June 1, 2015

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

Dear Dr. Regan:

RE: Hydrologic and Water Quality Calibration for the Pine River, Leech Lake River, Mississippi River Headwaters, Mississippi River–Grand Rapids, Mississippi River–Brainerd, Mississippi River–Sartell Watersheds, Mississippi River–St. Cloud and Rum River HSPF Models

Please review the following methodology and results for the hydrologic and water quality calibration and validation for the following HSPF watershed model applications:

- Mississippi River Headwaters (07010101)
- Leech Lake River (07010102)
- Pine River (07010105)
- Mississippi River–Grand Rapids (07010103)
- Mississippi River–Brainerd (07010104)
- Mississippi River–Sartell (07010201)
- Mississippi River–St. Cloud (07010203)
- Rum (07010207).

These areas are collectively referred to as the Upper Mississippi River Watershed (Figure 1). Figures of the subwatersheds and reaches for each model application are shown in Attachment A. The hydrology calibration has been updated since the initial hydrology calibration for these HUCs was completed in December of 2013 [RESPEC, 2013]. Therefore, this memorandum was updated to show both the hydrologic calibration results and water quality calibration results.

HYDROLOGIC CALIBRATION

Hydrologic calibration is critical to parameter development for an HSPF model application, particularly for parameters that cannot be readily estimated by watershed characteristics. Calibrating hydrology is also necessary to form the basis for a sound water-quality calibration. Calibrating an HSPF model application is 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 hydrology and water-quality calibration

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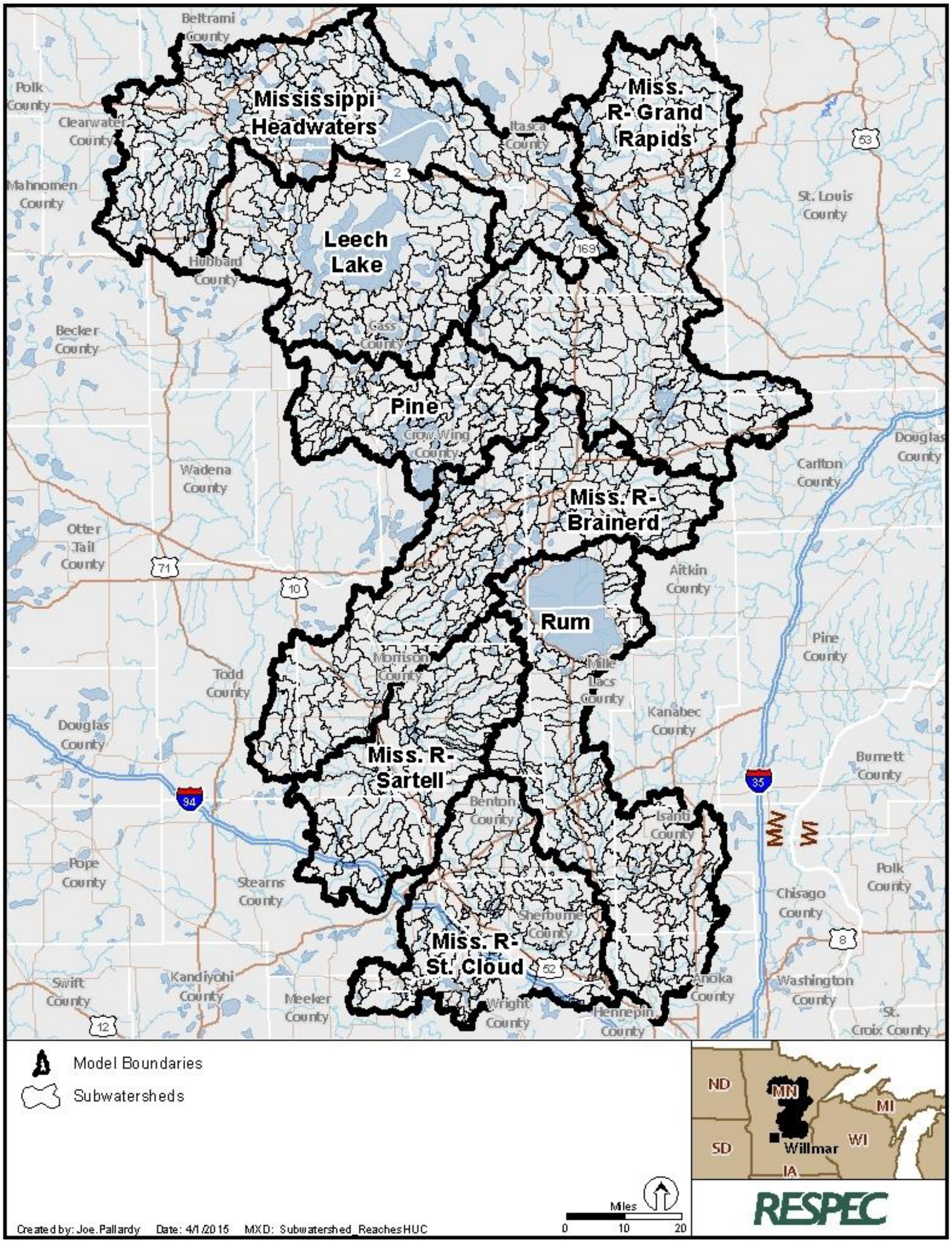


Figure 1. Model Boundaries Within the Upper Mississippi Watershed.

include continuous stream flow (collected at gaging stations) for hydrology and ambient water-quality samples obtained from reputable sources. Calibration is typically evaluated with visual and statistical performance criteria and a validation of model performance that is separate from the calibration effort. The methods and results for the hydrologic calibration and the water-quality calibration are explained in the following sections.

HYDROLOGIC CALIBRATION DATA

The continuous, observed stream flow data required for calibration and validation are available at five gages within the Mississippi River Headwaters Watershed, one gage within the Leech Lake River Watershed, two gages within the Pine River Watershed, five gages within the Mississippi River–Grand Rapids Watershed, six gages within the Mississippi River–Brainerd Watershed, five gages within the Mississippi River–Sartell Watershed, four gages within the Mississippi River–St. Cloud Watershed, and four gages within the Rum River Watershed. Table 1lists the stream flow gages and their period of record to support model calibration and validation of hydrology; mainstem gages are indicated in bold. Mainstem gages are located on mainstem reaches or below lakes that intersect a mainstem reach. Observed flow data downstream of Lake Bemidji (reach 400), and Lake Winnibigoshish (reach 520) in the Mississippi River Headwaters Watershed, Leech Lake (reach 160) in the Leech Lake River Watershed, Cross Lake (reach 280) in the Pine River Watershed, and Big Sandy Lake (Reach 463 in the Mississippi River-Grand Rapids Watershed were used as inputs to each respective watershed model. At these locations, observed outflow data were used to represent reservoir outflows. Flow data were downloaded from the DNR/MPCA Cooperative Stream Gaging Web Interface (www.dnr.state.mn.us/waters/csg/index.html) and from the Army Corps of Engineers, St. Paul District Water Control Center website (http://www.mvp-wc.usace.army.mil/). MPCA provided stream flow data at an additional 14 locations within the project area. Fourteen of the calibration sites have discharge data for the entire modeling period, while others have data only for a subset of those years (Table 1). The locations of all flow gages for the Upper Mississippi River Watershed are illustrated in Figure 2, and more detailed locations for each model application are illustrated in Attachment B.

The drainage area of the Upper Mississippi River Watershed is more than 11,500 square miles and was split into eight separate models. The models were linked using the simulated reach outflows from the upstream applications as boundary conditions for the downstream models. Flow time series were created by writing the reach outflows to a watershed data management (WDM) file by using the external targets block in the User Control Input (UCI). Individual time series were assigned to its corresponding downstream reaches via the external sources block of the UCI. The locations of these reaches and their respective downstream reaches are provided in Table 2 along with inputs from the Crow Wing River and Sauk River model applications.

Table 1. Discharge Calibration Gages Within the Upper Mississippi River Watershed (Page 1 of 2)

Watershed	Gage	Gage Description	HSPF Reach I.D.	Drainage Area (mi²)	Data Availability	Sample Count
Mississippi River Headwaters	**7115001**	**Stump Lake near Bemidji**	**400**	**615**	**1995-2009**	**3,875**
Mississippi River Headwaters	**23232323**	**Lake Pokegama Army Corps of Engineers Dam**	**640**	**1,921**	**1995-2009**	**5,479**
Mississippi River Headwaters	**11014700**	**Lake Winnibigoshish Army Corps of Engineers Dam**	**520**	**1,471**	**1995-2009**	**5,479**
Mississippi River Headwaters	**7052001**	**Mississippi River at County Highway 40**	**210**	**86**	**2001-2009**	**1,907**
Mississippi River Headwaters	**7062001**	**Mississippi River at County Highway 11**	**290**	**555**	**2006-2009**	**597**
Leech Lake River	**8022001**	**Leech Lake Army Corps of Engineers Dam**	**160**	**859**	**1995-2009**	**5,479**
Pine River	**11051001**	**Pine River near Mission**	**330**	**781**	**2008-2009**	**545**
Pine River	**18031200**	**Pine River at Army Corps of Engineers Dam on Cross Lake**	**280**	**583**	**1995-2009**	**5,479**
Mississippi River Grand Rapids	**E09064001**	**Mississippi River at Grand Rapids**	**220**	**3,279**	**1995–2009**	**5,479**
Mississippi River Grand Rapids	**E09020001**	**Prairie River near Taconite**	**150**	**328**	**2001–2009**	**3,197**
Mississippi River Grand Rapids	H09065001	Swan River near Jacobson, MN	309	255	2007–2009	520
Mississippi River Grand Rapids	H09069001	Tamarack River near McGregor, MN	423	53	2004–2009	921
Mississippi River Grand Rapids	H0100620	Big Sandy Lake Outlet near McGregor, MN	463	1,393	1995–2009	5,455
Mississippi River Grand Rapids	**E09118001**	**Willow River near Palisade**	**690**	**450**	**2007–2009**	**698**
Mississippi River Grand Rapids	H09079001	Prairie River near McGregor	431	160	2005–2008	799
Mississippi River Brainerd	**E10015001**	**Mississippi River at Aitkin, MN**	**110**	**5648**	**1995–2009**	**5,479**
Mississippi River Brainerd	**H10082002**	**Mississippi River at Brainerd, MN**	**270**	**7,245**	**1995–2009**	**5,479**
Mississippi River Brainerd	**H10048001**	**Mississippi River near Fort Ripley, MN**	**470**	**7,517**	**1995–2000**	**2,100**
Mississippi River Brainerd	H10065002	Swan River near Sobieski, MN	585	173	2001–2003	847
Mississippi River Brainerd	H10018001	Rice River near Kimberly, MN	53	248	2007–2009	669
Mississippi River Brainerd	**H10103001**	**Nokassippi River near Ft. Ripley**	**450**	**193**	**2004–2009**	**1,338**

Table 1. Discharge Calibration Gages Within the Upper Mississippi River Watershed (Page 2 of 2)

Watershed	Gage	Gage Description	HSPF Reach I.D.	Drainage Area (mi^2)	Data Availability	Sample Count
Mississippi River Sartell	**H15001002**	**Mississippi River near Royalton**	**610**	**7,489**	**2006–2009**	**1,402**
Mississippi River Sartell	H15028001	Bunker Hill Creek near Rice	933	17	2006–2009	956
Mississippi River Sartell	H15031001	Little Rock Cr near Rice	935	67	2006–2009	1,011
Mississippi River Sartell	**H15030001**	**Platte River near Royalton**	**890**	**428**	**2003–2009**	**1,644**
Mississippi River Sartell	H15001001	Two River near Bowlus	625	154	2004–2009	1,134
Mississippi River St. Cloud	**H17046001**	**Elk River near Big Lake, MN**	**710**	**554**	**1995–2009**	**5,479**
Mississippi River St. Cloud	**H17022001**	**Mississippi River at St. Cloud**	**10**	**8,881**	**1995–2009**	**5,479**
Mississippi River St. Cloud	H17063001	Mayhew Creek near St. Cloud	457	51	2007–2009	698
Mississippi River St. Cloud	**H17024001**	**Elk River near Clear Lake**	**490**	**169**	**2008–2009**	**404**
Rum River	**H21095001**	**Rum River near St. Francis, MN**	**410**	**1,405**	**1995–2009**	**5,479**
Rum River	E05284305	Seguchie Creek at Holt Lake Outlet	45	17	2004–2006	858
Rum River	**A22222222**	**Rum River near Anoka**	**450**	**1,523**	**1995–2009**	**5,479**
Rum River	**H21021001**	**Rum River near Milaca, MN**	**170**	**581**	**1995–2009**	**5,479**
Rum River	H21040002	West Branch Rum River nr Princeton	261	164	2004–2009	1,343

Calibration is typically performed over multiple years to capture a range of hydrologic conditions. The model simulation year (1995) was not compared to measured flows but rather was used to “spin up” the model to the existing soil moisture and flow conditions. The models were calibrated to observed flows between 1996 and 2009.

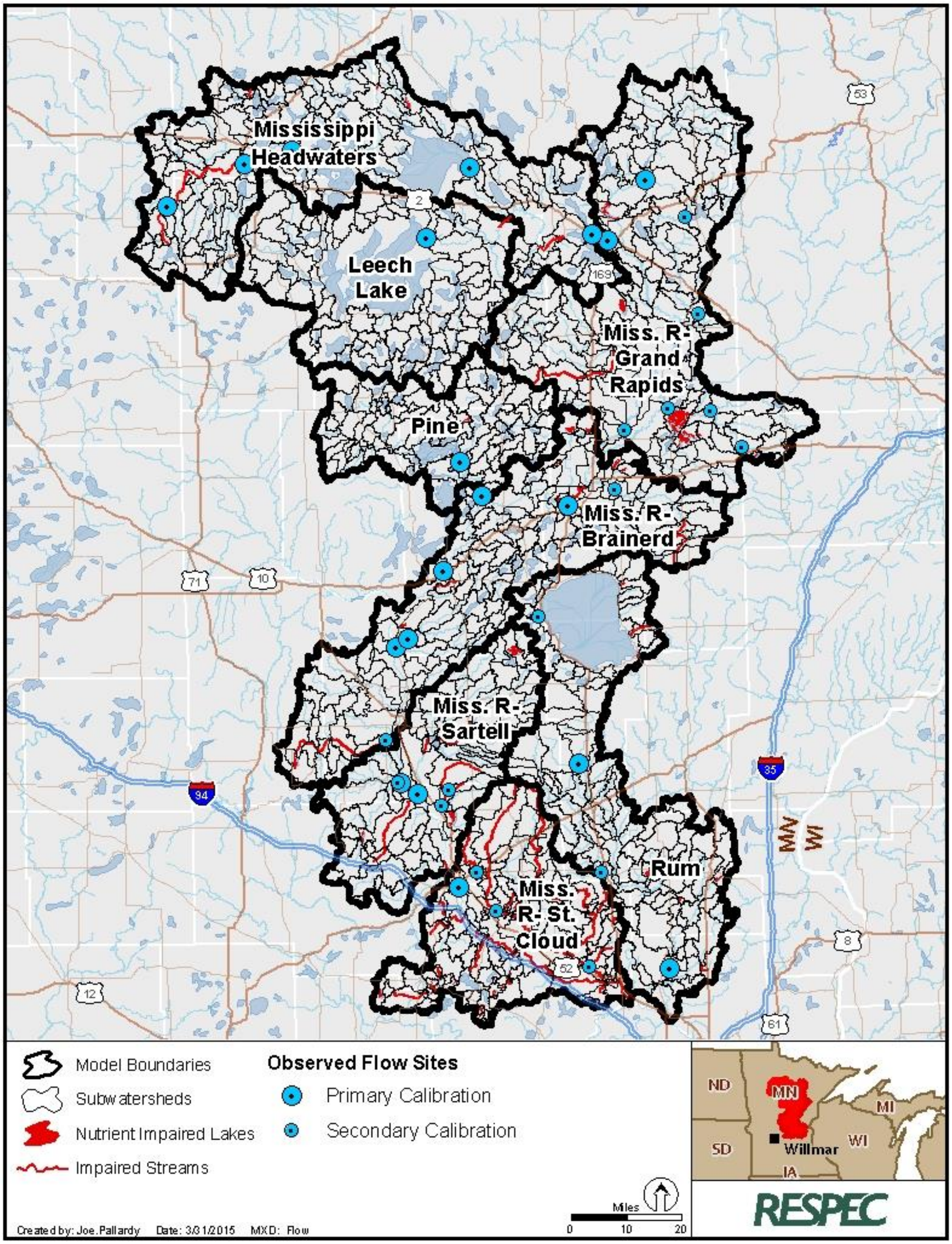


Figure 2. Flow Calibration Gages Within the Upper Mississippi River Watershed.

Table 2. Reach Outflows Used as Boundary Conditions to Downstream Model Applications

Upstream Reach—Boundary Condition		Downstream Receiving Reach	
Model Application	**Reach I.D.**	**Model Application**	**Reach I.D.**
Leech Lake River	190	Mississippi River – Headwaters	590
Mississippi River – Headwaters	650	Mississippi River – Grand Rapids	220
Mississippi River – Grand Rapids	470	Mississippi River – Brainerd	10
Mississippi River – Grand Rapids	690	Mississippi River – Brainerd	10
Mississippi River – Grand Rapids	693	Mississippi River – Brainerd	10
Pine River	330	Mississippi River – Brainerd	220
Crow Wing River	700	Mississippi River – Brainerd	290
Mississippi River – Brainerd	590	Mississippi River – Sartell	600
Mississippi River – Sartell	970	Mississippi River – St. Cloud	10
Sauk River	490	Mississippi River – St. Cloud	10

STANDARD HYDROLOGIC CALIBRATION

The standard hydrologic calibration is an iterative process intended to match simulated flow to observed flow by methodically adjusting model parameters. Water-quality simulations are highly dependent on the hydrology process. Therefore, water-quality calibration cannot begin until the hydrology calibration is considered acceptable. The standard **HSPF** hydrologic calibration is divided into four sequential phases of adjusting appropriate parameters to improve the performance of their respective components of watershed hydrology simulation. The following four phases are described in order of application.

- **Establish an annual water balance.** This consists of comparing the total annual simulated and observed flows (in inches) and is governed by meteorological inputs (rainfall and evaporation); the listed parameters LZSN (lower zone nominal storage), LZETP (lower zone evapotranspiration parameter), DEEPFR (deep groundwater recharge losses), and INFILT (infiltration index); and the factor applied to pan evaporation to calculate potential evapotranspiration (ET).
- **Make seasonal adjustments.** Differences in the simulated and observed total flow over summer and winter are compared to see if runoff (defined for calibration purposes as total stream discharge) needs to be shifted from one season to another. These adjustments are generally accomplished by using seasonal (monthly variable) values for the parameters CEPSC (vegetal interception), UZSN (upper zone storage), and LZETP.LZETP will vary greatly by land cover, especially during summer months, because evapotranspiration differs. KVARY (variable groundwater recession) and

BASETP (baseflow ET index) as well as snow accumulation and melt parameters are also adjusted.

- **Adjust low-flow/high-flow distribution.** This phase compares high- and low- flow volumes by using flow percentile statistics and flow duration curves. Parameters typically adjusted during this phase include INFILT, AGWRC (groundwater recession), and BASETP.
- **Adjust storm flow/hydrograph shape.** Storm flow, which is largely composed of surface runoff and interflow, is evaluated by using daily and hourly hydrographs. Adjustments are made to the UZSN, INTFW (interflow parameter), and IRC (interflow recession). INFILT may also be adjusted slightly.

Monthly variation of the CEPSC and LZETP parameters was initially applied to all pervious (PERLND) categories. Monthly variations in UZSN, NSUR, INTFW, and IRC parameters were applied, as necessary, to improve model performance.

By iteratively adjusting specific calibration parameter values within accepted ranges, the simulation results were improved until an acceptable comparison of simulated results and measured data was achieved. The procedures and parameter adjustments involved in these phases are more completely described in Donigian et al. [1984] and in the HSPF hydrologic calibration expert system (HSPEXP) [Lumb et al., 1994].

Land cover and soil properties typically control most of the variability in the hydrologic responses of a watershed; thus, they were the basis for estimating initial hydrologic parameters. RESPEC's previous work in northern Minnesota model applications includes work in the Lake of the Woods Watershed including the Big Fork and Little Fork Watersheds. The land cover characteristics and climatic conditions present in the Big Fork and Little Fork Watershed calibration provided a starting point for estimating some of the initial hydrologic parameters. The land cover characteristics primarily affect water losses from evaporation or transpiration by vegetation. The movement of water through the system is also affected by vegetation cover and associated characteristics (e.g., type, density, and roughness). Soil properties primarily affect infiltration, interflow, and soil storage parameters. HSPF model categories were developed based on aggregating the existing land cover and hydrologic soil group classifications into representative hydrologic areas. Initial parameter estimates and their relative variances between land segment categories are crucial to maintaining an appropriate representation of the hydrologic components. Engineering judgment is used to adjust parameters congruently within land segment categories during calibration because of parameter diversity and spatial distribution within the watershed.

SNOW ACCUMULATION AND MELT CALIBRATION

Snow accumulation and melt are significant components of the hydrologic cycle in Minnesota; thus, snow simulation is an integral part of the hydrology calibration. Calibration of snow parameters is generally completed early in the calibration process, along with the seasonal phase of the standard calibration procedure. Snow was simulated in HSPF with meteorological time-series data (air temperature, solar radiation, wind, and dew point temperature) along with a suite of adjustable parameters. Initial values for TSNOW (the wet bulb air temperature, below which precipitation occurs as snow under saturated conditions), CCFACT (the factor to adjust the rate of heat transfer from the atmosphere to the snowpack because of condensation and convection), MGMELT (the maximum rate of snowmelt by ground heat), SNOEVP (the factor to adjust evaporation/sublimation from the snowpack), and MWATER (the maximum liquid water holding capacity of the snowpack) were attained from previous HSPF applications in Minnesota and were adjusted as necessary. The initial snow parameter calibration was supported using comparisons of observed and simulated snowfall and snow depth data to verify a reasonable representation of snow accumulation and melt processes. A more detailed calibration of snow parameters was based on comparisons of observed and simulated flow data during the standard hydrologic calibration process. Observed snowfall and depth data were downloaded from the High Plains Regional Climate Center Climate Information for Management and Operational Decisions (CLIMOD) website (*http://climod.unl.edu/*) for the two locations in the Mississippi River –Headwaters Watershed, the two locations in the Leech Lake River Watershed, the one location in the Pine River Watershed, the three locations in the Mississippi River–Grand Rapids Watershed, the four locations in the Mississippi River–Brainerd Watershed, the two locations in and near the Mississippi River–Sartell Watershed, the two locations in the Mississippi River–St. Cloud Watershed and the three locations in the Rum River Watershed (Figure 3). Calibration figures were constructed to compare observed snowfall to simulated snowfall (Figure 4, top) and observed snow depth to simulated snow levels (Figure 4, bottom). Air temperature is included on the snowfall figure to help estimate parameters such as TSNOW and to verify accuracy of the snowfall data.

HYDRAULIC CALIBRATION

Because of the high number of lakes in these watersheds, lake level and resulting outflow is an important factor in the hydrology calibration. Lake level data were available for 70 percent of the modeled lakes and were used for comparison to simulated lake levels. The initial lake level calibration, which was completed as an early portion of the hydrology calibration, involved adjusting the reference outlet elevations to represent lake volumes before outflow occurs. Lake geometry parameters as well as outlet depths and outflow calculations were adjusted to modify the F-tables in congruence with the storm flow phase of the standard calibration with the overall goal of adequately representing lake volumes and outflows. Figure 5 shows an example of the calibration figures developed to compare observed and simulated lake levels. Storm hydrographs were also used to calibrate lake F-tables to represent flow attenuation throughout the watershed. In cases where multiple lakes are represented as one F-table, simulated lake levels cannot be directly compared to observed lake levels because the combined F-table represents cumulative volume and surface area with absolute depths. Outlet levels can be adjusted but lake level variations will be less variable because of greater storage volumes associated with the same depths. These combined F-tables were evaluated by comparing patterns in the lake level data instead of actual lake level values.

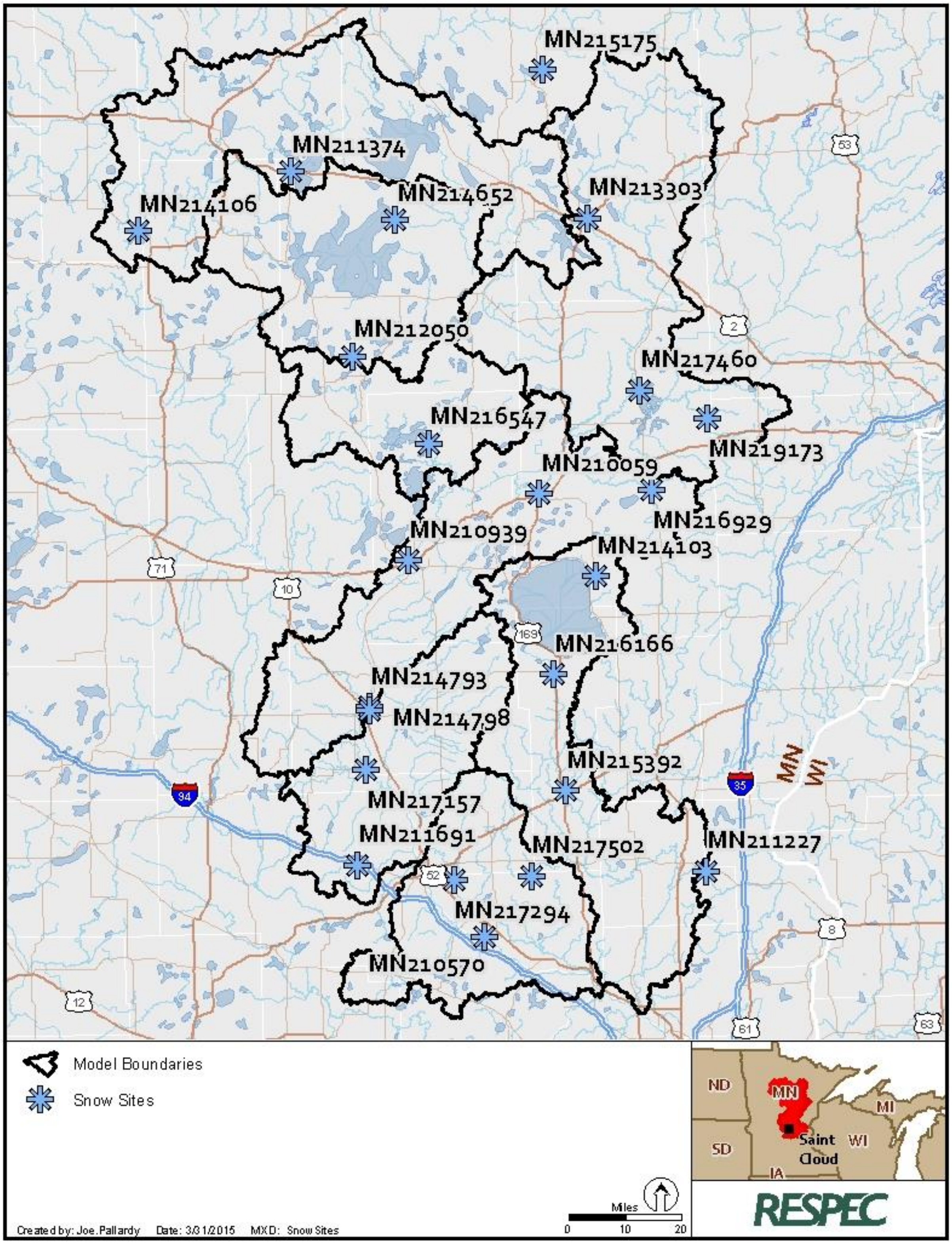


Figure 3. Meteorological With Snow Data Used for Calibration.

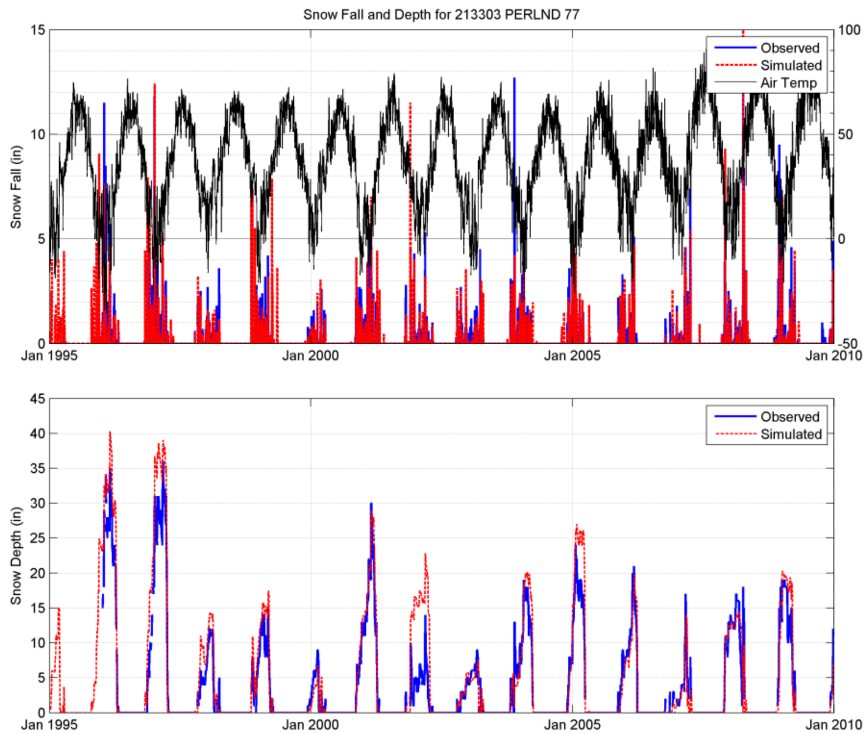


Figure 4. **Examples of Snowfall (Top) and Snow Depth (Bottom) Calibration Figures.**

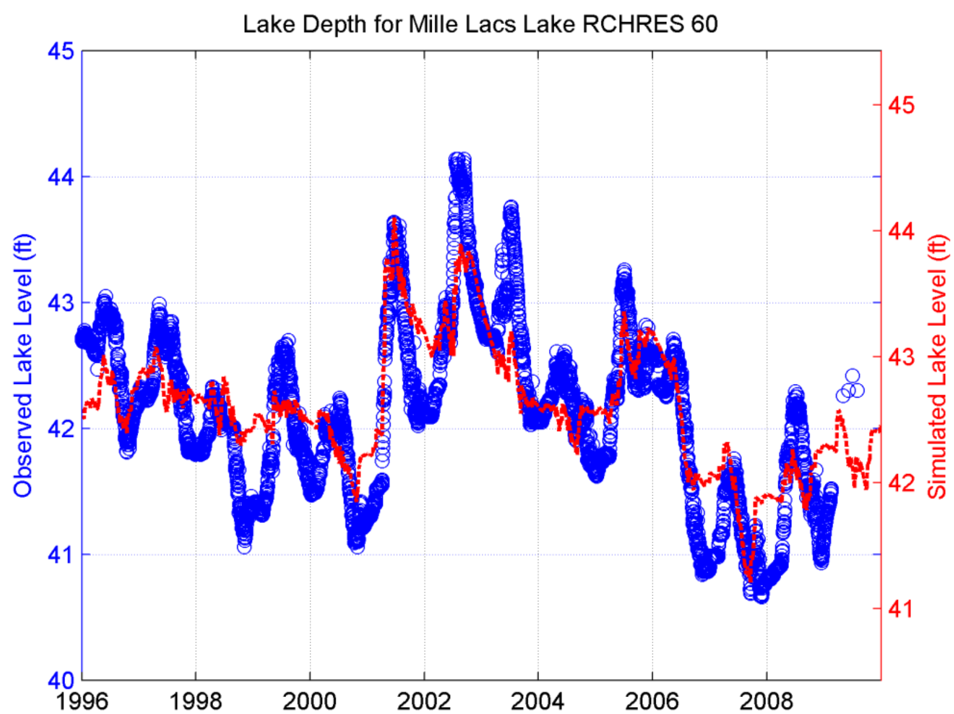


Figure 5. **Lake Level Calibration.**

Army Corps of Engineers Large Reservoir Outflow

Seven large reservoirs are located in the Upper Mississippi River Watershed. The U.S. Army Corps of Engineers (USACE) is responsible for controlling water levels on five of them: Leech Lake, Lake Winnibigoshish, Lake Pokegama, Cross Lake, and Big Sandy Lake. The other two reservoirs are operated by Otter Tail Power (Lake Bemidji/Stump Lake) and the U.S. Forest Service (Knutson Dam on Cass Lake). The USACE maintains outflow gages at Leech Lake, Lake Winnibigoshish, Lake Pokegama, and Cross Lake while Otter Tail Power maintains a flow gage on Lake Bemidji. Recorded outflow measurements at these sites were computed based on the hydraulic head (difference between the elevation of water above the dam and the elevation of the water below the dam) and the number of gates open at any given time. A sliding rating table based on the number of gates open, hydraulic head, and design of the dam was used to compute the discharge leaving the dam. The large size of the reservoirs (Leech Lake: 112,000 acres, Lake Winnibigoshish: 58,544 acres, Cass Lake: 16,000 acres) allows for the accumulation of large volumes of water at the face of the dam from wind and wave action [Johnson, 2013]. Water accumulation on the windward side of the lake occasionally results in an inaccurate reading of the true lake level [Kleinert, 2013]. Therefore, during these periods of time, the computed release of water may be higher than the expected precipitation records. Despite these potential discrepancies, the observed flow time series at these reservoirs were used in model calibration because these data reflect the USACE management strategy and the operating rules for each reservoir. The operating rules for each reservoir are designed to maintain a summer pool through July 15 and then fall at a rate of approximately 2 inches per month to allow for flood storage in the following spring. This management style provides maximum recreational and wildlife benefit which allows flood storage to protect downstream municipalities during the spring. This management style is aimed at providing maximum recreational and wildlife benefit while allowing for flood storage to protect downstream municipalities during the spring.

Weight-of-Evidence Approach

Model performance was evaluated by using a weight-of-evidence approach described in Donigian [2002]. This approach uses both visual and statistical methods to best define the performance of the model. The approach was integrated into the hydrologic calibration to continuously evaluate model results to efficiently improve calibration performance until there was no apparent improvement from further parameter adjustment. This process was performed at each flow gage by adjusting parameters for land segments upstream while maintaining a consistent parameter set throughout the model domain with only small variations to account for unique local conditions. Moreover, greater weight was applied to the performance of the model at gages where there is a larger contributing area and a longer period of record. Maintaining comparable parameter values and intraparameter variations for each land segment category throughout the watershed are also preferred. The specific model-data comparisons of simulated and observed values for the calibration period are grouped below with their associated phase of the standard hydrologic calibration.

- **Establish an annual water balance**
  - Total runoff volume errors for calibration/validation period
  - Annual runoff volume errors

- **Make seasonal adjustments**
  - Monthly runoff volume errors
  - Monthly model-fit statistics
  - Summer/winter runoff volume errors
  - Summer/winter storm volume errors
- **Adjust low-flow/high-flow distribution**
  - Highest 5 percent, 10 percent, and 25 percent of flow volume errors
  - Lowest 5 percent, 10 percent, 15 percent, 25 percent, and 50 percent of flow volume errors
  - Flow frequency (flow duration) curves
- **Adjust storm flow/hydrograph shape**
  - Daily/hourly flow time-series graphs to evaluate hydrograph shape
  - Daily model-fit statistics
  - Average storm peak flow errors
  - Summer/winter storm volume errors.

Common model-fit statistics used for evaluating hydrologic model applications include a correlation coefficient (r), a coefficient of determination (r^2), Nash-Sutcliffe efficiency (NSE), mean error, mean absolute error, and mean square error. Statistical methods help provide definitive answers but are still subject to the modeler's best judgment for the overall model performance.

Annual and monthly plots were used to visually compare runoff volumes over the contributing area. This method includes transferring the amount of flow measured at each calibrated gage to a volume of water (measured in inches spread over the entire contributing area) to normalize the data for the drainage area. Monthly plots help verify the model's ability to capture the variability in runoff among the watersheds and also verify that the snowfall and snowmelt processes are simulated accurately. Average yearly plots help verify that the annual water balances are reasonable and allow trends to be considered. Flow frequency distributions, or flow duration curves, present measured flow and simulated flow versus the corresponding percent of time the flow is exceeded. Thus, the flow duration curves provide a clear way to evaluate model performance for various flow conditions (e.g., storm events or baseflow) and determine which parameters to adjust to better fit the data. Daily flow time-series plots allow for the analyses of individual storm events, snow accumulation and snowmelt processes, and baseflow trends. Examples of the daily flow time-series plots, monthly plots, annual plots, and flow duration curves used for the calibration/validation process are shown in Figure 6 through Figure 9, respectively.

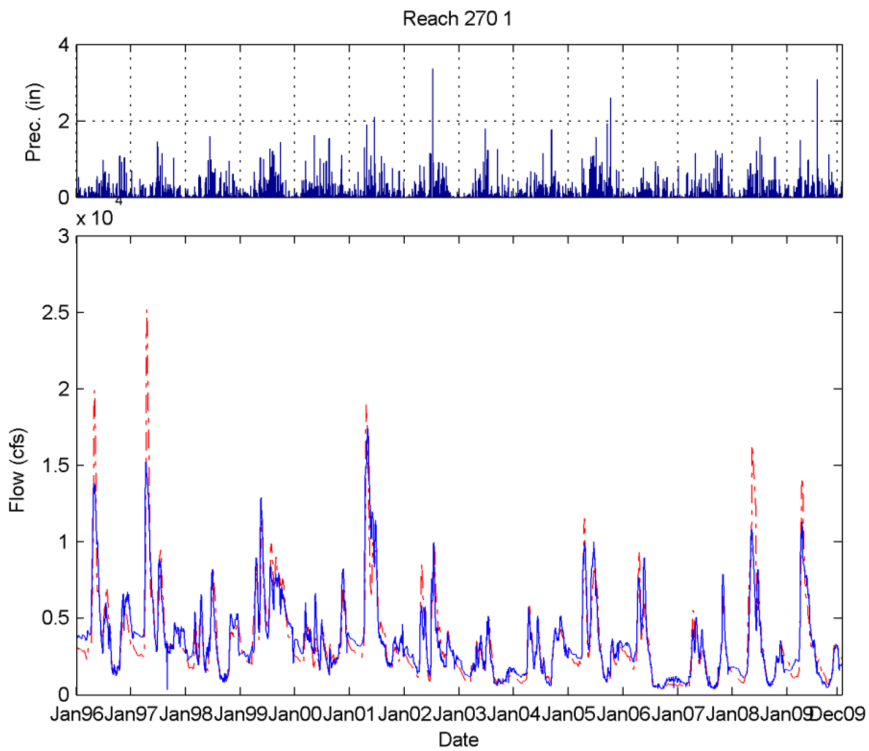


Figure 6. Daily Flow Time-Series Plot Example.

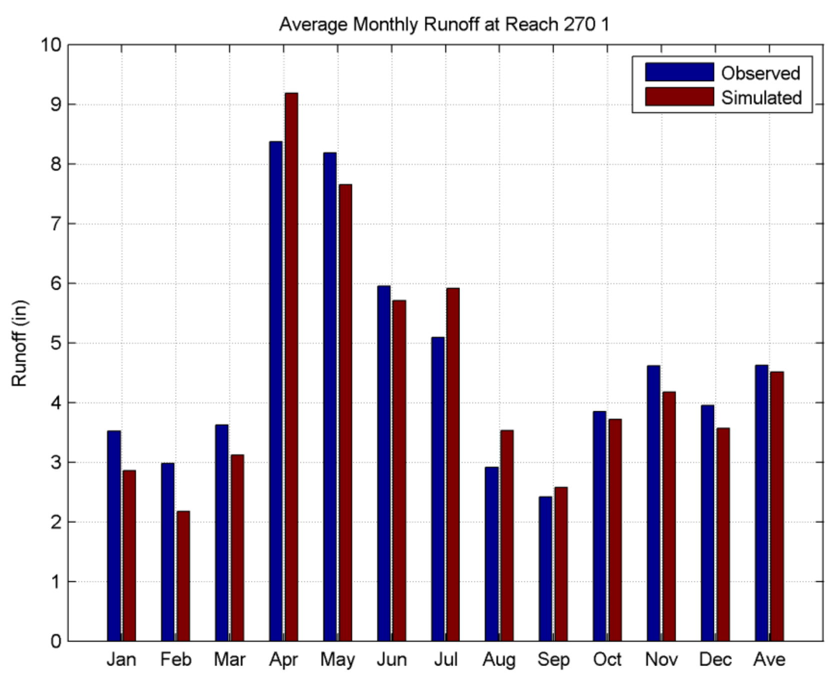


Figure 7. Average Monthly Runoff Plot Example.

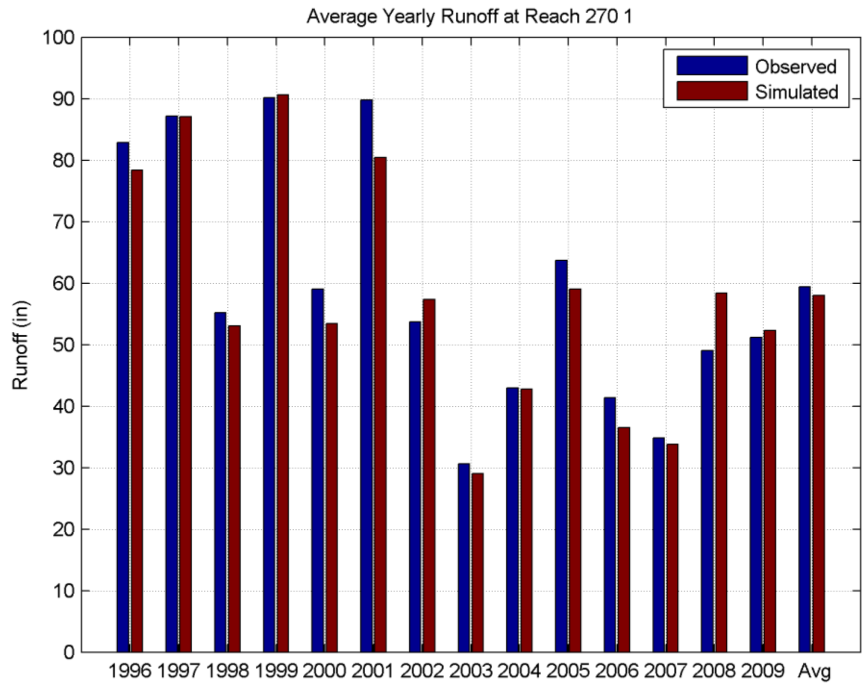


Figure 8. Average Yearly Runoff Plot Example.

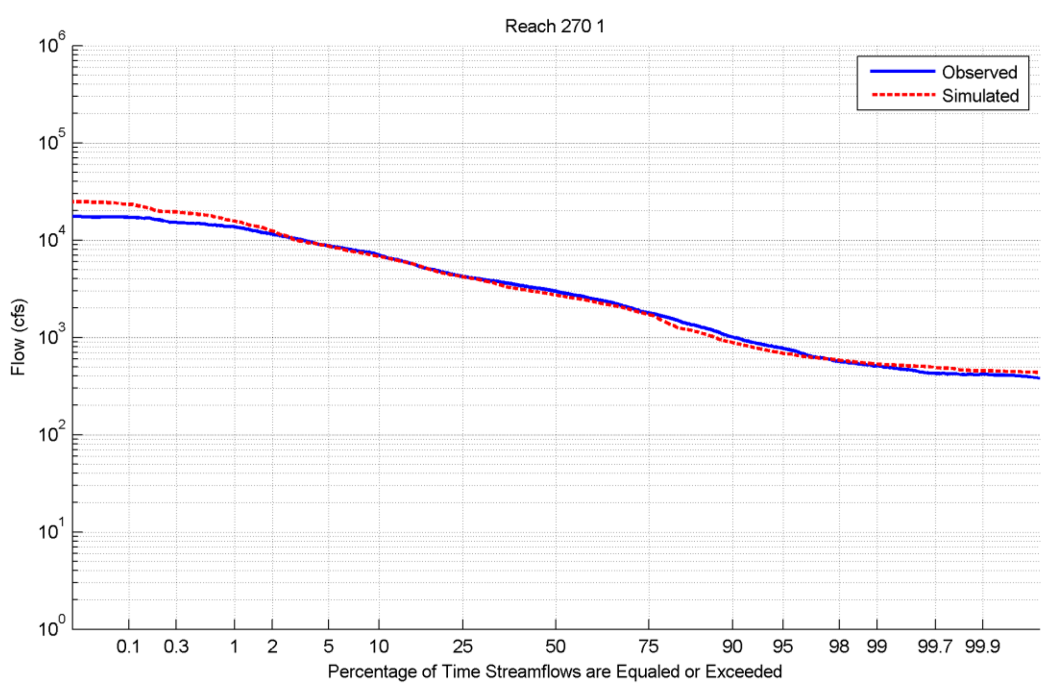


Figure 9. Flow Duration Curve Example.

In addition to the above comparisons, the water balance components of watershed hydrology were reviewed. This involved summarizing outflows from each individual land cover and soil group classification for the following hydrologic components:

- **Precipitation**
- **Total runoff (sum of following components)**
  - Overland flow
  - Interflow
  - Baseflow
- **Potential evapotranspiration**
- **Total actual ET (sum of following components)**
  - Interception ET
  - Upper zone ET
  - Lower zone ET
  - Baseflow ET
  - Active groundwater ET
- **Deep groundwater recharge/losses**

Although observed values are not available for each of the water balance components listed above, the average annual values must be consistent with expected values for the region and for the individual land cover and soil group categories.

Model Performance Criteria

The calibration parameters were adjusted to improve the performance of the model until the desired performance criteria were met or there was no apparent improvement from parameter refinement. The graphical plots were visually evaluated to objectively assess the model performance and the statistics were compared to objective criteria. The percent error statistics were evaluated with the hydrology criteria in Table 3. The correlation coefficient (r) and coefficient of determination (r^2) were compared with the criteria in Figure 10to evaluate the performance of the daily and monthly flows. These measures allow the user to assess the quality of the overall model application performance in descriptive terms to aid in deciding to accept or reject the model application. The developed performance criteria are explained in detail in Donigian [2002].

Table 3. 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].

Figure 10. General Calibration/Validation *r* and r^2 Targets for HSPF Applications.

Hydrology Calibration Results

The calibration was performed by using the primary mainstem stream gages located in each HUC-8 watershed. Secondary gages on tributaries were used to help calibrate parameters for less influential land segment categories. The calibration results for all mainstem gages rate good or very good with respect to the calibration and validation targets (Figure 10). Table 4provides results for primary gages in the Upper Mississippi River Watershed model applications. The weighted overall statistic represents a drainage area weighted average. Table 5summarizes the weighted water balance components at the outlets of each watershed model applications and Attachment C contains hydrologic calibration figures for primary gages in the Upper Mississippi River Watershed model application.

A transition in the dominant land uses in each watershed is reflective of the transition from the Northern Lakes and Forest Ecoregion to the North Central Hardwood Forest Ecoregion. This transition required modifications in the parameterization of each modeled watershed. For example, the Mississippi River – Headwaters, Leech Lake River, Pine River, Mississippi River-Grand Rapids and Mississippi River-Brainerd Watersheds are primarily located in the Northern Lakes and Forests Ecoregion; these watersheds are comprised of a greater percentage of forests. In comparison, the Mississippi River-St. Cloud and Mississippi River-Sartell Watersheds are located primarily in the North Central Hardwood Forest Ecoregion and contain a larger percentage of cropland and pasture. The Rum River watershed is divided into two ecoregions with 43 percent of the watershed located in the Northern Lakes and Forests Ecoregion and 57 percent in the North Central Hardwood Forest Ecoregion. Changes in the parameterization of the Rum River Watershed were reflective of the transition in ecoregions. The presence of Mille Lacs Lake in the Rum River Watershed also makes the open water area of the Rum River Watershed substantially higher than other modeled watersheds. A discussion of the hydrology calibration methodology and final results is included in the Kenner [2013]. To use the largest possible dataset, the calibration was completed on the entire modeling period (1995 through 2009) and was based on the NLCD 2006 land-use data.

Table 4. Summary Statistics for Primary Calibration Gages in the Upper Mississippi Watershed

Model Application	Observed Flow Gage	HSPF Reach	Total Runoff Volume			Monthly			Daily			Storm % Error	
			Obs (in)	Sim (in)	% Δ	*R*	R^2	MFE	*R*	R^2	MFE	Volume	Peak
Mississippi River Headwaters	23232323	640	11.25	11.47	1.95	0.95	0.90	0.90	0.90	0.81	0.81	0.90	4.61
Pine River	11051001	330	4.11	4.03	1.81	0.98	0.96	0.95	0.95	0.91	0.90	2.14	0.59
Mississippi River Grand Rapids	E09118001	690	5.48	5.60	2.27	0.93	0.86	0.75	0.90	0.81	0.70	1.45	3.53
Mississippi River Brainerd	H10048001	470	90.9	90.51	0.44	0.95	0.91	0.86	0.91	0.82	0.76	1.01	2.83
Mississippi River Sartell	H15030001	890	5.58	5.91	5.89	0.89	0.79	0.79	0.81	0.65	0.63	2.16	28.49
Mississippi River St. Cloud	H17046001	710	6.40	6.89	7.70	0.94	0.88	0.87	0.87	0.76	0.74	4.02	2.30
Rum River	A22222222	450	8.34	7.87	5.69	0.95	0.89	0.87	0.92	0.85	0.82	4.04	6.47

Table 5. Summary of Water Balance Components

Water Balance Component	Water Balance Component Description	Inches of Water							
		Mississippi River Headwaters	Leech Lake River	Pine River	Mississippi River Grand Rapids	Mississippi River Brainerd	Mississippi River Sartell	Mississippi River St. Cloud	Rum River
SURO	Surface outflow	0.13	0.06	0.07	0.10	0.11	0.23	0.42	0.29
IFWO	Interflow outflow	0.46	0.38	0.50	1.00	0.86	1.24	1.04	1.22
AGWO	Active groundwater outflow	5.21	4.92	5.06	8.21	6.59	5.83	5.82	6.05
IGWI	Inflow to inactive groundwater	0.03	0.07	0.21	0.10	0.25	0.42	0.58	0.07
CEPE	Evaporation from interception storage	5.77	5.66	5.88	5.28	4.96	4.93	5.27	4.63
UZET	Evapotranspiration from upper zone	3.79	3.70	4.34	4.89	5.01	5.54	5.40	5.04
LZET	Evapotranspiration from lower zone	10.78	11.40	11.20	9.20	10.10	10.03	10.60	10.57
AGWET	Evapotranspiration from active groundwater storage	0.52	0.56	0.64	0.60	0.58	0.25	0.25	0.51
BASET	Evapotranspiration from active groundwater outflow (baseflow)	0.84	0.96	1.02	0.80	0.78	0.55	0.60	0.64

WATER QUALITY CALIBRATION

Simulated water-quality constituents in the Upper Mississippi River Watershed included total suspended solids (TSS), temperature, dissolved oxygen (DO), biochemical oxygen command (BOD), and nutrients (nitrogen and phosphorus speciation). The methods described in the following section provide RESPEC with the ability to estimate TSS, temperature, DO, and nutrient loads; calculate contributions from point, nonpoint, and atmospheric sources where necessary; and provide a means to evaluate the impacts of alternative management strategies to reduce these loads and improve water quality conditions.

Ideally, parameters reflecting the nutrient behavior within each land-use category throughout the Upper Mississippi River Watershed should remain consistent as part of the regional watershed calibration. However, there were instances where those processes differed based on the empirical monitoring data in lower order streams. As previously mentioned, the Mississippi River - Headwaters, Leech Lake River, Pine River, Mississippi River-Grand Rapids and Mississippi River–Brainerd Watersheds are dominated by forests and wetlands. In comparison, the Mississippi River-St. Cloud and Mississippi River–Sartell Watersheds are located primarily contain a larger percentage of cropland and pasture. The Rum River Watershed is divided into two ecoregions; changes in the parameterization of the Rum River Watershed were reflective of the transition in ecoregions. Differences in the dominant land uses within these ecoregions drove slight differences in model parameterization. However, overall parameterization maintained a high level of consistency throughout the region.

Sediment Approach

TSS was used as a surrogate for turbidity, based on an observed, strong correlation between the two. A regression analysis can be completed to determine the relationship of TSS and turbidity, which allows the model TSS predictions to support future total maximum daily load (TMDL) studies. The calibration focus was at locations where TSS concentration data are available. TSS concentration data are widely available, while suspended sediment concentrations (SSC) are more limited. The model application is 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.

Before completing sediment calibration, RESPEC reviewed the NRCS Rapid Watershed Assessment documents for each HUC-8 watershed. These documents contain soil loss estimates derived from the Universal Soil Loss Equation. Unlike HSPF, the Universal Soil Loss Equation does not take into account delivery of sediment to the waterbody. Therefore, the estimated soil loss rates were multiplied by 10% to determine calibration targets for the watershed. These documents included:

- Rapid Watershed Assessment Mississippi Headwaters MN HUC: 7010101 [NRCS, 2008]
- Rapid Watershed Assessment Leech Lake MN HUC: 7010102 [NRCS, 2008]
- Rapid Watershed Assessment Prairie-Willow MN HUC: 7010103 [NRCS, 2008]

- Rapid Watershed Assessment Elk-Nokasippi MN HUC: 7010104 [NRCS, 2008]
- Rapid Watershed Assessment Platte-Spunk MN HUC: 7010201 [NRCS, 2008]
- Rapid Watershed Assessment Clearwater-Elk MN HUC: 7010101 [NRCS, 2008]
- Rapid Watershed Assessment Rum (Wahkon) River MN HUC: 7010207 [NRCS, 2008].

The sediment parameter estimation and calibration was performed following guidance from the U.S. Environmental Protection Agency (EPA) [2006]. The steps for sediment calibration included estimating model parameters, adjusting parameters to represent estimated landscape erosion loading rates and delivery to the stream, adjusting parameters to represent in-stream transport and bed behavior, and analyzing sediment budgets for landscape and in-stream contributions. Observed, local data are rarely sufficient enough to accurately calibrate all land use parameters for each stream and waterbody. Therefore, the majority of the calibration is based on those sites with observed data. Simulations in all parts of the watershed were reviewed to ensure that the model results were consistent with congruent analyses, field observations, historical reports, and expected behavior from past experience. This was especially critical for sediment modeling because the behavior of sediment erosion and transport processes is extremely dynamic [U.S. Environmental Protection Agency, 2006].

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 the rainfall impact equation; KSER and JSER are the coefficient and exponent, respectively, from the soil washoff or transport equation; and KGER and JGER are the coefficient and exponent, respectively, from the matrix soil equation, which simulates gully erosion. KRER was estimated as the soil erodibility coefficient from the RUSLE equation and can be estimated from the Soil Survey Geographic (SSURGO) spatial soils database. Landscape fractionation of sand, silt, and clay were represented using data from the SSURGO spatial soils database. The remaining parameters were initially given a combination of the recommended initial values from the U.S. EPA [2006], values from the Minnesota River model application and other literature information that RESPEC compiled.

After landscape sediment erosion rates were adjusted to provide the expected loading to the stream channel, calibration was continued with adjusting parameters that govern the processes of deposition, scour, and transport of sediment within the stream. Calibration was performed on a reach-by-reach basis from upstream to downstream because downstream reaches are influenced by upstream parameter adjustments. Bed behavior and sediment budgets were analyzed at each reach to ensure that results are consistent with field observations, historical reports, and expected behavior from past experience. The initial composition of the channel beds was estimated by using any available particle, size distribution data. The calibration focus was at locations where observed data are available, with TSS concentration and suspended sediment concentration (SSC) used as a surrogate for turbidity. Both TSS and SSC data are available within the Minnesota Pollution Control Agency (MPCA) dataset and were used in the model calibration.

The primary parameters that were involved in calibrating 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 noncohesive (sand) transport power function. TAUCD and TAUCS are the critical deposition and scour shear stress parameters, respectively. They were initially estimated as the 25^{th} percentile of the simulated bed shear stress for TAUCD and the 75^{th} percentile for TAUCS. Cohesive sediment is transported when the bed shear stress is higher than TAUCD, and it settles and deposits when the bed shear stress is lower than TAUCD. Sediment is 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 it is occurring. KSAND and EXPSAND are the coefficient and exponent of the sand transport power function, respectively.

Agricultural modifications during planting and harvesting can increase the amount of sediment that is readily transported by overland flow. Detached sediment storage (DETS) in HSPF represents the sediment on the surface that is available to wash off. To represent agricultural practices on cropland, DETS was increased at four different days of the year to simulate the increases in sediment available to wash off from plowing, planting, cultivating, and harvesting practices. Cropland classified as high-till was given higher increases in DETS than cropland classified as low-till. After landscape sediment erosion rates were adjusted to provide the expected loading to the stream channel, calibration was continued with adjusting parameters governing the processes of deposition, scour, and transport of sediment within the stream. Calibration was performed on a reach-by-reach basis from upstream to downstream because downstream reaches are influenced by upstream parameter adjustments. Sediment behavior was adjusted to approximate a dynamic steady-state condition where none of the sediment classes (sand, silt and clay) were dramatically accumulating or eroding. Bed behavior and sediment budgets were analyzed at each reach to ensure that the results are consistent with field observations, than TAUCS. The erodibility parameter (M) for silt and clay determines the intensity of scour when it is occurring. KSAND and EXPSAND are the coefficient and exponent of the sand transport power function, respectively. The sediment behavior for each size class was investigated to ensure that sediment dynamics were reflective of field observations. Field observations in the watersheds note that many of the streams have streambanks contributing to the overall sediment export from the system. HSPF does not explicitly simulate those dynamics. The contributions from streambanks were included by allowing the streambed to contribute to those loads.

Temperature, Dissolved Oxygen, Biochemical Oxygen command Dynamics, and Nutrient Approach

The approach for modeling temperature, DO and BOD dynamics, and nutrients was similar to the Minnesota River Model Application's approach. The model application simulates in-stream 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). The adsorption/desorption of total ammonia and orthophosphate to sediment was also simulated. The modeled output can support the MPCA's activities for TMDL development, in-stream nutrient criteria compliance testing, and future support for point-source permitting. Initial calibration parameters were estimated from the Big/Little Fork model application.

Overall sources considered for nutrients included point sources such as water treatment facilities and nonpoint sources from the watershed, atmospheric deposition (nitrate, ammonia and phosphorus), subsurface flow, and soil-bed contributions. Point-source facility contributions were explicitly modeled for future permitting purposes. Nonpoint sources of total ammonia, inorganic nitrogen, orthophosphate, and BOD were simulated through accumulation and depletion/removal and a first-order washoff rate from overland flow as well as inputs from interflow and active groundwater. Modeled land use yields were compared to information gathered from regional (e.g. Discovery Farms monitoring) and national sources to ensure that the model predictions compared favorably with expected values.

The atmospheric deposition of nitrogen and ammonia were applied to all of the land areas and contribute to the nonpoint-source load through the buildup and washoff processes. The atmospheric deposition of both nitrogen and phosphorus onto water surfaces was represented in the model as a direct input to the lakes and river systems. Subsurface flow concentrations were estimated on a monthly basis for calibration.

Septic system loads in the watersheds were also estimated for all counties using information provided by Minnesota Pollution Control Agency [2004].The number of ISTS in each subwatershed were estimated using Geographic Information System (GIS). Loads from ISTSs were included in the models as a constant point source based on information from the MPCA [2004]. The numbers of residences with an ISTS were allocated evenly across the county and subwatershed. The MPCA [2004] report estimates the percentage of failing ISTSs by county, and those values were multiplied by the number of residences to estimate the ISTSs that would contribute excessive nutrients to the receiving waters. The residences that had properly functioning ISTSs were assumed to have an effluent indistinguishable from background groundwater concentrations.

Loads from the failing septic systems were included in the model as constant and were based on local information and literature values. The 2.5 persons within each residence (see http://quickfacts.census.gov/qfd/states/27000.html) were assumed to discharge 50 gallons per day per person [MPCA, 2004]. Nutrient concentrations for phosphate (20 mg/L) and total nitrogen (53 mg/L, evenly divided between ammonia and nitrate) and BOD5 (175 mg/L) were based on values presented in Tetra Tech [2002]. Those loads were also assumed to be reduced by 57, 28, and 0 percent, respectively, based on information from EPA [1980; 1993]. BOD5 loads were converted to CBOD by using a factor of 1.2 for untreated waste [Thomann and Mueller, 1987]. Biochemical reactions that affect DO were represented in the model application. The overall sources considered for BOD and DO include point sources such as wastewater treatment facilities, nonpoint sources from the watershed, interflow, and active groundwater flow.

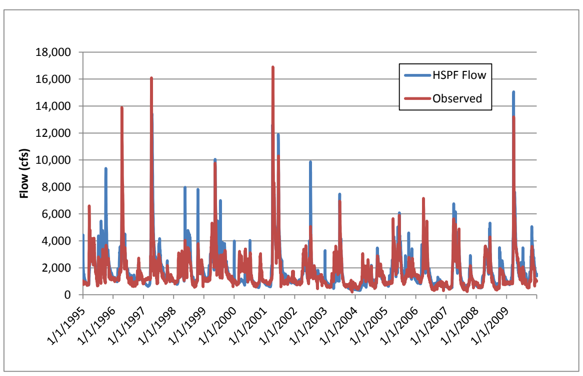
The model was configured to simulate the in-stream and lake processes which contribute to algal growth, nutrient consumption, and dissolved oxygen dynamics. All required in-stream parameters were specified for total ammonia, inorganic nitrogen, orthophosphate, and BOD. The processes in the in-stream portion of the model include BOD accumulation, storage, decay rates, benthic algal oxygen demand, settling rates, and re-aeration rates. Phytoplankton dynamics (respiration, growth, settling rates, density, and nutrient requirements) are included in addition to the similar demands of attached benthic algae.

Boundary Condition Input Validation

The modeled watershed have areas upstream (boundary conditions) which contribute both flow and water quality to the system and need to be properly accounted for within the model to ensure accurate predictions. Contributing watersheds to the Upper Mississippi River watershed model application include inputs from the Crow Wing River watershed to the Mississippi River-Brainerd model and inputs from the Sauk River watershed to the Mississippi River-St. Cloud model. Those areas have been previously modeled with HSPF and those outputs were initially used to develop daily time series from Crow Wing and Sauk Rivers. During the model water quality calibration, boundary conditions from the Crow Wing River resulted in poor calibrations downstream. To investigate this, and find a better way to represent those boundary conditions, we use FLUX32 with observed flow and grab sample to develop water quality time series.

Following the methodology for the HSPF model calibration for the Upper Mississippi River Watershed, the flows at the boundary from the Crow Wing River were first compared. The HSPF model compared well with the observations (Figure 11and Table 6).

With confidence in the hydrology predictions, comparisons were made of daily average sediment and nutrient concentrations from the HSPF model and FLUX. In both approaches, the load was divided by the daily volume to obtain daily average concentrations. Table 7 and Table 8 compare both of those estimates with observations and each other. Total phosphorous is shown as an example of the nutrient analysis where both approaches compare well to observed concentrations (Table 7) with the exception of the higher concentrations where the HSPF model overpredicts by more than double. The TSS predictions show a greater difference where the HSPF model underpredicts at the lower concentrations and greatly overpredicts at the higher concentrations (Table 8). Because of those discrepancies between the HSPF predictions and observations, the FLUX32 estimates were used to define the boundary conditions of flow, TSS, ammonia, nitrate/nitrite, phosphate and total phosphorous for the Crow Wing River.



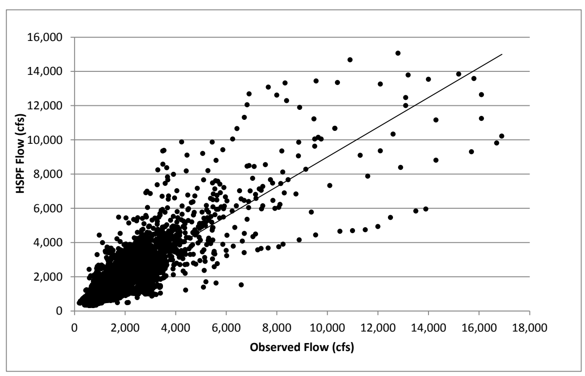


Figure 11. **Comparison of Daily Flows From Crow Wing River HSPF Model and Measured Flows the Crow Wing River at Pillager**

Table 6. Boundary Condition Summary Statistics (HSPF and measured) for Daily Flows for the Crow Wing River at Pillager

Model	25th Percentile	Mean	Median	75th Percentile
Crow Wing HSPF Reach 290	902	1,796	1,335	2,142
Flux 32 Crow Wing River at Pillager	873	1,710	1,220.0	2,100

Table 7. Boundary Condition Summary Statistics (HSPF and measured) for Daily Average TP Concentrations (mg/L) for the Crow Wing River at Pillager

Model	Min	25th Percentile	Mean	Median	75th Percentile	Max
Crow Wing HSPF Reach 290	0.028	0.049	0.065	0.059	0.071	0.776
FLUX 32 Crow Wing River	0.021	0.049	0.059	0.055	0.066	0.340
Observed Concentration	0.021	0.046	0.065	0.056	0.071	0.340

Table 8. Boundary Condition Summary Statistics (HSPF and measured) for Daily Average TSS Concentrations for the Crow Wing River at Pillager

Model	Min	25th Percentile	Mean	Median	75th Percentile	Max
Crow Wing HSPF Reach 290	0.00	0.00	20.87	1.67	7.49	1,426.44
FLUX 32 Crow Wing River	1.0	3.56	4.28	4.12	4.96	17.00
Observed Concentration	1.0	2.80	4.76	3.90	6.00	17.00

Ambient Water Quality Data Available

Under an ideal model development, all the processes that are represented would be characterized by ambient monitoring throughout the watershed. Those parameters would include DO and BOD dynamics, and primary production ideally would have observed values of temperature, DO, BOD, nitrogen species (nitrate nitrite, ammonia, and Kjeldahl nitrogen), phosphorus species (total and inorganic phosphorus), organic carbon, and chlorophyll *a* (representing phytoplankton). However, obtaining all the information that would fully characterize a system is rarely available and model performance is compared to available data.

Observed, ambient water-quality data throughout the watershed were obtained from the MPCA and the U.S. Geological Survey (USGS). PERLND parameters from adjacent models were transferred. To ensure consistency in results, the calibration was further refined by using land-use loading outputs for total nitrogen and total phosphorus. In-stream parameters were also transferred based on model stream order.

Lake water quality calibrations are often difficult in HSPF because the model represents lakes as a completely mixed system. The main issues include an overestimation/accumulation of nitrogen or phosphorus and low chlorophyll *a* concentrations. These problems are amplified on larger, deeper lakes or headwater lakes with little outflow. To address these issues, in-stream parameters are generally very different compared to reaches.

Tables summarizing water quality data for the streams and lakes with the greatest amount of data of applicable constituents, in addition to figures that illustrate the spatial locations for each Upper Mississippi River model application, are provided in Attachment D. TSS, water temperature, DO, BOD, chlorophyll *a*, ammonia, Kjeldahl nitrogen, nitrate/nitrate, orthophosphate, and total phosphorus ambient water-quality monitoring data are available throughout the watershed for both lakes and streams.

Total nitrogen is often not available in either of the ambient water-quality datasets, but it 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.

Atmospheric Deposition Data Available

The atmospheric deposition of nitrate and ammonia was explicitly accounted for in the model applications by input of separate wet and dry deposition fluxes. Wet atmospheric deposition data were downloaded from the National Atmospheric Deposition Program (NADP). The NADP site chosen to represent wet deposition in was MN16 as shown in Figure 12. Wet deposition includes the deposition of pollutants from the atmosphere that occurs during precipitation events. Thus, nitrate and ammonia wet deposition were applied to the watersheds in the model application as concentrations (milligrams per liter (mg/L)) to observed precipitation.

The dry atmospheric deposition data were downloaded from the U.S. EPA's Clean Air Status and Trends Network (CASTNet). The CASTNet site chosen to represent dry deposition was VOY413 [CASTNet, 2012]. Dry deposition does not depend on precipitation; therefore, nitrate and ammonia dry deposition data (originally in in kg/ha) was applied in the model application using a lb/acre approach. Both the wet and dry atmospheric deposition sites are shown in Figure 2.

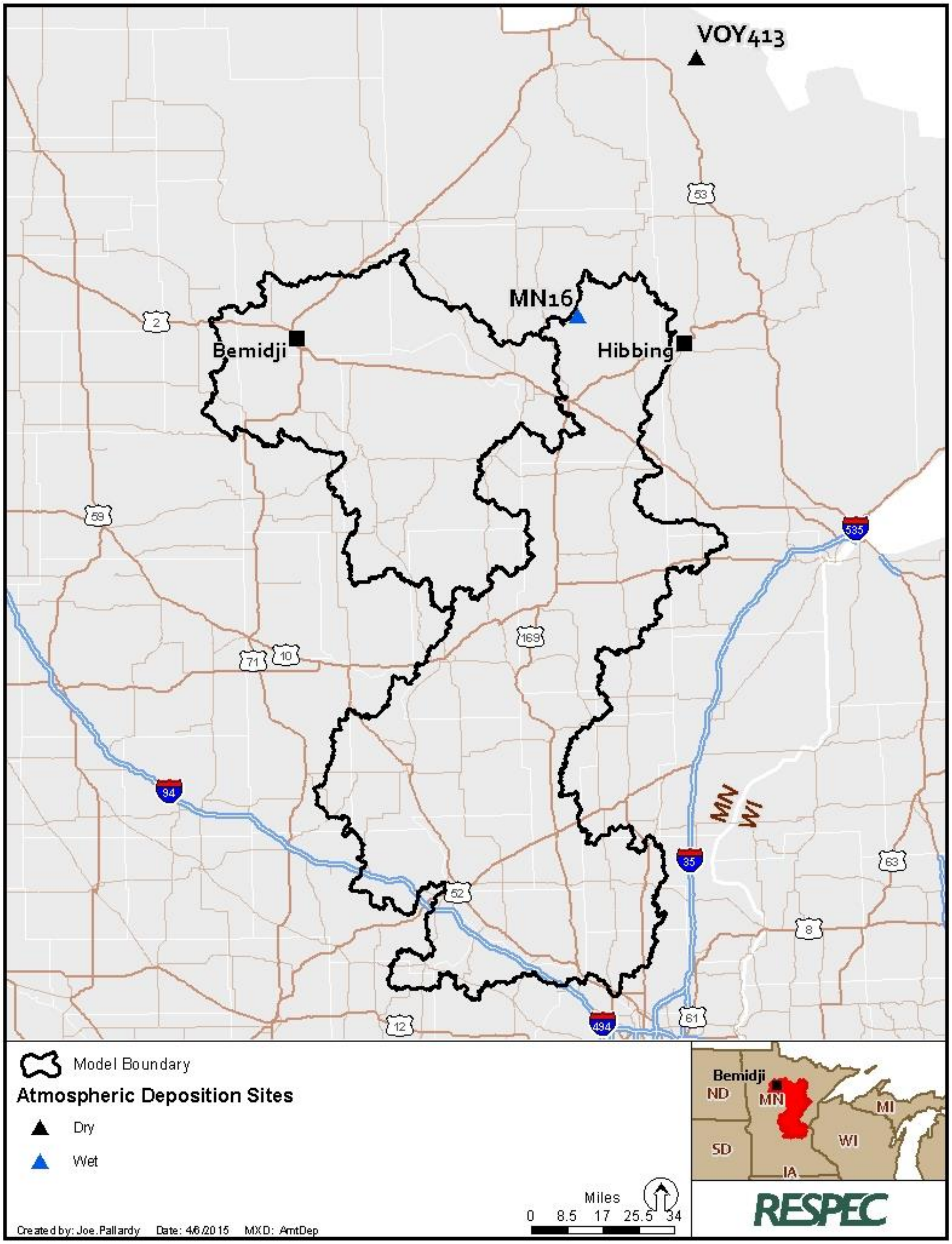


Figure 12. Atmospheric Wet and Dry Deposition Sites.

Dry atmospheric deposition of phosphorus is estimated to account for approximately 16.7 percent of the total phosphorus load in the Upper Mississippi River Basin [Barr Engineering, 2007] and was included in the model applications. Because of the lack of temporal data, atmospheric phosphorus deposition was represented by using monthly values of daily dry fluxes using the MONTH-DATA block in HSPF. A value of 0.17 kg/ha/yr (0.00042 lbs/ac/day) was provided by Barr Engineering and was distributed throughout the months with higher values in the summer and lower values in the winter.

Point-Source Data Available

Twelve major point sources and 88 minor point sources are located in the project area shown in Figure 13. The minor point sources are a combination of municipal and industrial facilities that generally discharge intermittently for variable lengths of time. 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. The point sources included in the model refer to permit identification numbers that sometimes included more than one surface water discharge. For example, MN0001422 (Wausau Paper Mill) discharges non-contact cooling water at one location and processed wastewater at another location slightly downstream. An estimate of the number of discharge days was supplied by the MPCA and incorporated using the following logic supplied by the MPCA [Weiss 2012a; Weiss 2012b]:

1. If there are only a few discharge days in one month followed by a month with only a few discharge days, or if the first month has only a couple and the next month has up to approximately 10 discharge days, discharge 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 approximately 18, they can be placed anywhere consecutively. If there are over approximately 18 discharge days, half should be placed in the first half of the month and half in the second half of the month.

For each facility, the period of record and completeness were assessed. All minor point sources in the watersheds are shown in Figure 13. Available parameters from the point sources applicable to the model application include carbonaceous 5-day biological oxygen demand (CBOD5), TSS, TP,DO, NH3, NO2 and NO3. Available point-source, water-quality data were filled using monthly mean values. Where monthly means were unavailable, interpolation was used. The effluent water-quality parameters available vary by site, but, in general, CBOD, TSS, and TP were available at most locations.

Classes for each point source are provided in Table 9[Weiss, 2012a]. Point-source loads for nitrogen species were calculated by using the numbers supplied by Weiss [2012b] provided in Table 10for those facilities with missing nitrogen data. Facility classes applicable to the

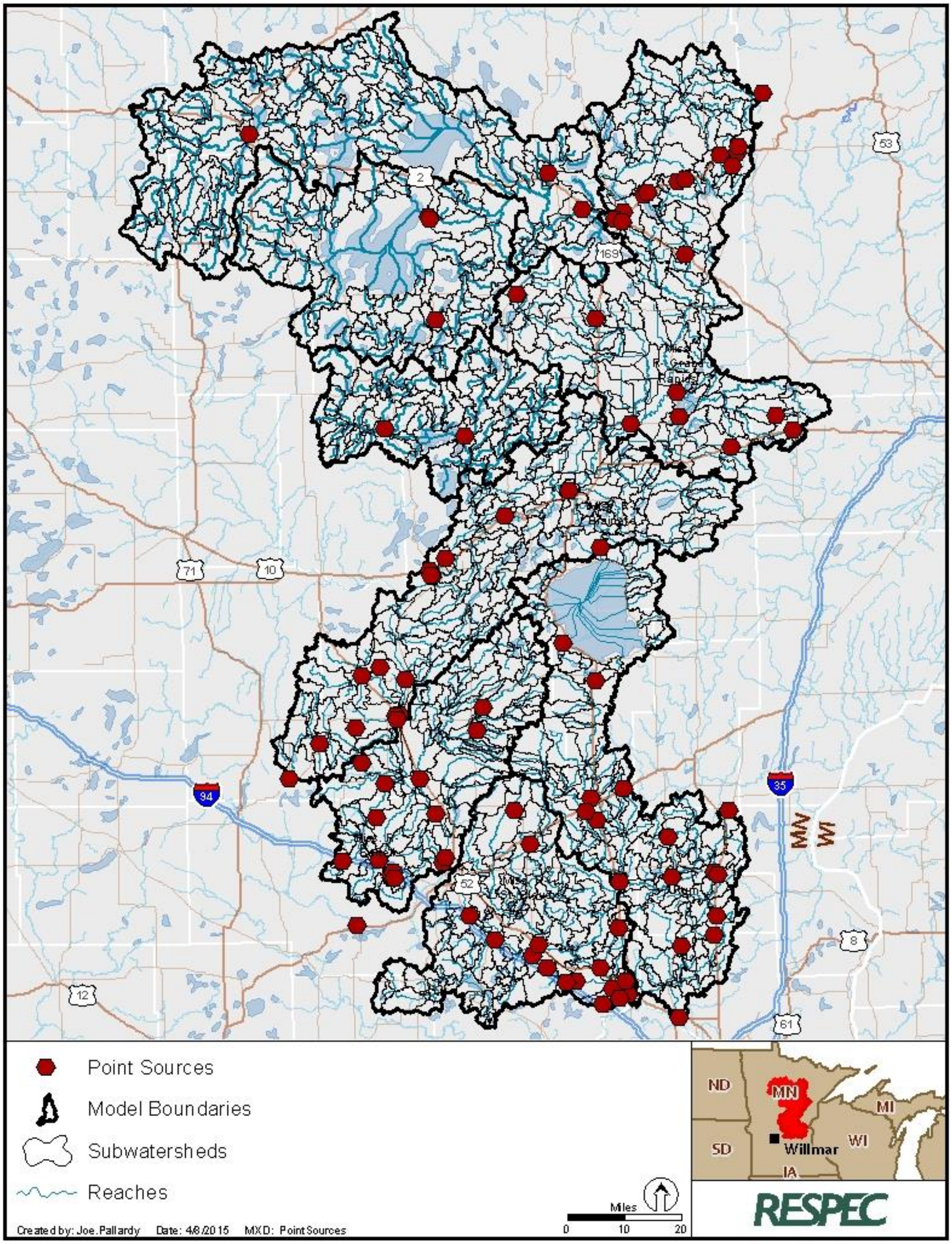


Figure 13. Modeled Point Sources in the Upper Mississippi River Watershed.

Table 9. Categorical Concentration Assumptions (mg/L) [Weiss, 2012a] (Page 1 of 3)

Name	Watershed	Site I.D.	Type
Federal Dam WWTP	Leech Lake River	MN0063487	C
Longville WWTP	Leech Lake River	MNG580208	D
USCOE Leech Lake Rec Area WWTP	Leech Lake River	MN0110027	B
Aitkin WWTP	Mississippi River - Brainerd	MN0020095	B
Baxter WWTP	Mississippi River - Brainerd	MNG820012	B
BNSF RR - Former Tie Treating Plant	Mississippi River - Brainerd	MN0055387	O
Camp Ripley - Area 22 Washrack	Mississippi River - Brainerd	MN0063070	O
Camp Ripley WWTP	Mississippi River - Brainerd	MN0025721	B
Flensburg WWTP	Mississippi River - Brainerd	MNG580016	D
Grey Eagle WWTP	Mississippi River - Brainerd	MN0023566	D
Hennepin Paper Co	Mississippi River - Brainerd	MN0000302	P
Little Falls WTP	Mississippi River - Brainerd	MN0003182	A
Randall WWTP	Mississippi River - Brainerd	MN0024562	B
Sampson Farms	Mississippi River - Brainerd	MN0057533	O
Serpent Lake WWTP	Mississippi River - Brainerd	MNG580215	D
Sobieski WWTP	Mississippi River - Brainerd	MNG580217	D
Swanville WWTP	Mississippi River - Brainerd	MN0020109	C
Upsala WWTP	Mississippi River - Brainerd	MNG580053	D
Wausau Paper Mills LLC	Mississippi River - Brainerd	MN0001422	GW
Aitkin agri-peat Inc - McGregor	Mississippi River - Grand Rapids	MN0062375	PEAT
Blandin Paper Co	Mississippi River - Grand Rapids	MN0000345	P
Bovey WTP	Mississippi River - Grand Rapids	MNG640018	WTP
Coleraine-Bovey-Taconite Joint WWTP	Mississippi River - Grand Rapids	MN0053341	B
Cromwell WWTP	Mississippi River - Grand Rapids	MN0051101	D
Hibbing Taconite Co - Tails Basin Area	Mississippi River - Grand Rapids	MN0049760	C
Hill City WWTP	Mississippi River - Grand Rapids	MNG580182	D
Keewatin Taconite Operations - Tailings	Mississippi River - Grand Rapids	MN0055948	GW
Keewatin WWTP	Mississippi River - Grand Rapids	MN0022012	B
Marble WWTP	Mississippi River - Grand Rapids	MN0020214	B
McGregor WWTP	Mississippi River - Grand Rapids	MN0024023	D
MDNR Hill Annex State Park	Mississippi River - Grand Rapids	MN0030198	GW
Nashwauk WWTP	Mississippi River - Grand Rapids	MNG580184	D
Palisade WWTP	Mississippi River - Grand Rapids	MN0050997	C
Premier Horticulture Inc - Black Lake Site	Mississippi River - Grand Rapids	MN0055115	O
Remer WWTP	Mississippi River - Grand Rapids	MNG580210	D
Tamarack WWTP	Mississippi River - Grand Rapids	MN0064564	C
U of M - Research Lab	Mississippi River - Grand Rapids	MN0051802	GW
US Steel Corp - Keetac	Mississippi River - Grand Rapids	MN0031879	C

Table 10. Categorical Concentration Assumptions (mg/L) [Weiss, 2012a] (Page 2 of 3)

Name	Watershed	Site I.D.	Type
USCOE Sandy Lake WWTP	Mississippi River - Grand Rapids	MN0110035	C
Warba WWTP	Mississippi River - Grand Rapids	MN0020974	D
Deer River WWTP	Mississippi River - Headwaters	MNG580181	D
Minnesota Power - Boswell Energy Center	Mississippi River - Headwaters	MN0001007	POWER
Northwoods Ice of Bemidji Inc	Mississippi River - Headwaters	MNG25007	GW
Benton Utilities WWTP	Mississippi River - Sartell	MN0065391	C
Albany WWTP	Mississippi River - Sartell	MN0020575	C
Avon WWTP	Mississippi River - Sartell	MN0047325	A
Bowlus WWTP	Mississippi River - Sartell	MN0020923	D
DeZURIK Inc	Mississippi River - Sartell	MNG255084	GW
DeZURIK Inc	Mississippi River - Sartell	MN0002216	O
Holdingford WWTP	Mississippi River - Sartell	MN0023710	B
Order of St Benedict - NCC	Mississippi River - Sartell	MNG250039	POWER
Order of St Benedict - Power Plant	Mississippi River - Sartell	MN0046035	POWER
Order of St Benedict WTP	Mississippi River - Sartell	MNG640082	B
Order of St Benedict WWTP	Mississippi River - Sartell	MN0022411	B
Pierz WWTP	Mississippi River - Sartell	MN0024503	D
Rice WWTP	Mississippi River - Sartell	MN0056481	D
Rich Prairie Sewer Treatment Facility	Mississippi River - Sartell	MN0063657	D
Royalton WWTP	Mississippi River - Sartell	MN0020460	C
Sysco Western Minnesota	Mississippi River - Sartell	MN0052728	GW
Verso Paper Co - Sartell Mill	Mississippi River - Sartell	MN0000973	P
Albertville WWTP	Mississippi River - St. Cloud	MN0050954	B
Aspen Hills WWTP	Mississippi River - St. Cloud	MN0066028	C
Big Lake WWTP	Mississippi River - St. Cloud	MN0041076	B
Clear Lake/Clearwater WWTP	Mississippi River - St. Cloud	MN0047490	A
Elk River Municipal Utilities	Mississippi River - St. Cloud	MNG250016	POWER
Foley WWTP	Mississippi River - St. Cloud	MN0023451	D
Gilman WWTP	Mississippi River - St. Cloud	MNG580021	D
Great River Energy - Elk River Station	Mississippi River - St. Cloud	MN0001988	POWER
Otsego WWTP West	Mississippi River - St. Cloud	MN0066257	B
Riverbend Mobile Home Park WWTP	Mississippi River - St. Cloud	MN0042251	C
Xcel - Monticello Nuclear Generating Plt	Mississippi River - St. Cloud	MN0000868	POWER
Zimmerman WWTP	Mississippi River - St. Cloud	MN0042331	B
Crosslake WWTP	Pine River	MN0064882	B
Pine River Area Sanitary District	Pine River	MN0046388	B
Bock WWTP	Rum River	MN0022845	C
Braham WWTP	Rum River	MN0022870	B

Table 10. Categorical Concentration Assumptions (mg/L) [Weiss, 2012a] (Page 3 of 3)

Name	Watershed	Site I.D.	Type
Castle Towers WWTP	Rum River	MN0042196	B
Dairi Concepts LP - Dalbo	Rum River	MN0044628	GW
Federal Cartridge Co - Anoka	Rum River	MN0001848	O
Foreston WWTP	Rum River	MN0047503	D
Isanti Estates LLC	Rum River	MN0054518	C
Isanti Sites Trust - Schumacher	Rum River	MNG790143	D
Isanti WWTP	Rum River	MN0023795	C
Milaca WWTP	Rum River	MN0024147	D
Mille Lacs WWTF	Rum River	MN0064637	D
Onamia WWTP	Rum River	MNG580050	D
Pease WWTP	Rum River	MNG580167	D
Saint Francis WWTP	Rum River	MN0021407	B

Table 10. Categorical Concentration Assumptions (mg/L) [Weiss, 2012b]

Category	General Description	TN	NOx	TKN	NHx
A	Class A municipal—large mechanical	19	15	4	3
B	Class B municipal—medium mechanical	17	10	7	4
C	Class C municipal—small mechanical/ pond mix	10	7	3	1
D	Class D municipal—mostly small ponds	6	3	3	1
O	Other—generally very low volume effluent	10	7	3	2
PEAT	Peat mining facility—pump out/drainage from peat	10	7	3	2
T	Tile line to surface discharge	10	7	3	3
P	Paper industry	10	7	3	2
NCCW	Noncontact cooling water	4	1	3	2
POWER	Power industry	4	1	3	2
WTP	Water treatment plant	4	3	1	1
GRAV	Gravel mining wash water	2	1	1	1
GW	Industrial facilities—primarily private groundwater well	0.25	0.25	0	0

modeled watersheds are shown in bold. Methods for estimating other phosphorus species from point sources were derived from methods similar to those used in the Minnesota River model application [TetraTech, 2009]. The nutrient portions of each model's external sources blocks contain estimates where nutrient data were unavailable and these are included in Appendix A. All available data for model inputs have been uploaded into the project Watershed Data Management (WDM) file and all available data for comparison to model simulations is in an observed data Excel file.

Besides temperature, the concentrations of all available constituents, including BOD as CBODU (converted from CBOD5 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 British Thermal Units (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:

$L_0 = \mathrm{CBOD}_u$

$y_5 = \mathrm{CBOD}_5$

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

Estimated daily time series were then imported into the binary WDM files, and loads were applied to the corresponding stream in the external sources block in the model input file.

Water Quality Calibration Results

In general, the model was able to reproduce the observed water quality conditions across the all modeled watersheds. The water quality calibration focused on developing an accurate representation of the loads from the watersheds to the Upper Mississippi River. The models were developed to characterize the temperature, suspended sediment, nutrient, dissolved oxygen, and chlorophyll a concentrations in the streams and lakes. The nine individual HSPF models successfully represented the overall conditions in the streams over the 15 year simulation period. Results from the most data-intensive downstream reach in the Upper Mississippi River watershed which falls in Reach 710 of the Mississippi River -St. Cloud River model application are included in Attachment F. Three figures are included for each available water quality constituent at this location. The figures show comparisons of observed data (blue) and model simulations (red) and include a concentration duration curve, a monthly average plot, and a time-series plot for each site. Results at additional water quality monitoring sites from that model, and the other eight, are included in the Upper Mississippi River deliverables results folder.

The thermal and suspended sediment conditions were well represented across the monitored streams and lakes. Thermal conditions in lower and higher order streams as well as the lakes mimicked the observed conditions well. Observations of stream conditions in the simulated watersheds indicate that many of the streams have sediment contributions from the stream banks, which is not explicitly simulated by HSPF. To account for those additional inputs, the model was allowed to have a net erosion in the bed sand, silt and clay in the reaches and deposition in the lakes. Model QAQC procedures confirmed that those additions were in line with what field observations and the mean contributions by stream mile increased with stream order. During the development of the nine models, great care was taken to represent nutrients, BOD, dissolved oxygen, and algal dynamics in a consistent manner. This model development was in line with our regional model development strategy where we focused on characterizing the watershed accurately. The higher order streams typically had a better match between simulated and observed conditions for those nutrients, BOD, dissolved oxygen, and chlorophyll a. The chlorophyll a concentrations in some of the lakes were slightly under-predicted which is an artifact of how the lakes are simulated within HSPF (they are a homogenous waterbody with no vertical stratification). Dissolved oxygen conditions in the lakes and streams reflected the seasonal variability observed; however, many of the data points did not have critical time stamp included with those measurements which made those comparisons difficult since dissolved oxygen varies throughout the day.

REFERENCES

Brigham, M. E., C. J. McCullough, and P. Wilkinson, 2001. *Analysis of Suspended-Sediment Concentrations and Radioisotope Levels in the Wild Rice River Basin, Northwestern Minnesota, 1973–98,* Water Resources Investigations Report 01-4192, prepared by the U.S. Geological Survey and the Freshwater Institute, Department of Fisheries and Oceans, Mounds View, MN.

Kenner, S. J., 2013. *Hydrology Calibration of Mississippi River–Grand Rapids (07010103), Mississippi River–Brainerd (07010104), Mississippi River–Sartell (07010201), Mississippi River–St. Cloud (07010203), and Rum River (07010207) Watersheds HSPF Model Applications,* Memorandum RSI(RCO)-2216/12-13/24, prepared by RESPEC, Rapid City, SD, to C. Reagan, Minnesota Pollution Control Agency, St. Paul, MN, December 31.

Burke M. P., 2012. *Red Lake River and Clearwater River Model Development,* Memorandum RSI(RCO)-2111/7-12/20, prepared by RESPEC, Rapid City, SD, to M. Vavricka, Minnesota Pollution Control Agency, Detroit Lakes, MN, July 13.

Chapra, S. C., 1997. *Surface Water Quality Modeling,* McGraw-Hill Companies, pp. 357–358.

CASTNet, 2012. *CASTnet*, retrieved September 1, 2012, from *http://java.epa.gov/castnet/maps.do?mapType=MAPCON*

Minnesota Pollution Control Agency, 2004. *10-Year Plan to Upgrade and Maintain Minnesota's On-Site (ISTS) Treatment Systems*, prepared by Minnesota Pollution Control Agency, Minneapolis, MN.

Schottler, S. P. and D. R. Engstrom, 2011. *Sediment Loading Sources to Agassiz National Wildlife,* St. Croix Watershed Research Station Final Report, prepared for U.S. Fish and Wildlife Service, Marine, MN, 22 p.

TetraTech, 2009. *River Basin Turbidity TMDL and Lake Pepin Excessive Nutrient TMDL Model Calibration and Validation Report*, prepared by TetraTech, Research Triangle Park, NC, for Minnesota Pollution Control Agency, St. Paul, MN.

Weiss, S., 2012a. Personal Communication between C. McCutcheon, RESPEC, Rapid City, SD, and S. Weiss, Minnesota Pollution Control Agency, Minneapolis, MN, February 1.

Weiss, S., 2012b. *Point Source Nitrogen Load Estimates for Minnesota*, Minnesota Pollution Control Agency, Minneapolis, MN.

U.S. Environmental Protection Agency, 2006. *EPA Basins Technical Note 8: Sediment Parameter and Calibration Guidance for HSPF*, U.S. Environmental Protection Agency Office of Water, Washington, DC.

We would be happy to discuss these methods with you and collect feedback you may have regarding the water-quality calibration methods and results of the Upper Mississippi River Watershed HSPF application.

Sincerely,

Drew C Ackerman
Principal Consultant

DCA:krl

cc: Project Central File 2111 — Category A

ATTACHMENT A

SUBWATERSHEDS AND REACHES FOR EACH UPPER MISSISSIPPI RIVER WATERSHED MODEL APPLICATION

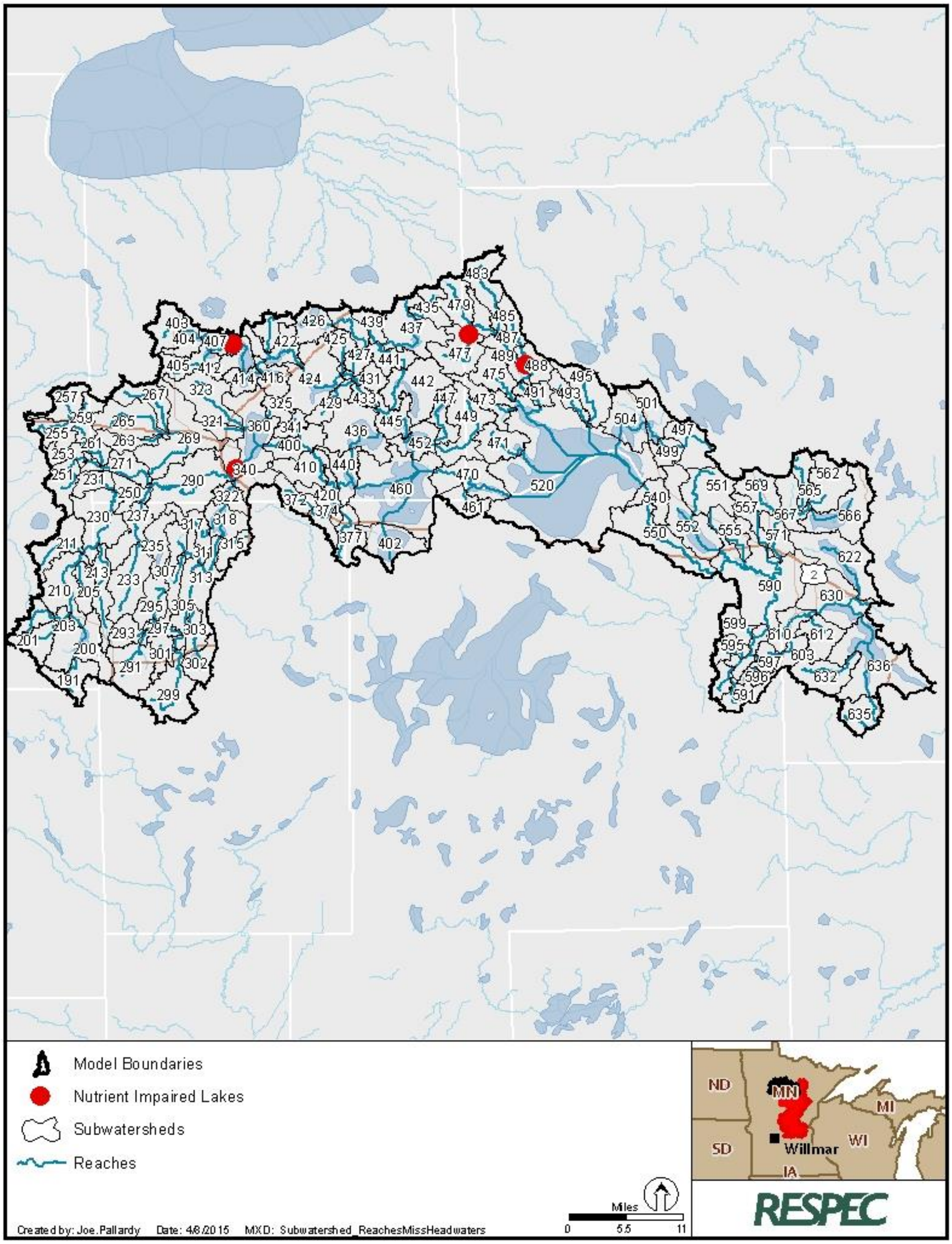


Figure A-1. Mississippi River Headwaters Watershed Reach and Subwatershed I.D.s.

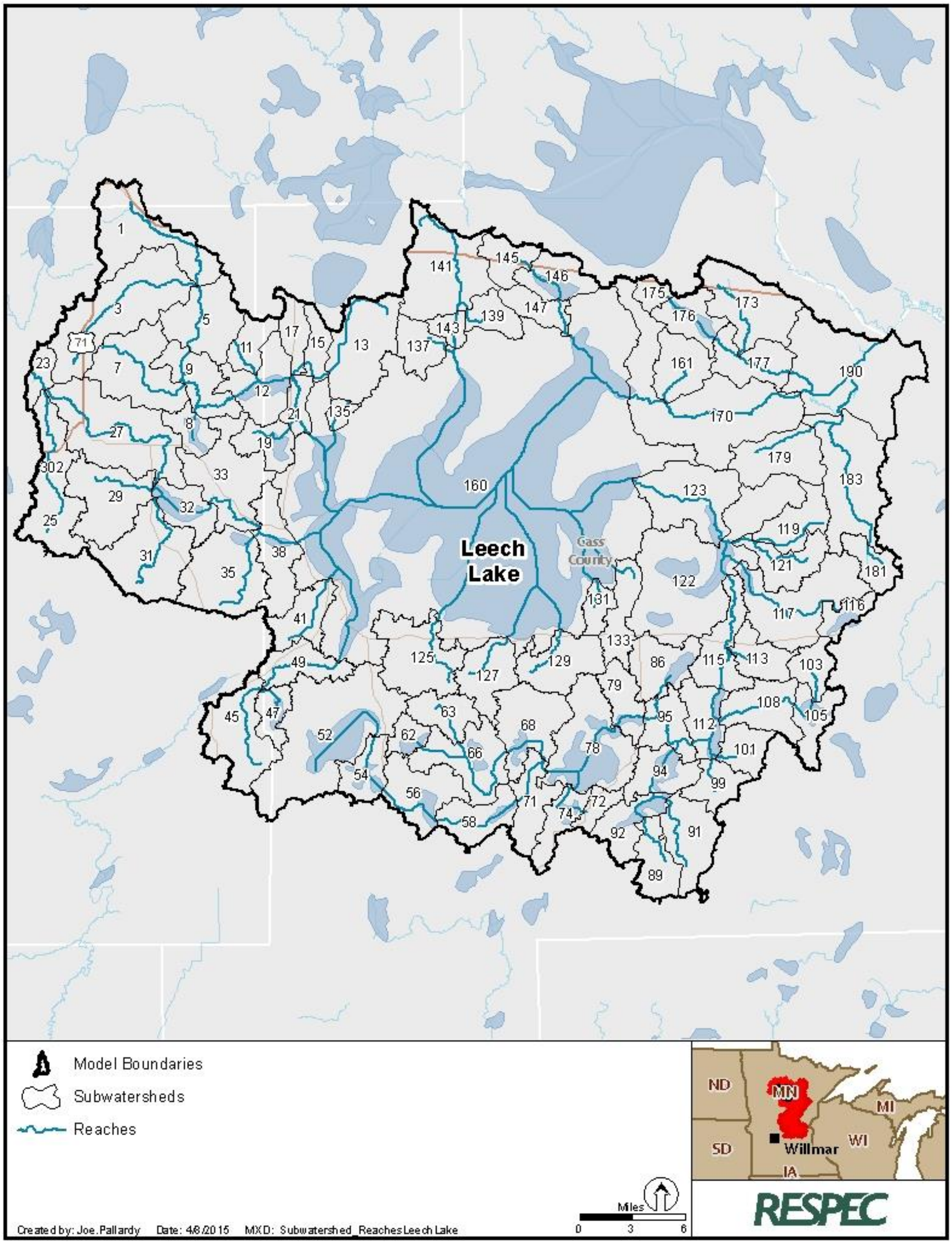


Figure A-2. Leech Lake River Watershed Reach and Subwatershed I.D.s.

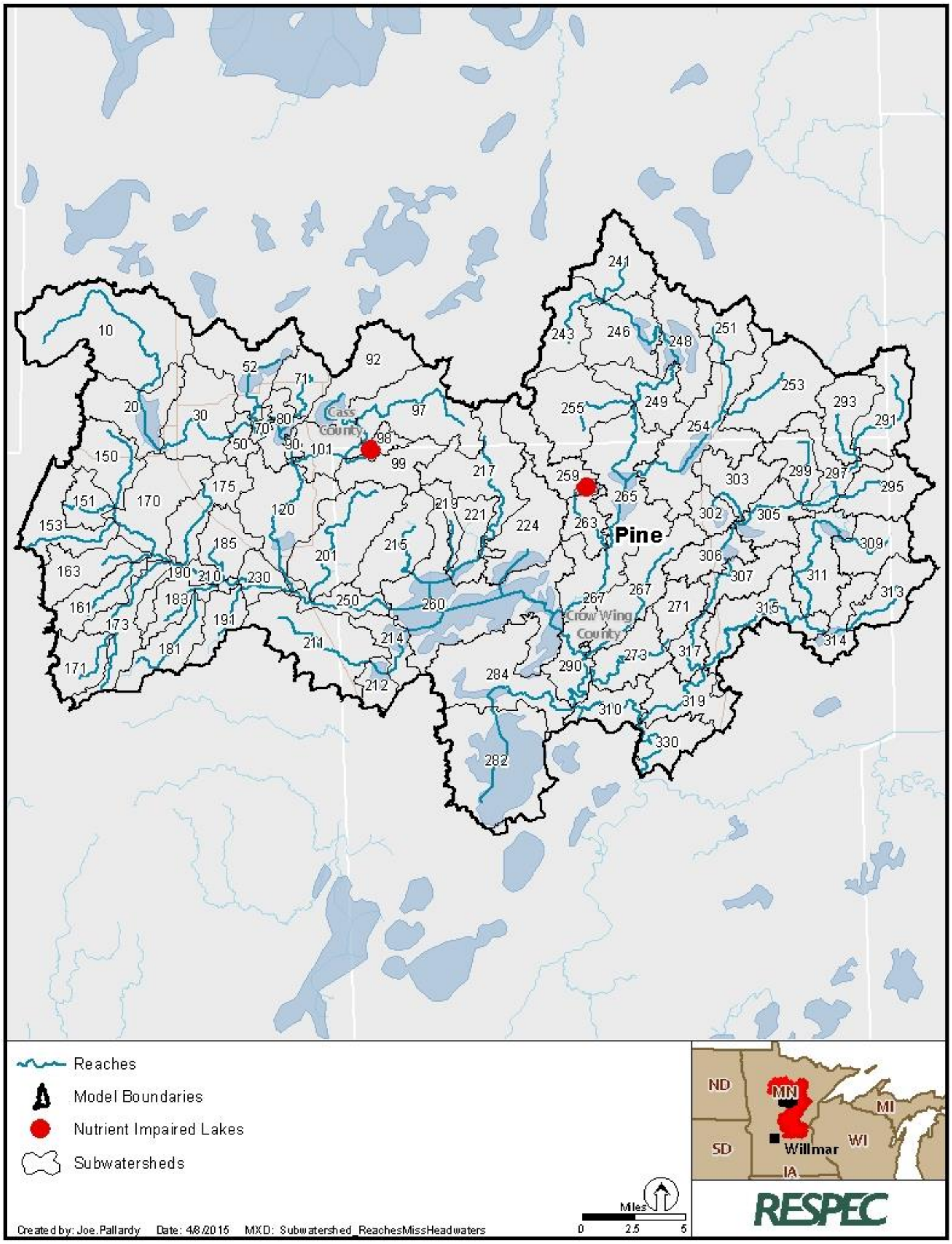


Figure A-3. Pine River Watershed Reach and Subwatershed I.D.s.

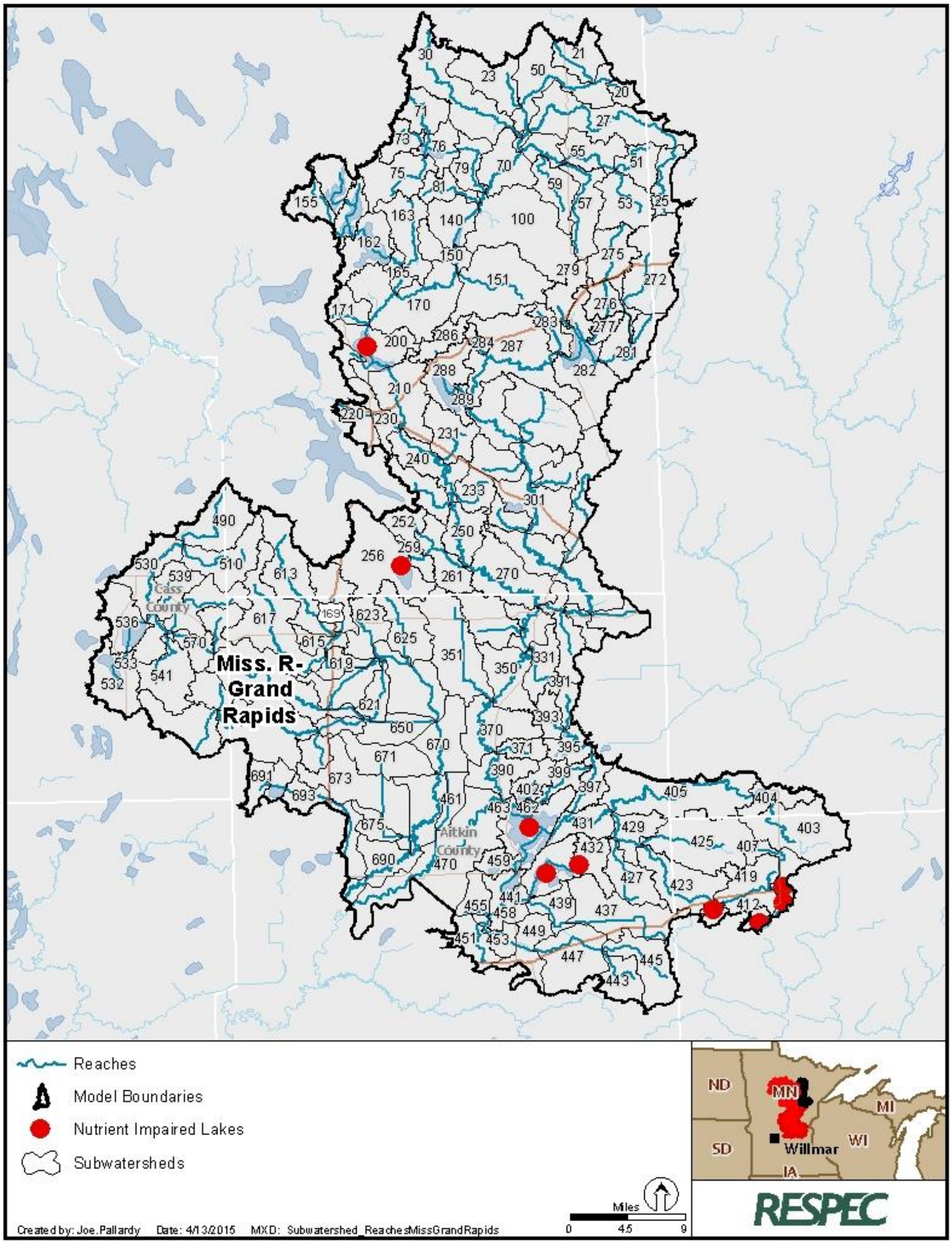


Figure A-4. Mississippi River–Grand Rapids Watershed Reach and Subwatershed I.D.s.

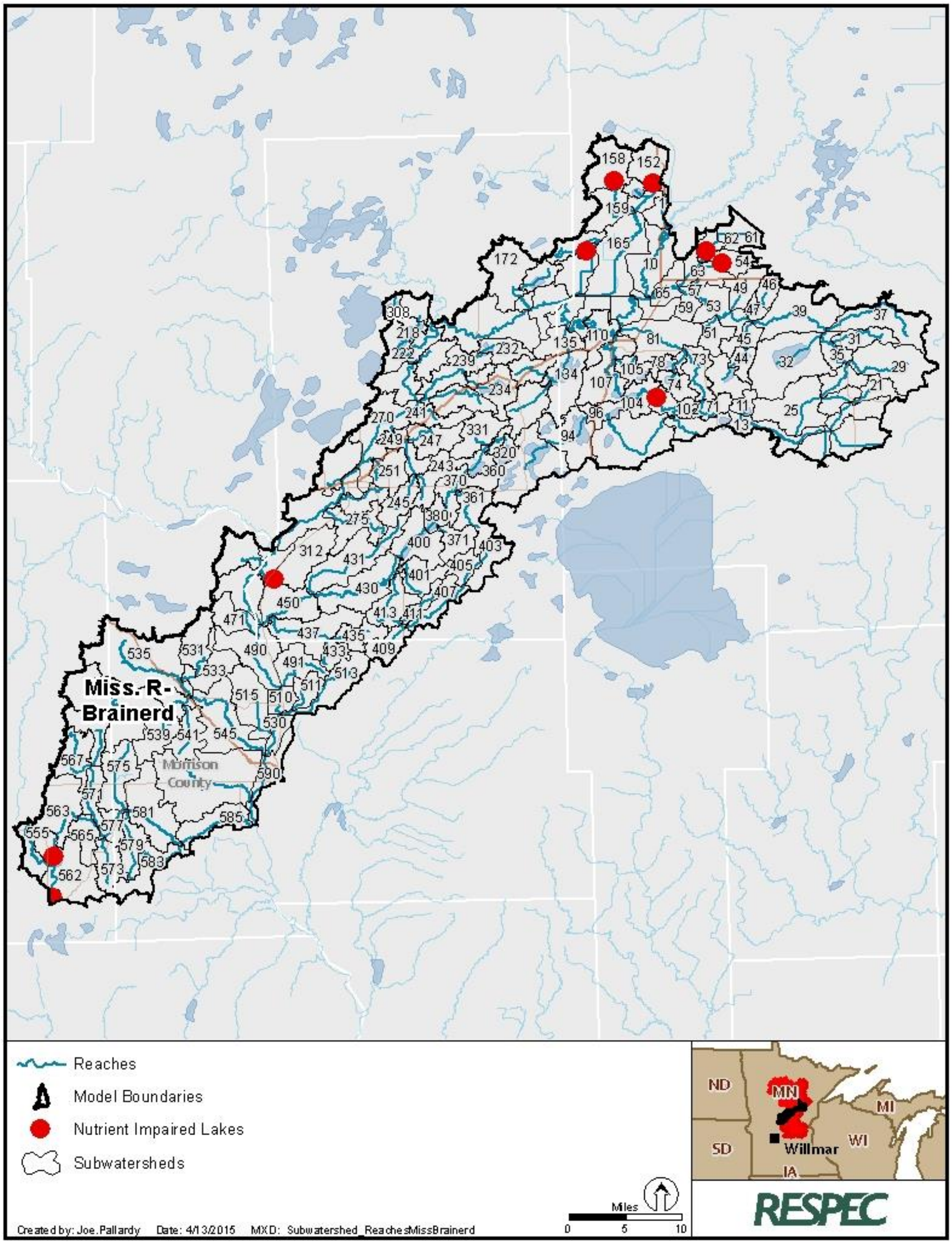


Figure A-5. Mississippi River–Brainerd Watershed Reach and Subwatershed I.D.s.

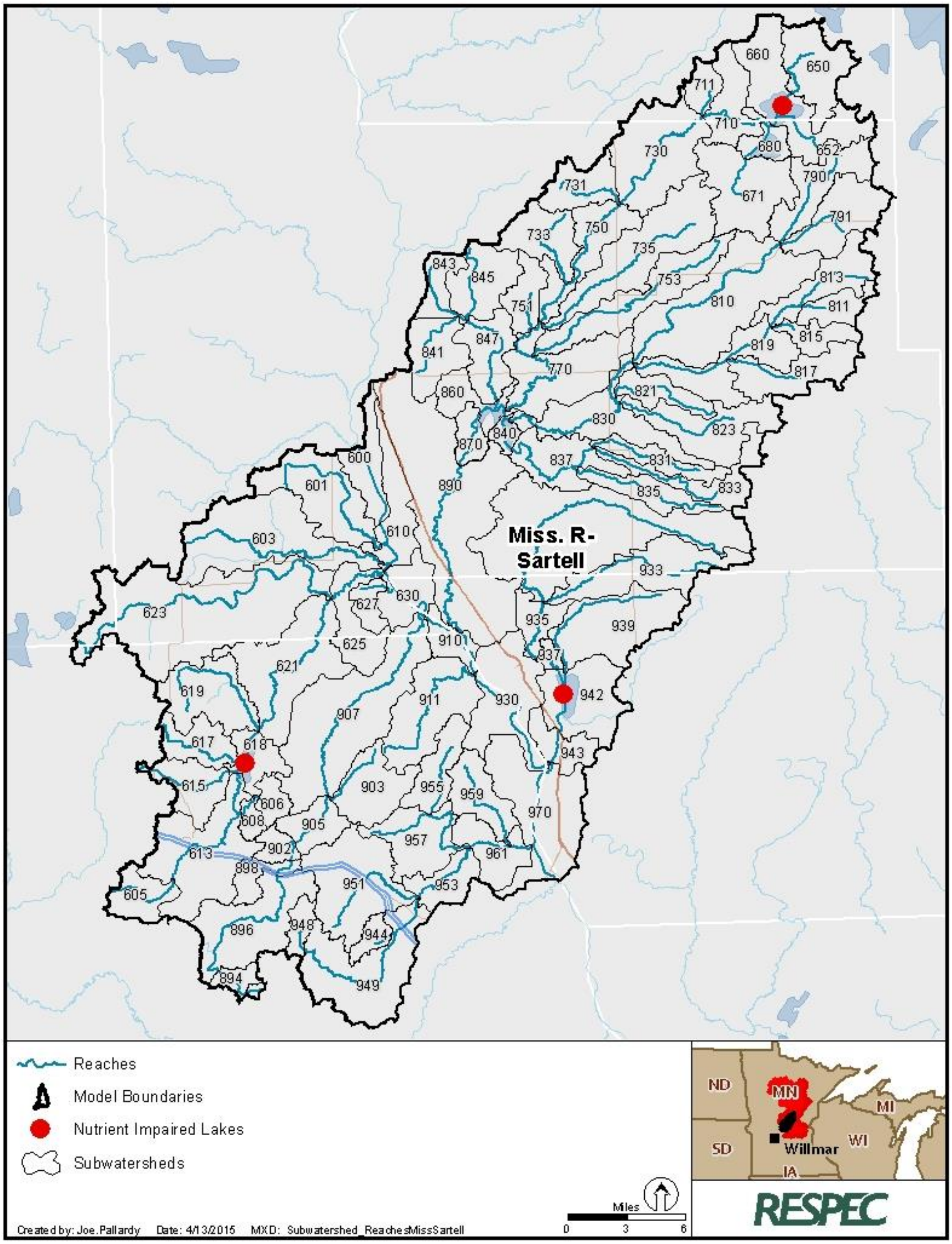


Figure A-6. Mississippi River-–Sartell Watershed Reach and Subwatershed I.D.s.

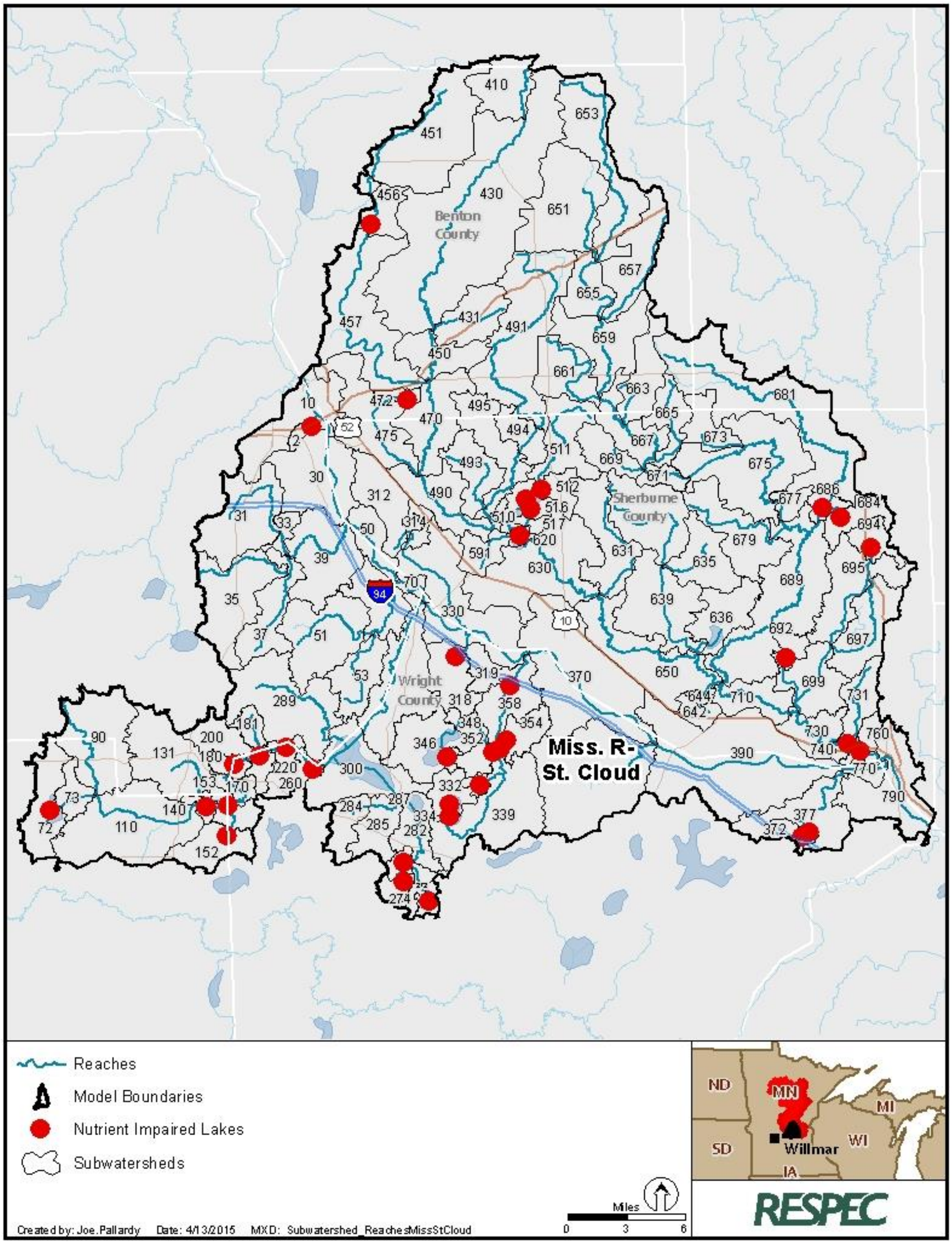


Figure A-7. Mississippi River–St. Cloud Watershed Reach and Subwatershed I.D.s.

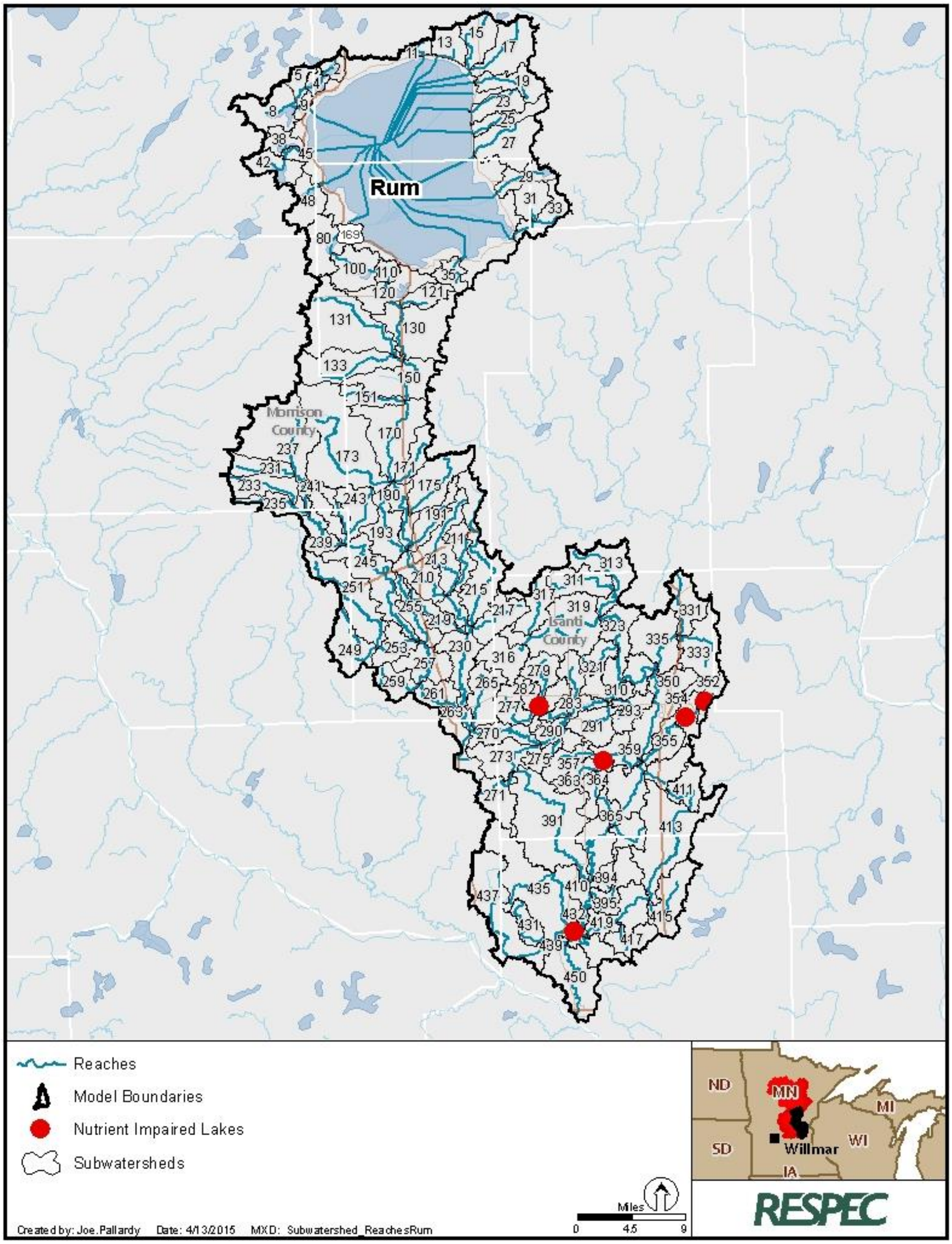


Figure A-8. Rum River Watershed Reach and Subwatershed I.D.s.

ATTACHMENT B

OBSERVED FLOW GAGE LOCATIONS FOR THE UPPER MISSISSIPPI RIVER WATERSHED MODEL APPLICATIONS

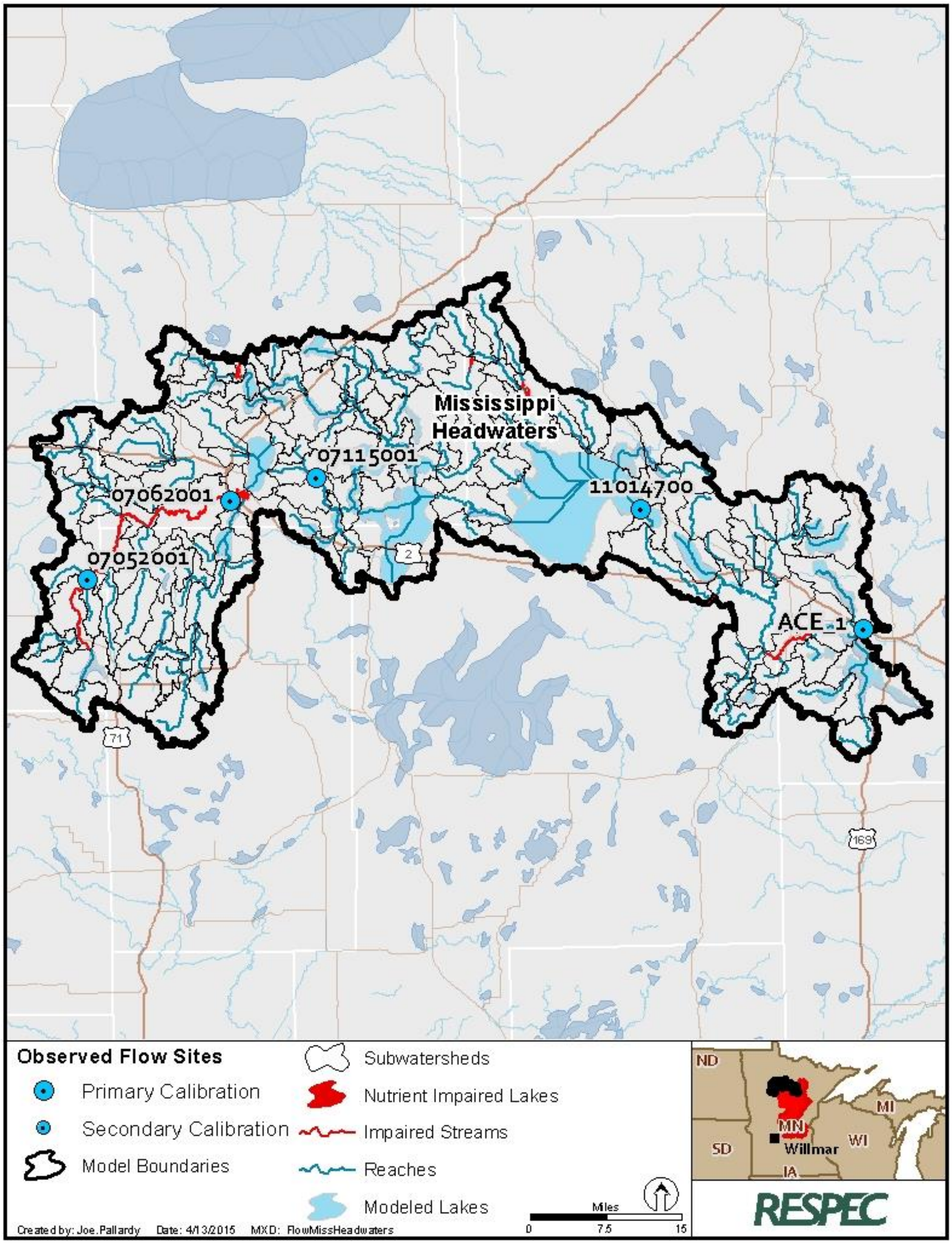


Figure B-1. Flow Calibration Gages Within the Mississippi River Headwaters Watershed.

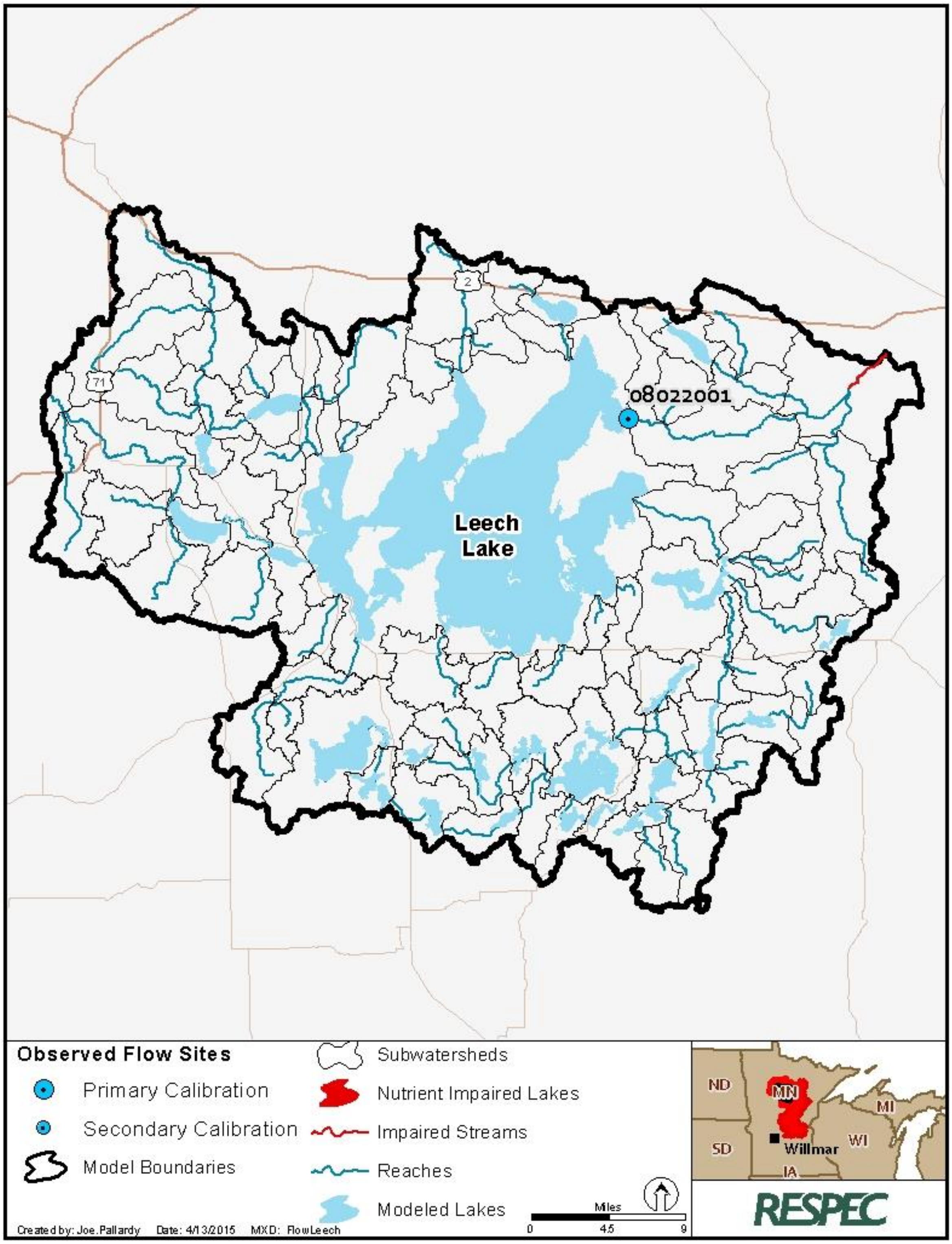


Figure B-2. Flow Calibration Gages Within the Leach Lake River Watershed.

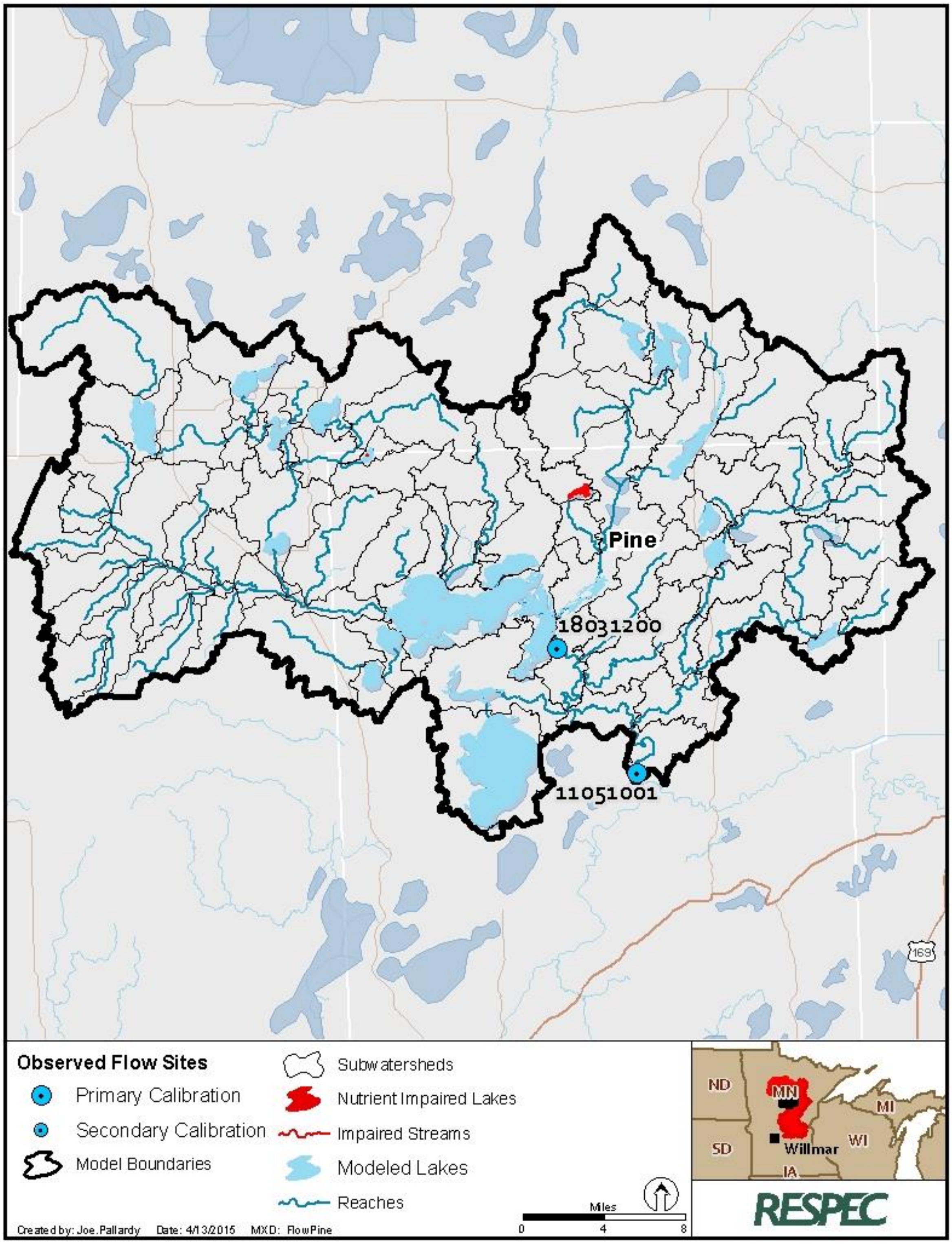


Figure B-3. Flow Calibration Gages Within the Pine River Watershed.

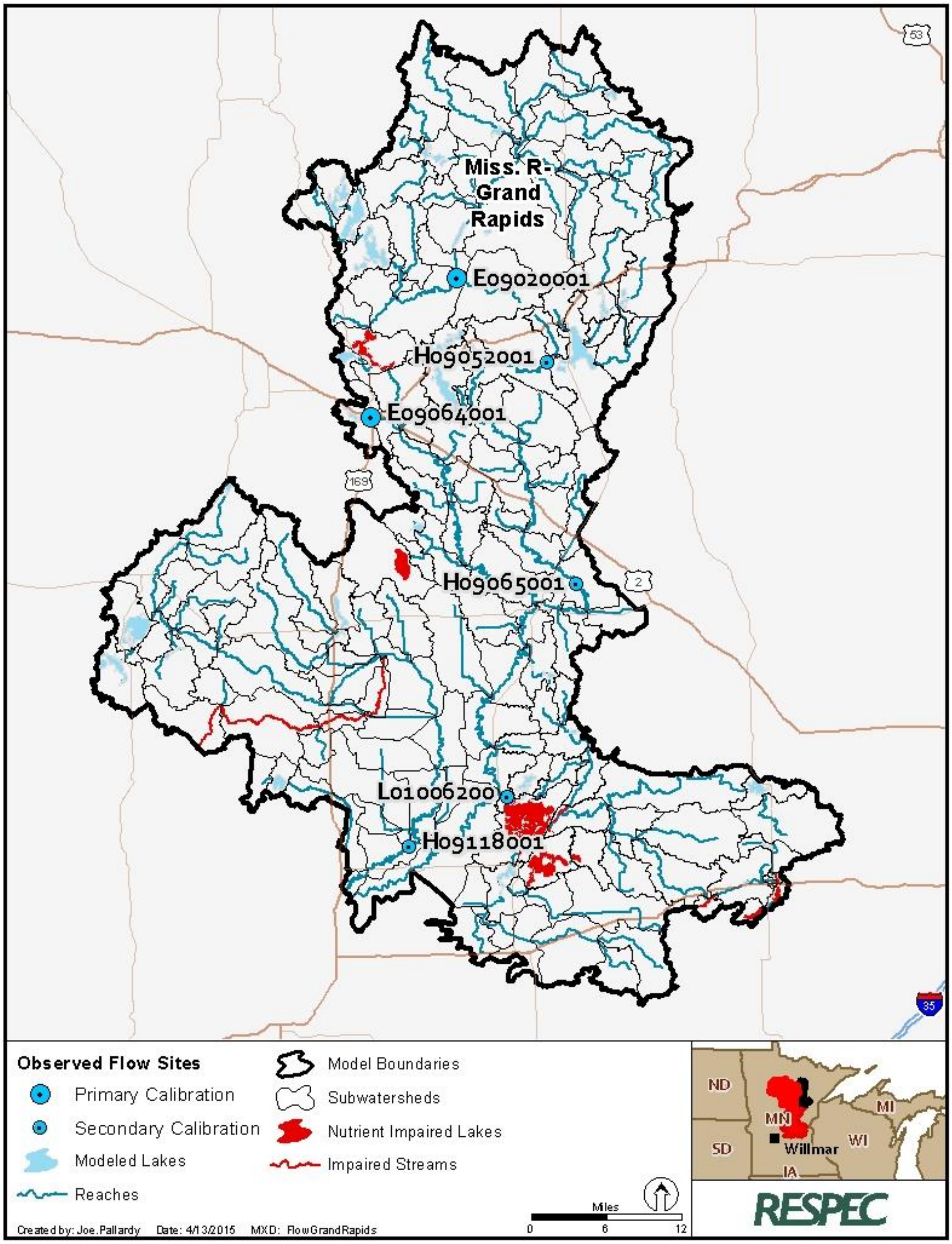


Figure B-4. Flow Calibration Gages Within the Mississippi River–Grand Rapids Watershed.

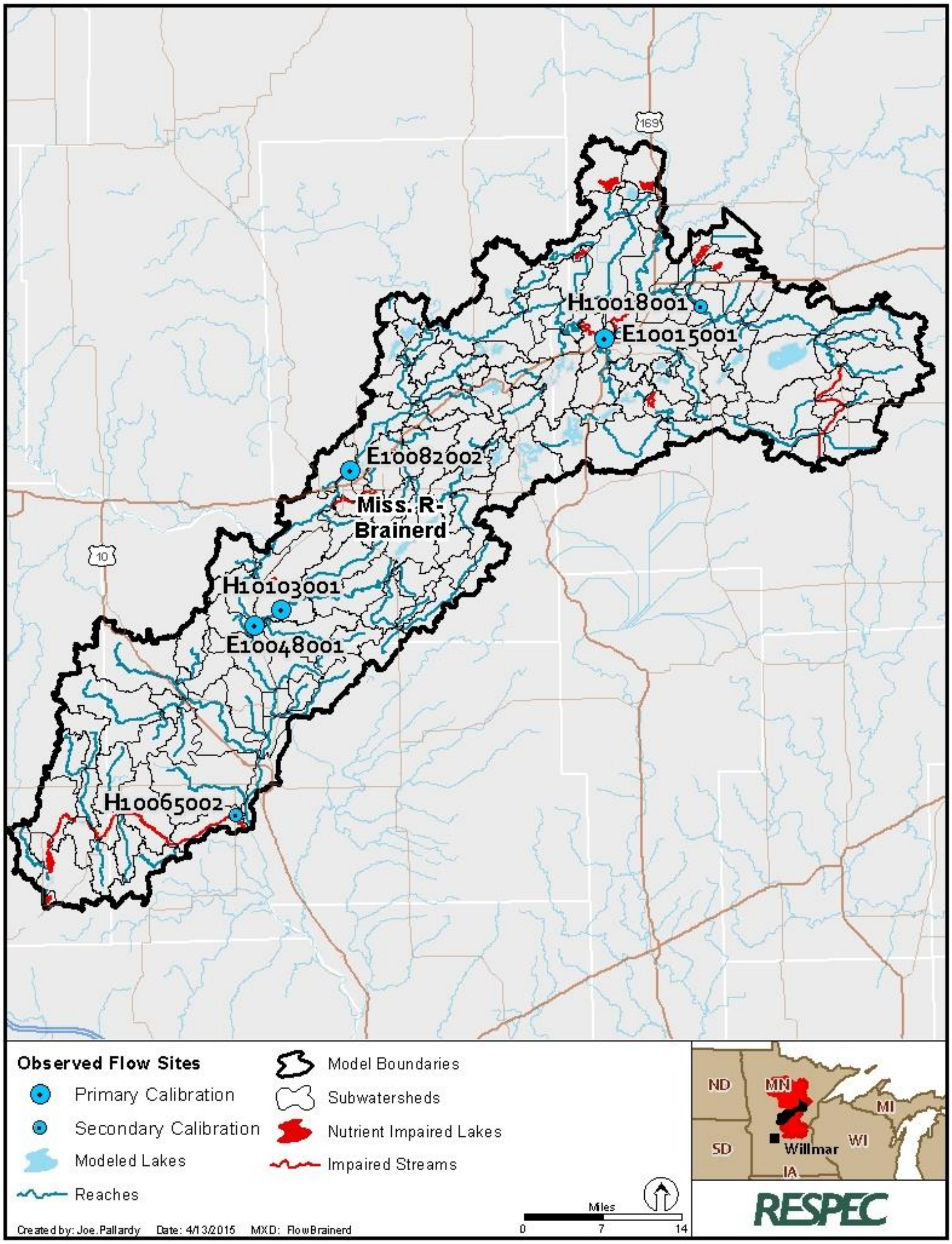


Figure B-5. Flow Calibration Gages Within the Mississippi River–Brainerd Watershed.

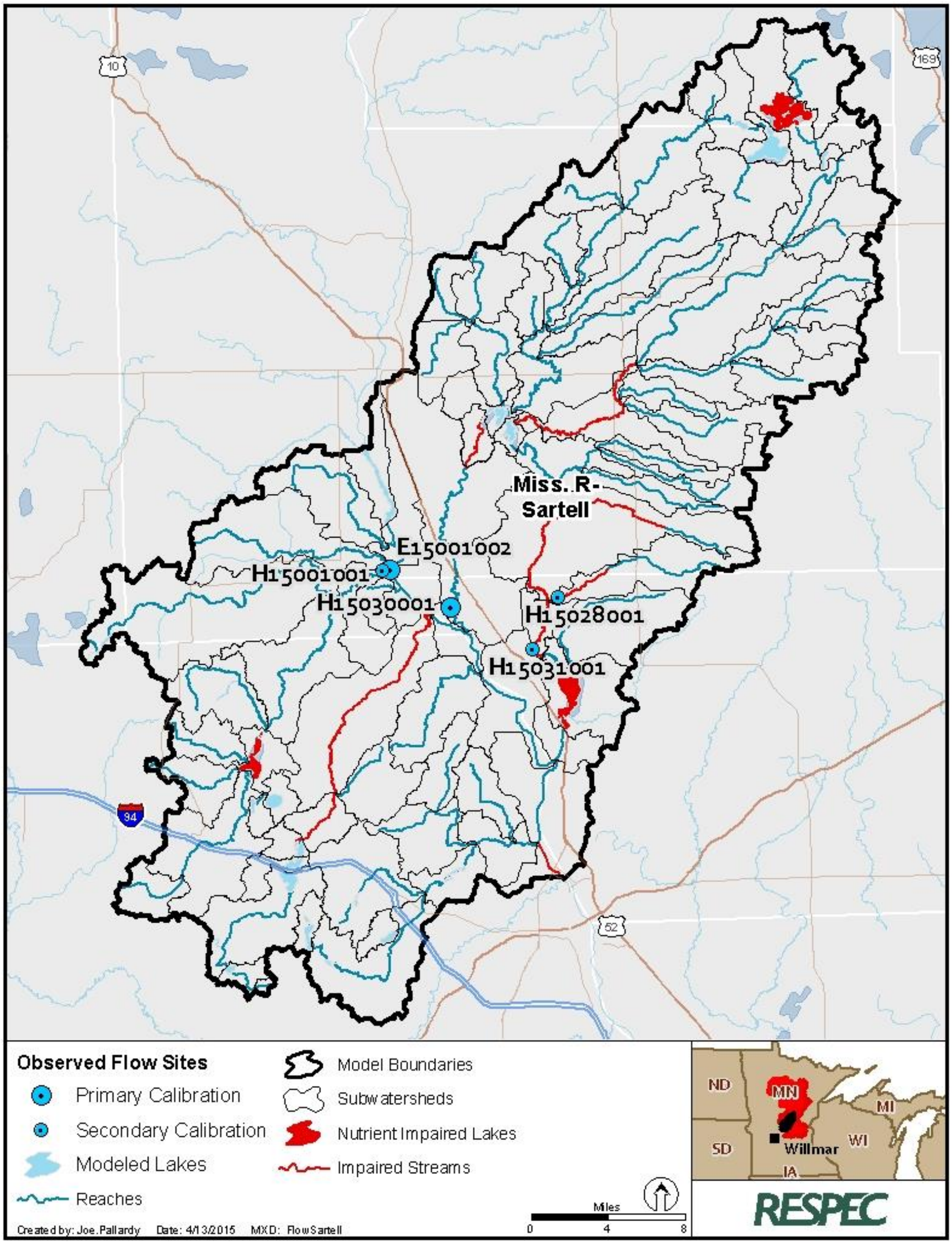


Figure B-6. Flow Calibration Gages Within the Mississippi River–Sartell Watershed.

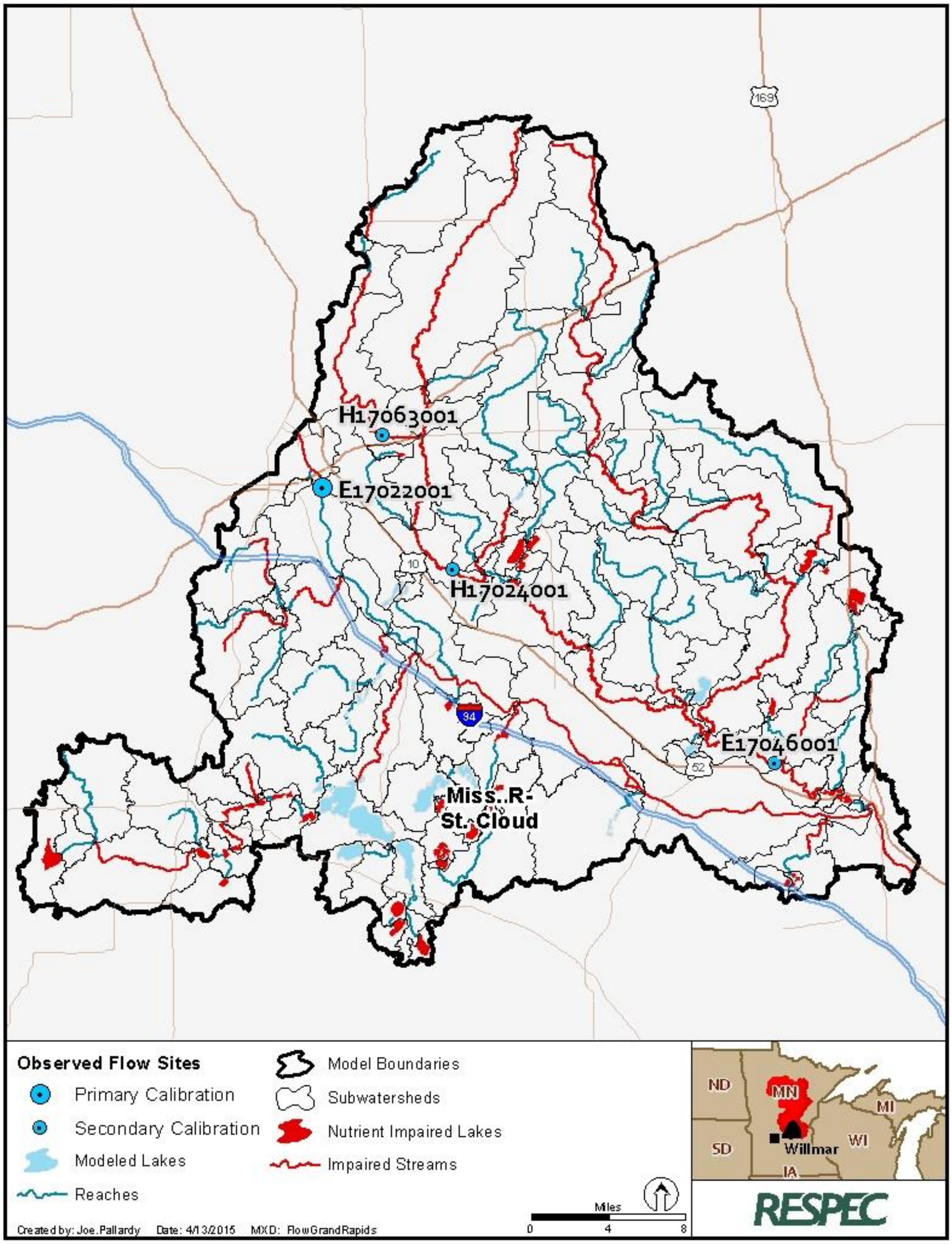


Figure B-7. Flow Calibration Gages Within the Mississippi River–St. Cloud Watershed.

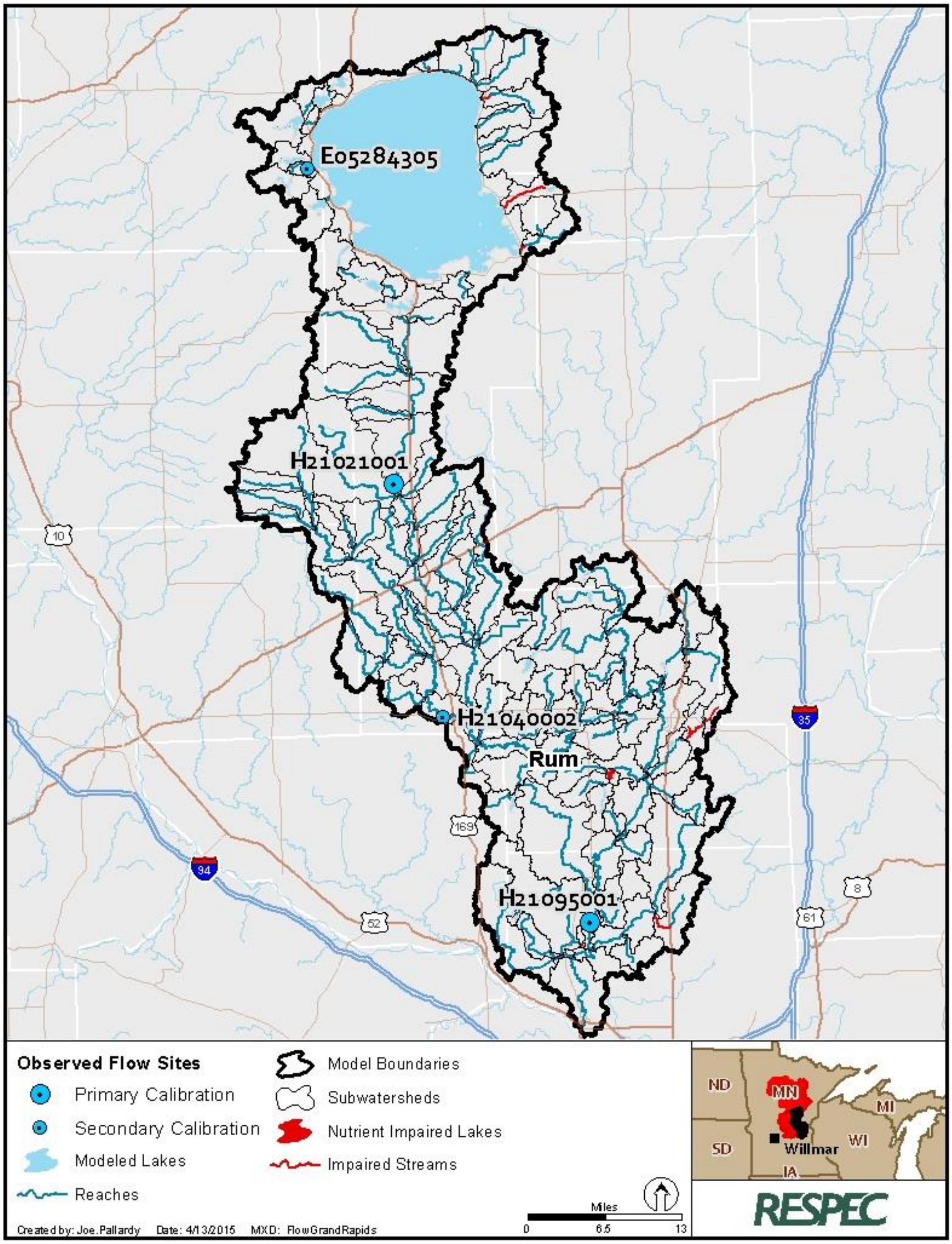


Figure B-8. Flow Calibration Gages Within the Rum River Watershed.

ATTACHMENT C

HYDROLOGY CALIBRATION RESULTS AT PRIMARY GAGES FOR THE UPPER MISSISSIPPI RIVER WATERSHED MODEL APPLICATIONS

ATTACHMENT D

OBSERVED WATER QUALITY DATA AND LOCATIONS FOR THE UPPER MISSISSIPPI RIVER WATERSHED MODEL

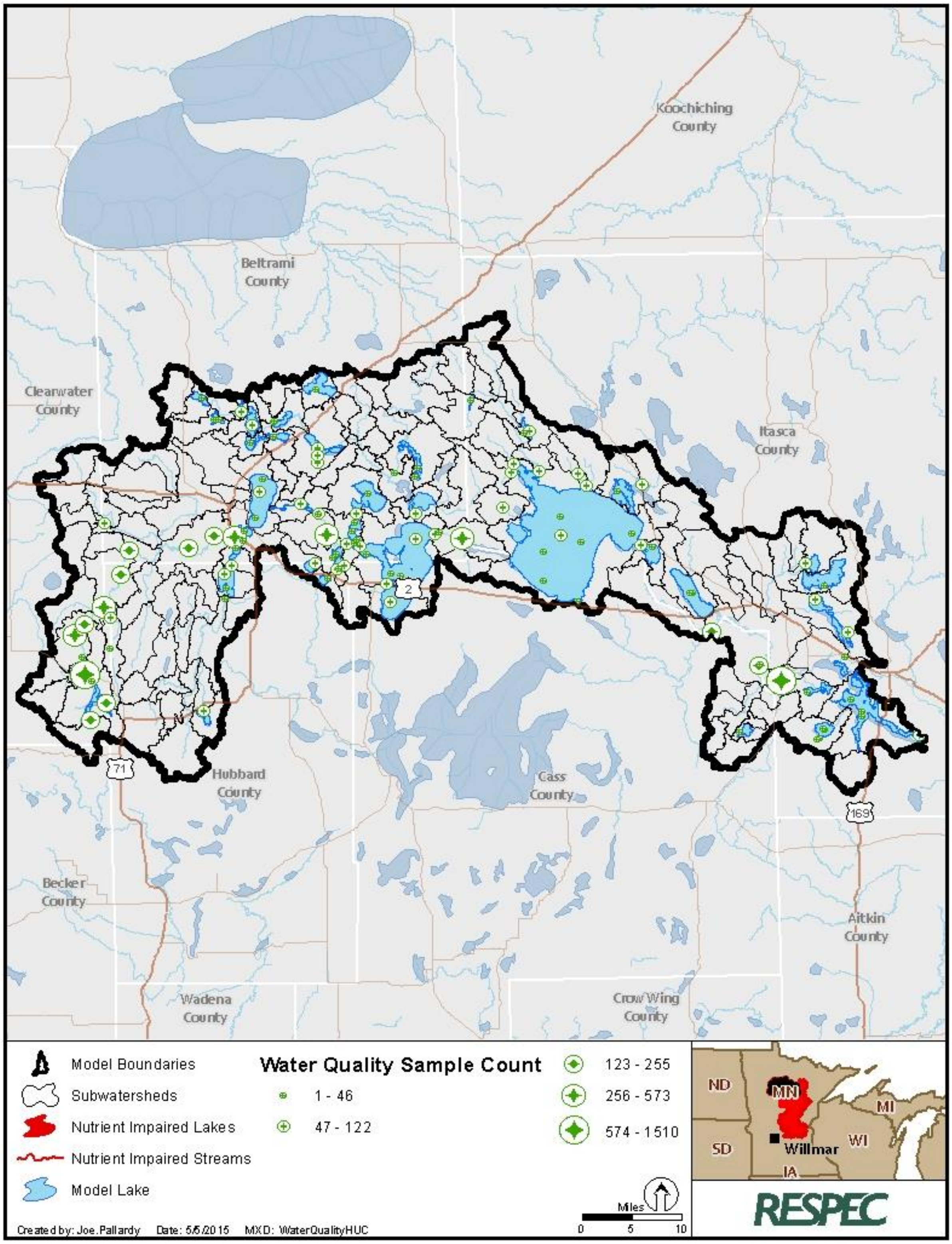


Figure D-1. Observed Water Quality Locations Within the Mississippi River–Headwaters Watershed.

Table D-1. Observed Water Quality Locations Within the Mississippi River–Headwaters Watershed (Page 1 of 3)

Monitoring Site I.D.	Reach I.D.	Number of Samples										
		BOD[a]	Chlorophyll *a*	DO[b]	Suspended Solids	TAM[c]	Water Temp.	TKN[d]	NO2+NO3[e]	T-ORTHO[f]	T-P[g]	Total
15-0010-00-101	191		12	59	6		59	11	11		12	170
15-0016-00-203	200		13	49	10		49	10	10		13	154
S000-105	210	11	44	105	66	95	107	33	102	1	75	640
S001-892				10			10		7		10	37
S001-893			30	39	29	31	39	31	39	1	40	280
S001-902			28	28	28	30	28	30	30	1	28	232
15-0001-00-201	213		16				5				16	37
29-0309-00-101			10	27	10		27	10			10	94
S001-895	230		31	40	31	31	40	32	40	2	41	289
S001-900			31	29	30	31	29	32	32	2	31	248
S001-901	250		31	30	31	31	30	32	32	2	31	251
04-0342-00-201	271		17	11			17				17	62
S001-896	290		28	28	29	29	28	29	29	1	28	230
S001-897			28	39	28	28	38	28	39	1	39	269
S001-903			31	30	31	31	30	31	31	1	30	247
29-0216-00-202	302		21	14	7		14	7			24	87
S004-311	313		5				33				5	43
29-0156-00-100	318		14								14	28
29-0156-00-201			35								35	70
29-0156-00-202			29								29	58
S002-618	330			11			11		9		10	42
04-0140-00-204	340		15								15	30
04-0130-02-104	360		11	33	11		33	11	11		11	121
04-0130-02-203			5	9			9				5	28
29-0071-00-201	372		30				2				30	62

Table D-1. Observed Water Quality Locations Within the Mississippi River–Headwaters Watershed (Page 2 of 3)

Monitoring Site I.D.	Reach I.D.	Number of Samples										
		BOD[(a)]	Chlorophyll *a*	DO[(b)]	Suspended Solids	TAM[(c)]	Water Temp.	TKN[(d)]	NO2+NO3[(e)]	T-ORTHO[(f)]	T-P[(g)]	Total
29-0066-00-201	374		10				5				10	25
S001-379	375			12	12		2	12		12	12	62
S001-380	377			12	11		2	12		12	12	61
04-0130-01-201	400		24								25	49
11-0415-00-101	402		11	33	11		33	11	11		11	121
S002-286				12	12			12		12	12	60
04-0227-00-201	404		18								20	38
04-0155-00-201	408		29								29	58
S000-155	410	15	15	66	33	61	67		61		33	351
S002-034	410			11	12			12		12	12	59
04-0159-00-203	412		25								25	50
04-0152-00-201	414		23								23	46
04-0135-00-202	416		21								21	42
04-0079-00-201	420		14	6			4				14	38
04-0134-00-202	422		23								23	46
04-0111-00-202	424		34								34	68
04-0111-00-205			26								26	52
04-0111-00-206			26								26	52
S002-035	430			11	12			12		12	12	59
04-0038-00-201	440		20								20	40
S002-036				11	11			12		12	12	58
S002-278				13	14	1	1	14	1	14	14	72
S002-291	452		1	13	12	1	1	13	1	13	13	69
04-0030-00-204	460			36	5			5		5	5	56
04-0030-00-208				29	2			2		2	2	37
04-0030-00-213				29	1			1		1	1	33
S002-037	470			10	11			11		11	11	54
S002-283				45	46	34	34	47	34	46	47	333

Table D-1. Observed Water Quality Locations Within the Mississippi River–Headwaters Watershed (Page 3 of 3)

Monitoring Site I.D.	Reach I.D.	Number of Samples										
		BOD[(a)]	Chlorophyll *a*	DO[(b)]	Suspended Solids	TAM[(c)]	Water Temp.	TKN[(d)]	NO2+NO3[(e)]	T-ORTHO[(f)]	T-P[(g)]	Total
S002-287	471			11	12			12		12	12	59
S002-282	473			12	13			13		13	13	64
S002-279	475			12	13			13		13	13	64
31-0921-00-101	488		22	6	2		24	2			24	80
S002-290	491		1	13	14	1	1	14	1	14	14	74
S002-281	493			12	13			13		13	13	64
S002-285	495			12	13			13		13	13	64
S002-280	501			12	13			13		13	13	64
31-0857-01-102	504		10		8						10	28
11-0147-00-101	520		10	27	10		27	9	9		9	101
11-0147-00-201			5	9			9				5	28
11-0147-00-206				28	1			1		1	1	32
11-0147-00-207				29	1			4		3	4	41
11-0147-00-208			1	28	1		3	3	1	2	3	42
31-0850-00-202	540		10		9						10	29
S002-284				11	12			12		12	12	59
31-0722-00-102	562		9	6	2		24	2			9	52
S003-654	590			95	9		95					199
S003-655				93	10		93					196
11-0026-00-101	596		5	12	5		12	5			5	44
S000-154	610	15	15	144	67	85	147	21	91	21	56	662
31-0717-00-201	612		10		9						10	29
31-0576-00-201	622		10	14	5		15	5			10	59
31-0576-00-204			10	13	5		14	5			10	57
31-0554-00-100	632		12		2						11	25

(a) BOD = Biochemical Oxygen Demand
(b) DO = Dissolved Oxygen
(c) TAM = Total Ammonia
(d) TKN = Total Kjeldahl Nitrogen
(e) NO2 + NO3 = Nitrate Nitrite
(f) T-ORTHO = Total Orthophosphate
(g) T-P = Total Phosphorus
* Highlighted cells indicate lake data

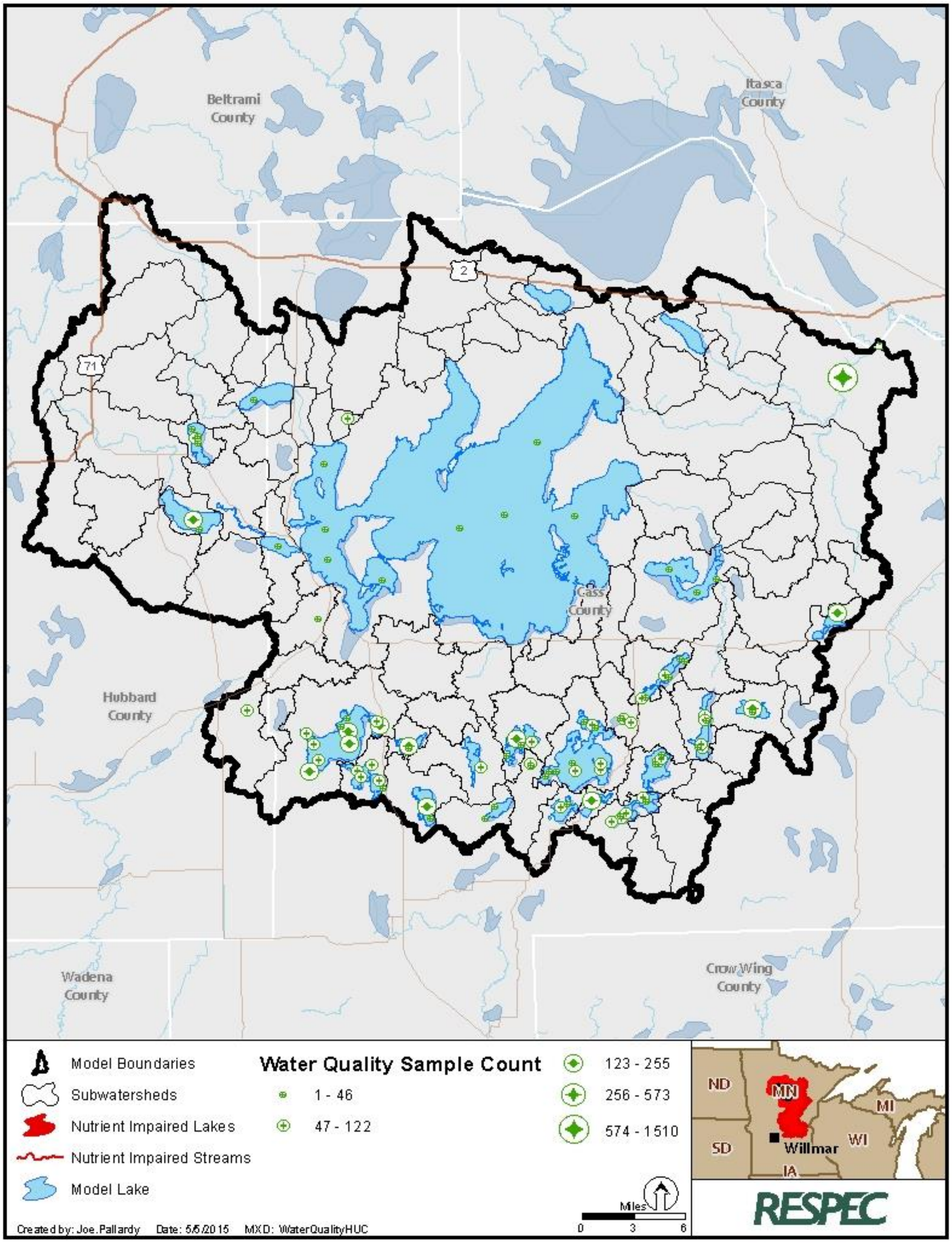


Figure D-2. Observed Water Quality Locations Within the Leech Lake River Watershed.

Table D-2. Observed Water Quality Locations Within the Leech Lake River Watershed

Monitoring Site I.D.	Reach I.D.	Number of Samples										
		BOD(a)	Chlorophyll *a*	DO(b)	Suspended Solids	TAM(c)	Water Temp.	TKN(d)	NO2+NO3(e)	T-ORTHO(f)	T-P(g)	Total
29-0061-00-100	8		15								15	30
29-0061-00-204			15								15	30
S003-805	45						62					62
11-0413-00-210	52			47			47					94
11-0412-00-203	54		5	15	3		15	5			6	49
11-0277-00-202	58			14			14					28
11-0277-00-203				15			15					30
11-0282-00-203	68		9	30			32				9	80
11-0274-00-202	74		15	3			4				15	37
11-0201-01-102	78		13	12	1		12	1			13	52
11-0201-02-201			7	14	5		15	5			6	52
11-0174-00-101	79		15	15	5		19	5			15	74
11-0142-04-100	86			15			15					30
11-0171-02-201	92			28			28					56
11-0167-00-201	94		13	15			15				13	56
11-0167-00-202				12			12				1	25
11-0120-01-102	112		5	15	4		15	5			5	49
11-0143-00-201	122		15				2				15	32

(a) BOD = Biochemical Oxygen Demand
(b) DO = Dissolved Oxygen
(c) TAM = Total Ammonia
(d) TKN = Total Kjeldahl Nitrogen
(e) NO2 + NO3 = Nitrate Nitrite
(f) T-ORTHO = Total Orthophosphate
(g) T-P = Total Phosphorus* Highlighted cells indicate lake data

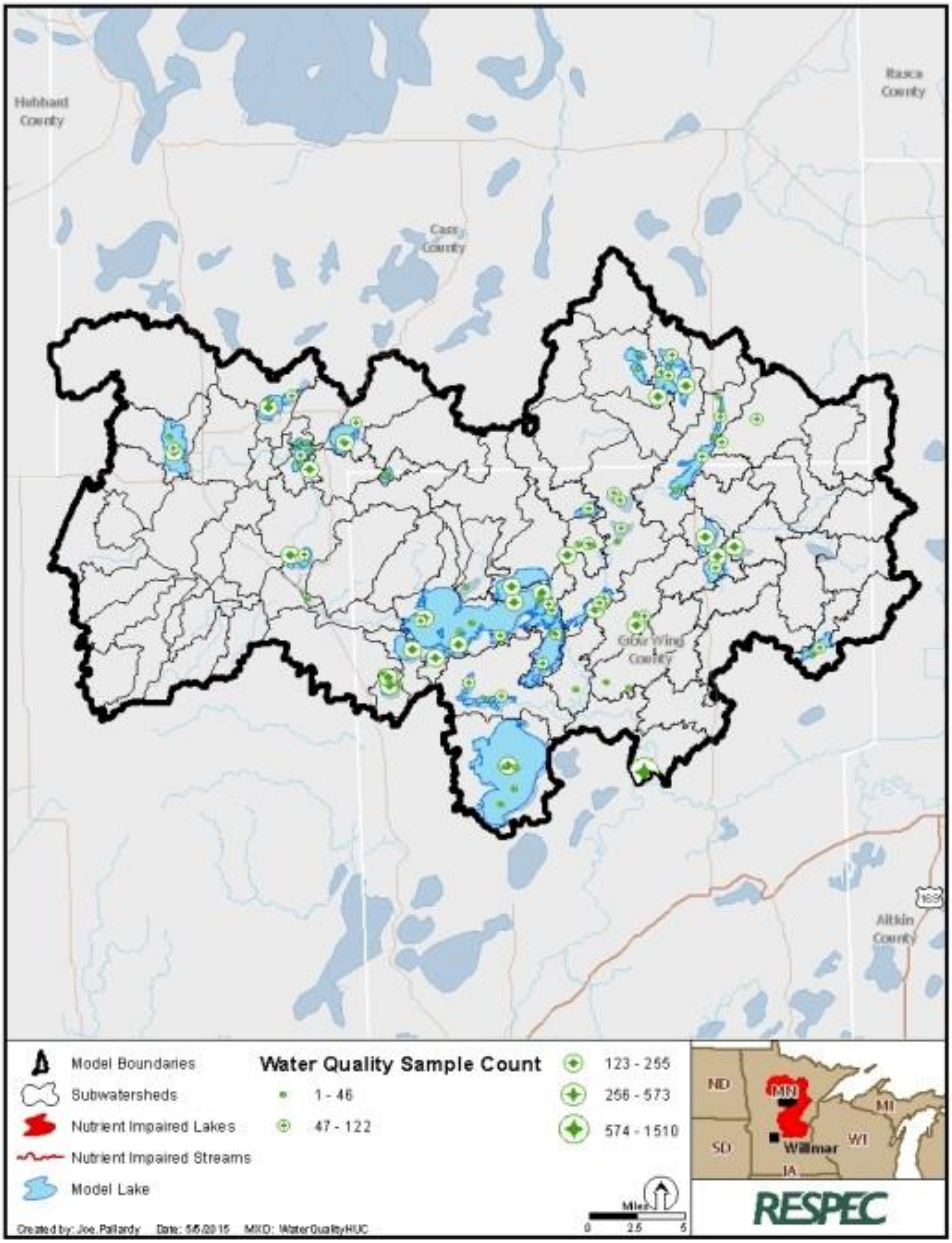


Figure D-3. Observed Water Quality Locations Within the Pine River Watershed.

Table D-3. Observed Water Quality Locations Within the Pine River Watershed (Page 1 of 2)

Monitoring Site I.D.	Reach I.D.	Number of Samples										
		BOD[(a)]	Chlorophyll *a*	DO[(b)]	Suspended Solids	TAM[(c)]	Water Temp.	TKN[(d)]	NO2+NO3[(e)]	T-ORTHO[(f)]	T-P[(g)]	Total
11-0411-00-201	20			28			28					56
11-0411-00-202			14				5				14	33
11-0232-00-202	80		19	15			19				19	72
18-0415-00-201	98			20			18				2	40
S001-345	130			3	3		40					46
11-0101-00-101	246		5	12	5		12	5			5	44
11-0059-00-203	248		5	24			24				5	58
11-0059-00-206			25				6				25	56
11-0037-00-203	253		14	15			15				14	58
11-0053-00-203			14	15			15				14	58
11-0043-01-203	254		10		2		24	2			11	49
11-0043-01-204				14			14					28
11-0043-01-205				14			14					28
11-0043-01-206			5	18			18				5	46
11-0043-02-213			5	14			14				5	38
18-0311-00-205	260		25	12			12				25	74
18-0311-00-209			5	42			42				5	94
18-0312-00-100				28			28					56
18-0312-00-101			20	14			16				20	70
18-0312-00-205			10	12			12				10	44
18-0298-00-100	263		5	18			18				5	46
18-0294-00-100	265		4	23			23				4	54
18-0266-00-203	266		5	19			20				5	49
18-0266-00-204			25	12			12				25	74
18-0287-00-101	273		3	8	3		8	3			3	28

Table D-3. Observed Water Quality Locations Within the Pine River Watershed (Page 2 of 2)

Monitoring Site I.D.	Reach I.D.	Number of Samples										
		BOD[a]	Chlorophyll *a*	DO[b]	Suspended Solids	TAM[c]	Water Temp.	TKN[d]	NO2+NO3[e]	T-ORTHO[f]	T-P[g]	Total
18-0308-00-205	282			28			28					56
18-0251-02-201	308		14				5				14	33
18-0165-00-201	314		19	15			19				19	72

(a) BOD = Biochemical Oxygen Demand
(b) DO = Dissolved Oxygen
(c) TAM = Total Ammonia
(d) TKN = Total Kjeldahl Nitrogen
(e) NO2 + NO3 = Nitrate Nitrite
(f) T-ORTHO = Total Orthophosphate
(g) T-P = Total Phosphorus
* Highlighted cells indicate lake data

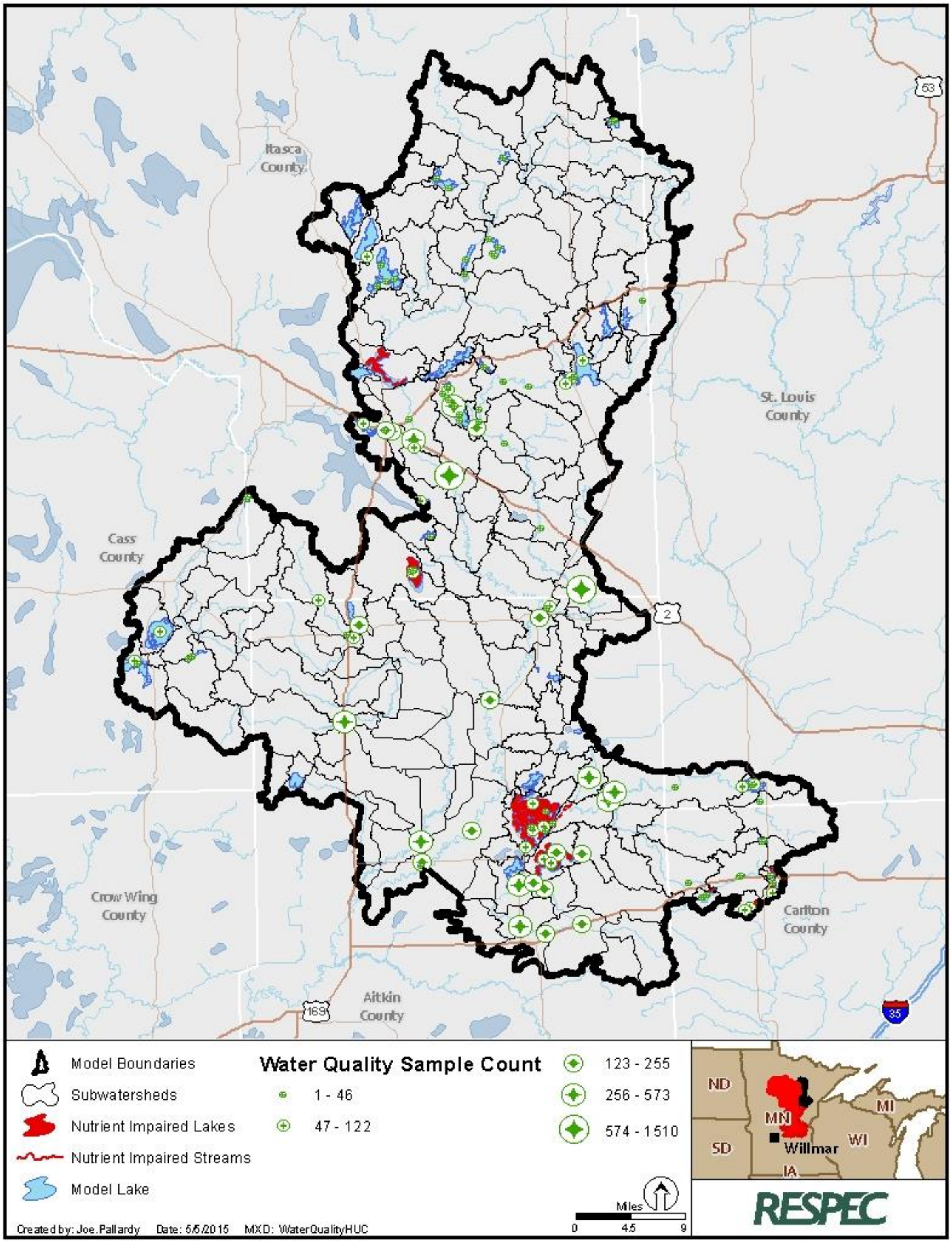


Figure D-4. Observed Water Quality Locations Within the Mississippi River–Grand Rapids Watershed.

Table D-4. Observed Water Quality Locations Within the Mississippi River–Grand Rapids Watershed (Page 1 of 2)

Monitoring Site I.D.	Reach I.D.	Number of Samples										
		BOD[(a)]	Chlorophyll *a*	DO[(b)]	Suspended Solids	TAM[(c)]	Water Temp.	TKN[(d)]	NO2+NO3[(e)]	T-ORTHO[(f)]	T-P[(g)]	Total
31-0154-00-203	30		10		10						10	30
31-0193-00-204	100		10		9						10	29
31-0231-00-101	140		10		9						10	29
31-0238-00-202			10		10						10	30
31-0392-00-205	162		5	12	3		12	5			5	42
S002-634	220 240			14			16		13		13	56
S002-636				14			16		14		14	58
31-0361-00-201	241		10	9	4		27	4			10	64
31-0353-00-202	256		10	9	3		27	3			10	62
31-0067-01-100	282		24		9						26	59
31-0067-01-101			10	9	3		27	3			10	62
31-0067-02-201			10	9	3		27	3			10	62
31-0227-00-201	284		10		10						10	30
S003-666	287			11	3		11					25
31-0216-00-103	288		20								23	43
S005-777	403			10	12		11				13	46
S005-776	405			10	11		11				12	44
09-0060-02-100	414		26								26	52
09-0060-02-101			4	12	4		12	4			4	40
S004-613	431			12			9				16	37
01-0033-00-101	434		15	9	3		9	3			15	54
01-0033-00-201			13	21			39				14	87
S003-491	459			12	12		12				13	49

Table D-4. Observed Water Quality Locations Within the Mississippi River–Grand Rapids Watershed (Page 2 of 2)

Monitoring Site I.D.	Reach I.D.	Number of Samples										
		BOD[(a)]	Chlorophyll *a*	DO[(b)]	Suspended Solids	TAM[(c)]	Water Temp.	TKN[(d)]	NO2+NO3[(e)]	T-ORTHO[(f)]	T-P[(g)]	Total
11-0062-00-203	532		12				5				13	30
11-0062-00-212			9	27			27				9	72
11-0009-01-101	541		4	6	2		6	3			4	25

(a) BOD = Biochemical Oxygen Demand
(b) DO = Dissolved Oxygen
(c) TAM = Total Ammonia
(d) TKN = Total Kjeldahl Nitrogen
(e) NO2 + NO3 = Nitrate Nitrite
(f) T-ORTHO = Total Orthophosphate
(g) T-P = Total Phosphorus
* Highlighted cells indicate lake data

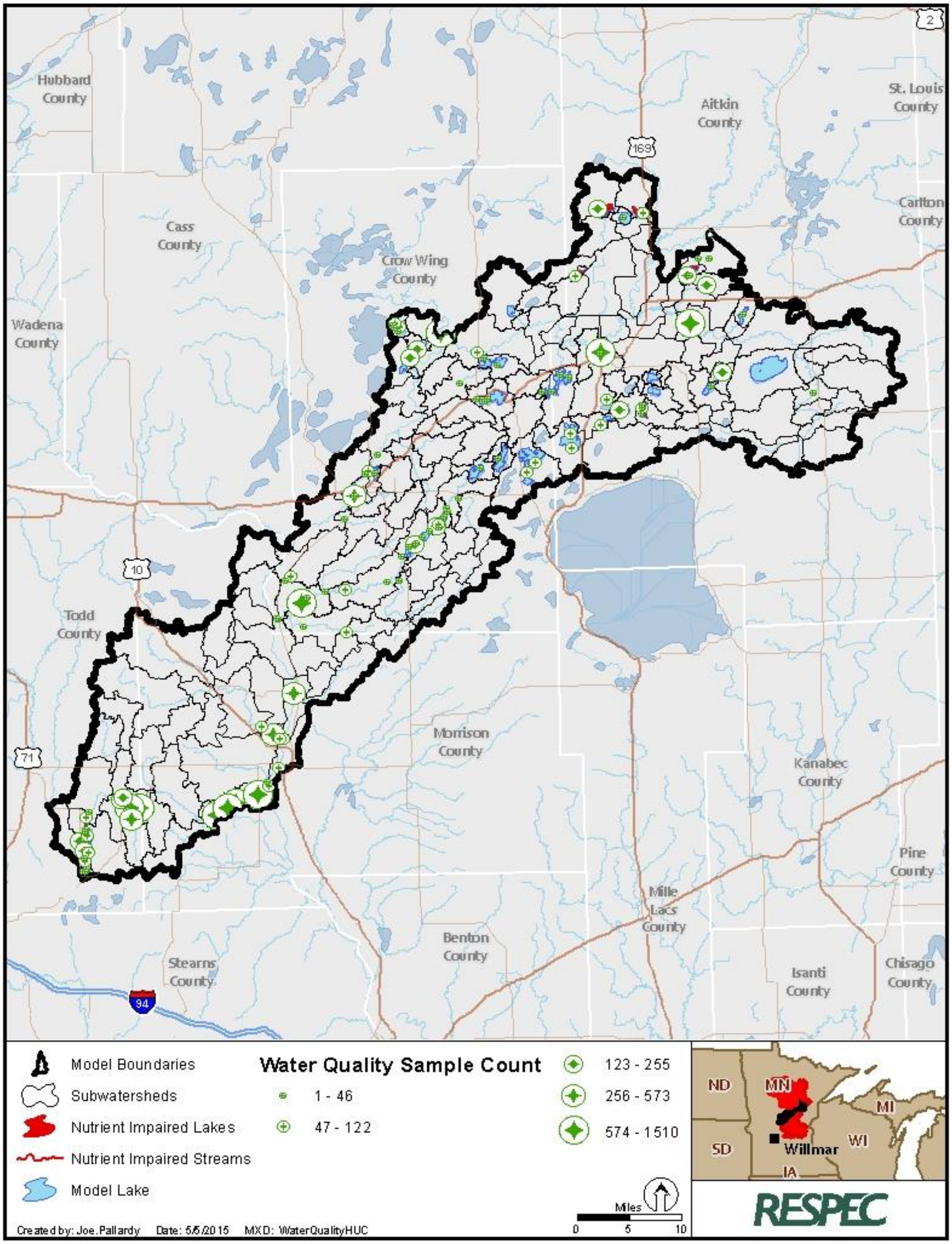


Figure D-5. Observed Water Quality Locations Within the Mississippi River–Brainerd Watershed.

Table D-5. Observed Water Quality Locations Within the Mississippi River–Brainerd Watershed (Page 1 of 2)

Monitoring Site I.D.	Reach I.D.	Number of Samples										
		BOD[(a)]	Chlorophyll *a*	DO[(b)]	Suspended Solids	TAM[(c)]	Water Temp.	TKN[(d)]	NO2+NO3[(e)]	T-ORTHO[(f)]	T-P[(g)]	Total
S005-402	27						25					25
18-0034-00-203	92		10		2		24	2			11	49
18-0034-00-206			10		2		24	2			11	49
01-0159-00-205	94		10	6			30				10	56
01-0123-00-101	102		8	6	3		9	3			8	37
01-0170-00-202	107		14	6	3		30	3			14	70
01-0137-00-101	154		14								15	29
S000-152	190	8	8	7	8		7	8	8		8	62
18-0090-00-201	234		10	9			9				10	38
18-0090-00-203			23								23	46
S000-572	270			10			10		10		10	40
S002-640	290			10			10		10		10	40
18-0155-00-203	312		17	13	5		13	5			17	70
S004-651	370				14						14	28
18-0096-00-101	380		10	15	5		15	5			10	60
S004-328					14						14	28
18-0136-00-100	400		4	12	4		12	4			4	40
18-0136-00-102			4	12			12				4	32
S004-329	430				15						15	30
S004-331					14		22				14	50
S004-650					14						14	28
S004-706	431				14						14	28
S004-349	435				30		1				31	62

Table D-5. Observed Water Quality Locations Within the Mississippi River–Brainerd Watershed (Page 2 of 2)

Monitoring Site I.D.	Reach I.D.	Number of Samples										
		BOD[(a)]	Chlorophyll *a*	DO[(b)]	Suspended Solids	TAM[(c)]	Water Temp.	TKN[(d)]	NO2+NO3[(e)]	T-ORTHO[(f)]	T-P[(g)]	Total
S004-332	450				14						14	28
S002-641	530			15			14		14		15	60
S002-644	545			15			14		15		14	60
S002-645	547			9			8		10		8	37
77-0009-00-101	558		11	5	2		5	3			11	37
77-0023-00-100	562		4	12	4		12	4	4		4	44
77-0023-00-101			4	12	4		12	4	4		4	44
77-0023-00-201			14	18			18				14	64
77-0023-00-202			10	18			18				10	56
77-0032-00-101			10	14	5		14	5			10	58
S005-040		4		11	11	11	11	11			11	70
S002-643	590			15			13		15		15	60

(a) BOD = Biochemical Oxygen Demand
(b) DO = Dissolved Oxygen
(c) TAM = Total Ammonia
(d) TKN = Total Kjeldahl Nitrogen
(e) NO2 + NO3 = Nitrate Nitrite
(f) T-ORTHO = Total Orthophosphate
(g) T-P = Total Phosphorus
* Highlighted cells indicate lake data

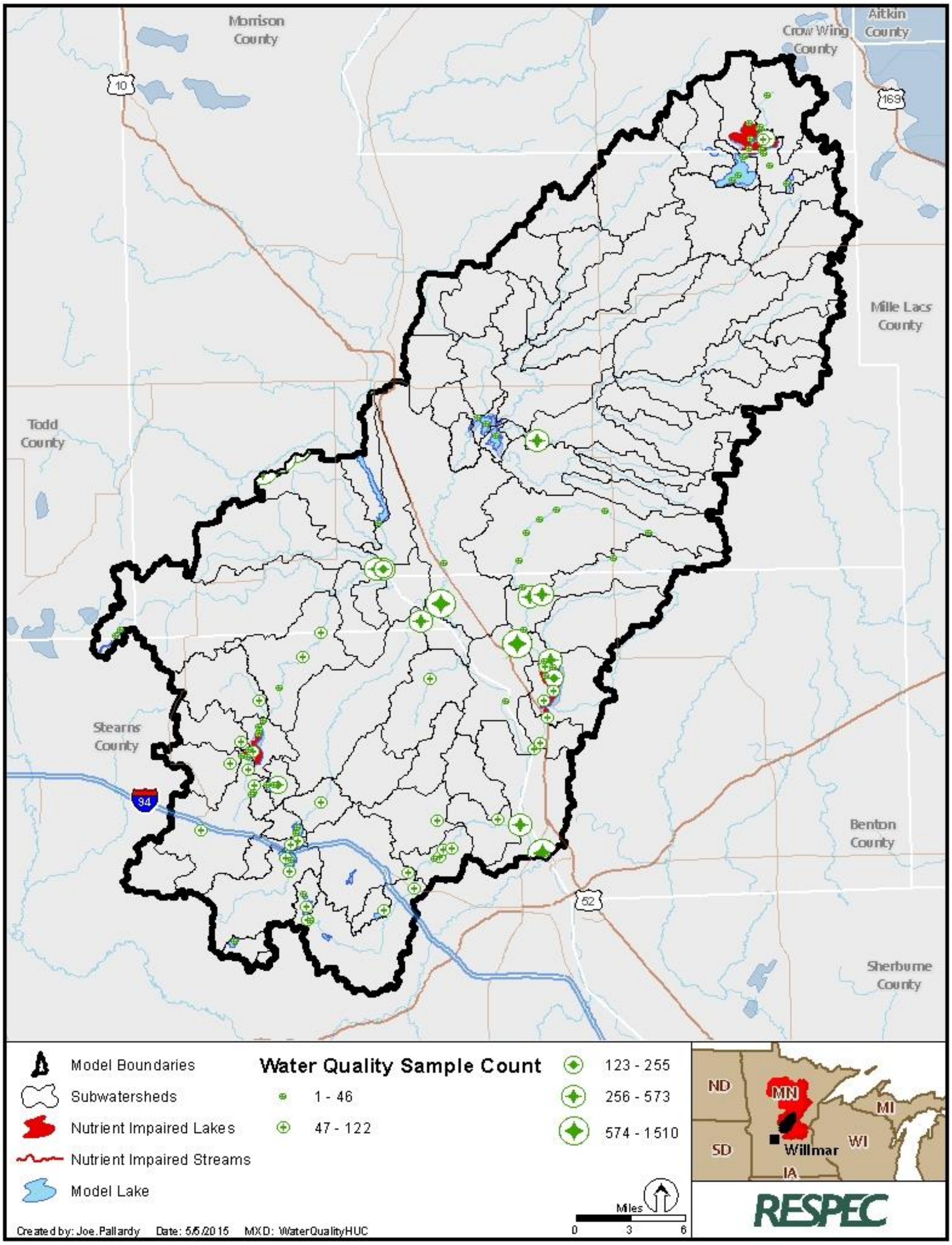


Figure D-6. Observed Water Quality Locations Within the Mississippi River–Sartell Watershed.

Table D-6. Observed Water Quality Locations within the Mississippi River–Sartell Watershed (Page 1 of 2)

Monitoring Site I.D.	Reach I.D.	Number of Samples										
		BOD[(a)]	Chlorophyll *a*	DO[(b)]	Suspended Solids	TAM[(c)]	Water Temp.	TKN[(d)]	NO2+NO3[(e)]	T-ORTHO[(f)]	T-P[(g)]	Total
S001-678	600	6	6	5	6		5	6	6		6	46
73-0118-00-100	606		4	12			12				4	32
73-0136-00-202	608		16	12			14				19	61
73-0136-00-203			4	12			12				4	32
73-0138-00-207	618		6	15	2		15	2			6	46
S000-424	621		8	12	12		12	8	8		8	68
S000-425							80					80
77-0019-00-101	623		5	13	5		13	5			5	46
18-0088-00-101	660		4	12	4		12	4			4	40
18-0088-00-203			11		2		24	2			11	50
18-0088-00-208			10				5				10	25
18-0088-00-209			10				5				10	25
18-0088-00-210			10				5				10	25
49-0016-00-206	680		5	15			15				5	40
S003-809	890						44					44
73-0117-00-203	896		16	12			13				20	61
73-0117-00-204			4	12			12				4	32
73-0128-00-204	898		16	12			13				20	61
73-0128-00-206			16	12			13				16	57
73-0123-00-203	902		4	12			12				4	32
S004-238	905						69					69
S005-031	931			13		3	13		3	3	3	38
S005-397	935			2			41					43

Table D-6. Observed Water Quality Locations within the Mississippi River–Sartell Watershed (Page 2 of 2)

Monitoring Site I.D.	Reach I.D.	Number of Samples										
		BOD[(a)]	Chlorophyll *a*	DO[(b)]	Suspended Solids	TAM[(c)]	Water Temp.	TKN[(d)]	NO2+NO3[(e)]	T-ORTHO[(f)]	T-P[(g)]	Total
S004-332	942				14						14	28
S002-641				15			14		14		15	60
S002-644	948			15			14		15		14	60

(a) BOD = Biochemical Oxygen Demand
(b) DO = Dissolved Oxygen
(c) TAM = Total Ammonia
(d) TKN = Total Kjeldahl Nitrogen
(e) NO2 + NO3 = Nitrate Nitrite
(f) T-ORTHO = Total Orthophosphate
(g) T-P = Total Phosphorus
* Highlighted cells indicate lake data

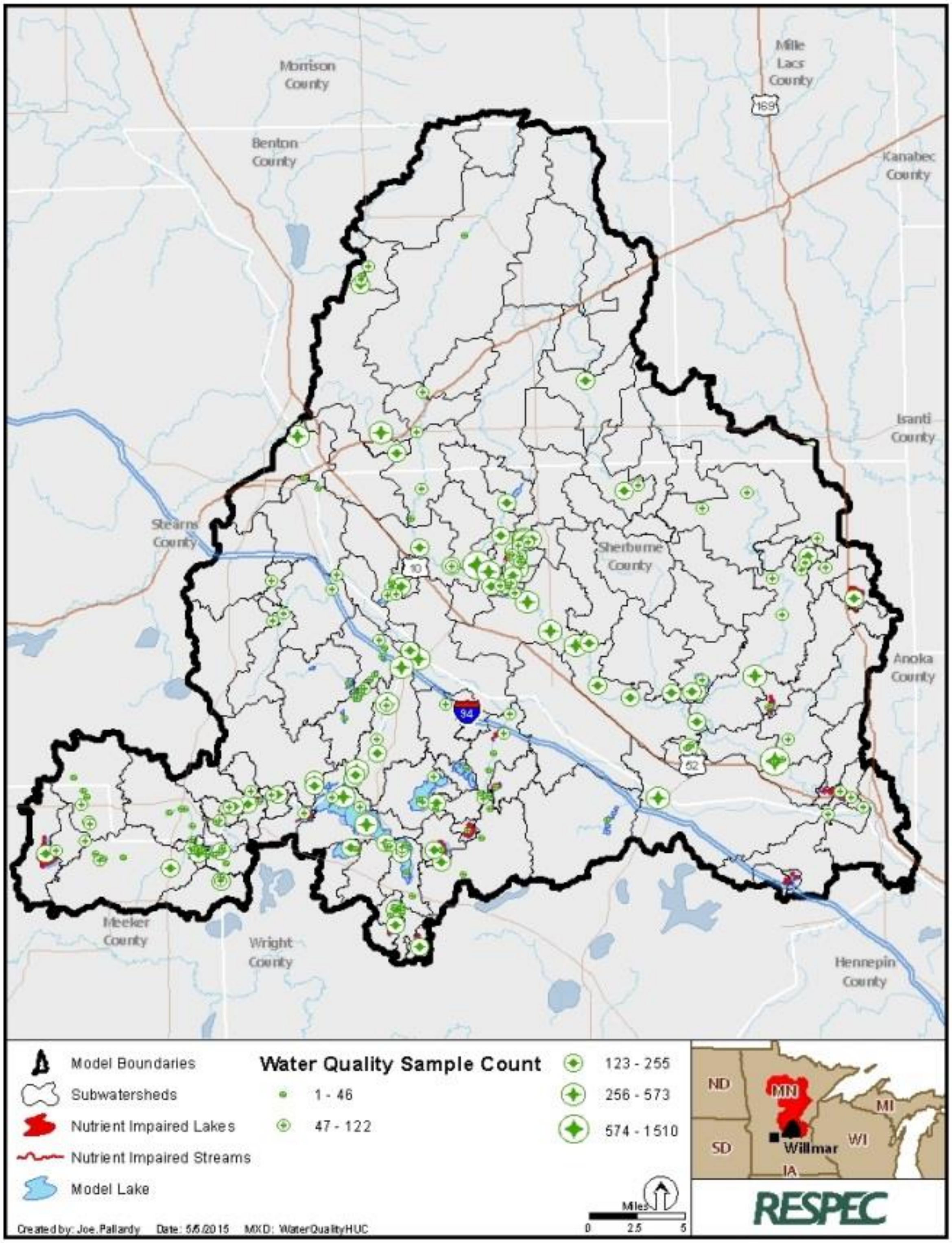


Figure D-7. Observed Water Quality Locations Within the Mississippi River – St. Cloud Watershed.

Table D-7. Observed Water Quality Locations within the Mississippi River–St. Cloud Watershed (Page 1 of 2)

Monitoring Site I.D.	Reach I.D.	Number of Samples										
		BOD[(a)]	Chlorophyll *a*	DO[(b)]	Suspended Solids	TAM[(c)]	Water Temp.	TKN[(d)]	NO2+NO3[(e)]	T-ORTHO[(f)]	T-P[(g)]	Total
S005-711	37		8	12	12		12	8	8		8	68
S003-765	39		8	12	12		12	8	8		8	68
73-0006-00-201	53		4	12			12				4	32
S003-369	55		4	4	4		4	4	4		4	28
S005-721			8	12	12		12	8	8		8	68
S003-404	90			9	7	6	9	7	7	7	9	68
S003-406				8	8		8	8	8	8	8	56
S003-411	110			11	10	9	11	10	10	10	13	94
S003-428	153			5	6		5			6	10	32
S003-814	170						37					37
S004-249				6	6	2	6	6	6	6	6	50
73-0014-00-202	200		4	24			12				4	44
86-0281-00-201	220		9	24			12				9	54
86-0284-00-201	260		13	12			12	4		8	13	62
S006-500	273			7	4		7			7	7	32
86-0227-00-201	282		23								23	46
S003-601	287			8	3		10		1	17	22	61
71-0159-00-201	312		14	18			18	8			14	72
86-0183-00-201	318		40								40	80
86-0140-00-201	352		27								27	54
S004-503	450			30			30					60
S005-539				10	10	10	10	10	10		10	70
S003-008	470			6	14		6	3	3	12	14	58

Table D-7. Observed Water Quality Locations within the Mississippi River–St. Cloud Watershed (Page 2 of 2)

Monitoring Site I.D.	Reach I.D.	Number of Samples										
		BOD[(a)]	Chlorophyll *a*	DO[(b)]	Suspended Solids	TAM[(c)]	Water Temp.	TKN[(d)]	NO2+NO3[(e)]	T-ORTHO[(f)]	T-P[(g)]	Total
S003-868	490						62					62
71-0146-00-101			4	24	4		12	4			4	52
71-0146-00-201	514		6	18			18	3	3		6	54
71-0146-00-206			48	28			28	4	4		58	170
71-0147-00-201	516		49	27			27	4	4		59	170
S004-259	687						59					59
S004-260	689						60					60
S004-261							61					61
71-0057-00-100	692		4	18	3		9	4			4	42
71-0013-02-206	760		6	5	11		5				23	50
S004-755	770						57					57

(a) BOD = Biochemical Oxygen Demand
(b) DO = Dissolved Oxygen
(c) TAM = Total Ammonia
(d) TKN = Total Kjeldahl Nitrogen
(e) NO2 + NO3 = Nitrate Nitrite
(f) T-ORTHO = Total Orthophosphate
(g) T-P = Total Phosphorus
* Highlighted cells indicate lake data

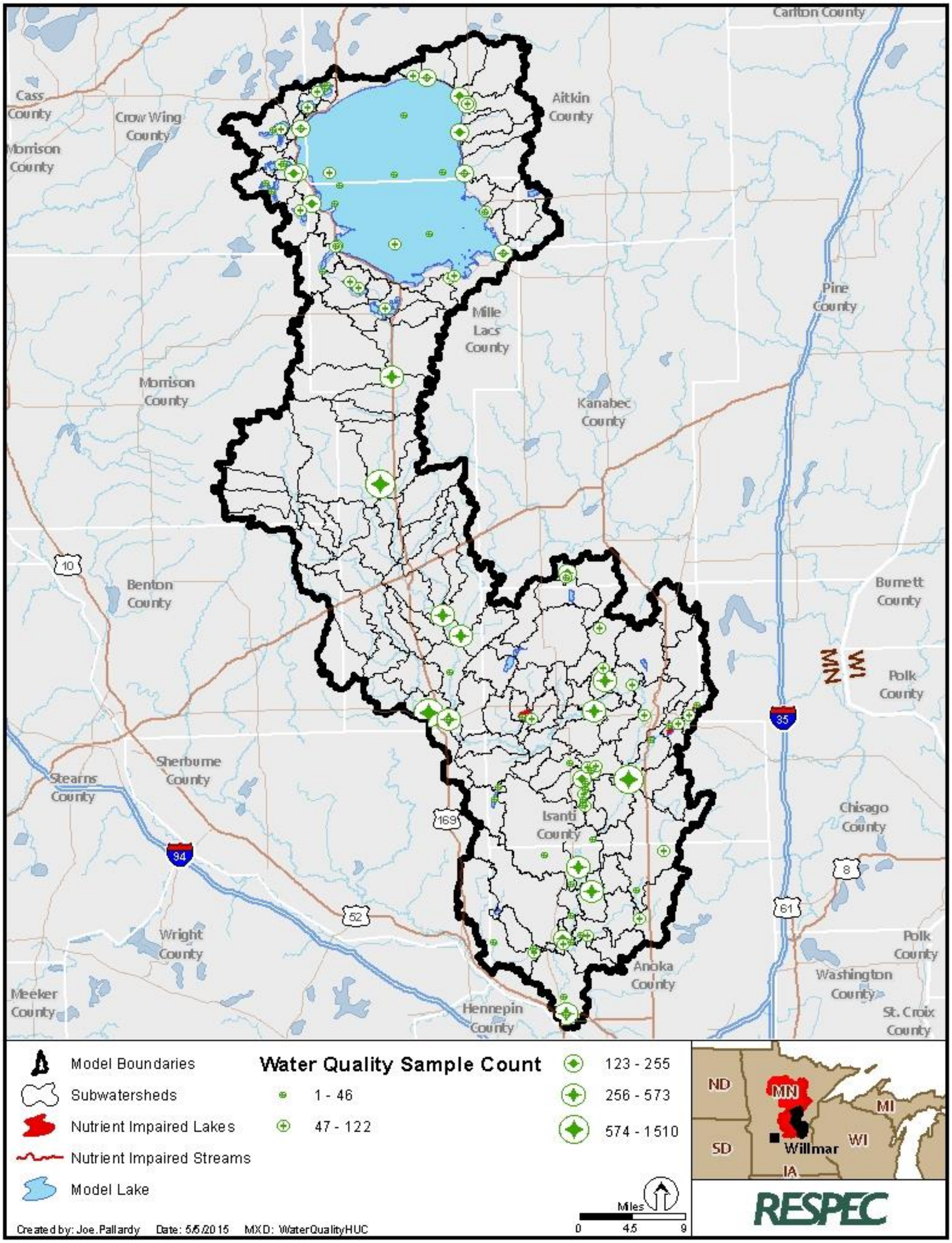


Figure D-8. Observed Water Quality Locations Within the Rum River Watershed.

Table D-8. Observed Water Quality Locations within the Rum River Watershed (Page 1 of 2)

Monitoring Site I.D.	Reach I.D.	Number of Samples										
		BOD[(a)]	Chlorophyll *a*	DO[(b)]	Suspended Solids	TAM[(c)]	Water Temp.	TKN[(d)]	NO2+NO3[(e)]	T-ORTHO[(f)]	T-P[(g)]	Total
01-0157-00-201	2		6				20				6	32
01-0157-00-203			8	6			27				9	50
01-0204-00-204	4		15	6	3		27	3			14	68
S001-468	19						57					57
S001-466	27						29					29
S001-289	35			3	10		33				10	56
18-0028-00-201	38		5	15			15				5	40
18-0028-00-202	38		15		2		24	2			15	58
18-0018-00-203	42		5	15			15				5	40
48-0002-00-208	60			36			36					72
48-0002-00-222				36			36					72
S003-856	70			12	13		42				13	80
S002-039	90			6	7		13				7	33
48-0009-00-101	120		10	11	10		12	10	10		11	74
30-0107-02-101	271		4	12	4		12	4			4	40
30-0136-00-202	282		23	3	1		3	1			23	54
33-0032-00-202	313		5	42			42				5	94
S001-711	323						94					94
S004-980			36	33	36	36	33	35	35		36	280
S005-327	330			32			32					64
S005-326	350			32			32					64
30-0022-00-101	352		5	12	4		12	4			4	41
30-0022-00-102			13	12	1		12	1			13	52

Table D-8. Observed Water Quality Locations within the Rum River Watershed (Page 2 of 2)

Monitoring Site I.D.	Reach I.D.	Number of Samples										
		BOD[(a)]	Chlorophyll *a*	DO[(b)]	Suspended Solids	TAM[(c)]	Water Temp.	TKN[(d)]	NO2+NO3[(e)]	T-ORTHO[(f)]	T-P[(g)]	Total
30-0043-00-202	354		13	12	4		12	4			13	58
30-0043-00-203			4	12			12				4	32
30-0035-00-100	355		3	9	3		9	3			3	30
S004-111	357			13	3	2	13	3	3	3	3	43
30-0072-00-202	364				1	4		8	9	8	10	40
30-0072-00-205			10				10				10	30
30-0072-00-206			10				10				10	30
30-0072-00-207					1	5		8	9	8	10	41
S003-513	365				13	13		13	13	14	14	80
S004-239	419						37					37
S004-026	430			14	16		17				17	64

(a) BOD = Biochemical Oxygen Demand
(b) DO = Dissolved Oxygen
(c) TAM = Total Ammonia
(d) TKN = Total Kjeldahl Nitrogen
(e) NO2 + NO3 = Nitrate Nitrite
(f) T-ORTHO = Total Orthophosphate
(g) T-P = Total Phosphorus
* Highlighted cells indicate lake data

ATTACHMENT E

UPPER MISSISSIPPI RIVER WATERSHED
POINT-SOURCE LOCATIONS

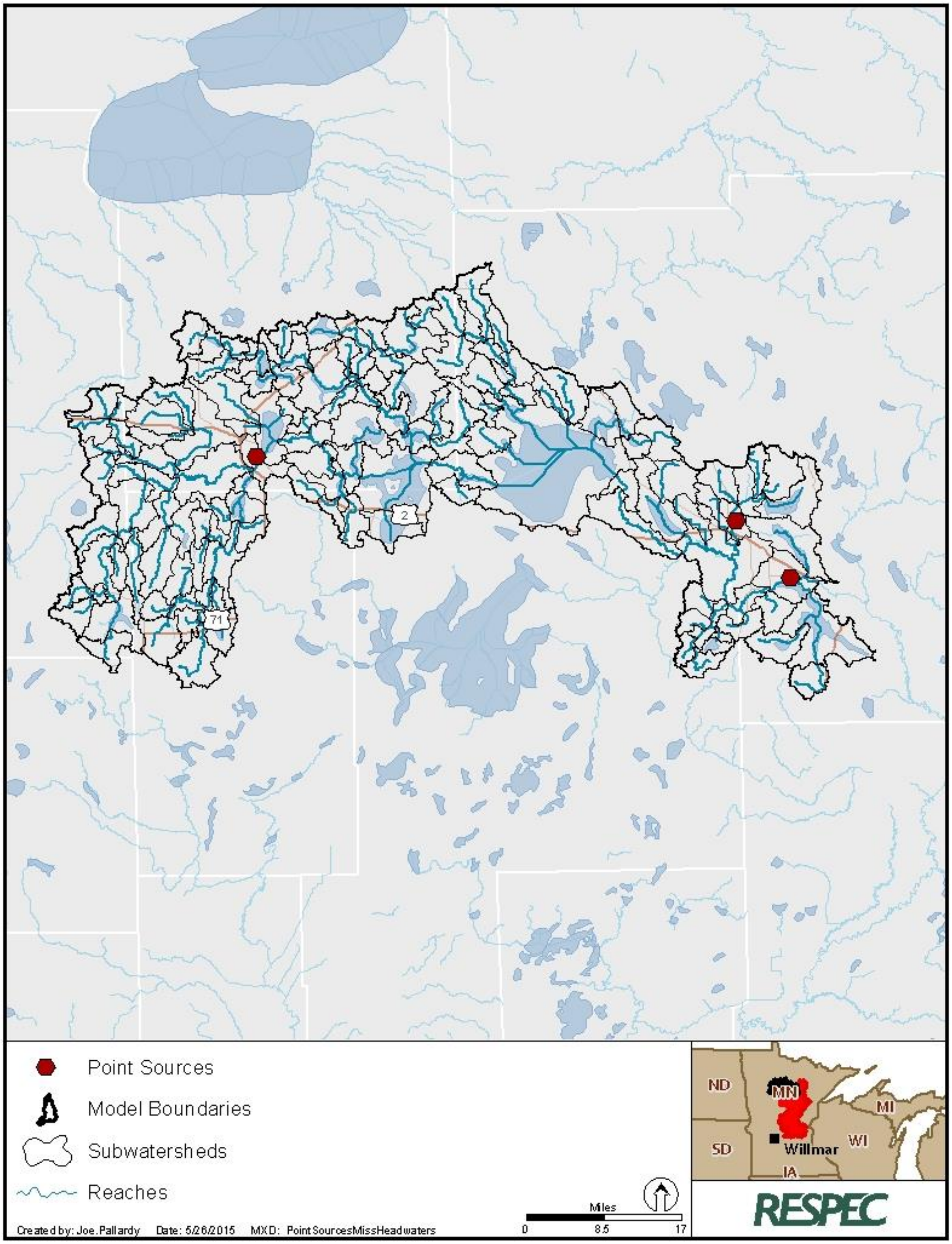


Figure E-1. Point-Source Locations in the Mississippi River–Headwaters Watershed.

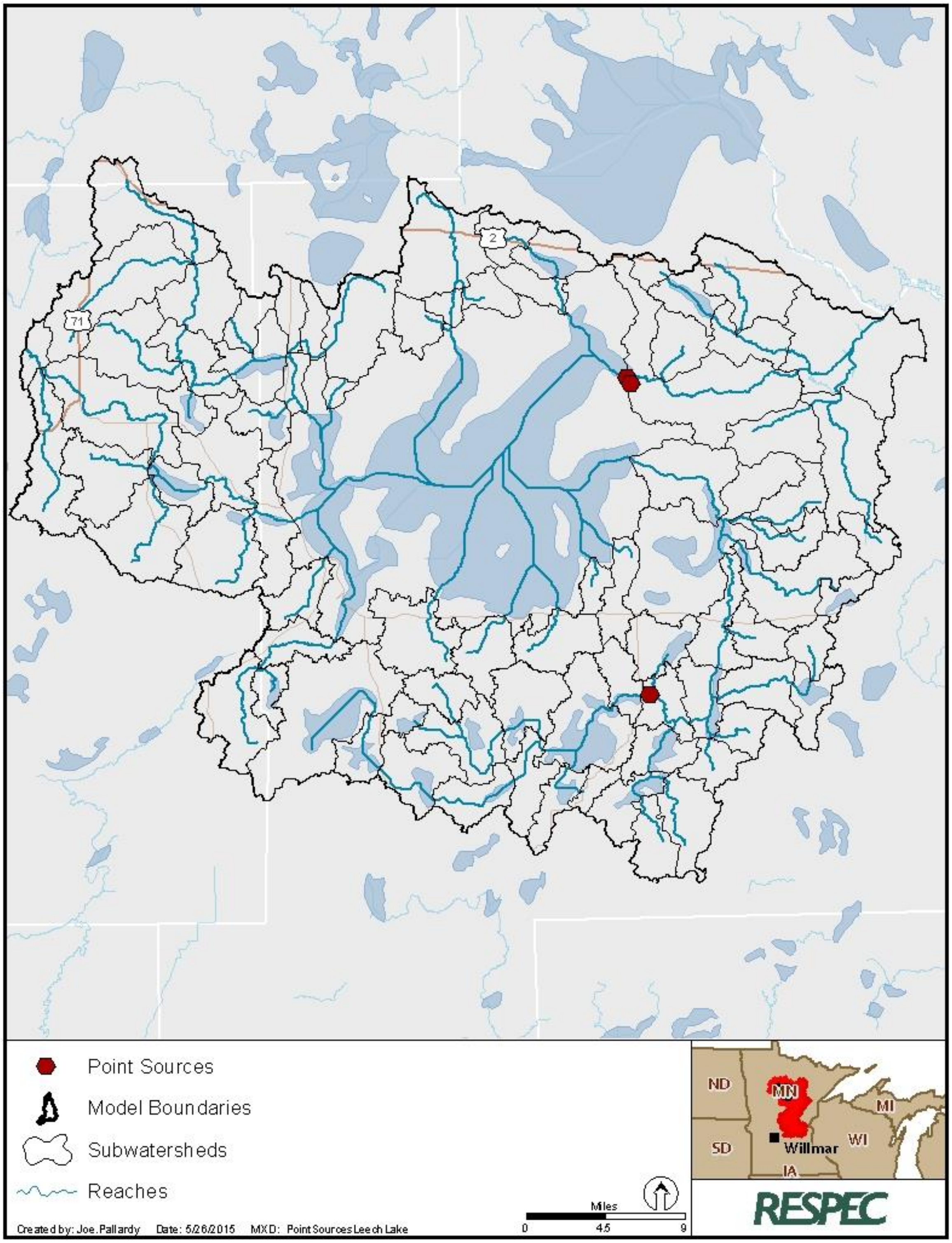


Figure E-2. Point-Source Locations in the Leech Lake River Watershed.

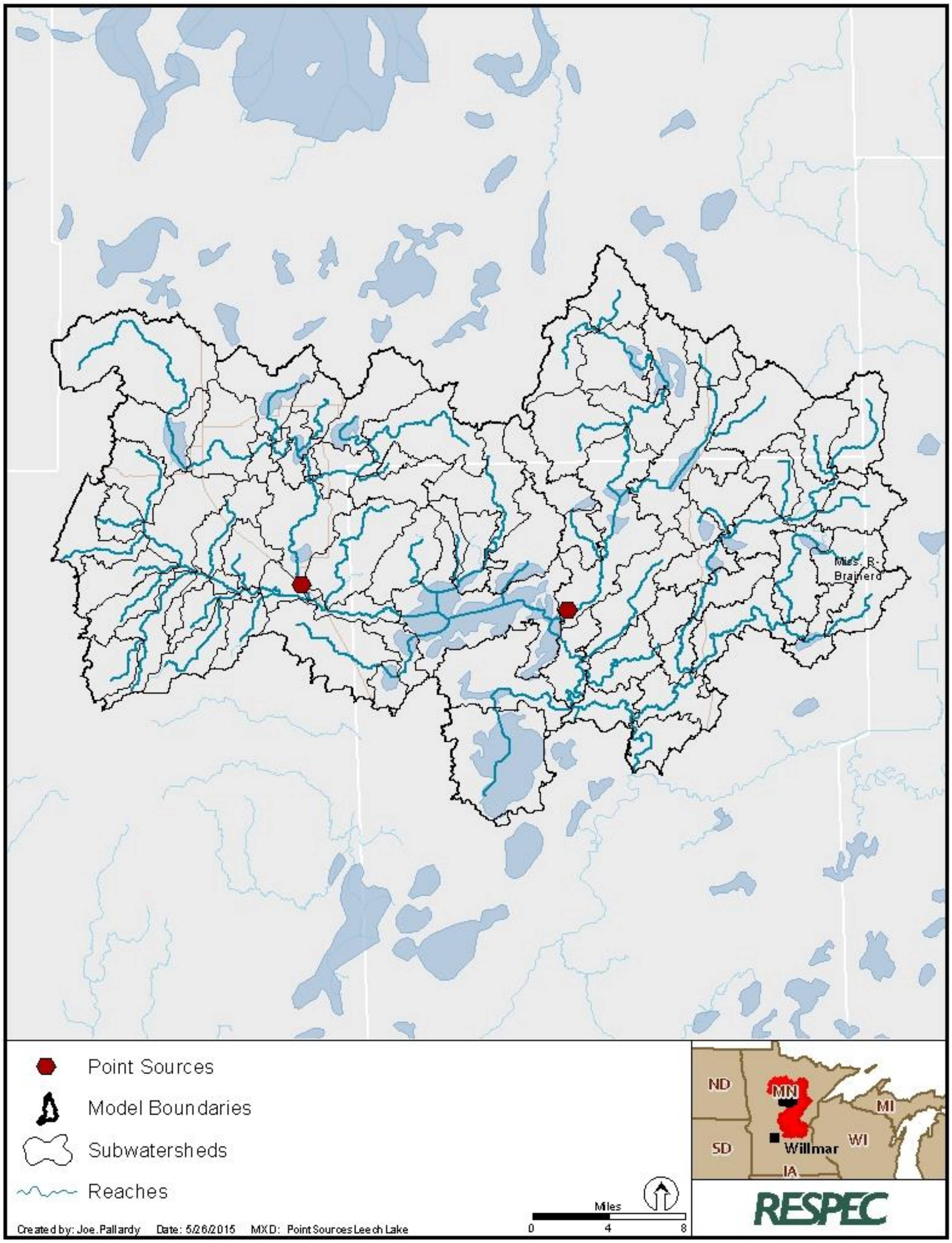


Figure E-3. Point-Source Locations in the Pine River Watershed.

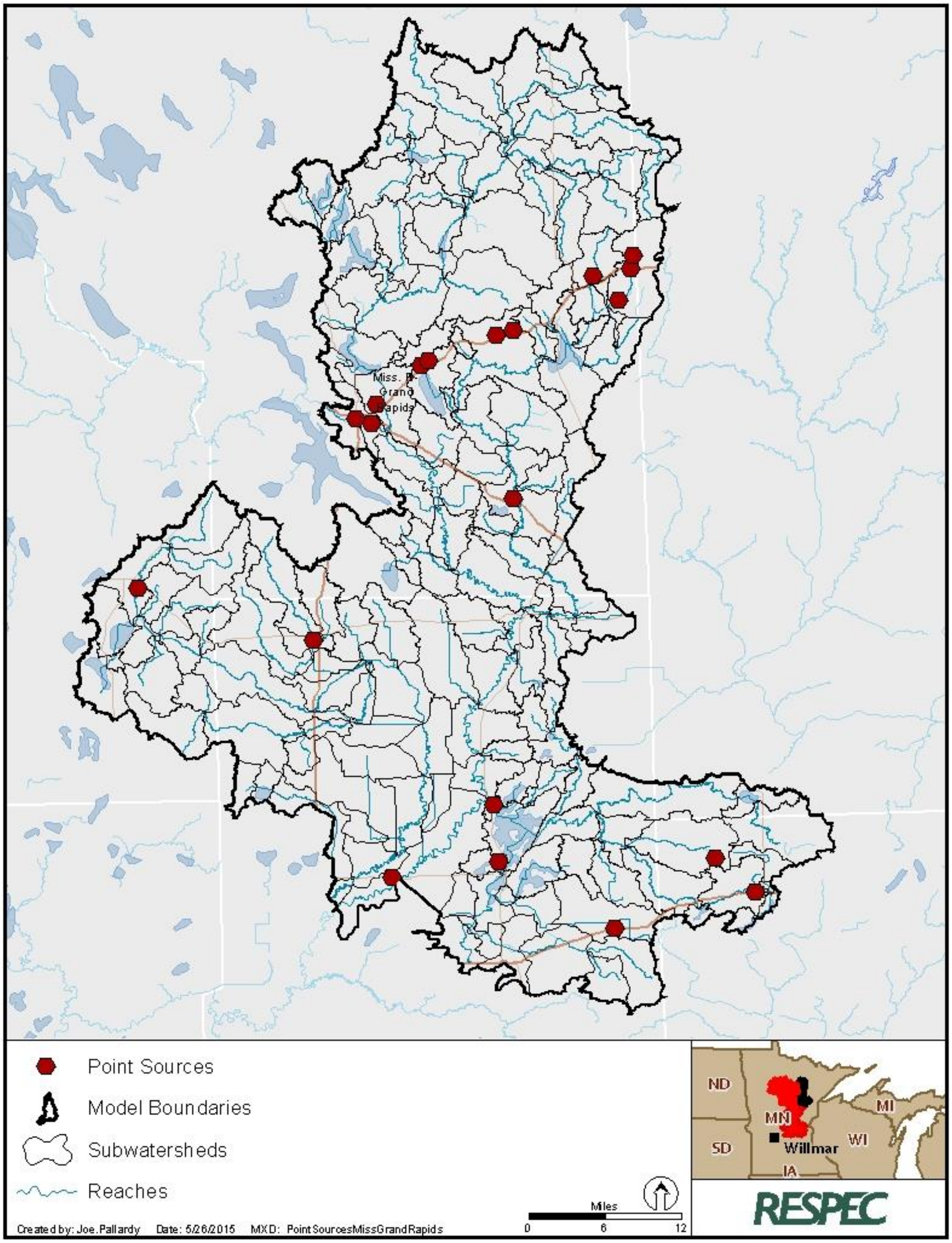


Figure E-4. Point-Source Locations in the Mississippi River–Grand Rapids Watershed.

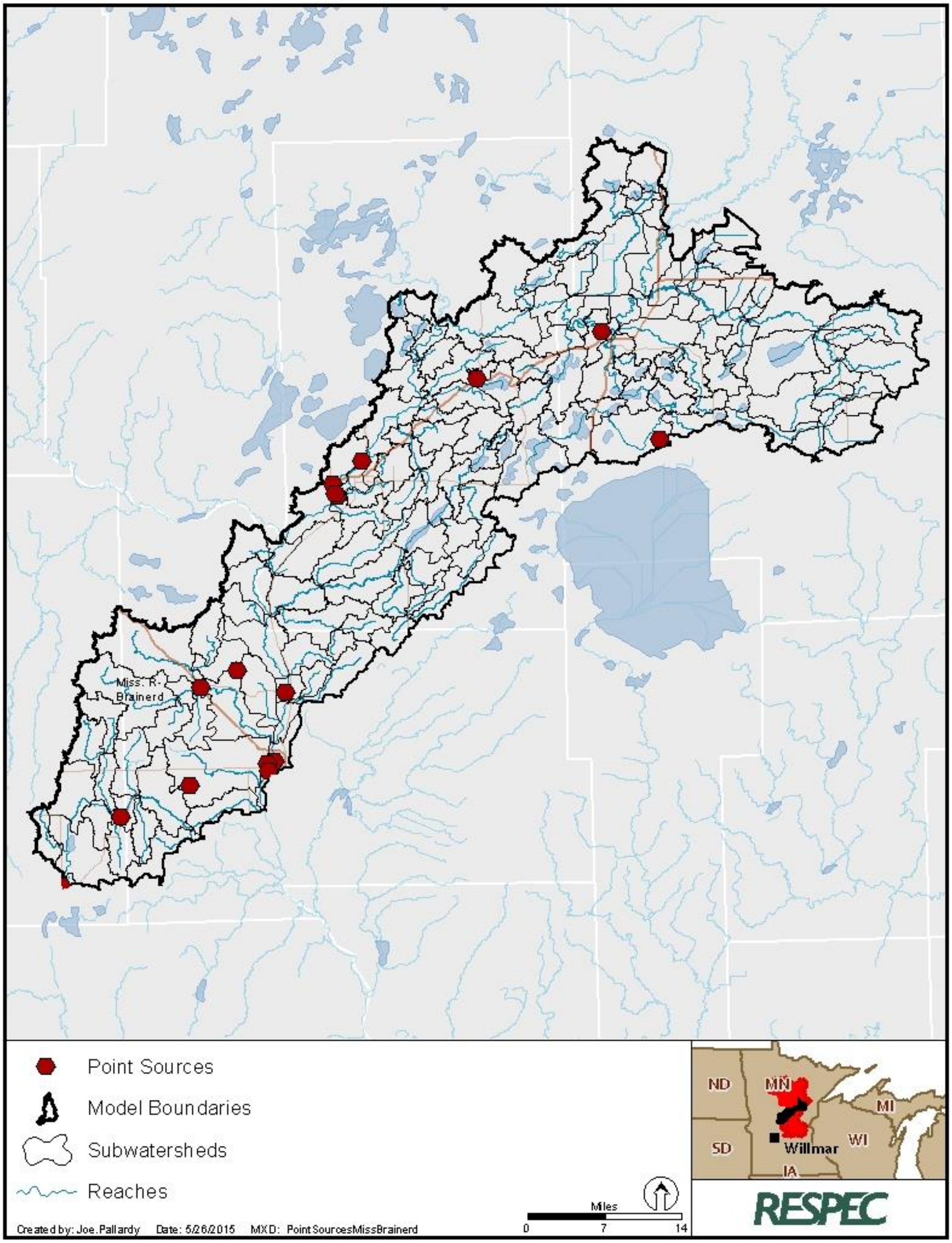


Figure E-5. Point-Source Locations in Mississippi River–Brainerd Watershed.

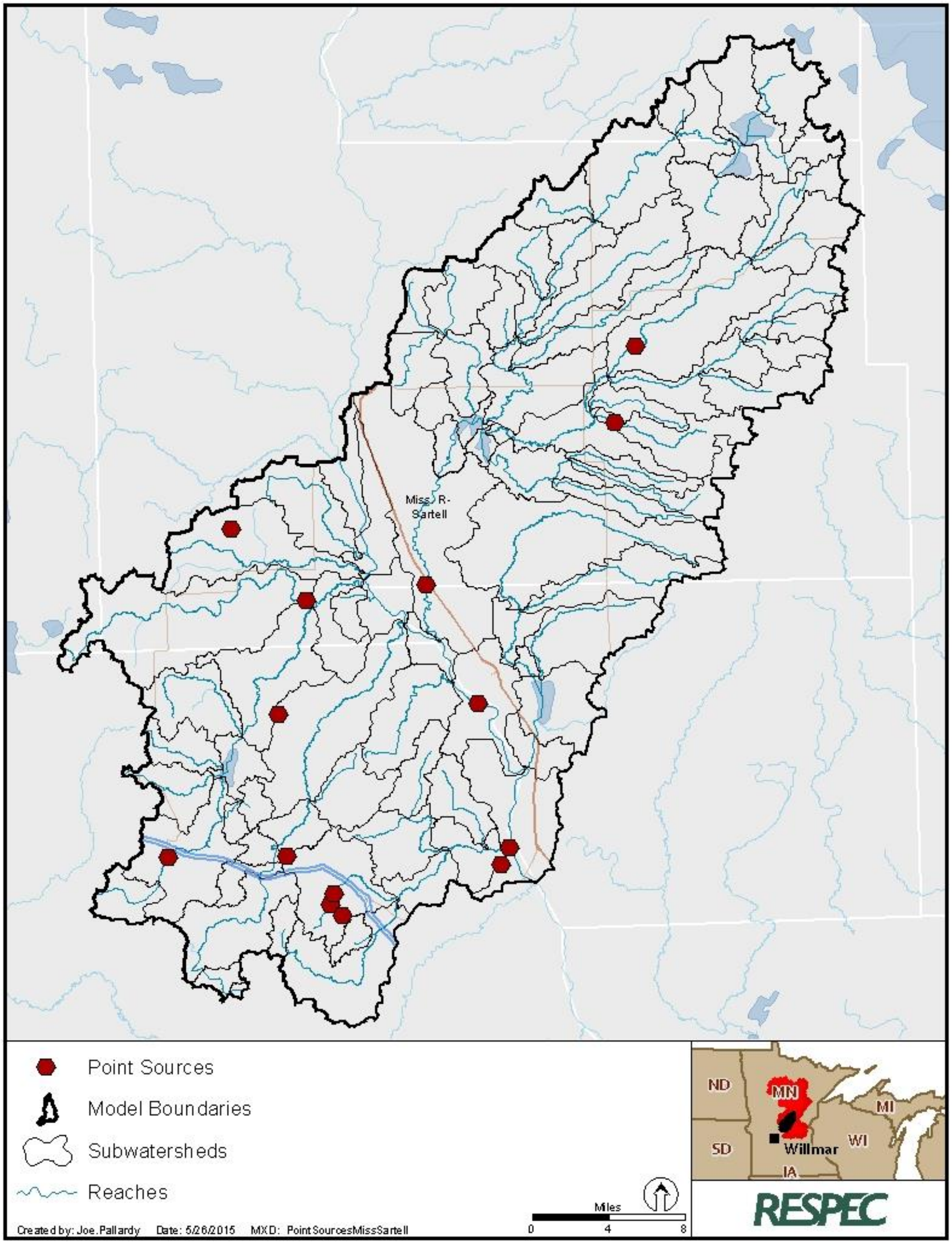


Figure E-6. Point-Source Locations in Mississippi River–Sartell Watershed.

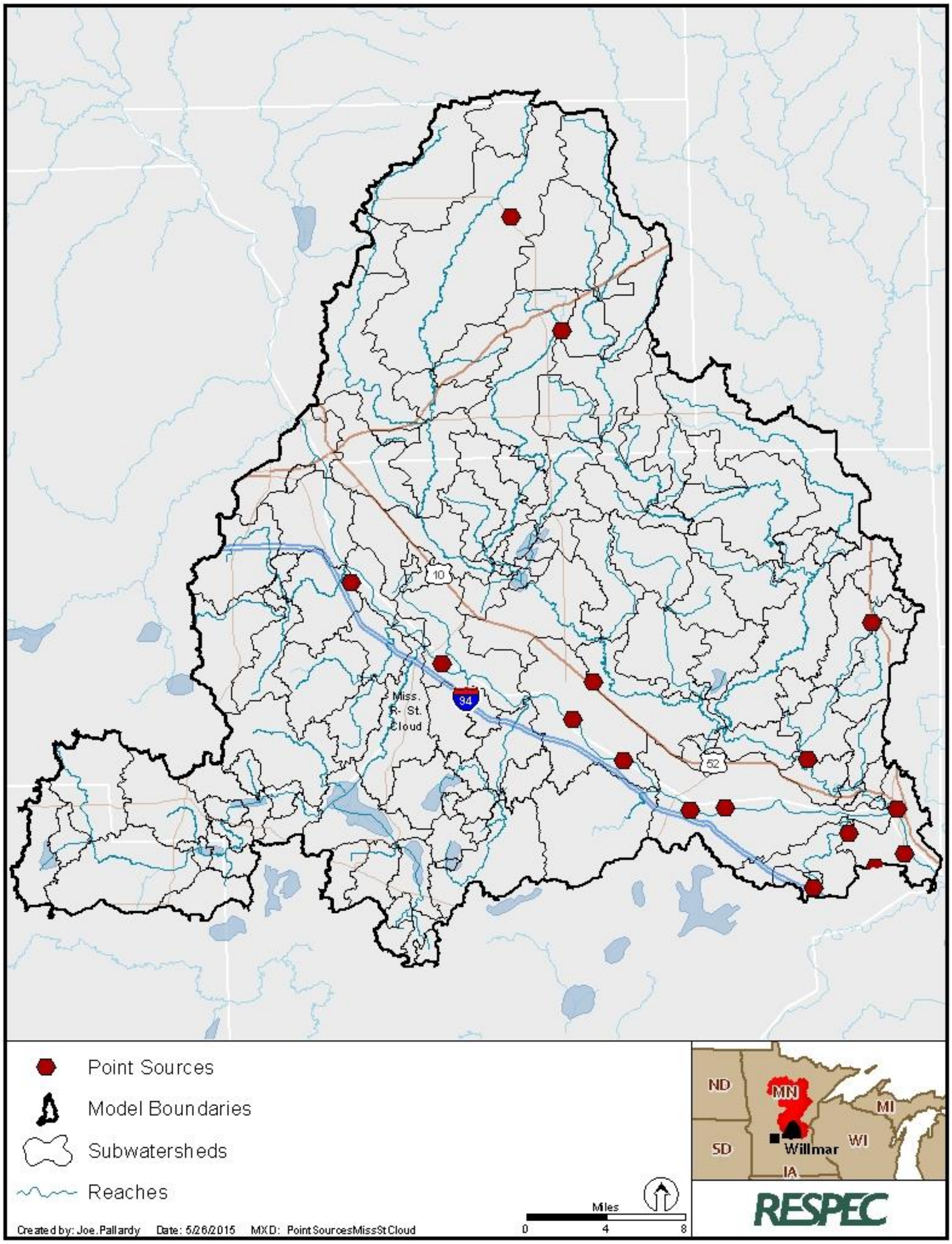


Figure E-7. Point-Source Locations in the Mississippi River–St. Cloud Watershed.

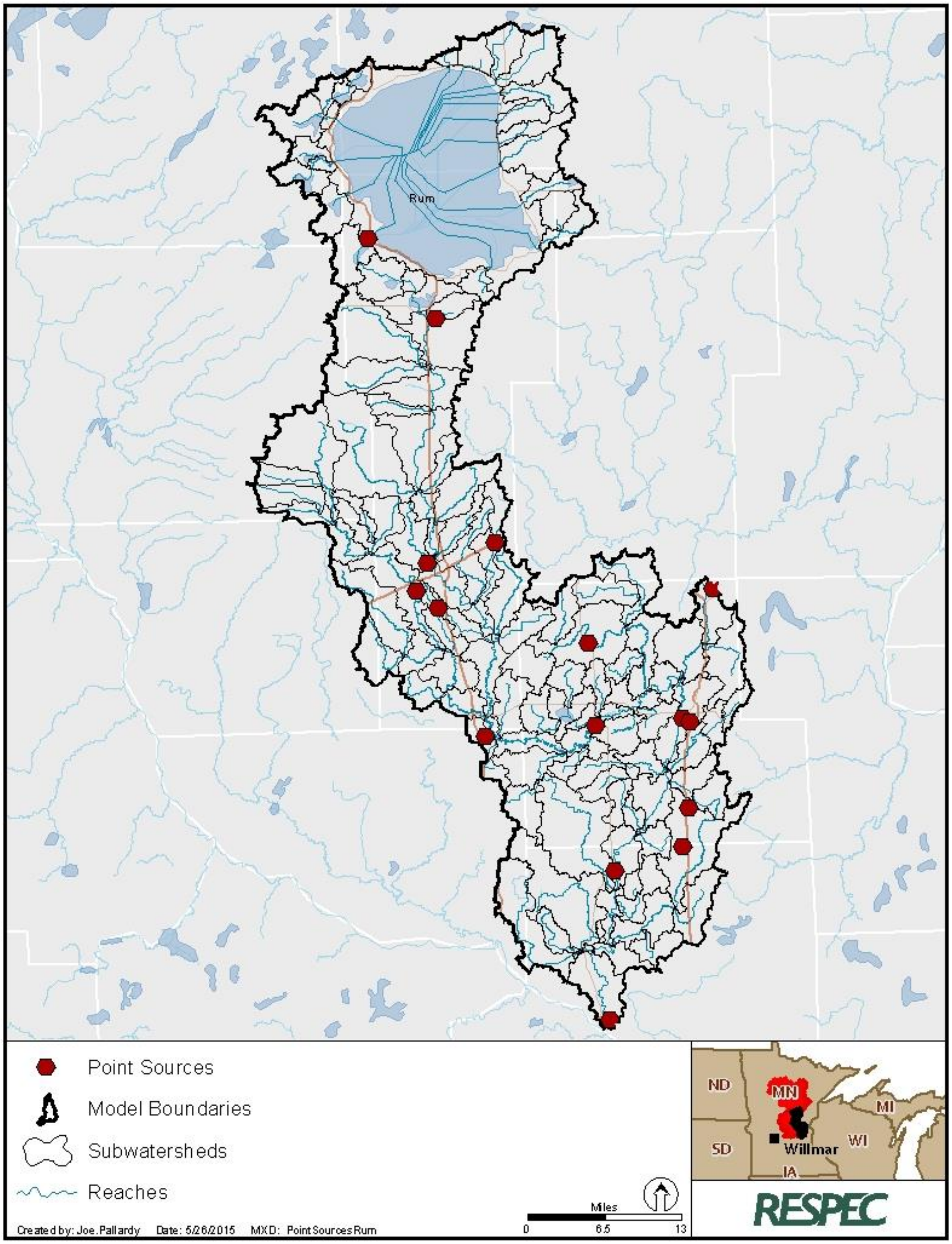


Figure E-8. Point-Source Locations in the Rum River Watershed.