June 20, 2013

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

Dear Dr. Regan:

RE: Model Development for Mississippi River Headwaters (07010101), Leech Lake River (07010102), and Pine River Watersheds (07010105)

The methodology documentation the developing the User Control Input (UCI) and Watershed Data Management (WDM) files for the Mississippi River Headwaters, Leech Lake River, and Pine River Watersheds **HSPF** model applications is completed for your review. The methodology include the following:

- Subwatershed delineation and primary reach selection
- Lake selection
- Reach/subwatershed numbering scheme
- Lake and stream F-table development
- Time-series development
- Pervious (PERLND) and impervious (IMPLND) category development.

Each of these items is discussed below.

SUBWATERSHED DELINEATION AND PRIMARY REACH SELECTION

This section describes the procedures followed for the delineation of subwatersheds and selection of primary reaches to be explicitly modeled in the Mississippi River Headwaters, Leech Lake River, and Pine River Watershed **HSPF** model applications. A Geographic Information System (GIS) map was created containing the following data layers: Minnesota Department of Natural Resources (MN DNR) Level 7 and Level 8 watersheds, National Hydrography Dataset (NHD) flowlines and waterbodies, draft 2012 impaired streams and lakes, 2010 Minnesota assessment streams and waterbodies, monitoring site locations, a Digital Elevation Model (DEM), and an imagery basemap. The data were used to delineate the model subwatersheds and define the primary reach network.

In the model applications, each subwatershed typically corresponds to only one reach (stream segment or lake), and subwatersheds were defined to consider not only the drainage network but also the locations of impaired streams and lakes and the available monitoring data. These were used as the basis for the **HSPF** model subwatersheds layer and adjusted as needed. MN DNR Level 7 watersheds were used rather than the U.S. Geological Survey (USGS) Hydrologic Unit Code-12 (HUC12) watersheds, because they provided more detailed breaks and minimized further processing. When a discharge or water-quality data station or an impairment endpoint occurred within a Level 7 watershed boundary, the basin was divided into two subwatersheds using the MN DNR Level 8 watersheds, DEM, and imagery basemap.

The NHD flowlines layer and the **ArcHydro** toolbar were used to create the primary reach network. The primary reach layer was edited using the DEM and imagery basemap. A continuous reach that connects the upstream and downstream subwatersheds typically was chosen as the primary reach to be modeled. Thus, if the stream passed through only the corner of the subwatershed, as shown in Figure 1, but influenced upstream and downstream connectivity, it was selected as the primary reach. This process ensured that mainstem reaches (i.e., the Mississippi, Leech Lake, and Pine Rivers) and major tributary reaches were always selected to be explicitly modeled. In headwater subwatersheds, the longest, continuous drainage pathway connected to the downstream subwatershed was selected as the primary reach. Because impaired streams are assumed to be the highest priority, selecting these streams took precedence over 2010 assessment streams, regardless of their length. Similarly, selecting 2010 assessment streams took precedence over all nonimpaired streams, regardless of their length. Finally, if the subwatershed was a watershed for an impaired lake, the stream flow through the lake was selected as the primary reach.

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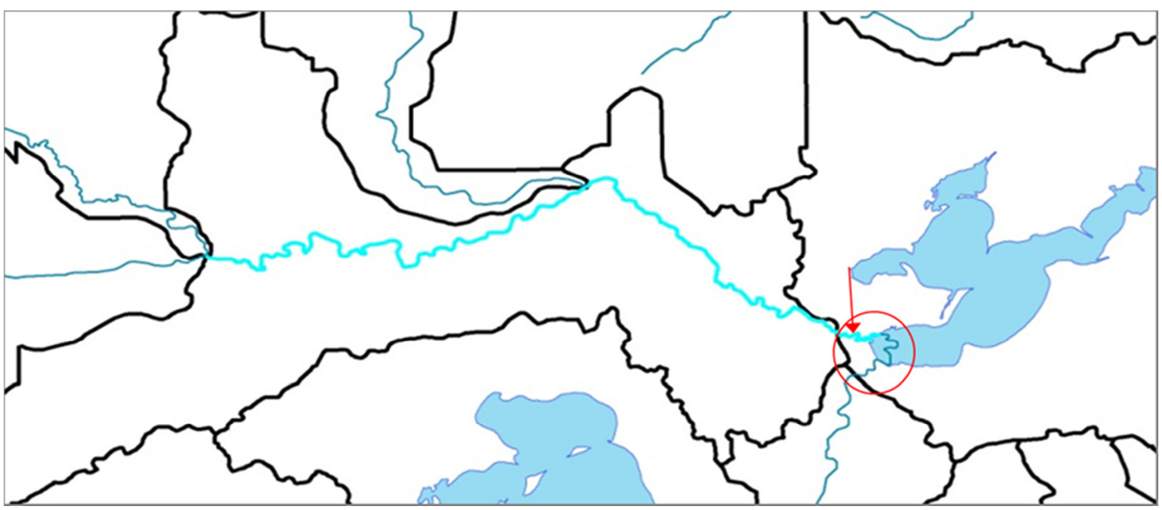

Figure 1. Reach Passing Through a Small Portion (Circled) of Subwatershed and Extended Reach in a Lake Watershed (Arrow).

Reach length and slope are required to determine physically based parameters in the model application and to develop the function tables (F-tables, which are described in a later section). These were calculated using **ArcGIS** for all nonlake reaches. Generally, if a reach upstream or downstream of a lake crossed a subwatershed by a substantial distance (greater than approximately 0.1 mile), that reach was extended into that upstream or downstream subwatershed to avoid stream-length misrepresentation (Figures 1 and 2). Reaches representing a modeled lake were given a length of zero and a slope of one. All lakes chosen to be explicitly modeled were assumed to have an outflow; however, this can be easily changed during calibration if any of the modeled lakes are determined to have an isolated drainage area.

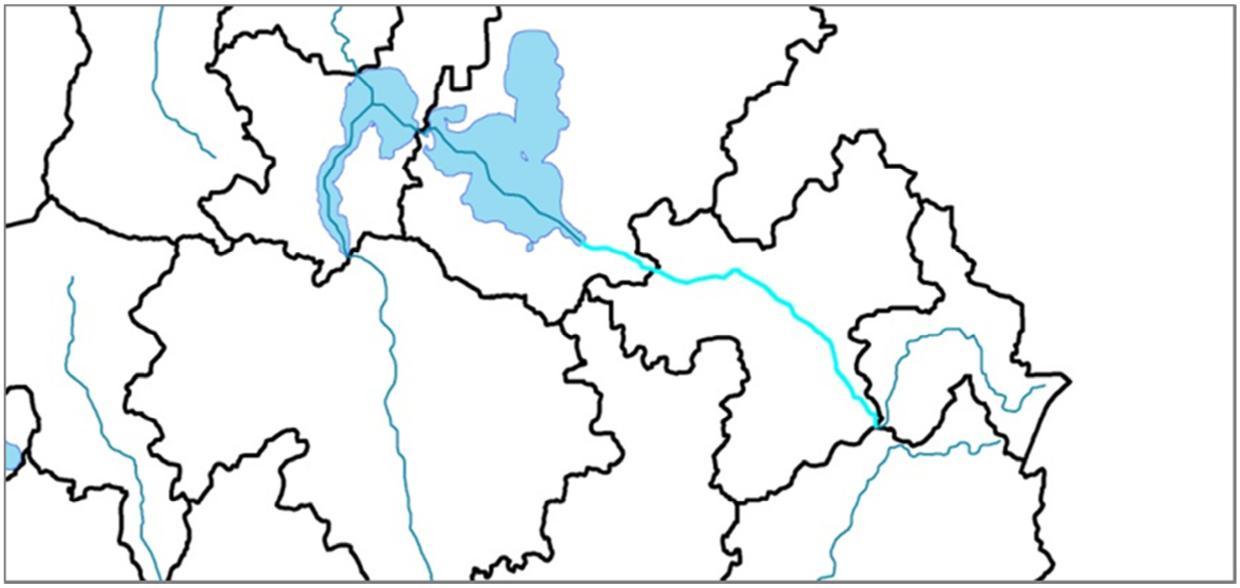

Figure 2. Extended Reach in a Lake Watershed.

LAKE SELECTION

The draft 2012 Minnesota-impaired lakes and wetlands shapefile was supplemented with the 2010 Minnesota Pollution Control Agency (MPCA) Assessment Lake GIS layer and the NHD waterbodies GIS layer. These combined layers resulted in 3,524 waterbodies (wetlands, swamps, and lakes); 2,368 were classified as a lake, pond, or reservoir.

Figure 3 is a schematic of the lake selection. The following 91 lakes were selected to be explicitly modeled:

- Lakes that are impaired for aquatic recreation because of high nutrients (six lakes). The model does not need to include mercury-impaired lakes because the dominant source (99 percent) of mercury is atmospheric deposition [Minnesota Pollution Control Agency, 2007[1]] (i.e., not watershed-related).
- Lakes with a surface area greater than 500 acres (78 additional lakes). Lakes greater than 500 acres are likely to have the largest impacts on the hydrology of the three watersheds.

1 **Minnesota Pollution Control Agency, 2007.** *Minnesota Statewide Mercury Total Maximum Daily Load*, wq0iw4-01b, prepared for Minnesota Pollution Control Agency, St. Paul, MN.

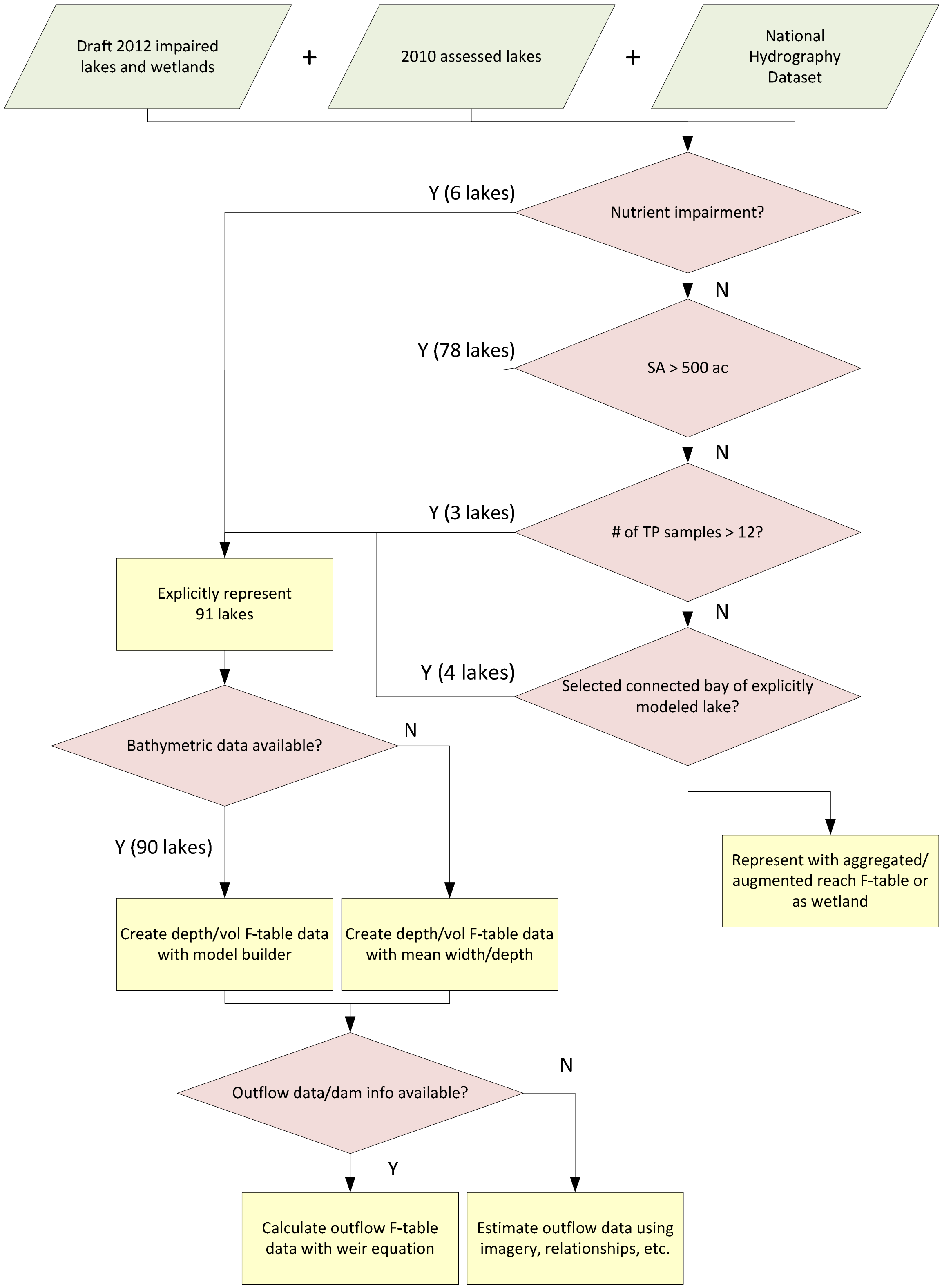

Figure 3. Lake Selection Schematic.

- Lakes with more than 12 growing-season total phosphorus samples collected (three additional lakes). The availability of 12 or more growing-season total phosphorus samples serves as a surrogate for public interest in a given waterbody.
- Selected lakes that are hydrologically connected bays of an explicitly modeled lake (four additional lakes).

Bathymetric data are available for 90 of the 91 lakes chosen to be explicitly modeled; **ModelBuilder** (see the section on F-table development) was used for these lakes to create the depth and volume data required for the F-table. The mean depth and width of the one lake without bathymetric data (Sugar Lake, 31-0926-00) was used to determine the lake volume, which will be represented in the F-table. Lakes that are not being explicitly modeled will either be represented with aggregated/augmented reach F-tables or will be modeled as wetlands.

REACH/SUBWATERSHED NUMBERING SCHEME

This section describes the numbering scheme used for the watershed drainage network, as shown in the reach I.D. numbering schematic illustrated in Figure 4. Reach I.D.s consist of one to three numeric digits. Mainstem reaches along the Mississippi River Headwaters, Leech Lake River, and Pine River were given I.D.s that end in zero (##0). Reaches were assigned an odd 10s digit (middle number) if they represented a stream segment (e.g., 110, 130, 150, and 190 in the schematic) and an even 10s digit if they represented a lake (e.g., 120 and 160 in the schematic). Tributaries were assigned an odd reach I.D. for the 1s digit (end number) if they represented a reach (e.g., 141, 143, and 153 in the schematic) and an even number if they represented a reservoir (e.g., 142 in the schematic). The 10s digit of the tributary reach I.D.s corresponds with the downstream mainstem reach I.D. (e.g. 111 and 113 flow into 120).

Overall, subwatersheds and reaches were numbered in order, beginning with low I.D. numbers upstream and ending with high I.D. numbers downstream. If the logical next-down mainstem reach I.D. was not used, then the downstream reach was given the next largest mainstem reach I.D. For example, in Figure 4, downstream of Mainstem Reach 160, six nonlake tributary reaches (e.g., 171, 173, 175, 177, 179, 183) flow into Mainstem Reach 190. Each subwatershed typically contained only one reach and was given the corresponding reach I.D. In the case that a subwatershed will be modeled with both a reach and a reservoir, the reach I.D. of the dominant feature was given (e.g., 102 and 151 of the numbering schematic). If the dominant feature is a reach (e.g., 151), then the model will route the subwatershed's overland flow into the reach, then to the downstream lake. If the dominant feature is a lake (e.g., 102), then the model will route overland flow into the lake, and then to the downstream reach. A total of 296 subwatersheds and 339 reaches were delineated, and these are illustrated in Figure 5.

Two separate models are being developed: one for the Mississippi River Headwaters and Leech Lake River (which flows into the Headwaters) and one for the Pine River Watershed, which is hydrologically separate. The reach and subwatershed numbering scheme reflects these separate models; distinct numbering schemes were used for the two models.

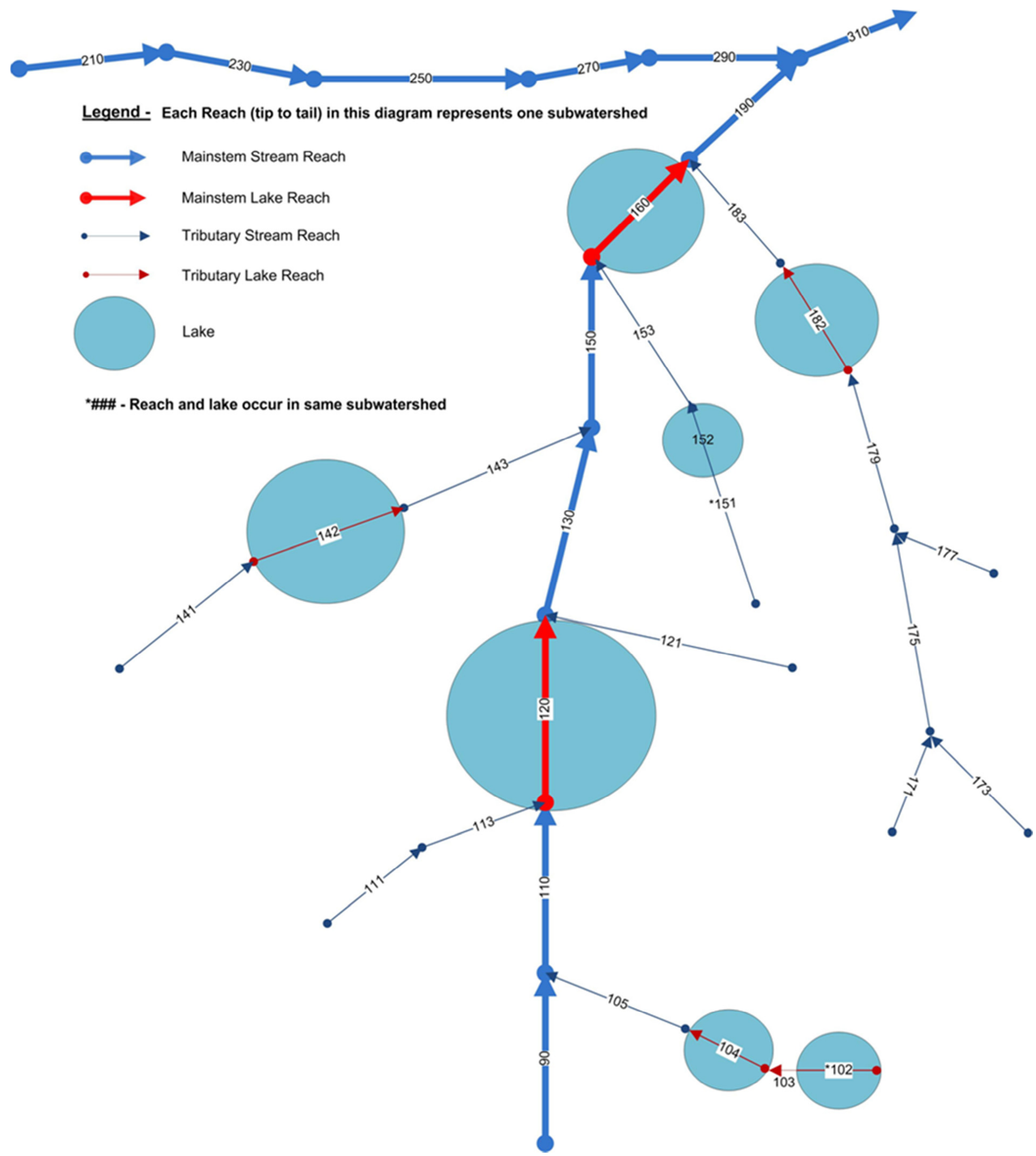

Figure 4. Reach Numbering Schematic.

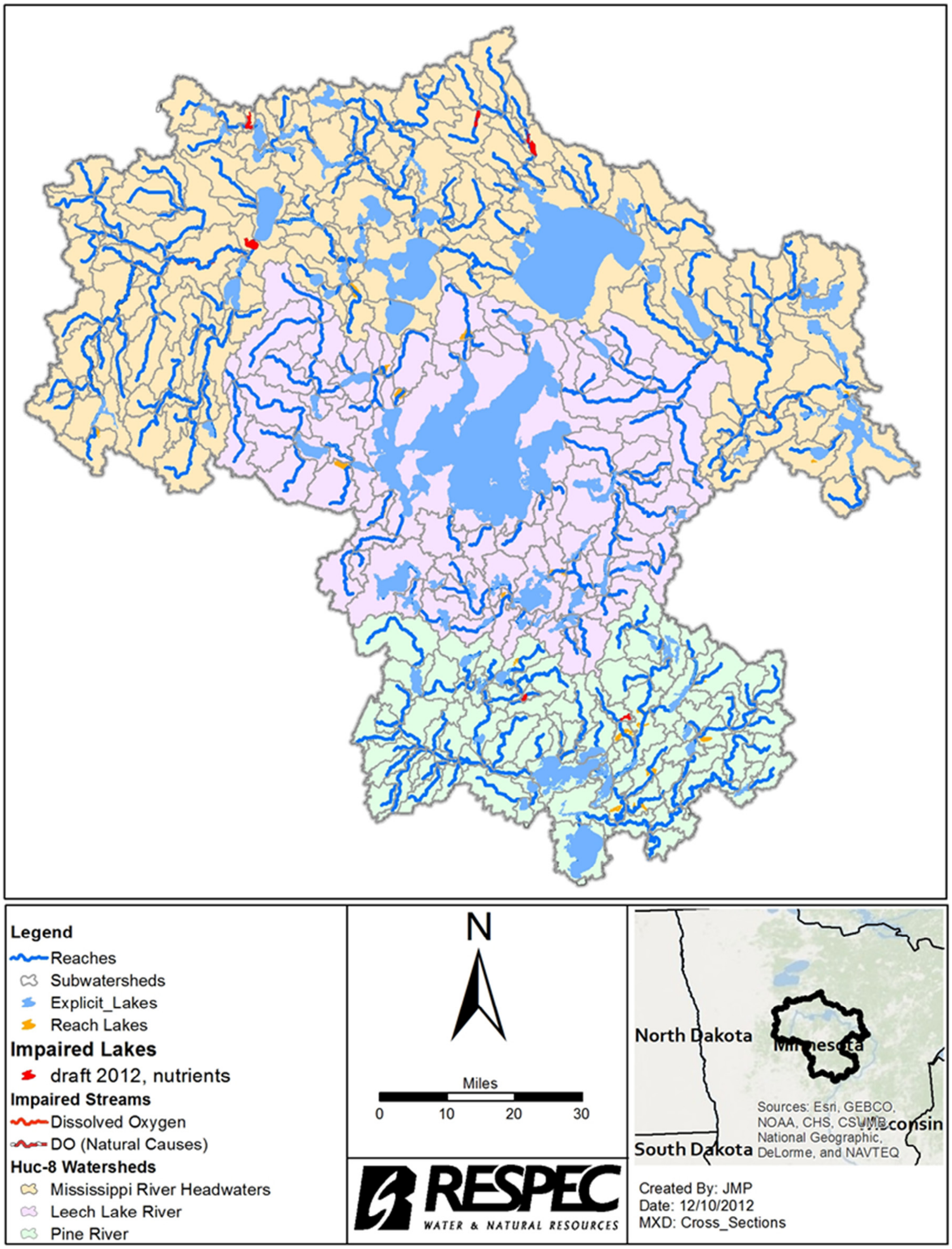

Figure 5. Mississippi River Headwaters, Leech Lake River, and Pine River Watersheds Subwatershed Boundaries.

LAKE AND STREAM F-TABLE DEVELOPMENT

This section describes the development of function tables (F-tables), which are used by the **HSPF** model to route water through each modeled reach (lake or stream). An F-table summarizes the hydraulic and geometric properties of a reach and is used to specify functional relationships among surface area, volume, and discharge at a given depth. Essentially, it can be thought of as an extended rating curve for either a lake or a stream.

Data for lake F-table calculations included surface area and volume at a variety of water elevations (depths), overflow information (spillway width and runout elevation), and discharge, if applicable. Ninety-one lakes were selected to be explicitly modeled in the Mississippi River Headwaters (40), Leech Lake River (25), and Pine River (26) Watersheds based on management priorities, lake size, and data availability. The locations of the explicitly modeled lakes are illustrated in Figure 5. Surface area, volume, and depth data were supplied as GIS contour layers by the MN DNR for all but one of the explicitly modeled lakes. Spillway length, height above sill, and lake runout elevation data were obtained from the National Inventory of Dams dataset, the MN DNR State Dam Inventory, the MN DNR staff, and the Chippewa National Forest staff. However, these data were only available for a subset of the modeled lakes, and overflow information was largely unavailable. Because of the paucity of data, the models were created using average values for spillway lengths and height above sill when no reference data were available. This level of detail is sufficient for the purposes of this model. If additional data become available, it will be incorporated into the existing model application.

The equations used to calculate flows from lakes at different water elevations and any assumptions made are discussed below. For simplicity and because of the lack of overflow data, the equation of discharge for overflow spillways was used to calculate discharge from lakes (Equation 1). Because of the large scale of this project, coefficient correction factors for all overflow calculations were not used, and side contractions of the overflow as well as approach velocity have been neglected, which allows the equation in to be used its simplest form:

$$Q = C \times L_e \times H^{1.5} \tag{1}$$

where

$$Q = \text{discharge } \left(\text{cubic feet per second } (\text{cfs})\right)$$

$$H = \text{water depth above weir } \left(\text{head } (\text{feet})\right)$$

$$L_e = \text{effective length of crest } (\text{feet})$$

$$C = \text{variable coefficient of discharge.}$$

The total head (H) used in the equation was calculated at variable water levels as the difference between water surface and outlet elevations. The outlet was assumed to be at the maximum recorded depth (if available) or the maximum contour depth. The effective length of the crest (L_e) was derived from the spillway length obtained from either the National Inventory of Dams dataset or the MN DNR State Dam Inventory. When a spillway length was not available, the median length of all available sites was assumed. At lake depths below the outlet,

L_e was set equal to the spillway length. At lake depths above the outlet, L_e varied as a function of depth and was increased, assuming a 0.02 flood plain slope at each end of the crest. The variable coefficient of discharge (C) was calculated using an empirical relationship derived by plotting x-y points along a basic discharge coefficient curve for a vertical-faced section with atmospheric pressure on the crest from the U.S. Bureau of Reclamation[2] (Equation 2):

$$C = 0.1528 \times In\left(\frac{P}{H_d}\right) + 3.8327 \tag{2}$$

where:

$P =$ crest Height (feet)

$H =$ head (feet).

The crest height (P) was assumed to be the height above sill, which was available from the MN DNR State Dam (inventory) dataset. The head (H_d) varied with the water surface and was calculated as described previously. When the height above sill was unavailable, the mean value from all available sites was assumed.

After all of the available data were collected and combined, an F-table was developed for each lake by calculating the surface area, volume, and discharge over a range of depths. F-tables for lakes with contour data were created using the depths, surface areas, and volumes calculated with the Bathymetry Volume and Surface Area **ArcGIS ModelBuilder** tool. This tool created a separate triangulated area network (TIN) for each lake on which a “Surface Volume” tool was used to calculate the area and volume below specified depths. The F-table for the lake without contour data was developed using the calculated surface area, volume, and depth relations. The volume and surface area at incremental depths were estimated using conical geometry and assuming a flat bottom for an inner circle with half the radius of the maximum surface area. The highest contour (if available) or maximum depth was assumed to be the outlet. Depths were added incrementally above the outlet until the F-table discharge exceeded the maximum observed discharge levels. The surface area and volume above the outlet were calculated using conical geometry with an assumed floodplain slope of 0.01. The discharge at each height above the outlet was calculated using Equations 1 and 2. The discharge values at depths at or below the outlet were zero. The assumed value of the floodplain slope is arbitrary and can be easily adjusted during the calibration process. A similar data-compilation process was completed for reach-intersecting lakes that were not chosen to be explicitly modeled or to be represented as wetlands and is discussed further in the stream F-tables section.

Data requirements for stream F-table development included cross-section and discharge measurements (Figure 6). A total of 85 cross-section measurements were obtained from the following sources:

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2 **U.S. Bureau of Reclamation, 1987.** *Design of Small Dams,* 3rd Edition, U.S. Department of Interior, Washington, DC.

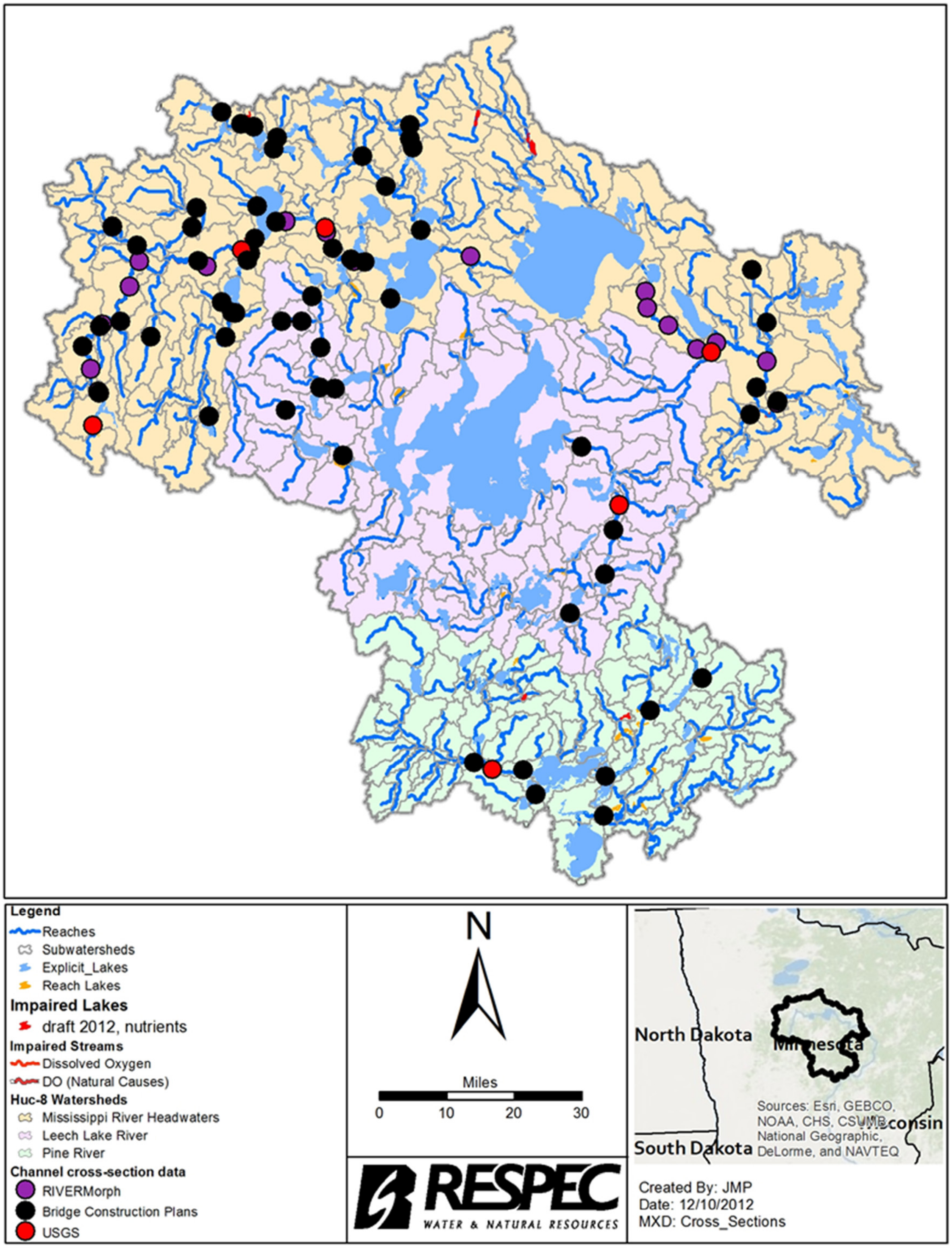

Figure 6. Locations of Lake and Cross-Section Data Used to Develop Model F-Tables.

- Minnesota Department of Transportation bridge construction plans: MN DNR area hydrologists provided Minnesota Department of Transportation bridge construction plans from Beltrami, Cass, Clearwater, Crow Wing, Hubbard, and Itasca Counties. The bridge plans included scanned images of channel cross sections sketched on gridded paper upstream and downstream of bridge locations. Some of the cross sections were provided directly by the Beltrami County staff.
- Width, depth, and area measurements taken at USGS monitoring sites: The USGS maximum width, depth, and area data were used to calculate cross sections that assumed a trapezoidal channel and a bank slope of 1/3.
- Stream morphology, longitudinal profile, and channel cross-section data extracted from **RIVERMorph** model application files: Data had been collected by the Minnesota Department of Natural Resources for fisheries and habitat assessments on the Mississippi River.

After each reach was assigned the most appropriate cross section based on location and drainage area, discharge was calculated for each reach using length, slope, and data geometry with the Manning's equation shown in Equation 3. Channel slope (*S*) for each reach was calculated by dividing the difference between the maximum and minimum elevations by the reach length.

$$Q = \frac{1.486}{n} \times A \times R^{2/3} \times S^{1/2} \tag{3}$$

where:

$Q = \text{discharge (cfs)}$

$n = \text{Manning's roughness coefficient}$

$A = \text{cross-section area (square feet)}$

$R = \text{hydraulic radius (feet)}$

$S = \text{channel slope.}$

Manning's roughness coefficients (*n*) of 0.035 and 0.045 were used for the channel and floodplain, respectively. The values for the floodplain slope, channel slope, Manning's roughness coefficient, and horizontal bank extension length were defined based on local topography and using best engineering judgment; the values can be easily adjusted during the calibration process. Once all required data were collected and compiled, an F-table was developed for each reach by calculating the surface area, volume, and discharge over a range of depths. To allow the F-table to handle large storm flows, the cross section was extended 1,000 feet horizontally beyond each bank. The floodplain slope was assumed to be 0.05. The volume and surface area were calculated with the cross sections and stream segment lengths.

TIME-SERIES DEVELOPMENT

This section describes the procedures used to create the WDM file that is accessed directly by **HSPF** during a model simulation. The following data were loaded into a WDM file:

- Meteorological data to drive the **HSPF** model application were obtained from the U.S. Environmental Protection Agency's (EPA's) **BASINS** system, and extensive supplementary HIgh spatial DENsity (HIDEN), daily observations precipitation data were provided by the MPCA.
- Observed discharge time-series data were obtained from the USGS gaging stations, the U.S. Army Corps of Engineers reservoir gaging stations, and the MN DNR/MPCA cooperative stream gaging stations for comparison to simulated discharge during model calibration. Data at six of the sites will be used for flow calibration; time-series data at these sites were assigned to the corresponding reach and loaded into the WDM file. Discharge data at an additional site (Cross Lake outlet) were used as model input (as opposed to being used for model calibration) and were added to the WDM file; discharge at this site is controlled and will not be modeled.
- Point-source data from facilities discharging within the watershed will be provided by the MPCA and loaded into a point-source WDM file.

One WDM file contains both the meteorological and calibration time-series data; the WDM was developed to store observed data and the model outputs to facilitate model calibration. Minimal processing was required for the observed discharge data. Processing the meteorological data was more intensive and is detailed below.

The **BASINS** system provides all meteorological time-series data in a WDM file that is specific to each station and constituent, including air temperature (ATEM), cloud cover (CLOU), dew point temperature (DEWP), precipitation (PREC), potential evapotranspiration (PEVT), solar radiation (SOLR), and wind movement (WIND). These data were preprocessed into hourly time series by AQUA TERRA Consultants for the **BASINS** stations that were selected in the model application. PREC and PEVT are the minimum requirements to drive the model; however, hydrologic processes to be represented within the model applications require all of the time-series data listed above. Hourly Penman Pan evaporation was obtained by loading hourly time series data from two selected **BASINS** stations into the WDMutil and aggregating these data to calculate daily PEVT as a function of minimum and maximum daily ATEM, mean daily DEWP, total daily WIND, and total daily SOLR. The data were then disaggregated back to hourly time-series (Figure 7). Pan evaporation is converted to potential evapotranspiration in the external sources block of the UCI (where model inputs are called and distributed) using a factor of 0.79, which was derived from the NOAA Evaporation Atlas. Additionally, the hydrologic processes within the modeled area are greatly influenced by snow accumulation and melting. **HSPF** uses ATEM, DEWP, WIND, SOLR, and CLOU to calculate snow processes using an energy balance method. Although there is an option to compute snow processes based on temperature alone, the data needed for the more accurate energy balance method were available and complete for the simulation time period.

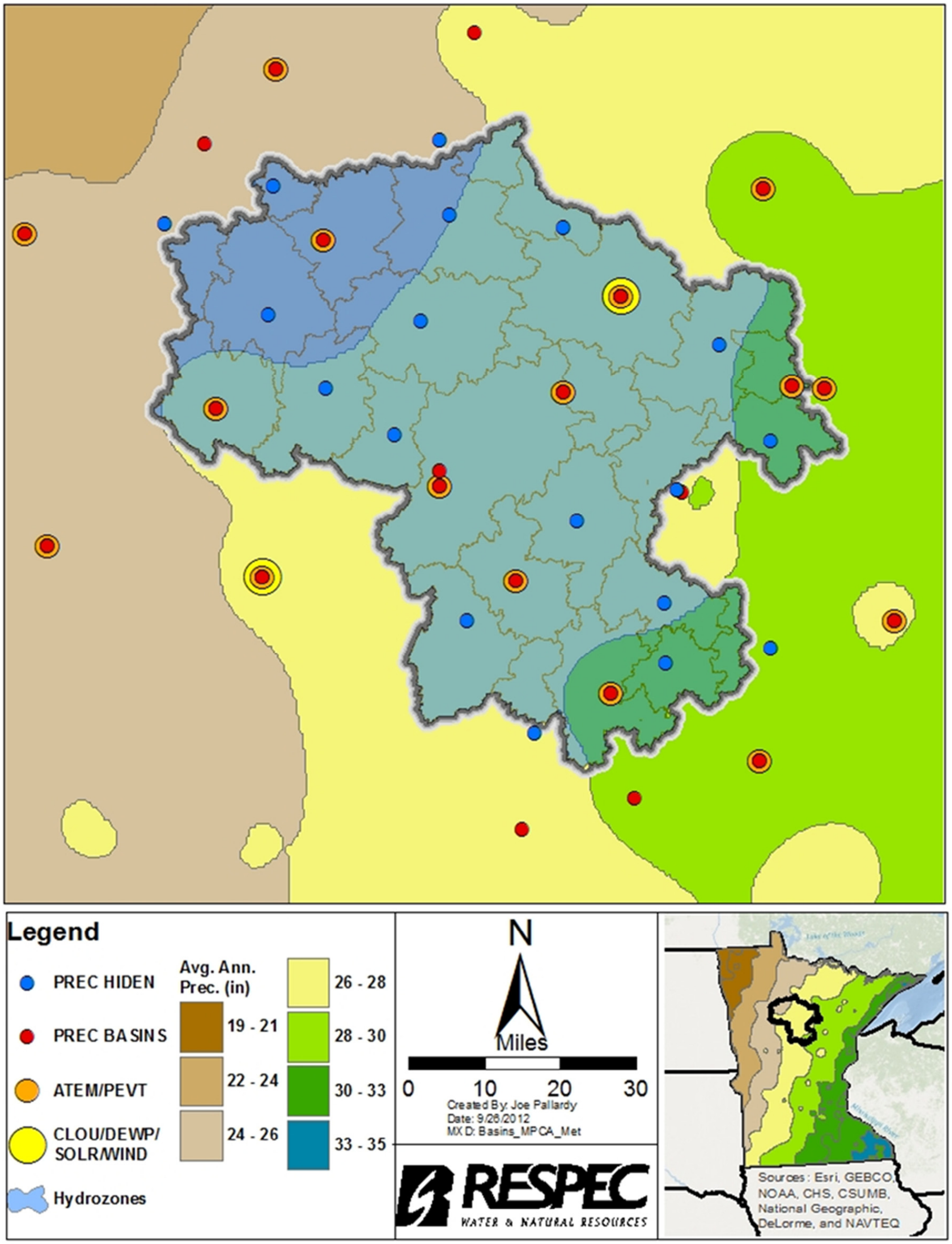

Figure 7. BASINS and HIDEN Meteorological Stations, PRISM Precipitation Distribution.

PREC time-series data were obtained through a combination of BASINS and HIDEN stations selected to provide comprehensive spatial coverage of the modeled area. The area was divided into hydrozones to account for the precipitation distribution within the watersheds. To verify that the defined hydrozones captured regional precipitation patterns, the average annual precipitation over the study period within each hydrozone was compared to a gridded average annual precipitation dataset that was created using Oregon State University's Parameter-Elevation Regression on Independent Slopes Model (PRISM) climate mapping system. BASINS stations were selected based on the availability of the required meteorological data and their proximity to the project area while HIDEN stations were chosen to fill spatial precipitation data gaps based on location and period of record. Preference was given to HIDEN stations with a complete period of record and minimal missing data. Stations with an incomplete period of record were extended through the entire modeling period using available data from the nearest station. Missing data and accumulated values from the HIDEN stations were filled or disaggregated using data from the closest station available, including the BASINS stations. Daily HIDEN PREC time series were loaded into a WDM file and disaggregated into hourly time series with WDMutil using the daily precipitation distributions of the five closest BASINS stations as follows: if the daily totals of the hourly PREC of any of the BASINS stations were within 90 percent of the daily PREC of the station to be disaggregated on a given day, then the station's daily PREC was disaggregated according to the hourly distribution of the nearest BASINS station. Otherwise, the station's daily PREC total was disaggregated using a triangular distribution with the peak in the middle of the day. A data tolerance of 90 percent was used to maximize the use of available hourly PREC data and because of the inaccuracy of the triangular distribution method. The overall average distance from a station used to fill missing data was approximately 5 miles, while the average distance to a disaggregation station was approximately 20 miles. The disaggregated/filled HIDEN daily PREC time series used 26 unique PREC base stations (18 HIDEN and 8 BASINS) to provide comprehensive, spatial coverage of the watersheds (Figure 7).

PERLND AND IMPLND CATEGORY DEVELOPMENT

This section describes determining the selected PERLND and IMPLND land use categories for explicit representation in the model applications. The PERLND and IMPLND blocks of the UCI file contain the majority of the parameters that describe the way water flows over and through the watershed. Therefore, the objective of this task was to separate the watershed into unique land segments using physical watershed characteristics to effectively represent the variability of hydrologic and water-quality responses in the watershed. The primary watershed characteristics selected for PERLND and IMPLND categories included drainage patterns, meteorological variability, land cover, soil properties, and agricultural practices. These characteristics were selected based on the significance of their influence on hydrologic processes and water-quality constituents of interest as well as the quality and availability of spatial data associated with the characteristics.

Delineation of model subwatersheds based on drainage patterns allowed for the contributing area of each uniquely represented pervious or impervious land segment within each subwatershed to be linked to the appropriate reach section in the schematic block of the UCI file. Aggregating the subwatersheds into hydrozones based on meteorological variability and station distribution provided initial boundaries for the pervious and impervious land segments and accurately represented the hydrologic processes while reducing computational demands. Procedures for determining the PERLND and IMPLND categories within each hydrozone are described below.

The National Land Cover Datasets (NLCD) were the sources of the land cover distribution used for this modeling effort and supplied the basis for the PERLND and IMPLND classification within each hydrozone. Land cover identification is necessary because the movement of water through the system (i.e., infiltration, surface runoff, and water losses from evaporation or transpiration) is significantly affected by the land cover and associated characteristics. In addition, characteristics such as manure application and other anthropogenic practices, which clearly impact the accumulation of pollutants such as sediment, bacteria, and nutrients, can be represented within land cover classes. Because of the length of the simulation period (1995–2009), it was preferable to represent the changes in land cover over time by incorporating both the updated NCLD 2001 version 2 and the NLCD 2006 in the PERLND and IMPLND development process. The NLCD 1992 was disregarded because it was based on Landsat images from years outside of the simulation period. In addition, Multi-Resolution Land Characteristics Consortium (MRLC) discourages direct comparisons of the NLCD 1992 to later versions because of the differences in image processing techniques. Therefore, the NLCD 2001 was used to represent the early portion of the simulation period (1995–2003), and the NLCD 2006 was used for the remaining portion (2004–2009).

Comparing the 2001 and 2006 NLCDs revealed large-scale differences in the areas of the forest categories and the woody wetland category, as provided in Table 1. These differences appear to be too large-scale to represent actual land cover change on the landscape. (When the forest categories were combined with the woody wetland category, less than 1 percent change in the total forested area observed between 2001 and 2006.) Throughout the watershed, the areas designated as woody wetland are slightly larger in the 2006 NLCD as compared to 2001. Even though these differences may not accurately represent the landscape, other real land cover changes are likely represented in the dataset (e.g., decreases in cover crops and increases in developed land). The current plan is to use the NLCD 2001 for a portion of the simulation period from 1995–2003 and use NLCD 2006 for the remaining portion from 2004–2009. During the hydrologic calibration process, if one land cover file leads to a better calibration, that file may be used for the entire simulation period. Because the apparent changes in forest and woody wetland categories are on a much larger scale than the likely true changes in other land covers, the disadvantages of using both files may outweigh the advantages.

Forestry is an ongoing practice in these watersheds. A land cover category called “young forest” was developed from an MN DNR forest change GIS file to represent forests that had been harvested within the last 15 years. The MN DNR file identifies areas with significant disturbance as determined by remote sensing, and the year of change (2001–2010). The types of disturbances identified for this study included forest harvesting and shifts from forest to developed or agriculture. Eighty-five percent of the areas showing disturbance are located in forested areas, as indicated by the 2001 NLCD. It is assumed that the majority of the areas represent change from old forest to young forest. Fifteen years was selected because studies have shown that it takes between approximately 10 and 20 years or more for stream-yields to return to preharvest quantities [Keppeler et al., 2008,[3] Sebestyen et al., 2011,[4] Moore and Wondzell, 2005[5]].

Table 1. Changes in NLCD Classifications Across the Three Modeled Watersheds

NLCD Category	Area (ac)		Change (2001–2006)	
	2001	2006	Area (ac)	Percent
Developed, open space	46,494	52,344	5,851	13%
Developed, low intensity	10,764	11,234	470	4%
Developed, medium intensity	2,562	2,683	120	5%
Developed, high intensity	904	986	82	9%
Deciduous forest	1,191,306	1,026,145	–165,161	–14%
Evergreen forest	285,722	184,189	–101,533	–36%
Mixed forest	3,485	61,029	57,544	1,651%
Shrub/scrub	63,381	83,995	20,613	33%
Grassland/herbaceous	19,564	22,128	2,564	13%
Barren land (rock/sand/clay)	663	1,718	1,055	159%
Pasture/hay	126,342	122,301	–4,042	–3%
Cultivated crops	28,874	25,757	–3,118	–11%
Woody wetlands	208,952	406,149	197,196	94%
Emergent herbaceous wetlands	197,035	178,613	–18,422	–9%
Open water	399,850	406,629	6,779	2%

3 **Keppeler E., L. Reid, and T. Lisle, 2008.** *Long Term Patterns of Hydrologic Response After Logging in a Coastal Redwood Forest*, U.S. Department of Agriculture, Forest Service Pacific Southwest Research Station, Arcata, CA.

4 **Sebestyen, S. D., E. S. Verry, and K. N. Brooks, 2011**. *Peatland Biogeochemistry and Watershed Hydrology at the Marcell Experimental Forest, Chapter 13: Hydrological Responses to Changes in Forest Cover on Uplands and Peatlands*, CRC Press, Boca Raton, FL.

5 **Moore, D. R. and S. M. Wondzell, 2005.** "Physical Hydrology and the Effects of Forest Harvesting in the Pacific Northwest: A Review," *Journal of the American Water Resources Association*, Vol. 41, No. 4, pp. 763–784.

Forestry is an ongoing practice in these watersheds. A land cover category called “young forest” was developed from an MN DNR forest change GIS file to represent forests that had been harvested within the last 15 years. The DNR file identifies areas with significant disturbance as determined by remote sensing, along with the year of change (2001–2010). Types of disturbances identified for this study included forest harvesting and shifts from forest to developed or agriculture. Eighty-five percent of the areas showing disturbance are located in forested areas as indicated by the 2001 NLCD. It is assumed that the majority of the areas represent change from old forest to young forest. Fifteen years was selected because studies have shown that it takes between approximately 10 and 20 years or more for stream-yields to return to pre-harvest quantities [Keppeler et al., 2008[3], Sebestyen et al., 2011[4], Moore and Wondzell, 2005[5]].

Forests harvested within 15 years before each NLCD year (2001 and 2006) were chosen to represent “young” forest in the model. For the 2001 Version 2 NLCD, which will be used to represent 1995–2003, “young” forest includes forest that changed in 2001 (the MN DNR dataset starts at 2001). For the 2006 NLCD, which will be used to represent 2004–2009, “young” forest includes forest that changed between 2001 and 2006.

The number of operations (e.g., PERLND, IMPLND, RCHRES, PLTGEN, and COPY) allowed in one HSPF model application is limited; consequently, the 15 categories represented in the NLCD 2001, NLCD 2006, and the DNR forest change file were aggregated into relatively homogeneous model categories (Figure 8). Because forests represent a majority (65 percent) of the watershed, the forest categories were left as distinct categories, with the exception of the aggregation of mixed forest and evergreen forest. When forest harvest occurs, deciduous trees (primarily aspen) are often the first to propagate. Thus, young forest areas were not separated by forest type (deciduous versus evergreen). The remainder of the watersheds is composed of developed areas, grassland, pasture/hay, cultivated crops, and wetlands. Because of the relatively small areas represented by each of these classes, they were aggregated (Table 2). Lakes that were not explicitly modeled or joined to reach geometry were modeled with the wetland category. The open water land cover areas for those lakes were converted to the wetland model category.

The impervious area was represented using the NLCD 2001 version 2 and 2006 Percent Developed Imperviousness from the MRLC (Figure 9Figure 9). The data represent mapped impervious area (MIA) and were used to determine the effective impervious area (EIA) using the following equation from Sutherland [1995][6]:

The term “effective” implies that the impervious region is directly connected to a local hydraulic conveyance system (e.g., gutter, curb drain, storm sewer, open channel, or river); consequently, the resulting overland flow will not have the opportunity to infiltrate along its respective overland flow path before reaching a stream or waterbody. The percent EIA was used to separate the developed urban land cover areas into urban impervious and pervious land segment categories.

6 **Sutherland, R. C., 1995.** “Technical Note 58: Methodology for Estimating the Effective Impervious Area of Urban Watersheds,” *Watershed Protection Techniques*, Vol. 2, No. 1.

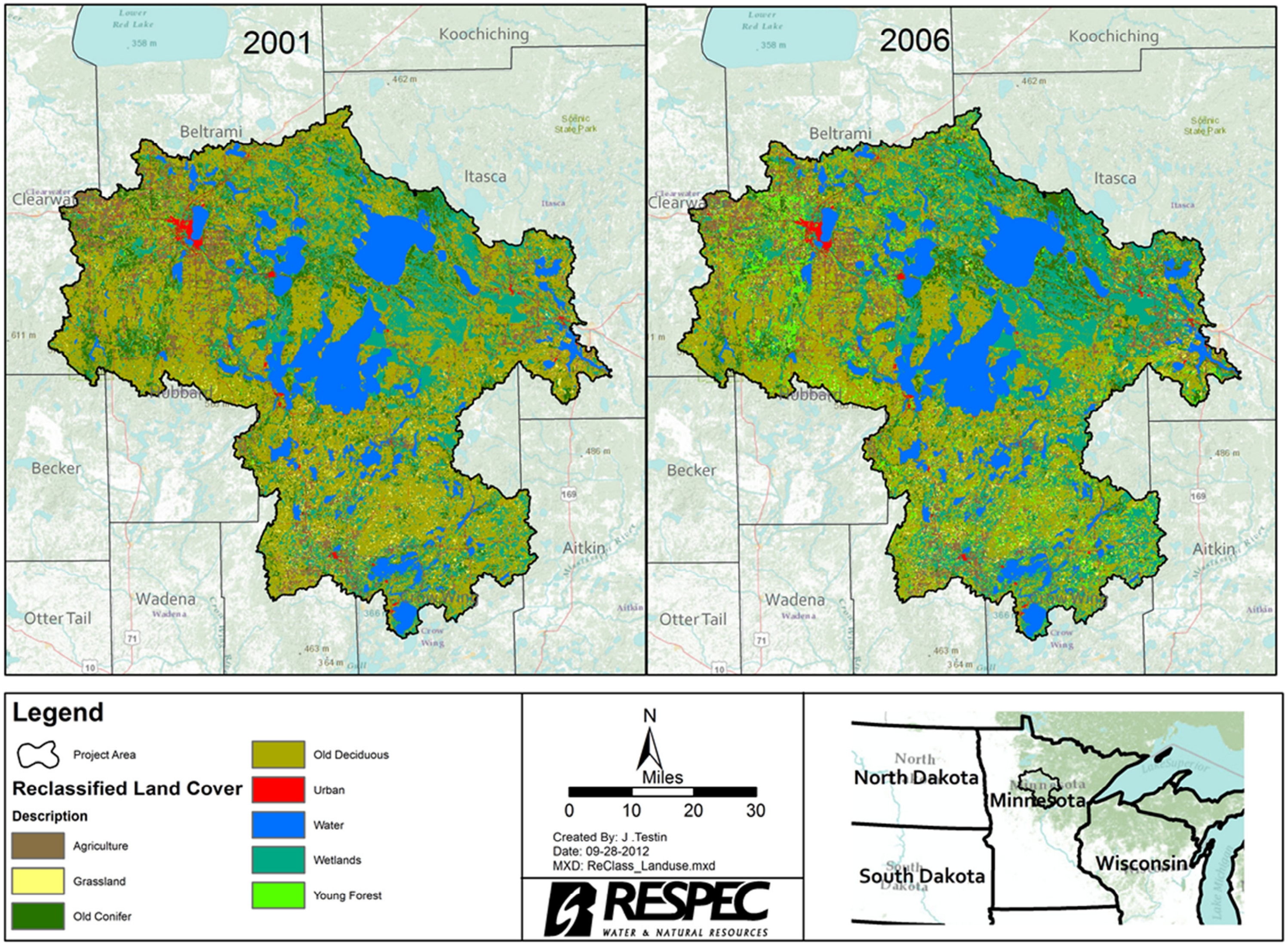

Figure 8. Reclassified Land Cover, Based on 2001 and 2006 National Land Cover Datasets and Supplemental Information.

Table 2. Summary Of 2006 NLCD Categories Aggregated Into Model Categories

2006 NLCD Category	Percent of Watershed			Model Category	Percent of Watershed		
	Mississippi Headwaters (%)	Leech Lake River (%)	Pine River (%)		Mississippi Headwaters (%)	Leech Lake River (%)	Pine River (%)
Developed, open space	2.4	1.6	1.9	Urban	3.1	1.7	2.1
Developed, low intensity	0.68	0.21	0.22				
Developed, medium intensity	0.19	0.028	0.028				
Developed, high intensity	0.067	0.012	0.011				
Deciduous forest	34	44	45	Old deciduous	32	41	41
Evergreen forest	9.7	5.6	3.3	Old evergreen	12	6.1	3.8
Mixed forest	4.0	0.83	0.91				
Young forest	NA	NA	NA	Young forest	5.4	3.8	5.5
Shrub/scrub	3.2	2.3	5.0	Grassland	3.4	2.7	6.2
Grassland/ herbaceous	0.81	0.59	1.4				
Barren land (rock/sand/ clay)	0.12	0.015	0.017				
Pasture/hay	5.8	3.5	4.2	Agriculture	6.8	3.9	5.6
Cultivated crops	1.1	0.51	1.5				
Woody wetlands	17	13	17	Wetlands	25	23	28
Emergent herbaceous wetlands	6.0	7.9	7.5				
Open water	15	19	12	Open water	12	17	7.8

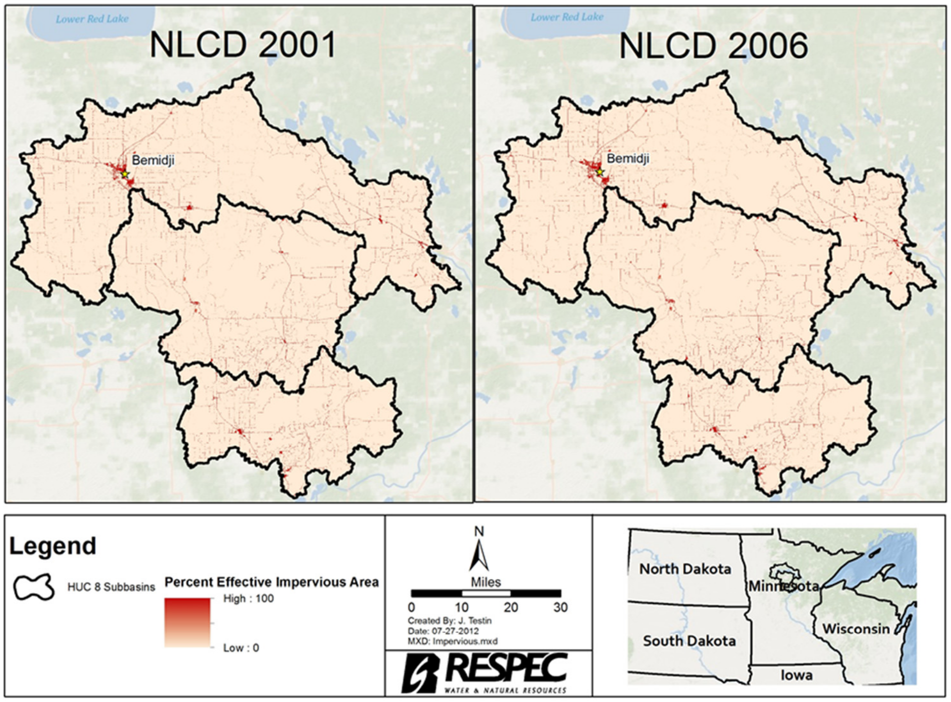

Figure 9. National Land Cover Dataset 2001 and 2006 Percent Imperviousness.

Soil properties were also examined in conjunction with land cover to guide PERLND categorization, because soil type can significantly affect the hydrologic processes such as infiltration, surface runoff, interflow, groundwater storage, and deep groundwater losses. A GIS analysis was conducted using soil data obtained from the Soil Survey Geographic (SSURGO) Database to investigate the soil distribution within the watersheds and determine the potential for runoff generation. Figure 10 10 illustrates the spatial extent of the primary Hydrologic Soil Groups (HSG) A, B, C, and D, which represent well-drained to poorly drained soil. In the original SSURGO soil classification, B and C soils were classified differently in Hubbard County as compared to the surrounding counties. This did not change the classification schematic for this project, but it will be taken into account during the hydrologic calibration. Some soils within the watersheds received a dual classification (i.e., A/D, B/D, or C/D), which implies that the soil will respond like the higher runoff potential group (i.e., D) if the soil is not adequately drained. Soils were reclassified to explicitly represent runoff potential, where A and B soils were combined to define the low runoff potential class and C soils were combined with D soils to define the high runoff potential class. Soils with a dual classification were given the class of the higher runoff potential soil (e.g., D for A/D soils) because the majority of the dual classification soils were within wetlands and there is not a substantial amount of artificial drainage in the watersheds. Soils that were classified as not rated were grouped with the high runoff potential soils because they typically represented open water or urban areas.

Soils data for Crow Wing County are not yet available to download from the SSURGO database. Soils data for Crow Wing County were received from two different sources: the

National Resources Conservation Service (NRCS) and a Cummins and Grigal soil series layer. The NRCS provided a preliminary soil series layer that outlined the boundaries of soil series in the watershed. The preliminary NRCS soil series layer contained gaps where the soils data were unavailable. A Cummins and Grigal soil series layer was used to fill in those areas within Crow Wing County where the NRCS layer did not provide information. The Cummings and Grigal layer and the NRCS layer did not specifically list the hydrologic soil group; the hydrologic soil group was inferred based upon the soil series. The two sources of soils data were reclassified into their respective runoff potential group following the methodology outlined in the preceding paragraph and merged together using a raster mosaic function in **ArcGIS 10.1**. The mosaic function allows the user to control the source of data to use when two sources of data overlap. In this case, the NRCS layer was chosen over the Cummins and Grigal layer in areas where the two sources overlapped because it is a more precise dataset. The final Crow Wing County soils raster was then merged with the soils data from the other counties to form a single soils layer for the entire project area (Figure 10).

Runoff potential and model land cover geospatial datasets were intersected in the aggregated land cover categories that covered greater than 5 percent of the watershed area in the 2006 NLCD. An exception was made for wetlands and open water, where the high runoff potential category was assumed. The land cover categories that were intersected with runoff potential were old deciduous, old evergreen, young forest, and agriculture. The aggregated agriculture land cover category includes both pasture/hay and cultivated crops, with the majority being pasture/hay. If the majority of the agriculture were cultivated crops, it could be assumed that the soil behaves as A/B soils, because most C/D soils under row crops have likely been tile drained. However, because the majority of cover is pasture in these watersheds, runoff potential (soil classification) was used to further characterize the agricultural areas. Urban areas and grassland/shrub did not include runoff potential because they each represent less than 5 percent of the watershed area.

There are approximately 112 animal feedlot operations (AFOs) are loaded in the project area, with the highest density in the northwestern portion (Figure 11). The primary source of pollution from AFOs is manure. Manure introduces oxygen-demanding substances, ammonia, nutrients, solids, and bacteria into the surrounding water sources through accumulation and wash-off processes. Also, reduction in vegetation and densely packed subsurface soils that result from concentrated animal grazing can lower infiltration rates and increase sediment erosion. A stream dissolved oxygen impairment and several lake impairments are located downstream of some of the AFOs in the Mississippi River Headwaters Watershed. All feedlots in the project area except for one have fewer than 1,000 animal units and, thus, are allowed to discharge under Minnesota Administrative Rule 7020.2003. Based on the density of AFOs in portions of the project area and the location of AFOs upstream of known impairments, a feedlot land segment category was used. For modeling purposes, an area for each AFO was estimated based on the typical design specification of 300 square feet per animal unit [Murphy and Harner, 2001][7]. The individual calculated areas were shifted from the land category where each AFO was located to the feedlot category.

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[7] **Murphy, P. and J. Harner, 2001.** *Lesson 22: Open Lot Runoff Management Options*, Livestock and Poultry Environmental Stewardship Curriculum, Kansas State University, Midwest Plan Service, Iowa State University, Ames, IA.

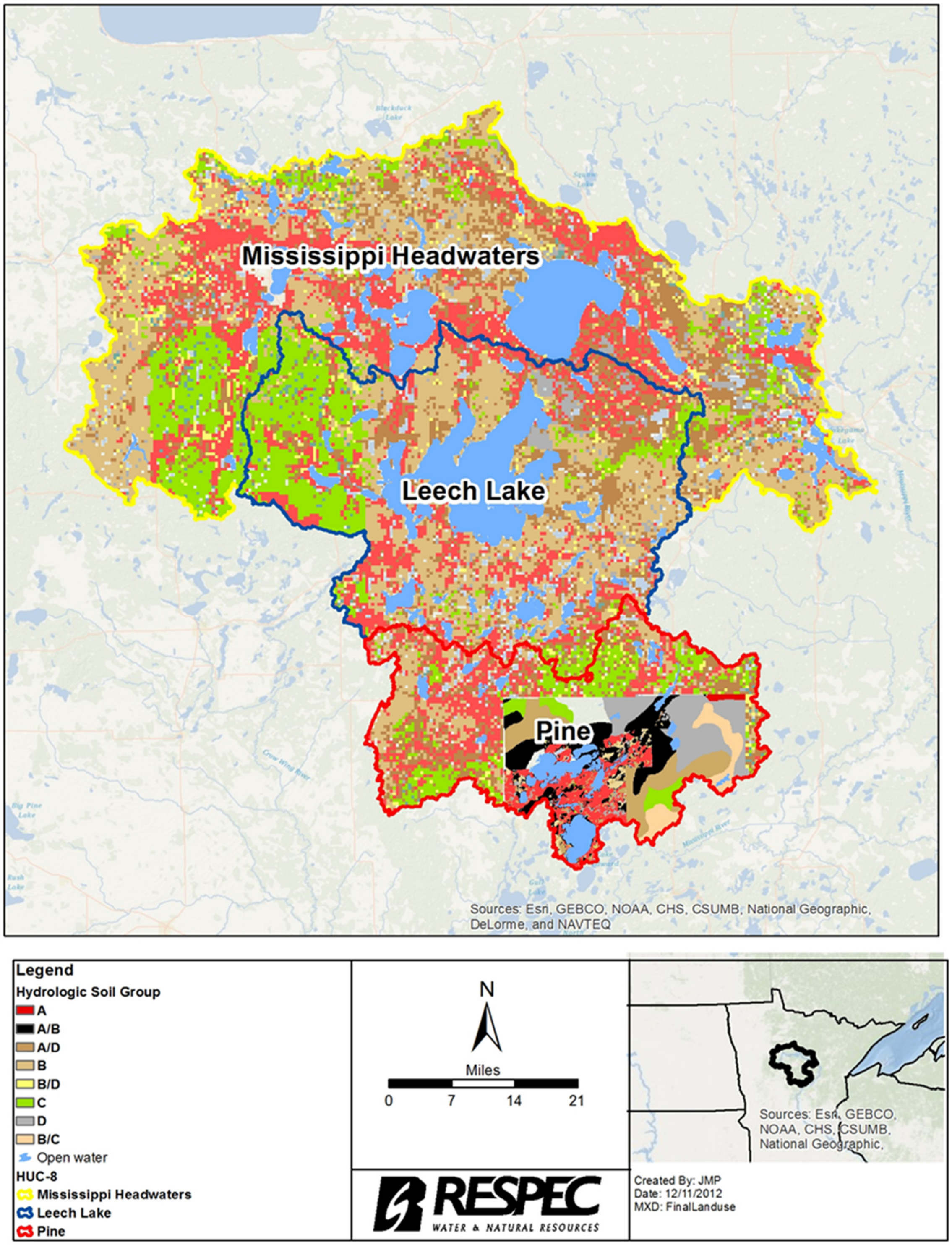

Figure 10. Distribution of Hydrologic Soil Group.

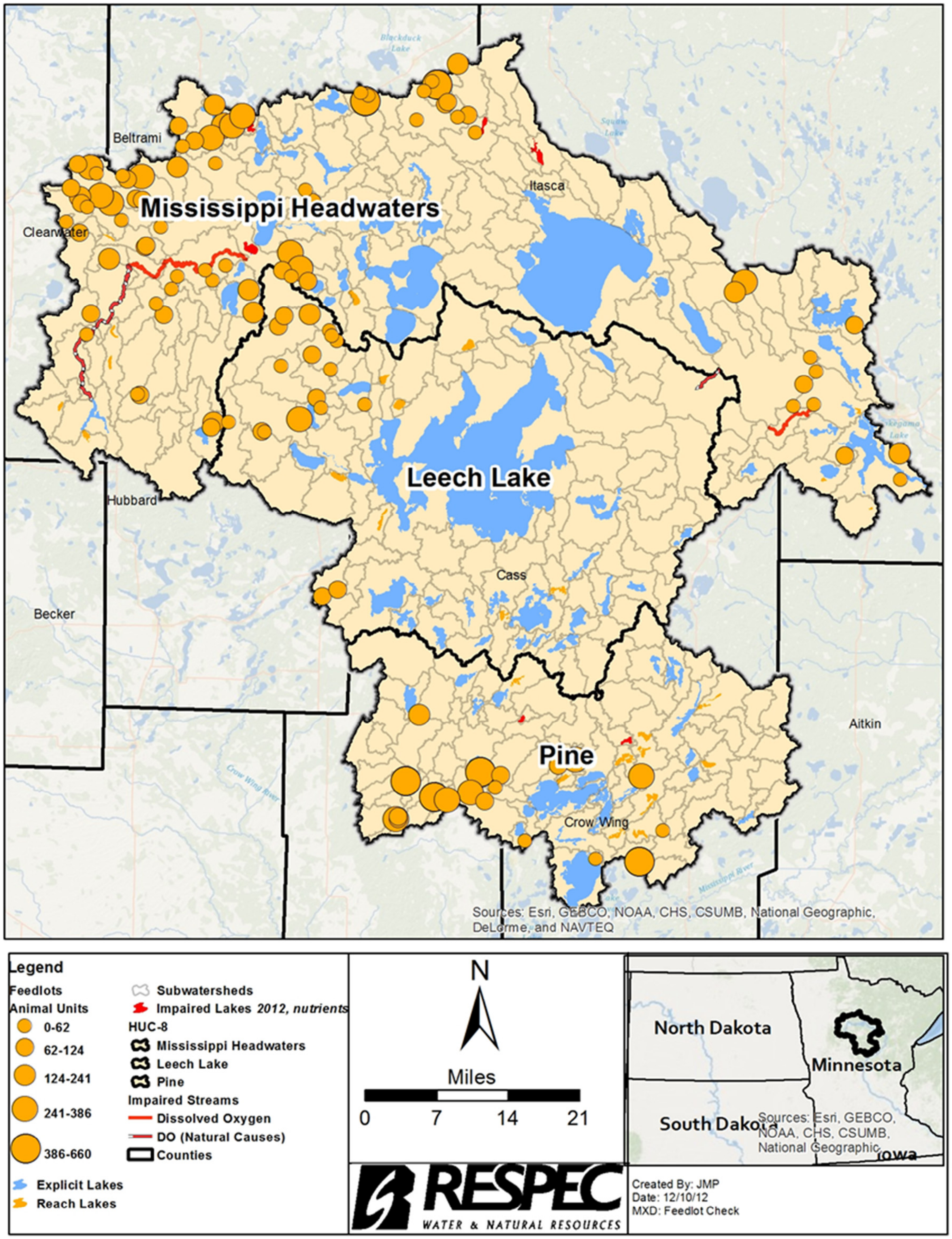

Figure 11. Distribution of Animal Feedlot Operations.

Two regulated Municipal Separate Storm Sewer Systems (MS4) have areas within the modeled watersheds. The city of Bemidji is completely within the Upper Mississippi River Headwaters Watershed, and a small portion of the city of Grand Rapids is within the same watershed. These areas will be parameterized the same way as the non-MS4 areas within the same land classification. However, the MS4 areas will be separated from non-MS4 areas in the schematic calculation and assigned a different mass link number to the lines in the schematic corresponding to MS4 areas.

Unique pervious and impervious classifications were developed using the watershed characteristics and classification methods (Figure 12). The NLCD categories were aggregated into model land cover categories, and urban areas were divided into pervious and impervious urban classifications. After separating forests into old and young categories, the forested and agricultural lands were further separated according to hydrologic soil group. A model category was developed to include AFOs. This process resulted in 12 unique pervious land cover classifications and one impervious classification (Table 3). Table 4 is a summary of the differences between the 2001 and 2006 NLCD layers in the watershed

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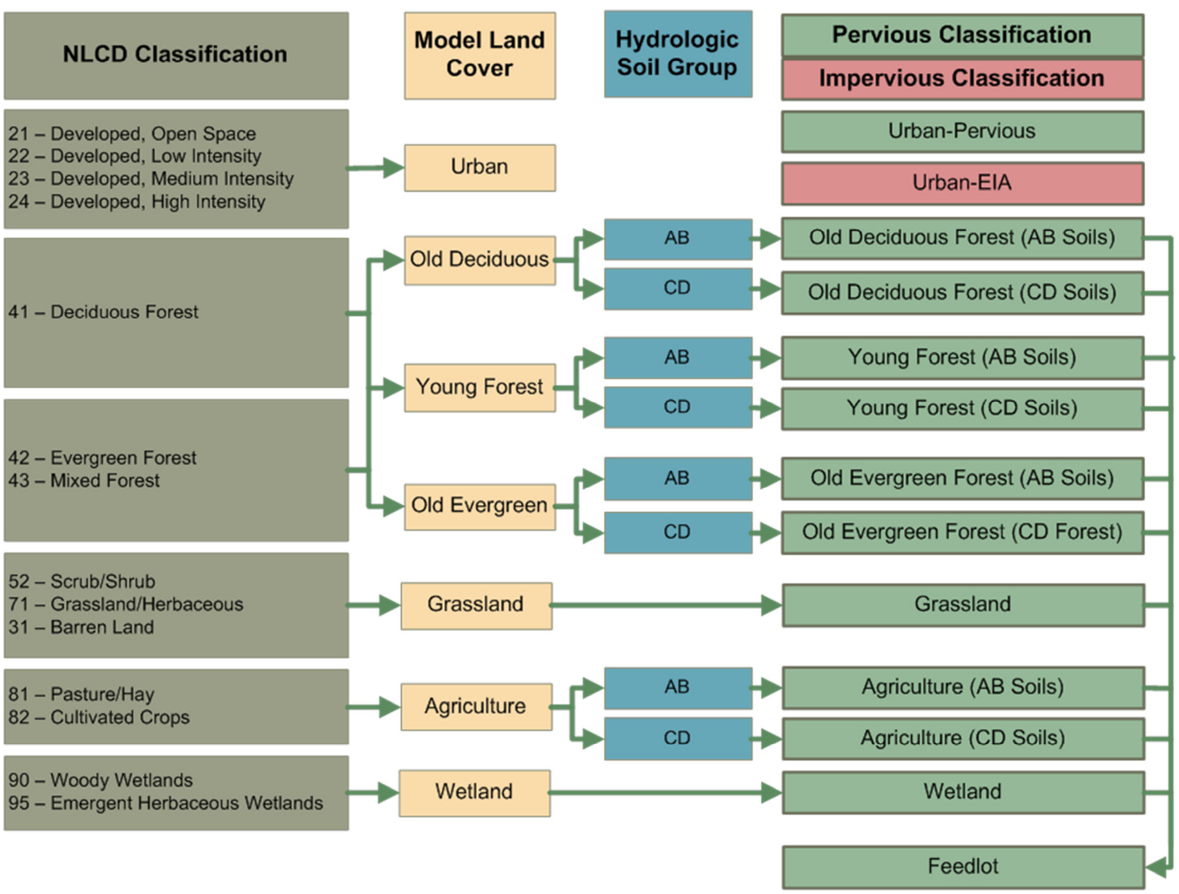

Figure 12. Model Classification for PERLND and IMPLND Development.

Table 3. Unique PERLND Operation Numbering Scheme

Hydrozone	Urban	Old Deciduous AB	Old Deciduous CD	Old Evergreen AB	Old Evergreen CD	Young Forest AB	Young Forest CD	Grassland	Agriculture AB	Agriculture CD	Wetlands	Feedlots
Hundreds, tens place	Ones place											
	0	1	2	3	4	5	6	7	8	9	0	1
01	010	011	012	013	014	015	016	017	018	019	020	021
03	030	031	032	033	034	035	036	037	038	039	040	041
05	050	051	052	053	054	055	056	057	058	059	060	061
07	070	071	072	073	074	075	076	077	078	079	080	081
09	090	091	092	093	094	095	096	097	098	099	100	101
11	110	111	112	113	114	115	116	117	118	119	120	121
13	130	131	132	133	134	135	136	137	138	139	140	141
15	150	151	152	153	154	155	156	157	158	159	160	161
17	170	171	172	173	174	175	176	177	178	179	180	181
19	190	191	192	193	194	195	196	197	198	199	200	201
21	210	211	212	213	214	215	216	217	218	219	220	221
23	230	231	232	233	234	235	236	237	238	239	240	241
25	250	251	252	253	254	255	256	257	258	259	260	261
27	270	271	272	273	274	275	276	277	278	279	280	281
29	290	291	292	293	294	295	296	297	298	299	300	301
31	310	311	312	313	314	315	316	317	318	319	320	321
33	330	331	332	333	334	335	336	337	338	339	340	341
35	350	351	352	353	354	355	356	357	358	359	360	361
37	370	371	372	373	374	375	376	377	378	379	380	381
39	390	391	392	393	394	395	396	397	398	399	400	401
41	410	411	412	413	414	415	416	417	418	419	420	421
43	430	431	432	433	434	435	436	437	438	439	440	441
45	450	451	452	453	454	455	456	457	458	459	460	461
47	470	471	472	473	474	475	476	477	478	479	480	481
49	490	491	492	493	494	495	496	497	498	499	500	501
51	510	511	512	513	514	515	516	517	518	519	520	521

Table 4. Summary of 2001 and 2006 Model Land Cover Categories

Model Land Cover Category	Mississippi Headwaters			Leech Lake River			Pine River		
	Area (ac)		% Change	Area (ac)		% Change	Area (ac)		% Change
	2001	2001		2001	2006		2001	2006	
Urban	35,389	40,812	15	15,147	15,712	4	10,209	10,639	4
Old deciduous forest (AB soils)	304,133	264,837	–13	250,149	241,808	–3	112,431	102,951	–8
Old deciduous forest (CD soils)	216,698	153,761	–29	158,682	139,629	–12	148,706	122,252	–18
Old evergreen forest (AB soils)	132,586	94,367	–29	49,699	37,001	–26	22,226	10,229	–54
Old evergreen forest (CD soils)	47,808	24,875	–48	20,055	11,426	–43	13,245	6,178	–53
Young forest (AB soils)	1,483	36,049	2,331	800	5,581	597	114	2,185	1,823
Young forest (CD soils)	558	13,301	2,286	418	1,541	269	87	2,339	2,603
Grasslands, scrub, shrub	32,515	49,105	51	22,143	24,680	11	28,231	32,238	14
Agricultural (AB soils)	64,531	62,007	–4	18,870	17,480	–7	18,718	17,898	–4
Agricultural (CD soils)	24,602	23,517	–4	17,607	16,585	–6	10,746	10,353	–4
Wetlands	191,654	282,204	47	138,084	179,823	30	75,502	122,045	61
Open water (not a model land cover)	176,070	181,940	3	166,463	166,726	0	57,456	58,142	1

The PERLND and IMPLND operation numbers in **HSPF** are limited to three digits and can range from 001–999. The large number of hydrozones are represented with the hundreds and tens places and labeled as odd numbers (01 through 51 for a total of 26 unique zones) to allow for 20 possible unique classifications of the remaining watershed land characteristics. Although the major watersheds of interest are represented as two model applications, the 26 hydrozones are labeled as one group to reduce processing time and because some zones will be used for both model applications. There were 12 pervious and one impervious unique classifications from the watershed land characterization model, which left eight classifications available for possible future expansion of model categories. The operations of the first ten classes are directly identified with the hydrozone number in the hundreds and tens place and with the land cover classification (0 through 9) in the ones place. The eleventh and twelfth classes, which are wetland and feedlot, are identified with an even number with one greater than the hydrozone number in the hundreds and tens place and a 0 or 1 in the ones place to identify the classification. For example, the fourth class, Old Evergreen-AB, in Hydrozone 17, is given a PERLND operation number of 173. The eleventh class, Wetlands, in the same Hydrozone 17, was given a PERLND operation number of 180.

The 26 hydrozones and 12 PERLND categories led to a total of 312 unique PERLND operations (Figure 13). The urban IMPLND will be given the same operation number as the urban PERLND. Initial **HSPF** parameters were assigned by land use class drawing from calibrated model applications of the Le Sueur and Minnesota River Watersheds.

SUMMARY

The Mississippi River Headwaters, Leech Lake River, and Pine River Watersheds were delineated into subwatersheds, and reach networks were defined to represent drainage properties within each basin. A numbering scheme was developed, and the physical properties of model reaches and subwatersheds were calculated and entered into the UCI. F-tables were developed using lake and reach properties to allow the models to route water effectively through the system. 26 unique hydrozones were created to maximize the use of available meteorological time-series data. These data were processed and loaded into WDM files to supply model inputs, including PREC, PEVT, ATEM, CLOU, DEWP, SOLR, and point sources, as well as discharge data for calibration purposes. Unique pervious and impervious classifications were developed based on spatial analysis of watershed characteristics. The twenty-six hydrozones, combined with the 13 land characteristic classifications, created a total of 338 possible land segment operations, which were initially parameterized based on existing model applications. Finally, PERLND and IMPLND land segments were linked to corresponding reaches in the model schematics, which resulted in developing completed model applications to represent hydrology within the three watersheds.

Thank you for your time in reviewing the methods for the development of the UCI and WDM files for the Mississippi River Headwaters, Leech Lake River, and Pine River Watersheds **HSPF** model applications. We are available to discuss the contents of this memorandum with you and appreciate any feedback you may have.

Sincerely,

Seth J. Kenner
Staff Engineer

SJK:llf

cc: Project Central File 2046 — Category A