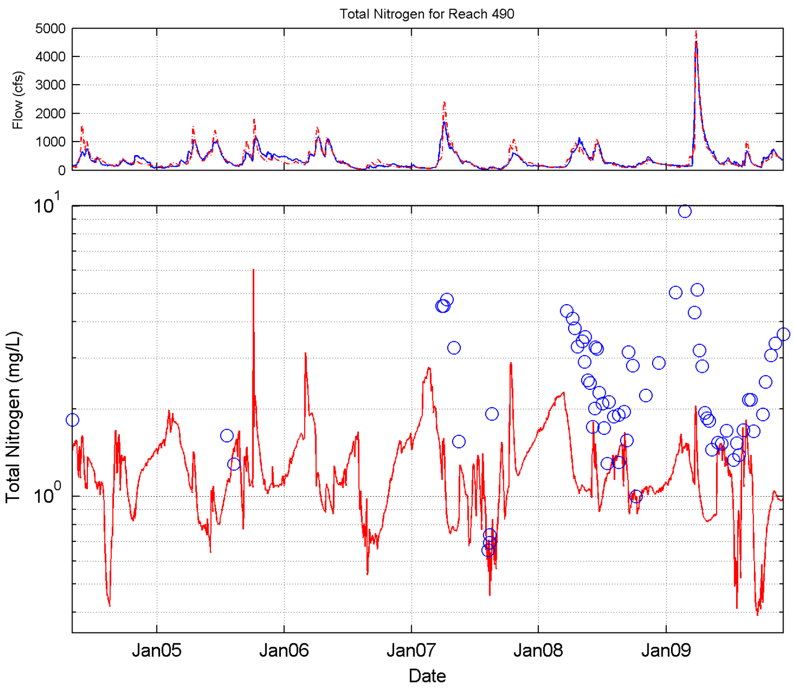

Figure 5-4. Total Nitrogen at the Sauk River Outlet, Reach 490.

RSI-1953-12-061

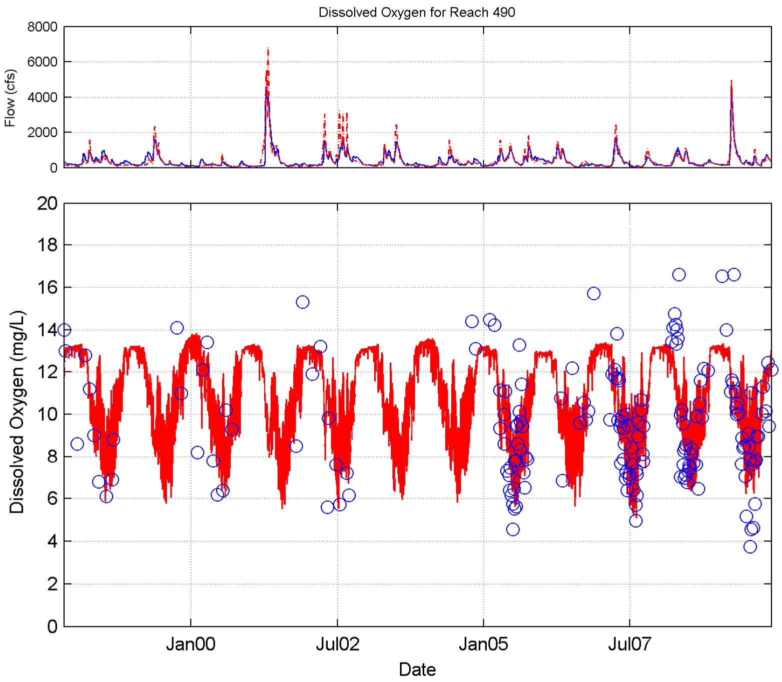

Figure 5-5. Dissovled Oxygen at the Sauk River Outlet, Reach 490.

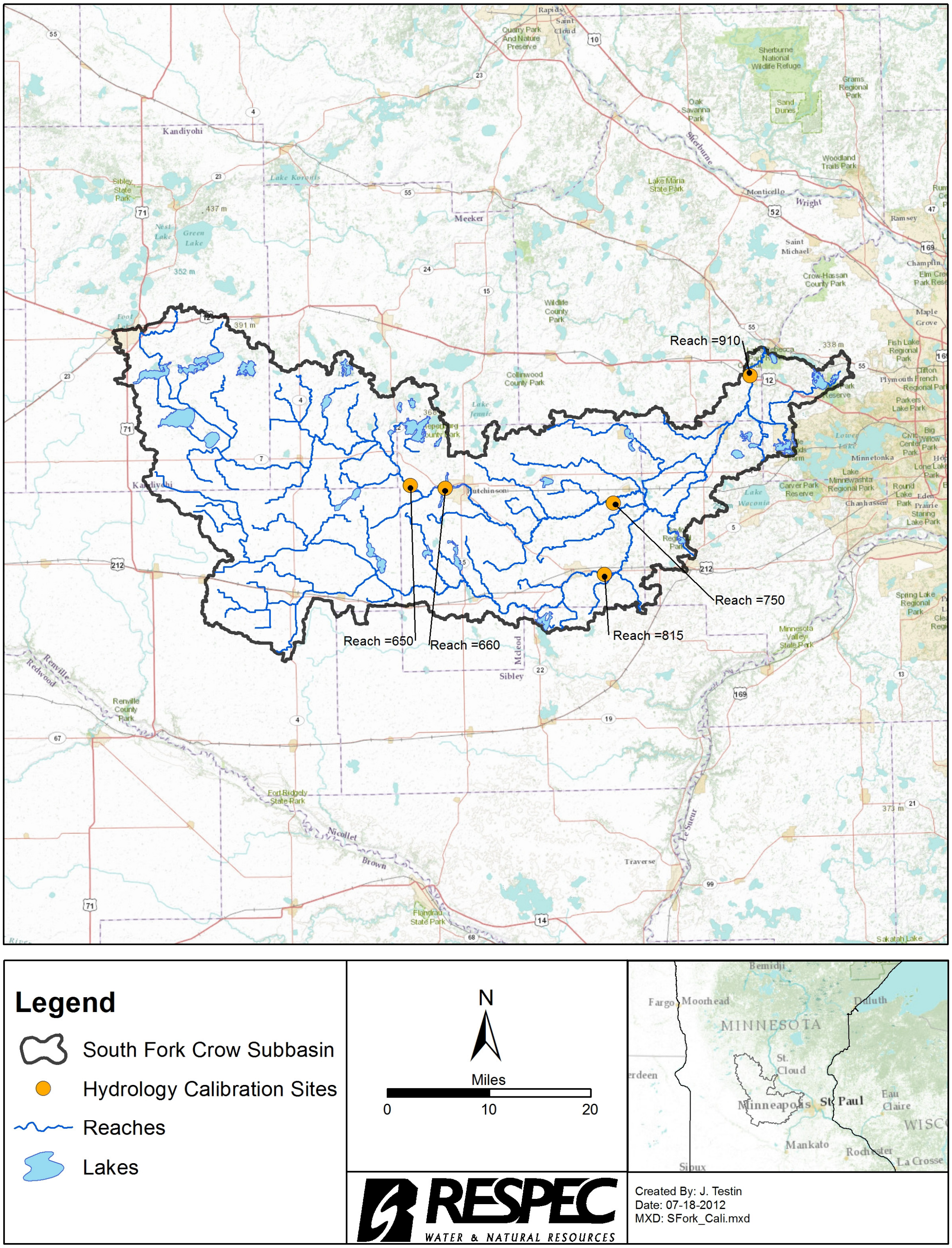

Figure 5-6. Primary Calibration Reaches for the South Fork Crow River Model Application.

and gully sources. The model results showed 47 percent of the sediment load occurring from stream bed, bank, and gully sources.

The sediment results at the South Crow outlet are presented in Figure 5-7. The calibration for sediment is considered good. The results at the South Crow outlet are presented for TP in Figure 5-8 and for TN in Figure 5-9. The calibration for nutrients is considered good. Croplands contributed the greatest nutrient load to the watershed. DO results are highly influenced by plankton growth and BOD decay. The results for DO, which were considered good, are presented in Figure 5-10. The results for other parameters and the nutrient speciation's are provided in Love [2012].

5.3 CROW RIVER

The Crow calibration for water quality represents the measured data well throughout the watershed. The main calibration/validations stations evaluated for the model are shown in Figure 5-11. This section presents the results for the North Fork Crow River outlet (Reach 530).

This section presents results at the Crow and North Fork outlets for four parameters: TSS, TP, TN, and DO. Lake Koronis is the North Crow's only in-stream lake; however, there are numerous lakes on its tributaries. These lakes play an important role in the overall calibration of the watershed, but do not limit calibration to the same extent as the Sauk River model calibration.

The sediment simulation in the Crow considered the in-stream concentration results and the apportionment of loading from overland sources versus stream bed, bank, and gully. As previously stated, an average of 45 percent of the sediment was from stream bed, bank, and gully sources used in the South Crow. Soils in North Crow are coarser (higher silt and sand fraction) than South Crow; therefore, an apportionment goal of 55 percent was set for the North Crow. The model results showed 60 percent of the sediment load occurring from stream bed, bank, and gully sources. No source apportionment goal was set for the Crow River outlet because the vast majority of the watershed was considered under the North Crow and South Crow calibrations.

The sediment results at the North Crow outlet are presented in Figure 5-12. The calibration for sediment is considered good. The results at the North Crow outlet are presented for TP in Figure 5-13 and for TN in Figure 5-14. The calibration for nutrients is considered good. Croplands contributed the greatest nutrient load to the watershed. The results at the Crow River outlet were considered fair. It is important to consider that the models performed well

RSI-1953-12-063

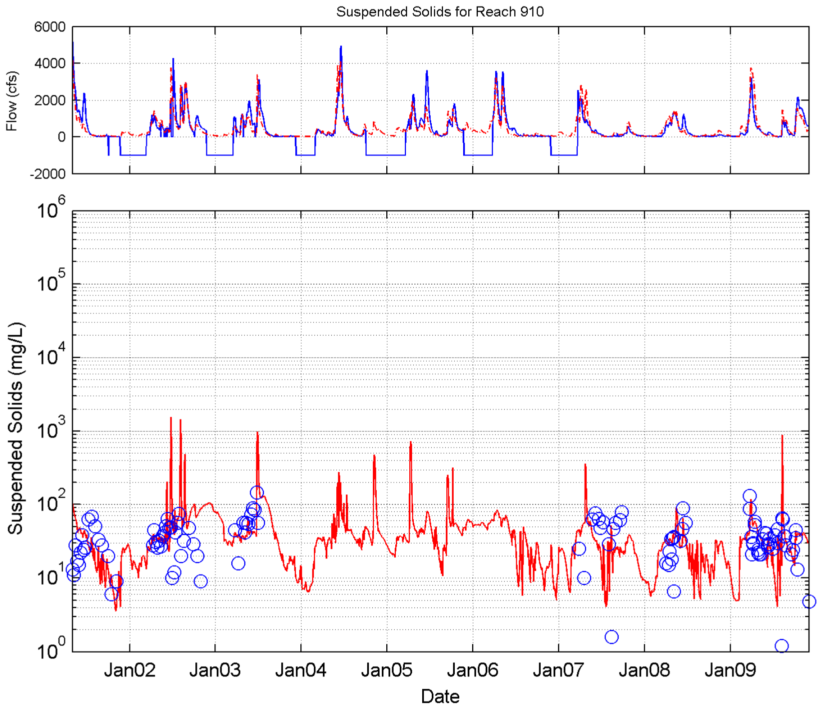

Figure 5-7. Suspended Solids at the South Fork Crow River Outlet, Reach 910.

RSI-1953-12-064

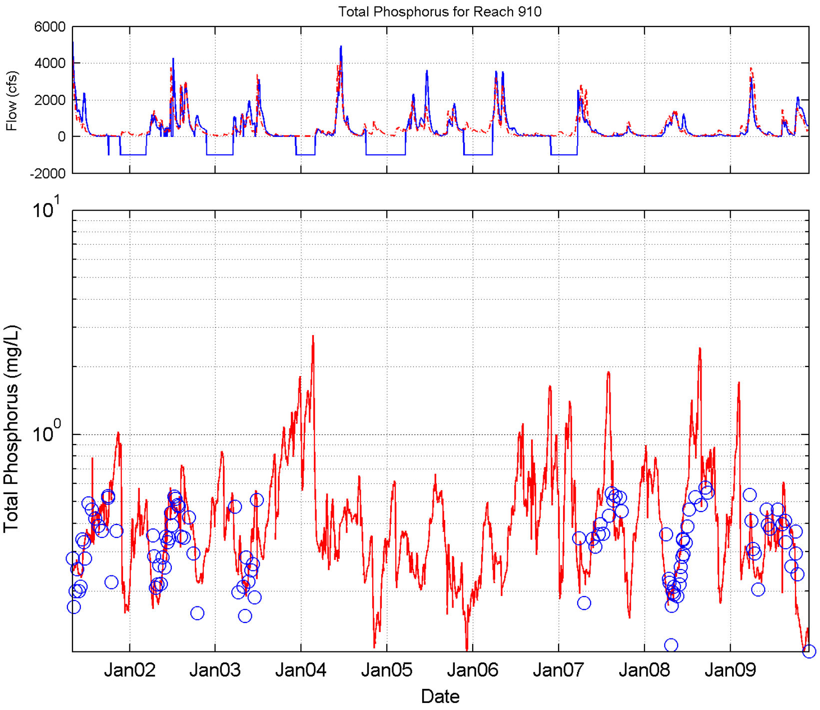

Figure 5-8. Total Phosphorus at the South Fork Crow River Outlet, Reach 910.

RSI-1953-12-065

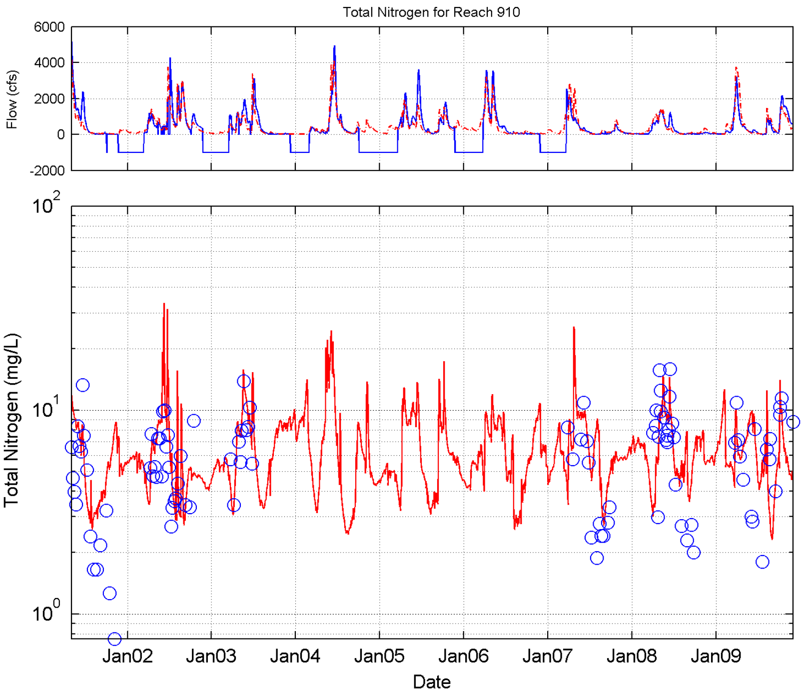

Figure 5-9. Total Nitrogen at the South Fork Crow River Outlet, Reach 910.

RSI-1953-12-066

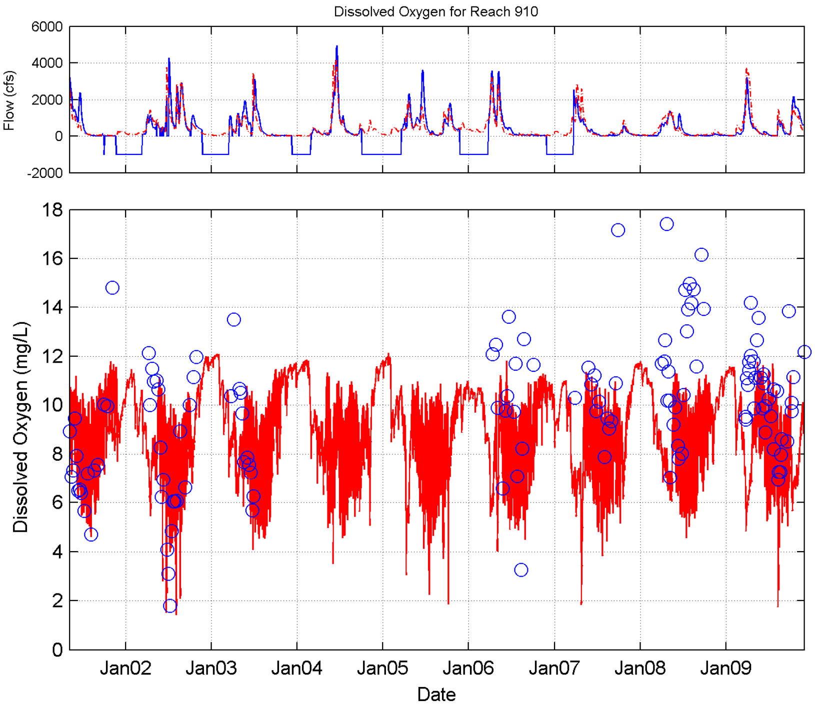

Figure 5-10. Dissolved Oxygen at the South Fork Crow River Outlet, Reach 910.

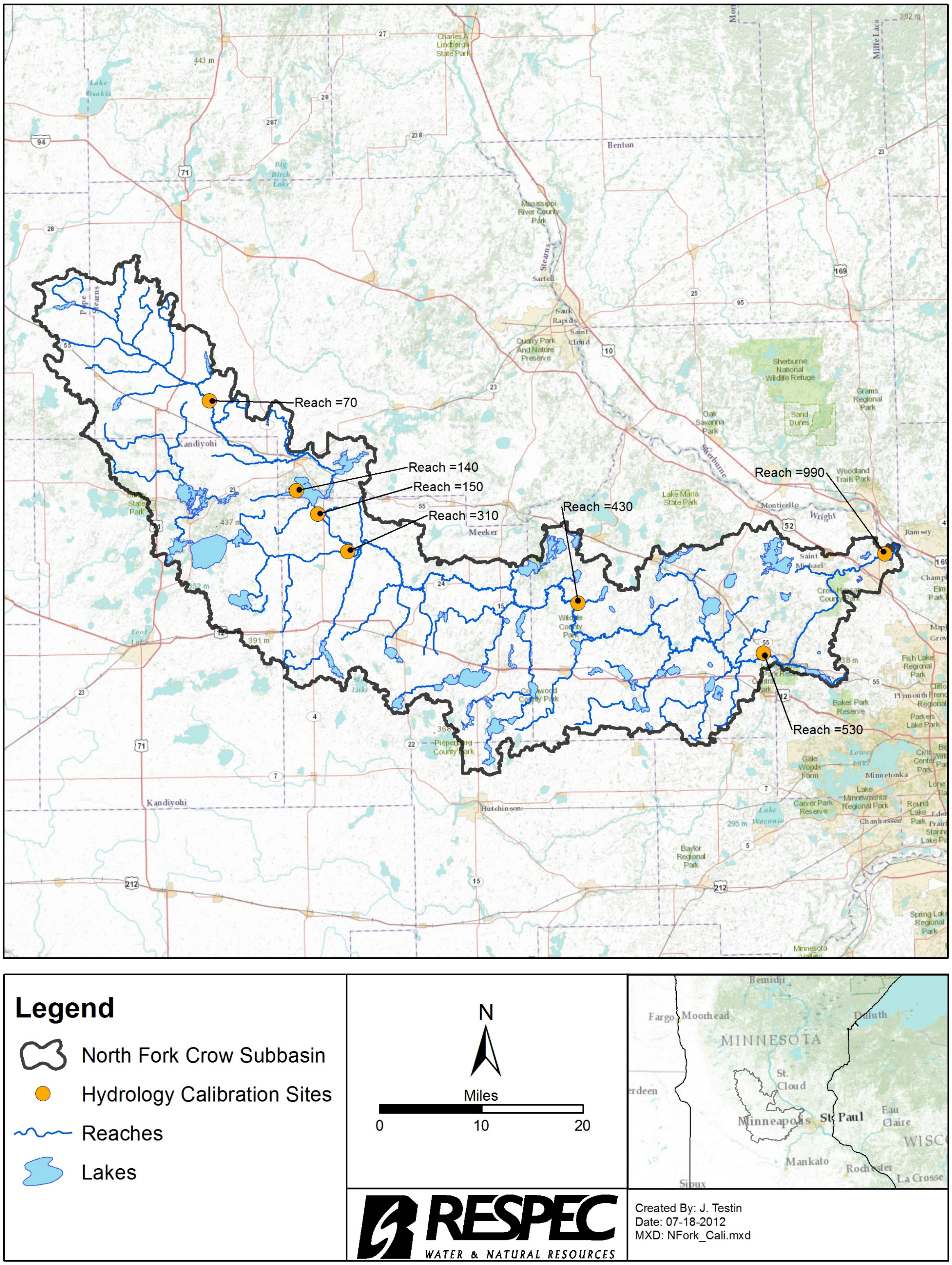

Figure 5-11. Primary Calibration Reaches for the Crow River Model Application.

RSI-1953-12-068

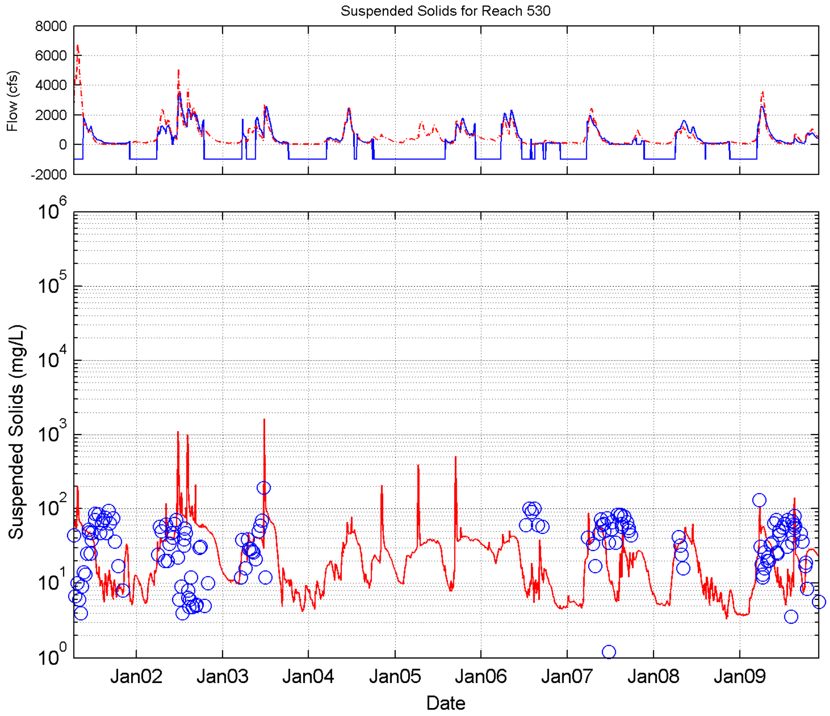

Figure 5-12. Suspended Solids at the North Fork Crow River Outlet, Reach 530.

RSI-1953-12-069

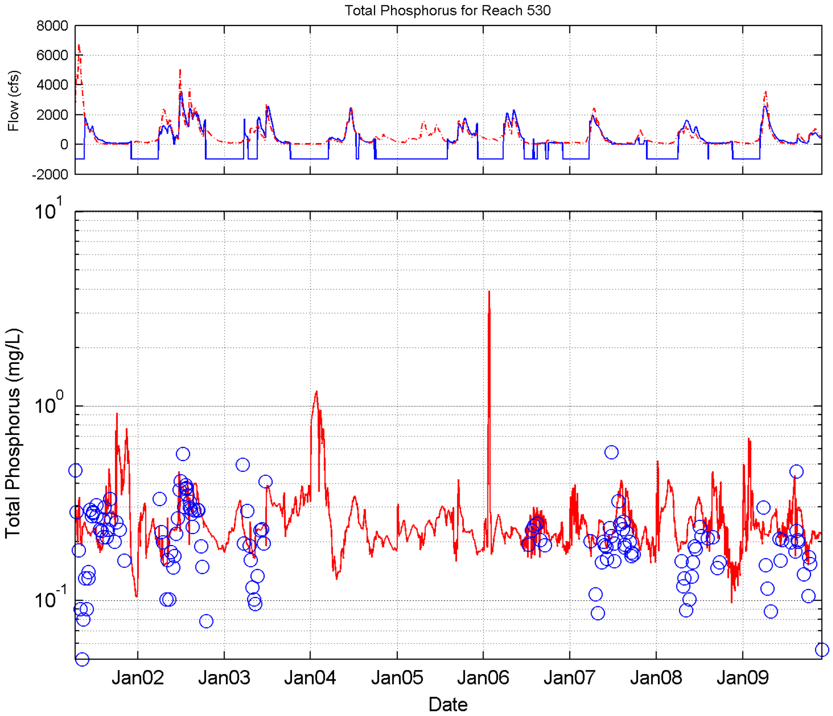

Figure 5-13. Total Phosphorus at the North Fork Crow River Outlet, Reach 530.

throughout the North Fork and South Fork. Additionally, there are three major point sources in the Crow, which may contribute to the fair calibration. The results for DO, which were considered good, are presented in Figure 5-15. The results for other parameters and the nutrient speciation's are provided in Love [2012].

RSI-1953-12-070

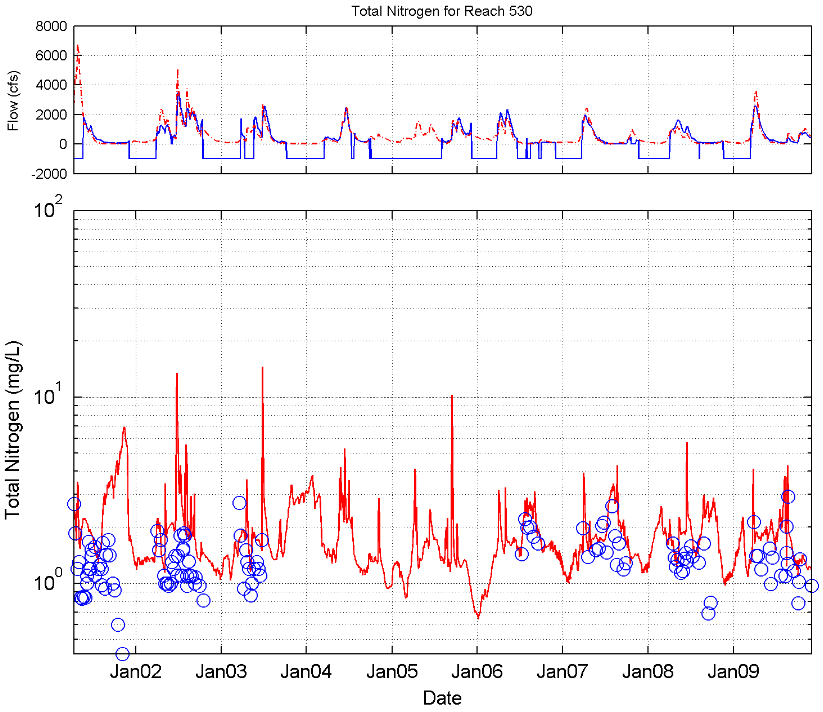

Figure 5-14. Total Nitrogen at the North Fork Crow River Outlet, Reach 530.

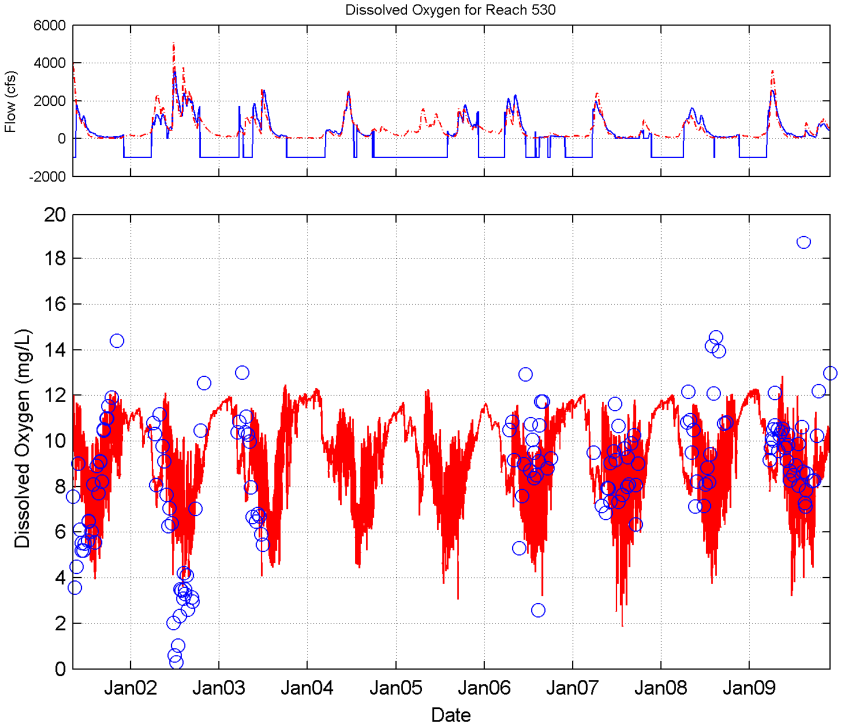

Figure 5-15. Dissolved Oxygen at the North Fork Crow River Outlet, Reach 530.

6.0 SCENARIOS

Three scenarios were evaluated for the Crow and Sauk Watersheds: (1) the "accelerating change" scenario from the Minnesota River Basin Turbidity TMDL Scenario Report [TetraTech, 2009], (2) removal of all point sources, and (3) all point sources at permitted capacity. A description of the scenario and the modeling approach used are presented in Table 6-1. The "accelerating change" scenario includes eight separate actions. Based on the Minnesota River work, all of the actions were determined to be necessary to meet the studies objectives. Consistent with that work, a single scenario was used in the Crow and Sauk Watersheds. However, each of the eight actions could be run as separate scenarios if requested.

The results of the three scenarios are presented in Tables 6-2, 6-3, and 6-4. Scenario 1, "accelerating change," results in decreased nutrient concentrations. The reduction of fertilizer and manure to agronomic levels was found to have the largest impact. Sediment results are largely driven by changes in hydrology and related bed/bank erosion. The **HSPF** model uses a coarse representation of the river channel; therefore, a more detailed study of in-stream sediment loading should be conducted if further refinement of this scenario is required. Conservation Reserve Program (CRP) lands and conversion to conservation tillage decreased sediment load and concentrations. Scenario 2, eliminating point-source discharges, substantially decreases nutrient concentrations. The results of Scenario 3 were not intuitive because of changes in point-source discharges over time. Results of Scenario 3 should be evaluated for each point source rather than the effect on the basin as a whole.

The results of the scenarios have been included in the **GENSCN** project provided with the Final Sauk, North Crow, and South Crow **HSPF** watershed model applications. The **GENSCN** includes the scenario results at the HUC10 level for flow, TSS, TP, TN, and DO. Providing results at the HUC10 level will allow further detailed analysis than provided in Tables 6-2 through 6-4, where results are summarized at the outlets of the three HUC 8s.

Table 6-1. Summary of Scenarios for the HSPF Watershed Model Applications (Page 1 of 2)

Scenario	Type	Name	Description	Approach
1—Accelerating Change	Point	TP in Wastewater Discharges	Constant discharge concentration of 1 mg/L TP for major point sources without an existing limit at or below that concentration	Only the Glencoe Plant in the South Fork of the Crow River was required to decreased TP concentrations. All other major point sources have an existing TP limit of 1 mg/L.
1—Accelerating Change	Nonpoint	Conventional Tillage to Pasture/Hay on High Slopes	CRP lands to 20% of cropland/pasture	CRP land was represented as grassland. The area needed to achieve 20 percent CRP was calculated based on the amount of cropland and pasture land uses. The new CRP lands were removed from conventional tillage cropland and added to grassland. Existing grasslands were assumed to be CRP for these calculations. Changes were applied to the schematic.
1—Accelerating Change	Nonpoint	From MN River Scenario 4—Cropping System–Conventional to Conservation Tillage on High Slopes	75% conservation tillage on slopes greater than 3%	The area of cropland with greater than 3 percent slope was calculated for each reach. The amount of conservation tillage on these lands was increased to 75 percent (conventional tillage was reduced to 25 percent). This conversion from conventional to conservation tillage was done after the shift to 20 percent CRP. Changes were applied to the schematic.
1—Accelerating Change	Nonpoint	From MN River Scenario 4—Cropping System–Tile Surface Inlet Removal	Eliminate all tiling surface inlets	The elimination of tile surface inlets were represented by a 0.25 decrease in INTFW and the removal of sediment loading from cropland to interflow.
1—Accelerating Change	Nonpoint	From MN River Scenario 4—Cropping System–Nutrient Management	Reduce fertilizer (commercial and manure) on cropland to agronomic rates	Mulla et al. [2001] reported that south-central Minnesota overapplies nitrogen by 44 percent and phosphorus by 186 percent, based on the recommended rates. The mass-link was changed to reduce TN and TP to the recommended rates.
1—Accelerating Change	Nonpoint	From MN River Scenario 4—Cropping System	30 percent reduction in sediment from ravines from drop structures	The multiplicative factor on ravine transport (KGER) was reduced by 30%.

Table 6-1. Summary of Scenarios for the HSPF Watershed Model Applications (Page 2 of 2)

Scenario	Type	Name	Description	Approach
1—Accelerating Change	Nonpoint	From MN River Scenario 4—Upland Drainage Management	Controlled drainage on cropland with <1% slope, two-stage ditch design, store 1-inch runoff for at least 24 hours	Cropland was adjusted based on the parameterization for the Minnesota River Scenario Report [TetraTech, 2009]. LSUR was increased to 2,350 for cropland land. INTFW reduced to the value for non-drained cropland during summer months on lands with <1% slope. For same lands, IRC was increased to a constant 0.95. Sediment transport capacity was unlinked from hydrology (SDOP option was turned off).
1—Accelerating Change	Nonpoint	From MN River Scenario 4—Urban Stormwater	Treat the first inch of runoff from both impervious urban surfaces	Urban BMPs were included based on the methods described in Tetra Tech [2009]. BMPs were only added to urban areas in MS4s. Up to 1 inch of urban runoff was treated by a pond-type BMP. It was assumed that TSS and PO4 are reduced to regional groundwater concentrations of 5 and 0.06 mg/L, respectively. TN concentrations were reduced by 50%. All organic matter was removed.
2—No Point Sources	Point	No Point Sources	Eliminate all point-source contributions	Removed all point sources from the external sources block, including flow.
3—Point Sources at Permitted Capacity	Point	Point Sources at Permitted Discharge Rates	All point sources at permitted limits	Calculated a representative concentration and flow-peaking factor to estimate permitted constituents.

Table 6-2. Scenario 1 Percent Change in Flow or Concentration From Accelerating Change as a Percent Difference From Baseline

Scenario	Flow (%)	Suspended Solids (%)	Total Phosphorus (%)	Total Nitrogen (%)	Dissolved Oxygen (%)
Sauk	1.0%	–4.3%	–4.6%	–6.1%	0.3%
South Crow	–0.3	–12.6	–23.5	–4.8	2.1
North Crow	3.1	–14.3	–16.8	2.8	–0.8
Crow	1.6	8.4	–10.9	–0.1	–0.1

Table 6-3. Scenario 2 Percent Change in Flow or Concentration From Eliminating Point-Source Discharges as a Percent Difference From Baseline

Scenario	Flow (%)	Suspended Solids (%)	Total Phosphorus (%)	Total Nitrogen (%)	Dissolved Oxygen (%)
Sauk	–2.1	–1.0	–48.0	–36.1	–7.0
South Crow	–0.8	–1.0	–58.2	–13.8	–1.9
North Crow	–1.1	–1.0	–38.0	–35.3	–5.1
Crow	–0.6	–0.3	–18.4	–13.9	–0.5

Table 6-4. Scenario 3 Percent Change in Flow or Concentration From Point-Source Discharges as a Permitted Capacity as a Percent Difference From Baseline

Scenario	Flow (%)	Suspended Solids (%)	Total Phosphorus (%)	Total Nitrogen (%)	Dissolved Oxygen (%)
Sauk	2.0	2.0	98.8	11.8	11.1
South Crow	3.4	4.5	–30.7	–10.8	5.2
North Crow	2.0	5.9	–25.7	39.2	3.6
Crow	2.0	3.4	–2.6	10.6	3.4

7.0 RECOMMENDATIONS

The Crow/Sauk **HSPF** applications provided good results for a wide range of parameters and at multiple locations throughout the watershed. Recommendations for future modeling were created based on “lessons learned” in the process of formulating, calibrating, and executing the models. These recommendations are provided below.

- The Crow/Sauk models are well calibrated and can be used for future evaluations and studies.
- Internal loading should be incorporated into lake modeling in the future. However, further refinement of internal loading approach is recommended to reduce the numerous runs required for its implementation and potentially represent additional internal loading processes.
- Scenario 3—Point Sources at Permitted Levels-should be refined with input from MPCA staff. The complex, interrelated nature of **HSPF** and the changes in discharges over time make the results from this scenario not intuitive to understand. Therefore, refinements should be made to add clarify on an individual point-source level.
- The Crow and Sauk Watersheds have an abundance of flow and water-quality data. This level of data collection should be continued if possible. Additionally, sediment source apportionment data, tillage transects, septic tank studies, and other supplemental information cited in this report were very helpful for modeling and should be continued.
- To further improve the model calibration, particularly for sediment and water temperature, additional stream cross-sectional and lake outlet hydraulics information should be collected.
- Currently, the model combines the watershed loading from chemical and organic fertilizers. If required for specific management scenarios, the watershed loading should be split to represent manure specifically. Additional information and methodology would be required to implement this recommendation.

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