May 30, 2014

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

Dear Dr. Regan:

RE: Model Development for the Minnesota Portions of the Big Sioux and the Little Sioux-Missouri River Watersheds

The methodology documentation for developing the User Control Input (UCI) and Watershed Data Management (WDM) files for the **HSPF** model applications is completed for your review. The memo covers the model development of Minnesota portions for the following major watersheds:

- Upper Big Sioux River (10170202)
- Lower Big Sioux River (10170203)
- Rock River (10170204)
- Little Sioux River (10230003).

Individual model applications were created for the Rock River and Little Sioux River Watersheds, while the drainage areas in the Upper and Lower Big Sioux River Watersheds were combined into one model application (Big Sioux River). This memo refers to all areas collectively as the Missouri River Watershed. The methodology includes the following:

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

Each of these items is discussed in the following sections.

SUBWATERSHED DELINEATION AND PRIMARY REACH SELECTION

The procedures followed for delineating subwatersheds and selecting primary reaches to be explicitly modeled in the Missouri River **HSPF** model applications are described in this section. A Geographic Information System (GIS) geodatabase was created containing the following data layers: National Hydrography Dataset (NHD) flowlines and waterbodies, Minnesota Pollution

Control Agency (MPCA) 2012 draft impaired streams and waterbodies, 2010 assessed streams and waterbodies, monitoring site locations, a Digital Elevation Model (DEM), and an imagery basemap. These data were used to delineate the model subwatersheds and define the primary reach network.

The Minnesota Department of Natural Resources (MNDNR) Level 7 watersheds were used as the basis for the HSPF model subwatersheds layer in the Minnesota portions, and United States Geological Survey (USGS) Hydrologic Unit Code-12 (HUC12) watersheds were used in the Iowa and South Dakota portions. In the model application, 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 and assessed streams and waterbodies, as well as monitoring data availability. When possible, MNDNR Level 7 watersheds were used as reference instead of USGS HUC12 watersheds because the Level 7 watersheds provided more detailed breaks and were closer to meeting the preferred subwatershed size.

The NHD flowline layer was used as the basis of the HSPF model reach network. In general, a continuous reach that connects the upstream and downstream subwatersheds was chosen as the primary reach to be modeled. This process ensured that mainstem reaches (i.e., Pipestone Creek, Rock River, and Little Sioux River) 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 the highest priority, selecting these streams took precedence over 2010 assessment streams, regardless of length. Similarly, selecting 2010 assessment streams took precedence over all nonimpaired streams, regardless of length.

Reach length and slope are required to determine physically based parameters in the model application, as well as for developing F-tables (described in a later section). These parameters were calculated by using ArcGIS for all nonlake reaches. 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, as illustrated in Figures 1 and 2. All lakes chosen to be explicitly modeled were assumed to have an outflow.

REACH AND SUBWATERSHED NUMBERING SCHEME

This section describes the numbering scheme used for the watershed drainage network, as illustrated in the reach numbering schematic in Figure 3. Reach identifications (I.D.s) consist of one to three numeric digits. Mainstem reaches were given I.D.s that end in zero (##0). Reaches were assigned an odd 10s place (middle number) if they represented a stream segment (e.g., 110, 130, 150, and 190 in the schematic) and an even 10s place if they represented a lake (e.g., 120 and 160 in the schematic). Tributaries were assigned an odd reach I.D. for the 1s place (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 place of the tributary reach I.D.s corresponds with the downstream mainstem reach I.D. (e.g., 111 and 113 flow into 120).

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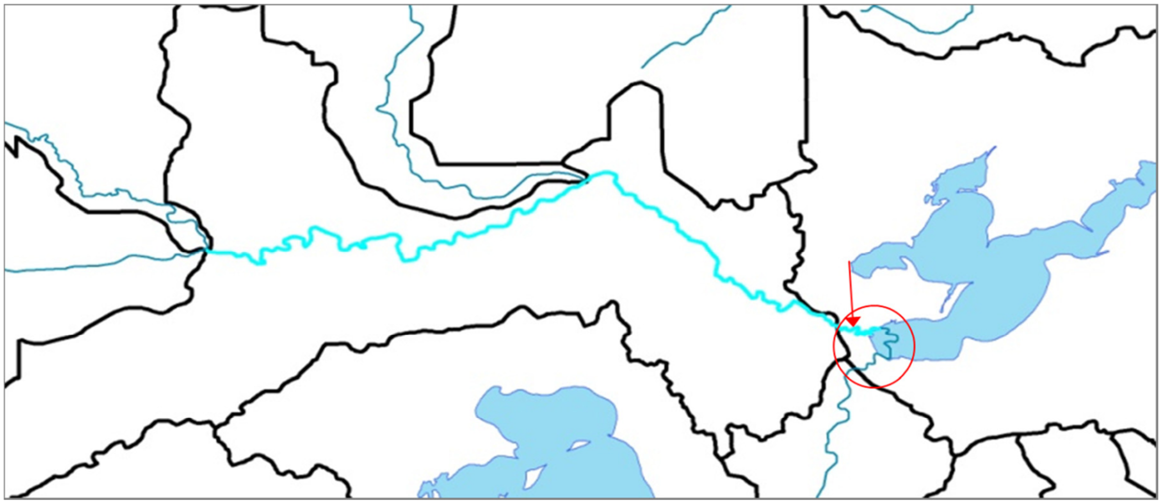

Figure 1. Reach (Highlighted) Passing Through a Small Portion (Circled) of a Subwatershed and Extended Reach in a Lakeshed (Arrow).

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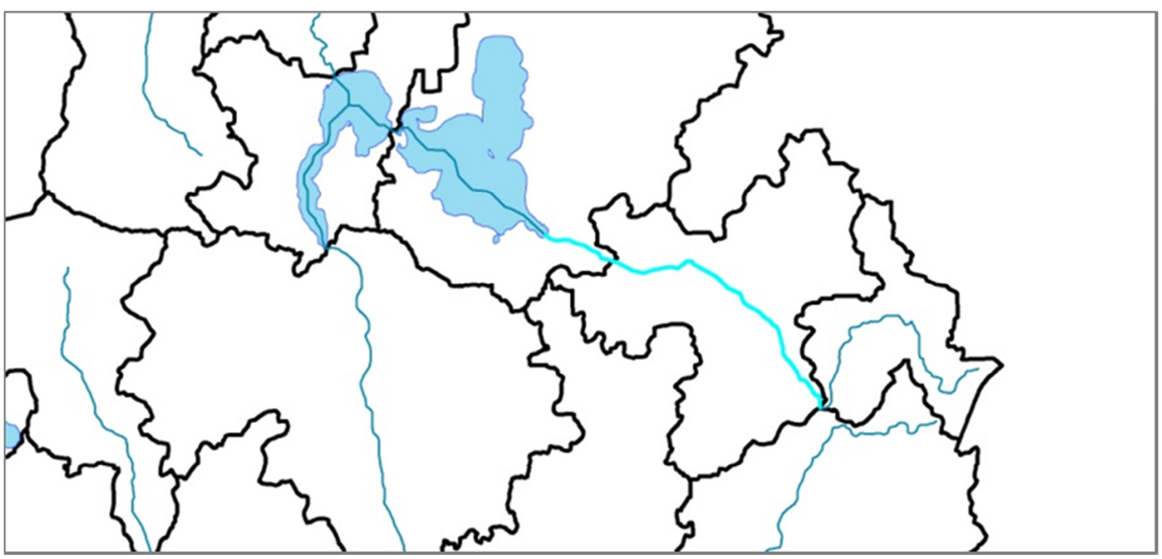

Figure 2. Extended Reach (Highlighted) in a Lakeshed.

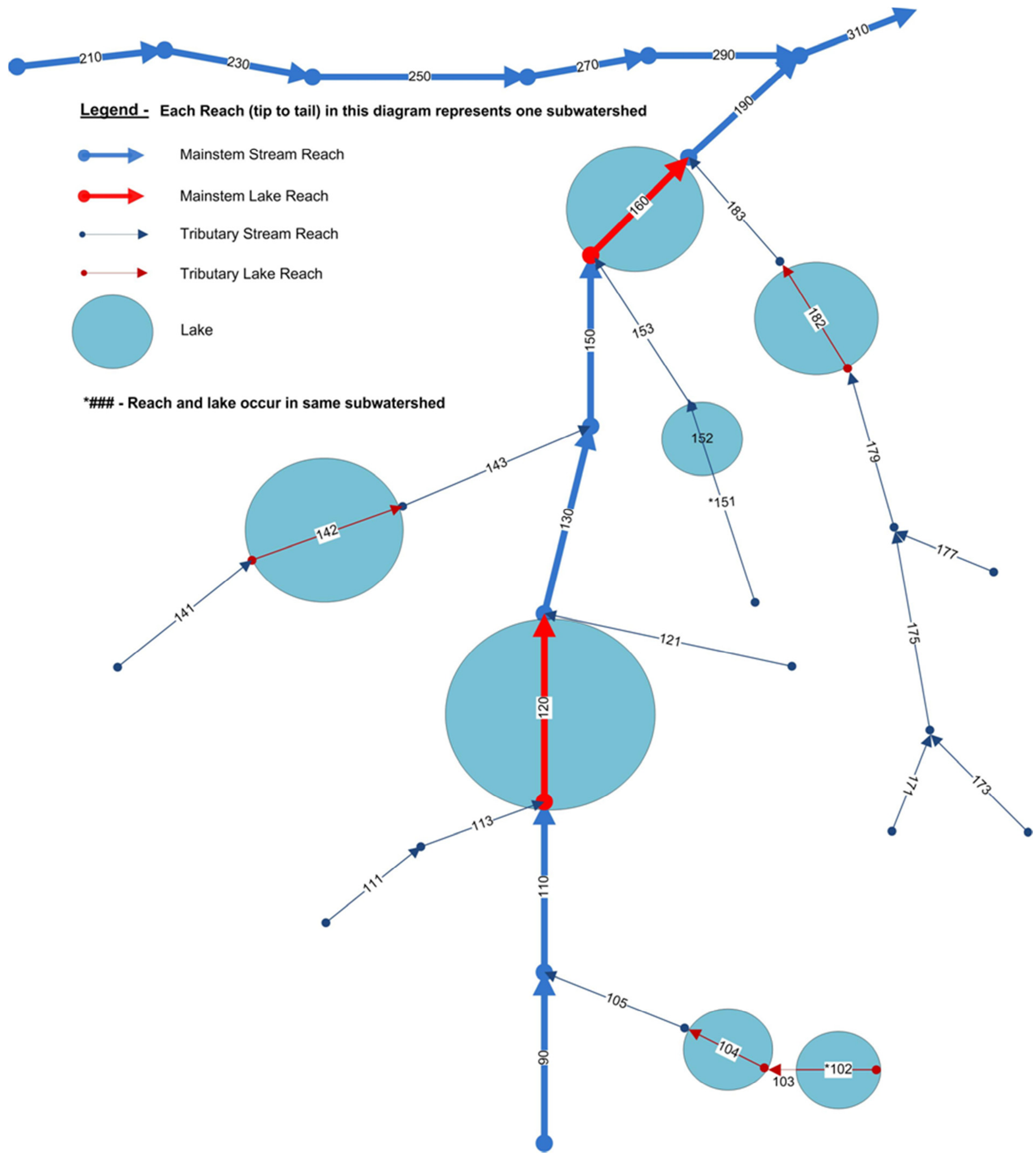

Figure 3. Example of a Reach Numbering Schematic.

Overall, subwatersheds and reaches were numbered in order, beginning with low I.D. numbers upstream and ending with high I.D. numbers downstream. The schematic structure allows for five tributary reach segments per mainstem reach I.D. If more than five tributary reaches contribute to the mainstem reach at any given point, the next chronological downstream mainstem reach I.D. was not used and the downstream reach was given the next largest mainstem reach I.D. For example, downstream of Mainstem Reach 160 in the sample schematic in Figure 3, a combination of seven tributary reaches (i.e., 171, 173, 175, 177, 179, 182, and 183) contribute to Mainstem Reach 190. Each subwatershed typically contained only one reach and was given the I.D. of the corresponding reach. In the case that a subwatershed is modeled with both a reach and a lake, the reach I.D. of the dominant feature was given (i.e., 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 261 subwatersheds and 268 reaches were delineated. The Rock River model application delineation is illustrated in Figure 4, and the delineations for the rest of the model applications are shown in Appendix A.

LAKE AND STREAM F-TABLE DEVELOPMENT

The 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.

Multiple criteria, which are illustrated in Figure 5, were used to determine which lakes to explicitly model in the Missouri River Watershed. Lake selection was based on management priorities, lake size, and data availability. Modeled lakes included all nutrient-impaired lakes (5 lakes), and all lakes greater than 100 acres that intersect a primary reach (21 lakes). Headwater lakes with no data or lakes that resemble wetlands were removed from the selection (10 lakes). All modeled lakes (16 lakes) are in the Little Sioux River Watershed. Surface area, volume, and depth data were supplied as contour layers or created from lake maps from the MNDNR and the Iowa Department of Natural Resources (IADNR) for 8 of the 16 lakes. Mean areas and depths were estimated for the lakes where these data were not available. Spillway length, height above sill, and lake run-out elevation data were obtained from both the National Inventory of Dams dataset and the MNDNR State Dam Inventory. However, these data were largely unavailable. Because of the lack of available data, the models were set up using average values for spillway lengths and height above sill. This level of detail is sufficient for the purposes of this model. If additional data become available during model development, they will be incorporated into the existing model application.

The equations used to calculate lake outflows at different water elevations, as well as assumptions made, are discussed below. For simplicity, and because of the lack of overflow data,

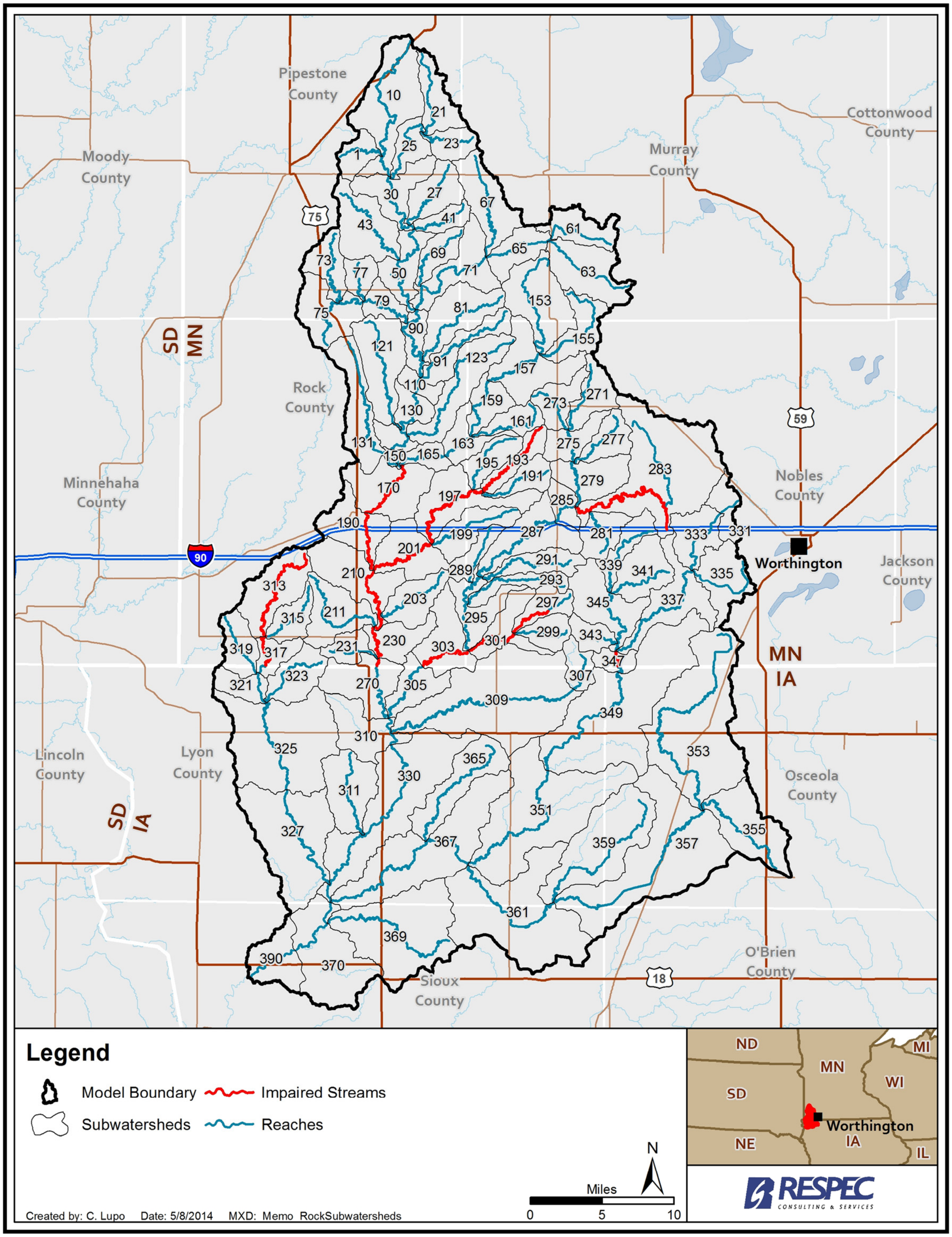

Figure 4. Rock River Watershed Reach and Subwatershed I.D.s.

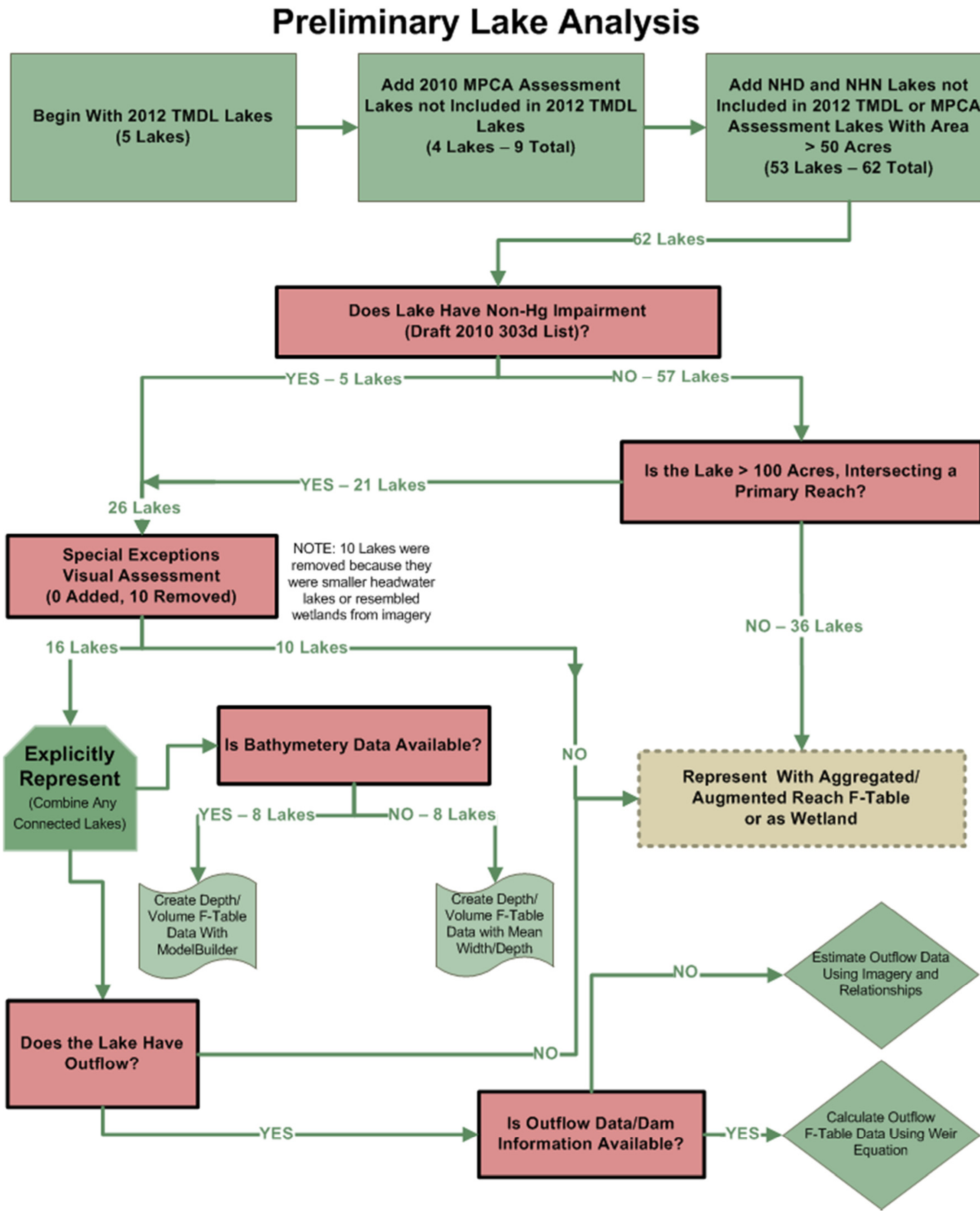

Figure 5. Lake Selection Schematic.

the equation of discharge for overflow spillways was used to calculate discharge from lakes (Equation 1)[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 were negligible, so the equation could be used in its simplest form:

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

where:

Q = Discharge (cubic feet per second (cfs))

C = Variable coefficient of discharge

L_e = Effective length of crest (feet)

H = Water depth above weir (head (feet))

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. Effective length of the crest (L_e) was derived from spillway length obtained from either the National Inventory of Dams dataset or the MNDNR State Dam Inventory. When a spillway length was not available, the mean 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 by 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).

Crest height (P) was assumed to be the height above sill, which was available from the MNDNR dam dataset. Head (H_d) varied with the water surface and was calculated as described previously.

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1 **Gupta, R. S., 2008.** *Hydrology and Hydraulic Systems*, 3rd edition, Waveland Press, Inc., p. 583.

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

Once all available data were collected and compiled, an F-table was developed by calculating the surface area, volume, and discharge over a range of depths. The F-table was created using the depths, surface areas, and volumes calculated from lake contours with the Bathymetry Volume and Surface Area **ArcGIS ModelBuilder** tool. This tool created a separate, triangulated area network (TIN) for the lake on which a "Surface Volume" tool was used to calculate the area and volume below specified depths. The highest contour, if available, or maximum depth, was assumed to be the outlet. Depths were added incrementally above the outlet until the discharge shown in the F-table 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 0.02. Discharge at each height above the outlet was calculated by 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.

Data requirements for stream F-table development included cross-section and discharge measurements. These were provided by the Pipestone and Nobles County Highway Departments (bridge cross sections), the Eastern Dakota Water Development District (EDWDD), USGS, and the MNDNR, as illustrated in Figure 6. When more than one cross section was available within the same reach, the cross section from the furthest downstream site was typically assigned to the entire reach, depending on the data quality. Mainstem reaches for which cross-section data were unavailable were assigned a representative cross section using best engineering judgment. Representative mainstem cross sections were assigned based on the nearest available downstream mainstem cross section, because cross section area generally increases from upstream to downstream. Similarly, tributary reaches for which cross section data were unavailable were assigned a representative tributary cross section based on proximity and drainage area similarities.

Once each reach was assigned the most appropriate channel cross section based on location and drainage area, discharge was calculated for each reach using length, slope, and cross-section data 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:

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

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

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

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

$S = \text{Channel slope.}$

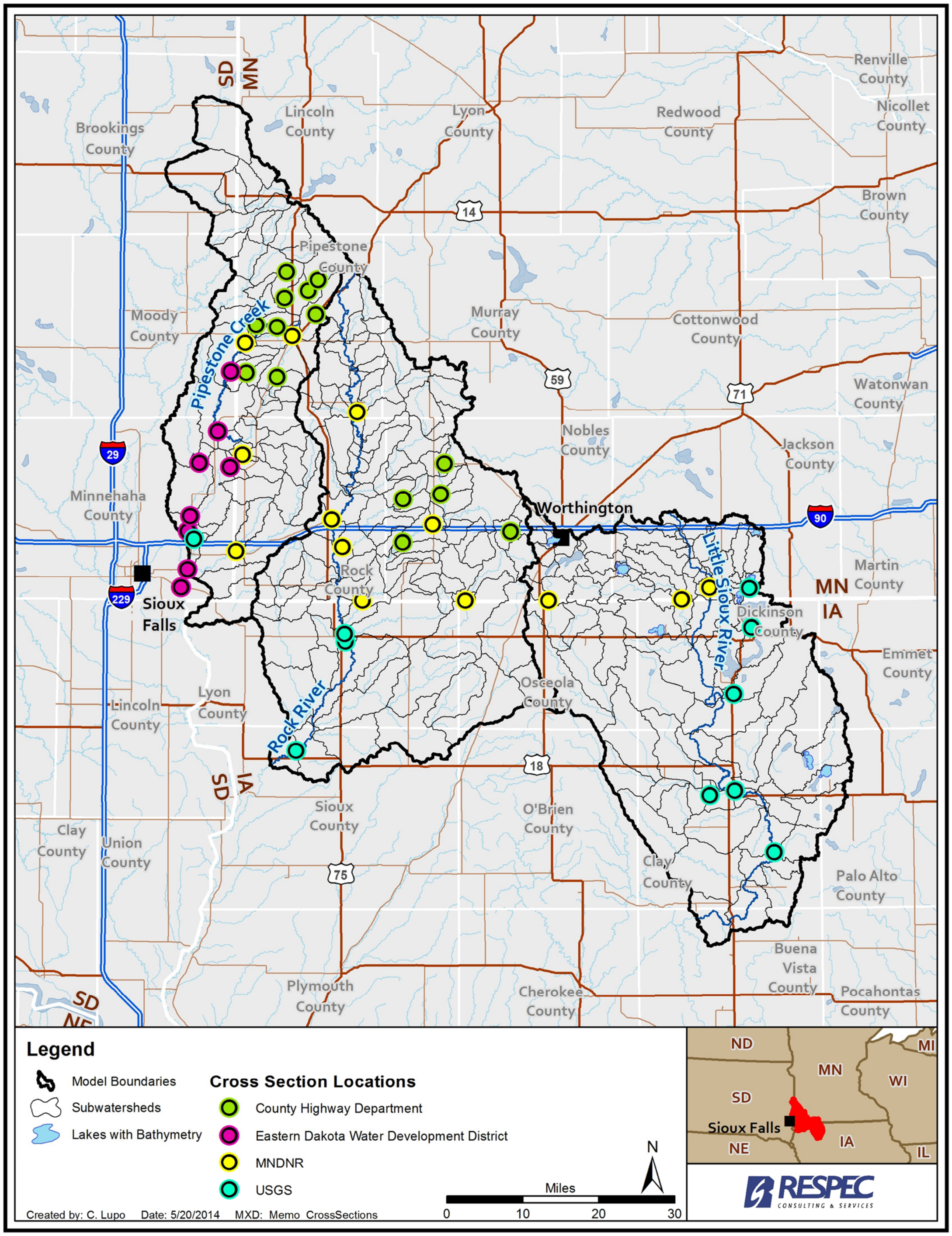

Figure 6. Locations of Lake Bathymetry and Cross-Section Data Used to Develop Model F-Tables.

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 set based on local topography and by 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 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 0.02. 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 watershed data management (WDM) files accessed directly by **HSPF** during a model simulation. Separate WDM files were created for meteorological time-series, point sources discharging within the watershed (i.e., added flow time-series and pollutant loading), and calibration time-series. These three WDM files were created for each individual model application.

Meteorological

Meteorological data to drive the **HSPF** model application were obtained from the U.S. Environmental Protection Agency's (EPA) **BASINS** system, National Weather Service Cooperative Network (COOP), Automated Weather Data Network (AWDN), and extensive supplementary **HIDEN** (HIgh spatial DENsity, daily observations) precipitation data were provided by MPCA. 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 selected for inclusion in the model application.

PREC and PEVT are the minimum requirements to drive the model; however, hydrologic processes to be represented within the Missouri River model application require all of the time-series data listed above. Hourly Penman Pan evaporation was obtained by loading hourly time-series data from selected **BASINS** and AWDN 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, as illustrated in Figure 7. Penman Pan evaporation is converted to potential evapotranspiration in the external sources block of the UCI (where model inputs are called and distributed) by using an adjusted pan factor of 0.67, which was initially derived from the National Oceanic and Atmospheric Administration (NOAA) Evaporation Atlas. Additionally, the hydrologic processes within the Missouri River Watershed are greatly influenced by snow that accumulates and melts. Two options are available when simulating snow with **HSPF**: the energy-balance method and the degree-day method. The energy-balance method uses ATEM, DEWP, WIND, SOLR, and CLOU to calculate snow processes, while the degree-day method only uses ATEM. Both methods were evaluated, and the method resulting in the best snow and hydrology calibrations was ultimately chosen.

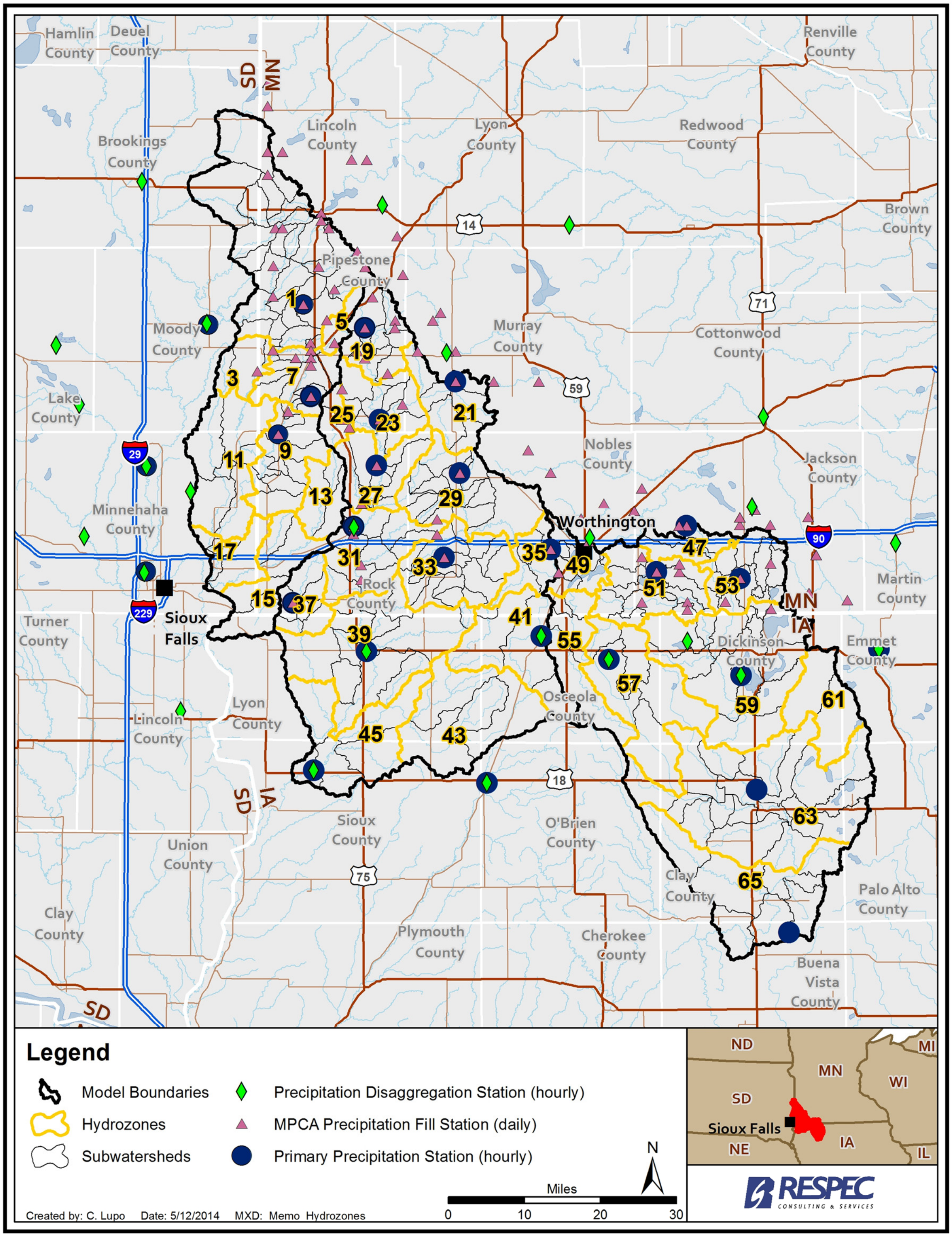

Figure 7. Hydrozones and Meteorological Stations.

PREC time-series data were obtained through a combination of **BASINS**, **COOP**, **AWDN**, and **HIDEN** stations selected to provide comprehensive spatial coverage of the Missouri River Watershed. The watershed was divided into hydrozones to account for the precipitation distribution within the watershed and was based on locations of available data. **BASINS**, **COOP**, and **AWDN** stations were selected based on the availability of the required meteorological data and their proximity to the watershed while **HIDEN** stations were chosen to fill spatial precipitation data gaps based on location and period of record (Figure 7). 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**, **COOP**, and **AWDN** stations were filled or disaggregated using data from the closest station available, including the **BASINS** stations. Daily 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 hourly stations as follows: if the daily totals of the hourly PREC of any of the hourly 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 hourly 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 4 miles while the average distance to a disaggregation station was approximately 21 miles. These distances are in the range of the average distances between the centroid of each defined meteorological zone and its nearest neighbor. The disaggregated-filled daily PREC time series allowed for the use of 27 unique PREC base stations (15 **HIDEN**, 9 **BASINS**, 2 **COOP**, and 1 **AWDN**) to provide comprehensive spatial coverage of the watershed (Figure 7).

Point Sources

Total monthly discharge data were provided by MPCA, IADNR, and the South Dakota Department of Environment and Natural Resources (SDDENR) for 56 point-source facilities within the watershed and are provided in Table 1 (major facilities are listed in bold). These data were processed into daily time series by distributing the total discharge from each source throughout the month. If a facility had multiple outfalls, the loads were summed to reduce the amount of input time-series data. Each time series was then assigned to its corresponding reach and loaded into a WDM to be called by the model in the external sources block of the UCI.

Calibration

Observed discharge time series were obtained for comparison to simulated discharge during model calibration. Observed discharge data were obtained as daily time series from the USGS and the MNDNR. Each time series was complete for its period of record. A summary of gage selection is provided in Table 2. Each calibration discharge time series was assigned to its corresponding reach and loaded into the WDM developed to store observed data as well as the model outputs to facilitate model calibration.

Table 1. Point Source Summary (Major Point Sources Are Indicated in Bold) (Page 1 of 2)

Model Application	Site ID	Facility Name	Reach
Big Sioux River	MNG580195	Heartland Colonies Residential WWTP[(a)]	10
Big Sioux River	MN0064351	Lincoln Pipestone Rural Wtr Holland Well	30
Big Sioux River	MNG580192	Woodstock WWTP	107
Big Sioux River	MN0054801	Pipestone WWTP	130
Big Sioux River	MNG790055	Clipper Oil Bassett Texaco	241
Big Sioux River	MNG580026	Jasper WWTP	245
Big Sioux River	SD0000299	USGS–EROS Data Center	310
Big Sioux River	SD0022560	City of Garretson	317
Big Sioux River	MN0003981	TYSON FOODS	375
Big Sioux River	MNG580055	Beaver Creek WWTP	379
Little Sioux River	IA3045001	Lake Park City of STP[(b)]	142
Little Sioux River	IA7128001	Hartley City of STP	241
Little Sioux River	IA7222001	Harris City of STP	231
Little Sioux River	**IA3050901**	**Iowa Great Lakes Sanitary District STP**	**174**
Little Sioux River	IA2100100	Corn Belt Power Cooperative–Wisdom Station	249
Little Sioux River	IA7239001	Ocheyedan City of STP	235
Little Sioux River	IA2166001	Royal City of STP	245
Little Sioux River	**IA2171004**	**Spencer City of STP**	**270**
Little Sioux River	IA7465001	Ruthven City of STP	275
Little Sioux River	IA2122001	Fostoria City of STP	263
Little Sioux River	IA3080001	Terril City of STP	271
Little Sioux River	IA2115001	Everly City of STP	243
Little Sioux River	IA2109001	Dickens Wastewater Treatment Facility	279
Little Sioux River	IA1175001	Sioux Rapids City of STP	330
Little Sioux River	IA2133001	Greenville City of STP	323
Rock River	MN0021270	Holland WWTP	10
Rock River	MN0023604	Hatfield WWTP	43
Rock River	MN0039748	Chandler WWTP	65
Rock River	MNG580011	Edgerton WWTP	90
Rock River	MNG580219	Leota Sanitary District WWTP	91
Rock River	MNG580194	Hardwick WWTP	121

Table 1. Point Source Summary (Major Point Sources Are Indicated in Bold) (Page 2 of 2)

Model Application	Site ID	Facility Name	Reach
Rock River	**MN0020141**	**Luverne WWTP**	**170**
Rock River	MNG640056	Luverne WTP–Plant 1	170
Rock River	MNG255020	LAND O' LAKES INC-LUVERNE	190
Rock River	MN0064033	Agri-Energy LLC	190
Rock River	MNG580190	Magnolia WWTP	199
Rock River	MNG640079	Rock County Rural WTP	210
Rock River	MNG580076	Lismore WWTP	273
Rock River	MNG580001	Adrian WWTP	285
Rock River	MNG580015	Ellsworth WWTP	301
Rock River	MNG580196	Hills WWTP	319
Rock River	MNG580199	Steen WWTP	319
Rock River	IA6055001	LESTER CITY OF STP	325
Rock River	IA6003001	ALVORD CITY OF STP	327
Rock River	IA6065001	ROCK RAPIDS CITY OF STP	330
Rock River	MNG580201	Rushmore WWTP	341
Rock River	MNG640080	RUSHMORE WTP	341
Rock River	IA6060001	LITTLE ROCK CITY OF STP	349
Rock River	IA6028001	GEORGE CITY OF STP	351
Rock River	MNG580224	Bigelow WWTP	353
Rock River	IA7245001	SIBLEY CITY OF STP	353
Rock River	IA7200108	POET BIOREFINING–ASHTON	357
Rock River	IA6015001	DOON CITY OF STP	367
Rock River	IA8444001	HULL CITY OF STP	369
Rock River	IA8482001	ROCK VALLEY CITY OF STP	390

(a) WWTP = Wastewater Treatment Plant
(b) STP = Sewage Treatment Plant

PERLND AND IMPLND CATEGORY DEVELOPMENT

This section describes the determination of the pervious and impervious land (PERLND and IMPLND) land-cover categories selected for explicit representation in the Missouri River Watershed model applications. The PERLND and IMPLND blocks of the UCI file contain the majority of the parameters that describe the way that water flows over and through the watershed. Therefore, the objective of this task was to separate the watershed into unique land segments using spatial 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 categorization included drainage patterns, meteorological variability, land cover, soil properties, and agricultural practices.

Table 2. Summary of Flow Gage Data

Model Application	Source	Site I.D.	Reach	Longitude	Latitude	Period of Record
Big Sioux River	MNDNR	H82042001	70	–96.403	44.024	2004
Big Sioux River	MNDNR	H82035001	105	–96.307	44.003	1999–2009
Big Sioux River	MNDNR	H82015001	270	–96.437	43.777	2008–2009
Big Sioux River	USGS	6482610	350	–96.565	43.616	2001–2009
Little Sioux River	USGS	6605000	251	–95.211	43.128	1995–2009
Little Sioux River	USGS	6605850	350	–95.243	42.896	1995–2009
Rock River	MNDNR	H83027001	130	–96.164	43.718	1998–2009
Rock River	MNDNR	H83016001	170	–96.201	43.654	1995–2009
Rock River	USGS	6483290	310	–96.165	43.423	2001–2009
Rock River	USGS	6483500	370	–96.294	43.214	1995–2009

Delineating 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 land segments and allowed for accurately representing hydrologic processes while reducing computational demands. As with the reaches and subwatersheds, a numbering scheme was developed to identify unique pervious and impervious land segments. The PERLND and IMPLND operation numbers in HSPF are limited to three digits and can range from 1 to 999. The 100s and 10s place of each PERLND or IMPLND category was selected to reflect the hydrozone in which the unique land segment was located. The 1s place of each PERLND or IMPLND corresponded to land cover, soil, and agricultural characteristics. These characteristics were systematically classified and combined to create unique pervious and impervious land segment categories to diversify and manage model parameterization. Procedures for determining the PERLND and IMPND categories within each hydrozone are described below.

The National Land Cover Database (NLCD) was used as the basis for the PERLND and IMPLND classification within each hydrozone. Water movement 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, anthropogenic practices (e.g., manure application, tillage, and artificial drainage) that 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 NLCD 2001 version 2 and NLCD 2006 in the PERLND and IMPLND development process. 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 directly comparing NLCD 1992 to later versions because of differences in image processing techniques. NLCD 2006 was used for calibration during the entire modeling period (1995–2009) and NLCD 2001 was used for validation during the early portion of the simulation period (1995–2003).

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 within the modeled area in the NLCD 2001 and 2006, as illustrated in Figure 8 were aggregated into relatively homogeneous model categories, as illustrated in Figure 9. Cropland was the predominant land cover class in the Missouri River Watershed. Because this land cover class accounted for approximately 80 percent of the total area, it was further segmented to represent distinct soil properties and agricultural practices within the watershed. The remainder of the Missouri River Watershed is composed of wetlands, forest, pasture, grassland, and developed area. Because of the relatively small areas represented by each of these classes, they were aggregated. The Missouri River Watershed has few lakes, and during the lake selection process, a number of smaller lakes with little data available were chosen to be modeled with the wetland land cover class.

The PERLND and IMPLND categorization for the Big Sioux River model application was previously developed and, therefore, has a different land cover aggregation scheme than the Little Sioux River and Rock River model applications. The main difference is that the grassland and forest model categories for the Big Sioux River model application were aggregated into the pasture model category because most of this land is grazed by cattle. Land cover aggregation for the model applications is illustrated in Table 3 (Big Sioux River) and Table 4 (Little Sioux River and Rock River).

The impervious area was represented using the NLCD 2001 version 2 and NLCD 2006 Percent Developed Imperviousness from the MRLC. The data represent mapped impervious area (MIA) and were used to determine the effective impervious area (EIA) using the following equation from Sutherland [1995][3]:

$$EIA = 0.1\left(MIA\right)^{1/2} \tag{4}$$

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 does 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 land cover class into developed pervious and impervious categories.

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

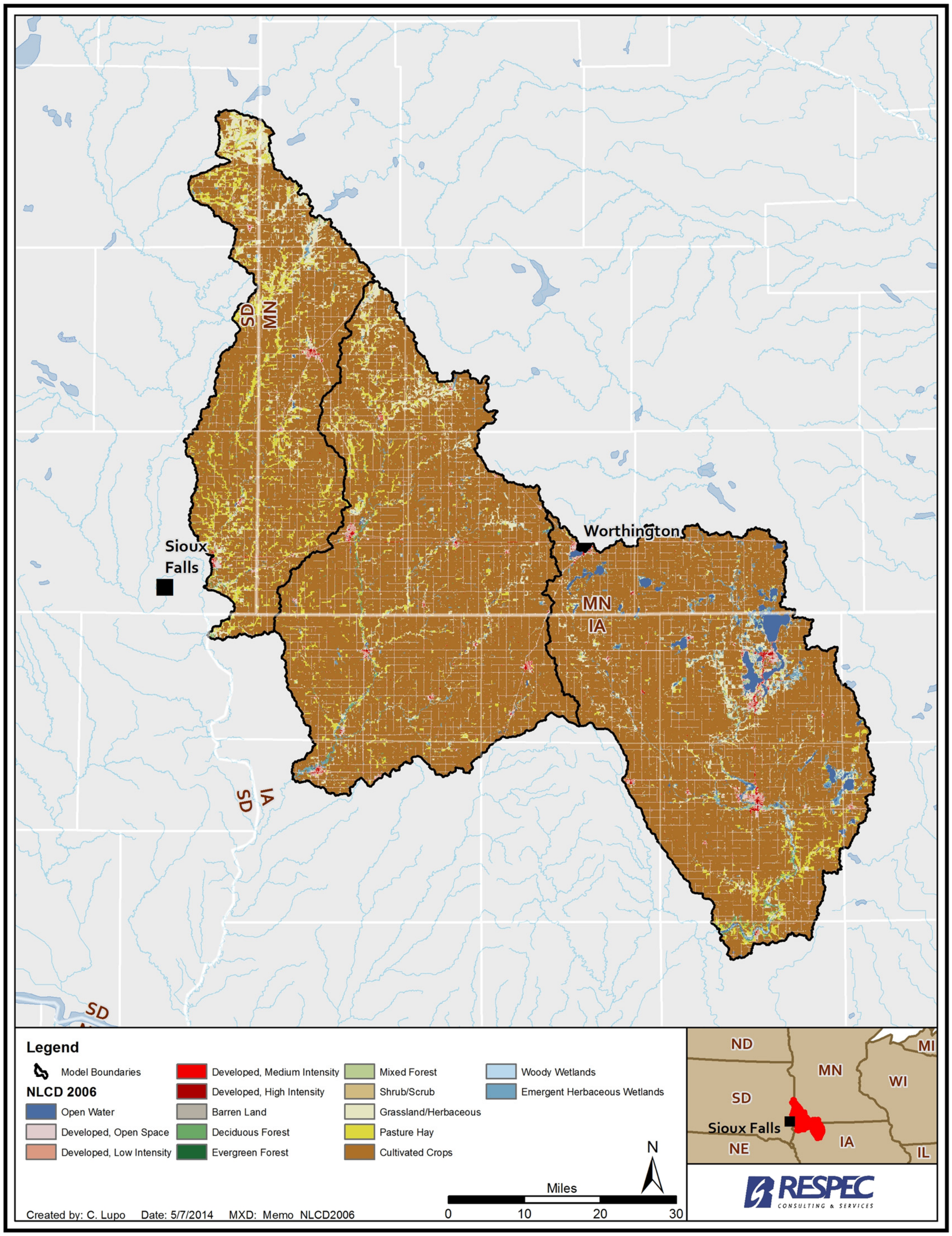

Figure 8. National Land Cover Database 2006 Land Cover Distribution Used to Develop Model Land Cover Categories.

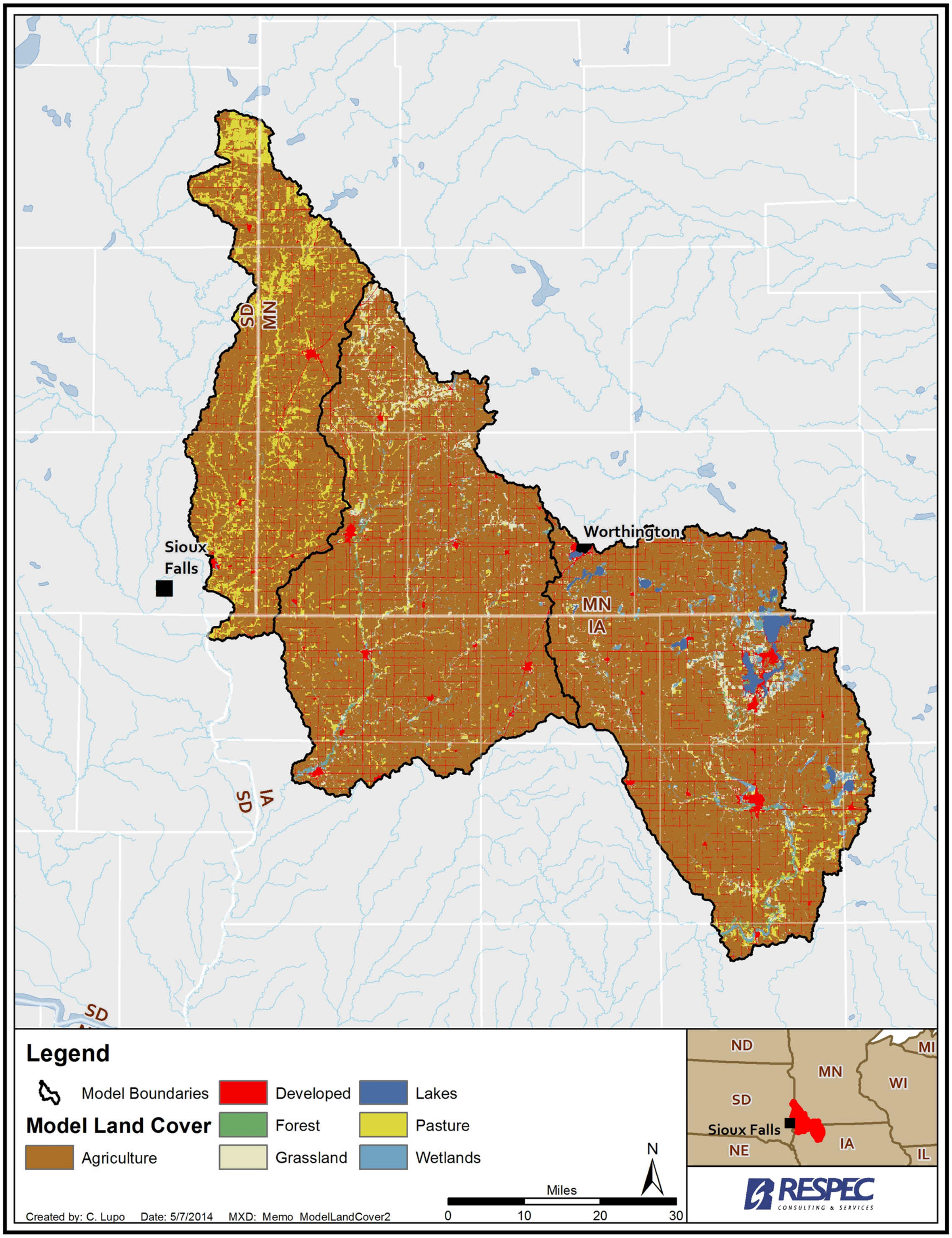

Figure 9. Aggregated Land Cover Categories Used in the Missouri River Watershed.

Table 3. Summary of 2001 and 2006 National Land Cover Database Categories Aggregated Into Model Categories for the Big Sioux River Model Application

NLCD Category	Percent of Watershed (2001)	Percent of Watershed (2006)	Model Category	Percent of Watershed (2001)	Percent of Watershed (2006)
Developed, Open Space	4.85	4.81	Developed	5.53	5.50
Developed, Low Intensity	0.47	0.46			
Developed, Medium Intensity	0.17	0.19			
Developed, High Intensity	0.04	0.04			
Barren Land	0.04	0.04	Pasture	20.34	20.16
Shrub/Scrub	0.01	0.06			
Grassland/ Herbaceous	10.22	10.02			
Deciduous Forest	0.73	0.72			
Evergreen Forest	0.00	0.00			
Mixed Forest	0.00	0.00			
Pasture/Hay	9.35	9.32			
Cultivated Crops	73.18	73.39	Cropland	73.18	73.39
Woody Wetlands	0.00	0.00	Wetland	0.95	0.95
Herbaceous Wetlands	0.80	0.79			
Open Water	0.14	0.16			

Soil properties within the Missouri River Watershed were also examined in conjunction with land cover to guide PERLND categorization, because soil type can significantly affect 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 and the NRCS Soil Data Viewer to investigate the soil distribution within the watershed and determine runoff potential. Maps were created to identify the spatial extent of the primary hydrologic soil groups (HSG), A, B, C, and D, which represent well-drained to poorly drained soil. Some soils within the watershed received a dual classification (i.e., A/D, B/D, or C/D), implying that the soil will respond like the poorly drained soil 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, as illustrated in Figure 10. Soils with a dual classification were given the class of the lower runoff potential soil (e.g., A for A/D soils) because they were primarily located in the cropland land cover class, where it was assumed that producers work to maintain ideal soil moisture conditions through practices such as irrigation, artificial drainage, tillage, and manure application. Soils that were classified as not rated were grouped with the high runoff potential soils because they typically represent open water or developed areas. Approximately 70 percent of the Big Sioux River Watershed was classified as A/B (low runoff potential) soils, and 70 percent of the Little Sioux River and Rock River Watershed was classified as C/D (high runoff potential) soils. The wetland and developed areas make up a small portion of the watershed and are typically categorized as having high runoff potential. The remaining categories (grassland, pasture, and forest) also make up a small portion of the watershed, and it is assumed that agricultural practices supersede the effects of HSG on croplands. Therefore, the soil distribution analysis did not result in additional PERLND categories; rather, it will serve to guide model parameterization and calibration.

Table 4. Summary of 2001 and 2006 National Land Cover Database Categories Aggregated Into Model Categories for the Little Sioux River and Rock River Model Applications

NLCD Category	Percent of Watershed (2001)	Percent of Watershed (2006)	Model Category	Percent of Watershed (2001)	Percent of Watershed (2006)
Developed, Open Space	5.34	5.27	Developed	6.54	6.50
Developed, Low Intensity	0.80	0.85			
Developed, Medium Intensity	0.33	0.31			
Developed, High Intensity	0.06	0.07			
Barren Land	0.05	0.06	Grassland	5.17	5.25
Shrub/Scrub	0.12	0.12			
Grassland/ Herbaceous	4.99	5.07			
Deciduous Forest	0.50	0.51	Forest	0.97	0.99
Evergreen Forest	0.002	0.003			
Mixed Forest	0.47	0.48			
Pasture/Hay	2.83	2.86	Pasture	2.83	2.86
Cultivated Crops	81.05	81.18	Cropland	81.05	81.18
Woody Wetlands	0.08	0.08	Wetland	2.41	2.19
Herbaceous Wetlands	1.78	1.66			
Open Water	0.56	0.46			

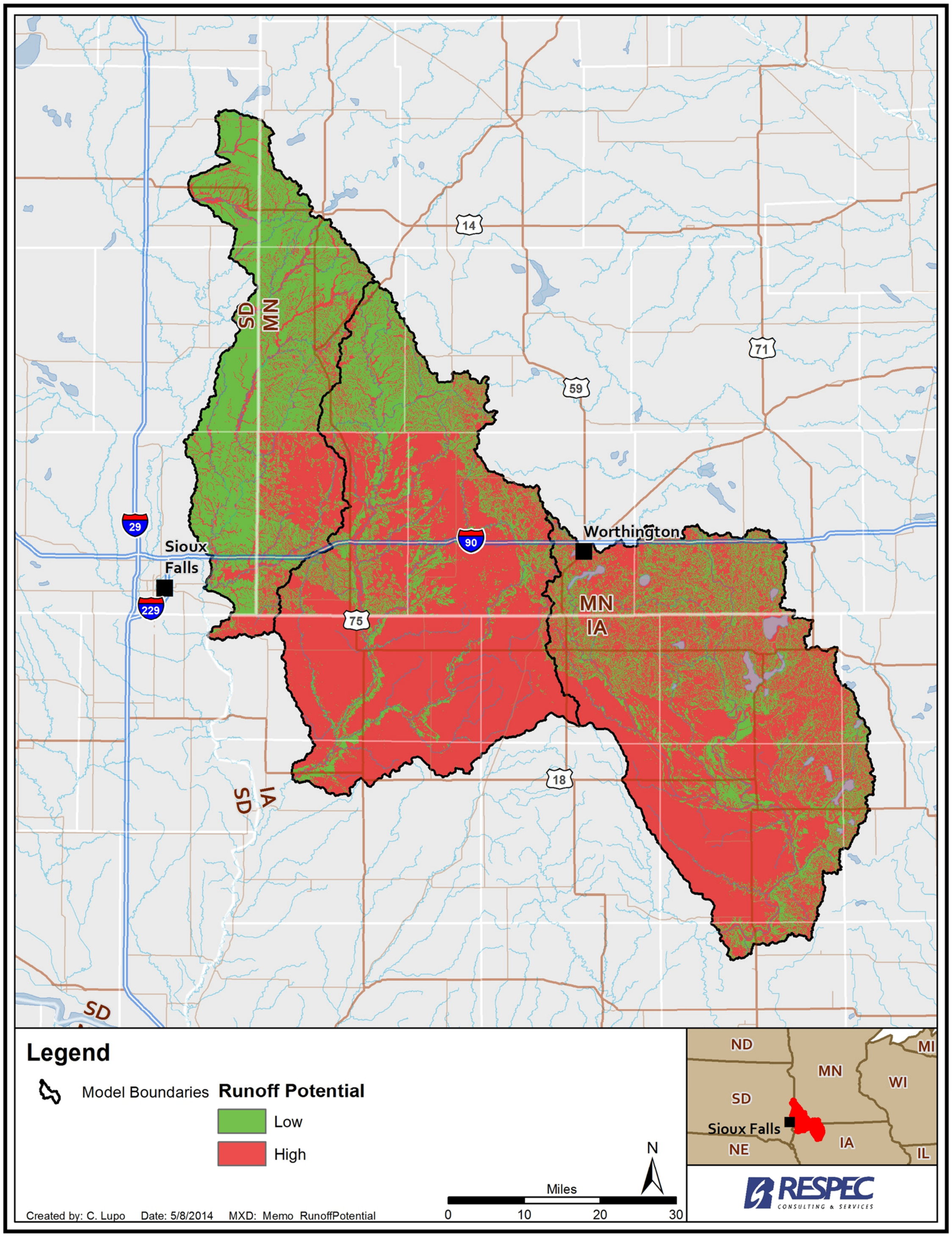

Figure 10. Distribution of Runoff Potential in the Missouri River Watershed.

Because the dominant land cover class within the Missouri River Watershed is cropland, representation of agricultural practices within the model application was necessary. The agricultural practices incorporated in the PERLND development procedures include tillage and animal feedlot operations (AFOs). These practices were selected for explicit representation not only for their influence on hydrologic and water-quality processes, but also for their future use in modeling management scenarios.

Minnesota Tillage Transect Survey Data Center data are available by county (*http://mrbdc.mnsu.edu/minnesota-tillage-transect-survey-data-center*). These tillage surveys include total farmed area, total conventional tillage area, and total conservation tillage area in 1995–1998, 2000, 2002, 2004, and 2007. Conventional tillage is categorized by 30 percent or less residue remaining on the field and includes intensive-till and reduced-till practices. Conservation tillage is categorized by greater than 30 percent of residue remaining on the field and includes no-till, ridge-till, and mulch-till practices. Leaving residue on the fields can increase the upper zone storage capacity, which in turn can decrease runoff, impacting sediment and other water-quality processes. Tillage data were processed in ArcGIS to estimate weighted area fractions of conventional tillage versus conservation tillage for each subwatershed, as illustrated in Figure 11. When data were not available for a subwatershed, the total model area weighted average was applied.

There are an estimated 3,180 AFOs within the Missouri River Watershed, as illustrated in Figure 12. Whereas AFOs represent a small percentage of the total watershed area (0.27 percent), they are important to represent because of their potential to significantly impact water quality. The primary source of pollution from AFOs is manure, which introduces oxygen-demanding substances, ammonia, nutrients, solids, and bacteria into the surrounding waterbodies through accumulation and wash-off processes. Also, reduction in vegetation and densely packed subsurface soils resulting from concentrated animal grazing can lower infiltration rates and increase sediment erosion. Spatial location (point features) and animal data (e.g., type and count) for the AFOs were obtained from the MPCA and IADNR for the Minnesota and Iowa portions of the Missouri River Watershed, respectively. For the South Dakota portion of the watershed, polygon features were digitized using data obtained from the SD DENR and by visual inspection. Areas for each AFO were estimated based on the typical design specification of 300 square feet per animal unit [Murphy and Harner, 2001][4]. The individual calculated areas were shifted from the land category where each AFO is located to the feedlot category. There is currently one regulated Municipal Separate Storm Sewer Systems (MS4) located in the northwest portion of the Little Sioux River Watershed (Worthington City MS4–MS400257), and was represented in the model application (Figure 12). The area was parameterized the same as non-MS4 areas within the same land classification, but were given different mass links in the schematic block. This method was selected because modeling scenarios with MS4s is still possible but does not need the input of additional operations.

4 **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.

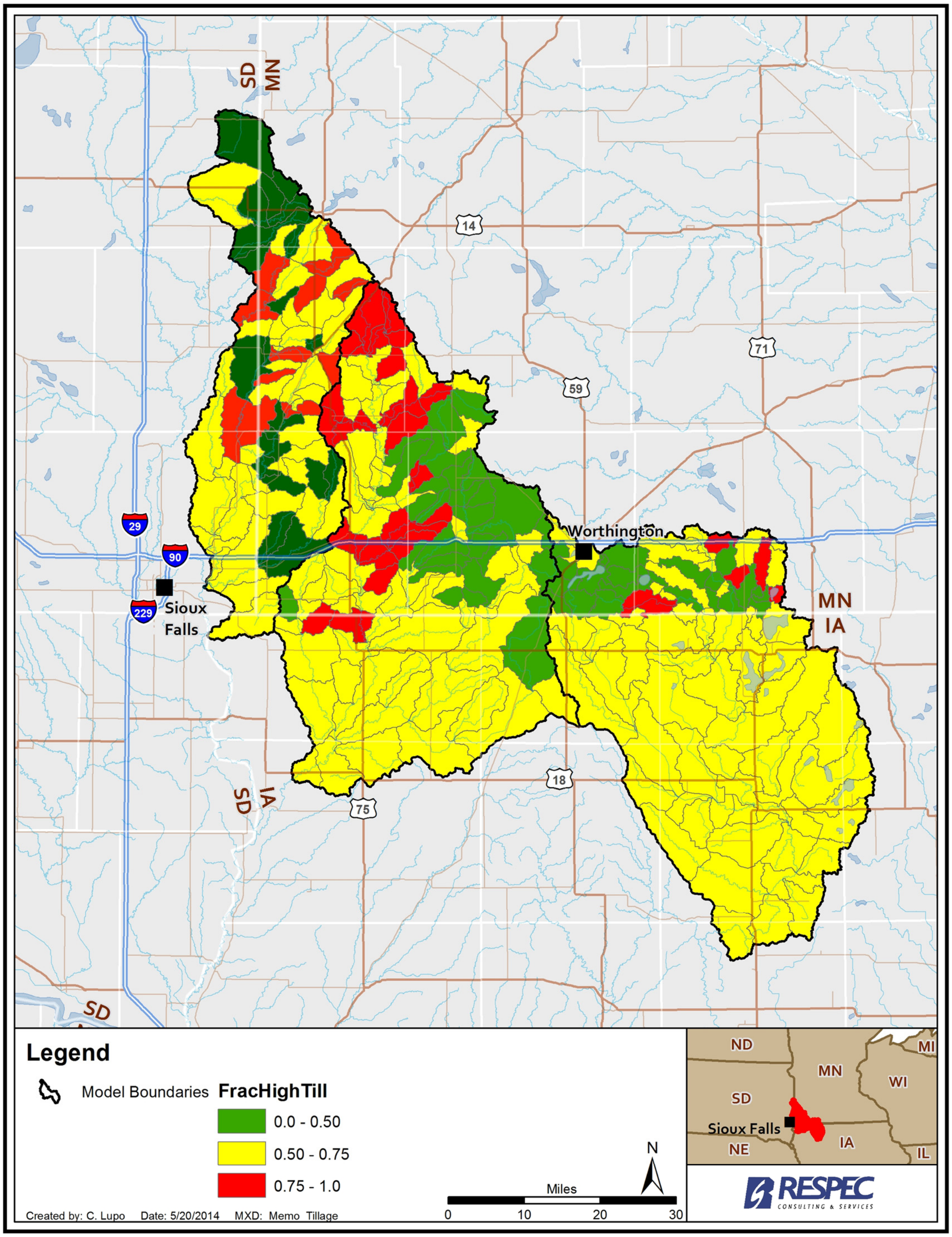

Figure 11. Percent Tillage Estimates Within Each Subwatershed in the Missouri River Watershed.

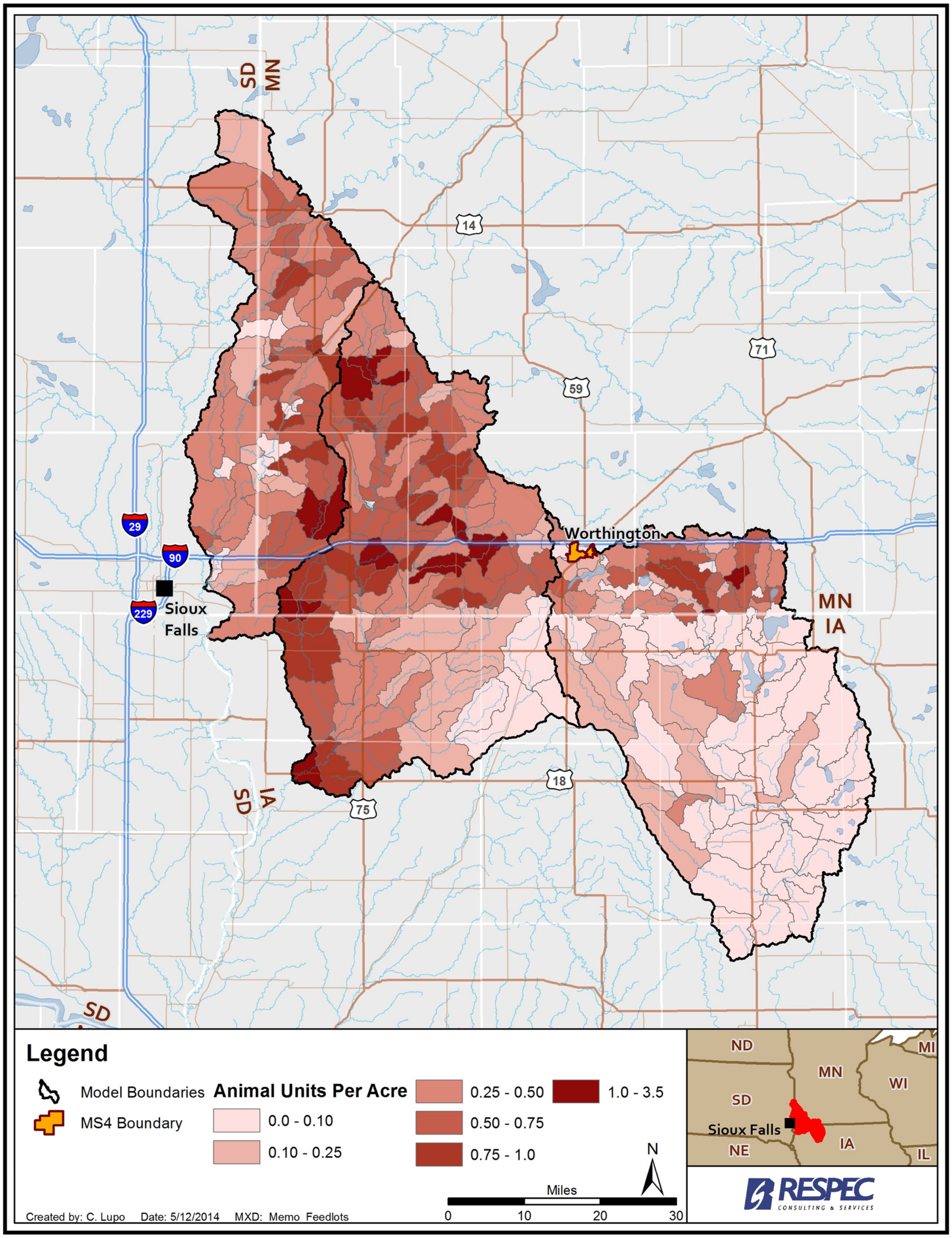

Figure 12. Animal Unit Density Within Each Subwatershed and the MS4 in the Missouri River Watershed.

Unique pervious and impervious classifications were developed using the watershed characteristics and the separate classification methods for the Big Sioux River Watershed, illustrated in Figure 13, and the Little Sioux River and Rock River Watersheds, illustrated in Figure 14. NLCD categories were aggregated into model land cover categories, developed areas were divided into pervious and impervious classifications, and cropland was divided into conventional and conservation tillage classifications. This process resulted in eight unique pervious land cover classifications and one impervious classification for the Little Sioux River and Rock River watersheds (Figure 13).

For the Big Sioux River Watershed, several additional pervious land categories were created based on the development of riparian zones. Riparian buffer distances were based on the NHD stream order attribute: 30 meters for first and second order streams, 50 meters for third order streams, 100 meters for fourth order streams, and 200 meters for fifth order streams. This process resulted in ten unique pervious land cover classifications and one impervious classification (Figure 13).

SUMMARY

The Missouri River Watershed was delineated into subwatersheds, and a reach network was defined to represent drainage properties within the basins. 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 by using lake and reach properties to allow the model to route water effectively through the system. Twenty-seven 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 watershed characteristics (Figure 11). The 27 hydrozones, combined with the ten land characteristic classifications in the Big Sioux River model application and eight land characteristic classifications in the Little Sioux River and Rock River model applications, created a total of 482 possible pervious land segment operations. Initial parameters were based on existing model applications. Finally, PERLND and IMPLND land segments were linked to corresponding reaches in the model schematic, which resulted in a completed model application to represent hydrology within the Missouri River Watershed.

Thank you for your time in reviewing the methods for the development of the UCI and WDM files for the Missouri River Watershed **HSPF** model application. We are available to discuss the contents of this memorandum with you and appreciate any feedback you may have.

Sincerely,

Seth Kenner
Staff Engineer

MPB:mjb

cc: Project Central File 2216 — Category A

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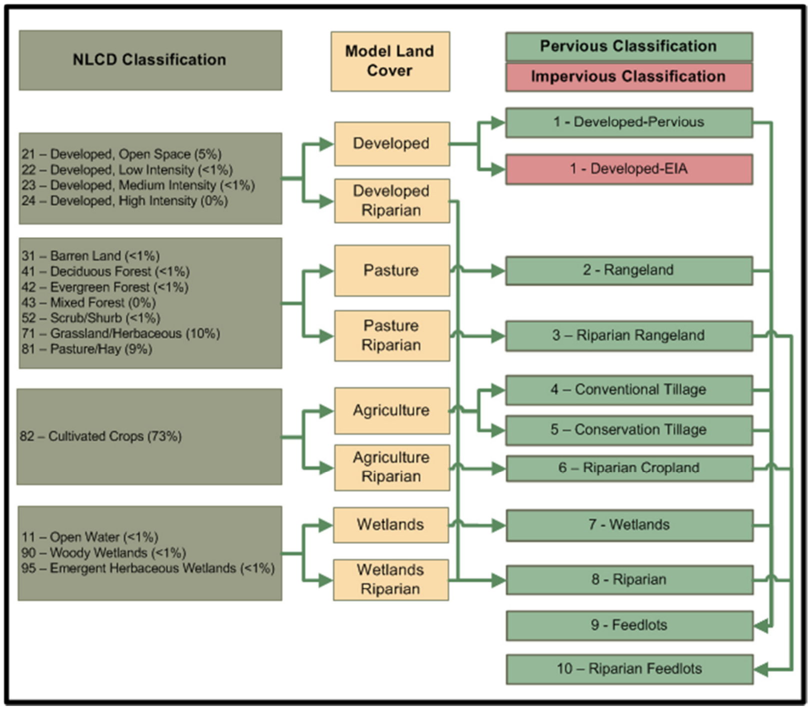

Figure 13. Model Classification for PERLND and IMPLND Development for the Big Sioux River Watershed.

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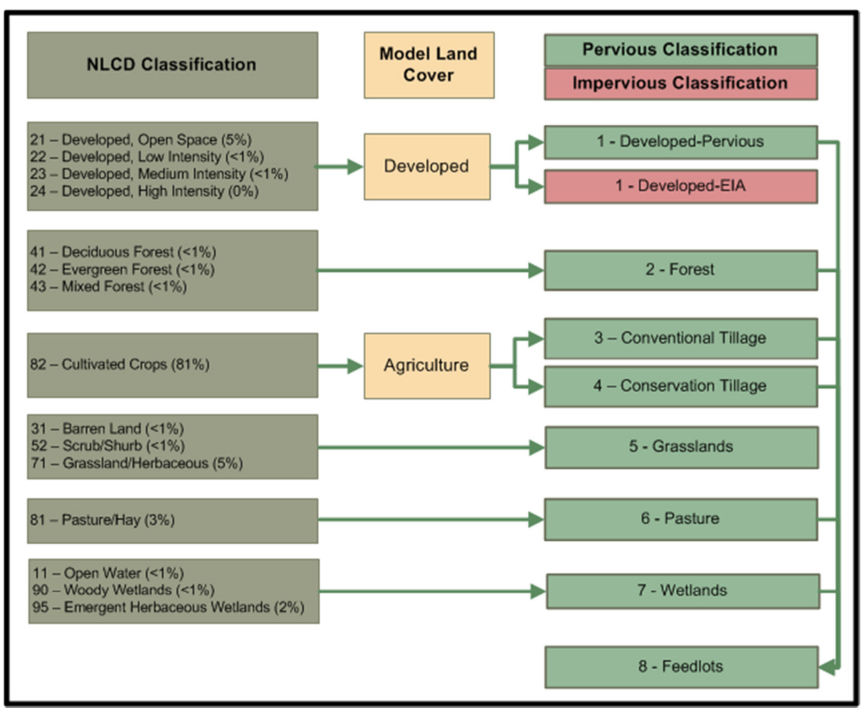

Figure 14. Model Classification for PERLND and IMPLND Development for the Little Sioux River and Rock River Watersheds.

ATTACHMENT A

MODEL APPLICATION REACHES AND SUBWATERSHEDS

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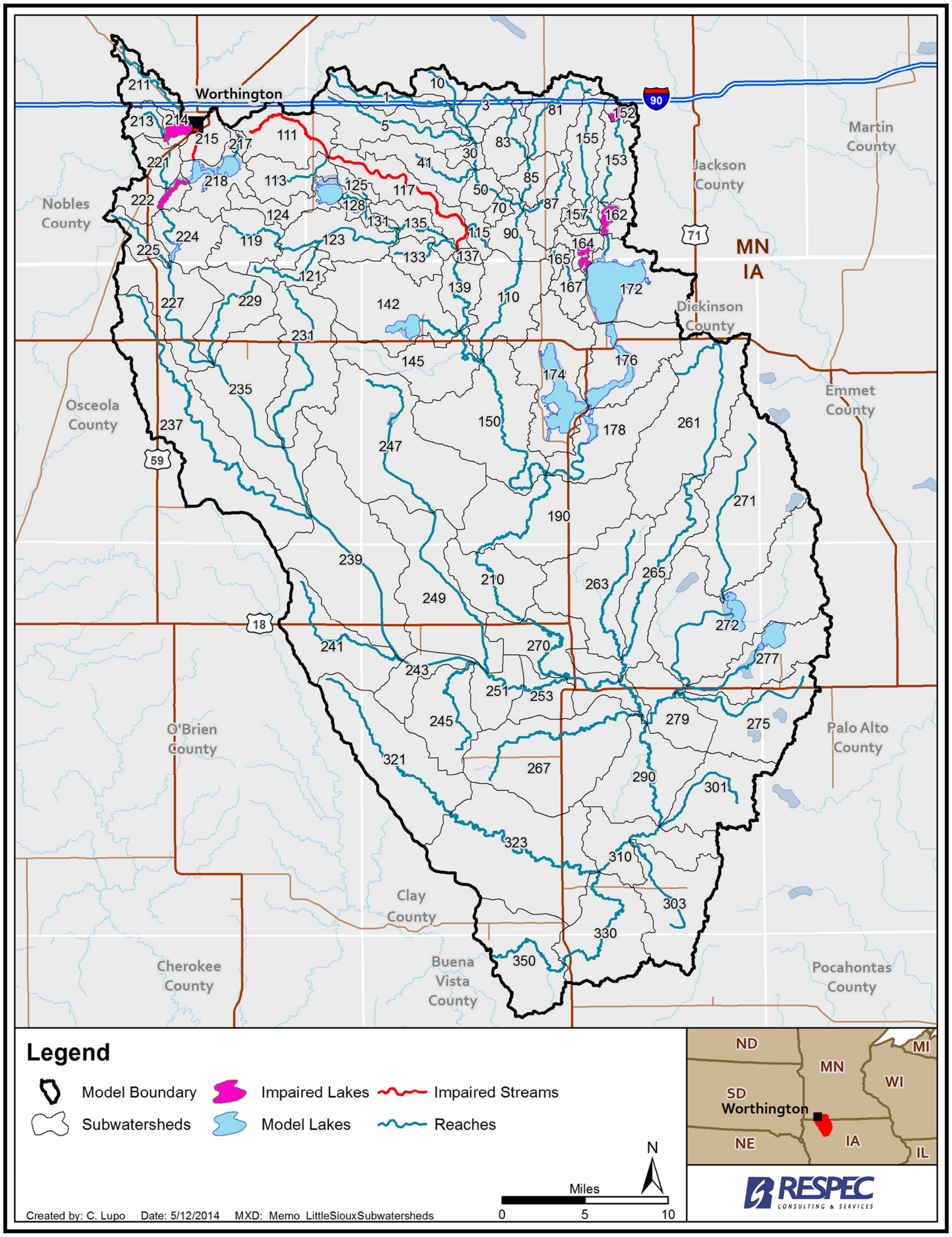

Figure A-1. Little Sioux Watershed Reach and Subwatershed I.D.s.

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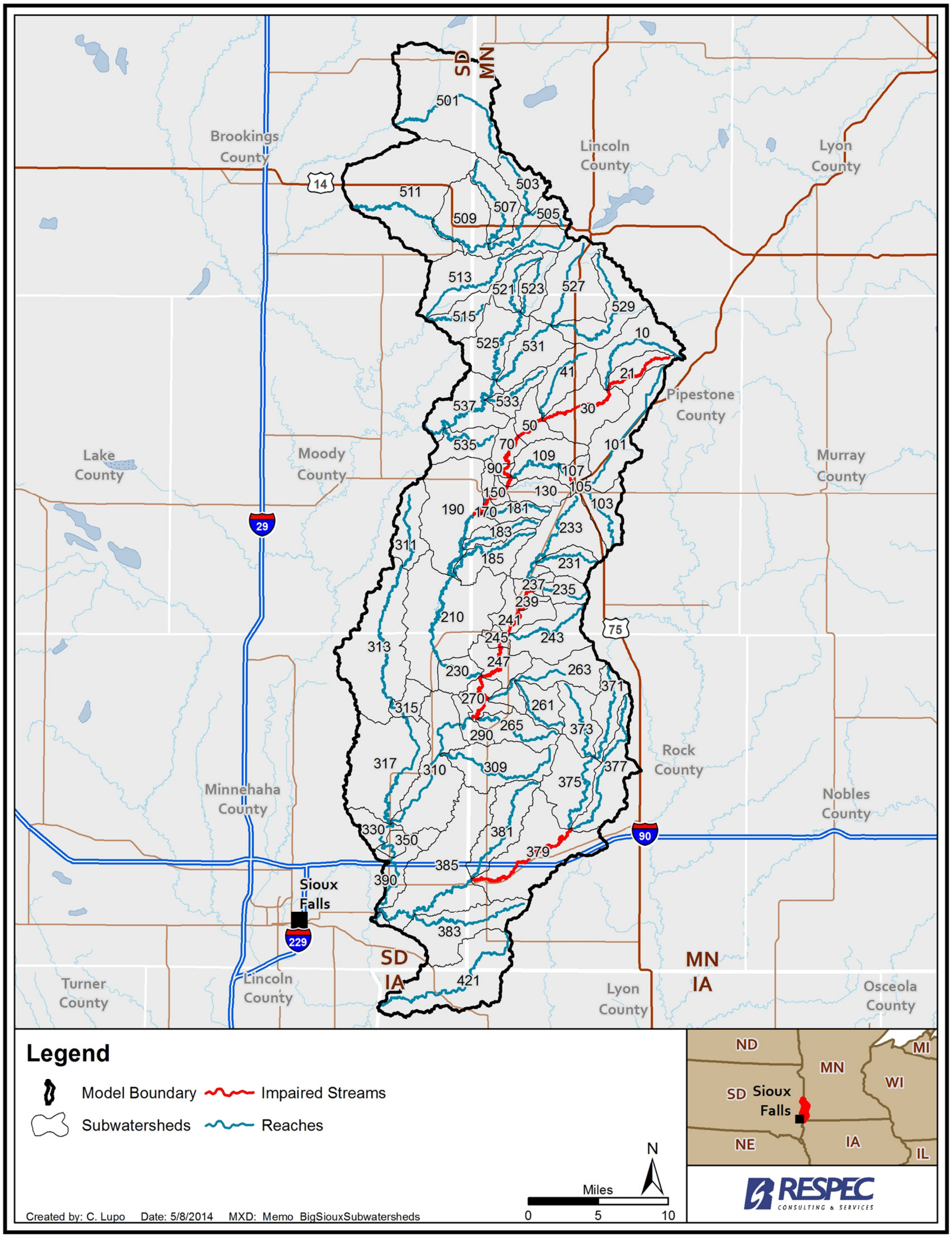

Figure A-2. Big Sioux Watershed Reach and Subwatershed I.D.s.