Appendix A – NPDES Wastewater Discharger DMR Summaries

Table A-1. Fecal coliform DMR summary.

Major Watershed	Facility	ID #	Months sampled since 2005 [count]	Minimum Monthly Fecal Coliform Geomean [cfu/100 ml]	Maximum Monthly Fecal Coliform Geomean [cfu/100 ml]	Sampled months with fecal coliform >200 cfu/100 ml since 2005 [count]	Average Monthly Fecal Coliform Geomean [cfu/100 ml]
Lower Big Sioux	Beaver Creek WWTP	MNG58005	27	<1	607	1	33
Lower Big Sioux	Jasper WWTP	MNG58002	28	1	35	0	8
Lower Big Sioux	Lake Benton WWTP	MN0023884	6	2	48	0	23
Lower Big Sioux	Pipestone WWTP	MN0054801	47	5	1,438	4	88
Lower Big Sioux	Brethern WWTP	MNG56019	11	10	530	1	80
Little Sioux	Round Lake WWTP	MNG580198	32	<1	129	0	18
Rock River	Magnolia WWTP	MNG580190	32	<1	158	0	14
Rock River	Hills WWTP	MNG580196	55	1	487	5	61
Rock River	Rushmore WWTP	MNG580201	34	<1	229	1	14
Rock River	Ellsworth WWTP	MNG580015	60	<1	257	1	27
Rock River	Adrian WWTP	MNG580001	56	2	200	6	37
Rock River	Wilmont WWTP	MNG580200	65	1	620	1	41
Rock River	Lismore WWTP	MNG580076	47	<1	167	0	17
Rock River	Hardwick WWTP	MNG580194	40	<1	376	1	17
Rock River	Edgerton WWTP	MNG580011	48	<1	414	1	29
Rock River	Chandler WWTP	MN0039748	40	4	247	1	41
Rock River	Woodstock WWTP	MNG580192	36	<1	136	0	36
Rock River	Holland WWTP	MN0021270	94	<1	1,274	12	96

Table A-2. TSS DMR summary.

Major Watershed	Facility	ID #	Months sampled since 2005 [count]	Minimum Monthly Average TSS Concentration [mg/l]	Maximum Monthly Average TSS Concentration [mg/l]	Sampled months with TSS greater than concentration limit [count]	Average Monthly TSS Concentration since 2005 [mg/l]
Little Sioux	Round Lake WWTP	MNG580198	43	2	57	0	20
Lower Big Sioux	Beaver Creek WWTP	MNG58005	37	3	63	0	27
Lower Big Sioux	Pipestone WWTP	MN0054801	61	4	53	0	27
Lower Big Sioux	Lincoln Pipestone Rural Holland Well	MN0064351	68	<1	34	0	4
Lower Big Sioux	Jasper WWTP	MNG58002	36	1	38	0	8
Rock River	Magnolia WWTP	MNG580190	35	<1	45	0	16
Rock River	Hills WWTP	MNG580196	81	<1	75	1	16
Rock River	Rushmore WWTP	MNG580201	46	3	160	2	16
Rock River	Ellsworth WWTP	MNG580015	76	1	111	1	16
Rock River	Adrian WWTP	MNG580001	86	2	332	9	37
Rock River	Wilmont WWTP	MNG580200	83	4	96	3	26
Rock River	Lismore WWTP	MNG580076	59	4	74	2	23
Rock River	Hardwick WWTP	MNG580194	60	1	54	0	15
Rock River	Edgerton WWTP	MNG580011	64	3	72	4	27
Rock River	Chandler WWTP	MN0039748	65	2	79	2	26
Rock River	Woodstock WWTP	MNG580192	48	7	82	3	36
Rock River	Holland WWTP	MN0021270	190	1	86	3	24

Appendix B – TSS Source Assessment

RUSLE Methodology

Average upland sediment loss in the impaired reach watersheds was modeled using the Revised Universal Soil Loss Equation (RUSLE). This model provides an assessment of existing soil loss from upland sources and the potential to assess sediment loading through the application of Best Management Practices (BMPs). RUSLE predicts the long term average annual rate of erosion on a field slope based on rainfall pattern, soil type, topography, land use and management practices. The general form of the RUSLE has been widely used in predicting field erosion and is calculated according to the following equation:

$$A = R \times K \times LS \times C \times P$$

Where A represents the potential long term average soil loss (tons/acre) and is a function of the rainfall erosivity index (R), soil erodibility factor (K), slope-length gradient factor (LS), crop/vegetation management factor (C) and the conservation/support practice factor (P). RUSLE only predicts soil loss from sheet or rill erosion on a single slope as it does not account for potential losses from gully, wind, tillage or streambank erosion.

For this exercise, it was assumed all agricultural practices are subject to maximum soil loss fall plow tillage methods and no support practices (P-factor = 1.00). Raster layers of each RUSLE factor were constructed in ArcGIS for the Lower Big Sioux, Little Sioux, and Rock River watershed study areas and then multiplied together to estimate the average annual potential soil loss for each grid cell. It is important to note that model results represent the maximum amount of soil loss that could be expected under existing conditions and have not been calibrated to field observations or observed/monitored data. Thus, results are intended to provide a first cut in identifying potential field erosion hot spots based on slope, landuse and soil attributes. Areas with high potential erosion should be verified in the field prior to BMP planning and targeting.

Channel Condition and Stability Index (CCSI)

The Channel Condition and Stability Index (CCSI) was evaluated at all invertebrate sampling sites in the Lower Big Sioux, Little Sioux, and Rock River Watersheds as part of the Missouri River Basin Monitoring and Assessment Study. The CCSI is intended to rate the geomorphic stability of the stream reach by evaluating three regions of the stream channel: upper banks, lower banks, and channel bottom. The CCSI provides an indication of stream channel geomorphic changes and loss of habitat quality, which may be related to changes in watershed hydrology, stream gradient, sediment supply, or sediment transport capacity. The CCSI was recently implemented in 2008, and was collected once at each biological station in the major watersheds. Consequently, the CCSI ratings are only available for biological stations sampled in 2010 or later, and therefore the CCSI has not been evaluated in every TSS impaired reach covered in this TMDL study. CCSI scoring ranges from 14 – 147 where lower scores indicate stable conditions and higher scores indicate unstable channel conditions. Below is the general guideline the MPCA uses to interpret CCSI scores:

Stable: 14–27
Fairly Stable: 28–45
Moderately unstable: 46–80
Severely unstable: 81–114
Extremely unstable: 115–14

Chlorophyll-a

In streams and rivers that receive high phosphorus loads from terrestrial sources, algal turbidity can be a major contributor to turbidity and TSS. Chlorophyll-a was measured at only one site, Split Rock Creek reach 512, in the Lower Big Sioux watershed (see table below). Average summer (June through September) chlorophyll-a in this reach is slightly below the State's eutrophication chlorophyll-a criteria of 35 µg/l for rivers and streams in the South River Nutrient Region. However, chlorophyll-a concentrations have exceeded state eutrophication criteria 55% of the time suggesting algal production may be source of turbidity and/or TSS, particularly during summer low flow conditions.

Average chlorophyll-a has been measured at one site (Little Sioux River reach 515) in the Little Sioux River Watershed and is typically below the State's chlorophyll-a criteria. Thus, algal production may not be a major contributor to turbidity and/or TSS in this particular reach. There have been no chlorophyll-a samples collected in the 11 TSS impaired watersheds in the Rock River Watershed. However, chlorophyll- a has been monitored at one site on Rock River reach 501, which is located downstream of several of the TSS impaired reaches in the Rock River watershed. Average chlorophyll-a concentration at this site is 32 µg/l and exceeded the state eutrophication criteria 32% of the time. This suggests algal production may be high in the impaired reaches upstream of this reach, particularly during summer low flow conditions. More chlorophyll-a monitoring in all of the TSS impaired reaches would help identify if algal turbidity is a major problem in these watersheds.

Table B-1. Available summer (June through September) chlorophyll-a data in the TSS impaired reaches covered in this TMDL study.

Major Watershed	Impaired Reach	EQUiS ID	Chl-a samples [count]	Minimum Chl-a [ug/l]	Maximum Chl-a [ug/l]	Average Chl-a [ug/l]	Samples > Chl-a criteria [percent]
Lower Big Sioux	Split Rock Creek reach 512	S004-528	11	7	73	33	55%
Little Sioux	Little Sioux River reach 515	S006-549	13	2	46	14	8%
Rock River	Rock River reach 501*	S000-097	34	3	117	32	32%

*This reach is located at the downstream end of the Rock River Watershed near the Minnesota-Iowa boarder and was covered as part of the Fecal Coliform and Turbidity TMDL Assessment for the Rock River Watershed, which was completed in 2008.

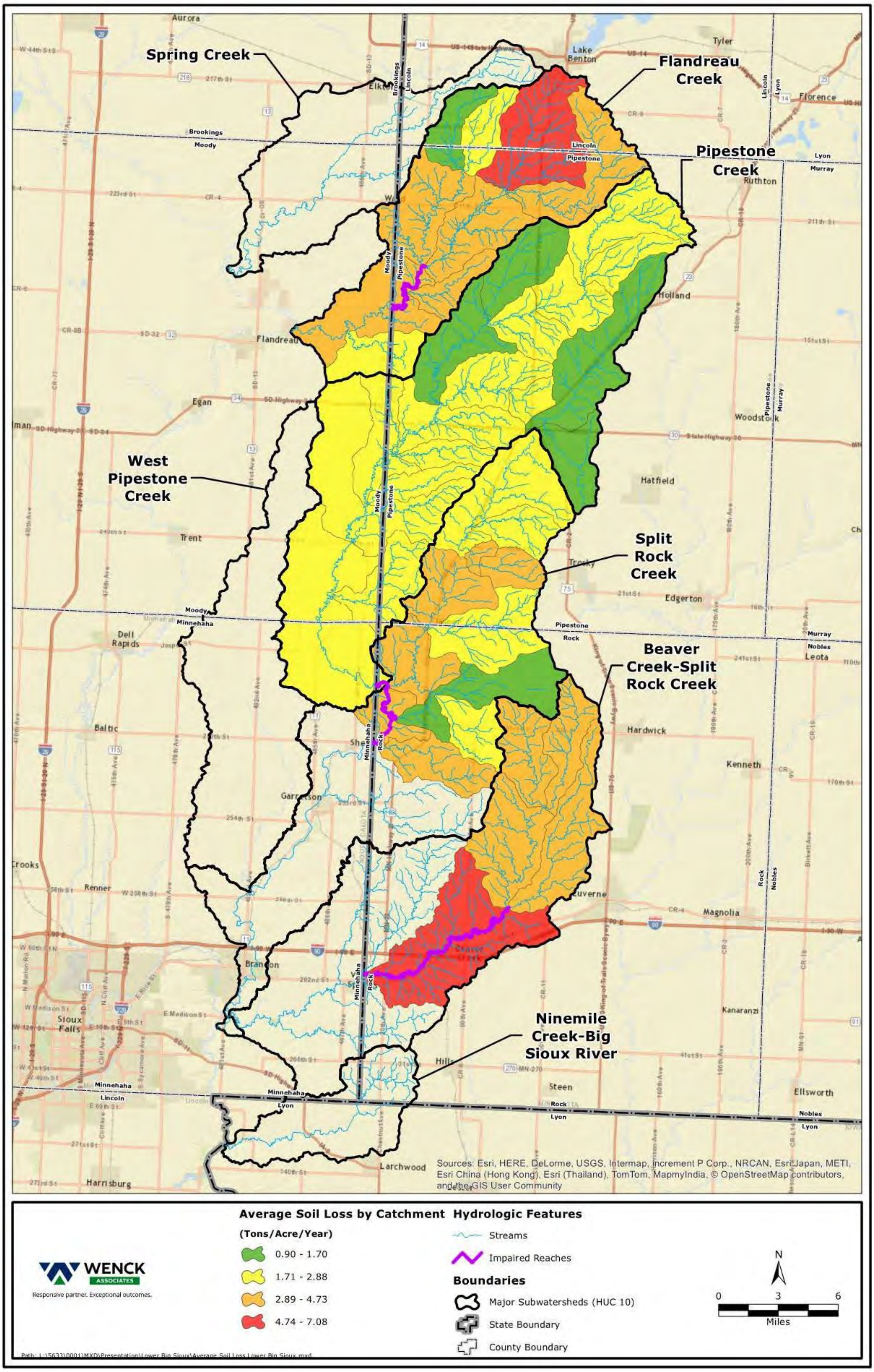


Figure B-1. Lower Big Sioux River Watershed potential soil loss (RUSLE) by subwatershed.

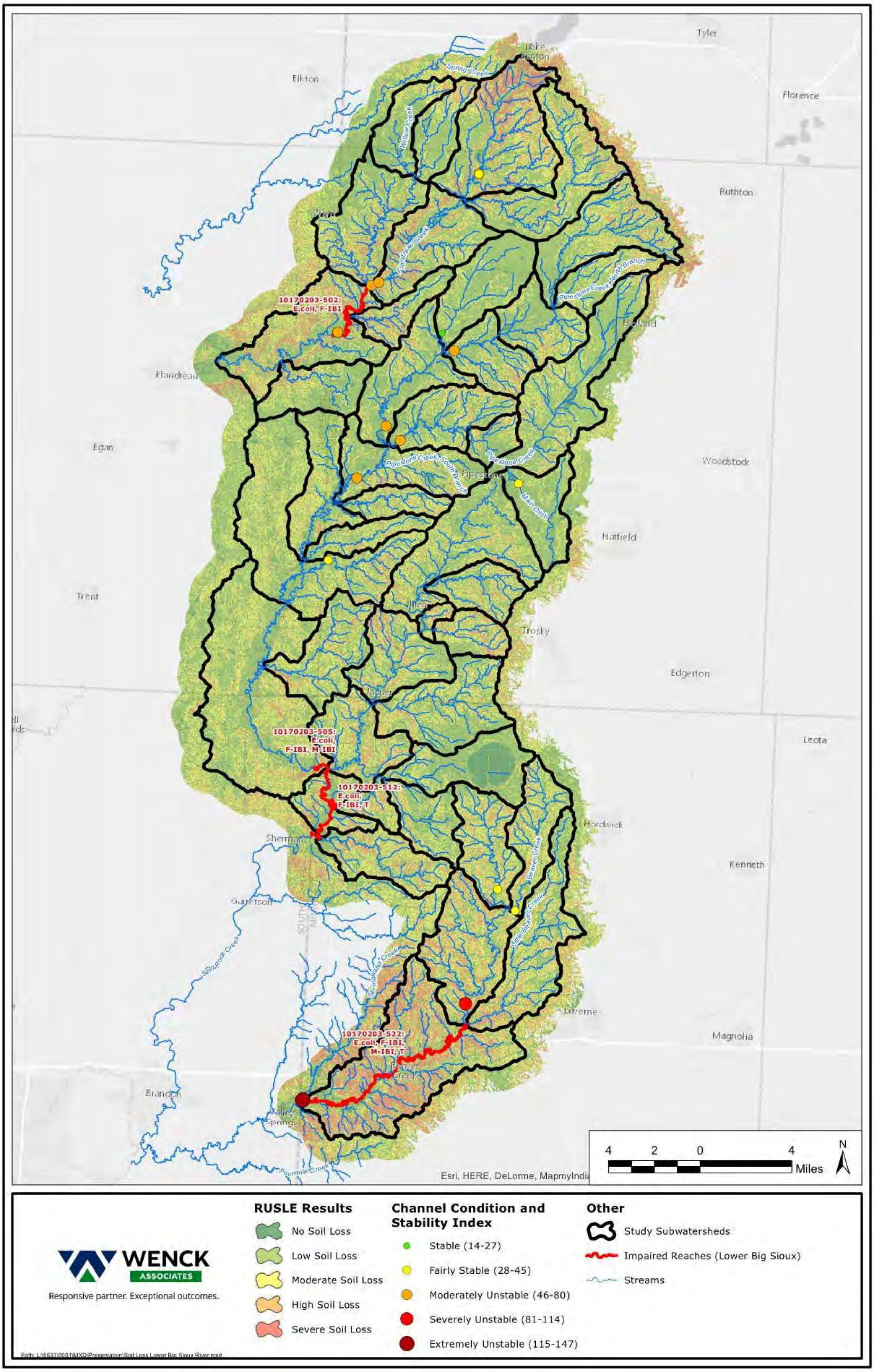


Figure B-2. Lower Big Sioux River Watershed potential soil loss (RUSLE).

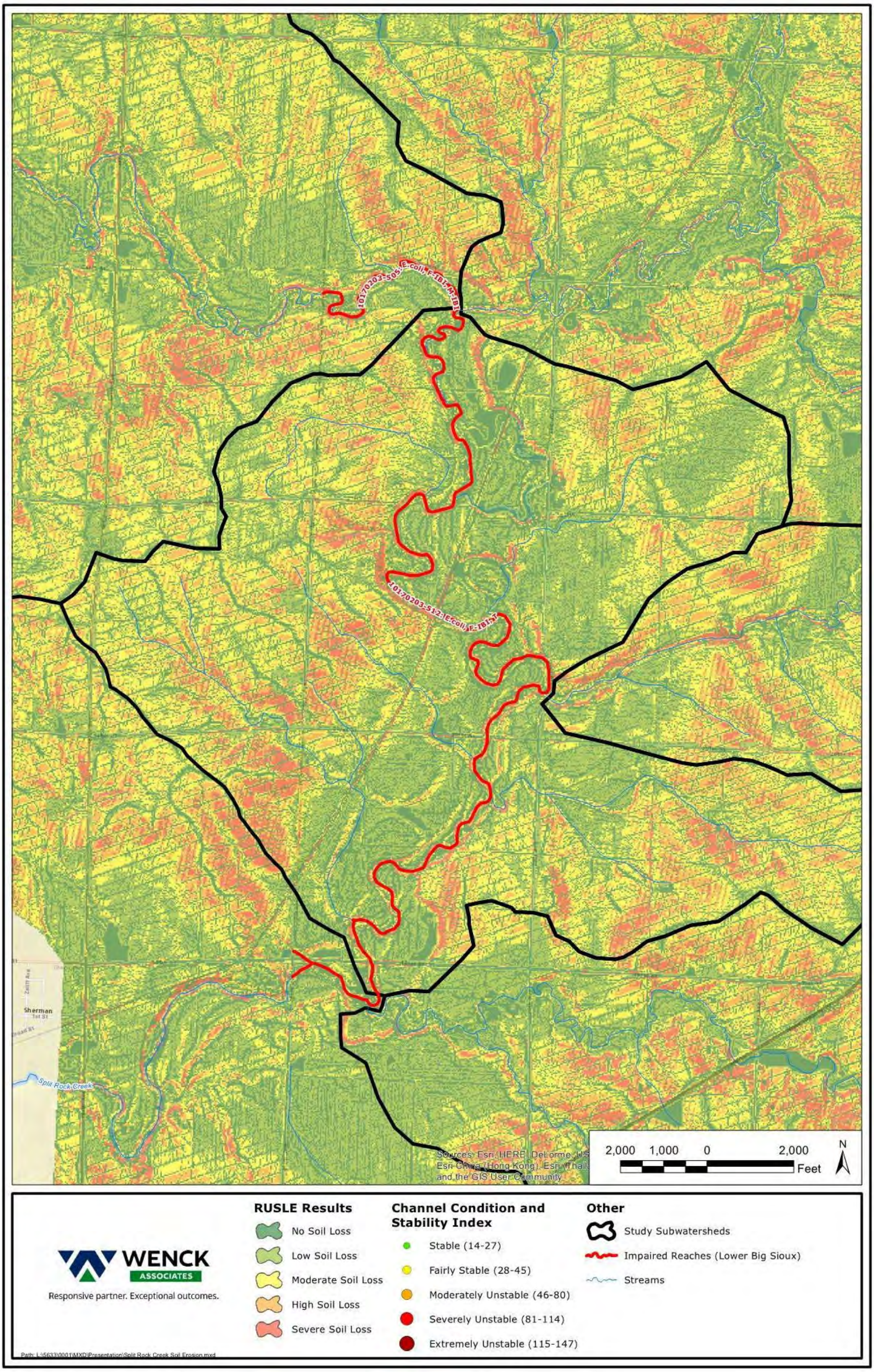


Figure B-3. Potential soil loss (RUSLE) in the Lower Big Sioux River Watershed Reach 512 (Split Rock Creek) direct watershed.

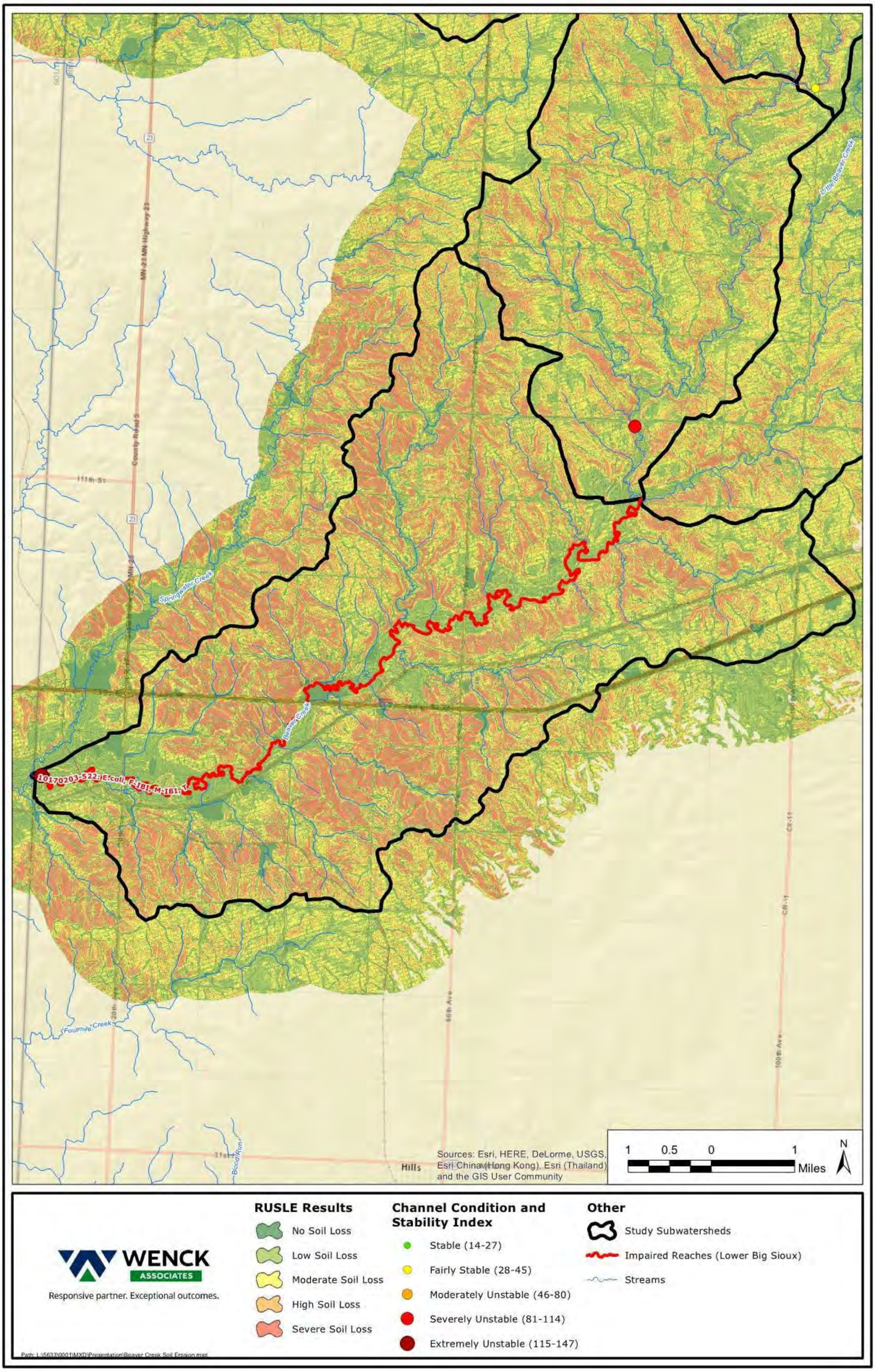
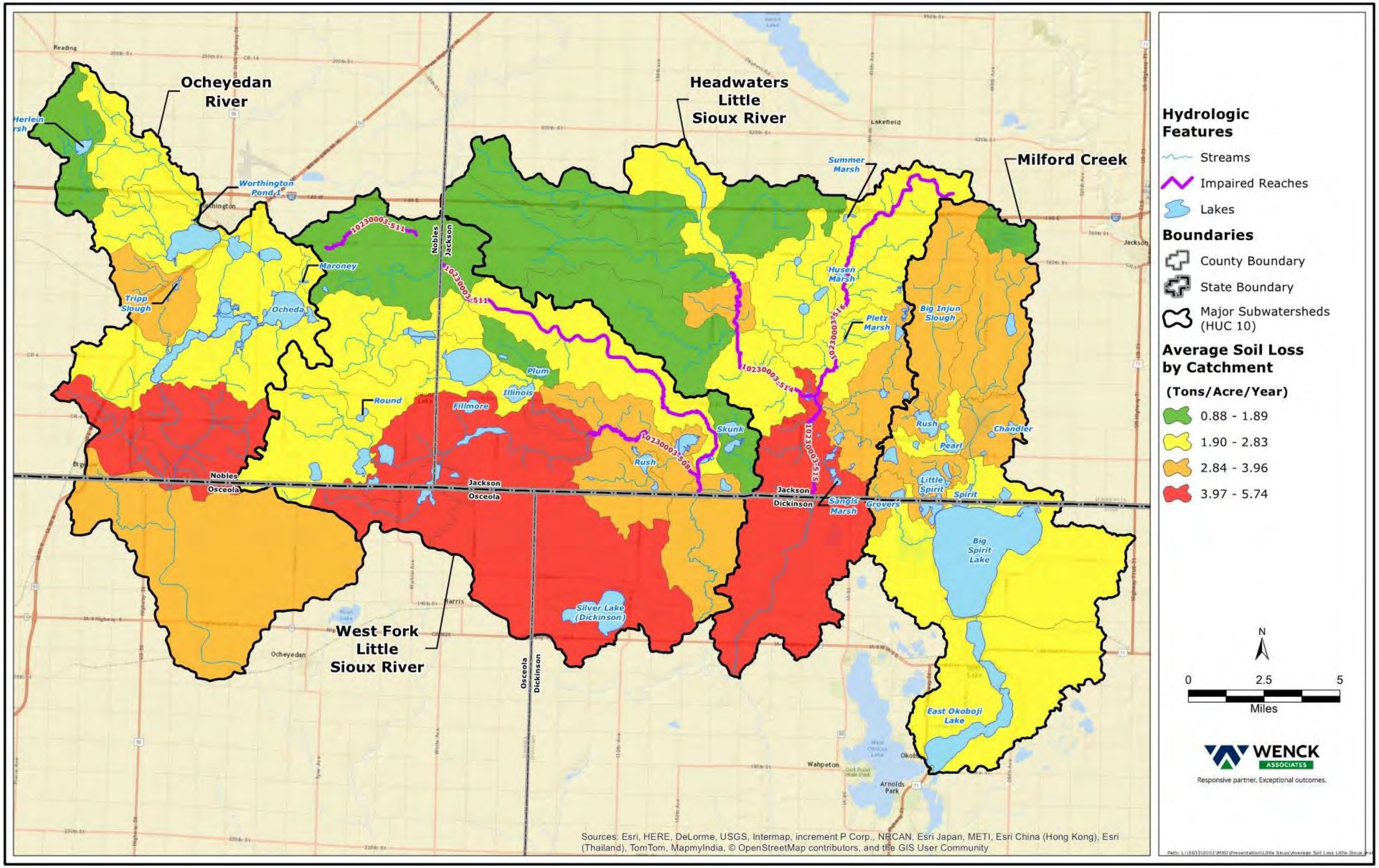


Figure B-4. Potential soil loss (RUSLE) in the Lower Big Sioux River Watershed Reach 522 (Beaver Creek) direct watershed.



Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Figure B-5. Little Sioux River Watershed potential soil loss (RUSLE) by subwatershed.

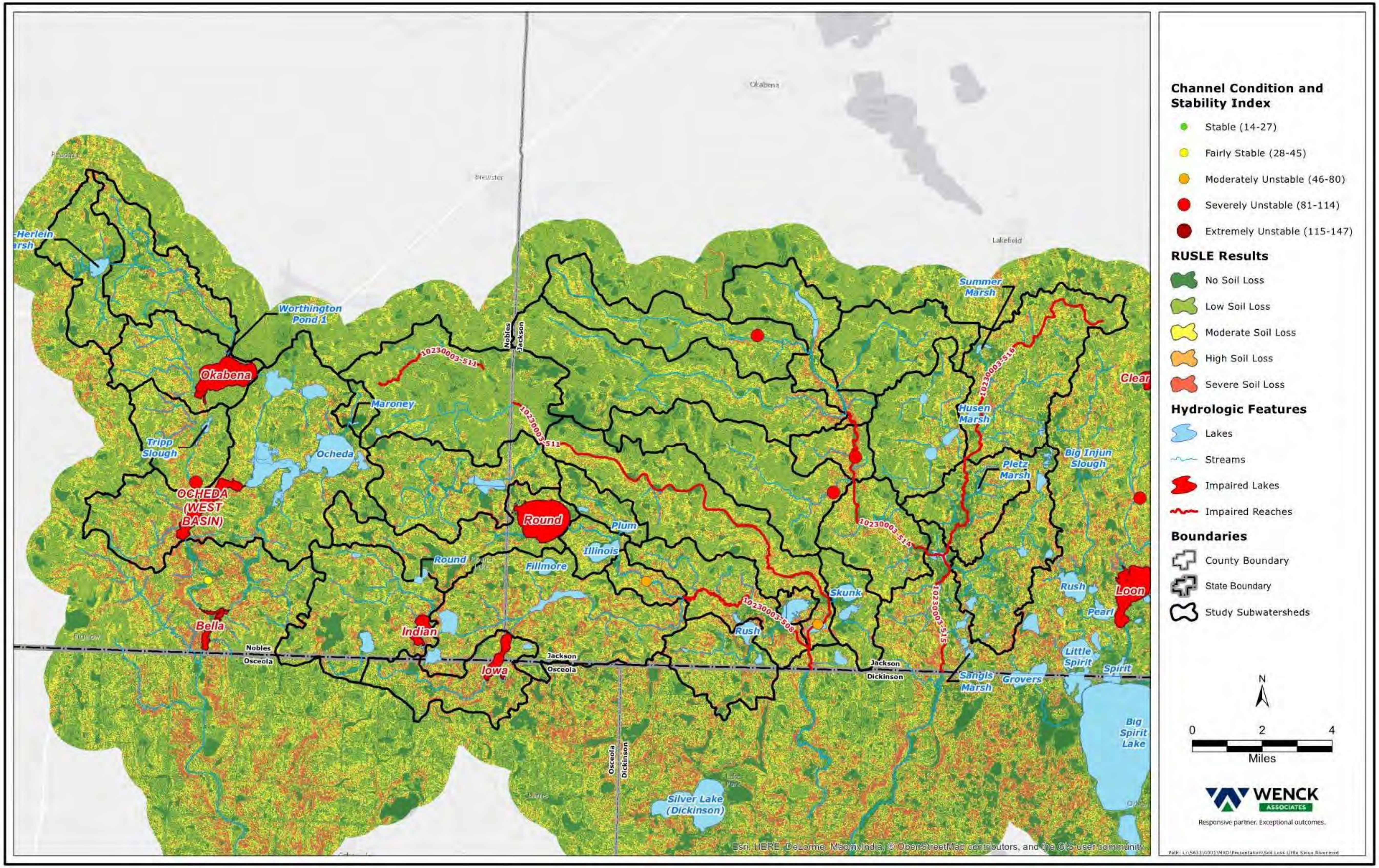


Figure B-6. Little Sioux River Watershed potential soil loss(RUSLE).

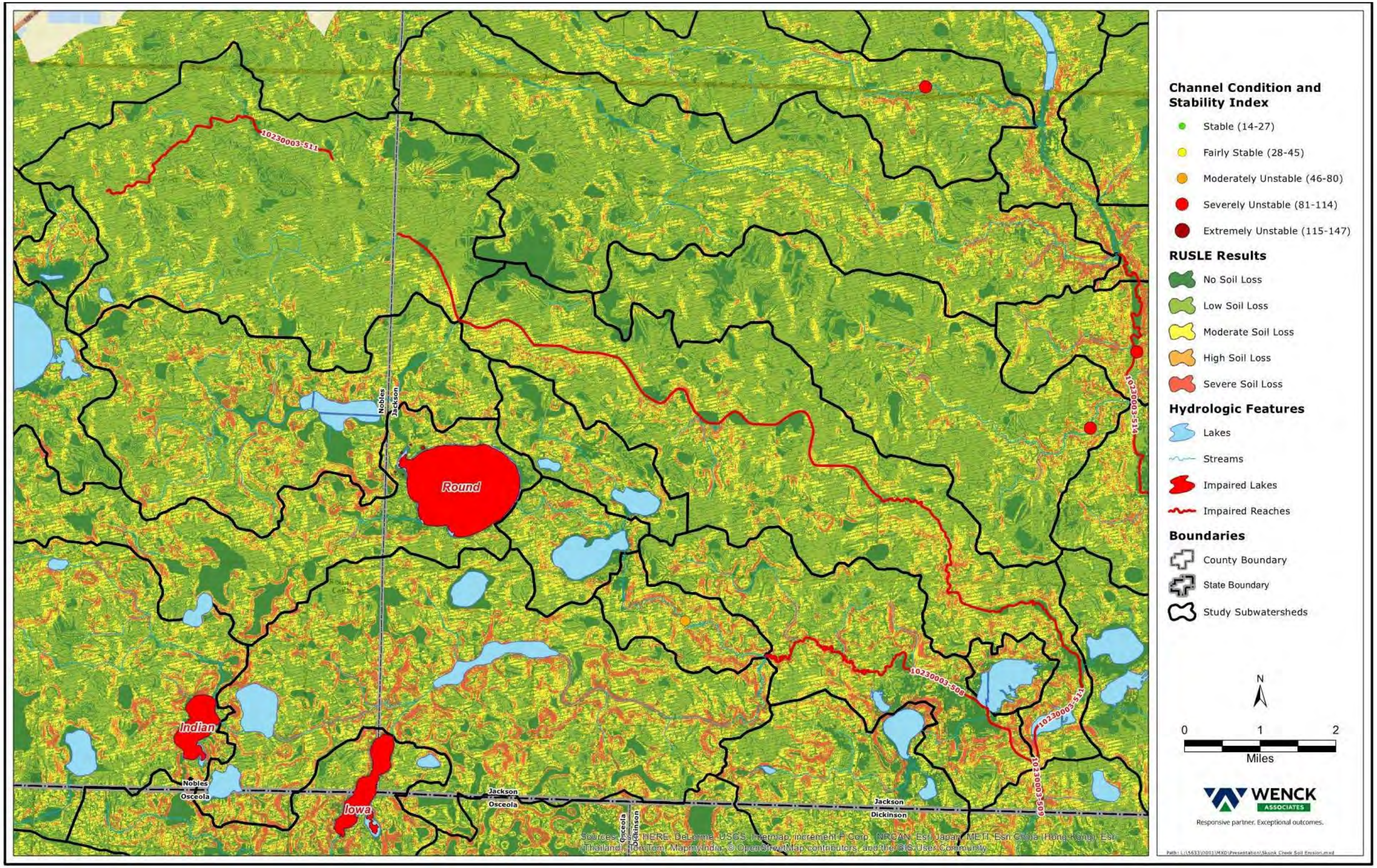
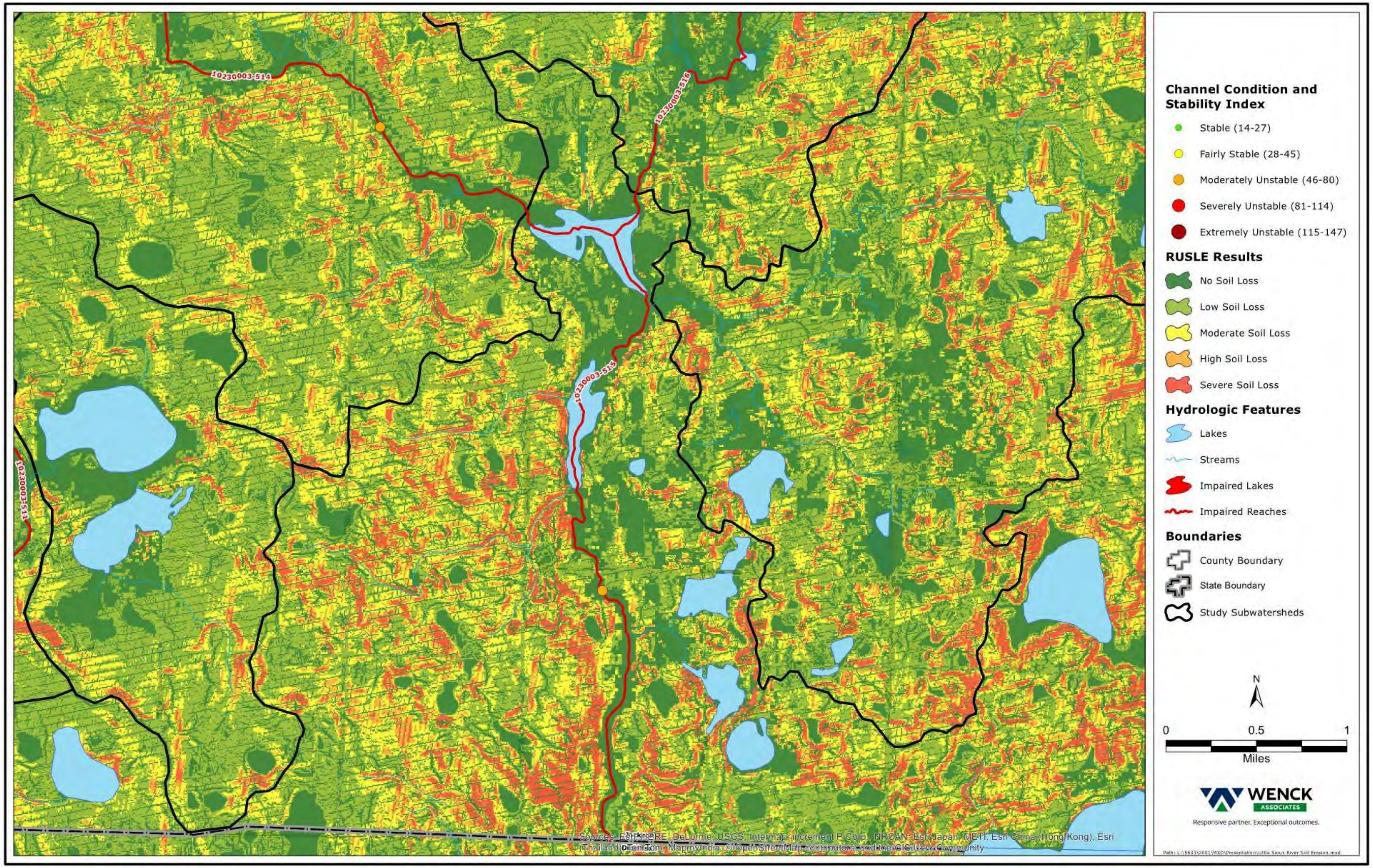


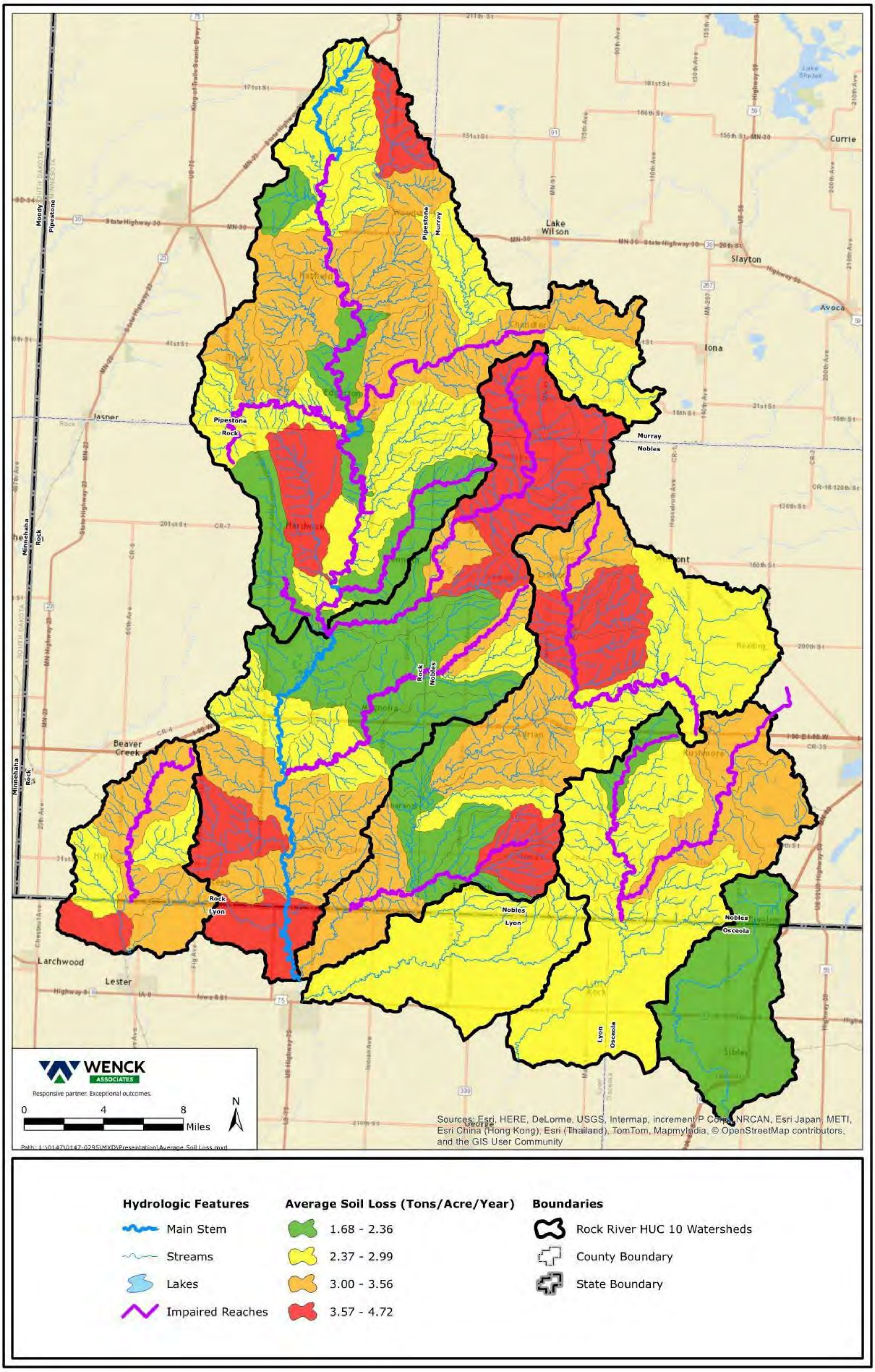
Figure B-7. Potential soil loss (RUSLE) in the Little Sioux River Watershed Reach 511 (Judicial Ditch 13 – Skunk Creek) watershed.



Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Path: L:\5633\0001\MXD\Presentation\Little Sioux River Soil Erosion.mxd

Figure B-8. Potential soil loss (RUSLE) in the Little Sioux River Watershed Reach 515 (Little Sioux River) direct watershed.



Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Path: L:\0147\0147-0295\MXD\Presentation\Average Soil Loss.mxd

Figure B-9. Rock River Watershed potential soil loss (RUSLE) bysubwatershed.

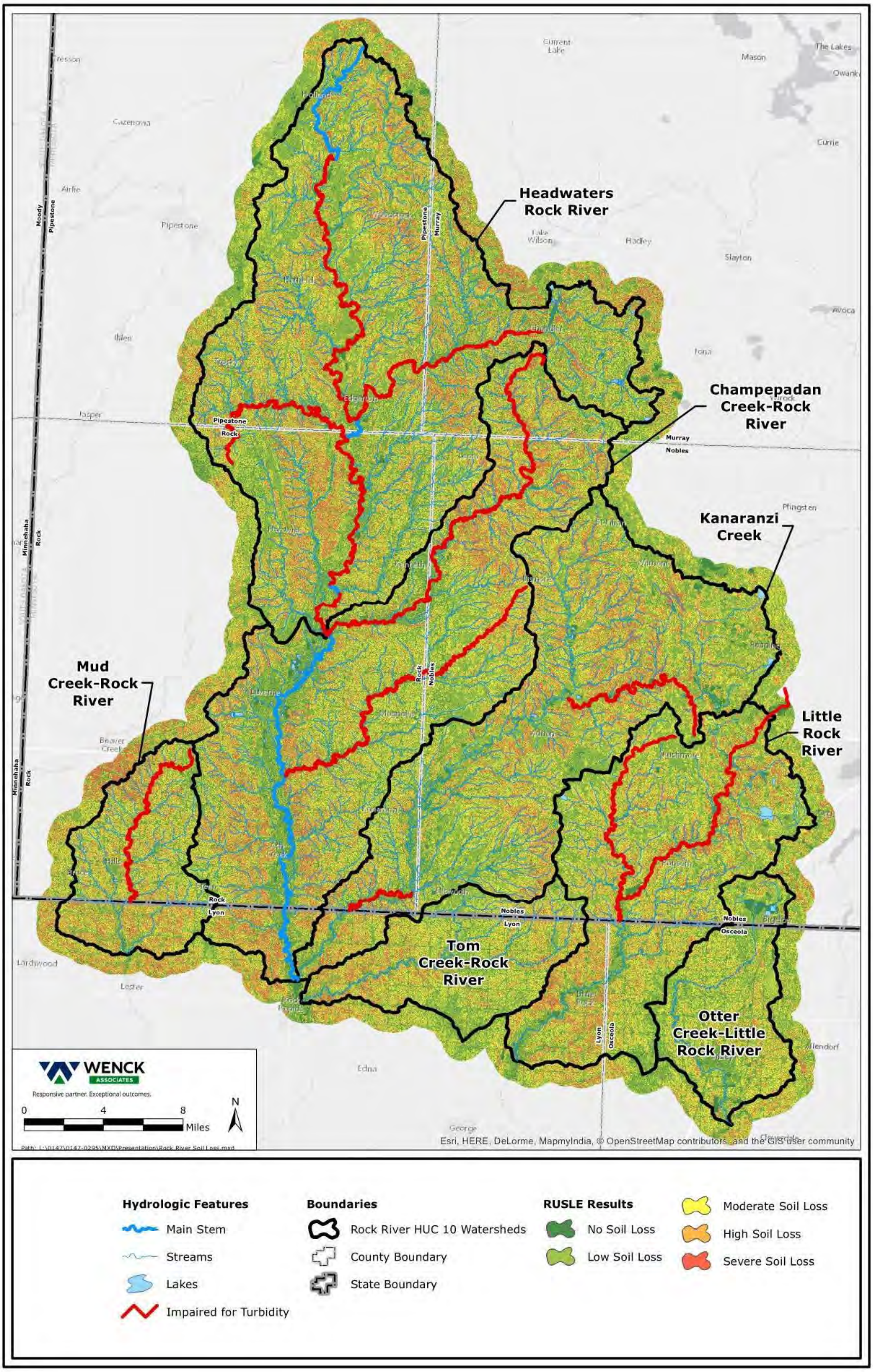
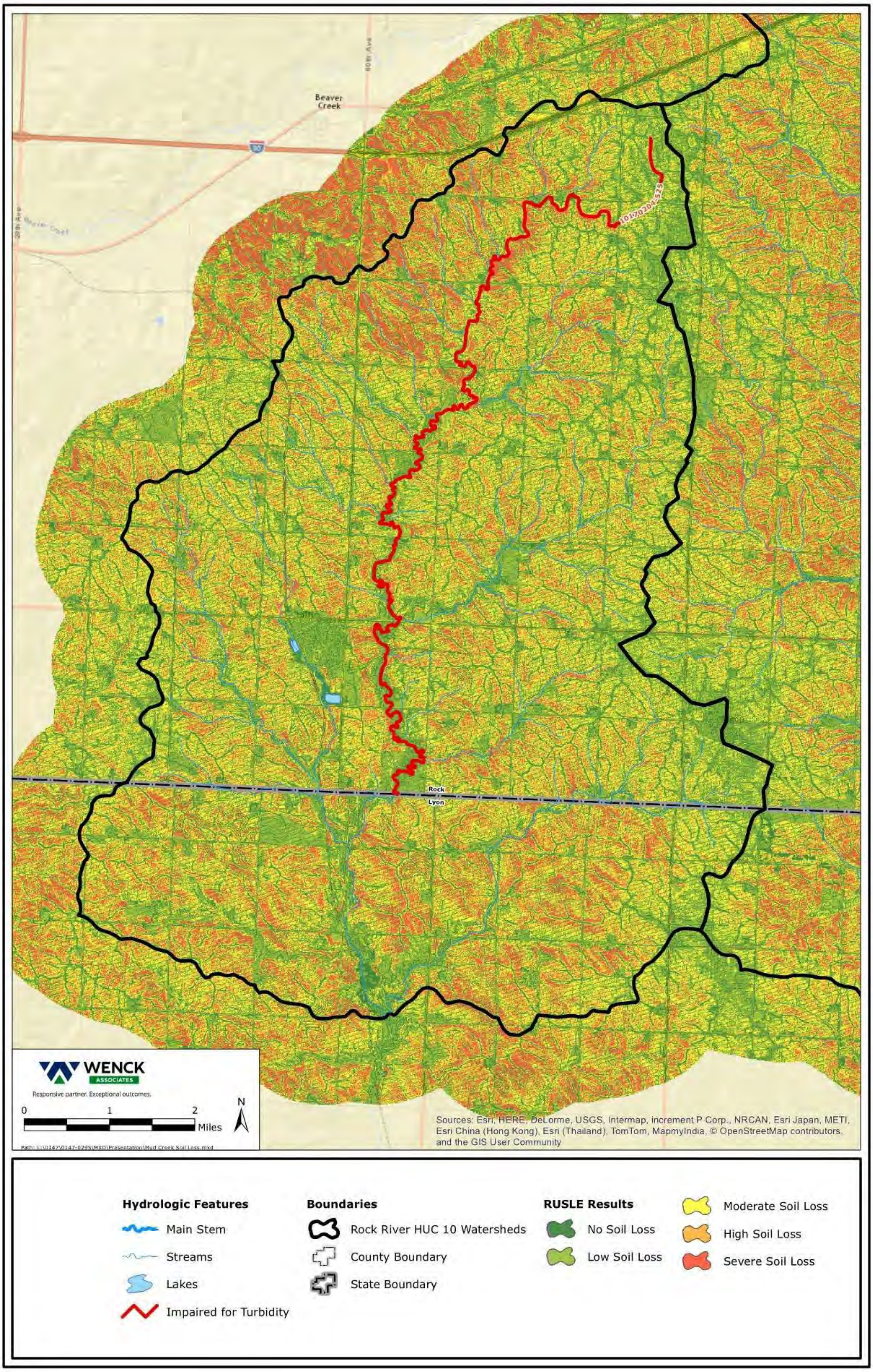


Figure B-10. Rock River Watershed potential soil loss (RUSLE).



Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Figure B-11. Mud Creek Subwatershed (Rock River watershed) potential soil loss (RUSLE).

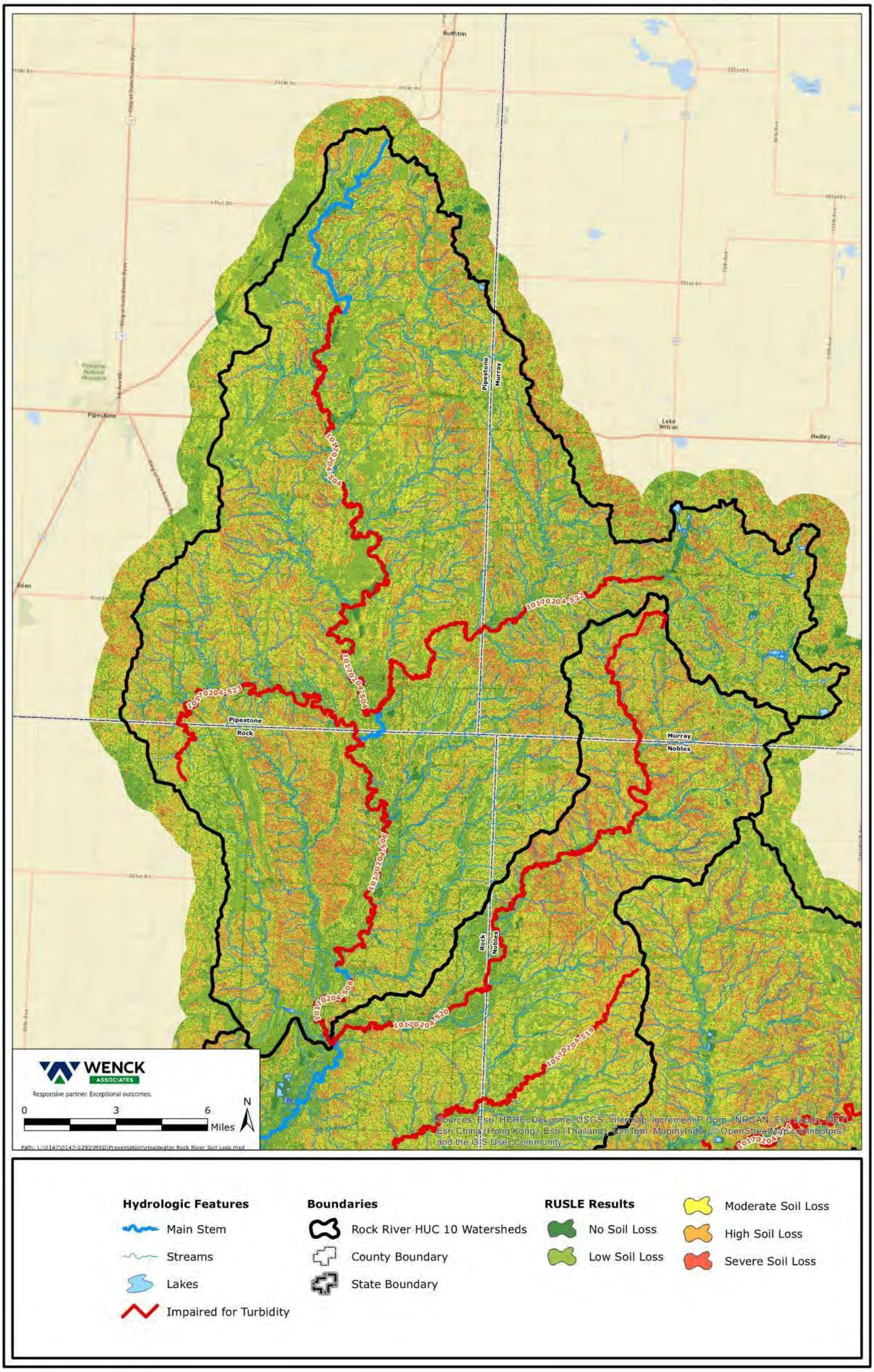


Figure B-12. Headwaters Rock River Subwatershed (Rock River Watershed) potential soil loss (RUSLE).

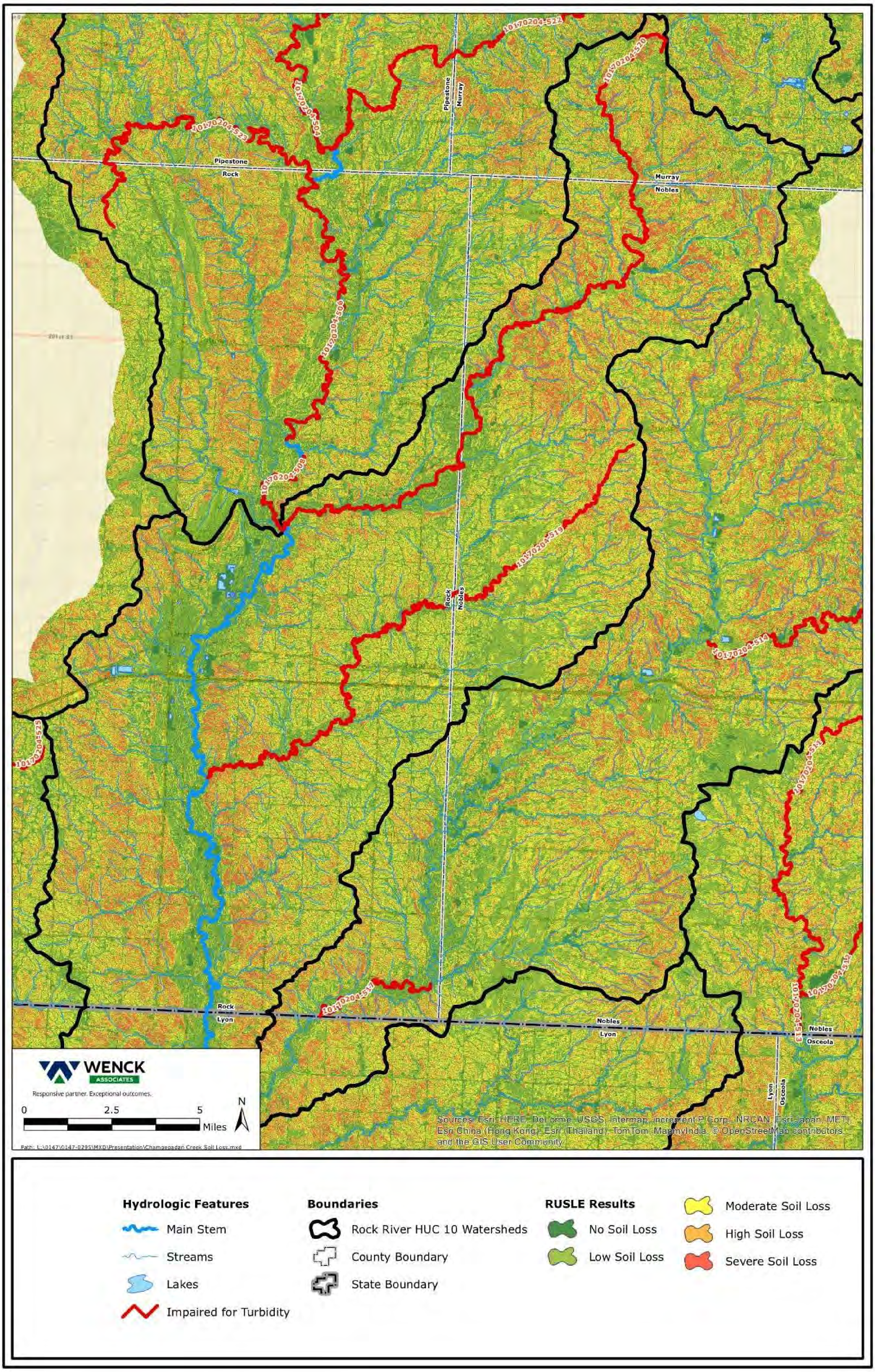


Figure B-13. Champepadan Creek Subwatershed (Rock River Watershed) potential soil loss(RUSLE).

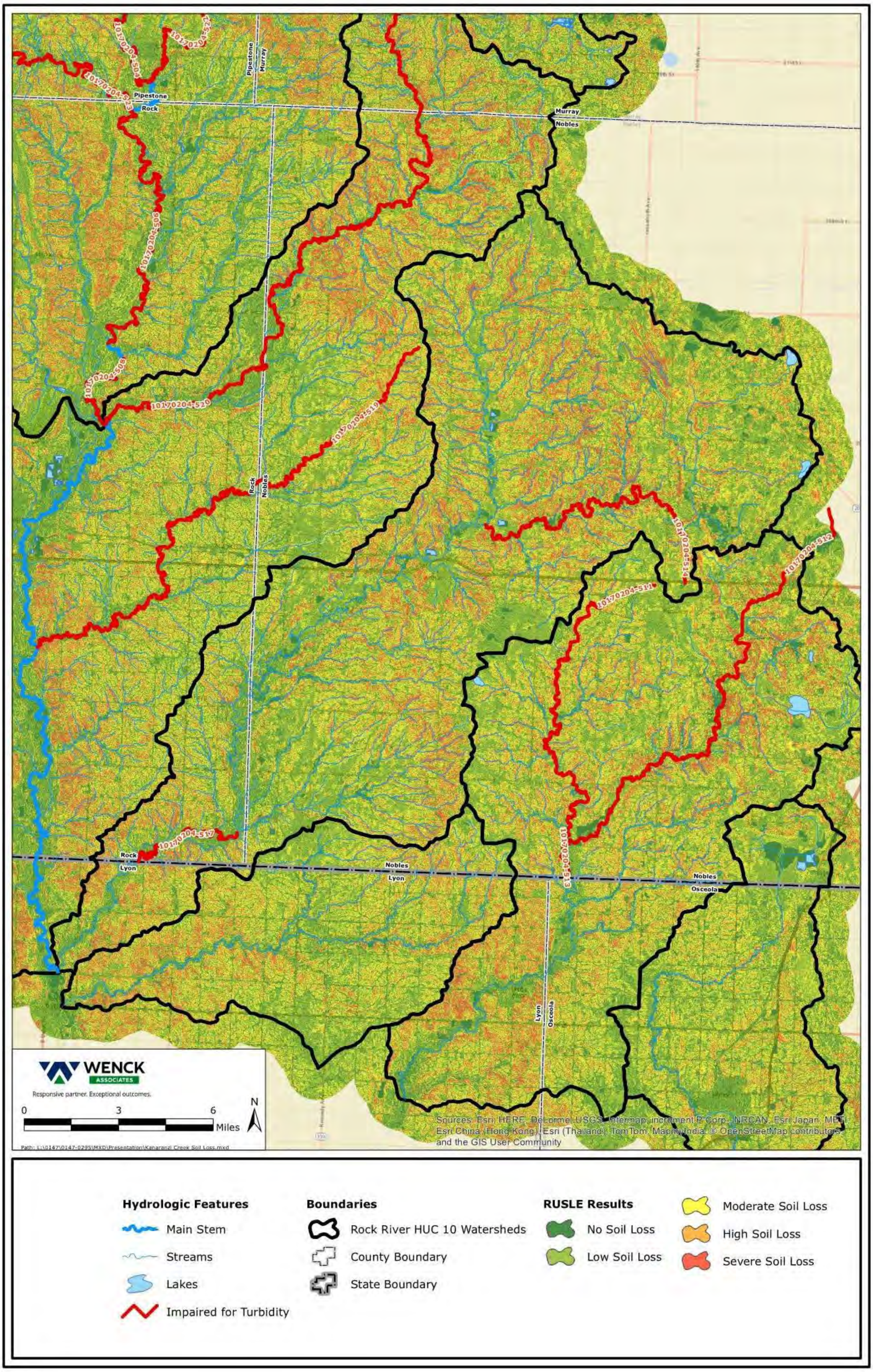


Figure B-14. Kanaranzi Creek Subwatershed (Rock River Watershed) potential soil loss (RUSLE).

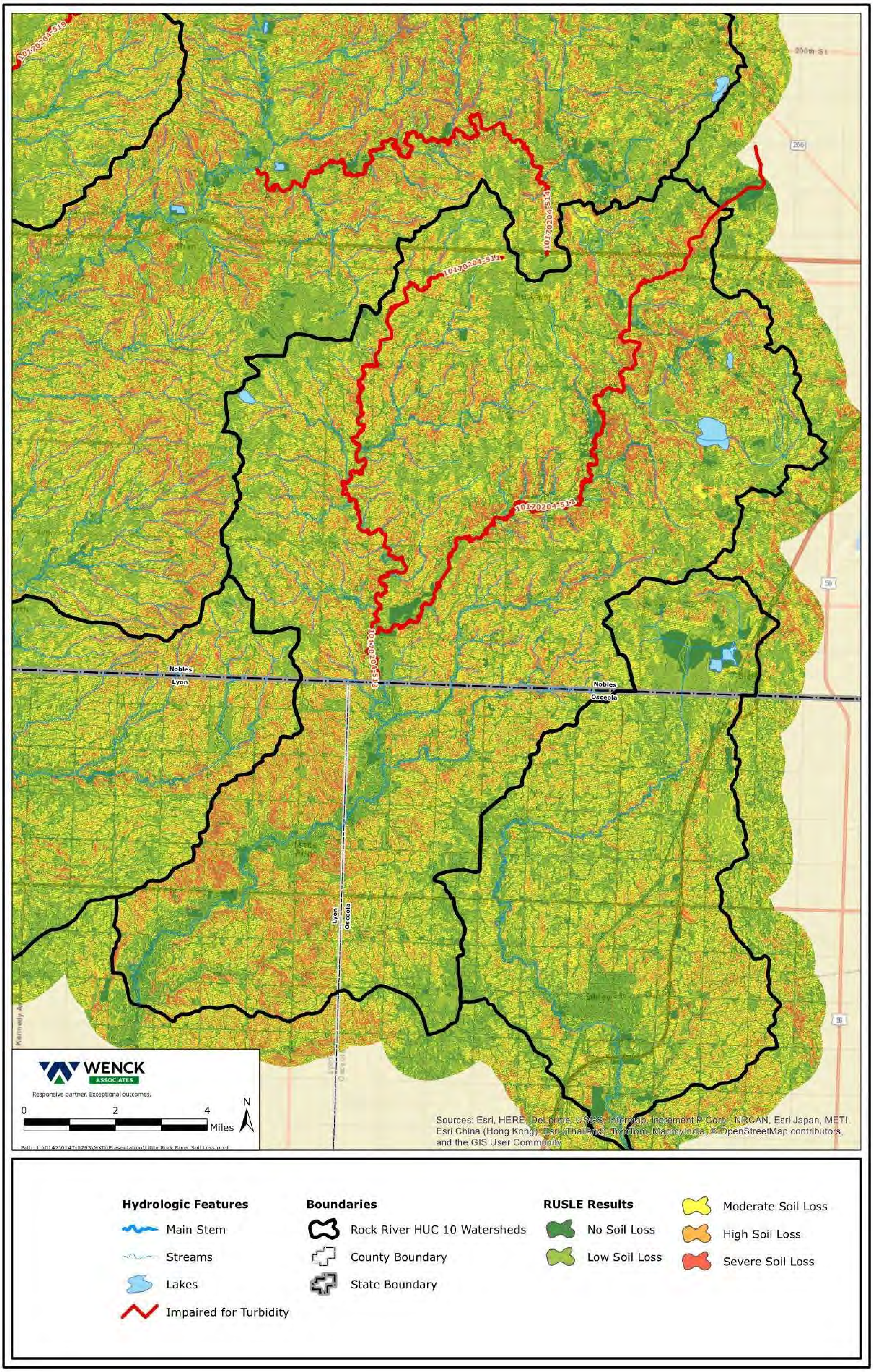


Figure B-15. Little Rock River Subwatershed (Rock River Watershed) potential soil loss (RUSLE).

Appendix C – Bacteria Source Assessment

Table C-1. Bacteria production in the watershed draining to Flandreau Creek reach 502. This subwatershed is located in the Lower Big Sioux River Watershed.

Major Category	Source	Animal Units* or Individuals in Subwatershed	Bacteria Organisms Produced Per Unit Per Day [Billions of Org.] [8]	Total Bacteria Produced Per Day [Billions of Org.]	Total Bacteria Produced Per Day by Major Category [Billions of Org.]	Percent by Category
Livestock[1*]	Horse	62	58.2	3,608	1,255,366	99.87
	Pig	25,256	32.7	825,858		
	Cattle	6,365	58.2	370,443		
	Chicken/Turkey	2,521	20.5	51,685		
	Other Cattle[9]	115	32.7	3,772		
Wildlife	Deer [3]	551	0.5	275	715	0.06
	Waterfowl [4]	1,099	0.4	440		
Human	Failing Septic Systems [5]	661	0.2	164	448	0.04
	WWTP effluent [6]	2	142	284		
Domestic Animals [2]	Improperly Managed Pet Waste [7]	866	0.6	487	487	0.04

* Values reported as Animal Units.

[1] Livestock animal units estimated based on MPCA registered feedlot database with animal units converted based on MN Dept. of Ag conversion units (http://www.mda.state.mn.us/animals/feedlots/feedlot-dmt/feedlot-dmt-animal-units.aspx).

[2] # of households in watershed multiplied by 0.58 dogs/ household and 0.73 cates/household according to the SE MN Regional TMDL (MPCA, 2002)

[3] Assumes average deer density of .0078 deer/acre (Monitoring Population Trends of White-tailed Deer in Minnesota, (2011a)

[4] Estimated from the MN DNR and US Fish & Wildlife Service 2011 Waterfowl Breeding Population Survey (Minnesota DNR, 2011b)

[5] Reported as population size in watershed with production values based on county SSTS inventory failure rates (MPCA, 2013) and rural population estimates (3 persons/ septic).

[6] Reported as # of facilities with production based on WWTP effluent data from facility discharge monitoring reports (DMRs)

[7] Estimated that 35% of the bacteria produced per month attributed to pet waste is improperly managed and available for runoff (CWP, 1999)

[8] Derived from literature rates in Metcalf and Eddy (1991), Horsley and Witten (1996), Alderisio and De Luca (1999), ASAE Standards (1998) and the Southeast Minnesota Regional TMDL (MPCA, 2002). Values have been reported to two significant digits.

[9] Other cattle include llama, goat, and sheep.

Table C-2. Bacteria production in the watershed draining to Pipestone Creek reach 505. This subwatershed is located in the Lower Big Sioux River watershed.

Major Category	Source	Animal Units* or Individuals in Subwatershed	Bacteria Organisms Produced Per Unit Per Day [Billions of Org.] [8]	Total Bacteria Produced Per Day [Billions of Org.]	Total Bacteria Produced Per Day by Major Category [Billions of Org.]	Percent by Category
Livestock[1*]	Horse	41	58.2	2,386	2,158,655	99.61
	Pig	36,272	32.7	1,186,094		
	Cattle	16,660	58.2	969,612		
	Chicken/Turkey	27	20.5	563		
	Other Cattle[9]	573	32.7	18,721		
Wildlife	Deer [3]	1,277	0.5	638	1,658	0.08
	Waterfowl [4]	2,549	0.4	1,020		
Human	Failing Septic Systems [5]	5,509	0.2	1,364	2,639	0.12
	WWTP effluent [6]	1	1275.7	1,276		
Domestic Animals [2]	Improperly Managed Pet Waste [7]	7,217	0.6	4,059	4,059	0.19

* Values reported as Animal Units.

[1] Livestock animal units estimated based on MPCA registered feedlot database with animal units converted based on MN Dept. of Ag conversion units (http://www.mda.state.mn.us/animals/feedlots/feedlot-dmt/feedlot-dmt-animal-units.aspx).

[2] # of households in watershed multiplied by 0.58 dogs/ household and 0.73 cates/household according to the SE MN Regional TMDL (MPCA, 2002)

[3] Assumes average deer density of .0078 deer/acre (Monitoring Population Trends of White-tailed Deer in Minnesota, (2011a)

[4] Estimated from the MN DNR and US Fish & Wildlife Service 2011 Waterfowl Breeding Population Survey (Minnesota DNR, 2011b)

[5] Reported as population size in watershed with production values based on county SSTS inventory failure rates (MPCA, 2013) and rural population estimates (3 persons/ septic).

[6] Reported as # of facilities with production based on WWTP effluent data from facility discharge monitoring reports (DMRs)

[7] Estimated that 35% of the bacteria produced per month attributed to pet waste is improperly managed and available for runoff (CWP, 1999)

[8] Derived from literature rates in Metcalf and Eddy (1991), Horsley and Witten (1996), Alderisio and De Luca (1999), ASAE Standards (1998) and the Southeast Minnesota Regional TMDL (MPCA, 2002). Values have been reported to two significant digits.

[9] Other cattle include llama, goat, and sheep.

Table C-3. Bacteria production in the watershed draining to Split Rock Creek reach 512. This subwatershed is located in the Lower Big Sioux River Watershed.

Major Category	Source	Animal Units or Individuals in Subwatershed	Bacteria Organisms Produced Per Unit Per Day [Billions of Org.] [8]	Total Bacteria Produced Per Day [Billions of Org.]	Total Bacteria Produced Per Day by Major Category [Billions of Org.]	Percent by Category
Livestock[1*]	Horse	117	58.2	6,809	4,324,476	99.79
	Pig	190,205	13.1	2,487,881		
	Cattle	31,070	58.2	1,808,274		
	Chicken/Turkey	1,432	0.7	969		
	Other Cattle[9]	628	32.7	20,542		
Wildlife	Deer [3]	1,832	0.5	916	2,379	0.06
	Waterfowl [4]	3,657	0.4	1,463		
Human	Failing Septic Systems [5]	6,989	0.7	1,554	1,629	0.04
	WWTP effluent [6]	1	75.7	76		
Domestic Animals [2]	Improperly Managed Pet Waste [7]	9,155	0.6	5,150	5,150	0.12

* Values reported as Animal Units.

[1] Livestock animal units estimated based on MPCA registered feedlot database with animal units converted based on MN Dept. of Ag conversion units (http://www.mda.state.mn.us/animals/feedlots/feedlot-dmt/feedlot-dmt-animal-units.aspx).

[2] # of households in watershed multiplied by 0.58 dogs/ household and 0.73 cates/household according to the SE MN Regional TMDL (MPCA, 2002)

[3] Assumes average deer density of .0078 deer/acre (Monitoring Population Trends of White-tailed Deer in Minnesota, (2011a)

[4] Estimated from the MN DNR and US Fish & Wildlife Service 2011 Waterfowl Breeding Population Survey (Minnesota DNR, 2011b)

[5] Reported as population size in watershed with production values based on county SSTS inventory failure rates (MPCA, 2013) and rural population estimates (3 persons/ septic).

[6] Reported as # of facilities with production based on WWTP effluent data from facility discharge monitoring reports (DMRs)

[7] Estimated that 35% of the bacteria produced per month attributed to pet waste is improperly managed and available for runoff (CWP, 1999)

[8] Derived from literature rates in Metcalf and Eddy (1991), Horsley and Witten (1996), Alderisio and De Luca (1999), ASAE Standards (1998) and the Southeast Minnesota Regional TMDL (MPCA, 2002). Values have been reported to two significant digits.

[9] Other cattle include llama, goat, and sheep.

Table C-4. Bacteria production in the watershed draining to Beaver Creek reach 522. This subwatershed is located in the Lower Big Sioux River Watershed.

Major Category	Source	Animal Units or Individuals in Subwatershed	Bacteria Organisms Produced Per Unit Per Day [Billions of Org.] [8]	Total Bacteria Produced Per Day [Billions of Org.]	Total Bacteria Produced Per Day by Major Category [Billions of Org.]	Percent by Category
Livestock[1*]	Horse	54	58.2	3,143	2,443,261	99.73
	Pig	42,526	32.7	1,390,613		
	Cattle	17,816	58.2	1,036,891		
	Chicken/Turkey	310	20.5	6,346		
	Other Cattle[9]	192	32.7	6,269		
Wildlife	Deer [3]	490	0.5	245	636	0.03
	Waterfowl [4]	978	0.4	391		
Human	Failing Septic Systems [5]	4,148	0.3	1,312	2,982	0.12
	WWTP effluent [6]	2	834.7	1,669		
Domestic Animals [2]	Improperly Managed Pet Waste [7]	5,434	0.6	3,057	3,057	0.12

* Values reported as Animal Units.

[1] Livestock animal units estimated based on MPCA registered feedlot database with animal units converted based on MN Dept. of Ag conversion units (http://www.mda.state.mn.us/animals/feedlots/feedlot-dmt/feedlot-dmt-animal-units.aspx).

[2] # of households in watershed multiplied by 0.58 dogs/ household and 0.73 cates/household according to the SE MN Regional TMDL (MPCA, 2002)

[3] Assumes average deer density of .0078 deer/acre (Monitoring Population Trends of White-tailed Deer in Minnesota, (2011a)

[4] Estimated from the MN DNR and US Fish & Wildlife Service 2011 Waterfowl Breeding Population Survey (Minnesota DNR, 2011b)

[5] Reported as population size in watershed with production values based on county SSTS inventory failure rates (MPCA, 2013) and rural population estimates (3 persons/ septic).

[6] Reported as # of facilities with production based on WWTP effluent data from facility discharge monitoring reports (DMRs)

[7] Estimated that 35% of the bacteria produced per month attributed to pet waste is improperly managed and available for runoff (CWP, 1999)

[8] Derived from literature rates in Metcalf and Eddy (1991), Horsley and Witten (1996), Alderisio and De Luca (1999), ASAE Standards (1998) and the Southeast Minnesota Regional TMDL (MPCA, 2002). Values have been reported to two significant digits.

[9] Other cattle include llama, goat, and sheep.

Table C-5. Bacteria production in the watershed draining to West Fork Little Sioux River reach 509. This subwatershed is located in the Little Sioux River Watershed and includes the subwatersheds that drain to impaired West Fork Little Sioux River reach 508 and Judicial Ditch 13 (Skunk Creek) reach 511.

Major Category	Source	Animal Units or Individuals in Subwatershed	Bacteria Organisms Produced Per Unit Per Day [Billions of Org.] [8]	Total Bacteria Produced Per Day [Billions of Org.]	Total Bacteria Produced Per Day by Major Category [Billions of Org.]	Percent by Category
Livestock[1*]	Horse	43	58.2	2,503	1,212,436	99.83
	Pig	29,142	32.7	952,930		
	Cattle	4,406	58.2	256,429		
	Chicken/Turkey	0.1	20.5	2		
	Other Cattle[9]	17.5	32.7	572		
Wildlife	Deer [3]	561	0.5	280	729	0.06
	Waterfowl [4]	1,122	0.4	449		
Human	Failing Septic Systems [5]	1,042	0.2	201	534	0.04
	WWTP effluent [6]	1	333.1	333		
Domestic Animals [2]	Improperly Managed Pet Waste [7]	1,365	0.6	768	768	0.06

* Values reported as Animal Units.

[1] Livestock animal units estimated based on MPCA registered feedlot database with animal units converted based on MN Dept. of Ag conversion units (http://www.mda.state.mn.us/animals/feedlots/feedlot-dmt/feedlot-dmt-animal-units.aspx).

[2] # of households in watershed multiplied by 0.58 dogs/ household and 0.73 cates/household according to the SE MN Regional TMDL (MPCA, 2002)

[3] Assumes average deer density of .0078 deer/acre (Monitoring Population Trends of White-tailed Deer in Minnesota, (2011a)

[4] Estimated from the MN DNR and US Fish & Wildlife Service 2011 Waterfowl Breeding Population Survey (Minnesota DNR, 2011b)

[5] Reported as population size in watershed with production values based on county SSTS inventory failure rates (MPCA, 2013) and rural population estimates (3 persons/ septic).

[6] Reported as # of facilities with production based on WWTP effluent data from facility discharge monitoring reports (DMRs)

[7] Estimated that 35% of the bacteria produced per month attributed to pet waste is improperly managed and available for runoff (CWP, 1999)

[8] Derived from literature rates in Metcalf and Eddy (1991), Horsley and Witten (1996), Alderisio and De Luca (1999), ASAE Standards (1998) and the Southeast Minnesota Regional TMDL (MPCA, 2002). Values have been reported to two significant digits.

[9] Other cattle include llama, goat, and sheep.

Table C-6. Bacteria production in the watershed draining to Little Sioux River reach 515. This subwatershed is located in the Little Sioux River Watershed and includes the subwatersheds that drain to impaired Little Sioux River reaches 514 and 516.

Major Category	Source	Animal Units* or Individuals in Subwatershed	Bacteria Organisms Produced Per Unit Per Day [Billions of Org.] [8]	Total Bacteria Produced Per Day [Billions of Org.]	Total Bacteria Produced Per Day by Major Category [Billions of Org.]	Percent by Category
Livestock[1*]	Horse	52	58.2	3,026	1,880,942	99.92
	Pig	40,615	32.7	1,328,117		
	Cattle	9,130	58.2	531,366		
	Chicken/Turkey	67	20.5	1,373		
	Other Cattle[9]	522	32.7	17,060		
Wildlife	Deer [3]	537	0.5	268	697	0.04
	Waterfowl [4]	1,072	0.4	429		
Human	Failing Septic Systems [5]	744	0.3	212	212	0.01
	WWTP effluent [6]	0	NA	NA		
Domestic Animals [2]	Improperly Managed Pet Waste [7]	974	0.6	548	548	0.03

* Values reported as Animal Units.

[1] Livestock animal units estimated based on MPCA registered feedlot database with animal units converted based on MN Dept. of Ag conversion units (http://www.mda.state.mn.us/animals/feedlots/feedlot-dmt/feedlot-dmt-animal-units.aspx).

[2] # of households in watershed multiplied by 0.58 dogs/ household and 0.73 cates/household according to the SE MN Regional TMDL (MPCA, 2002)

[3] Assumes average deer density of .0078 deer/acre (Monitoring Population Trends of White-tailed Deer in Minnesota, (2011a)

[4] Estimated from the MN DNR and US Fish & Wildlife Service 2011 Waterfowl Breeding Population Survey (Minnesota DNR, 2011b)

[5] Reported as population size in watershed with production values based on county SSTS inventory failure rates (MPCA, 2013) and rural population estimates (3 persons/ septic).

[6] Reported as # of facilities with production based on WWTP effluent data from facility discharge monitoring reports (DMRs)

[7] Estimated that 35% of the bacteria produced per month attributed to pet waste is improperly managed and available for runoff (CWP, 1999)

[8] Derived from literature rates in Metcalf and Eddy (1991), Horsley and Witten (1996), Alderisio and De Luca (1999), ASAE Standards (1998) and the Southeast Minnesota Regional TMDL (MPCA, 2002). Values have been reported to two significant digits.

[9] Other cattle include llama, goat, and sheep.

Table C-7. Bacteria production in the watershed draining to Rock River reach 508. This subwatershed is located in the Rock River Watershed and includes the subwatersheds that drain to impaired Rock River reach 504 and 506, Champepadan Creek reach 520, Unnamed Creek reaches 521 and 545, Chanarambie Creek reach 522, Poplar Creek reach 523, and Mound Creek reach 551.

Major Category	Source	Animal Units* or Individuals in Subwatershed	Bacteria Organisms Produced Per Unit Per Day [Billions of Org.] [8]	Total Bacteria Produced Per Day [Billions of Org.]	Total Bacteria Produced Per Day by Major Category [Billions of Org.]	Percent by Category
Livestock[1*]	Horse	309	58.2	17,984	8,299,620	99.87%
	Pig	108,528	32.7	3,548,879		
	Cattle	79,878	58.1	4,641,508		
	Chicken/Turkey	2,387	20.5	48,942		
	Other Cattle[9]	948	32.7	30,991		
Wildlife	Deer [3]	2,002	0.5	1,001	2,601	0.03%
	Waterfowl [4]	3,998	0.4	1,599		
Human	Failing Septic Systems [5]	4,585	0.8	3,679	4,780	0.06%
	WWTP effluent [6]	5	220.3	1,102		
Domestic Animals [2]	Improperly Managed Pet Waste [7]	6,006	0.6	3,379	3,379	0.04%

* Values reported as Animal Units.

[1] Livestock animal units estimated based on MPCA registered feedlot database with animal units converted based on MN Dept. of Ag conversion units (http://www.mda.state.mn.us/animals/feedlots/feedlot-dmt/feedlot-dmt-animal-units.aspx).

[2] # of households in watershed multiplied by 0.58 dogs/ household and 0.73 cates/household according to the SE MN Regional TMDL (MPCA, 2002)

[3] Assumes average deer density of .0078 deer/acre (Monitoring Population Trends of White-tailed Deer in Minnesota, (2011a)

[4] Estimated from the MN DNR and US Fish & Wildlife Service 2011 Waterfowl Breeding Population Survey (Minnesota DNR, 2011b)

[5] Reported as population size in watershed with production values based on county SSTS inventory failure rates (MPCA, 2013) and rural population estimates (3 persons/ septic).

[6] Reported as # of facilities with production based on WWTP effluent data from facility discharge monitoring reports (DMRs)

[7] Estimated that 35% of the bacteria produced per month attributed to pet waste is improperly managed and available for runoff (CWP, 1999)

[8] Derived from literature rates in Metcalf and Eddy (1991), Horsley and Witten (1996), Alderisio and DeLuca (1999), ASAE Standards (1998) and the Southeast Minnesota Regional TMDL (MPCA, 2002). Values have been reported to two significant digits.

[9] Other cattle include llama, goat, and sheep.

Table C-8. Bacteria production in the watershed draining to Elk Creek reach 519. This subwatershed is located in the Rock River Watershed.

Major Category	Source	Animal Units* or Individuals in Subwatershed	Bacteria Organisms Produced Per Unit Per Day [Billions of Org.] [8]	Total Bacteria Produced Per Day [Billions of Org.]	Total Bacteria Produced Per Day by Major Category [Billions of Org.]	Percent by Category
Livestock[1]*	Horse	85	58.2	4,947	2,154,414	99.94%
	Pig	41,218	32.7	1,347,816		
	Cattle	13,662	58.2	795,128		
	Chicken/Turkey	44	20.5	897		
	Other Cattle[9]	172	32.7	5,626		
Wildlife	Deer [3]	322	0.5	161	418	0.02%
	Waterfowl [4]	643	0.4	257		
Human	Failing Septic Systems [5]	553	0.4	195	377	0.02%
	WWTP effluent [6]	1	181.7	182		
Domestic Animals [2]	Improperly Managed Pet Waste [7]	724	0.6	407	407	0.02%

* Values reported as Animal Units.

[1] Livestock animal units estimated based on MPCA registered feedlot database with animal units converted based on MN Dept. of Ag conversion units (http://www.mda.state.mn.us/animals/feedlots/feedlot-dmt/feedlot-dmt-animal-units.aspx).

[2] # of households in watershed multiplied by 0.58 dogs/ household and 0.73 cates/household according to the SE MN Regional TMDL (MPCA, 2002)

[3] Assumes average deer density of .0078 deer/acre (Monitoring Population Trends of White-tailed Deer in Minnesota, (2011a)

[4] Estimated from the MN DNR and US Fish & Wildlife Service 2011 Waterfowl Breeding Population Survey (Minnesota DNR, 2011b)

[5] Reported as population size in watershed with production values based on county SSTS inventory failure rates (MPCA, 2013) and rural population estimates (3 persons/ septic).

[6] Reported as # of facilities with production based on WWTP effluent data from facility discharge monitoring reports (DMRs)

[7] Estimated that 35% of the bacteria produced per month attributed to pet waste is improperly managed and available for runoff (CWP, 1999)

[8] Derived from literature rates in Metcalf and Eddy (1991), Horsley and Witten (1996), Alderisio and De Luca (1999), ASAE Standards (1998) and the Southeast Minnesota Regional TMDL (MPCA, 2002). Values have been reported to two significant digits.

[9] Other cattle include llama, goat, and sheep.

Table C-9. Bacteria production in the watershed draining to Kanaranzi Creek reach 517. This subwatershed is located in the Rock River Watershed and includes the subwatersheds that drain to impaired Kanaranzi Creek reach 514 and 515, and Norwegian Creek reach 518.

Major Category	Source	Animal Units* or Individuals in Subwatershed	Bacteria Organisms Produced Per Unit Per Day [Billions of Org.] [8]	Total Bacteria Produced Per Day [Billions of Org.]	Total Bacteria Produced Per Day by Major Category [Billions of Org.]	Percent by Category
Livestock[1*]	Horse	51	58.2	2,968	5,221,557	99.88%
	Pig	79,469	32.7	2,598,630		
	Cattle	44,979	58.2	2,617,778		
	Chicken/Turkey	9	20.5	191		
	Other Cattle[9]	61	32.7	1,990		
Wildlife	Deer [3]	968	0.5	484	1,258	0.02%
	Waterfowl [4]	1,934	0.4	773		
Human	Failing Septic Systems [5]	3,269	0.4	1,232	2,428	0.05%
	WWTP effluent [6]	4	299.0	1,196		
Domestic Animals [2]	Improperly Managed Pet Waste [7]	4,282	0.6	2,409	2,409	0.05%

* Values reported as Animal Units.

[1] Livestock animal units estimated based on MPCA registered feedlot database with animal units converted based on MN Dept. of Ag conversion units (http://www.mda.state.mn.us/animals/feedlots/feedlot-dmt/feedlot-dmt-animal-units.aspx).

[2] # of households in watershed multiplied by 0.58 dogs/ household and 0.73 cates/household according to the SE MN Regional TMDL (MPCA, 2002)

[3] Assumes average deer density of .0078 deer/acre (Monitoring Population Trends of White-tailed Deer in Minnesota, (2011a)

[4] Estimated from the MN DNR and US Fish & Wildlife Service 2011 Waterfowl Breeding Population Survey (Minnesota DNR, 2011b)

[5] Reported as population size in watershed with production values based on county SSTS inventory failure rates (MPCA, 2013) and rural population estimates (3 persons/ septic).

[6] Reported as # of facilities with production based on WWTP effluent data from facility discharge monitoring reports (DMRs)

[7] Estimated that 35% of the bacteria produced per month attributed to pet waste is improperly managed and available for runoff (CWP, 1999)

[8] Derived from literature rates in Metcalf and Eddy (1991), Horsley and Witten (1996), Alderisio and De Luca (1999), ASAE Standards (1998) and the Southeast Minnesota Regional TMDL (MPCA, 2002). Values have been reported to two significant digits.

[9] Other cattle include llama, goat, and sheep.

Table C-10. Bacteria production in the watershed that drains to Mud Creek reach 525. This subwatershed is located in the Rock River Watershed.

Major Category	Source	Animal Units* or Individuals in Subwatershed	Bacteria Organisms Produced Per Unit Per Day [Billions of Org.] [8]	Total Bacteria Produced Per Day [Billions of Org.]	Total Bacteria Produced Per Day by Major Category [Billions of Org.]	Percent by Category
Livestock[1*]	Horse	48	58.2	2,794	1,048,783	99.92%
	Pig	10,838	32.7	354,416		
	Cattle	11,874	58.2	691,067		
	Chicken/Turkey	-	-	-		
	Other Cattle[9]	16	32.7	507		
Wildlife	Deer [3]	149	0.5	74	193	0.02%
	Waterfowl [4]	297	0.4	119		
Human	Failing Septic Systems [5]	347	0.3	118	342	0.03%
	WWTP effluent [6]	1	223.3	223		
Domestic Animals [2]	Improperly Managed Pet Waste [7]	454	0.6	255	255	0.02%

* Values reported as Animal Units.

[1] Livestock animal units estimated based on MPCA registered feedlot database with animal units converted based on MN Dept. of Ag conversion units (http://www.mda.state.mn.us/animals/feedlots/feedlot-dmt/feedlot-dmt-animal-units.aspx).

[2] # of households in watershed multiplied by 0.58 dogs/ household and 0.73 cates/household according to the SE MN Regional TMDL (MPCA, 2002)

[3] Assumes average deer density of .0078 deer/acre (Monitoring Population Trends of White-tailed Deer in Minnesota, (2011a)

[4] Estimated from the MN DNR and US Fish & Wildlife Service 2011 Waterfowl Breeding Population Survey (Minnesota DNR, 2011b)

[5] Reported as population size in watershed with production values based on county SSTS inventory failure rates (MPCA, 2013) and rural population estimates (3 persons/ septic).

[6] Reported as # of facilities with production based on WWTP effluent data from facility discharge monitoring reports (DMRs)

[7] Estimated that 35% of the bacteria produced per month attributed to pet waste is improperly managed and available for runoff (CWP, 1999)

[8] Derived from literature rates in Metcalf and Eddy (1991), Horsley and Witten (1996), Alderisio and DeLuca (1999), ASAE Standards (1998) and the Southeast Minnesota Regional TMDL (MPCA, 2002). Values have been reported to two significant digits.

[9] Other cattle include llama, goat, and sheep.

Table C-11. Bacteria production in the watershed that drains to Little Rock River reach 513. This subwatershed is located in the Rock River Watershed and includes the subwatersheds that drain to impaired Little Rock Creek reach 511 and Little Rock River reach 512.

Major Category	Source	Animal Units* or Individuals in Subwatershed	Bacteria Organisms Produced Per Unit Per Day [Billions of Org.] [8]	Total Bacteria Produced Per Day [Billions of Org.]	Total Bacteria Produced Per Day by Major Category [Billions of Org.]	Percent by Category
Livestock[1*]	Horse	51	58.2	2,968	5,221,557	99.96%
	Pig	79,469	32.7	2,598,630		
	Cattle	44,979	58.2	2,617,778		
	Chicken/Turkey	9	20.5	191		
	Other Cattle[9]	61	32.7	1,990		
Wildlife	Deer [3]	468	0.5	234	608	0.01%
	Waterfowl [4]	935	0.4	374		
Human	Failing Septic Systems [5]	957	0.4	362	718	0.01%
	WWTP effluent [6]	1	355.8	356		
Domestic Animals [2]	Improperly Managed Pet Waste [7]	1,253	0.6	705	705	0.01%

* Values reported as Animal Units.

[1] Livestock animal units estimated based on MPCA registered feedlot database with animal units converted based on MN Dept. of Ag conversion units (http://www.mda.state.mn.us/animals/feedlots/feedlot-dmt/feedlot-dmt-animal-units.aspx).

[2] # of households in watershed multiplied by 0.58 dogs/ household and 0.73 cates/household according to the SE MN Regional TMDL (MPCA, 2002)

[3] Assumes average deer density of .0078 deer/acre (Monitoring Population Trends of White-tailed Deer in Minnesota, (2011a)

[4] Estimated from the MN DNR and US Fish & Wildlife Service 2011 Waterfowl Breeding Population Survey (Minnesota DNR, 2011b)

[5] Reported as population size in watershed with production values based on county SSTS inventory failure rates (MPCA, 2013) and rural population estimates (3 persons/ septic).

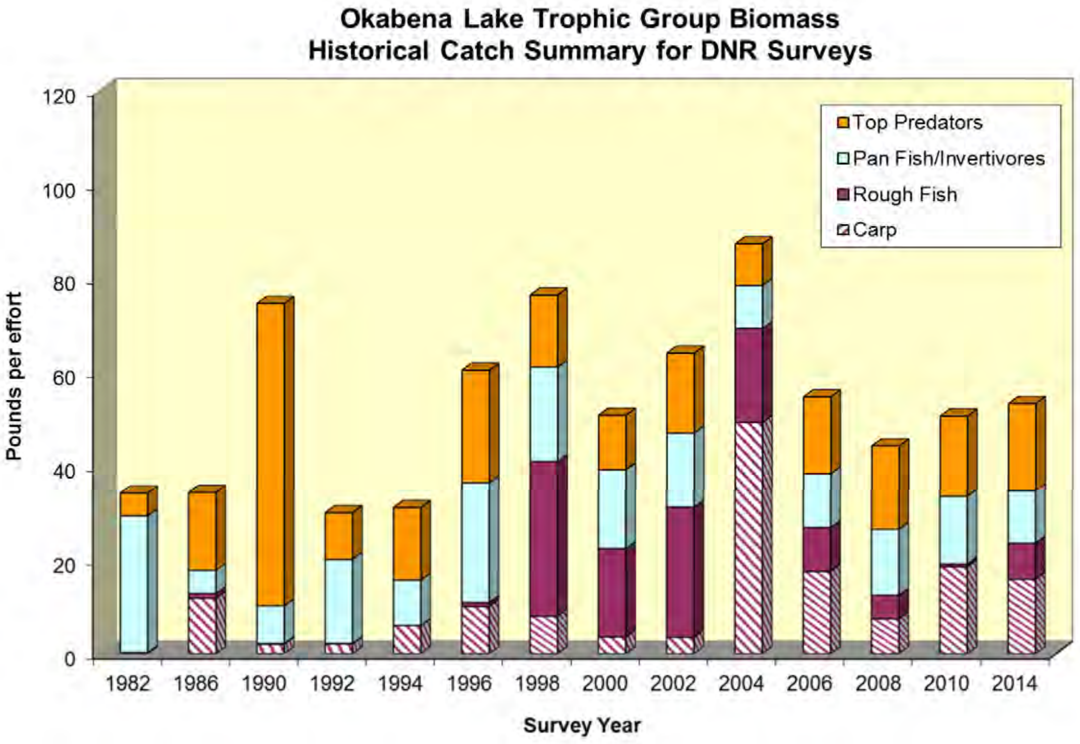
[6] Reported as # of facilities with production based on WWTP effluent data from facility discharge monitoring reports (DMRs)

[7] Estimated that 35% of the bacteria produced per month attributed to pet waste is improperly managed and available for runoff (CWP, 1999)

[8] Derived from literature rates in Metcalf and Eddy (1991), Horsley and Witten (1996), Alderisio and De Luca (1999), ASAE Standards (1998) and the Southeast Minnesota Regional TMDL (MPCA, 2002). Values have been reported to two significant digits.

[9] Other cattle include llama, goat, and sheep.

Appendix D – DNR Lake Fish Surveys



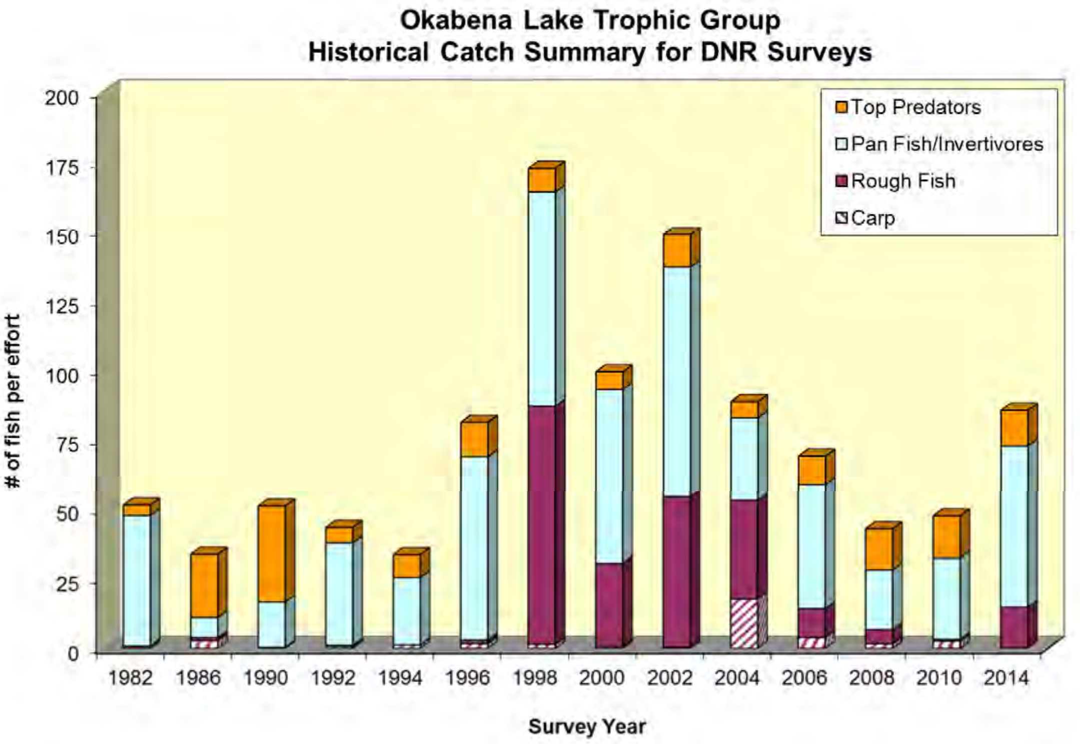
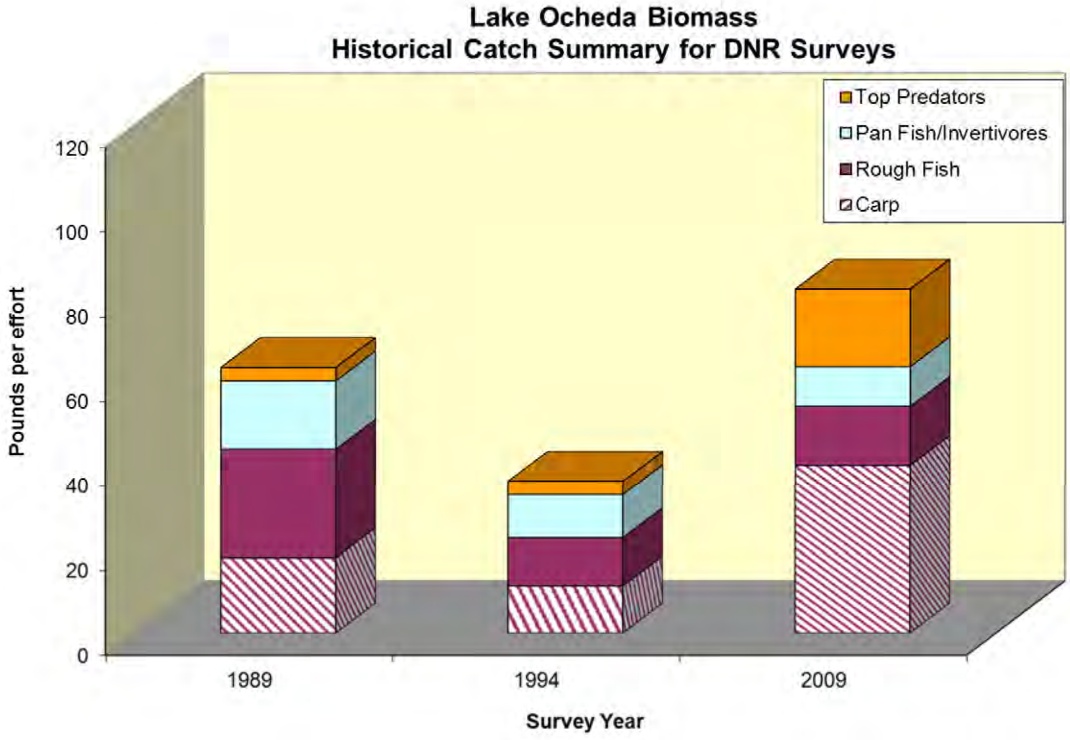


Figure D-1. Okabena Lake DNR fish survey results. Figures are presented in pounds per effort and number of fish per effort for each major trophic group.



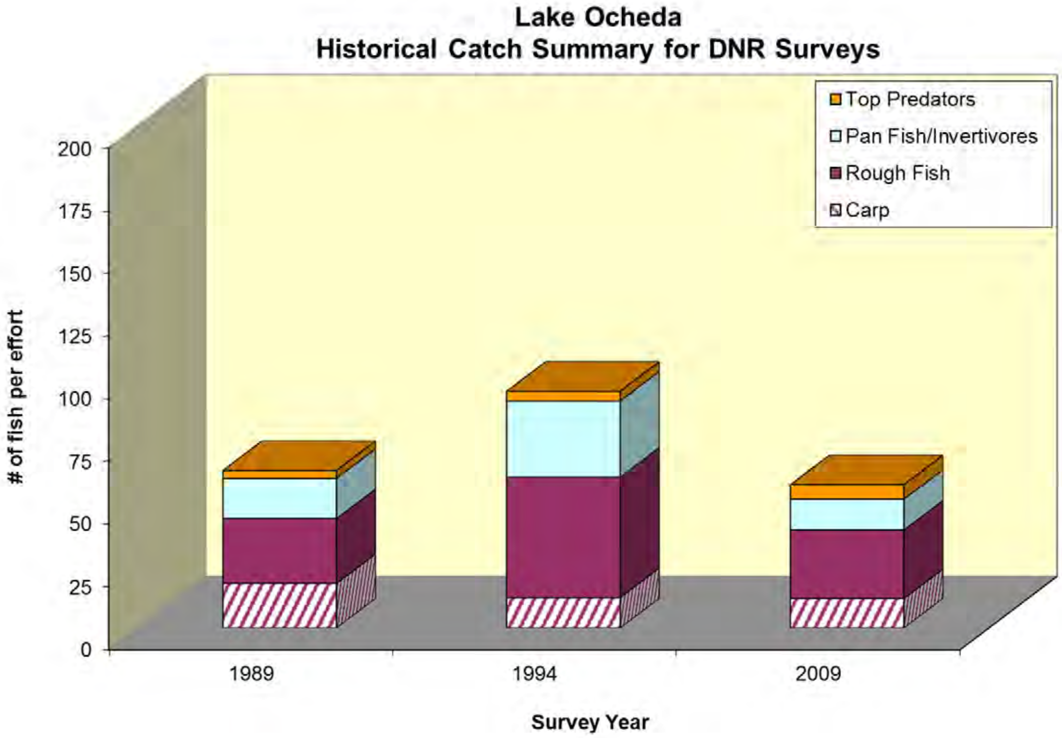
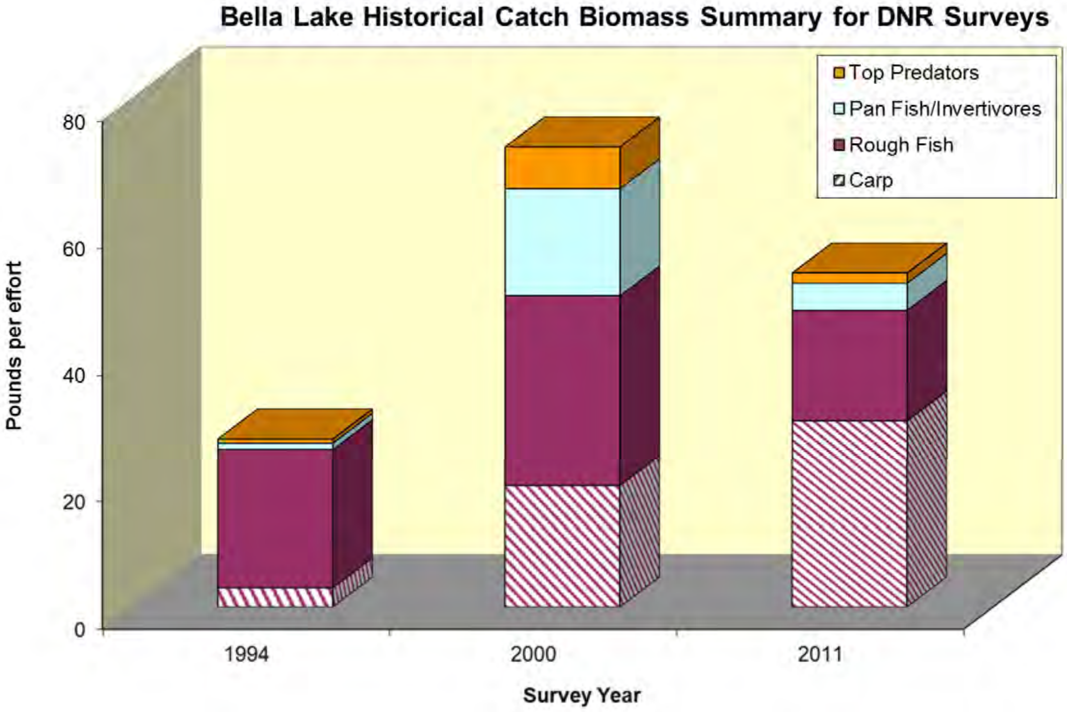


Figure D-2. Lake Ocheda DNR fish survey results. Figures are presented in pounds per effort and number of fish per effort for each major trophic group.



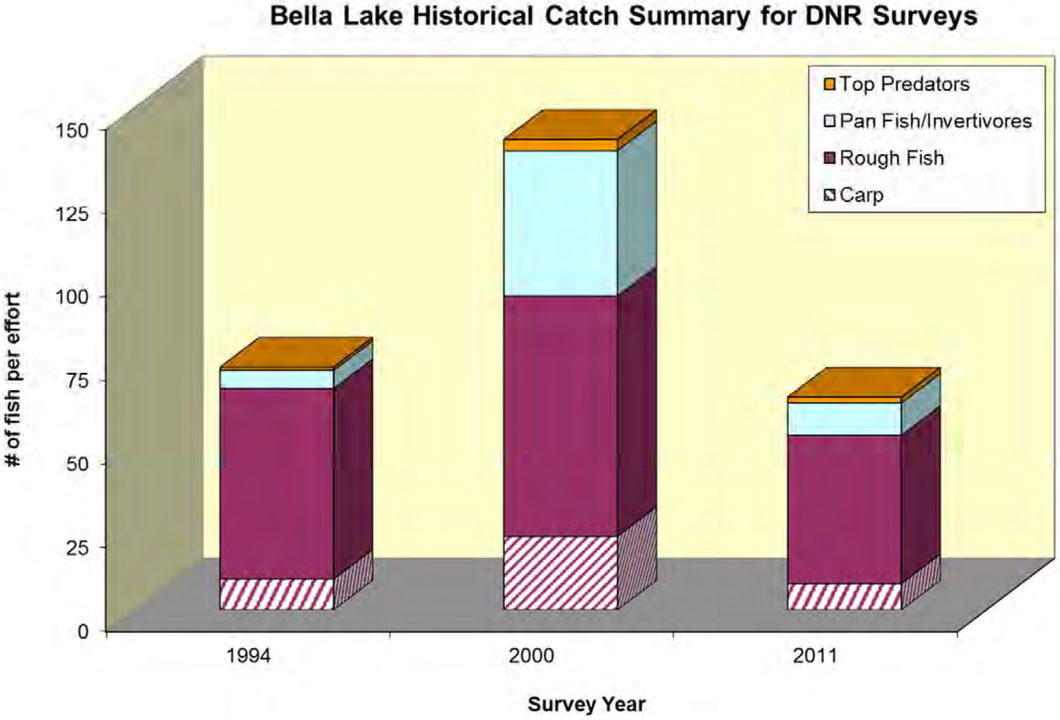
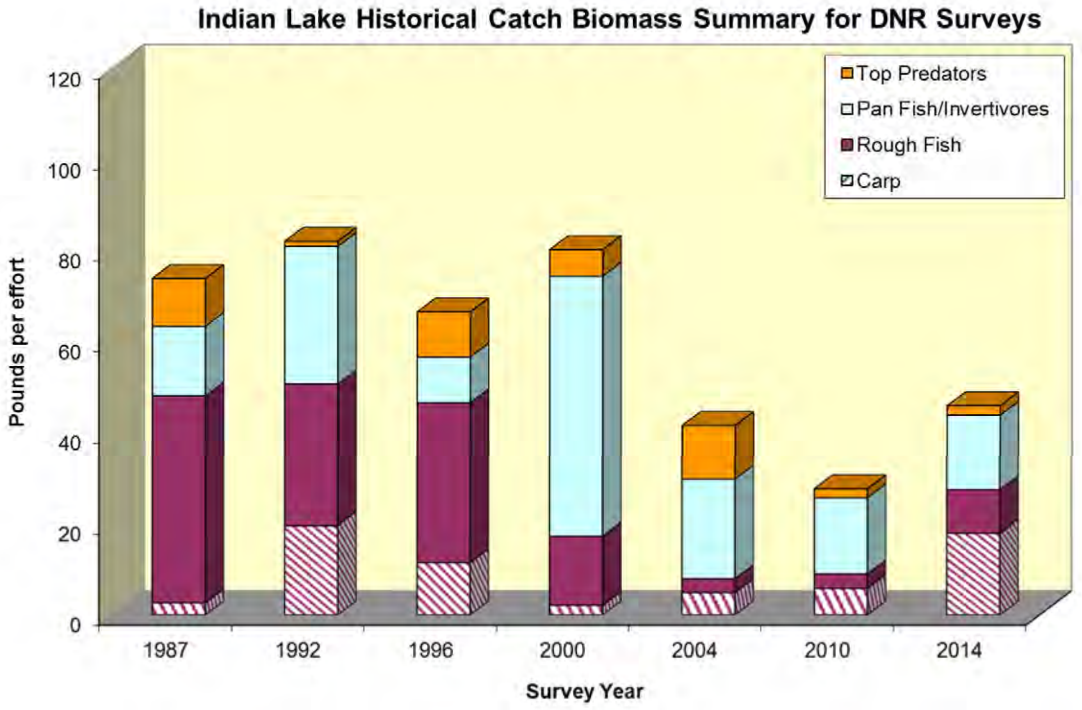


Figure D-3. Bella Lake DNR fish survey results. Figures are presented in pounds per effort and number of fish per effort for each major trophic group.



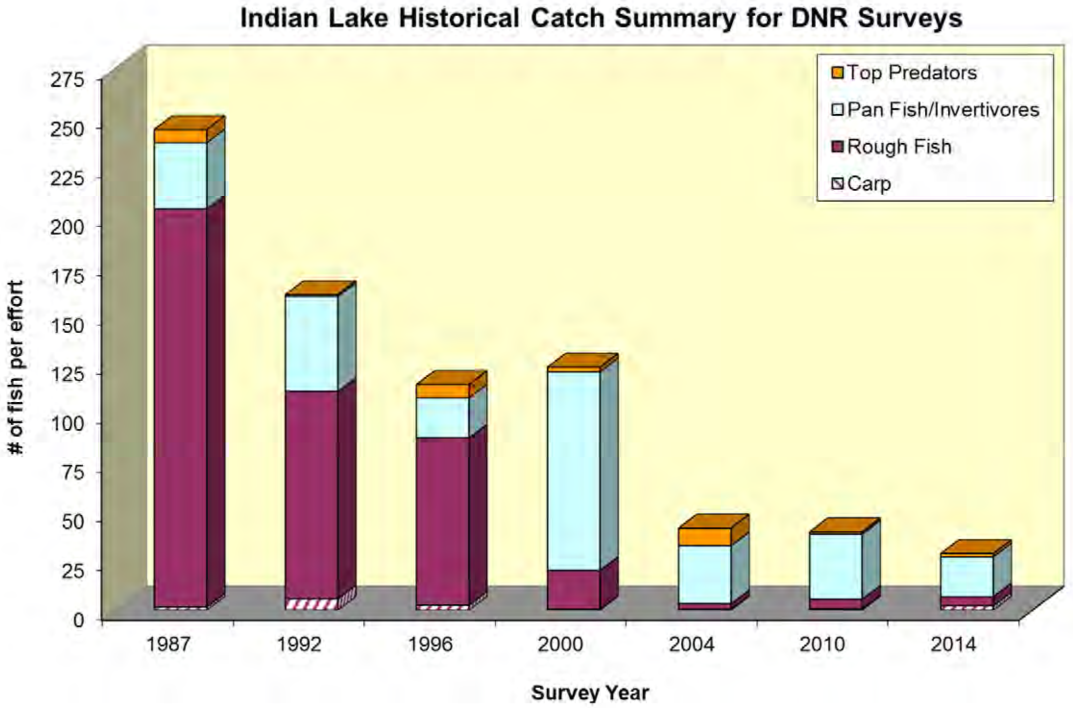
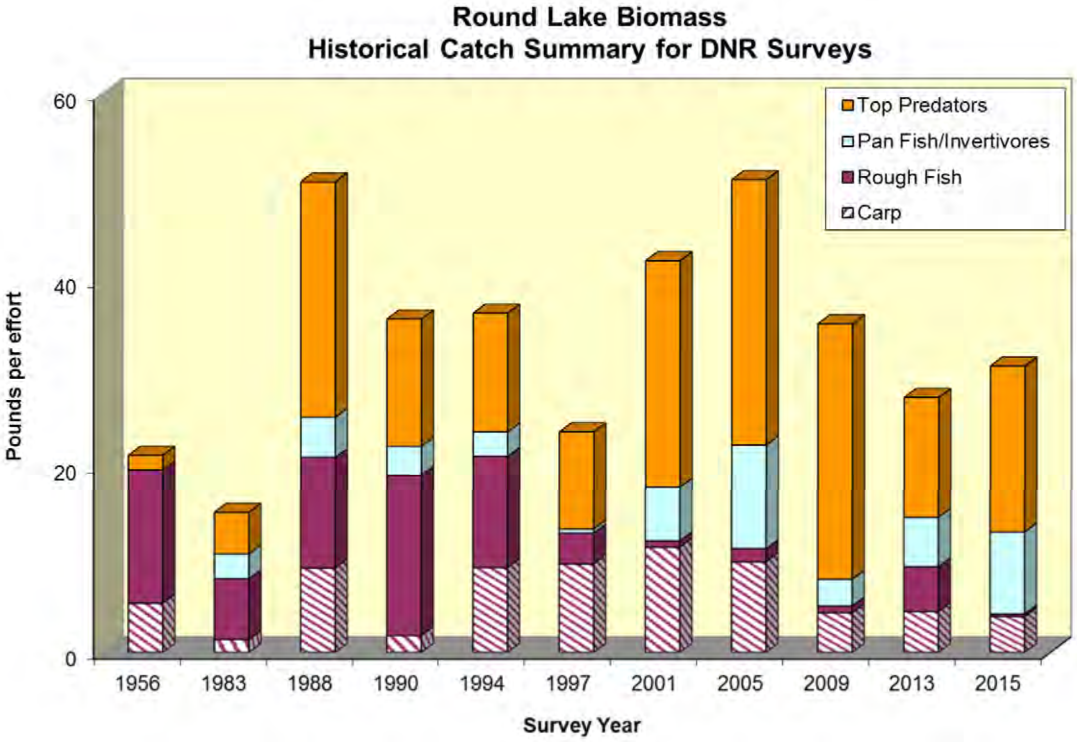


Figure D-4. Indian Lake DNR fish survey results. Figures are presented in pounds per effort and number of fish per effort for each major trophic group.



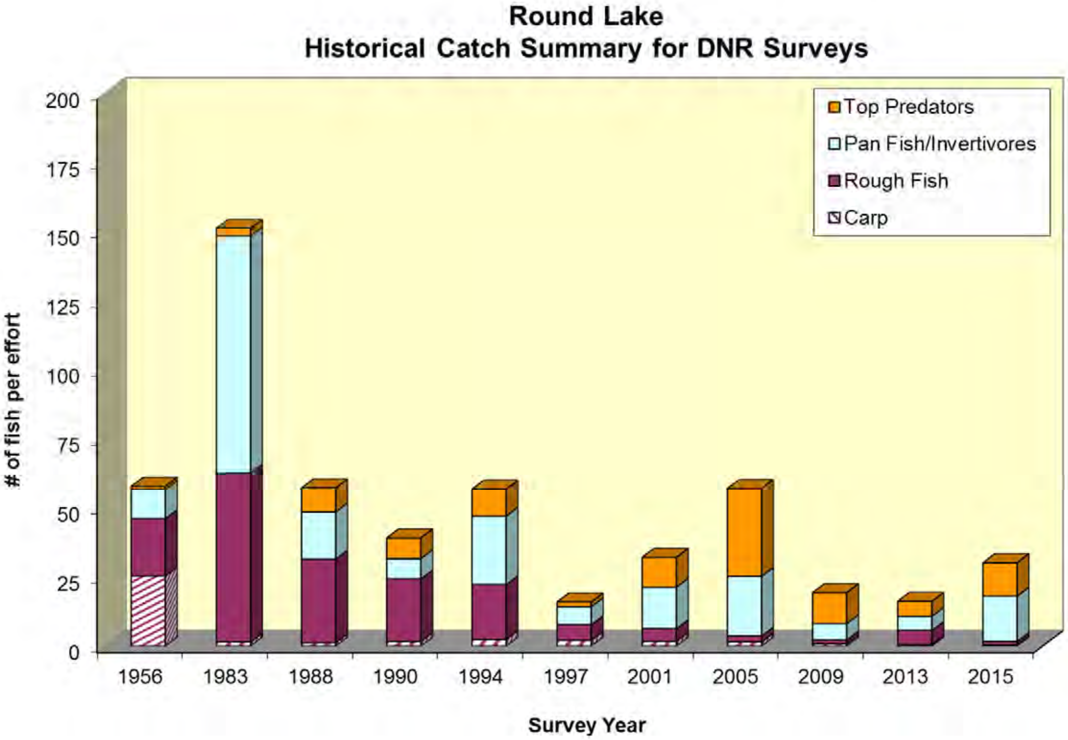
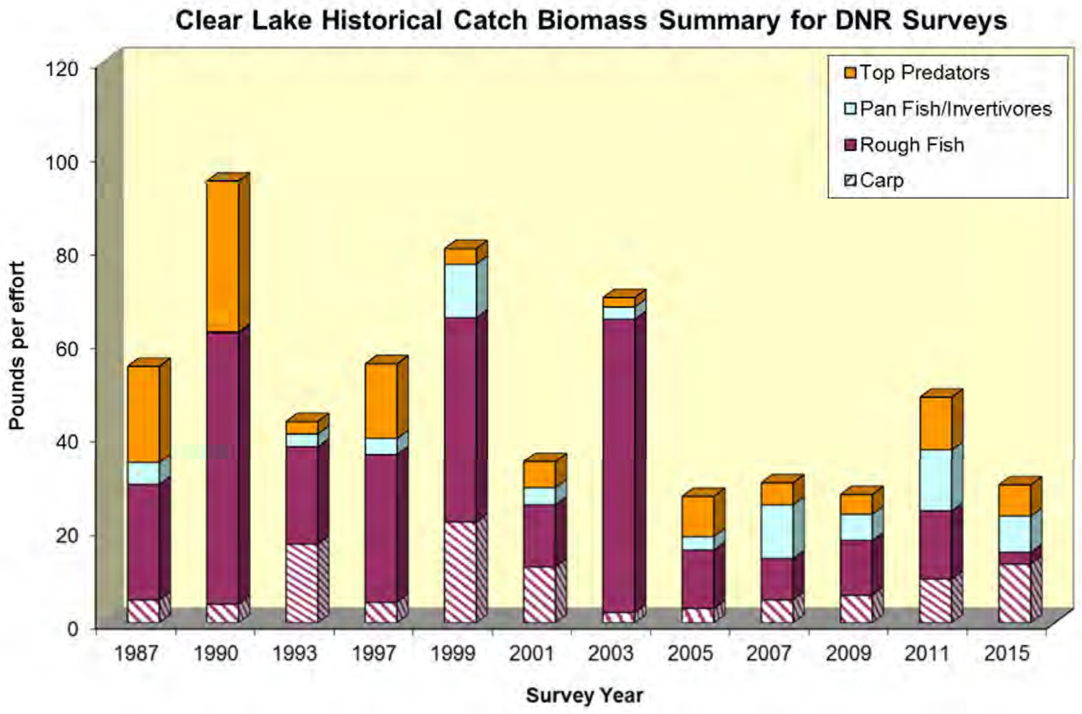


Figure D-5. Round Lake DNR fish survey results. Figures are presented in pounds per effort and number of fish per effort for each major trophic group.



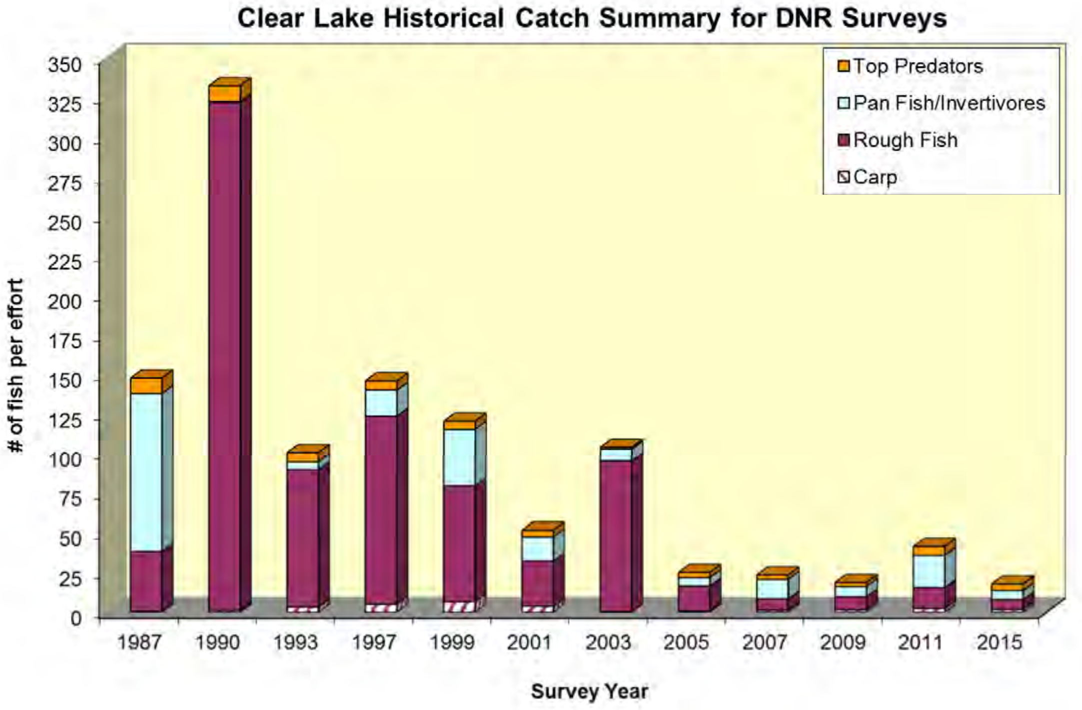
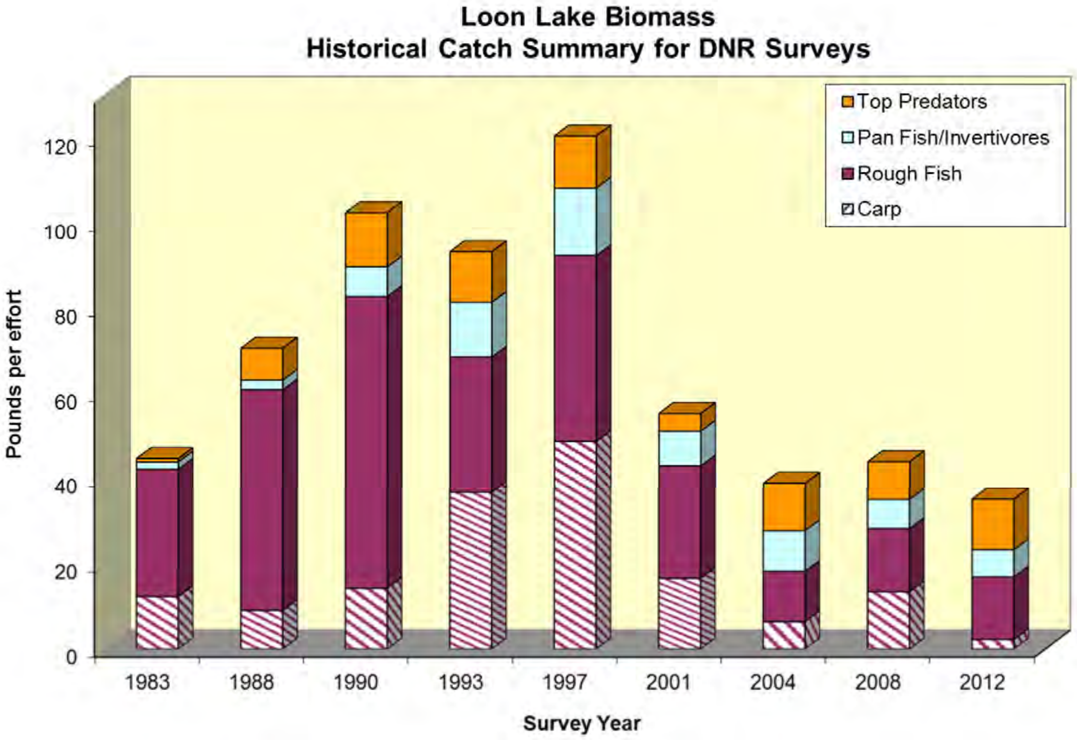


Figure D-6. Clear Lake DNR fish survey results. Figures are presented in pounds per effort and number of fish per effort for each major trophic group.



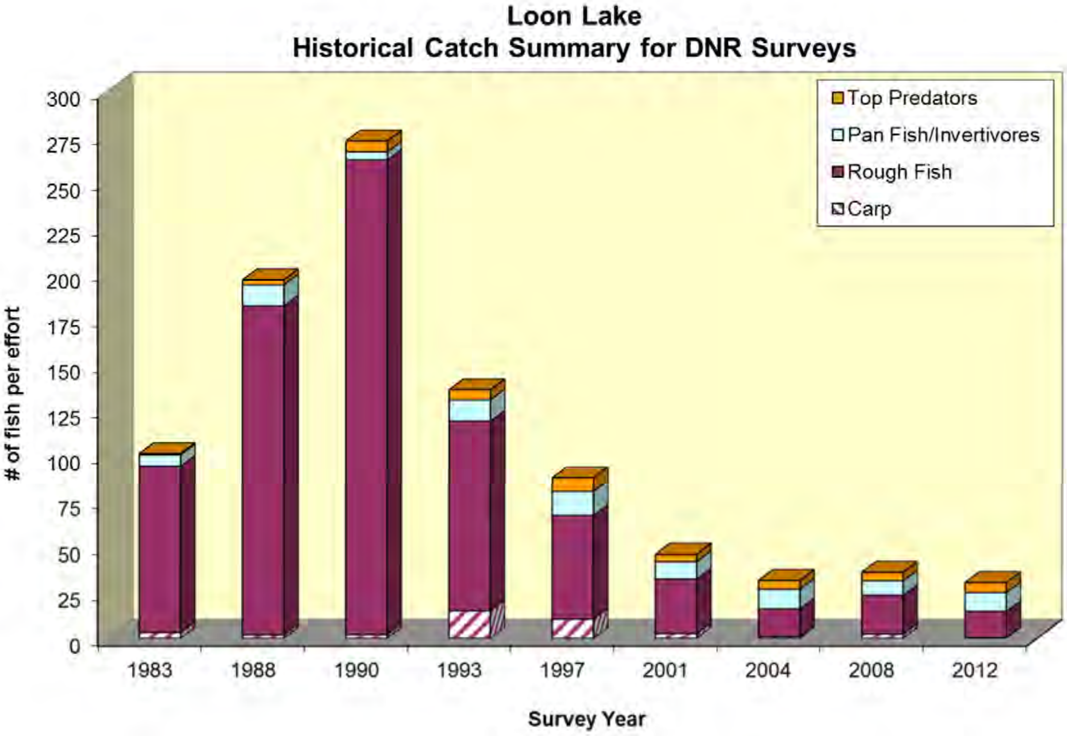


Figure D-7. Loon Lake DNR fish survey results. Figures are presented in pounds per effort and number of fish per effort for each major trophic group.

Appendix E – HSPF Model Documentation

RESPEC
WATER & NATURAL RESOURCES

RSI(RCO)-2216/5-14/25

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 (10170 202)
- Lower Big Sioux River (10170 203)
- 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 base map. 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 non-impaired 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 non-lake 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).

RSI-2279-14-001

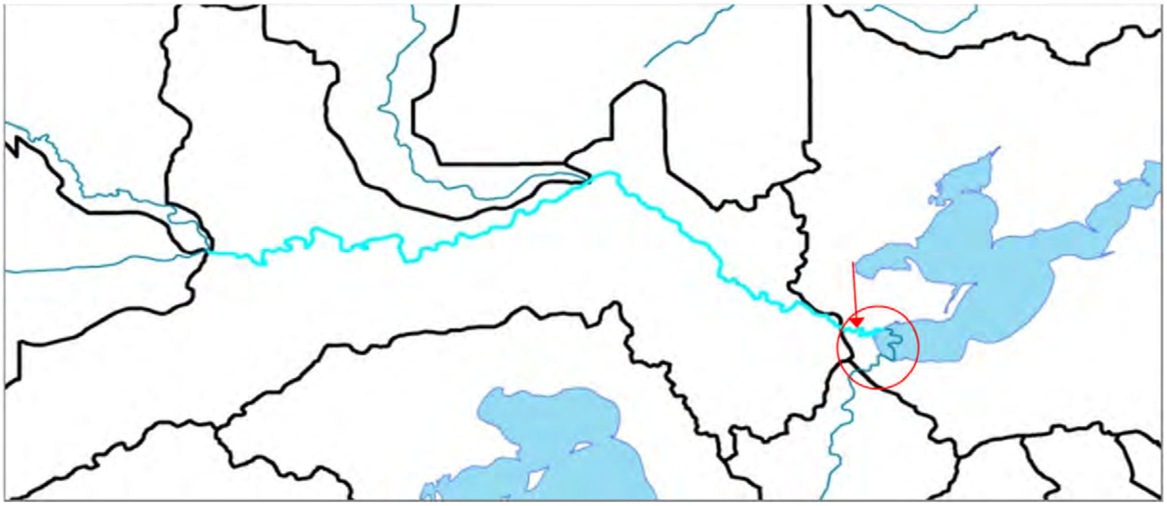


Figure 1. Reach (Highlighted) Passing Through a Small Portion (Circled) of a Subwatershed and Extended Reach in a Lakeshed (Arrow).

RSI-2279-14-002

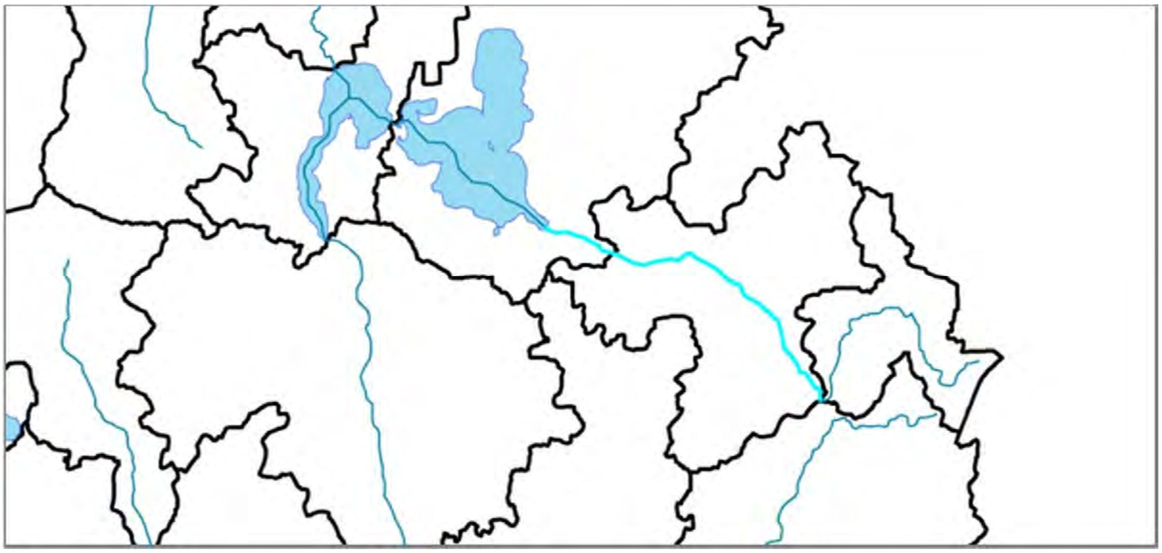


Figure 2. Extended Reach (Highlighted) in a Lakeshed.

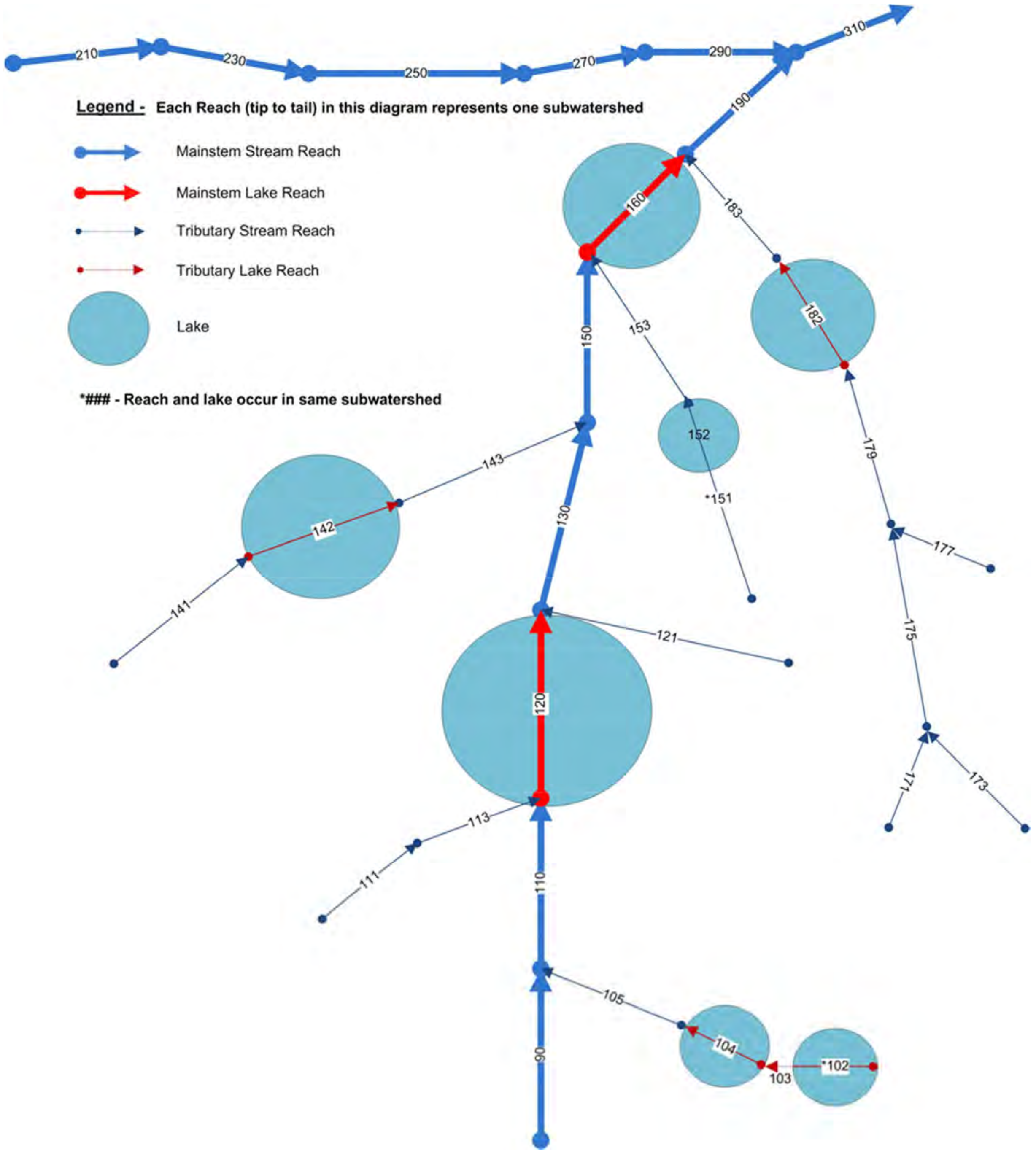


Figure 3. Example of a Reach Numbering Schematic.

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 corrsponding 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., 102and 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 managementpriorities, 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. Spillwaylength, 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 averagevalues 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,

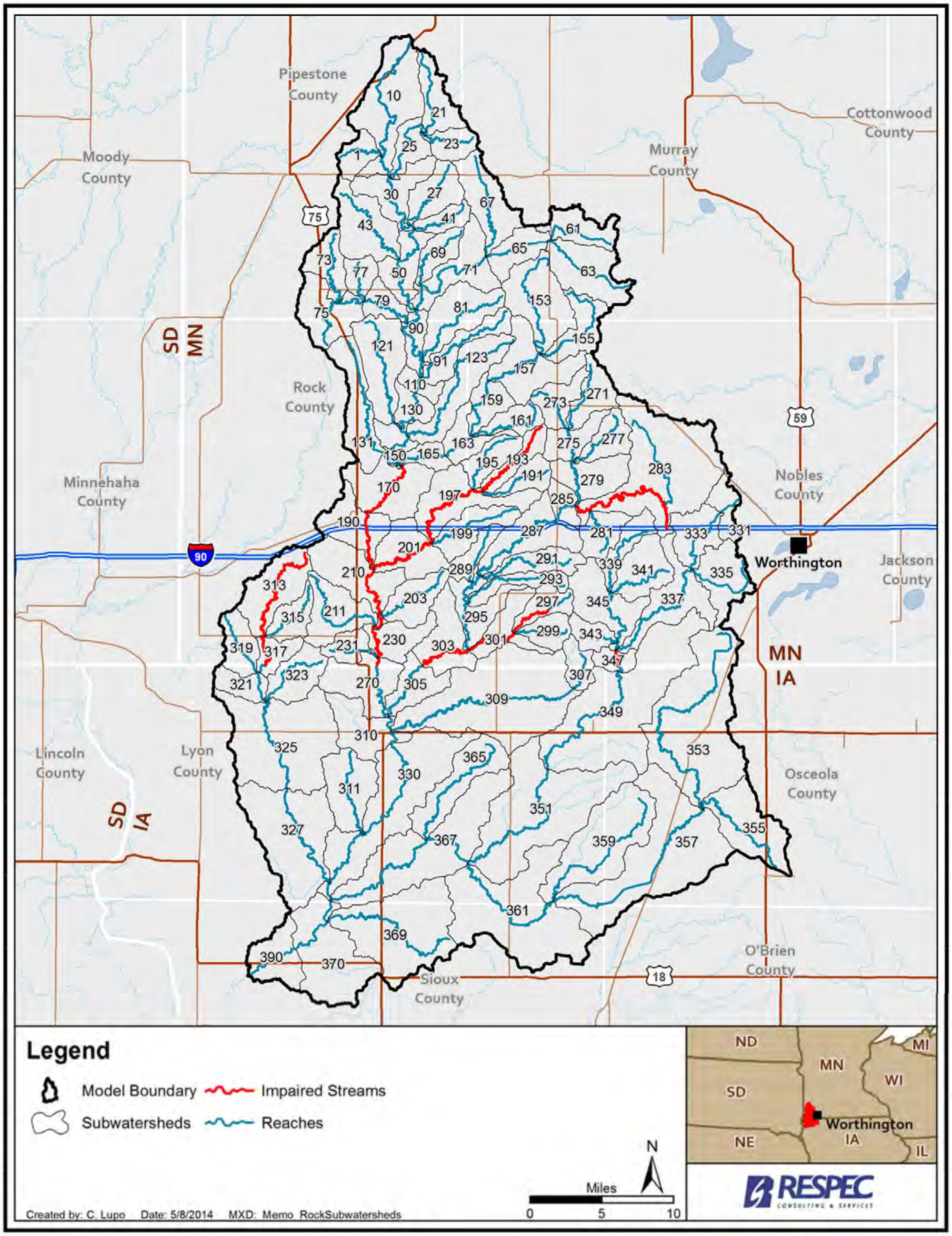


Figure 4. Rock River Watershed Reach and Subwatershed I.D.s.

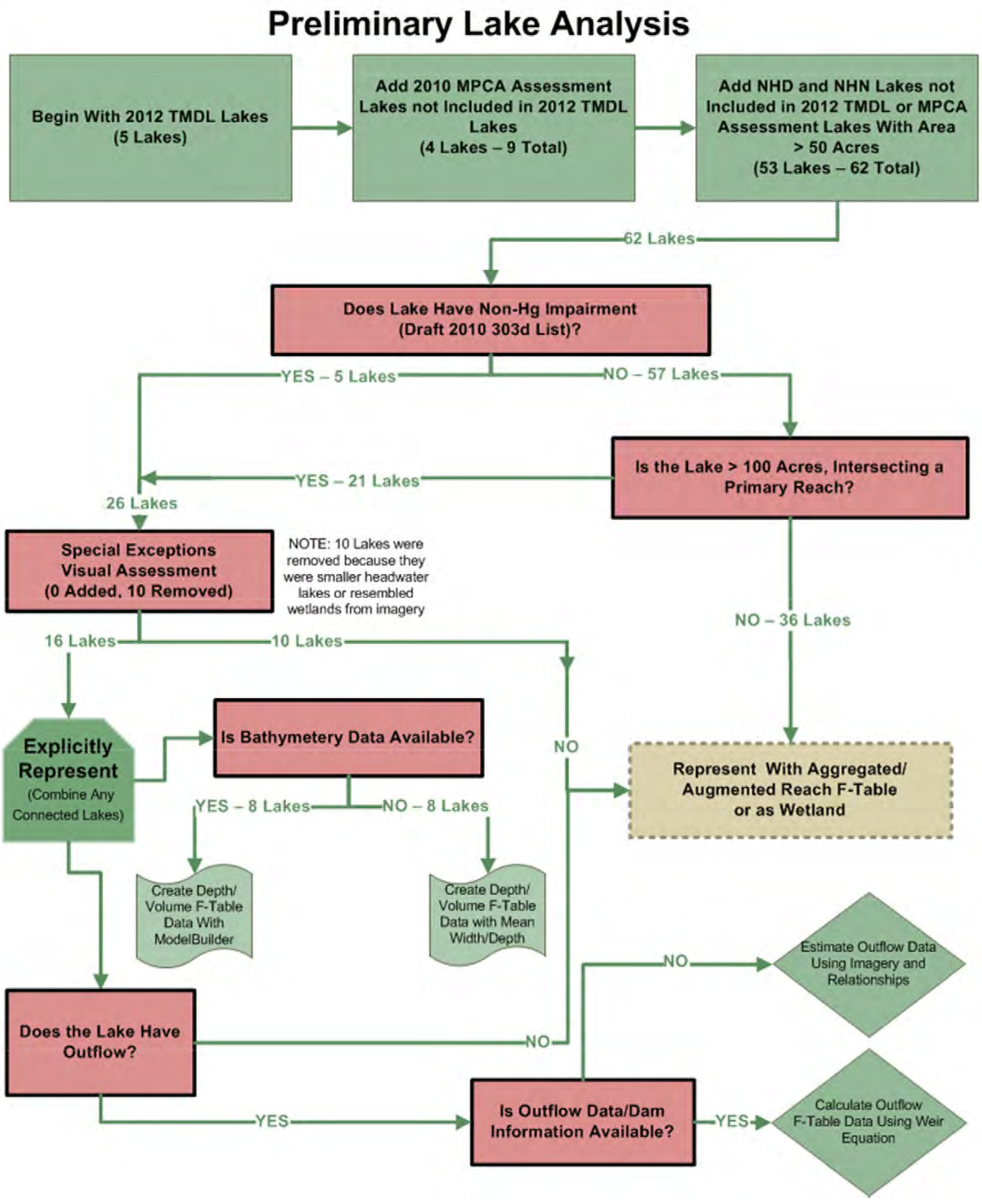


Figure 5. Lake Selection Schematic.

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 data set. 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:

$Q =$ Discharge (cfs)

$n =$ Manning's roughness coefficient

$A =$ Cross-section area (square feet)

$R =$ Hydraulic radius (feet)

$S =$ Channel slope.

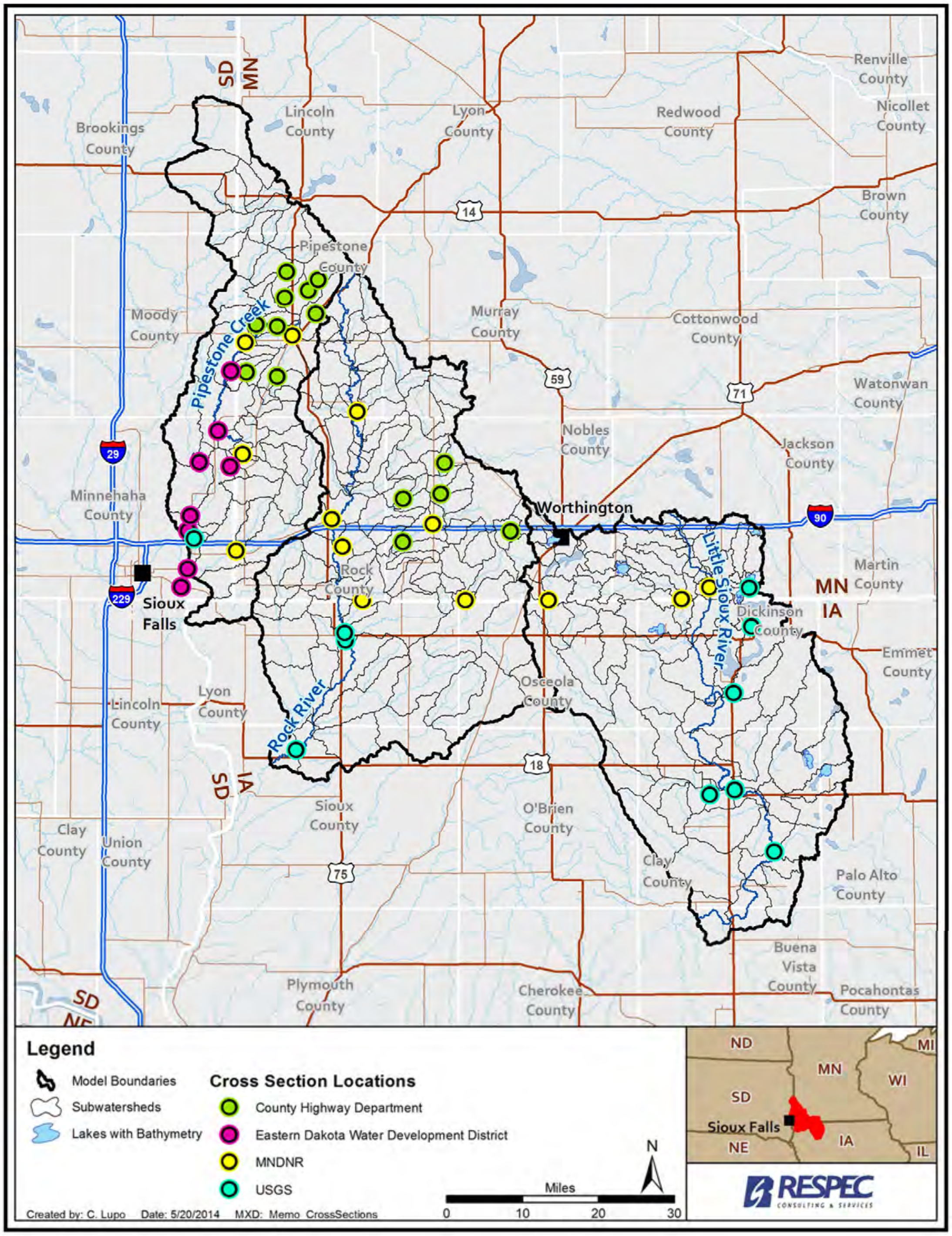

Figure 6. Locations of Lake Bathymetry and Cross-Section Data Used to Develop Model F-Tables.

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 areawere 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 WDMfile 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** stationsselected 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 datato 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 anddistributed) 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.

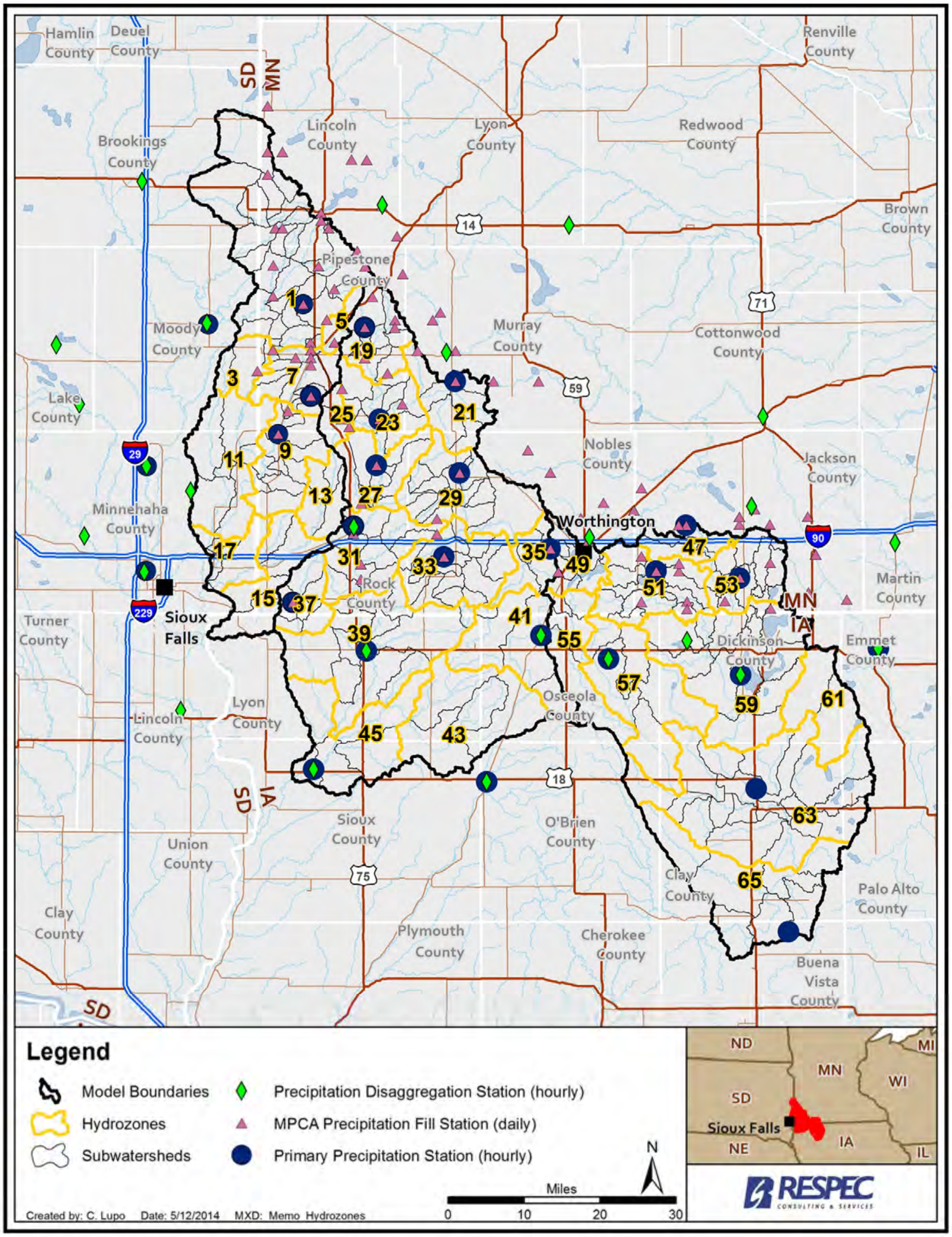

Figure 7. Hydrozones and Meteorological Stations.

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 Water 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.

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[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.

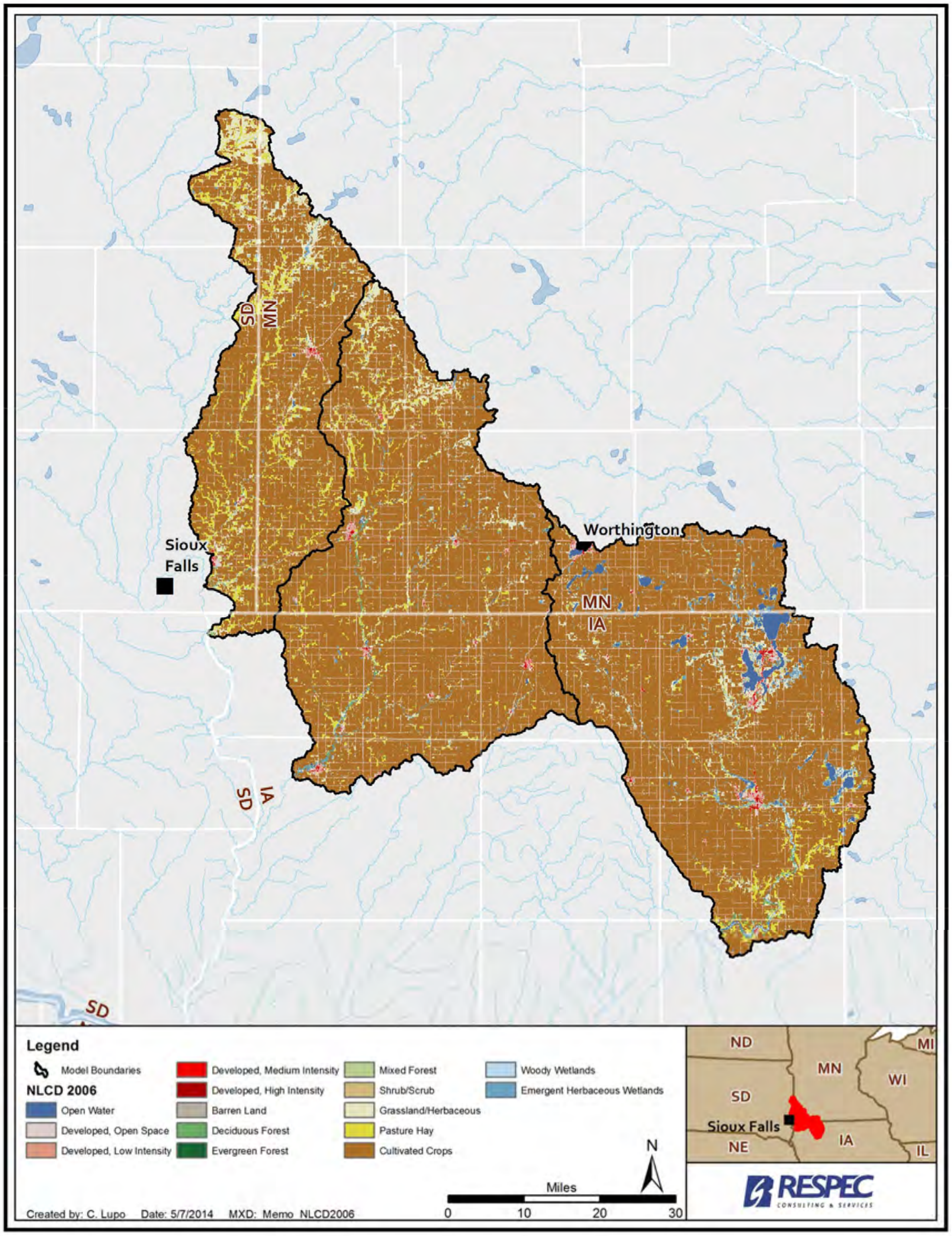

Figure 8. National Land Cover Database 2006 Land Cover Distribution Used to Develop Model Land Cover Categories.

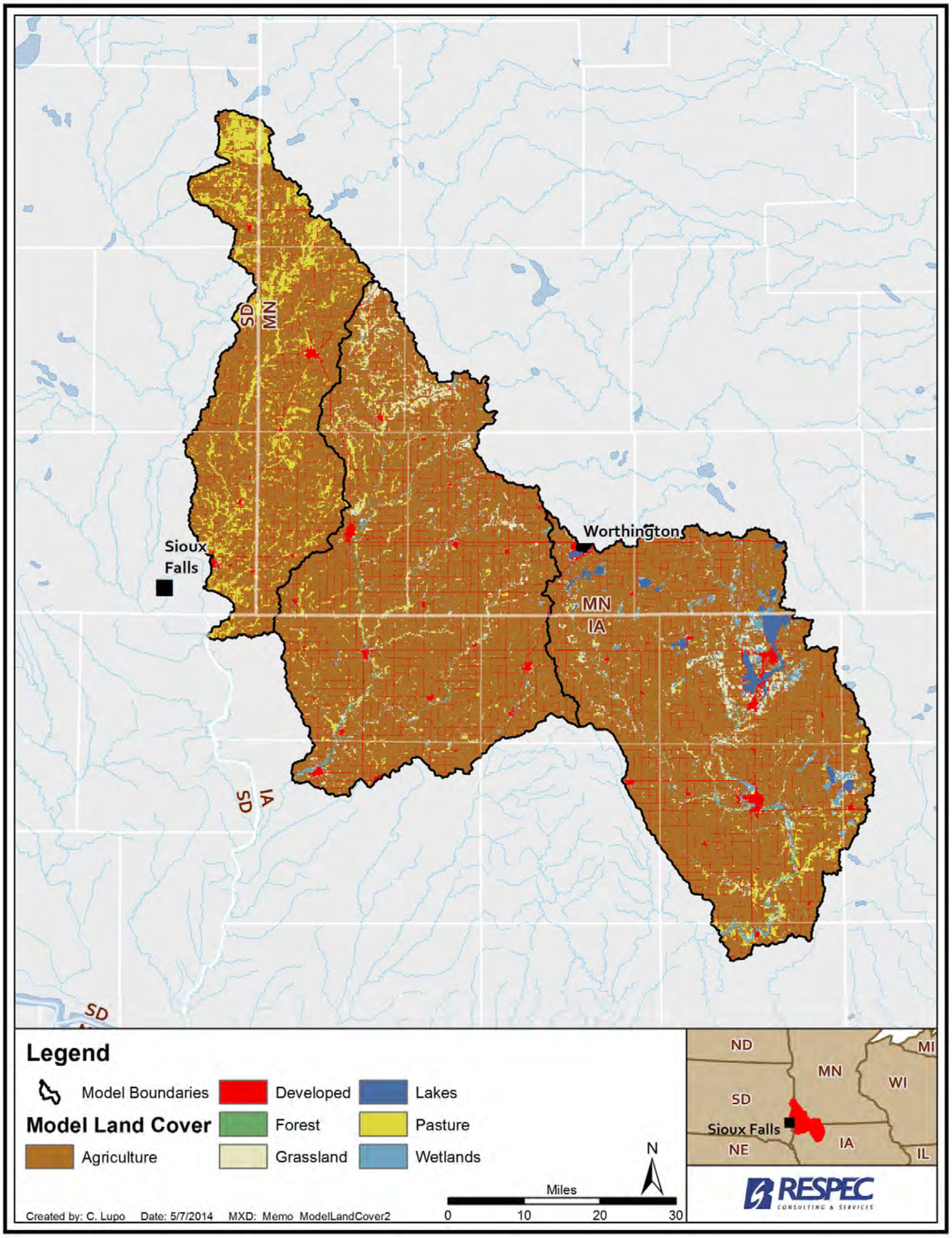

Figure 9. Aggregated Land Cover Categories Used in the Missouri River Watershed.

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 (highrunoff 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			

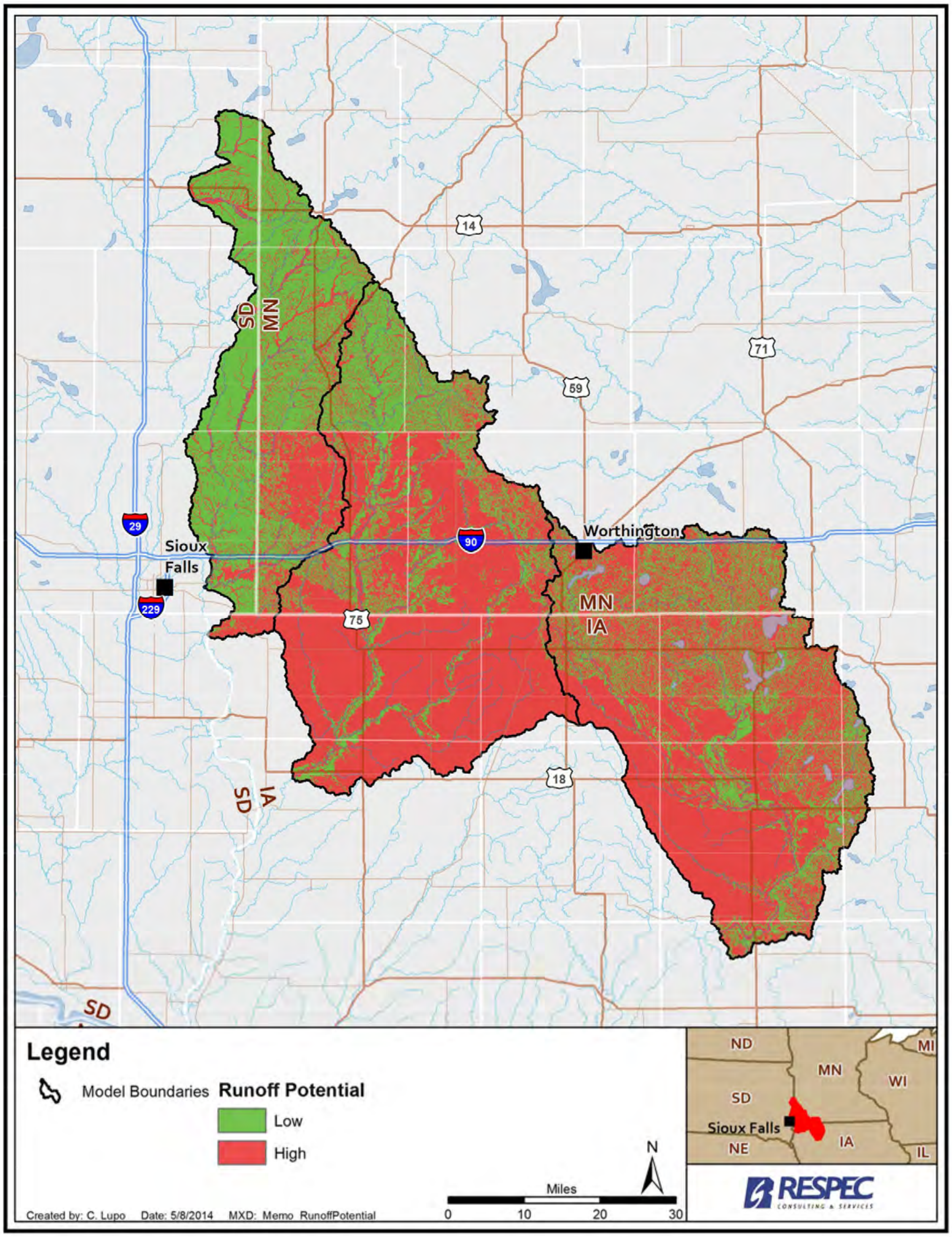

Figure 10. Distribution of Runoff Potential in the Missouri River Watershed.

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.

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[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.

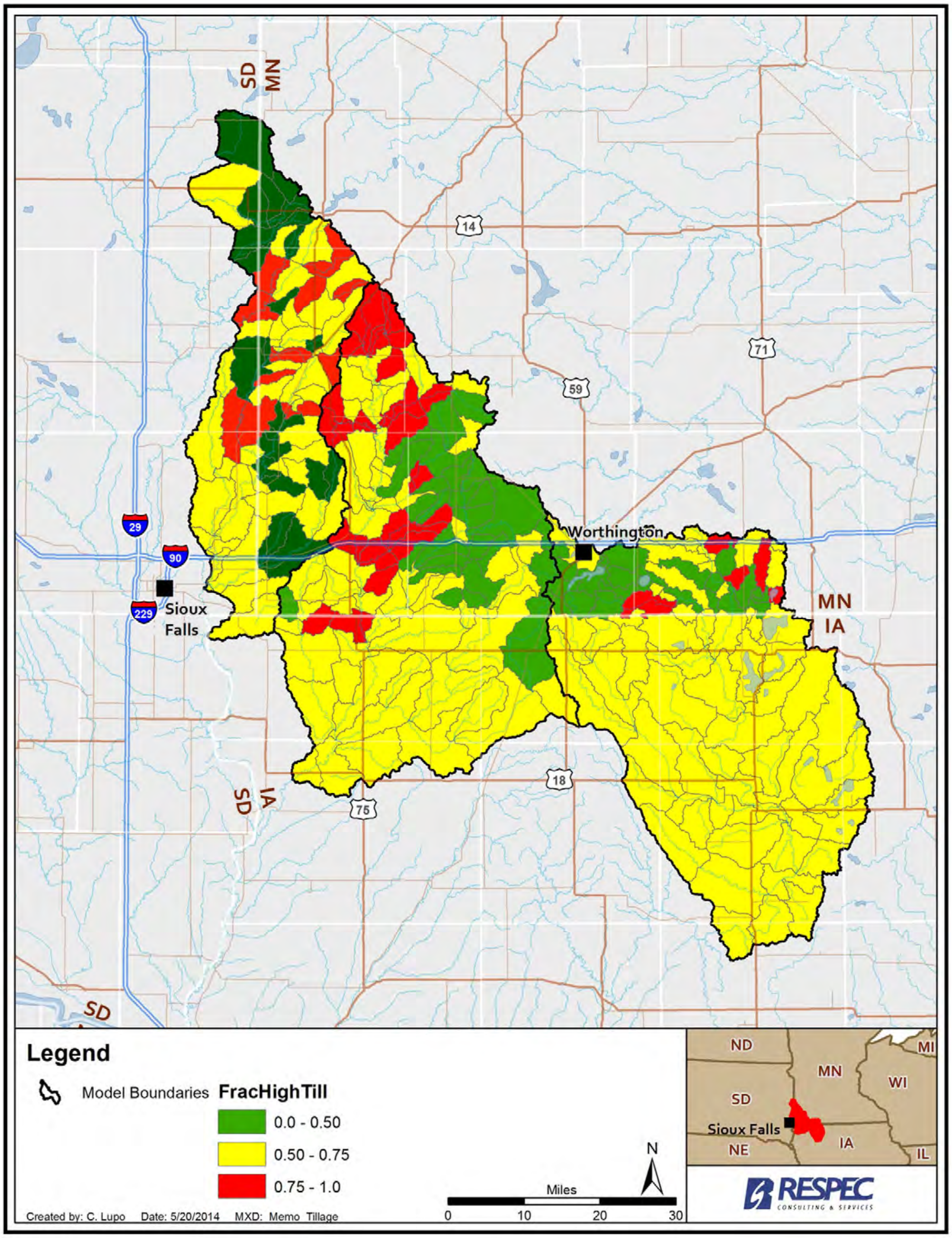

Figure 11. Percent Tillage Estimates Within Each Subwatershed in the Missouri RiverWatershed.

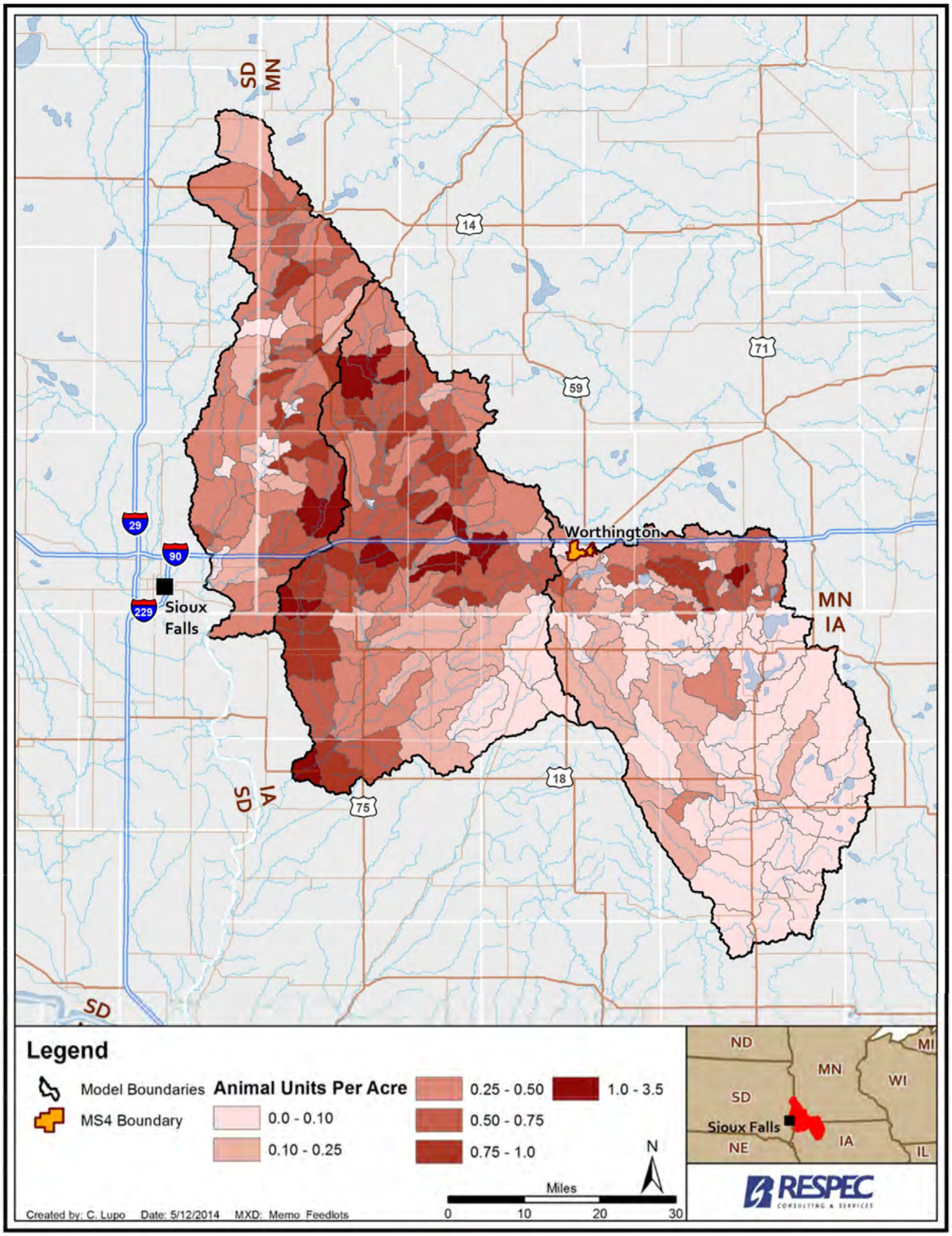

Figure 12. Animal Unit Density Within Each Subwatershed and the MS4 in the Missouri River Watershed.

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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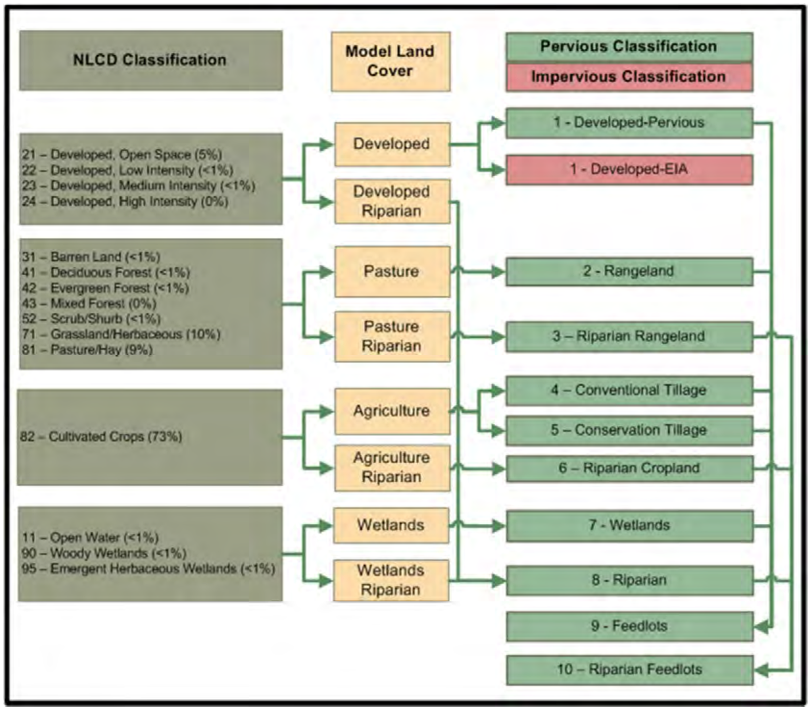

Figure 13. Model Classification for PERLND and IMPLND Development for the Big Sioux River Watershed.

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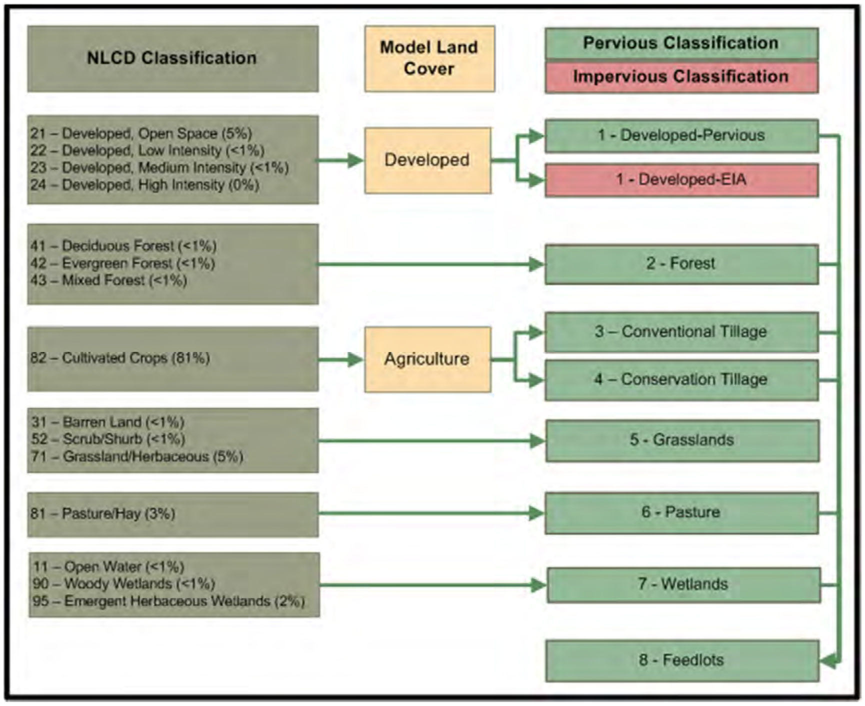

Figure 14. Model Classification for PERLND and IMPLND Development for the Little Sioux River and Rock River Watersheds.

ATTACHMENT A

MODEL APPLICATION REACHES AND SUBWATERSHEDS

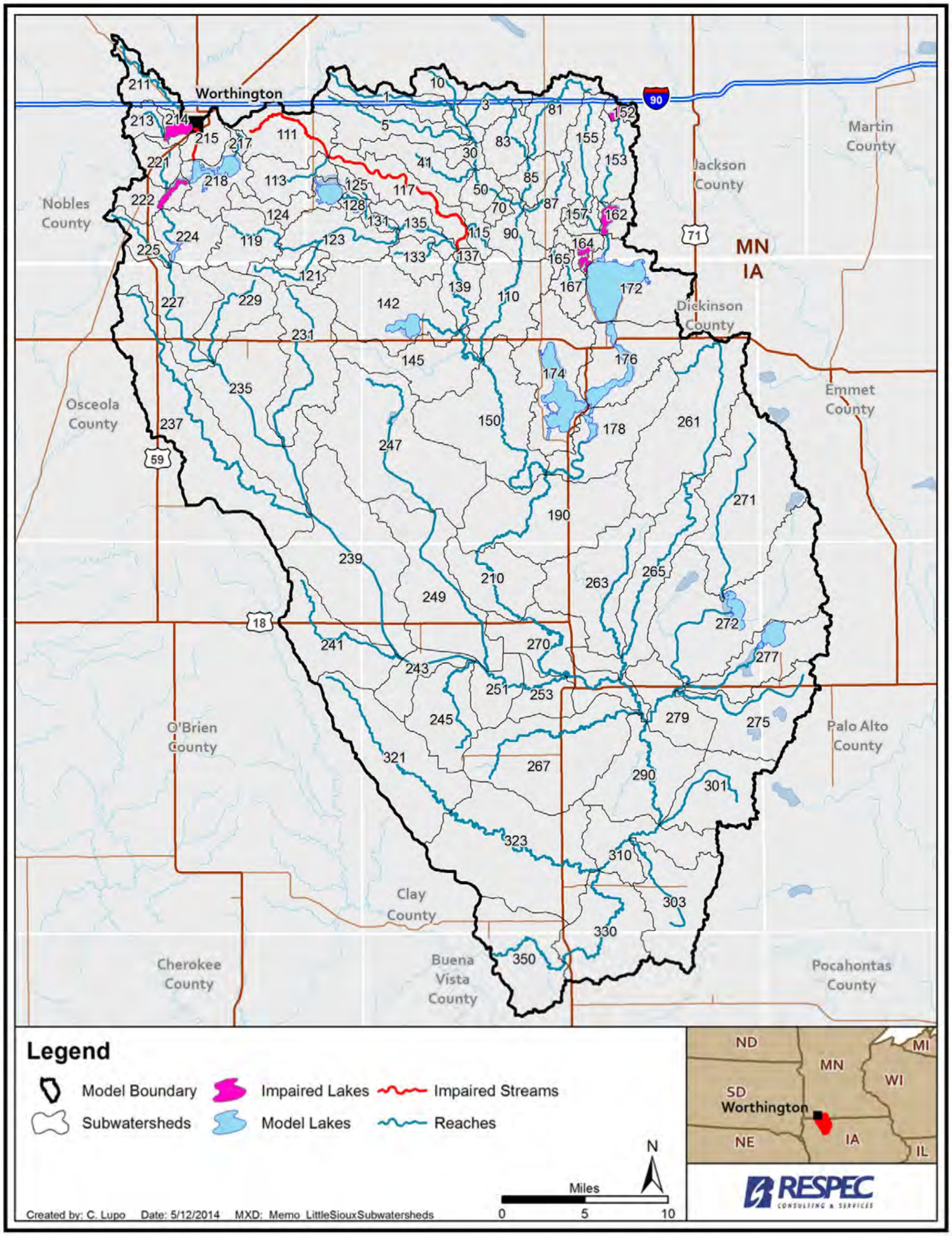

Figure A-1. Little Sioux Watershed Reach and Subwatershed ID.s.

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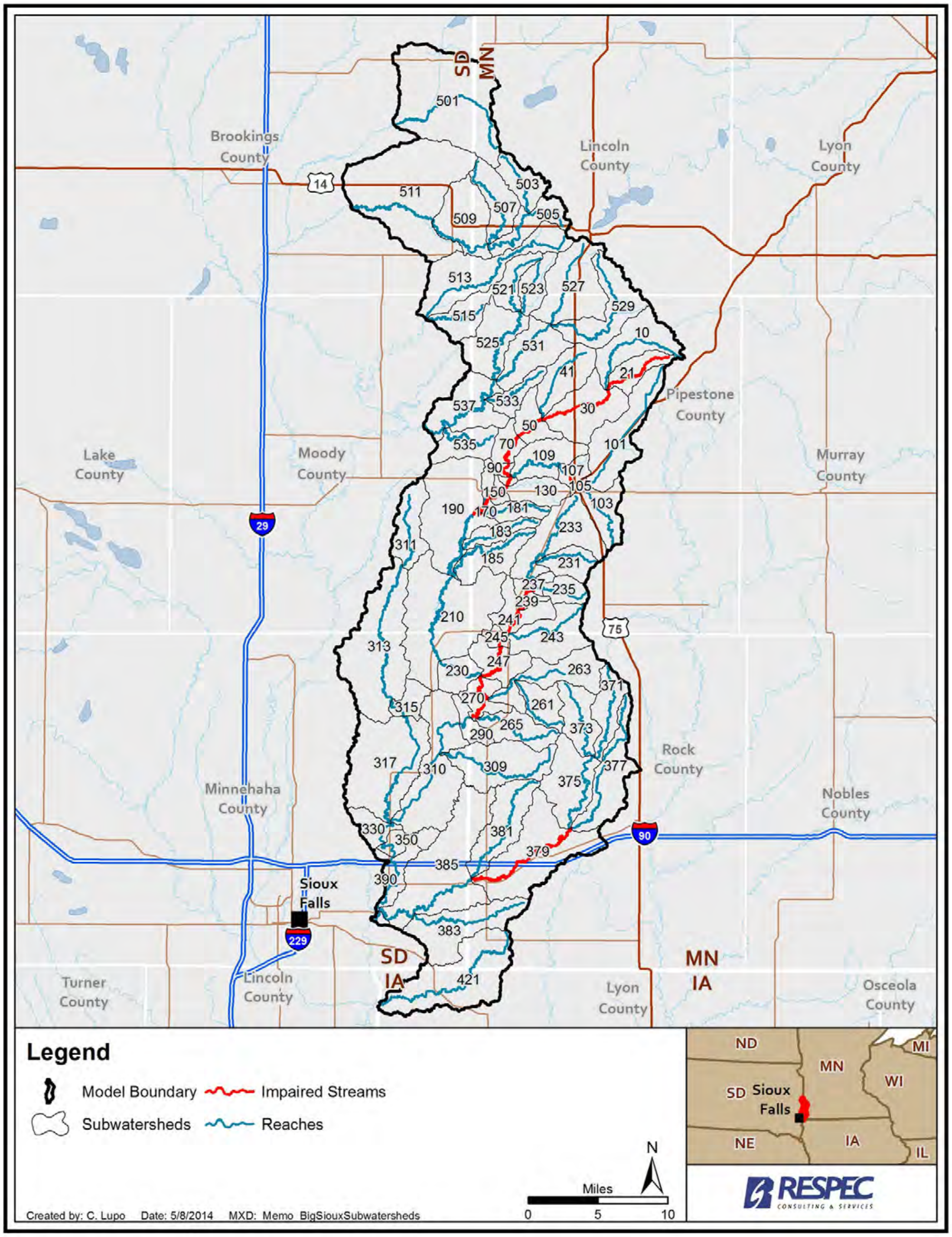

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Figure A-2. Big Sioux Watershed Reach and Subwatershed I.D.s.

RESPEC
WATER & NATURAL RESOURCES

RSI(RCO)-2276/5-14/22

May 30, 2014

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

Dear Dr. Regan:

RE: Hydrology and Water-Quality Calibration and Validation of Big Sioux and the Little Sioux-Missouri River Watershed Model Applications

Please review the following methodology and results for hydrologic and water-quality calibration and validation of the Big Sioux River, Little Sioux River, and Rock River **HSPF** Watershed model applications. This memorandum refers to all areas collectively as the Missouri River Watershed.

Hydrologic calibration is critical to parameter development for an **HSPF** model application, particularly for parameters that can not be readily estimated by characteristics of the watershed. Calibrating hydrology is also necessary to form the basis for a sound water-quality calibration. Calibrating an **HSPF** model application is a cyclical process of making parameter changes, running the model, producing graphical and statistical comparisons of simulated and observed values, and interpreting the results. Observed data for hydrology and water-quality calibration include continuous stream flow (collected at gaging stations) for hydrology and ambient water quality samples obtained from reputable sources. Calibration is typically evaluated with visual and statistical performance criteria and a validation of model performance that is separate from the calibration effort. Methods and results for hydrologic calibration are explained first, followed by methods and results for water-quality calibration.

HYDROLOGIC CALIBRATION DATA

The continuous, observed stream -flow data required for calibration are available at ten gages within the Missouri River Watershed. The mainstem calibration/validation gages are located on Pipestone Creek (three gages), Rock River (four gages), and Little Sioux River (one gage). Theninth gage is located on Ocheyedan River, and the tenth gage is on a small tributary near Pipestone, Minnesota. Table 1 provides the stream flow gages and their period of record to support model calibration and validation of hydrology, with the most downstream mainstemgage shown in bold. Locations of flow gages for Rock River Watershed are illustrated in Figure 1, and the locations for the rest of the model applications are shown in Attachment A. Flow data were downloaded from the U.S. Geological Survey (USGS) National Water Information System Web Interface (*http: // waterdata.usgs.gov / mn / nwis / dv / ?referred_module
=sw*).

Table 1. Discharge Calibration Gages Within the Missouri River Watershed

Model Application	Gage	Gage Description	HSPF Reach I.D.	Drainage Area (mi^2)	Data Availability	Sample Count
Big Sioux River	H82042001	North Branch Pipestone Creek near Airlie, CR71	70	62.7	2004	160
Big Sioux River	H82035001	Pipestone Creek at Pipestone, MN23	105	30.4	1999–2009	2,171
Big Sioux River	H82015001	Split Rock Creek nr Jasper, 201st St	270	331	2008–2009	391
Big Sioux River	**6482610**	**Split Rock Creek at Corson**	**350**	**482**	**2001–2009**	**2,922**
Little Sioux River	6605000	Ocheyedan River near Spencer, IA	251	433	1995–2009	5,113
Little Sioux River	**6605850**	**Little Sioux River at Linn Grove, IA**	**350**	**1,559**	**1995–2009**	**5,113**
Rock River	H83027001	Rock River nr Hardwick, CR8– USGS 6482945	130	306	1998–2009	3,082
Rock River	H83016001	Rock River at Luverne, CR4– USGS 6483000	170	419	1995–2009	3,761
Rock River	6483290	Rock River below Tom Creek at Rock Rapids, IA	310	851	2001–2009	3,166
Rock River	**6483500**	**Rock River near Rock Valley, IA**	**370**	**1,590**	**1995–2009**	**5,113**

Typically, calibration is performed over at least a 5-year period with a range of hydrologic conditions from wet to dry and then validated over a separate period of time (i.e.,a split-sample validation). A single User Control Input (UCI) was used for calibrating each model application.The calibration period is from 1996 to 2009 (based on the National Land Cover Database[NLCD] 2006); the initial year (1995) was simulated to let the model adjust to existingconditions. The availability of flow data allowed for a long-term (at least 5 years) calibration to be performed at all but except H82042001 .

For the validation, separate UCIs were creaed to represent land-use changes over the simulation period [Love, 2011]. One UCI represents 1995 through 2003 and was developed using land-cover data derived from the NLCD 2001. The other represents 2004 through 2009 and was developed by using the NLCD 2006. The primary calibration period is from 2004 to2009 (based on the NLCD 2006), and the validation period is from 1996 to 2003 (based on the NLCD 2001). Additionally, the model application's ability to maintain a high-quality calibrationat multiple gages that represent the variability of the watershed while maintaining consistent parameters throughout the watershed is, in itself, a form of validation.

After the model applications were calibrated and validated for the two time periods with alternate land-use configurations, a single application was developed for each model. These full-time period applications can be used for long-term scenario simulations.

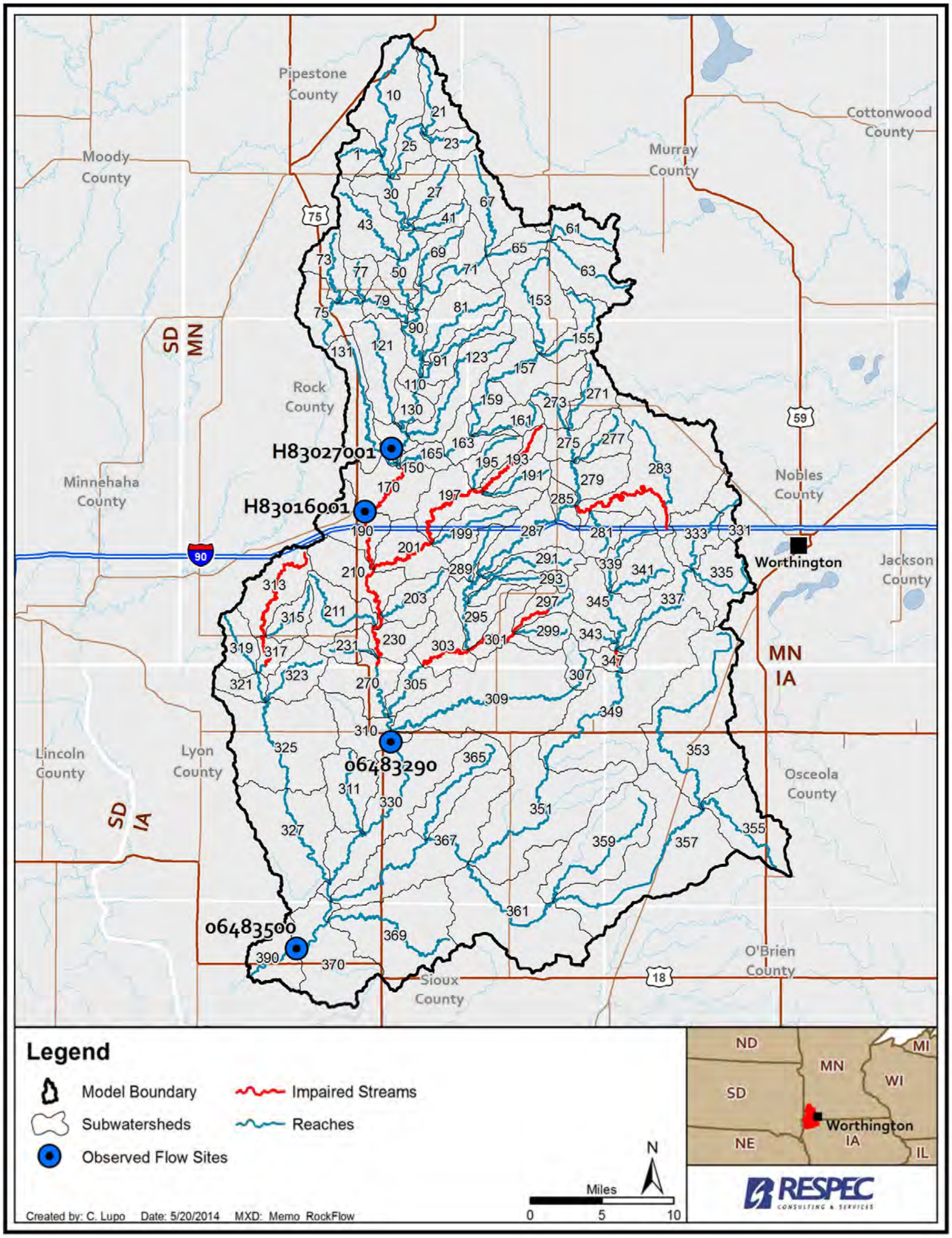

Figure 1. Flow Calibration Gages Within the Rock River Watershed.

STANDARD HYDROLOGIC CALIBRATION

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

- **Establish an annual water balance.** This consists of comparing the total annual simulated and observed flows (in inches) and is governed by meteorological inputs (rainfall and evaporation); the listed parameters LZSN (lower zone nominal storage), LZETP (lower zone evapotranspiration parameter), DEEPFR (deep groundwater recharge losses), and INFILT (infiltration index); and the factor applied to panevaporation to calculate potential evapotranspiration.
- **Make seasonal adjustments.** Differences in the simulated and observed total flow over summer and winter are compared to see if runoff (defined for calibration purposes as total stream discharge) needs to be shifted from one season to another. These adjustments are generally accomplished by using seasonal (monthly variable) values for the parameters CEPSC (vegetal interception), UZSN (upper zone storage), and LZETP.LZETP will vary greatly by land use, especially during summer months, because evapotranspiration differs. KVARY (variable groundwater recession) and BASETP(baseflow ET index) as well as snow accumulation and melt parameters are also adjusted.
- **Adjust low-flow/high-flow distribution.** This phase compares high- and low- flow volumes by using flow-percentile statistics and flow-duration curves. Parameters typically adjusted during this phase include INFILT, AGWRC (groundwater recession),and BASETP.
- **Adjust storm flow/hydrograph shape.** Storm flow, which is largely composed of surface runoff and interflow, is evaluated by using daily and hourly hydrographs.Adjustments are made to the UZSN, INTFW (interflow parameter), and IRC (interflow recession). INFILT may also be adjusted slightly.

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

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

Land cover properties typically control most of the variability in the hydrologic responses of a watershed; thus, they were the basis for estimating initial hydrologic parameters. The land cover characteristics primarily affect water losses from evaporation or transpiration by vegetation. The movement of water through the system is also affected by vegetation cover and associated characteristics (e.g., type, density, and roughness). Initial parameter estimates and their relative variances between land segment categories are crucial to maintaining an appropriate representation of the hydrologic components. Engineering judgment is used to adjust parameters congruently within land segment categories during model calibration because of parameter diversity and spatial distribution within the watershed.

INITIAL SNOW ACCUMULATION AND MELT CALIBRATION

Snow accumulation and melt are significant elements of hydrology in Minnesota; thus, snow simulation is an integral part of the hydrology calibration (especially during the winter and spring). The snow calibration is generally completed early in the calibration process along with the seasonal phase of the standard calibration procedure. Snow is simulated in **HSPF** with meteorological time-series data (precipitation, air temperature, solar radiation, wind, and dew point temperature) with a suite of adjustable parameters. Two options are available when simulating snowmelt with **HSPF**: the energy-balance method and the degree-day method. Both methods were evaluated, and the degree-day method was chosen because it resulted in a better hydrologic calibration. Initial values for the wet bulb air temperature below which precipitation occurs as snow under saturated conditions (TSNOW), the factor to adjust the rate of heat transfer from the atmosphere to the snowpack because of condensation and convection(CCFACT), the maximum rate of snowmelt by ground heat (MGMELT), the maximum snow pack at which the entire pervious land segment will be covered with snow (COVIND),monthly values of the degree-day factor (MON-MELT-FAC), a catch-efficiency factor(SNO WCF), a reference temperature (TBASE), the factor to adjust evaporation/sublimation from the snowpack (SNOEVP), and the maximum water content of the snow pack (MWATER) were attained from previous **HSPF** applications in Minnesota and were adjusted as necessary. The initial snow parameter calibration was supported by using comparisons of observed and simulated snowfall and snow-depth data to verify a reasonable representation of snow accumulation and melt processes. A more detailed calibration of snow parameters was based heavily on comparisons of observed and simulated flow data during the standard hydrologic calibration process. Observed data were downloaded from the Minnesota Climatology Working Group website (*http://climate.umn.edu/HIDradius/radius.asp*) and the National Climate Data Center (*https://www.ncdc.noaa.gov/*) for 17 locations within and near the Missouri River Watershed, illustrated in Figure 2. Greater weight was given to gages with a full period ofrecord and located within the watershed. Calibration figures were constructed to compare observed snowfall to simulated snowfall, illustrated in Figure 3 (top), and observed snow depth to simulated snow levels (bottom). Air temperature is included on the snowfall figure to help estimate parameters such as TSNOW and to verify the accuracy of the snowfall data.

HYDRAULIC CALIBRATION

Because of the high number of lakes occurring in these watersheds, lake level is considered an important factor for the hydrology calibration. Lake level data are available for approximately 7 of the 16 modeled lakes, and it can be used for comparison to simulated lake

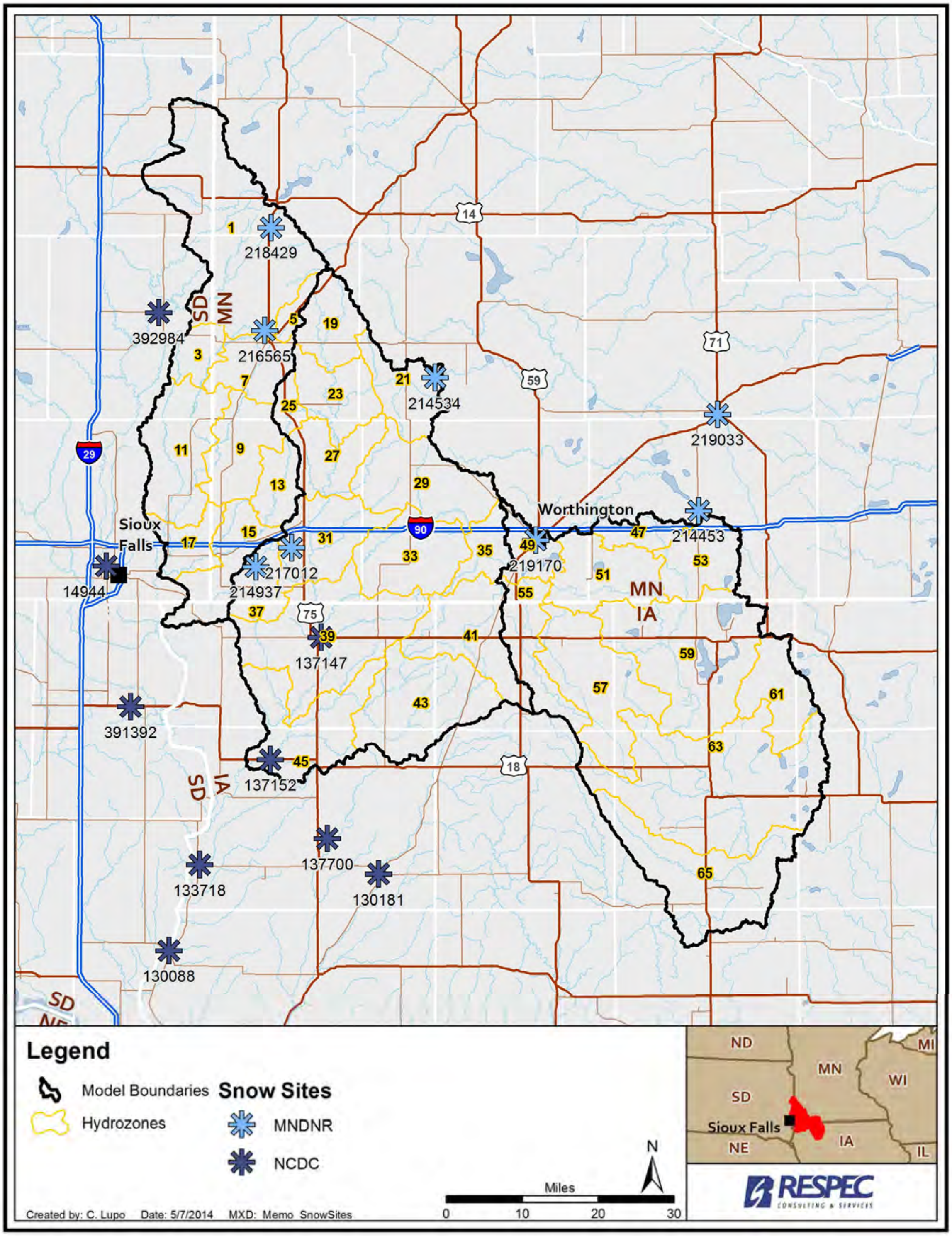

Figure 2. Meteorological Stations With Snow Data Used for Calibration.

levels. The initial lake level calibration, which was completed as an early portion of the hydrology calibration, involved adjusting the reference outlet elevations to accurately represent lake volumes before outflow occurs. Lake geometry parameters as well as outlet depths and outflow calculations were adjusted to modify the F-tables in congruence with the storm flow phase of the standard calibration with the overall goal of adequately representing lake volumes and outflows. Figure 4 illustrates an example of the calibration figures constructed for comparing observed lake-level data and simulated lake level. In cases where multiple lakes are represented as one F-table, simulated lake levels could not be effectively compared to observed lake levels because the combined F-table represents cumulative volume and surface area with absolute depths. Outlet levels can be adjusted but lake level variations will be less variable because of greater storage volumes associated with the same depths. These combined F-tables will be evaluated by comparing patterns in the lake level data instead of actual lake level values.

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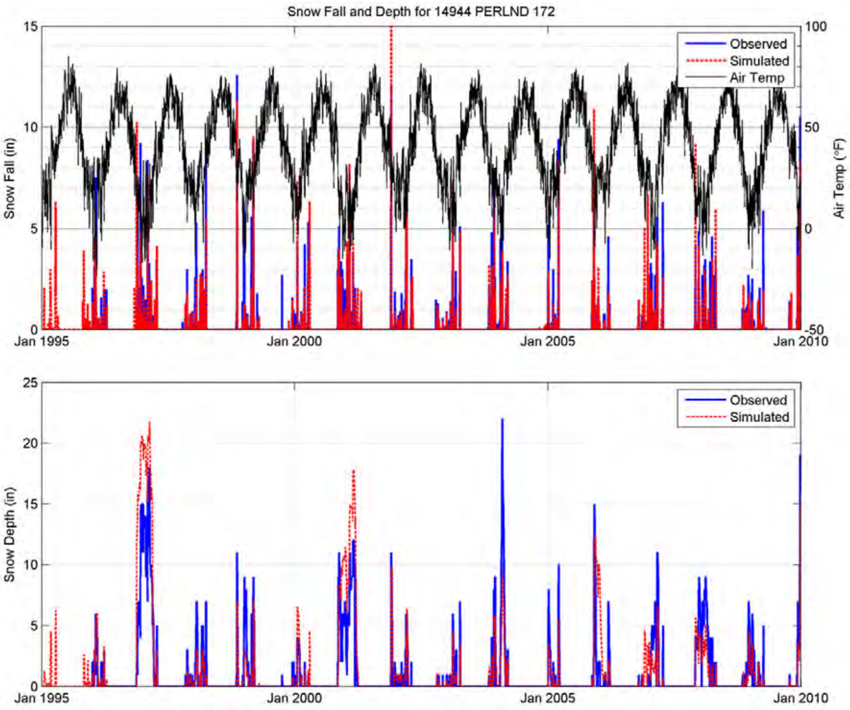

Figure 3. Snowfall (Top) and Snow Depth (Bottom) Calibration Figures.

WEIGHT-OF-EVIDENCE APPROACH

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

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

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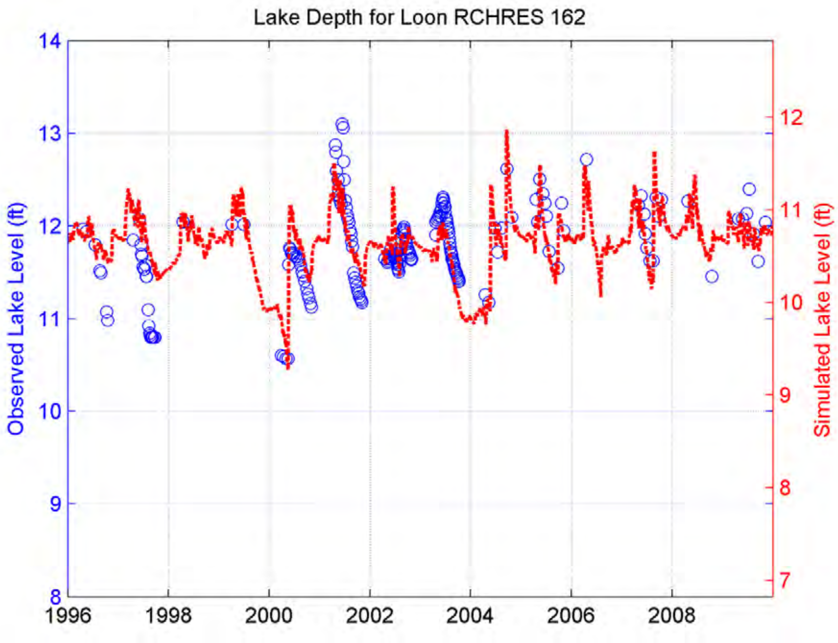

Figure 4. Lake Level Calibration.

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

Annual and monthly plots were used to visually compare runoff volumes over the contributing area. This method includes transferring the amount of flow, measured at each calibrated gage, to a volume of water, measured in inches and spread over the entire contributing area, to normalize the data for the drainage area. Monthly plots help to verify the model's ability to capture the variability in runoff among the watersheds and also to verify that the snowfall and snowmelt processes are simulated accurately. Average yearly plots help toverify that the annual water balances are reasonable and allow trends to be considered. Flow-frequency distributions, or flow-duration curves, present measured flow and simulated flow versus the corresponding percent of time the flow is exceeded. Thus, the flow-duration curves provide a clear way to evaluate model performance for various flow conditions (e.g., storm events or baseflow) and to determine which parameters to adjust to better fit the data. Daily flow time-series plots allow for the analyses of individual storm events, snow accumulation and snowmelt processes, and baseflow trnds. Examples of the daily flow time-series plots, monthly plots, annual plots, and flow-duration curves used for the calibration/validation process are illustrated in Figures 5 through 8, respectively.

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

- **Precipitation**
- **Total Runoff (Sum of Following Components)**
  - – Overland flow
  - – Interflow
  - – Baseflow
- **Potential Evapotranspiration (ET)**
- **Total actual ET (Sum of Following Components)**
  - – Interception ET
  - – Upper zone ET
  - – Lower zone ET
  - – Baseflow ET
  - – Active groundwater ET
- **Deep Groundwater Recharge/Losses**

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

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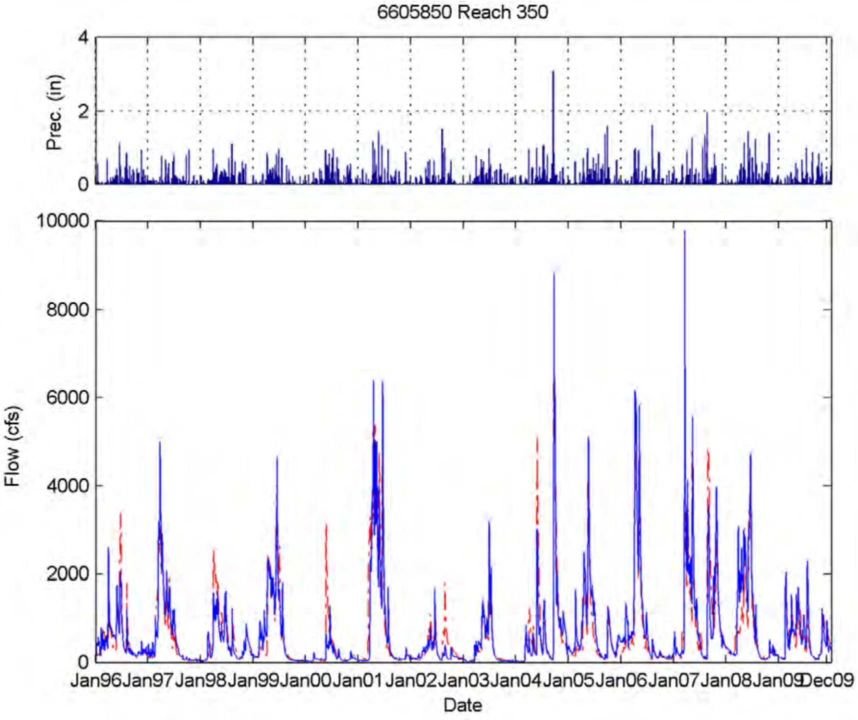

Figure 5. Daily Flow Time-Series Plot Example.

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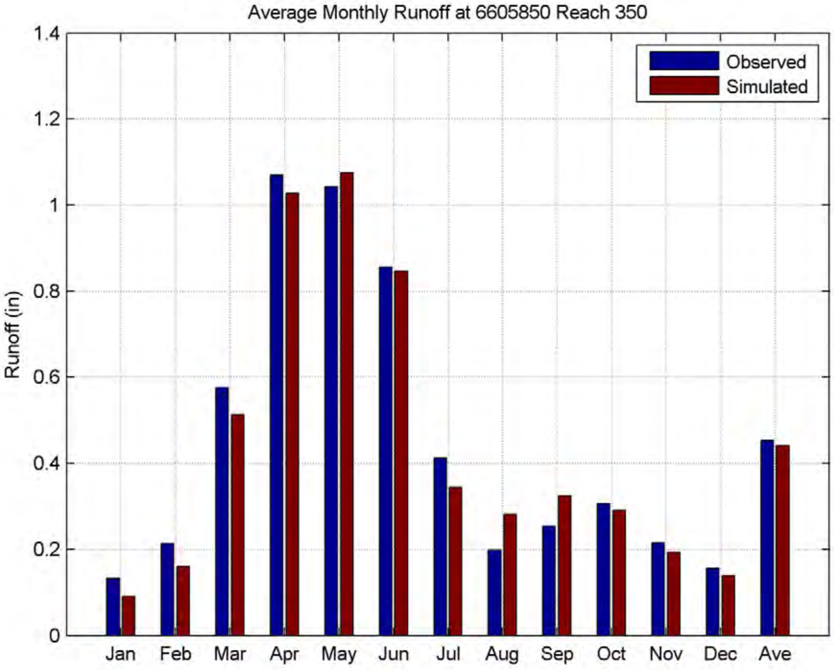

Figure 6. Average Monthly Runoff Plot Example.

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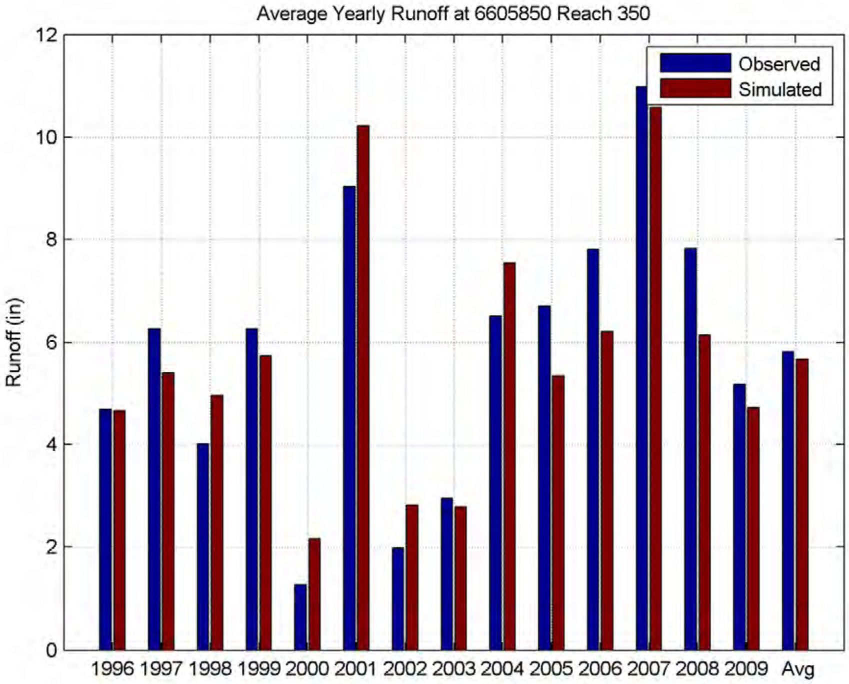

Figure 7. Average Yearly Runoff Plot Example.

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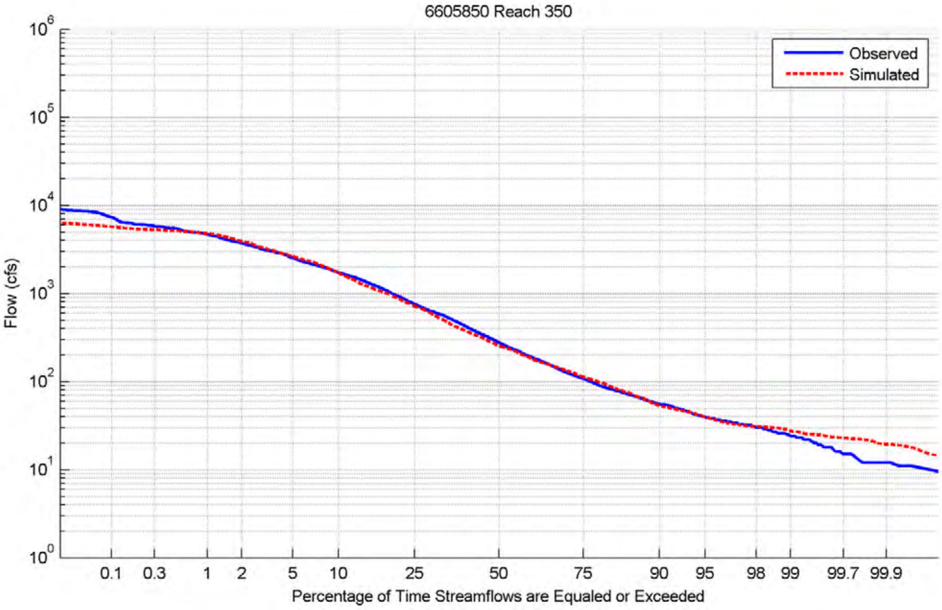

Figure 8. Flow-Duration Curve Example.

MODEL PERFORMANCE CRITERIA

The calibration parameters were adjusted to improve the performance of the model until the desired performance criteria were met or there was no apparent improvement from parameter refinement. The graphical plots were visually evaluated to objectively assess the model performance and the statistics were compared to objective criteria developed from 20 years of experience with HSPF applications. The percent-error statistics were evaluated with the hydrology criteria in Table 2. The correlation coefficient (*r*) and the coefficient of determination (r^2) were compared with the criteria illustrated in Figure 9 to evaluate the performance of the daily and monthly flows. These measures allow the user to assess the quality of the overall model application performance in descriptive terms to aid in deciding to accept or reject the model application. The developed performance criteria are explained in detail in Donigian[2002].

Table 2. General Calibration/Validation Targets or Tolerances for HSPF Applications

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

Caveats: Relevant to monthly and annual values; storm peaks may differ more.
Quality and detail of input and calibration data.
Purpose of model application.
Availability of alternative assessment procedures.
Resource availability (i.e., time, money, and personnel).Source:
Donigian [2000].

Figure 9. General Calibration/Validation *R* and R^2 Targets for HSPF Applications.

CALIBRATION RESULTS

The initial calibration was performed by using the primary downstream gages for each of the three model applications in the Missouri River Watershed. The gages on the smaller tributaries were used to help calibrate parameters for less influential land-segment categories; however, the focus of this hydrology calibration was the mainstem gages. The initial calibration results for the Missouri River Watershed most downstream, mainstem gages range from fair to very good with respect to the calibration and validation targets (Figure 9). Parameters were set to achieve a balance between the best possible results at the tributary gages and the best possible results at the mainstem gages. Table 3 displays the results for the Missouri River Watershed model applications, with the most downstream mainstem reaches shown in bold. Table 4 summarizes the weighted water balance components at the outlets of the Missouri River Watershed model applications, and Attachment B contains initial hydrologic calibration figures for primary gages in the Missouri River Watershed.

WATER-QUALITY CALIBRATION

The water-quality constituents that were modeled in the Missouri River Watershed include total suspended solids (TSS), temperature, dissolved oxygen (DO), biochemical oxygen demand (BOD), and nutrients. The methods described in the following section provide RESPEC with the ability to estimate turbidity, temperature, DO, and nutrient loads; calculate contributions from point, nonpoint, and atmospheric sources where necessary; and provide a means of evaluating the impacts of alternative management straegies to reduce these loads and improve water-quality conditions. The model applications apply empirical build-up/washoff functions. Separate UCIs were created to represent land-use changes for the hydrology calibration. To use the largest possible data set, the water-quality calibration was completed on the entire modeling period (1995 through 2009) and was based on the NLCD 2006 land-use data.

Turbidity Approach

TSS was used as a surrogate for turbidity, based on an observed, strong correlation between the two. A regression analysis can be completed to determine the relationship of TSS andturbidity, allowing the model TSS predictions to support future total maximum daily load(TMDL) studies. The calibration focus was at locations where TSS concentration data area vailable, and TSS was used as a surrogate for turbidity. TSS concentration data are widely available, while suspended sediment concentrations (SSC) are more limited. The model application is capable of identifying sources of sediment and the processes that drive sedimenterosion, delivery, an transport in the watersheds as well as point-source sediment contribution.

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

Sediment erosion and delivery and in-stream sediment transport were represented in the sediment model application. Parameters predicting sediment erosion from the landscape and

Table 3. Summary Statistics for Calibration Gages in the Missouri River Watershed

Model Application	Observed Flow Gage	HSPF Reach	Total Runoff Volume			Monthly			Daily			Storm % Error	
			Obs (in)	Sim (in)	% Δ	*R*	R^2	MFE	*R*	R^2	MFE	Volume	Peak
Big Sioux River	H82042001	70	2.96	2.03	–31.5	0.99	0.99	0.86	0.89	0.79	0.63	–32.9	–56.8
Big Sioux River	H82035001	105	3.78	3.31	–12.3	0.81	0.65	0.57	0.76	0.58	0.04	–11.9	14.9
Big Sioux River	H82015001	270	0.87	1.51	73.3	0.60	0.36	–2.17	0.51	0.27	–2.75	46.7	57.7
Big Sioux River	**6482610**	**350**	**2.95**	**2.94**	**–0.44**	**0.92**	**0.84**	**0.84**	**0.82**	**0.68**	**0.67**	**0.25**	**–10.2**
Little Sioux River	6605000	251	5.52	5.6	0.08	0.92	0.84	0.82	0.80	0.63	0.61	0.91	–22.5
Little Sioux River	**6605850**	**350**	**5.82**	**5.66**	**–2.69**	**0.94**	**0.89**	**0.89**	**0.91**	**0.82**	**0.82**	**–2.30**	**–11.9**
Rock River	H83027001	130	3.56	4.29	20.6	0.77	0.59	–0.21	0.73	0.54	–0.21	33.1	21.4
Rock River	H83016001	170	4.64	4.82	3.85	0.93	0.87	0.84	0.69	0.48	0.43	6.75	–17.3
Rock River	6483290	310	4.94	5.11	3.37	0.91	0.83	0.77	0.81	0.65	0.50	11.3	–0.19
Rock River	**6483500**	**370**	**5.67**	**5.57**	**–1.86**	**0.92**	**0.84**	**0.83**	**0.83**	**0.68**	**0.66**	**1.19**	**–10.7**

delivery to the stream were estimated and compared with results from the Revised Universal Soil Loss Equation (RUSLE). RUSLE provides an estimate of the average soil loss in tons per acre, based on numerical factors developed from spatial soil and land-use characterization data, slope, and rainfall and runoff-intensity estimates. A detailed procedure for RUSLE analysis is described by the EPA [2006]. A sediment delivery ratio (SDR), based on watershed area and slope, was applied to the average soil loss because RUSLE provides gross erosional estimates that are greater than the sediment load that is actually delivered to the stream. **HSPF** landscape loading rates represent the predicted sediment load delivered to the stream from the landscape. The annual sediment loads per acre, predicted by the model on a subwatershed scale, were compared to RUSLE loading rates adjusted with the SDR by using appropriate parameterization. Model sediment loading rates were also compared to typical ranges of expected erosion rates from literature for applicable land-use categories, as provided in Table 5, and to surficial geology and soils maps for information on particle size distribution.

Table 4. Summary of Water Balance Components

Water Balance Component	Water Balance Component Description	Percent of Water Supply		
		Big Sioux River	Little Sioux River	Rock River
SURO	Surface outflow	3.25	0.71	1.20
IFWO	Interflow outflow	6.98	11.79	9.21
AGWO	Active groundwater outflow	7.50	8.65	9.99
IGWI	Inflow to inactive groundwater	0.48	0.32	0.35
CEPE	Evaporation from interception storage	19.29	20.23	19.56
UZET	Evapotranspiration from upper zone	16.57	14.96	17.54
LZET	Evapotranspiration from lower zone	44.08	41.24	40.26
AGWET	Evapotranspiration from active groundwater storage	0.04	0.28	0.11
BASET	Evapotranspiration from active groundwater outflow (baseflow)	1.81	1.82	1.78

Sediment erosion and delivery and in-stream sediment transport were represented in the sediment model application. Parameters predicting sediment erosion from the landscape and delivery to the stream were estimated and compared with results from the Revised Universal Soil Loss Equation (RUSLE). RUSLE provides an estimate of the average soil loss in tons per acre, based on numerical factors developed from spatial soil and land-use characterization data, slope, and rainfall and runoff-intensity estimates. A detailed procedure for RUSLE analysis is described by the EPA [2006]. A sediment delivery ratio (SDR), based on watershed area and slope, was applied to the average soil loss because RUSLE provides gross erosional estimates that are greater than the sediment load that is actually delivered to the stream. **HSPF** landscape loading rates represent the predicted sediment load delivered to the stream from the landscape. The annual sediment loads per acre, predicted by the model on a subwatershed scale, were compared to RUSLE loading rates adjusted with the SDR by using appropriate parameterization. Model sediment loading rates were also compared to typical ranges of expected erosion rates from literature for applicable land-use categories, as provided in Table 5, and to surficial geology and soils maps for information on particle size distribution.

Table 5. Typical Ranges of Expected Erosion Rates [EPA, 2006]

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

The primary calibration parameters involved in landscape erosion simulation are the coefficients and exponents from three equations representing different soil detachment and removal processes. KRER and JRER are the coefficient and exponent, respectively, from the soil detachment from rainfall impact equation; KSER and JSER are the coefficient and exponent, respectively, from the soil washoff or transport equation; and KGER and JGER are the coefficient and exponent, respectively, from the matrix soil equation, which simulates gullyerosion. KRER was estimated as the soil erodibility coefficient from the RUSLE equation, which can be estimated from the Soil Survey Geographic (SSURGO) spatial soils database. Landscape fractionation of sand, silt, and clay were represented by using data from the SSURGO spatial soils database. The remaining parameters were initially given a combination of therecommended initial values from the EPA [2006] and values from the Minnesota River model application.

After landscape sediment erosion rates were adjusted to provide the expected loading to the stream channel, calibration was continued with adjusting parameters governing the processes of deposition, scour, and transport of sediment within the stream. Calibration was performed on a reach-by-reach basis from upstream to downstream because downstream reaches are influenced by upstream parameter adjustments. Bed behavior and sediment budgets were analyzed at each reach to ensure that results are consistent with field observations, historical reports, and expected behavior from past experience. The initial composition of the channel beds was estimated using available particle-size distribution data.

The primary parameters that were involved in calibrating in-stream sediment transport and bed behavior include critical shear stresses for deposition and scour for cohesive sediment (silt and clay) and the coefficient and exponent in the noncohesive (sand) transport power function.TAUCD and TAUCS are the critical deposition and scour shear stress parameters, respectively.They were initially estimated as the 25th percentile of the simulated bed shear stress for TAUCD and the 75th percentile for TAUCS and iteratively adjusted until predicted sediment concentrations matched the observed data. Cohesive sediment is transported when the bed shear stress is higher than TAUCD, and it settles and deposits when the bed shear stress is lower than TAUCD. Sediment is scoured from the bed when the shear stress is greater thanTAUCS. The erodibility parameter (M) for silt and clay determines the intensity of scour when it is occurring. KSAND and EXPSAND are the coefficient and exponent of the sand transport power function, respectively.

TEMPERATURE, DISSOLVED OXYGEN, BIOCHEMICAL OXYGEN DEMAND DYNAMICS, AND NUTRIENT APPROACH

The approach for modeling temperature, DO and BOD dynamics, and nutrients was similar to the Minnesota River model application's approach. The model application simulates in-stream temperature (using HTRCH), organic and inorganic nitrogen, total ammonia, organic and inorganic phosphorus (using NUTRX), dissolved oxygen and biochemical oxygen demand(using OXRX), and algae (using PLANK). The adsorption/desorption of total ammonia and orthophosphate to sediment was also simulated. The modeled output can be used to support the MPCA's activities for TMDL development, in-stream nutrient criteria compliance testing, and support for point-source permitting. Initial calibration parameters were estimated from the Minnesota River model application and near by calibrated models.

The overall sources considered for nutrients included point sources, such as water treatment facilities, nonpoint sources from the watershed, atmospheric deposition (nitrate, ammonia, and phosphorus), subsurface flow, and soil-bed contributions. Point-source facility contributions were explicitly modeled for future permitting purposes. Nonpoint sources of total ammonia,nitrate-nitrite, orthophosphate, and BOD were simulated through accumulation and depletion/removal and a first-order washoff rate from overland flow. All simulated, in-stream parameters were specified for total ammonia, inorganic nitrogen, orthophosphate, and BOD. Atmospheric deposition of nitrogen and ammonia were applied to all of the land areas and provide a contribution to the nonpoint-source load through the buildup/washoff process. Atmospheric deposition onto water surfaces was represented in the model as a direct input to the lakes and river systems. Subsurface flow concentrations were estimated on a monthly basis for calibration. Septic system loads in the watersheds were estimated for Kittson and Marshall Counties by using information provided by the MPCA [2004]. 2010 census information was used for South Dakota (SD) and Iowa (IA) counties because of the absence of data in the MPCA Individual Sewage Treatment Systems (ISTS) report [MPCA, 2004]. The number of ISTS ineach subwatershed were estimated by using Geographic Information System (GIS). The average number of individuals per household was then used to estimate the number of persons served by ISTS. Loading rates, which incorporated septic failure rates, were developed for ammonia,nitrate, orthophosphate, carbonaceous biochemical oxygen demand – ultimate (CBODU), and water on a per capita basis and were applied to each reach through a mass link.

Biochemical reactions that affect DO were represented in the model application. The overall sources considered for BOD and DO include point sources such as wastewater treatment facilities, nonpoint sources from the watershed, interflow, and active groundwater flow. The model application addresses BOD accumulation, storage, decay rates, benthic algal oxygen demand, settling rates, and re-aeration rates. The model also represents respiration, growth,settling rates, density, and nutrient requirements of benthic algae and phytoplankton.

AMBIENT WATER-QUALITY DATA AVAILABLE

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

Observed ambient water-quality data were obtained from the MPCA, IA Department of Natural Resources (IADNR), EPA's STOrage and RETrieval Data Warehouse (STORET), and the U.S. Geological Survey (USGS). Tables 6 through 8 provide available stream and lake data of applicable constituents for the Big Sioux River, Little Sioux River, and Rock River Watersheds, respectively. These sites for the Rock River model application are illustrated in Figure 10, and the sites for the Big and Little Sioux model applications are shown in Attachment C. TSS, water temperature, DO, BOD, chlorophyll *a*, ammonia, Kjeldahl nitrogen, nitrate/nitrate, orthophosphate, and total phosphorus ambient water-quality monitoring data are available throughout the watershed for both lakes and streams.

Total nitrogen is generally not available in either of the ambient water-quality data sets, but it can be calculated by summing concurrent samples of nitrate, nitrite, and Kjeldahl nitrogen. Similarly, organic nitrogen can be calculated as the difference between concurrent samples of Kjeldahl nitrogen and ammonia-nitrogen.

ATMOSPHERIC DEPOSITION DATA AVAILABLE

Atmospheric deposition of nitrate and ammonia was explicitly accounted for in the Missouri River Watershed model applications by input of separate wet and dry deposition fluxes. Wet atmospheric deposition data were downloaded from the National Atmospheric DepositionProgram (NADP). The NADP site chosen to represent the Missouri River Watershed wet deposition was MN27. Wet deposition includes the deposition of pollutants from the atmosphere that occur during precipitation events. Thus, nitrate and ammonia wet deposition was applied as concentrations (milligrams per liter [mg/L]) to the precipitation input time series.

Dry atmospheric deposition data were downloaded from the EPA's **Clean Air Status and Trends Network** (**CASTNet**). The **CASTNet** site chosen to represent the Missouri River Watershed dry deposition was PRK134. Dry deposition does not depend on precipitation; therefore, nitrate and ammonia dry deposition data (originally in kg/ha) were applied in the model application by using a pound-per-acre approach. Both the wet and dry atmospheric deposition sites are illustrated in Figure 11. Atmospheric deposition of phosphorus is estimated to account forapproximately 4.4 percent of the total phosphorus load in the Missouri River Basin [Barr Engineering, 2007] and was included in the Missouri River Watershed model applications. Because of the lack of temporal data, atmospheric phosphorus deposition was represented byusing monthly values of daily dry fluxes using the MONTH-DATA block in **HSPF**. A value of kg/ha/yr (0.00066 lbs/ac/day) was provided by Barr Engineering and was distributed throughout the months with higher values in the summer and lower values in the winter.

Original dry deposition data were supplied at a weekly time-step as kg/ha. To transform the data into daily time series, they were divided by the number of days in the sampling period.Similarly, the wet deposition was obtained at a weekly time-step, plus or minus multiple days.Because wet deposition was in units of concentration, it did not need to be divided by the number of days in the sampling period. Instead, the concentration was assigned to each day of

Table 6. Big Sioux River Watershed Stream Sites With any Applicable Constituent
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Big Sioux River Stream Site I.D.	Reach I.D.	Number of Samples											
		Biochemical Oxygen Demand	Chlorophyll *a*	Dissolved Oxygen	Suspended Solids	Total Ammonia	Water Temperature	Total Kjeldahl Nitrogen	Nitrate Nitrite	Dissolved Orthophosphate	Total Orthophosphate	Total Phosphorus	Total
11MS 049	10			1	1	1	1		1			1	6
11MS 056	30			1	1	1	1		1			1	6
11MS 055	41			1	1	1	1		1			1	6
S002-380	50			1			1						2
S001-904	70		3	47	47		155	45	45		24	43	409
11MS 050	90			1	1	1	1		1			1	6
07MS 001	101			1	1	1	1		1			1	6
10EM124				2	2	2	2		2			2	12
S000-644					12			12				12	36
11MS 057	103			1	1	1	1		1			1	6
S000-646	105		3	103	128	66	224	126	126		104	123	1003
04MS 055	107				1	1			1			1	4
S000-650							1						1
04MS 021	109			1	1	1	1		1			1	6
11MS 038				1	1	1	1		1			1	6
11MS 019	150			1	1	1	1		1			1	6
S000-099	170	16	15	75	42	65	63	1	66		1	41	385
CENTBSRT28	190			15	38	38	16	38	38		38		221
CENTBSRT29	210			15	18	18	16	18	18		18		121
WSDP99-0667				2	1		2						5
S004-530	230			16	2		16				2	2	38
04MS 031	233			2	2	2	2		2			2	12
S004-529	237			12			12						24
04MS 005	239			1	1	1	1		1			1	6
S002-358				16		1	16					1	34
S001-144	241			18		1	18					1	38
11MS 060	243			1	1	1	1		1			1	6
S001-142	245			18		1	18					1	38

Table 6. Big Sioux River Watershed Stream Sites With any Applicable Constituent
(Page 2 of 3)

Big Sioux River Stream Site I.D.	Reach I.D.	Number of Samples											
		Biochemical Oxygen Demand	Chlorophyll *a*	Dissolved Oxygen	Suspended Solids	Total Ammonia	Water Temperature	Total Kjeldahl Nitrogen	Nitrate Nitrite	Dissolved Orthophosphate	Total Orthophosphate	Total Phosphorus	Total
11MS052	247			1	1	1	1		1			1	6
S001-139				19		1	19					1	40
S001-141				18		1	18					1	38
11MS058	261			1	1	1	1		1			1	6
11MS046	263			1	1	1	1		1			1	6
11MS045	265			1	1	1	1		1			1	6
11MS013	270			1	1	1	1		1			1	6
S004-528				42	31	18	42	31	31		31	31	257
CENTBSRT30	290			15	16	16	16	16	16		16		111
11MS042	309			1	1	1	1		1			1	6
CENTBSRT26	315			14	14	14	14	14	14		14		98
CENTBSRT27	317			16	17	17	17	17	17		17		118
11MS043	371			1	1	1	1		1			1	6
11MS044	373			1	1	1	1		1			1	6
11MS040	375			1	1	1	1		1			1	6
11MS039	377			1	1	1	1		1			1	6
11MS012	379			1	1	1	1		1			1	6
S004-811	379			35	39	39	35	39	39			39	265
04MS027	381			1	1	1	1		1			1	6
11MS036				1	1	1	1		1			1	6
11MS041	383			1	1	1	1		1			1	6
CENTBSRT32	385			16	19	19	17	19	19		19		128
CENTBSRT33				17	17	17	17	17	17		17		119
WSDP02-R016				1			1						2
11MS030	421			1	1	1	1		1			1	6
11MS026	505			1	1	1	1		1			1	6
11MS007	509			1	1	1	1		1			1	6
CENTBSRT07				16	17	17	17	17	17		17		118

Table 6. Big Sioux River Watershed Stream Sites With any Applicable Constituent (Page 3 of 3)

Big Sioux River Stream Site I.D.	Reach I.D.	Number of Samples											
		Biochemical Oxygen Demand	Chlorophyll *a*	Dissolved Oxygen	Suspended Solids	Total Ammonia	Water Temperature	Total Kjeldahl Nitrogen	Nitrate Nitrite	Dissolved Orthophosphate	Total Orthophosphate	Total Phosphorus	Total
11MS 032	521			1	1	1	1		1			1	6
11MS 035	525			1	1	1	1		1			1	6
04MS 052	527			1	1	1	1		1			1	6
11MS 140				1	1	1	1		1			1	6
11MS 031	529			1	1	1	1		1			1	6
11MS 034	531			1	1	1	1		1			1	6
11MS 005	537			1	1	1	1		1			1	6
46BSA8				11	12		12	12	12		12		71
CENTBSRT12				15	17	17	15	17	17		17		115
WSDP04-R051							1						1

Table 7. Little Sioux River Watershed Stream Sites With any Applicable Constituent
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Little Sioux River Stream Site I.D.	Reach I.D.	Number of Samples											
		BOD$^{(a)}$	Chlorophyll *a*	DO$^{(b)}$	Suspended Solids	TAM$^{(c)}$	Water Temperature	TKN$^{(d)}$	NO2+NO3$^{(e)}$	D-ORTHO$^{(f)}$	T-ORTHO$^{(g)}$	T-P$^{(h)}$	Total
04MS014	1			1	1	1	1		1			1	6
11MS067				1	1	1	1		1			1	6
11MS078	3			1	1	1	1		1			1	6
11MS068	5			1	1	1	1		1			1	6
11MS143	30			1	1	1	1		1			1	6
11MS077	41			1	1	1	1		1			1	6
11MS072	50			1	1	1	1		1			1	6
S004-922				31	19	19	32						101
S004-921	85			24	14	14	25						77
11MS010	90			1	1	1	1		1			1	6
S004-219								46				46	92
12300001	110	1	1	1	1	1	1	1		1		1	9
11MS079	111			1	1	1	1		1			1	6
11MS023	113			1	1	1	1		1			1	6
04MS018	117			1	1	1	1		1			1	6
11MS066				1	1	1	1		1			1	6
S004-923				35	21	21	36						113
53-0007-00-201	119		8	6			8					8	30
11MS065	123			1	1	1	1		1			1	6
32-0069-00-101	124		10	23	10		23	10	10			10	96
11MS073	131			1	1	1	1		1			1	6
11MS062	135			1	1	1	1		1			1	6
S004-924				35	21	21	36						113
11MS008	137			1	1	1	1		1			1	6
S000-100								45				45	90
22300007	142		56	54	57	45	57	30	56	50		54	459
10300001	150	161	164	164	164	164	164	164	164	161		164	1634
12300002		1	1	1	1	1	1	1		1		1	9
32-0022-00-201	152		5	15	5		15	5				5	50

Table 7. Little Sioux River Watershed Stream Sites With any Applicable Constituent
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Little Sioux River Stream Site I.D.	Reach I.D.	Number of Samples											
		BOD$^{(a)}$	Chlorophyll *a*	DO$^{(b)}$	Suspended Solids	TAM$^{(c)}$	Water Temperature	TKN$^{(d)}$	NO2+NO3$^{(e)}$	D-ORTHO$^{(f)}$	T-ORTHO$^{(g)}$	T-P$^{(h)}$	Total
32-0022-00-202			49	50			50	49				50	248
11MS 024	153			1	1	1	1		1			1	6
11MS 144	155				1	1	1		1			1	5
32-0020-00-101	162		4	11	4		11	4				4	38
32-0020-00-102			1	2	1		2	1				1	8
32-0020-00-201			46	50			50	48				50	244
32-0024-00-201	164		48	48			48	49				50	243
22300 014	172		50	51	51	40	52	26	52	45		49	416
22300 009	174		50	46	49	40	50	26	52	45		49	407
11300 004	176			2	2	2	2	2	2	2		2	16
22300 008			51	50	50	40	52	26	52	45		49	415
11300 001	178	12	4	14	14	14	14	14	14	14		14	128
11300 003				2	2	2	2	2	2	2		2	16
22300 001			38	38	39	27	40	13	39	33		37	304
22300 004			36	36	37	24	38	11	36	30		34	282
22300 011			51	49	52	39	51	26	51	44		49	412
22300 012			22	22	22	22	22	23	23	22		22	200
22300 013			22	21	22	22	22	23	23	22		22	199
11300 002	179	29	6	28	29	29	28	29	29	29		29	265
11300 012		4	4	4	4	4	4	4	4	4		4	40
11300 015		4	4	4	4	4	4	4	4	4		4	40
10210 002	210	151	153	157	154	154	157	154	157	154		154	1545
11MS 075	211			1	1	1	1		1			1	6
04MS 025	213			1	1	1	1		1			1	6
53-0028-00-101	214		76		76	56	15	75	69			75	442
11MS 063	215			1	1	1	1		1			1	6
53-0024-02-201	218											1	1
53-0024-03-201												1	1
11MS 076	221			1	1	1	1		1			1	6

Table 7. Little Sioux River Watershed Stream Sites With any Applicable Constituent
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Little Sioux River Stream Site I.D.	Reach I.D.	Number of Samples											
		BOD[(a)]	Chlorophyll *a*	DO[(b)]	Suspended Solids	TAM[(c)]	Water Temperature	TKN[(d)]	NO2+NO3[(e)]	D-ORTHO[(f)]	T-ORTHO[(g)]	T-P[(h)]	Total
53-0024-01-202	222		17		17							17	51
53-0024-01-203												1	1
11MS022	224			1	1	1	1		1			1	6
53-0045-00-201			18		18							18	54
16210005	249		1	1	1	1	1	1	1	1		1	9
6605000	251			2									2
10210001		164	163	170	167	167	170	167	170	167		167	1672
16210002			2	2	2	2	2	2	2	2		2	18
12210001	265	1	1	1	1	1	1	1	1	1		1	10
10210003	270	151	154	157	154	154	157	154	157	154		154	1546
16210004			1	1	1	1	1	1	1	1		1	9
13210001	271					9		9	9	9		9	45
13210004						5		5	5	5		5	25
13210005						5		5	5	5		5	25
13300001						5		5	5	5		5	25
11210001	272		11	11	13	13	11	13	13	13		13	111
11210002			10	10	10	18	10	18	18	18		18	130
22210001			56	55	57	44	56	31	58	51		54	462
16210003	303		1	1	1	1	1	1	1	1		1	9
11210005	321	30	30	15	30	30	15	30	30	30		30	270
11210003	323	38	38	20	38	38	20	38	38	38		38	344
11210004		36	36	18	36	36	18	36	36	36		36	324
16210001			2	2	2	2	2	2	2	2		2	18
22110002	330		6	6	6	6	6		6	5		5	46

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

Table 8. Rock River Watershed Stream Sites With any Applicable Constituent
(Page 1 of 4)

Rock River Stream Site I.D.	Reach I.D.	Number of Samples											
		BOD(a)	Chlorophyll *a*	DO(b)	Suspended Solids	TAM(c)	Water Temperature	TKN(d)	NO2+NO3(e)	D-ORTHO(f)	T-ORTHO(g)	T-P(h)	Total
04MS 009	10			3	3	3	3		3			3	18
04MS 051				1	1	1	1		1			1	6
11MS 116				1	1	1	1		1			1	6
11MS 136				1	1	1	1		1			1	6
04MS 035	21			1	1	1	1		1			1	6
11MS 145				1	1	1	1		1			1	6
04MS 012	25			1	1	1	1		1			1	6
11MS 088				1	1	1	1		1			1	6
11MS 117	27			1	1	1	1		1			1	6
11MS 147	30			1	1	1	1		1			1	6
11MS 089	43			1	1	1	1		1			1	6
11MS 138				1	1	1	1		1			1	6
04MS 010	50			1	1	1	1		1			1	6
11MS 011				1	1	1	1		1			1	6
11MS 124	61			1	1	1	1		1			1	6
11MS 122	63			1	1	1	1		1			1	6
11MS 091	65			1	1	1	1		1			1	6
10EM142	67			1	1	1	1		1			1	6
11MS 123				1	1	1	1		1			1	6
04MS 026	71			1	1	1	1		1			1	6
11MS 016				1	1	1	1		1			1	6
11MS 121				1	1	1	1		1			1	6
11MS 093	73			1	1	1	1		1			1	6
11MS 096	77			1	1	1	1		1			1	6
11MS 014	79			1	1	1	1		1			1	6
11MS 113	81			1	1	1	1		1			1	6
04MS 032	90			1	1	1	1		1			1	6
11MS 083	91			1	1	1	1		1			1	6
S000-147	110			19	18	6	19		20		20	20	122

Table 8. Rock River Watershed Stream Sites With any Applicable Constituent

(Page 2 of 4)

Rock River Stream Site I.D.	Reach I.D.	Number of Samples											
		BOD(a)	Chlorophyll *a*	DO(b)	Suspended Solids	TAM(c)	Water Temperature	TKN(d)	NO2+NO3(e)	D-ORTHO(f)	T-ORTHO(g)	T-P(h)	Total
11MS081	121			1	1	1	1		1			1	6
11MS084	123			1	1	1	1		1			1	6
11MS114	130			1	1	1	1		1			1	6
S004-390				19	18	6	19		20		20	20	122
11MS082	131			1	1	1	1		1			1	6
11MS003	150			1	1	1	1		1			1	6
11MS097	153			1	1	1	1		1			1	6
11MS094	155			1	1	1	1		1			1	6
11MS098	159			1	1	1	1		1			1	6
11MS095	161			1	1	1	1		1			1	6
S005-809	163			19	23		23						65
10EM014	165			2	2	2	2		2			2	12
6483000	170			15								1	16
04MS019				3	3	3	3		3			3	18
S005-381				30	31	31	30	31	31		31	31	246
11MS148	190			1	1	1	1		1			1	6
S001-359				1	1		1	1	1		1	1	7
11MS119	191			1	1	1	1		1			1	6
11MS118	193			1	1	1	1		1			1	6
11MS099	195			1	1	1	1		1			1	6
11MS100	197			1	1	1	1		1			1	6
07MS002	199			2	2	2	2		2			2	12
11MS020	201			1	1	1	1		1			1	6
04MS016	210			1	1	1	1		1			1	6
S000-687				19	18	6	19		20		20	20	122
04MS002	211				1	1	1		1			1	5
11MS085				1	1	1	1		1			1	6
11MS108	231			1	1	1	1		1			1	6

Table 8. Rock River Watershed Stream Sites With any Applicable Constituent
(Page 3 of 4)

Rock River Stream Site I.D.	Reach I.D.	Number of Samples											
		BOD[a]	Chlorophyll *a*	DO[b]	Suspended Solids	TAM[c]	Water Temperature	TKN[d]	NO2+NO3[e]	D-ORTHO[f]	T-ORTHO[g]	T-P[h]	Total
11600002	270			21	21	21	21	21	21	21		21	168
11MS001				1	1	1	1		1			1	6
S000-097		16	16	82	59	66	82		80		20	60	481
04MS008	271			1	1	1	1		1			1	6
11MS126				1	1	1	1		1			1	6
11MS125	273			1	1	1	1		1			1	6
11MS127	277			1	1	1	1		1			1	6
11MS004	279			1	1	1	1		1			1	6
04MS034	281			3	3	3	3		3			3	18
04MS050	283			1	1	1	1		1			1	6
11MS018				1	1	1	1		1			1	6
11MS109				1	1	1	1		1			1	6
S004-927				36	45	45	40	45	45			45	301
04MS020	285			1	1	1	1		1			1	6
11MS101	287			1	1	1	1		1			1	6
11MS129	291			1	1	1	1		1			1	6
11MS128	293			1	1	1	1		1			1	6
11MS102	297			1	1	1	1		1			1	6
11MS086	301			1	1	1	1		1			1	6
S001-016				38	45	45	41	45	45			45	304
11MS006	303			1	1	1	1		1			1	6
S004-717				37	45	45	93	45	45			45	355
11600001	310			23	23	23	23	23	23	23		23	184
11MS106	313			1	1	1	1		1			1	6
11MS107	315			1	1	1	1		1			1	6
11MS021	317			1	1	1	1		1			1	6
S004-391				31	18	6	31		20		20	20	146
10EM001	319			1	1	1	1		1			1	6
11600003	321			21	21	21	21	21	21	21		21	168

Table 8. Rock River Watershed Stream Sites With any Applicable Constituent
(Page 4 of 4)

Rock River Stream Site I.D.	Reach I.D.	Number of Samples											
		BOD(a)	Chlorophyll *a*	DO(b)	Suspended Solids	TAM(c)	Water Temperature	TKN(d)	NO2+NO3(e)	D-ORTHO(f)	T-ORTHO(g)	T-P(h)	Total
16600003	325		1	1	1	1	1	1	1	1		1	9
11600004	327			23	26	26	23	26	26	26		26	202
16600004			1	1	1	1	1	1	1	1		1	9
04MS003	331			1	1	1	1		1			1	6
11MS110	333			1	1	1	1		1			1	6
11MS111	335			1	1	1	1		1			1	6
04MS053	337			1	1	1	1		1			1	6
11MS047				1	1	1	1		1			1	6
11MS132	339			1	1	1	1		1			1	6
04MS011	341			2	2	2	2		2			2	12
11MS104				1	1	1	1		1			1	6
11MS105	343			1	1	1	1		1			1	6
11MS009	345			1	1	1	1		1			1	6
11720001	347			21	21	21	21	21	21	21		21	168
11MS002				1	1	1	1		1			1	6
S004-928				21			21						42
11MS115	349			1	1	1	1		1			1	6
12600001	351	1	1		1	1		1		1		1	7
11MS087	353			1	1	1	1		1			1	6
11600005	367			21	22	22	21	22	22	22		22	174
6483500	370			3								1	4
11840002				22	23	23	22	23	23	23		23	182
16840002			2	2	2	2	2	2	2	2		2	18

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

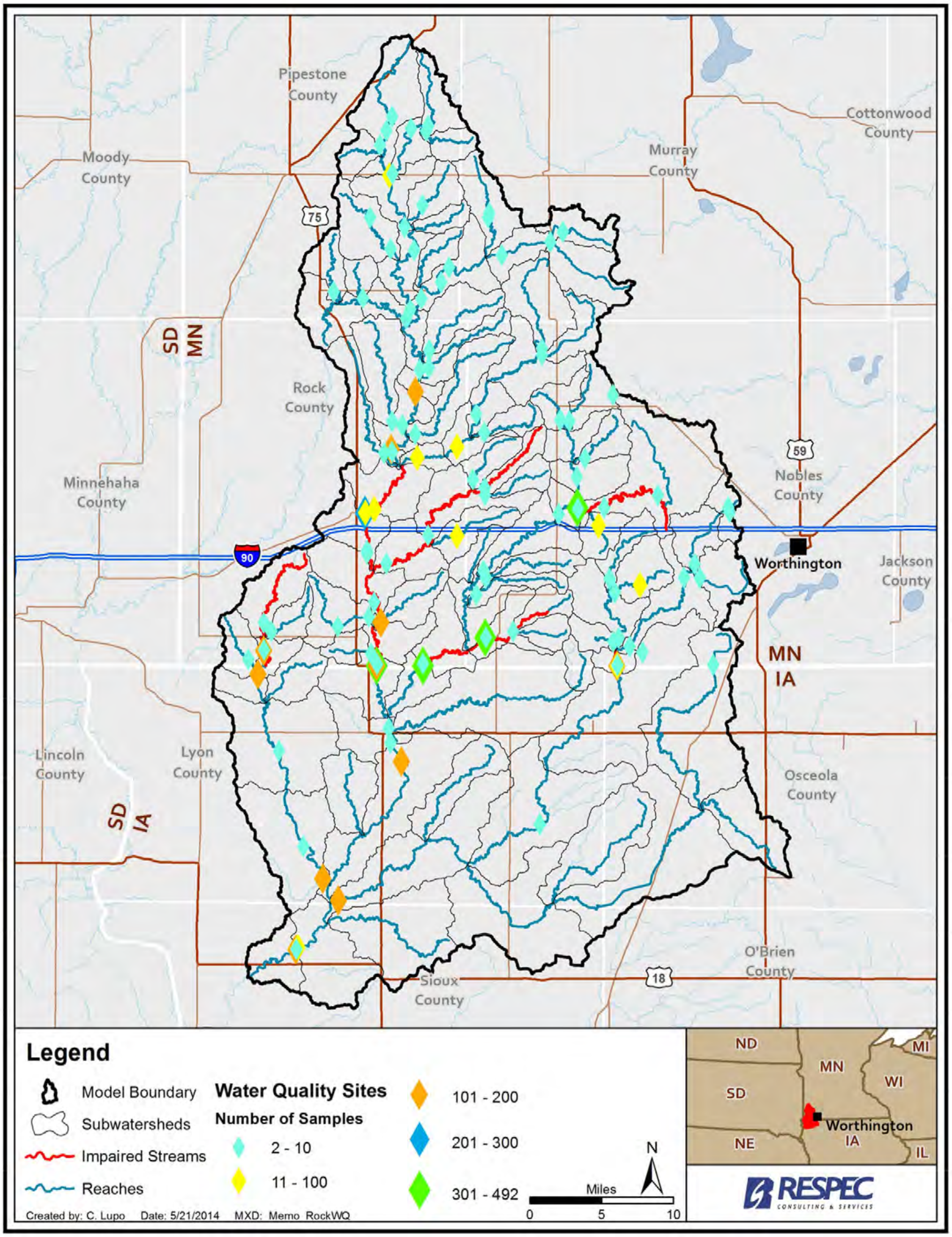

Figure 10. Ambient Water-Quality Monitoring Sites Within the Rock River Watershed.

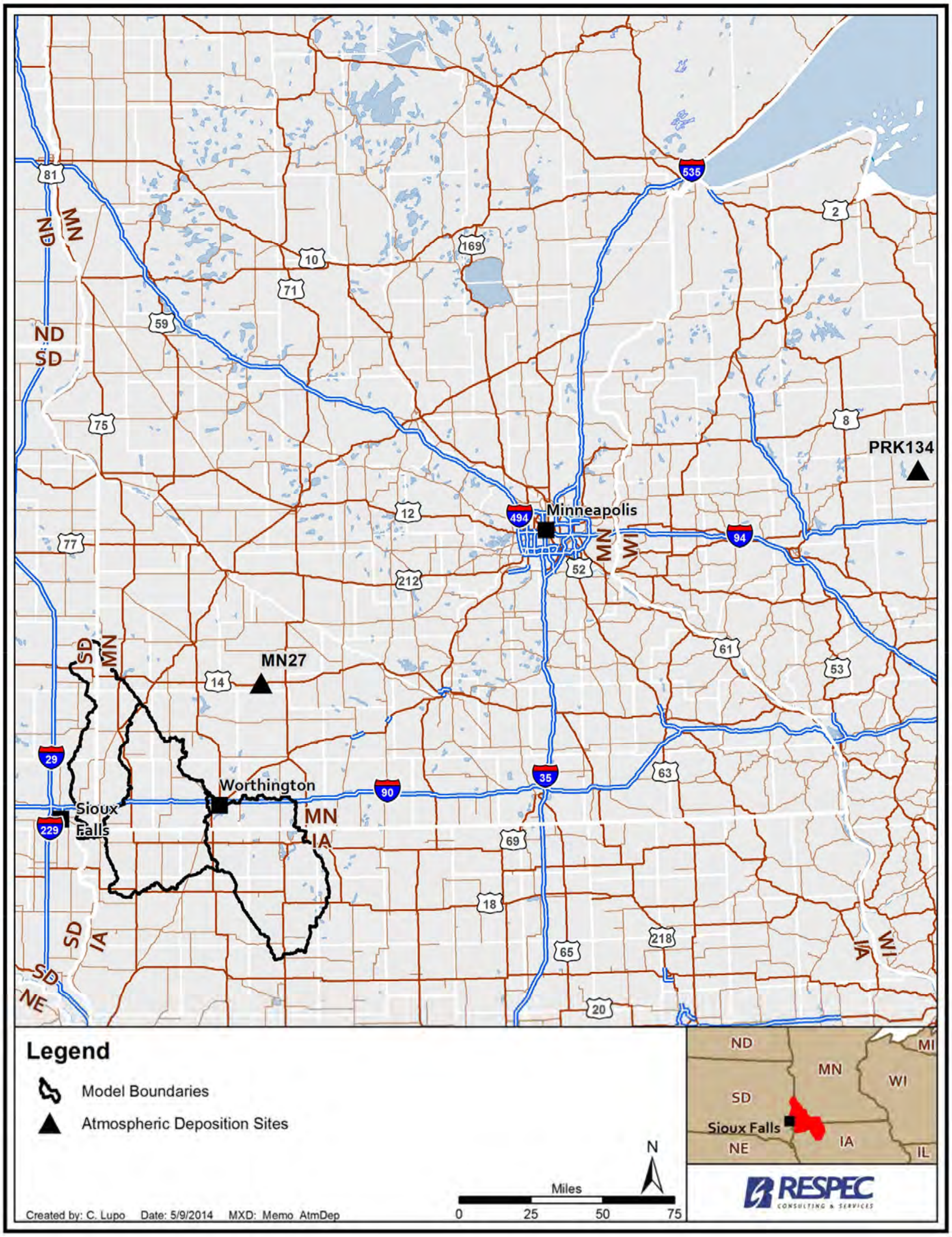

Figure 11. Atmospheric Wet and Dry Deposition Sites.

the sampling period. Once transformed to daily time-series data, missing dry and wet deposition data were patched by using interpolation between the previous and later dates, when fewer than 7 days occurred between values (rare with this data set), and by using monthly meanvalues, when more than 7 days occurred between values (likely scenario).

POINT-SOURCE DATA AVAILABLE

Three major point sources and 53 minor point sources are located in the Missouri River Watershed. The point source locations for the Rock River model application are illustrated in Figure 12 and the sites for the Big and Little Sioux model applications are illustrated in Attachment D. Four of the 55 facilities are mechanical and the remaining 51 point sources inthe watersheds are controlled ponds. Controlled ponds generally discharge intermittently for variable lengths of time, and data for the sites were provided as a combination of monthlyvolumes and monthly average flow. If a controlled pond was missing monthly discharge, it was assumed that the pond did not release effluent to the surface water during that month. Anestimate of the number of discharge days was supplied by the MPCA and was incorporated byusing the following logic supplied by Henningsgaard [2012]:

1. If there are only a few discharge days followed by a month with only a few discharge days, or if the first month has only a couple and the next month has up to approximately10 discharge days, they should be placed at both the end and beginning of the 2 months.
2. If there are over 6 discharge days in a month, but fewer than about 18, they can be placed anywhere consecutively.
3. If there are over approximately 18 discharge days, half should be placed in the first half of the month and half should be placed in the second half of the month.

For each facility, the period of record and completeness were assessed. Available constituents from point sources applicable for modeling purposes include carbonaceous 5-day biochemicaloxygen demand (CBOD5), TSS, total phosphorus (TP), and DO. Point-source water-quality data were filled using monthly mean values. Where monthly means were unavailable, interpolation was used. The available effluent water-quality parameters vary by site, but in general, mostparameters were available from wastewater treatment facilities (WWTF).

Nitrogen species data and orthophosphate-phosphorus were largely unavailable in the minor point-source data. Classes for each point source are provided in Table 9 [Weiss, 2012a]. Point-source loads for nitrogen species were calculated by using numbers supplied by Weiss [2012b]and are provided in Table 10. The facility classes applicable to the Missouri River Watershed are shown in bold. Methods for estimating other phosphorus species from point sources were derived from methods similar to those used in the Minnesota River model application [TetraTech, 2009]. The nutrient portions of the Missouri River Watershed external sources blockscontain estimates where nutrient data were unavailable. Temperature data were derived from aminor wastewater treatment facility located in the Sauk River Watershed and were adjusted fordifferences in temperature between the two watersheds. All available data for model inputs have been uploaded into the project Watershed Data Management (WDM) file, and all availabledata used for comparison to model simulations are in an observed data Excel file.

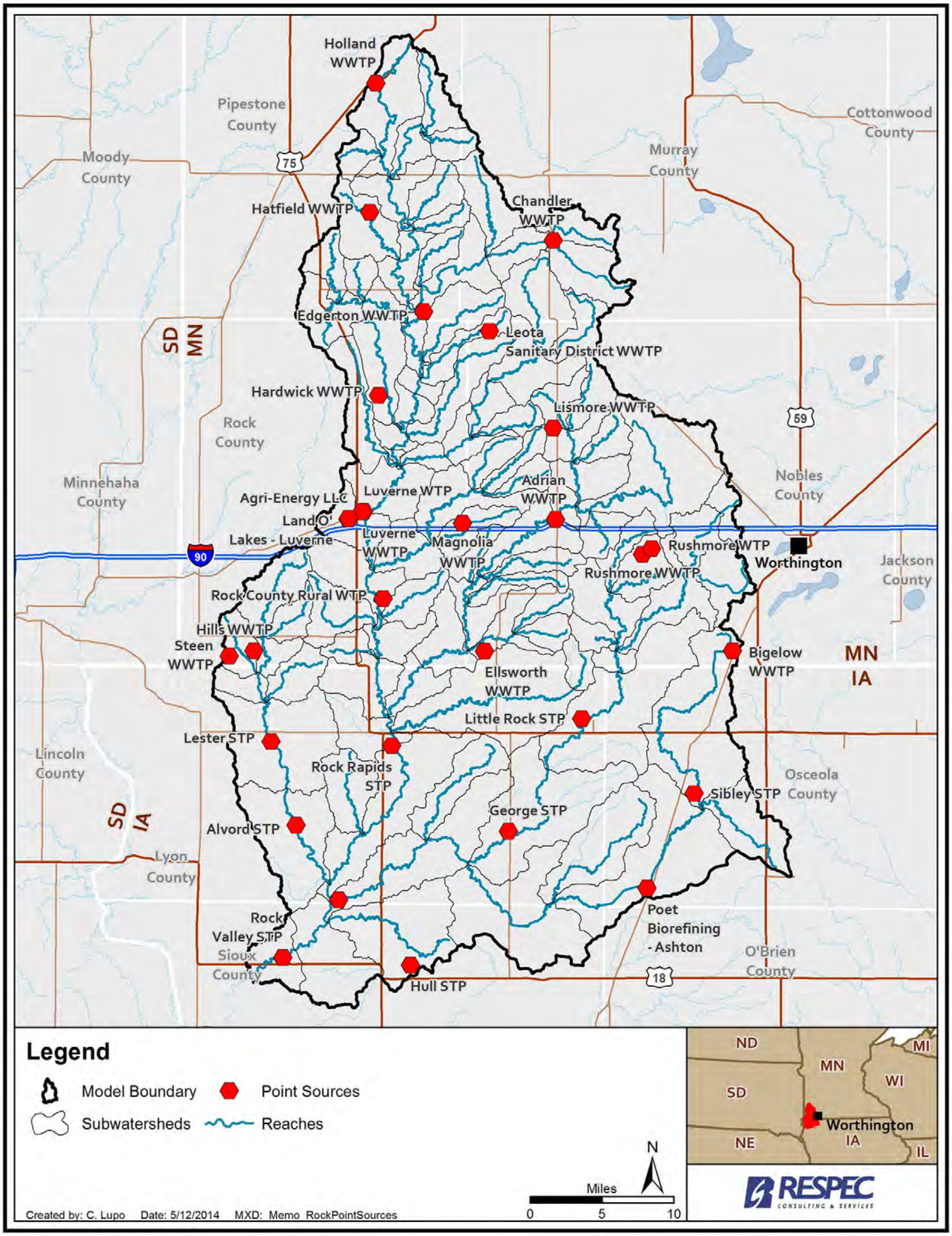

Figure 12. Minor Point Sources in the Rock River Watershed.

Table 9. Categorical Concentration Assumptions (m/L) [Weiss, 2012 a] (Page 1 of 2)

Model Application	Site I.D.	Facility Name	Type
Big Sioux River	MNG580195	Heartland Colonies Residential WWTP	D
Big Sioux River	MN0064351	Lincoln Pipestone Rural Water Holland Well	WTP[(a)]
Big Sioux River	MNG580192	Woodstock WWTP	D
Big Sioux River	MN0054801	Pipestone WWTP	C
Big Sioux River	MNG790055	Clipper Oil Bassett Texaco	D[(a)]
Big Sioux River	MNG580026	Jasper WWTP	D
Big Sioux River	SD0000299	USGS - EROS Data Center	D
Big Sioux River	SD0022560	City of Garretson	D
Big Sioux River	MN0003981	TYSON FOODS	D[(a)]
Big Sioux River	MNG580055	Beaver Creek WWTP	D
Little Sioux River	IA3045001	Lake Park City of STP	D[(a)]
Little Sioux River	IA7128001	Hartley City of STP	D[(a)]
Little Sioux River	IA7222001	Harris City of STP	D[(a)]
Little Sioux River	IA3050901	Iowa Great Lakes Sanitary District STP	C[(a)]
Little Sioux River	IA2100100	Corn Belt Power Cooperative - Wisdom Station	POWER[(a)]
Little Sioux River	IA7239001	Ocheyedan City of STP	D[(a)]
Little Sioux River	IA2166001	Royal City of STP	D[(a)]
Little Sioux River	IA2171004	Spencer City of STP	D[(a)]
Little Sioux River	IA7465001	Ruthven City of STP	D[(a)]
Little Sioux River	IA2122001	Fostoria City of STP	D[(a)]
Little Sioux River	IA3080001	Terril City of STP	D[(a)]
Little Sioux River	IA2115001	Everly City of STP	D[(a)]
Little Sioux River	IA2109001	Dickens Wastewater Treatment Facility	D[(a)]
Little Sioux River	IA1175001	Sioux Rapids City of STP	D[(a)]
Little Sioux River	IA2133001	Greenville City of STP	D[(a)]
Rock River	MN0021270	Holland WWTP	D
Rock River	MN0023604	Hatfield WWTP	D[(a)]
Rock River	MN0039748	Chandler WWTP	D
Rock River	MNG580011	Edgerton WWTP	D
Rock River	MNG580219	Leota Sanitary District WWTP	D
Rock River	MNG580194	Hardwick WWTP	D
Rock River	MN0020141	Luverne WWTP	A
Rock River	MNG640056	Luverne WTP - Plant 1	D(a)
Rock River	MNG255020	LAND O' LAKES INC-LUVERNE	D(a)
Rock River	MN0064033	Agri-Energy LLC	POWER(a)

Table 9. Categorical Concentration Assumptions (m/L) [Weiss, 2012 a] (Page 2 of 2)

Model Application	Site I.D.	Facility Name	Type
Rock River	MNG580190	Magnolia WWTP	D
Rock River	MNG640079	Rock County Rural WTP	D(a)
Rock River	MNG580076	Lismore WWTP	D
Rock River	MNG580001	Adrian WWTP	D
Rock River	MNG580015	Ellsworth WWTP	D
Rock River	MNG580196	Hills WWTP	D
Rock River	MNG580199	Steen WWTP	D
Rock River	IA6055001	LESTER CITY OF STP	D(a)
Rock River	IA6003001	ALVORD CITY OF STP	D(a)
Rock River	IA6065001	ROCK RAPIDS CITY OF STP	D(a)
Rock River	MNG580201	Rushmore WWTP	D
Rock River	MNG640080	RUSH MORE WTP	D(a)
Rock River	IA6060001	LITTLE ROCK CITY OF STP	D(a)
Rock River	IA6028001	GEORGE CITY OF STP	D(a)
Rock River	MNG580224	Bigelow WWTP	D
Rock River	IA7245001	SIBLEY CITY OF STP	D(a)
Rock River	IA7200108	POET BIOREFINING - ASHTON	D(a)
Rock River	IA6015001	DOON CITY OF STP	D(a)
Rock River	IA8444001	HULL CITY OF STP	D(a)
Rock River	IA8482001	ROCK VALLEY CITY OF STP	D(a)

(a) Assumed based on description of treatment and flow

Besides temperature, the concentrations of all available constituents, including BOD as CBODU (converted from CBOD5 using Equation 1 [Chapra, 1997]), were converted from concentration (mg/L) to load (lb/day), using a conversion factor of 8.34. Temperature wasconverted from degrees F to a heat load in British Thermal Units (BTU) per day (temperature ×flow × conversion factor, conversion factor = 8,339,145).

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

where:

$L_0 = \text{CBOD}_u$

$y_5 = \text{CBOD}_5$

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

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

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

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

(a) TN = Total Nitrogen
(b) NOx = Inorganic Nitrogen
(c) TKN = Total Kjeldahl Nitrogen
(d) NH x = Ammonia

The final results from the most data-intensive downstream reaches in the Missouri River Watershed are included in Attachment E. Three figures are included for each available water-quality constituent at this location. The figures show comparisons of observed data (blue) and model simulations (red) and include a concentration duration curve, a monthly average plot, and a time-series plot for each site. Results at additional water-quality monitoring sites are included in the Missouri River deliverables results folder.

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We would be happy to discuss these methods with you and hear any feedback you may have regarding the calibration and validation of the Missouri River **HSPF** Watershed model applications.

Sincerely,

Seth J. Kenner
Staff Engineer

SJK:blp

cc: Project Central File 2216 — Category A

ATTACHMENT A

OBSERVED FLOW GAGE LOCATIONS FOR THE LITTLE AND BIG SIOUX WATERSHED MODEL APPLICATIONS

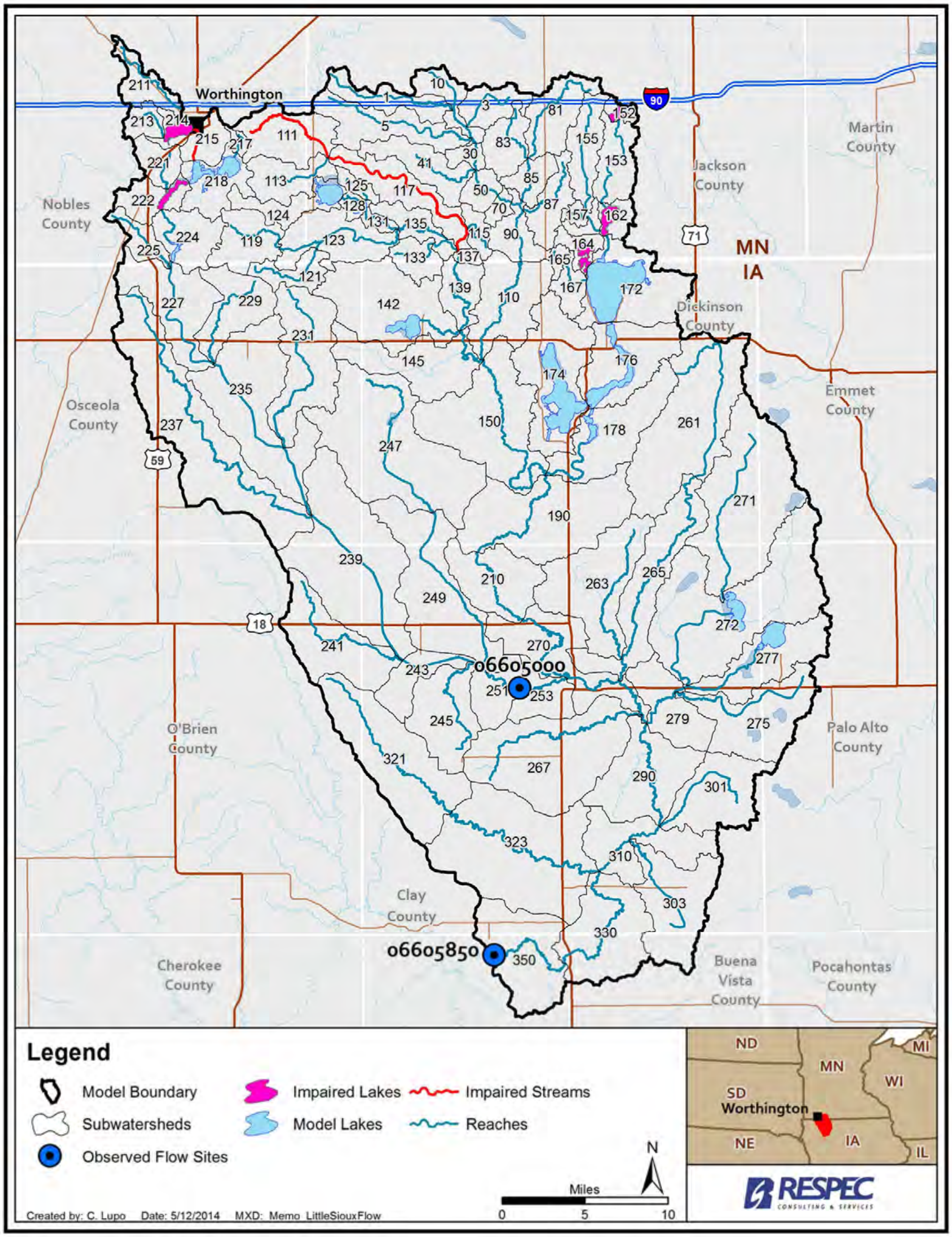

Figure A-1. Flow Calibration Gages Within the Little Sioux River Watershed.

RSI-2279-14-031

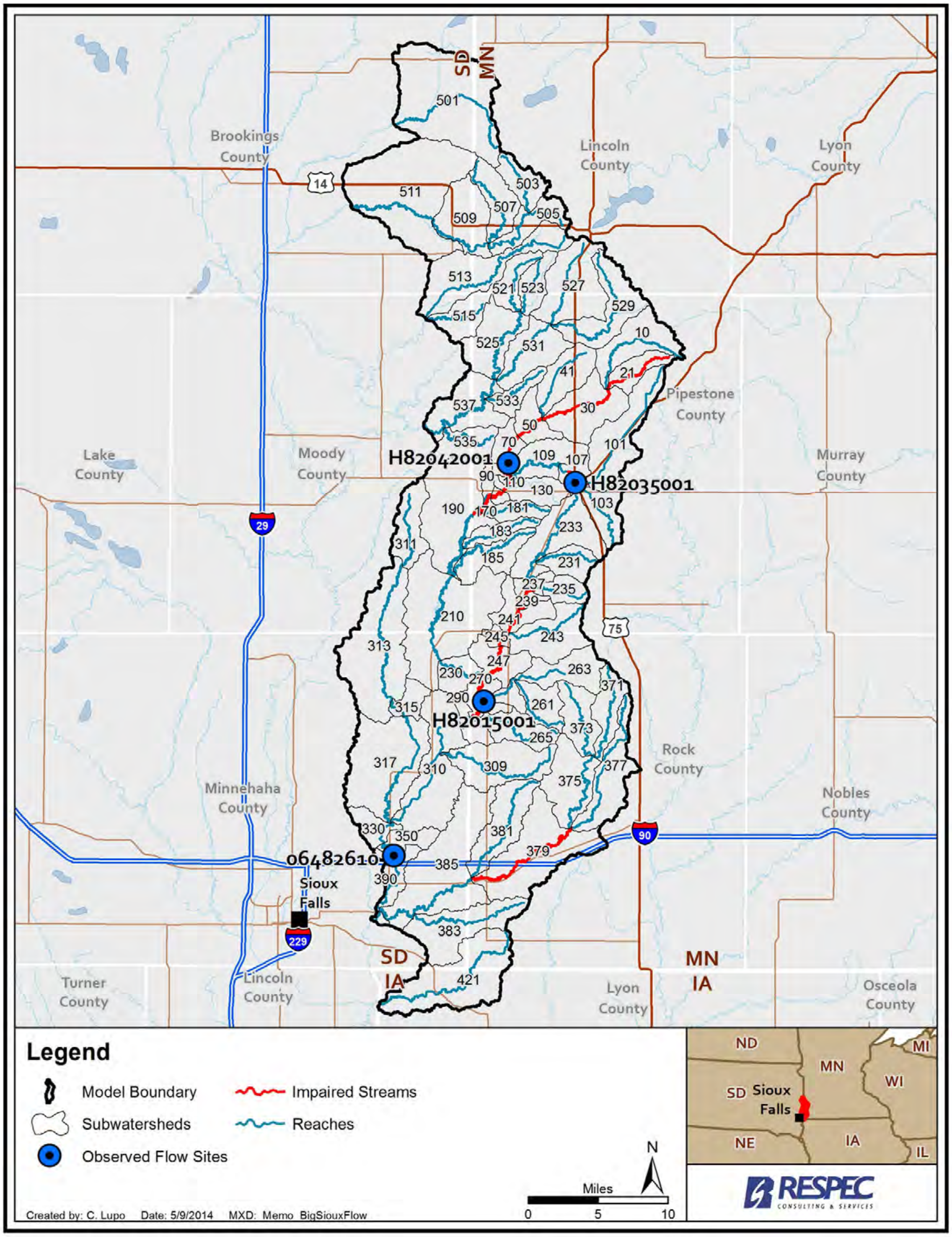

Figure A-2. Flow Calibration Gages Within the Big Sioux River Watershed.

ATTACHMENT B

HYDROLOGY CALIBRATION RESULTS AT PRIMARY GAGES FOR THE MISSOURI RIVER WATERSHED MODEL

RSI-2279-14-032

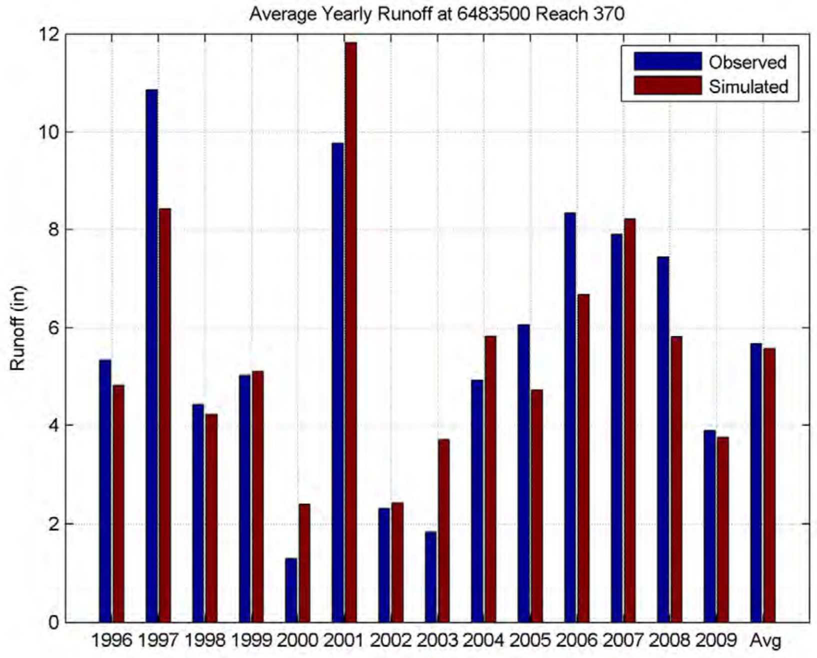

Figure B-1. Average Yearly Runoff – Rock River (Reach 370).

RSI-2279-14-033

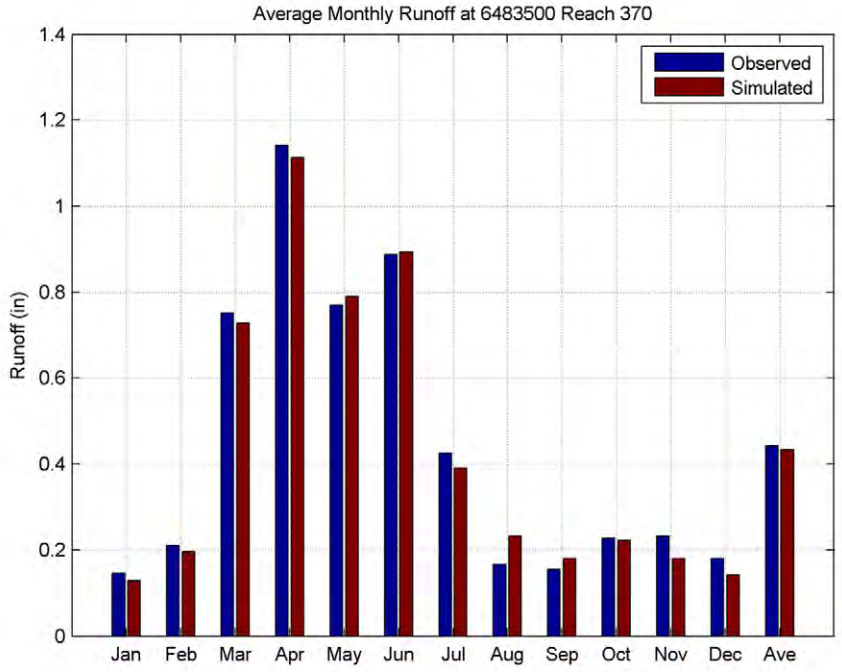

Figure B-2. Average Monthly Run off – Rock River (Reach 370).

RSI-2279-14-034

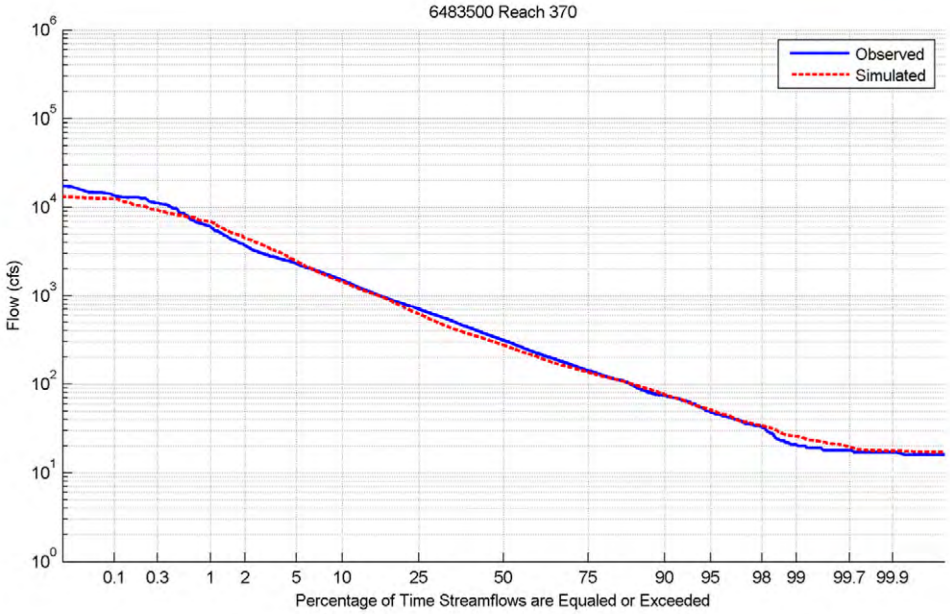

Figure B-3. Flow-Duration Plot – Rock River (Reach 370).

RSI-2279-14-035

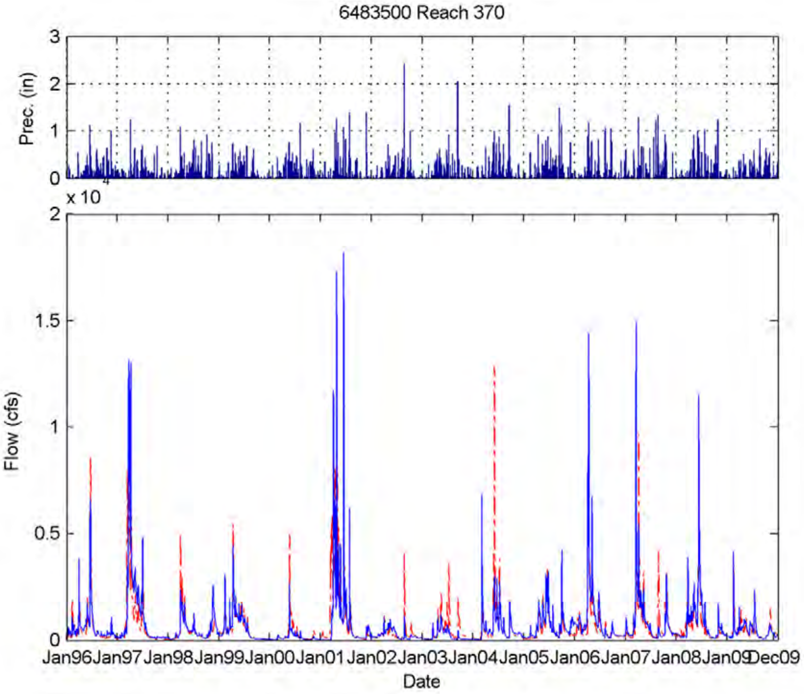

Figure B-4. Daily Hydrographs – Rock River (Reach 370).

RSI-2279-14-036

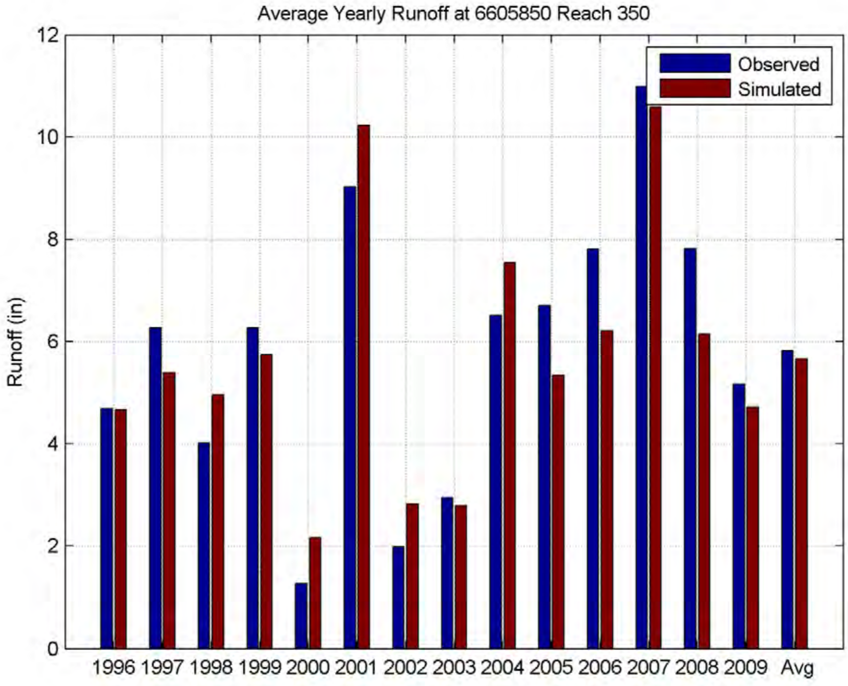

Figure B-5. Average Yearly Runoff – Little Sioux (Reach 350).

RSI-2276-14-037

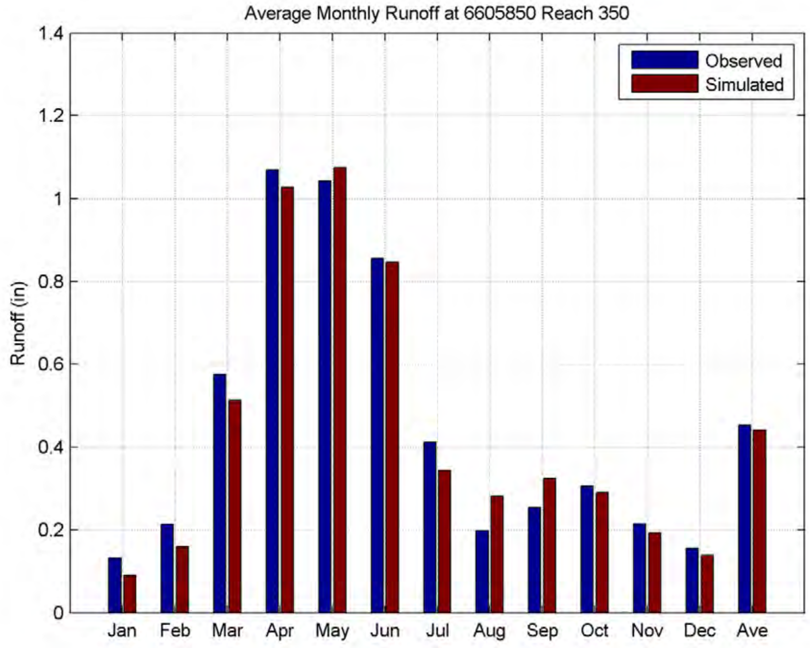

Figure B-6. Average Monthly Runoff – Little Sioux (Reach 350).

RSI-2276-14-038

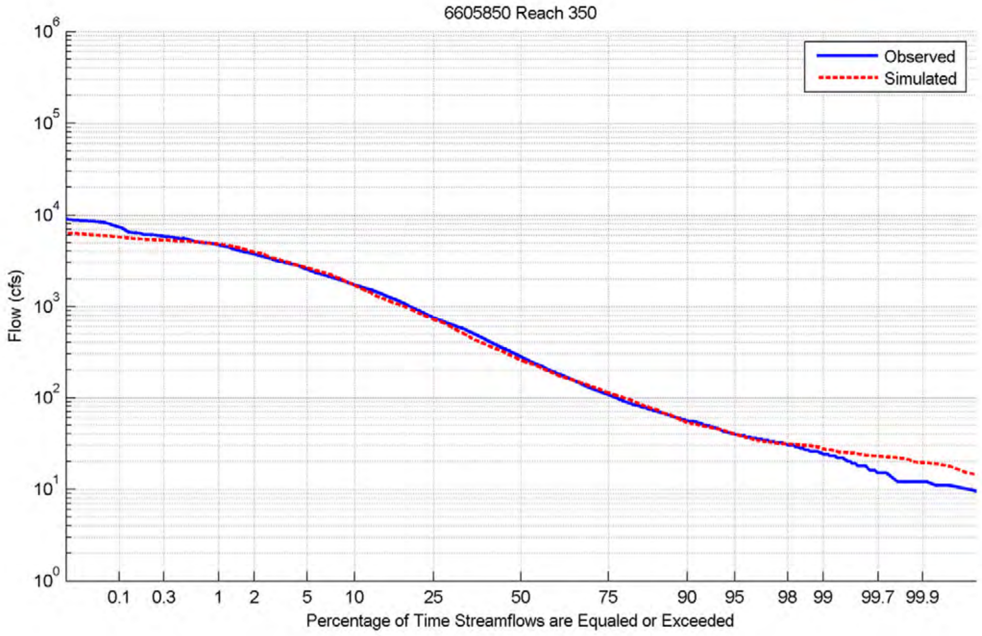

Figure B-7. Flow-Duration Plot – Little Sioux (Reach 350).

RSI-2276-14-039

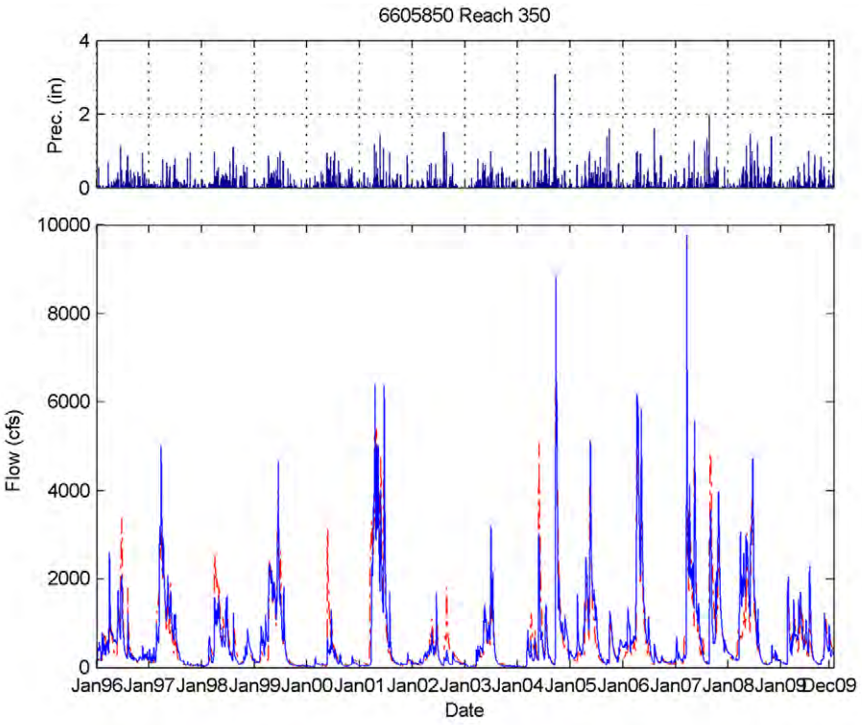

Figure B-8. Daily Hydrographs – Little Sioux (Reach 350).

RSI-2279-14-040

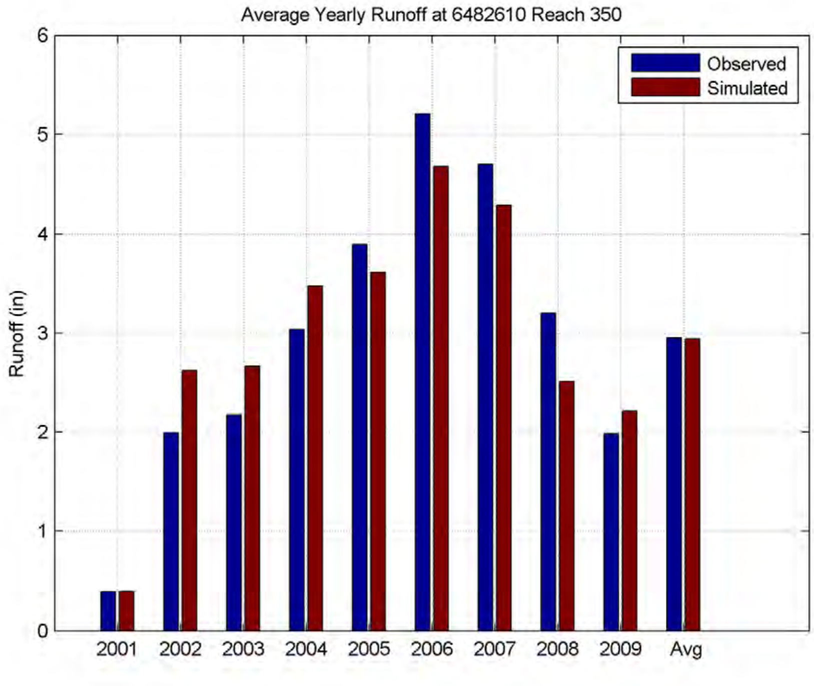

Figure B-9. Average Yearly Runoff – Big Sioux (Reach 350).

RSI-2276-14-041

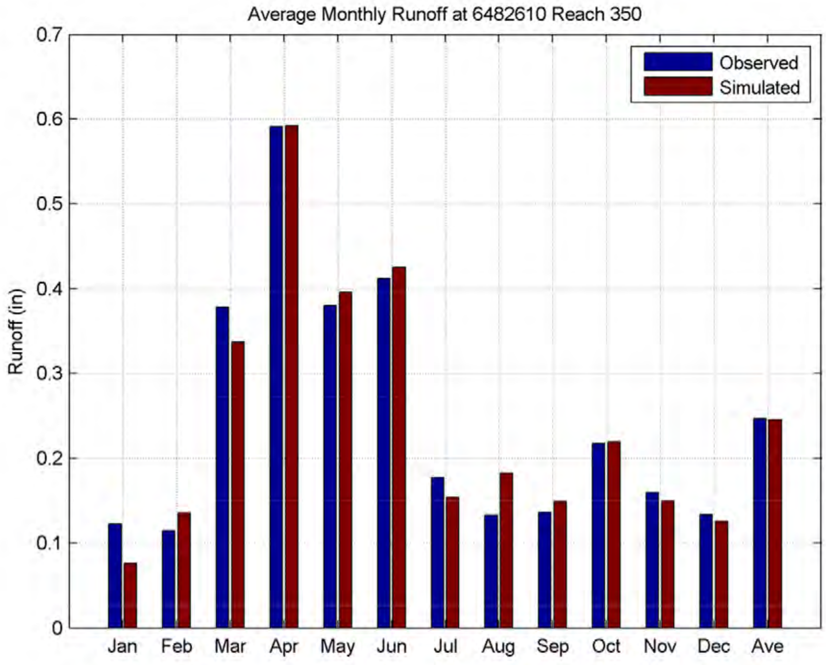

Figure B-10. Average Monthly Runoff – Big Sioux (Reach 350).

RSI-2279-14-042

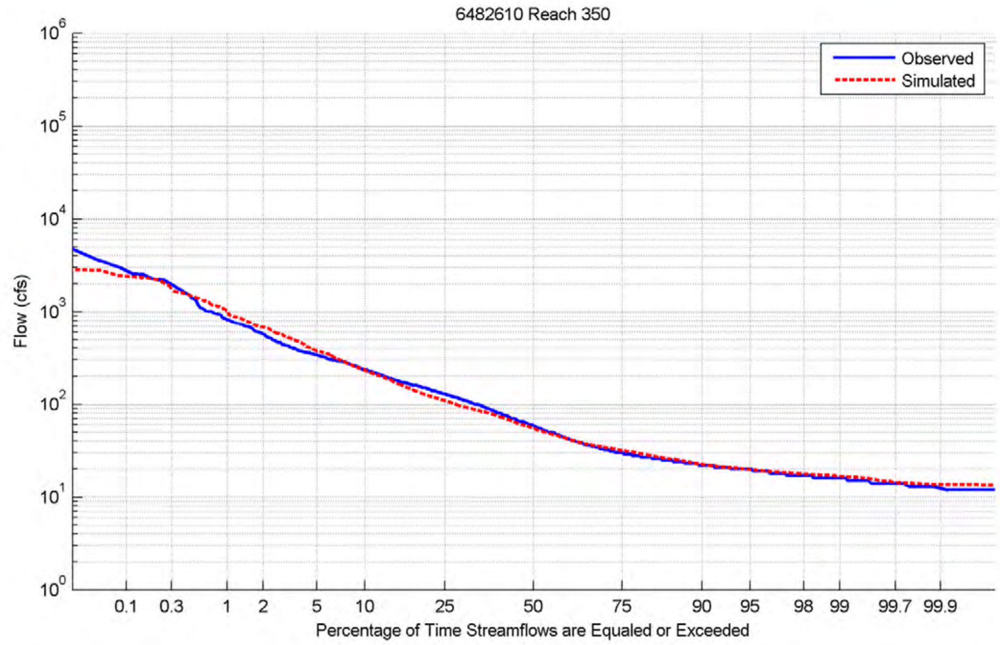

Figure B-11. Flow-Duration Plot – Big Sioux (Reach 350).

RSI-2279-14-043

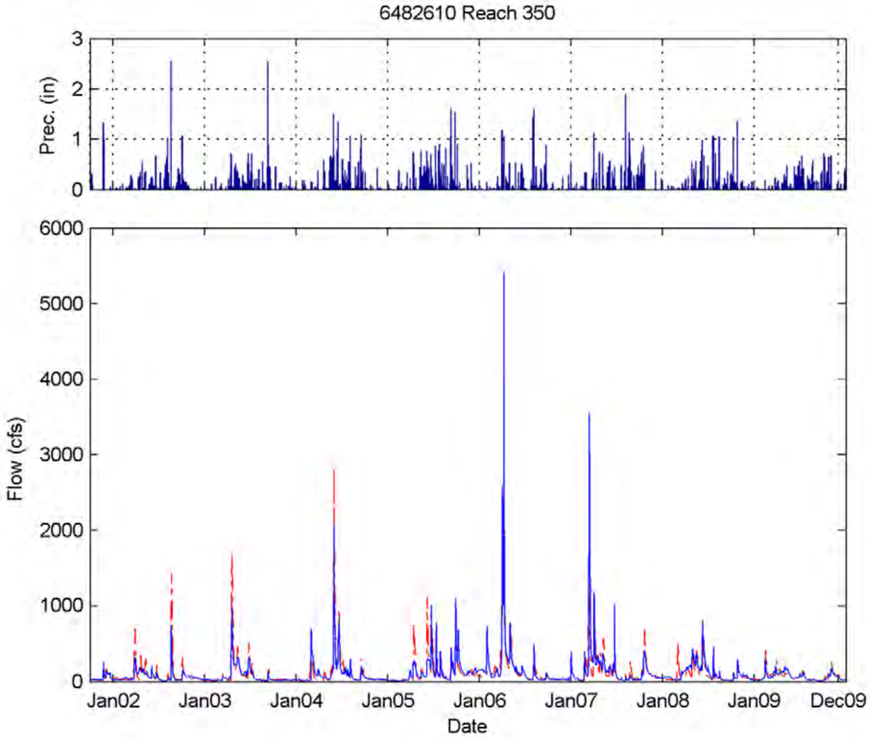

Figure B-12. Daily Hydrographs – Big Sioux (Reach 350).

ATTACHMENT C

OBSERVED WATER-QUALITY LOCATIONS FOR THE LITTLE AND BIG SIOUX WATERSHED MODEL APPLICATIONS

RSI-2279-14-044

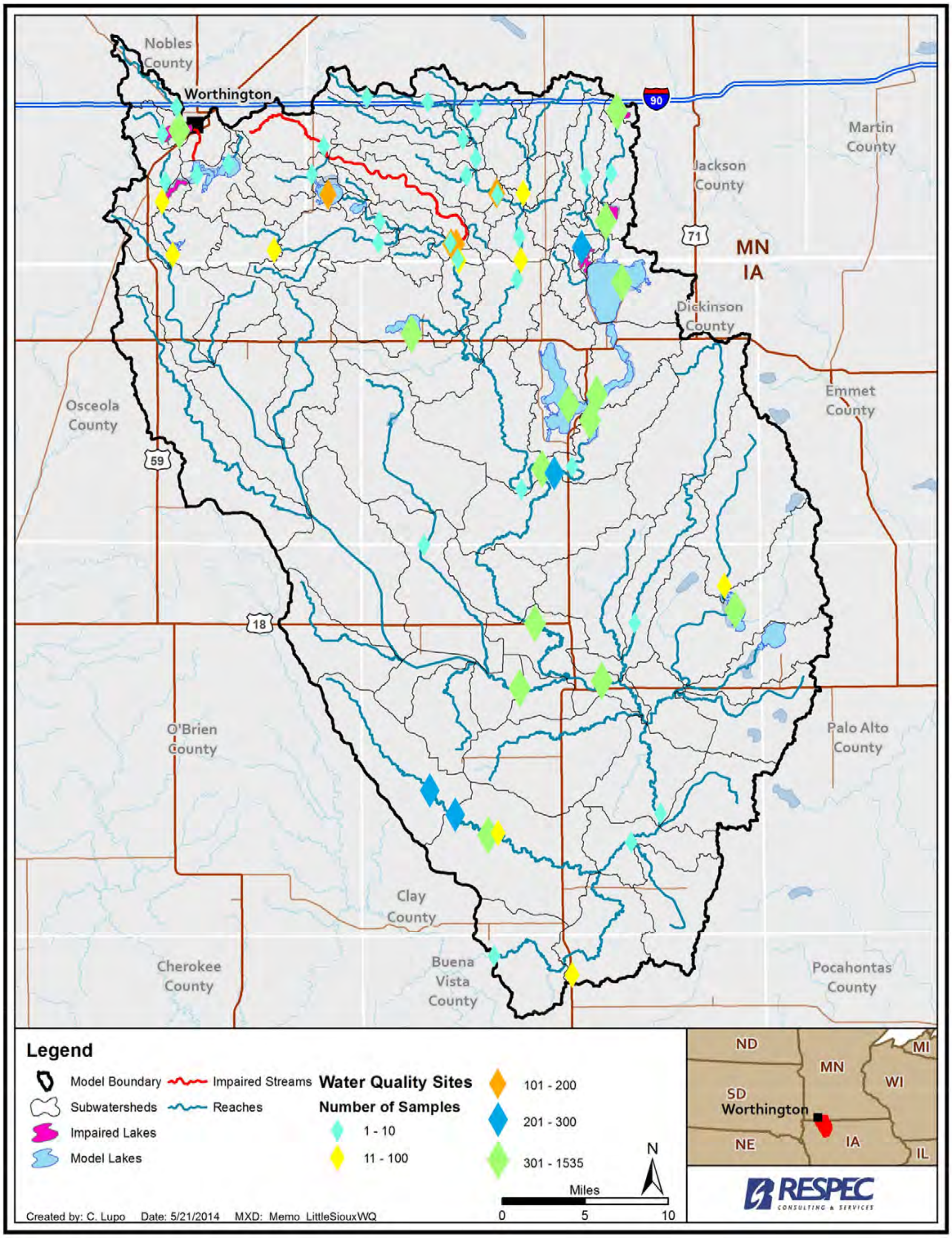

Figure C-1. Observed Water-Quality Locations Within the Little Sioux River Watershed.

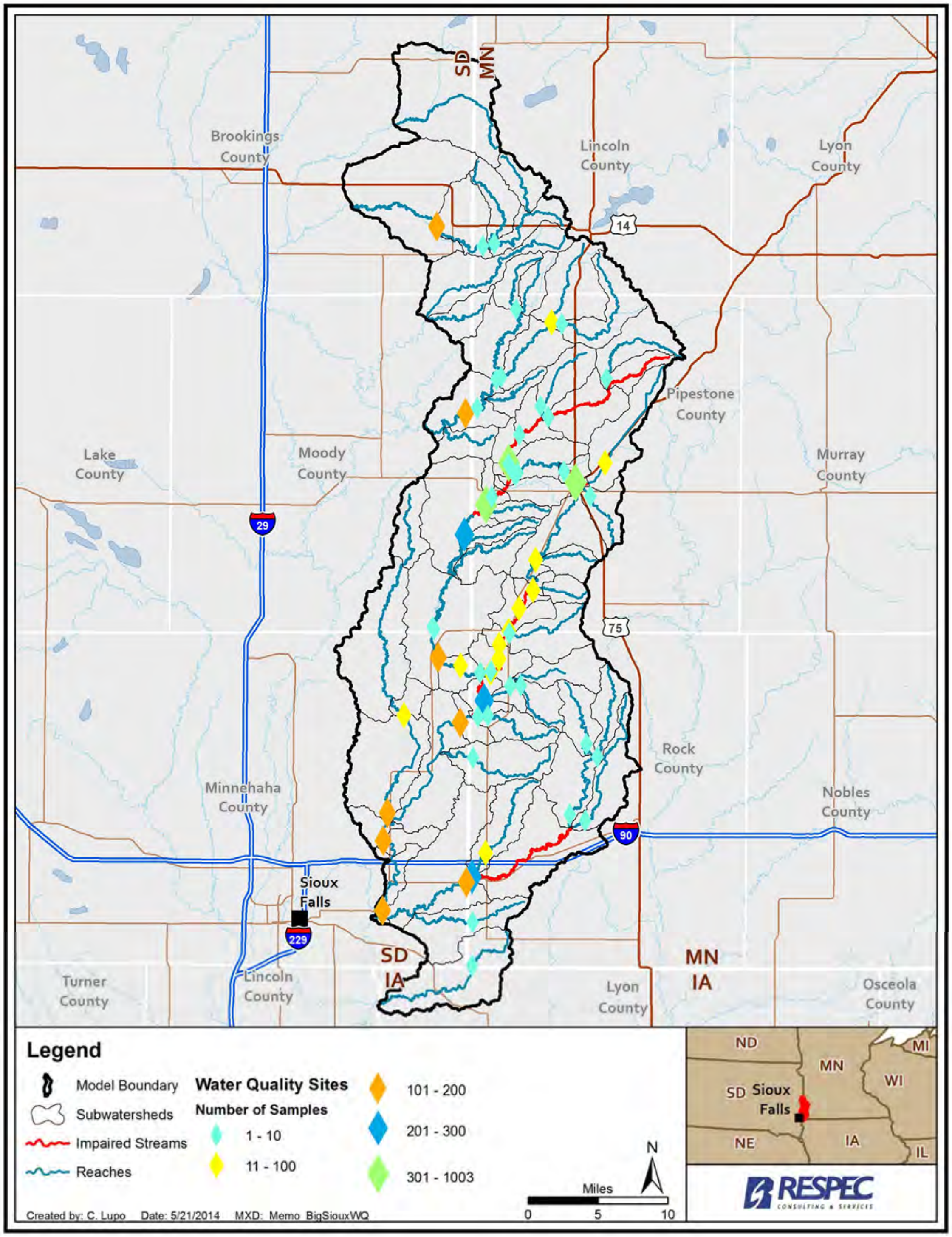

Figure C-2. Observed Water-Quality Locations Within the Big Sioux River Watershed.

ATTACHMENT D

POINT-SOURCE LOCATIONS FOR THE LITTLE AND BIG SIOUX WATERSHED MODEL APPLICATIONS

RSI-2279-14-046

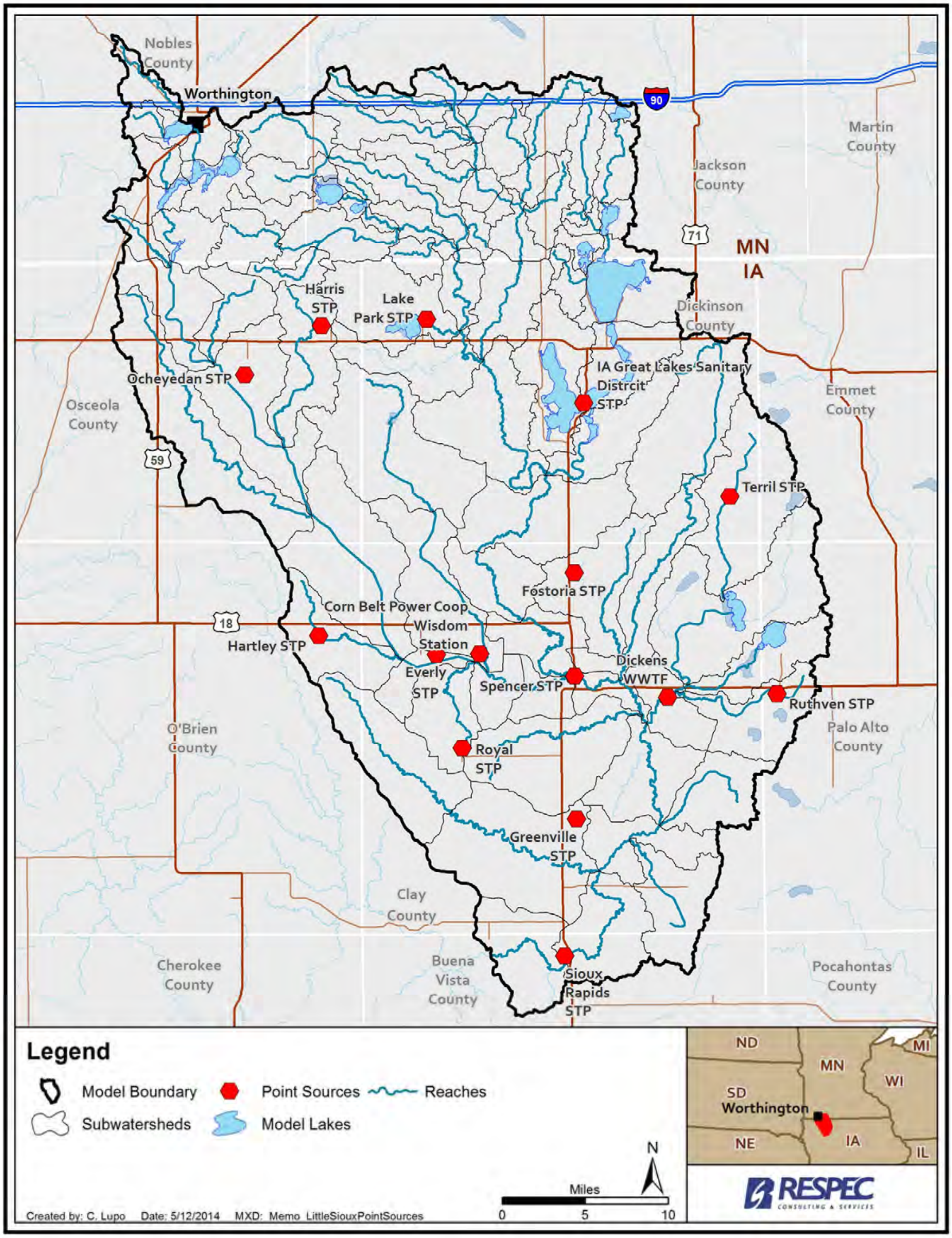

Figure D-1. Point-Source Locations Within the Little Sioux River Watershed.

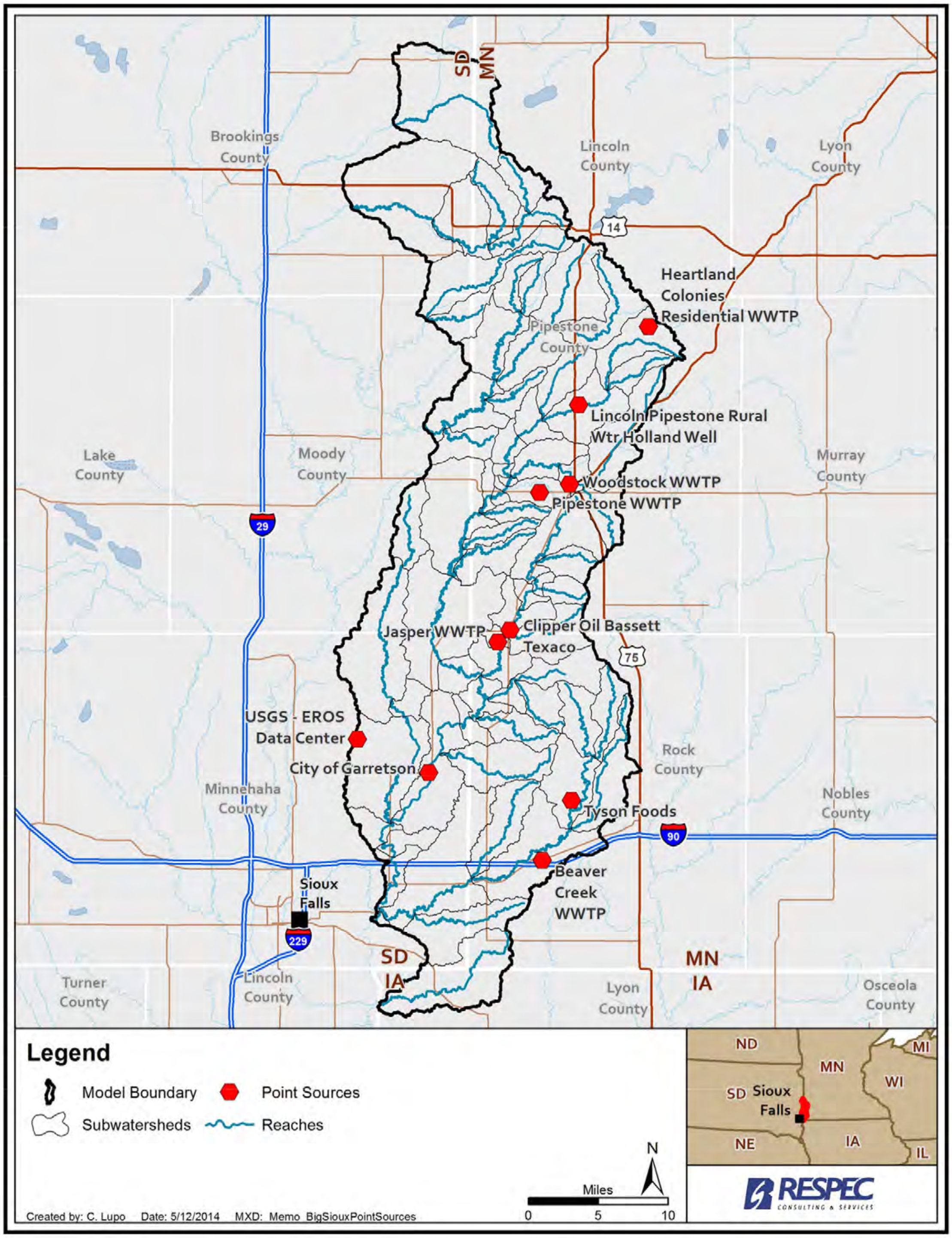

Figure D-2. Point-Source Locations Within the Big Sioux River Watershed.

ATTACHMENT E

MISSOURI RIVER WATERSHED
WATER-QUALITY CALIBRATION FIGURES

RSI-2279-14-048

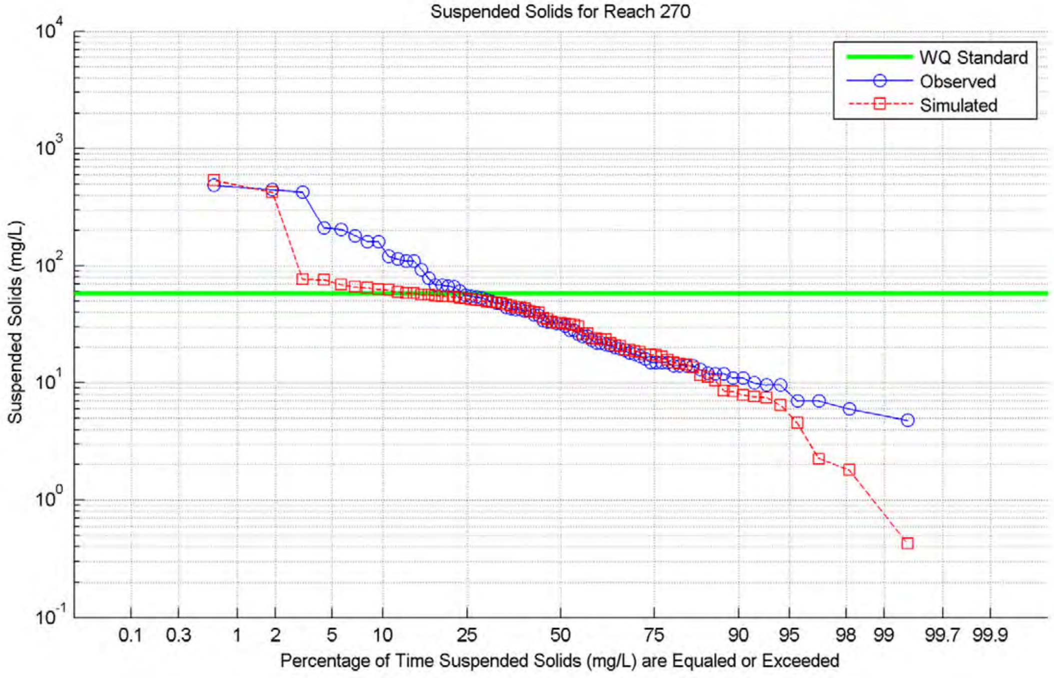

Figure E-1. Suspended Solids Duration Curve–Rock River (Reach 270).

RSI-2279-14-049

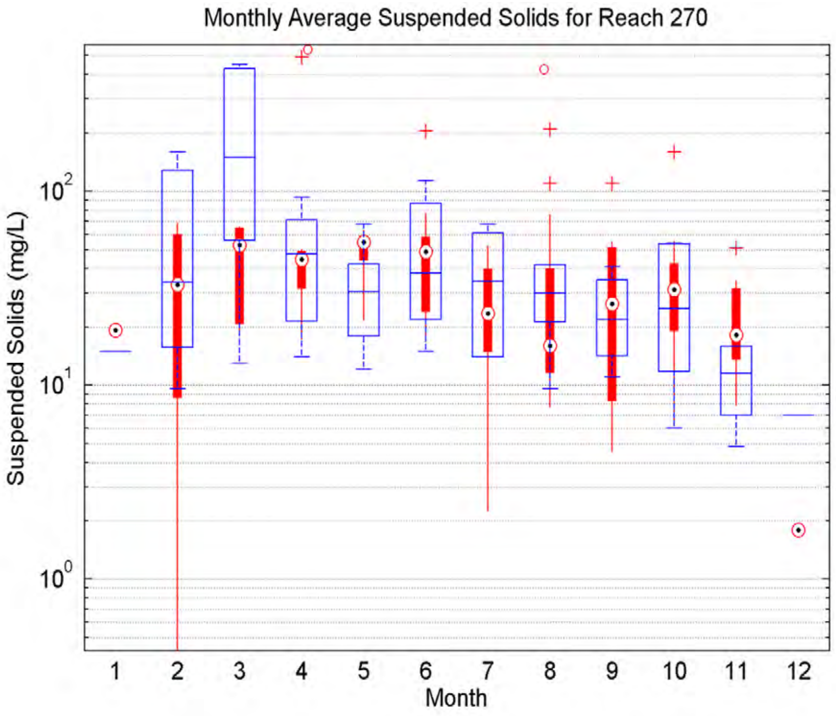

Figure E-2. Suspended Solids Monthly Averages–Rock River (Reach 270).

RSI-2279-14-050

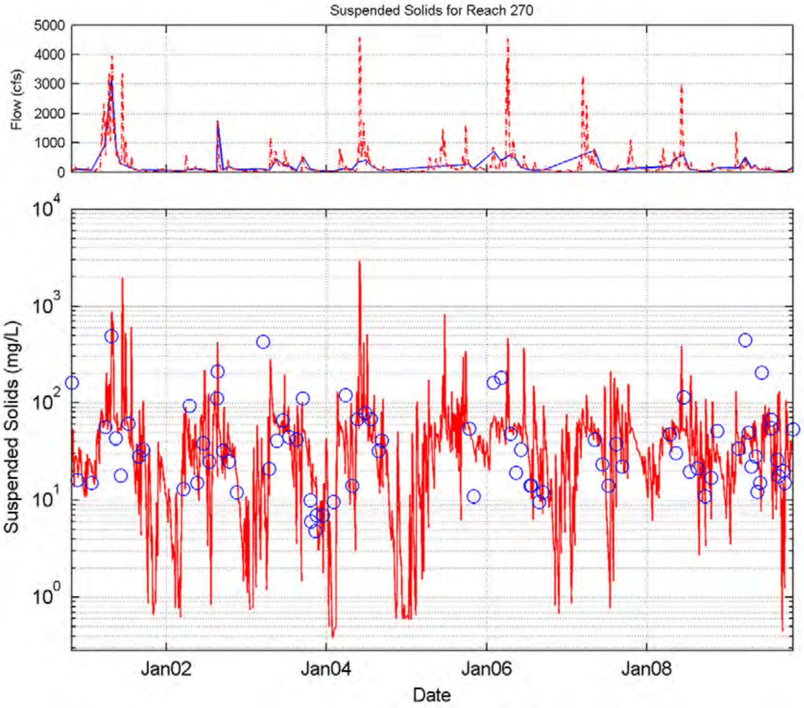

Figure E-3. Suspended Solids Daily Time Series–Rock River (Reach 270).

RSI-2279-14-051

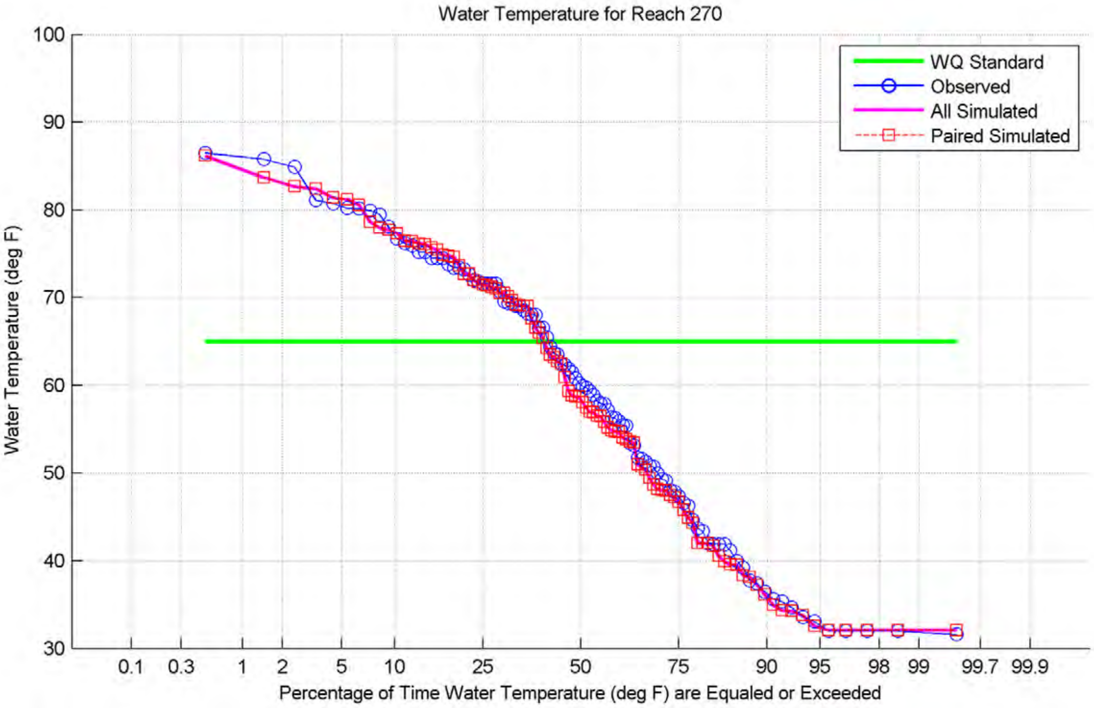

Figure E-4. Water Temperature Duration Curve–Rock River (Reach 270).

RSI-2279-14-052

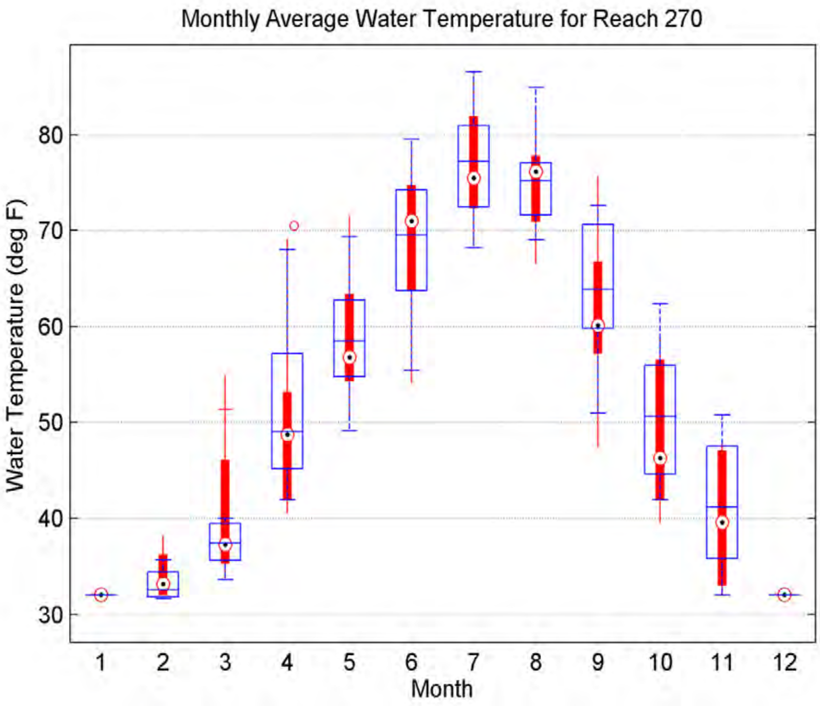

Figure E-5. Water Temperature Monthly Averages– Rock River (Reach 270).

RSI-2279-14-053

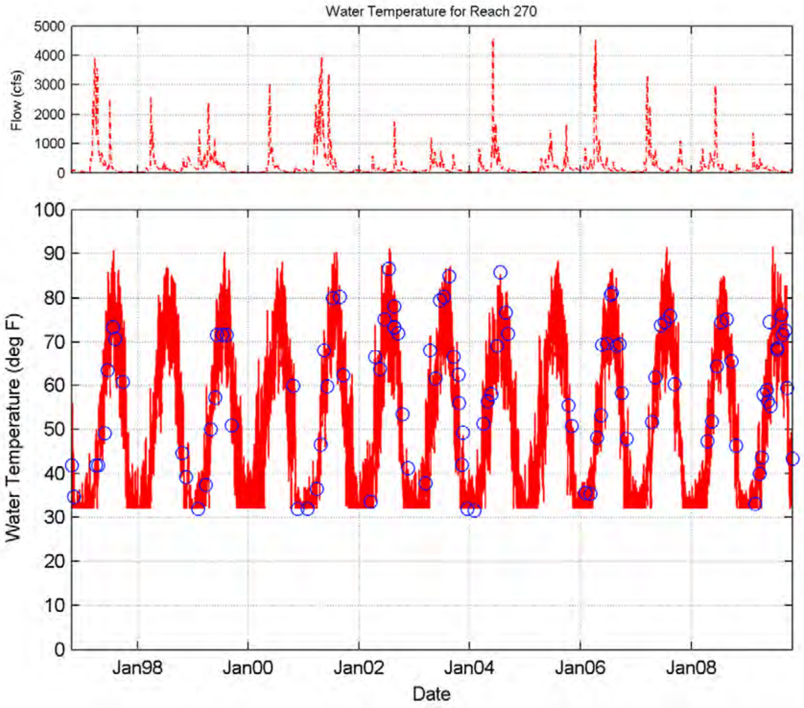

Figure E-6. Water Temperature Daily Time Series–Rock River (Reach 270).

RSI-2279-14-054

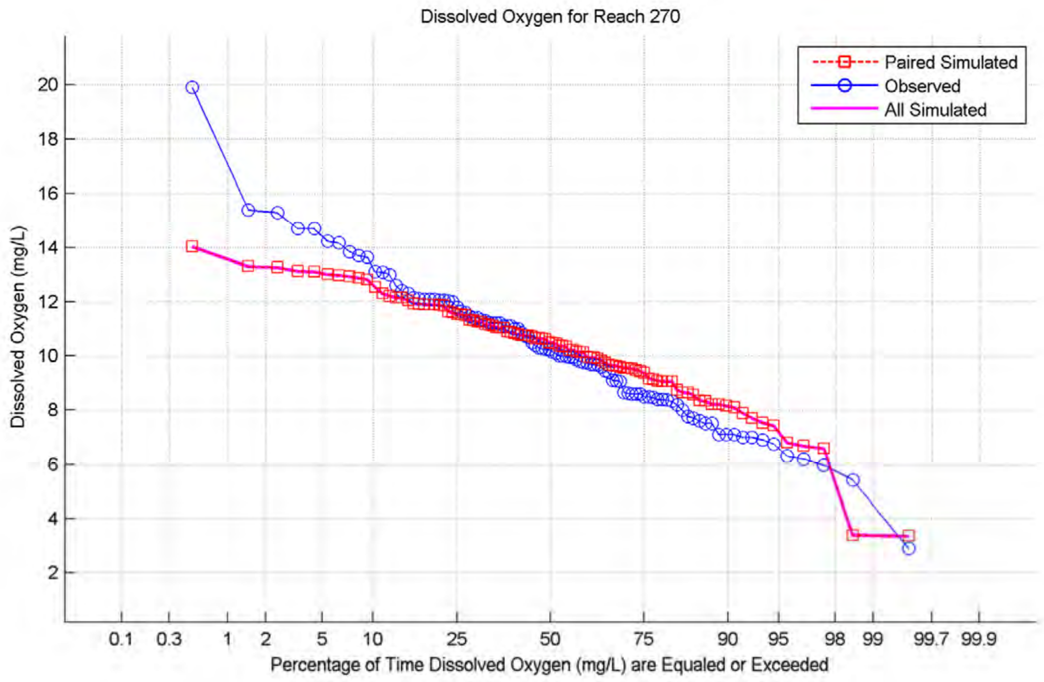

Figure E-7. Dissolved Oxygen Duration Curve– Rock River (Reach 270).

RSI-2279-14-055

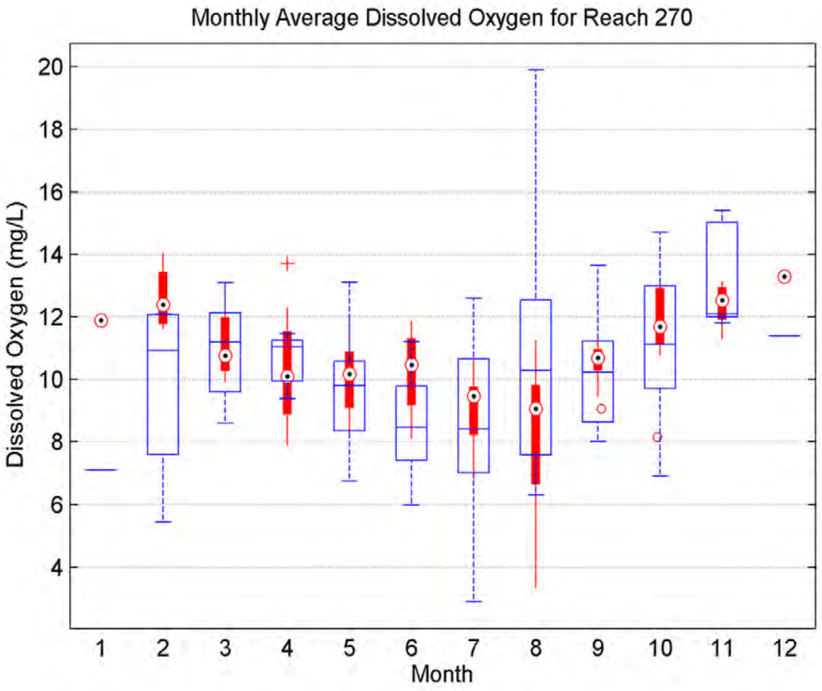

Figure E-8. Dissolved Oxygen Monthly Averages–Rock River (Reach 270).

RSI-2279-14-056

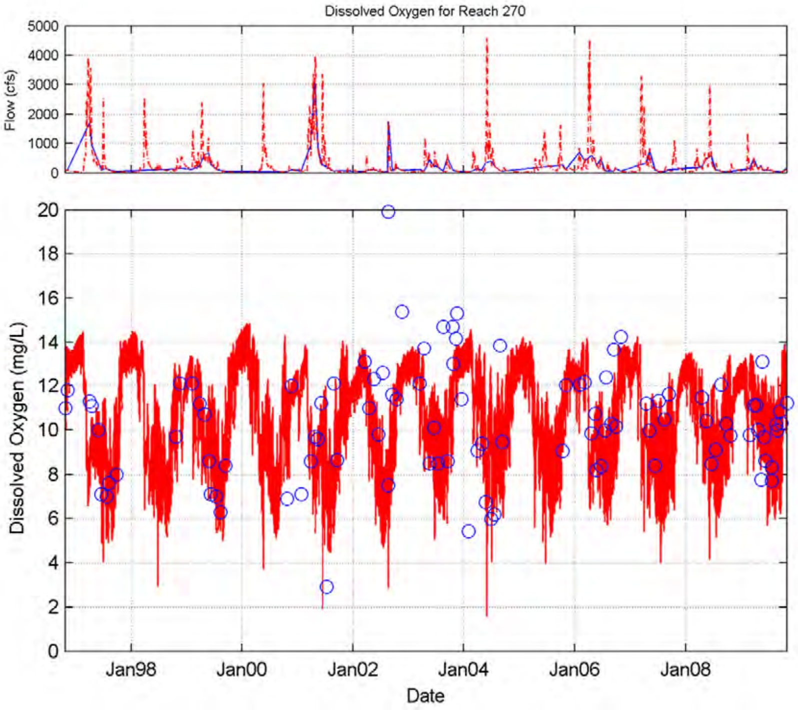

Figure E-9. Dissolved Oxygen Daily Time Series–Rock River (Reach 270).

RSI-2279-14-057

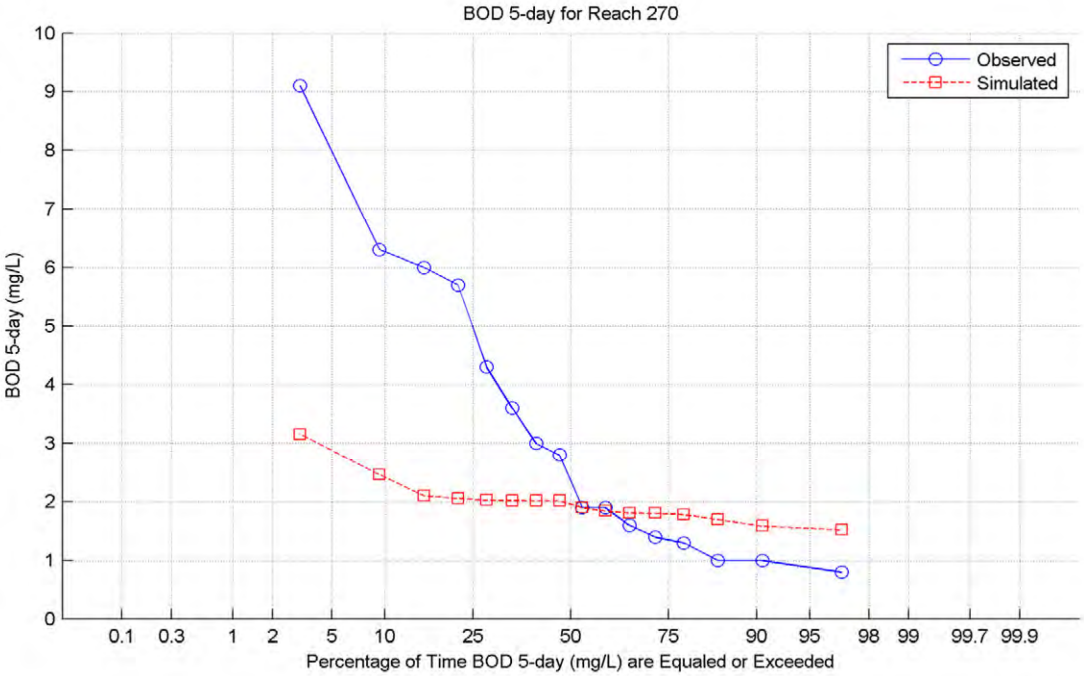

Figure E-10. Biological Oxygen Demand Duration Curve– Rock River (Reach 270).

RSI-2279-14-058

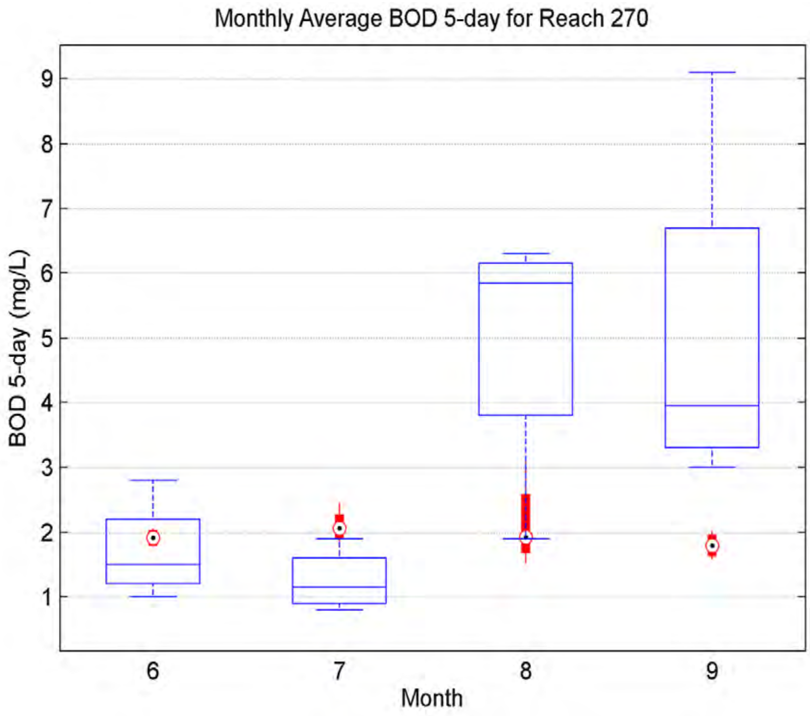

Figure E-11. Biological Oxygen Demand Monthly Averages–Rock River (Reach 270).

RSI-2279-14-059

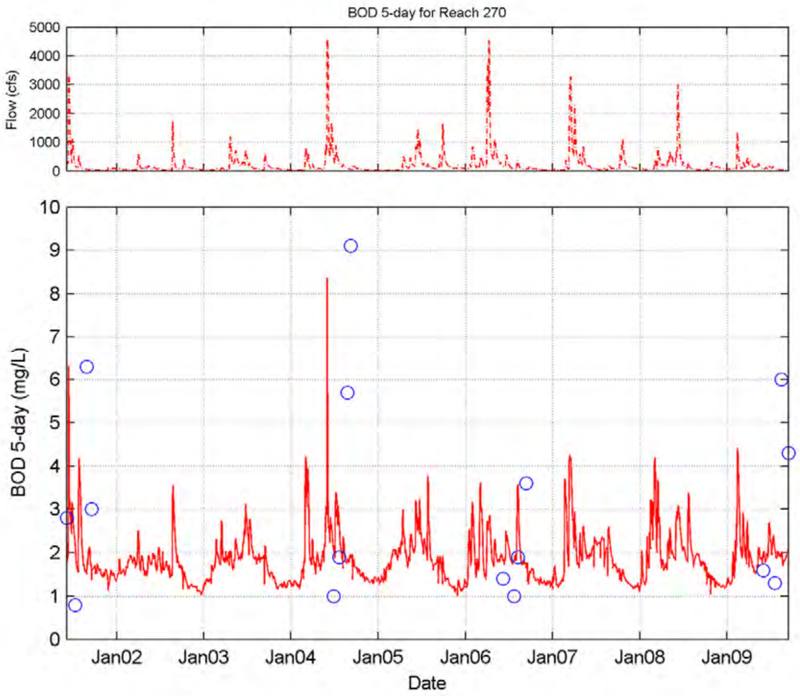

Figure E-12. Biological Oxygen Demand Time Series–Rock River (Reach 270).

RSI-2279-14-060

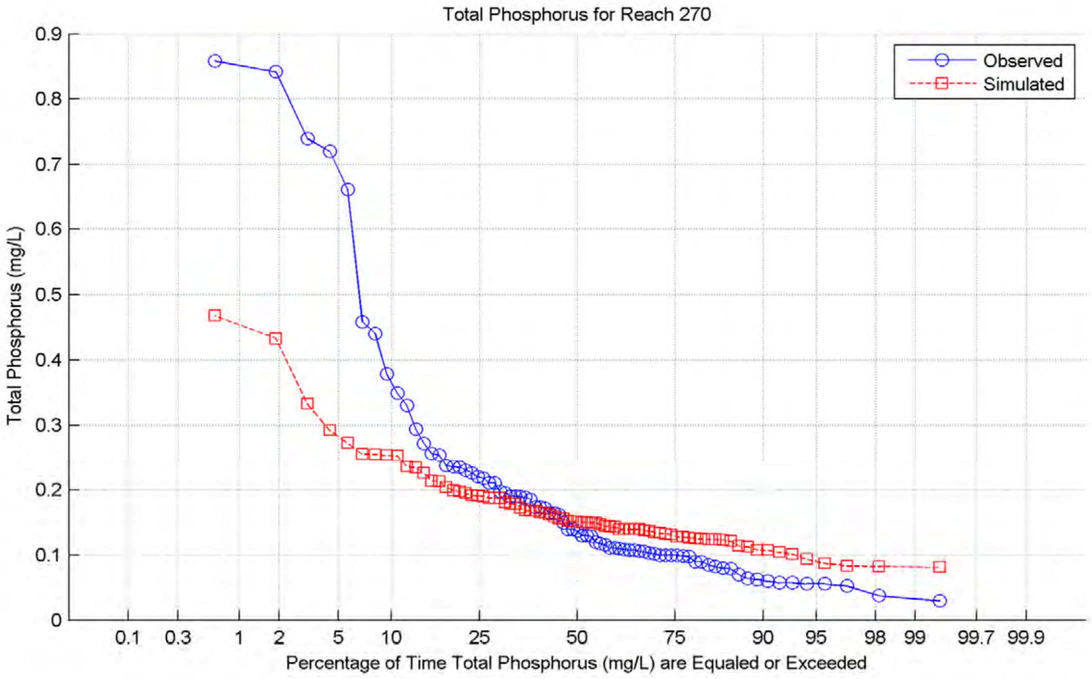

Figure E-13. Total Phosphorus Duration Curve–Rock River (Reach 270).

RSI-2279-14-061

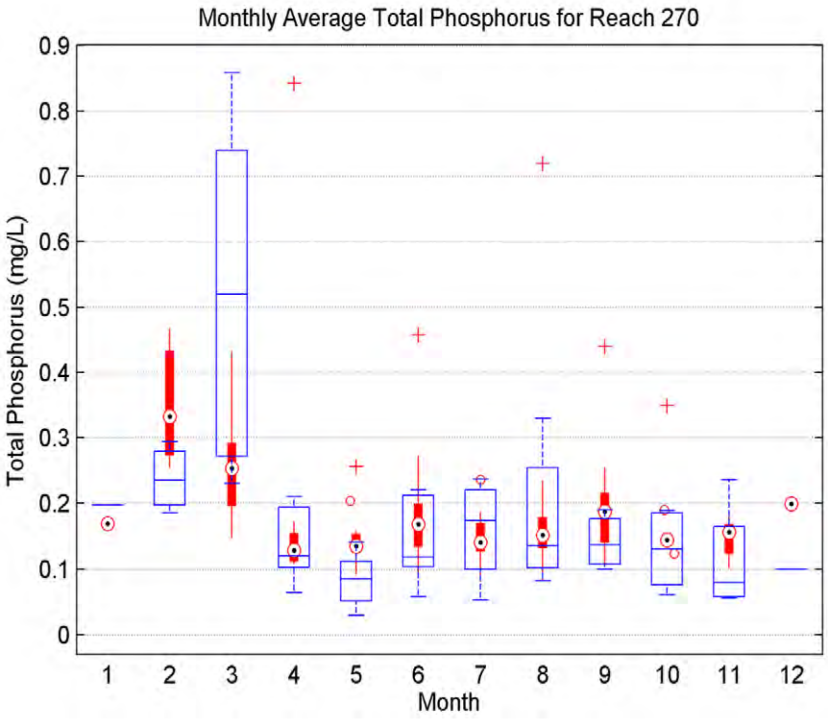

Figure E-14. Total Phosphorus Monthly Averages– Rock River (Reach 270).

RSI-2279-14-062

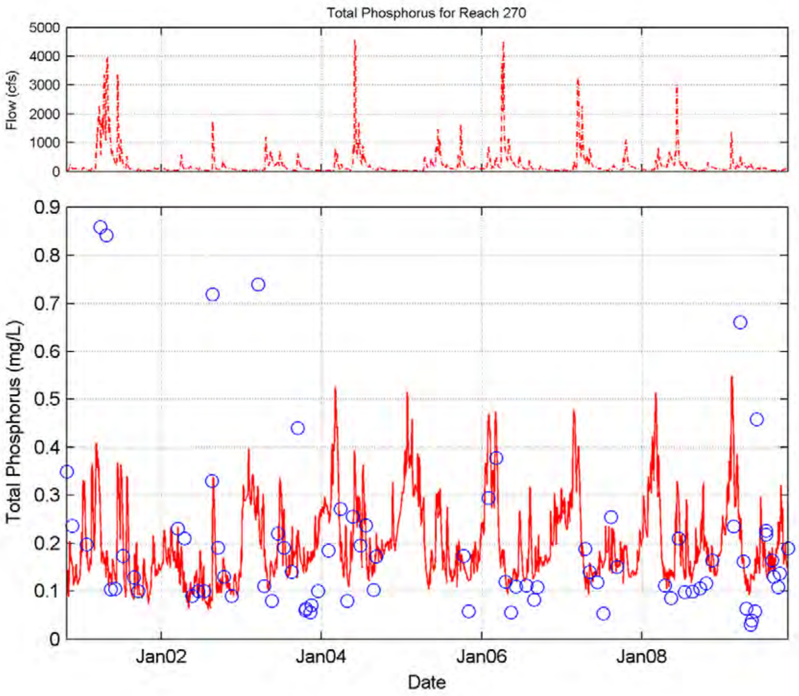

Figure E-15. Total Phosphorus Time Series–Rock River (Reach 270).

RSI-2279-14-063

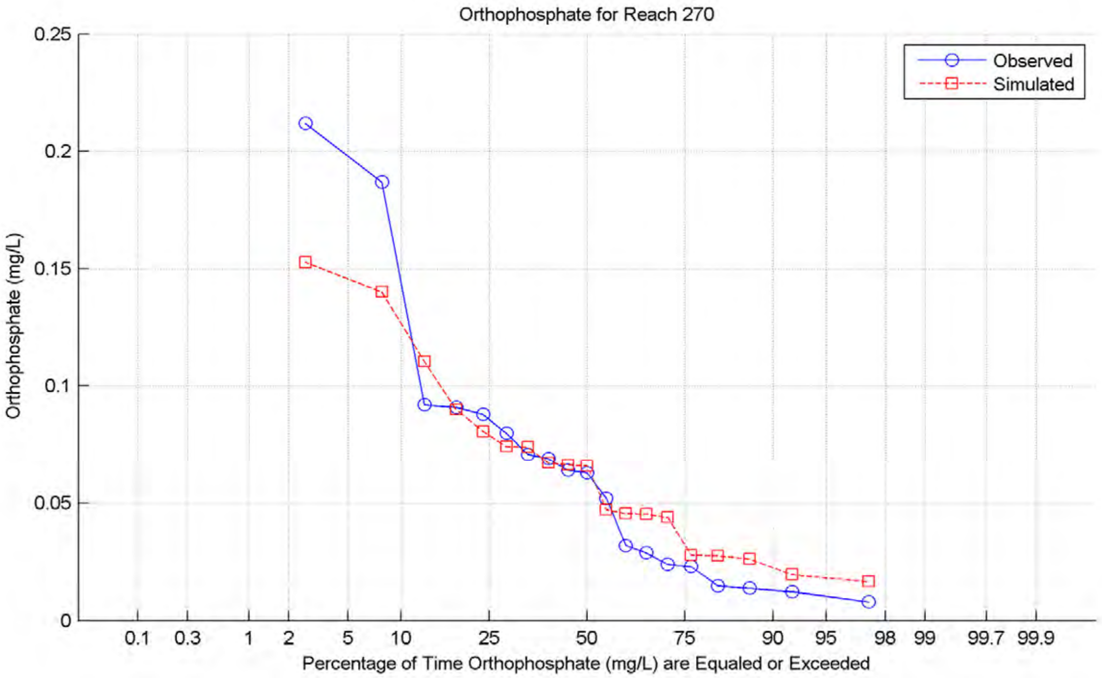

Figure E-16. Orthophosphate Duration Curve–Rock River (Reach 270).

RSI-2279-14-064

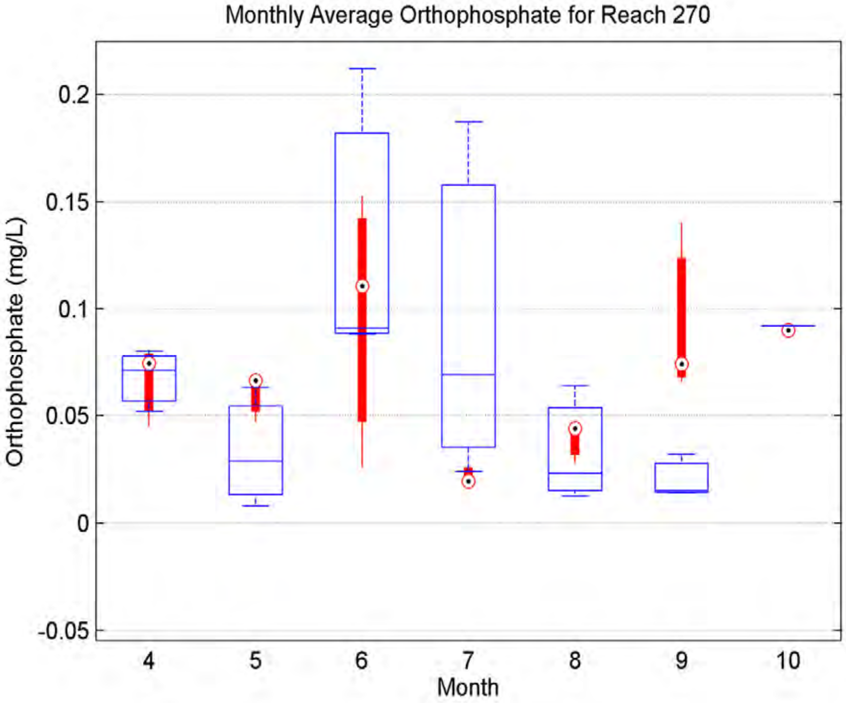

Figure E-17. Orthophosphate Monthly Averages–Rock River (Reach 270).

RSI-2279-14-065

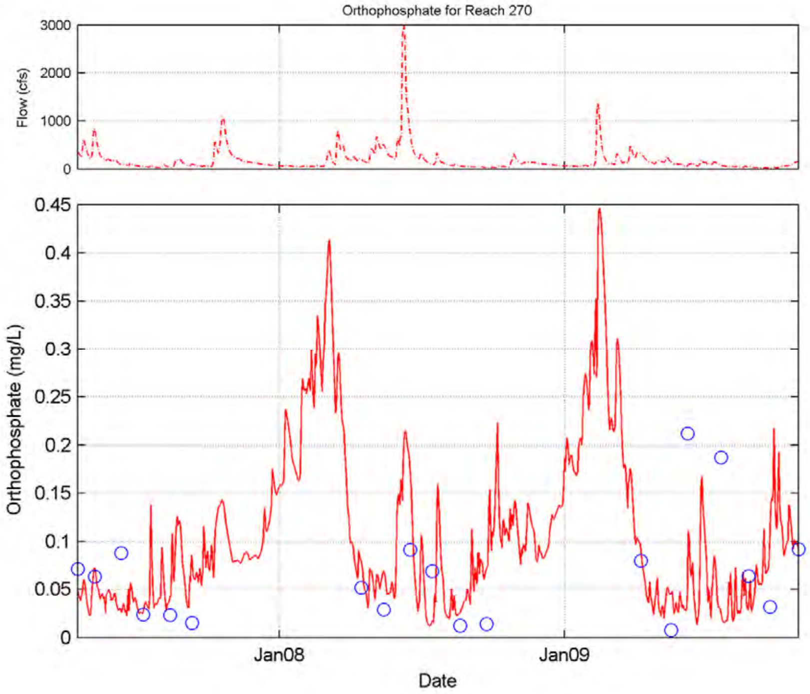

Figure E-18. Orthophosphate Time Series–Rock River (Reach 270).

RSI-2279-14-066

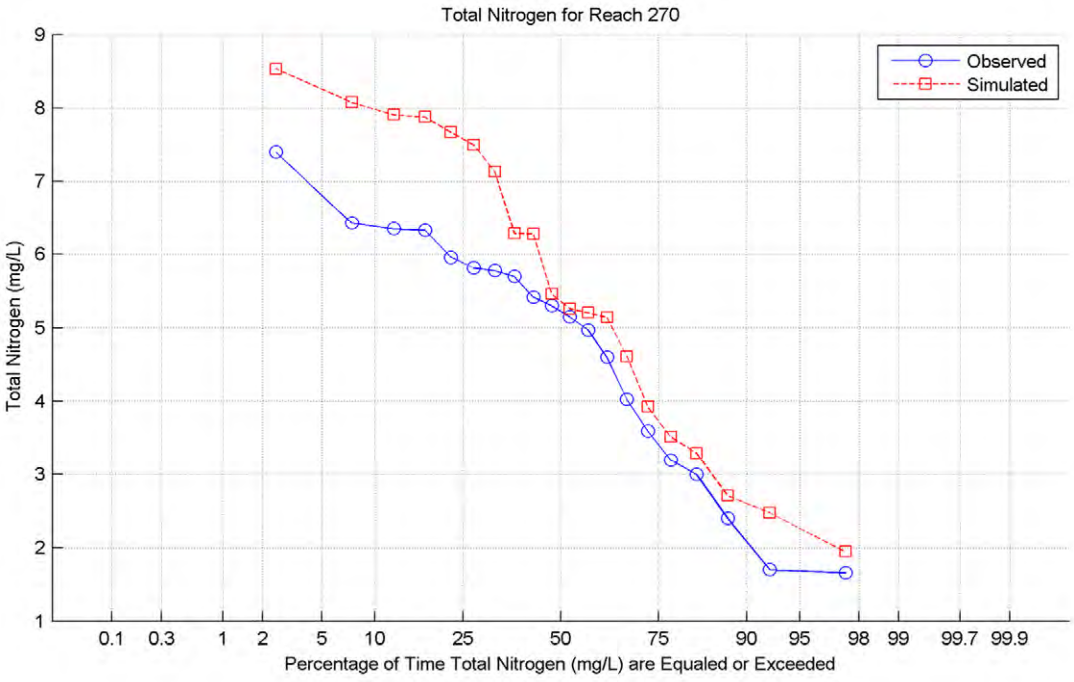

Figure E-19. Total Nitrogen Duration Curve–Rock River (Reach 270).

RSI-2279-14-067

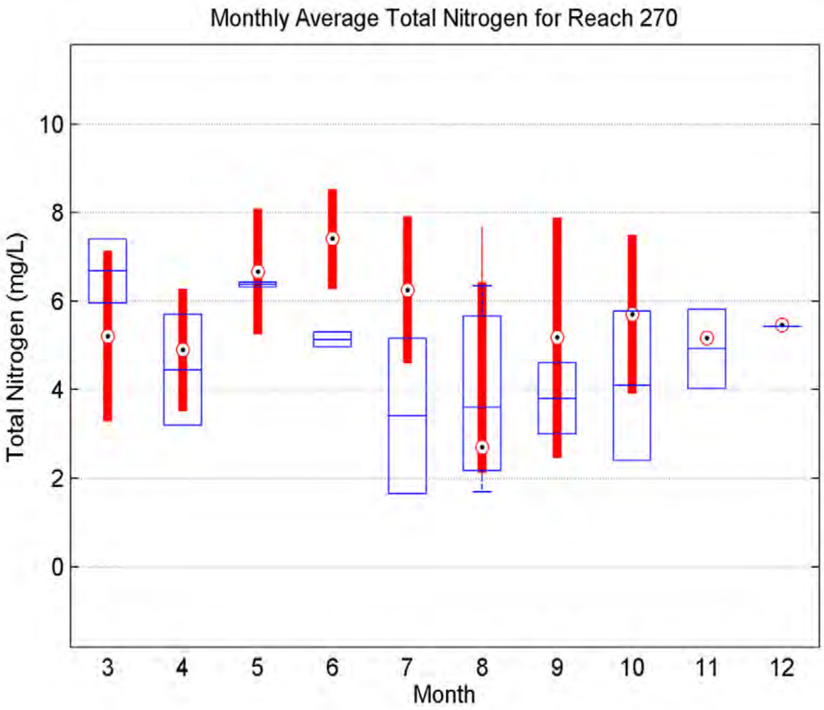

Figure E-20. Total Nitrogen Monthly Averages–Rock River (Reach 270).

RSI-2279-14-068

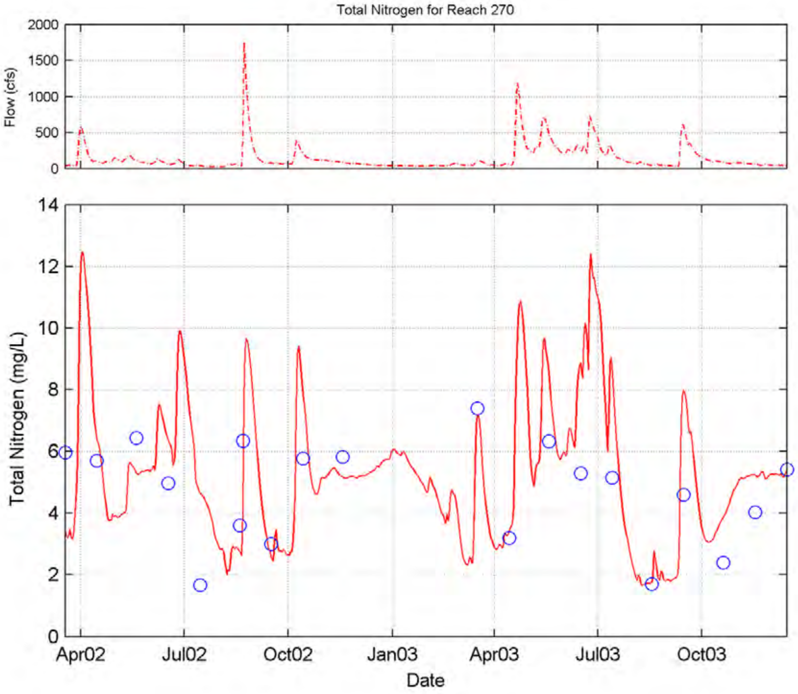

Figure E-21. Total Nitrogen Time Series–Rock River (Reach 270).

RSI-2279-14-069

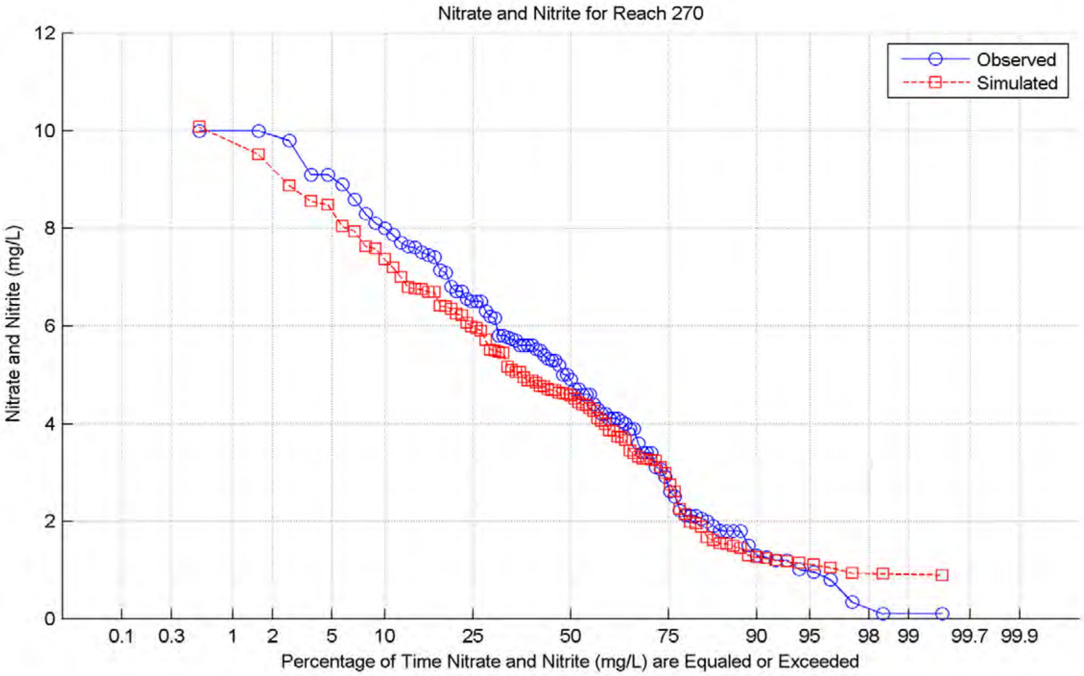

Figure E-22. Nitrate and Nitrite Duration Curve–Rock River (Reach 270).

RSI-2279-14-070

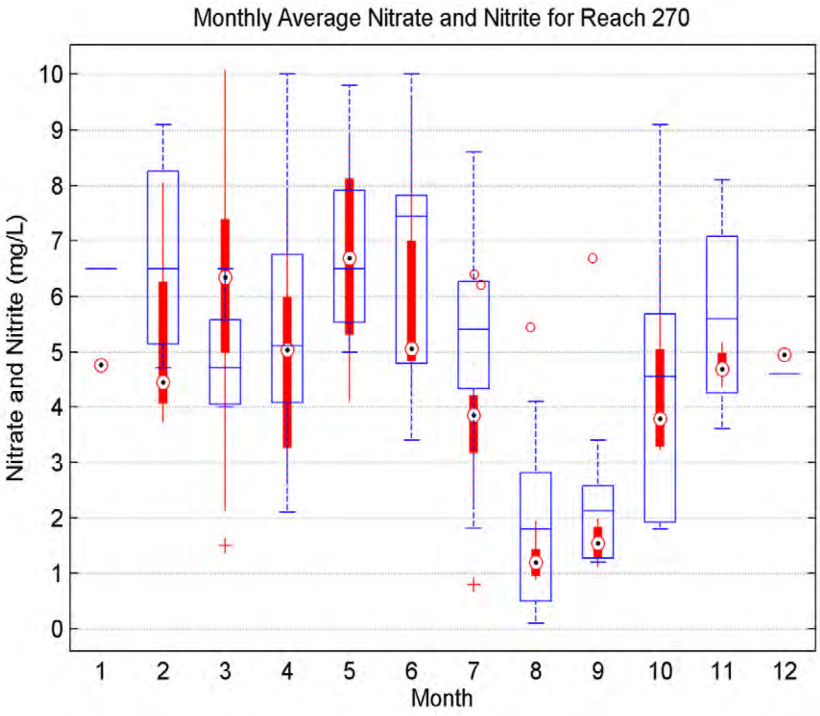

Figure E-23. Nitrate and Nitrite Monthly Averages–Rock River (Reach 270).

RSI-2279-14-071

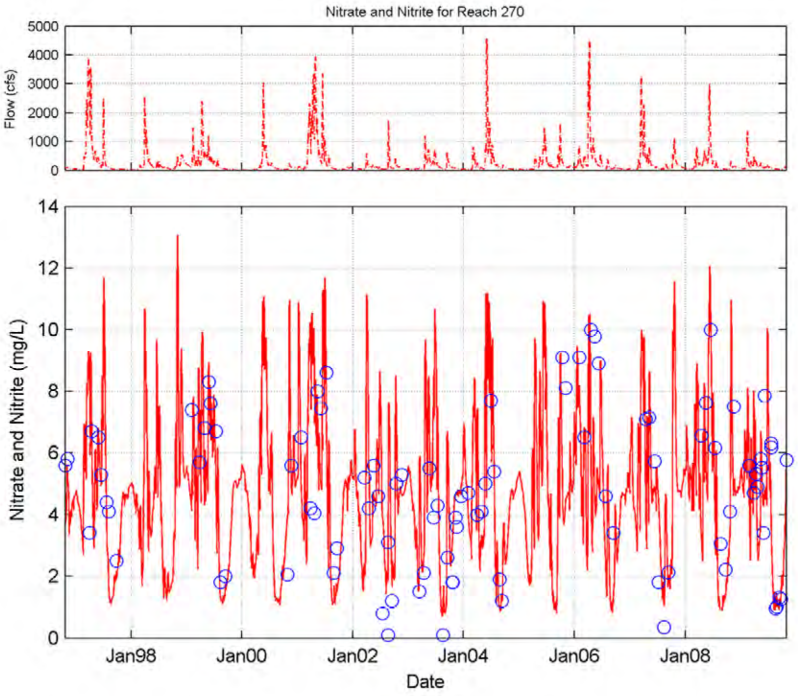

Figure E-24. Nitrate and Nitrite Time Series–Rock River (Reach 270).

RSI-2279-14-072

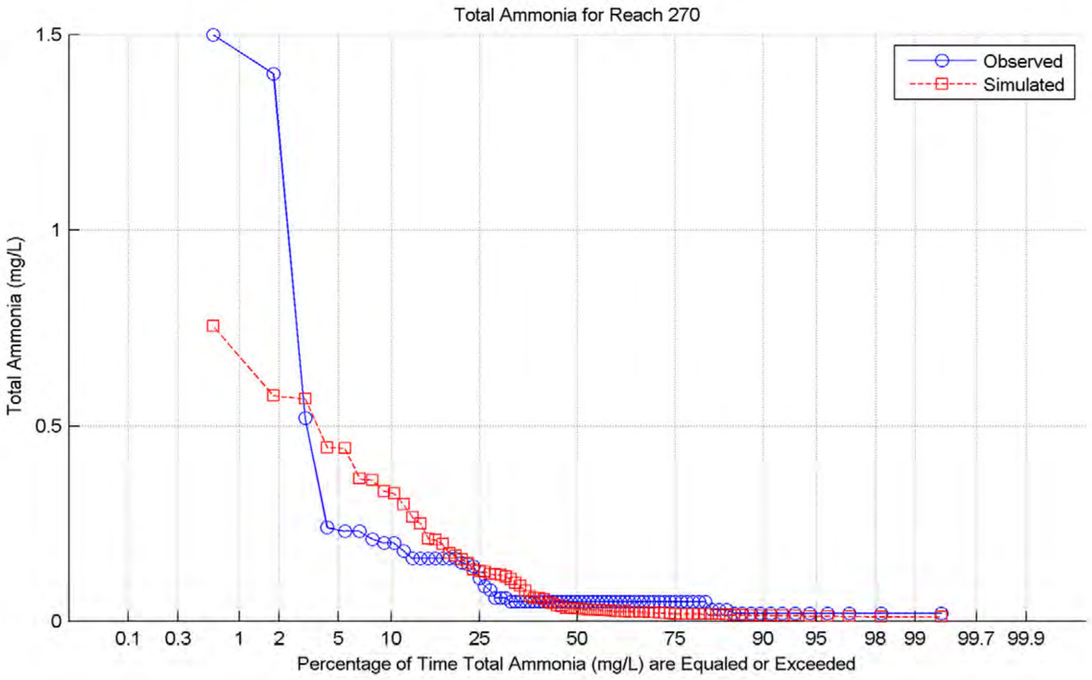

Figure E-25. Total Ammonia Duration Curve– Rock River (Reach 270).

RSI-2279-14-073

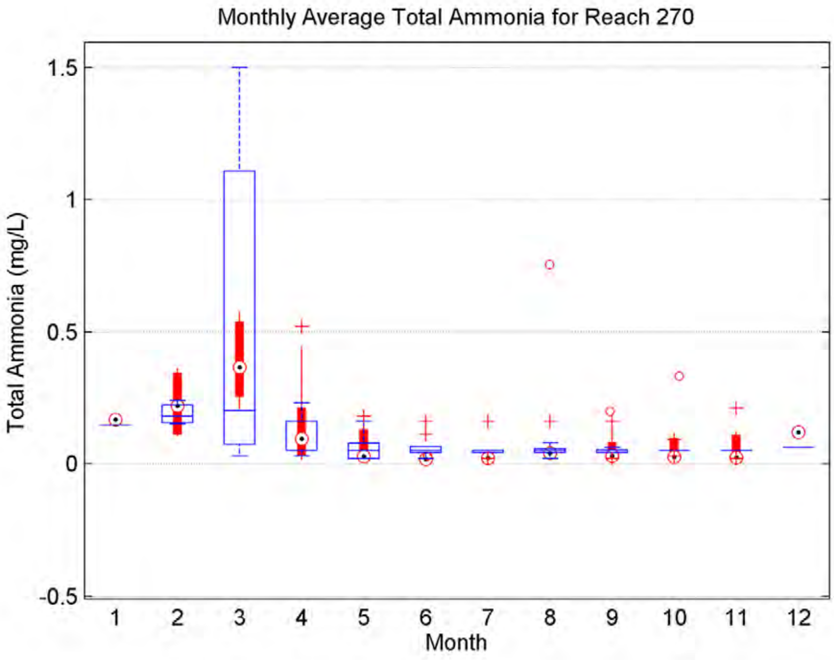

Figure E-26. Total Ammonia Monthly Averages–Rock River (Reach 270).

RSI-2279-14-074

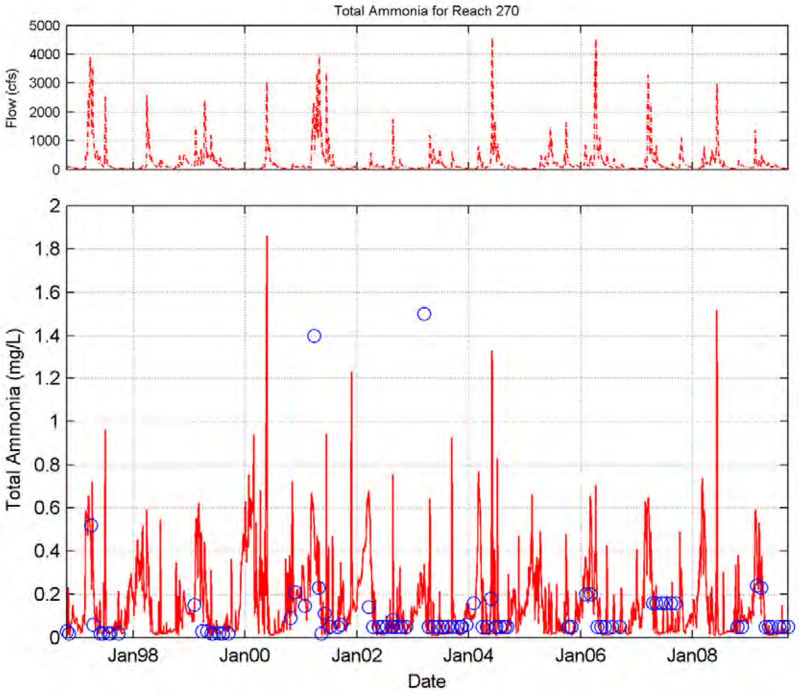

Figure E-27. Total Ammonia Time Series– Rock Rive r (Reach 270).

RSI-2279-14-076

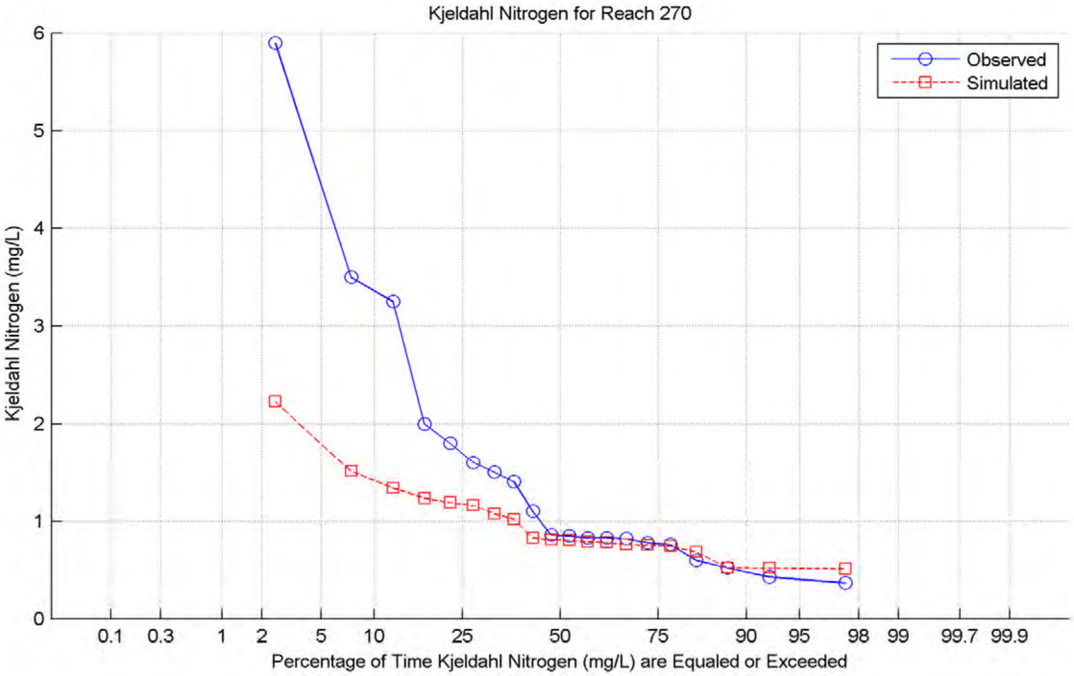

Figure E-28. Kjeldahl Nitrogen Duration Curve–Rock River (Reach 270).

RSI-2279-14-077

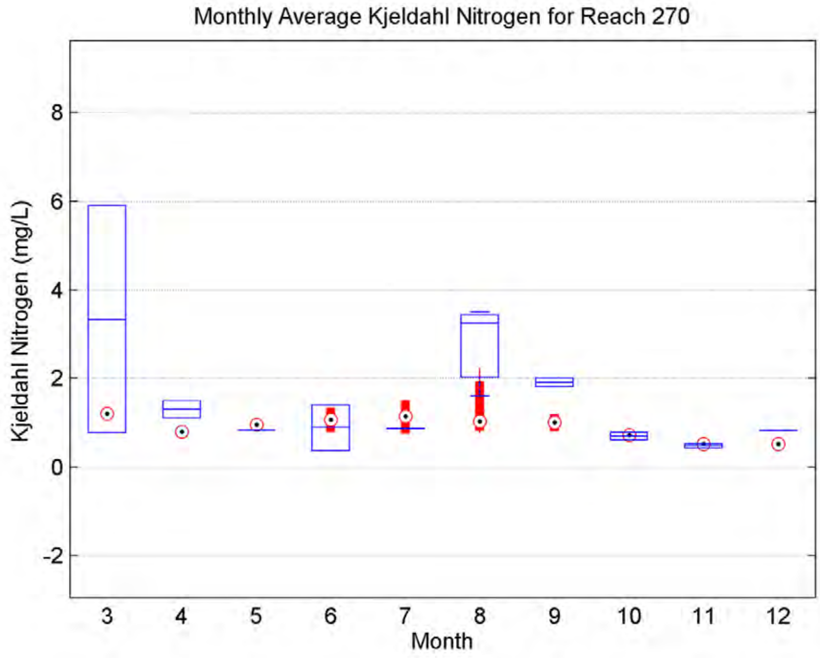

Figure E-29. Kjeldahl Nitrogen Monthly Averages–Rock River (Reach 270).

RSI-2279-14-078

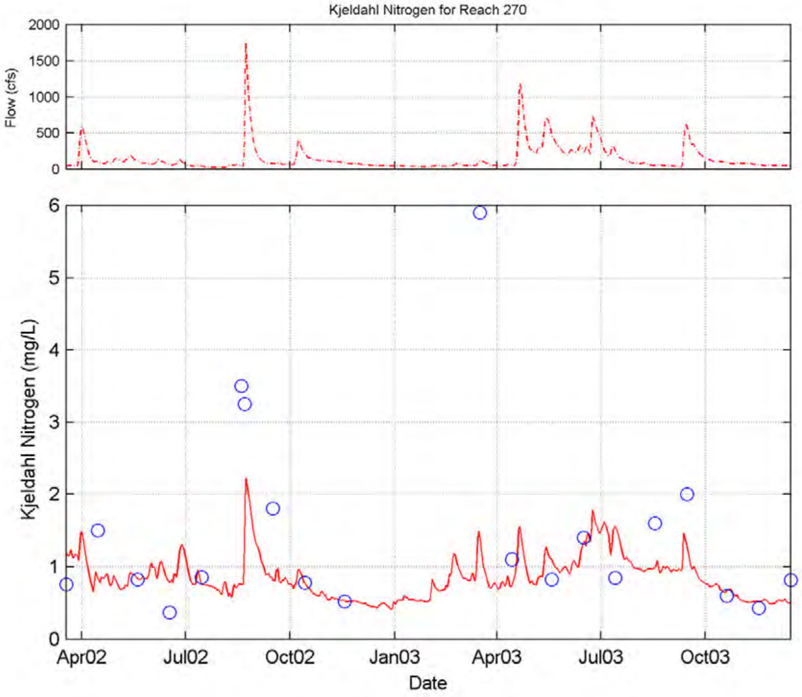

Figure E-30. Kjeldahl Nitrogen Time Series–Rock River (Reach 270).

RSI-2279-14-079

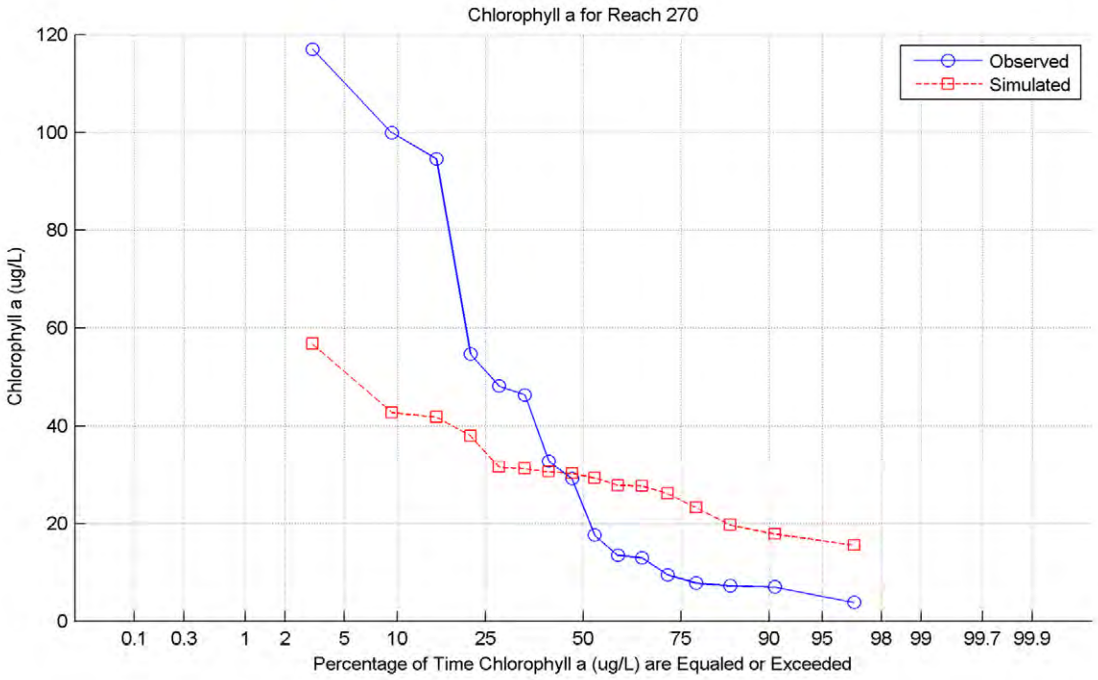

Figure E-31. Chlorophyll *a* Duration Curve–Rock River (Reach 270).

RSI-2279-14-080

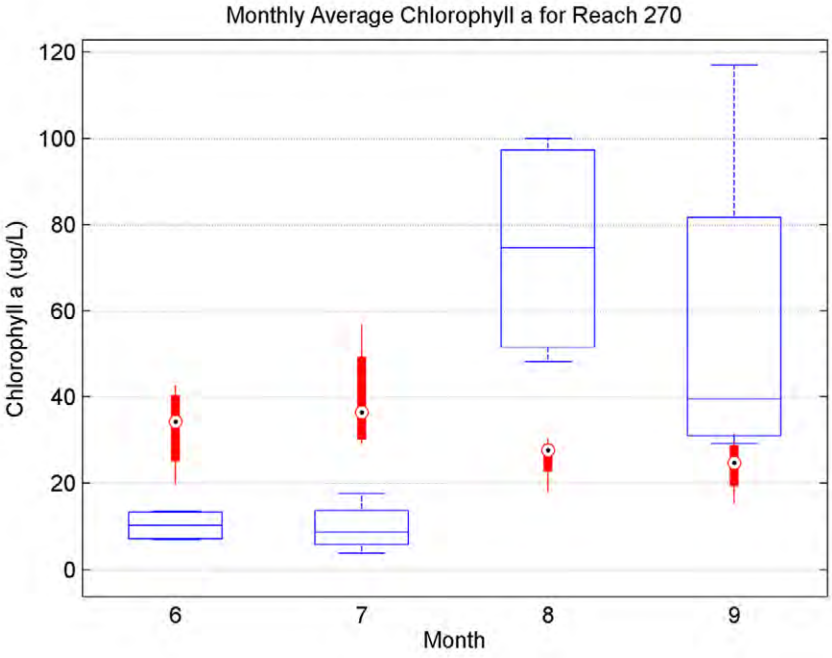

Figure E-32. Chlorophyll *a* Monthly Averages– Rock River (Reach 270).

RSI-2279-14-081

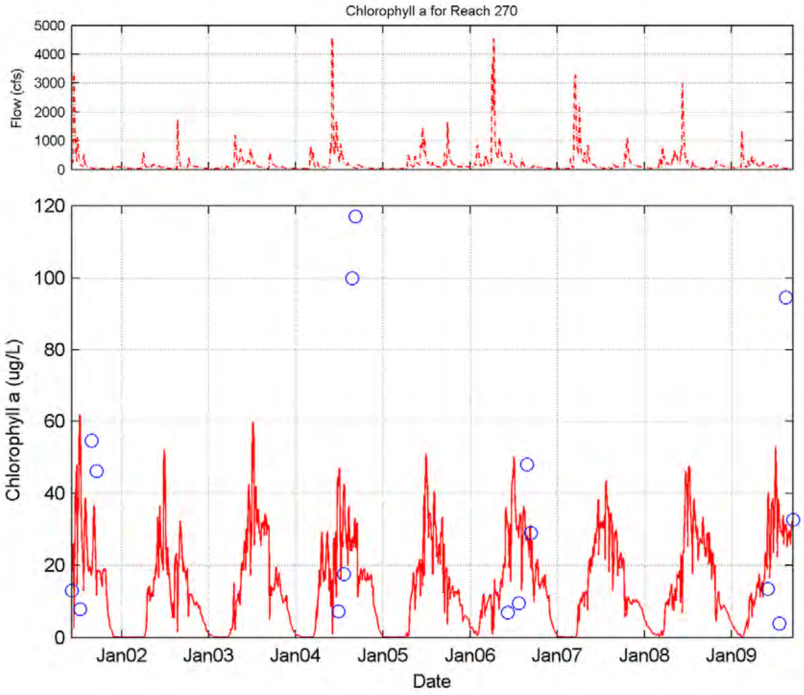

Figure E-33. Chlorophyll *a* Time Series–Rock River (Reach 270).

RSI-2279-14-082

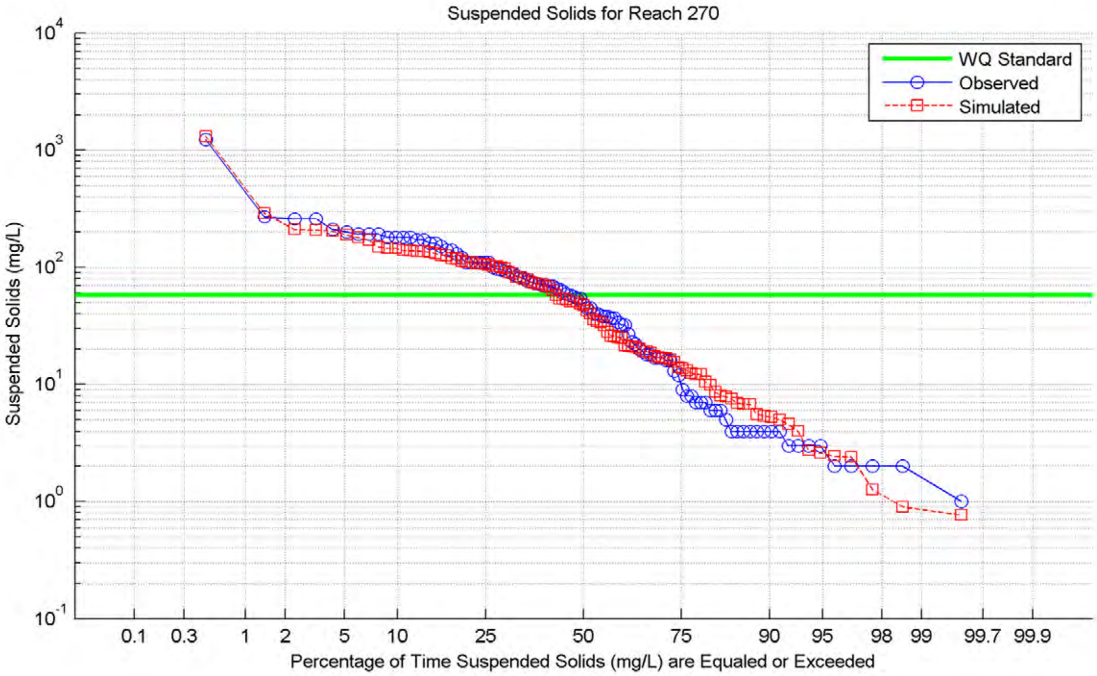

Figure E-34. Suspended Solids Duration Curve–Little Sioux (Reach 270).

RSI-2279-14-083

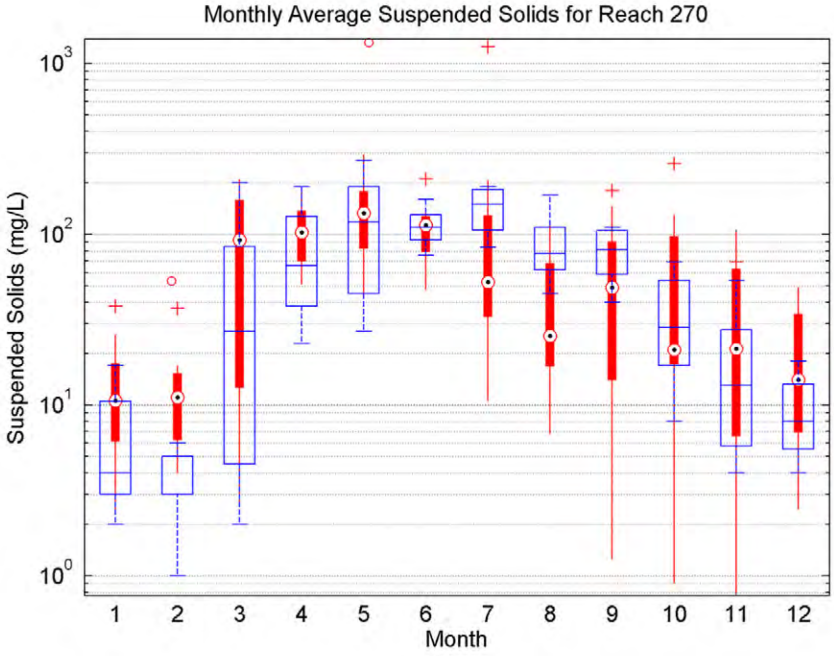

Figure E-35. Suspended Solids Monthly Averages–Little Sioux (Reach 270).

RSI-2279-14-084

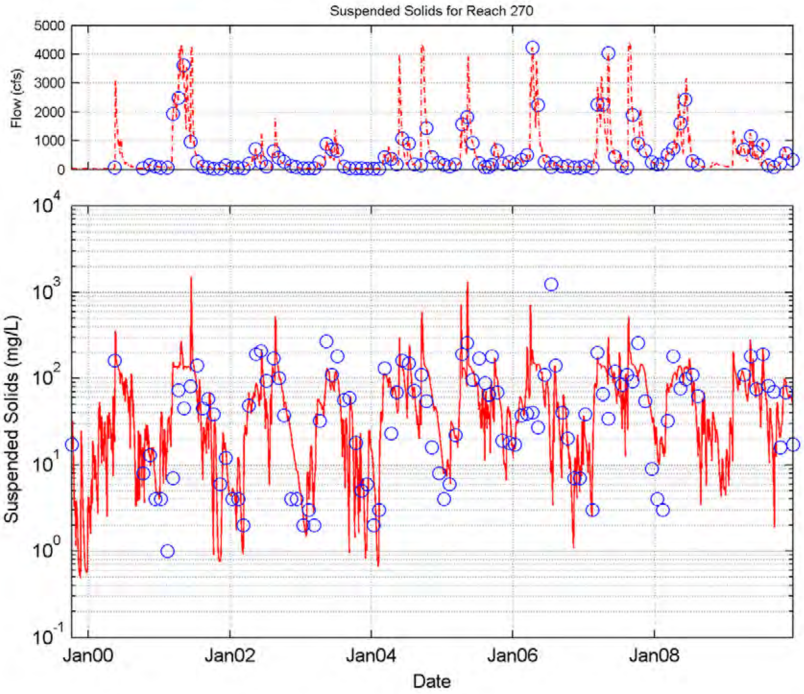

Figure E-36. Suspended Solids Daily Time Series–Little Sioux (Reach 270).

RSI-2279-14-085

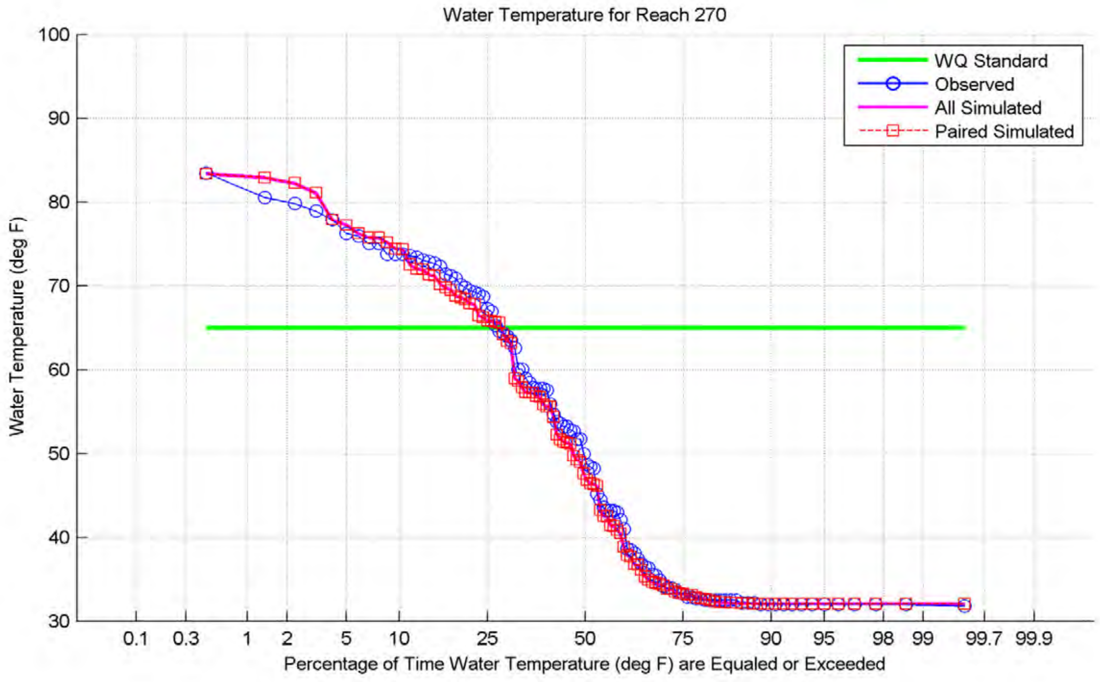

Figure E-37. Water Temperature Duration Curve–Little Sioux (Reach 270).

RSI-2279-14-086

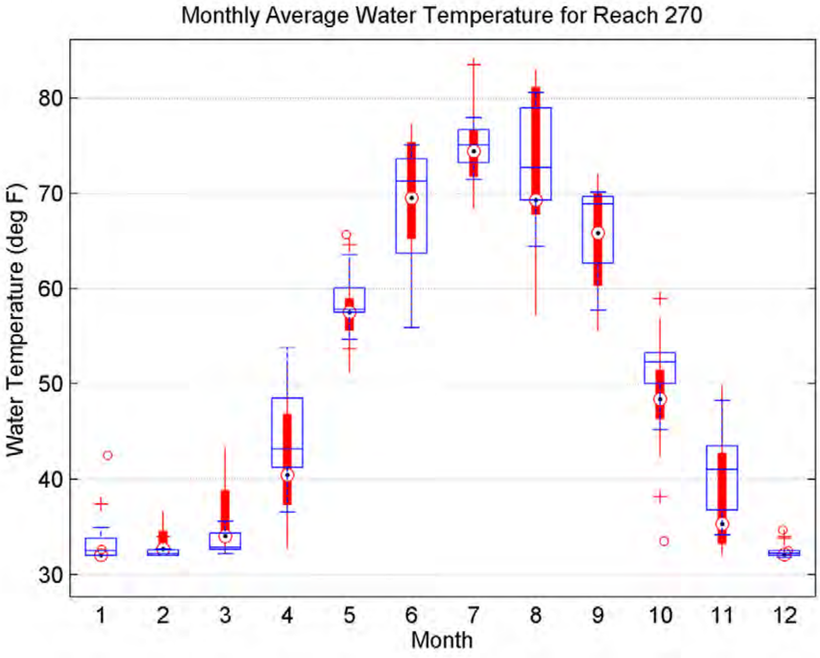

Figure E-38. Water Temperature Monthly Averages–Little Sioux (Reach 270).

RSI-2279-14-087

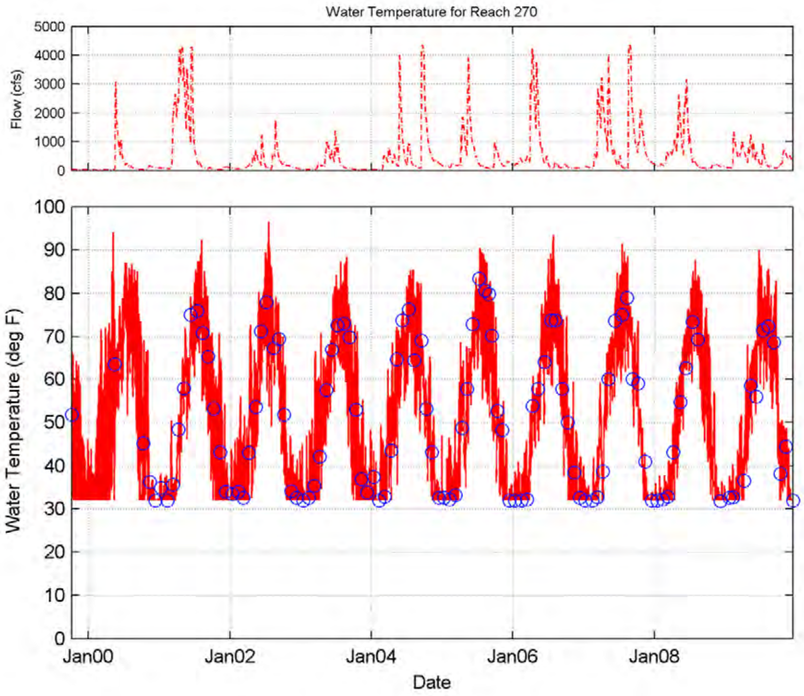

Figure E-39. Water Temperature Daily Time Series–Little Sioux (Reach 270).

RSI-2279-14-088

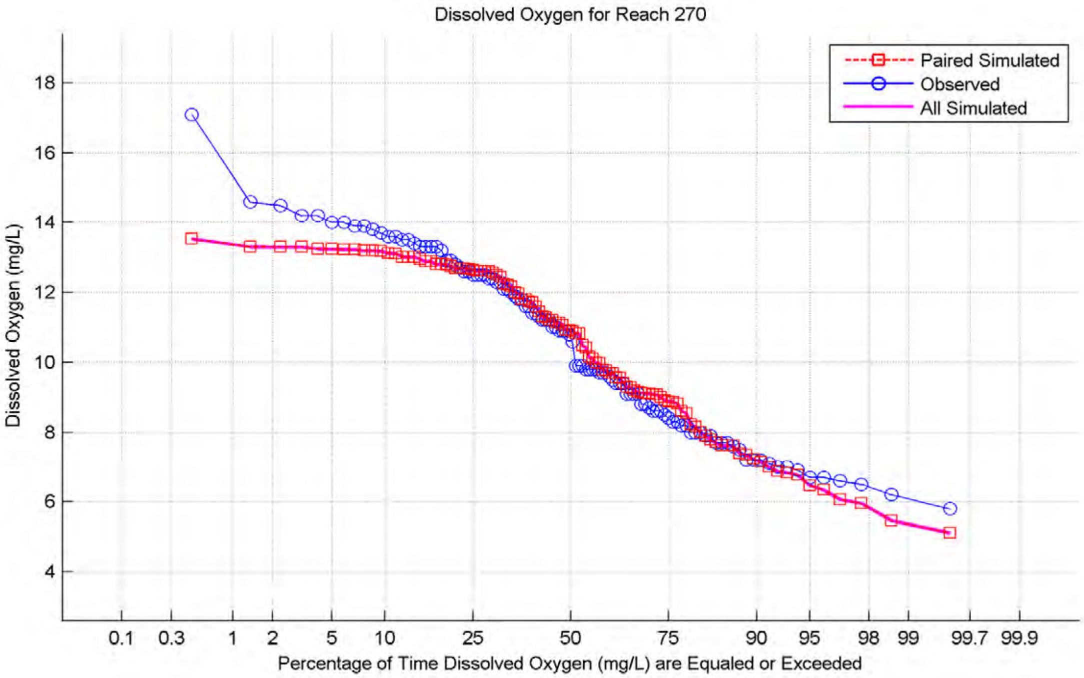

Figure E-40. Dissolved Oxygen Duration Curve– Little Sioux (Reach 270).

RSI-2279-14-089

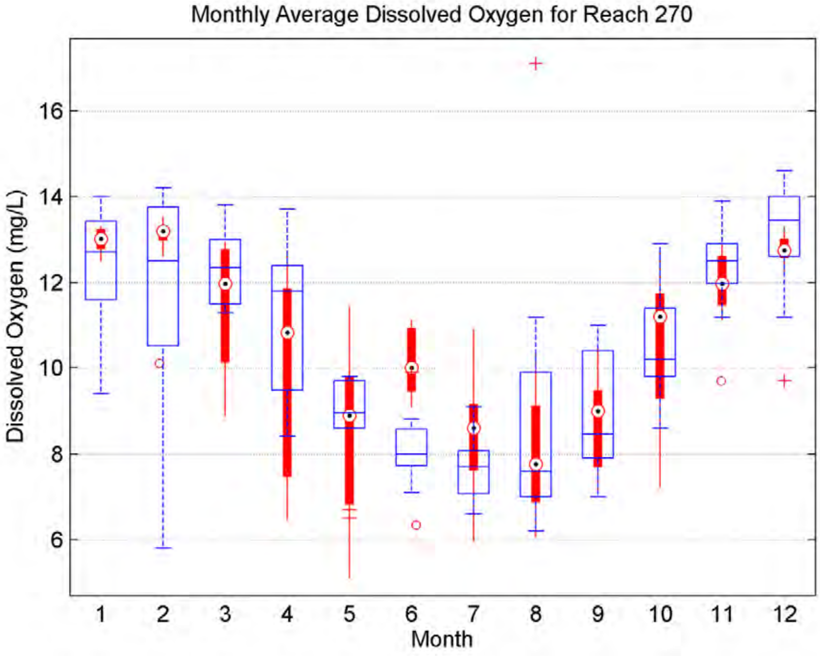

Figure E-41. Dissolved Oxygen Monthly Averages–Little Sioux (Reach 270).

RSI-2279-14-090

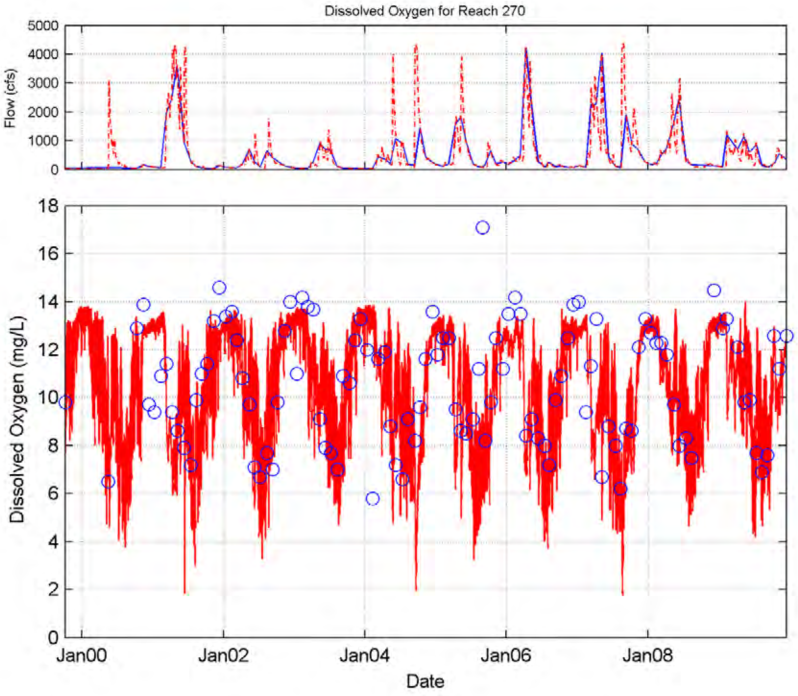

Figure E-42. Dissolved Oxygen Daily Time Series–Little Sioux (Reach 270).

RSI-2279-14-091

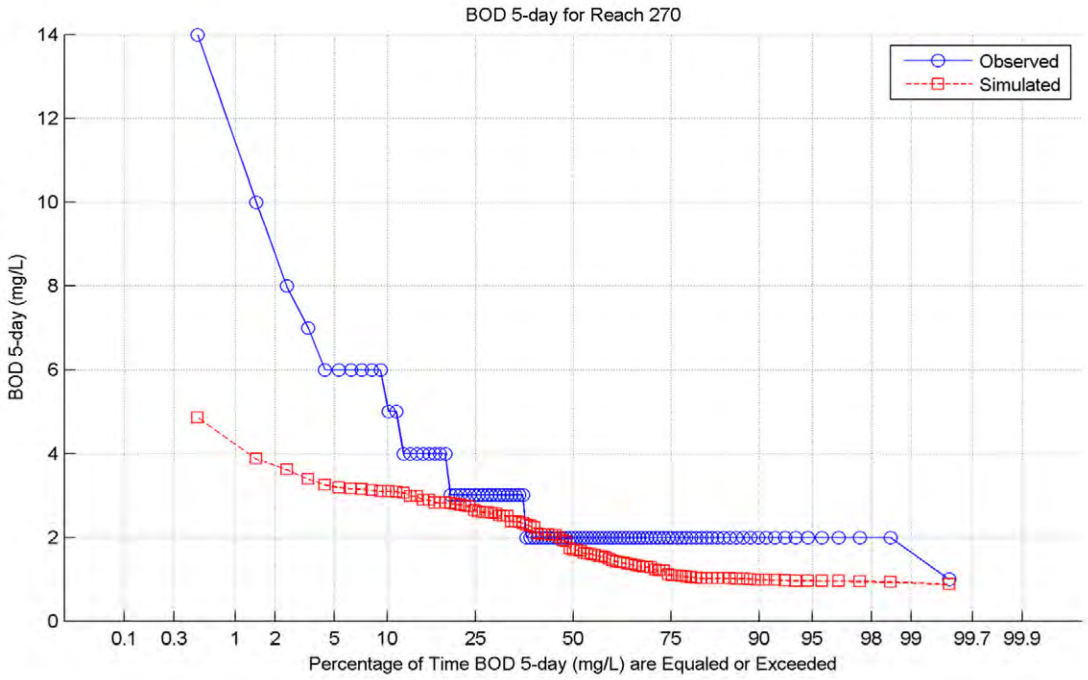

Figure E-43. Biological Oxygen Demand Duration Curve– Little Sioux (Reach 270).

RSI-2279-14-092

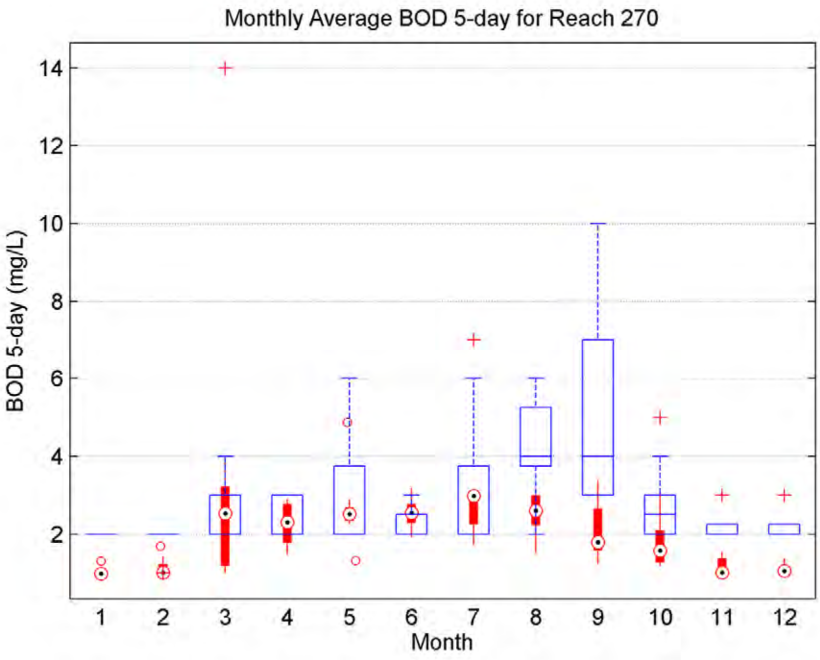

Figure E-44. Biological Oxygen Demand Monthly Averages–Little Sioux (Reach 270).

RSI-2279-14-093

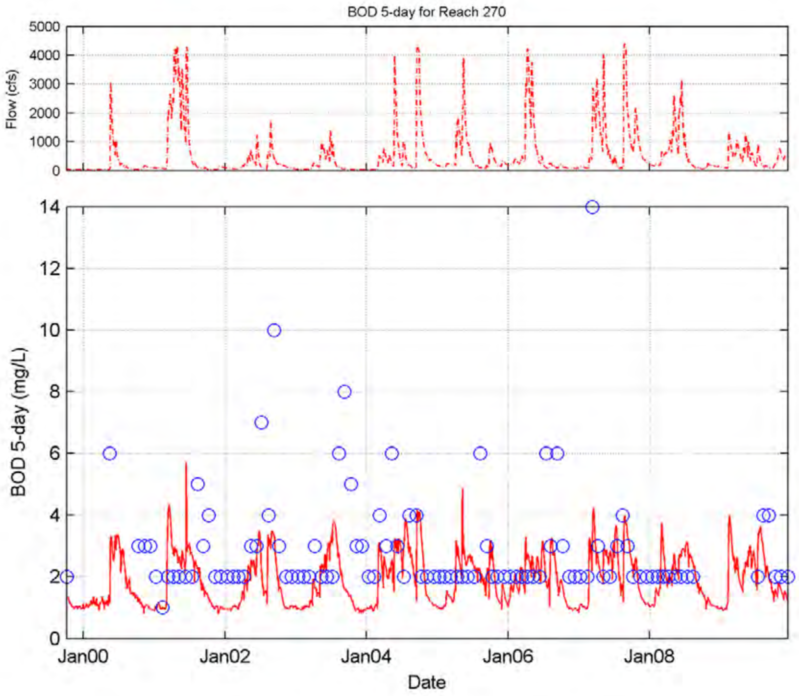

Figure E-45. Biological Oxygen Demand Time Series–Little Sioux (Reach 270).

RSI-2279-14-094

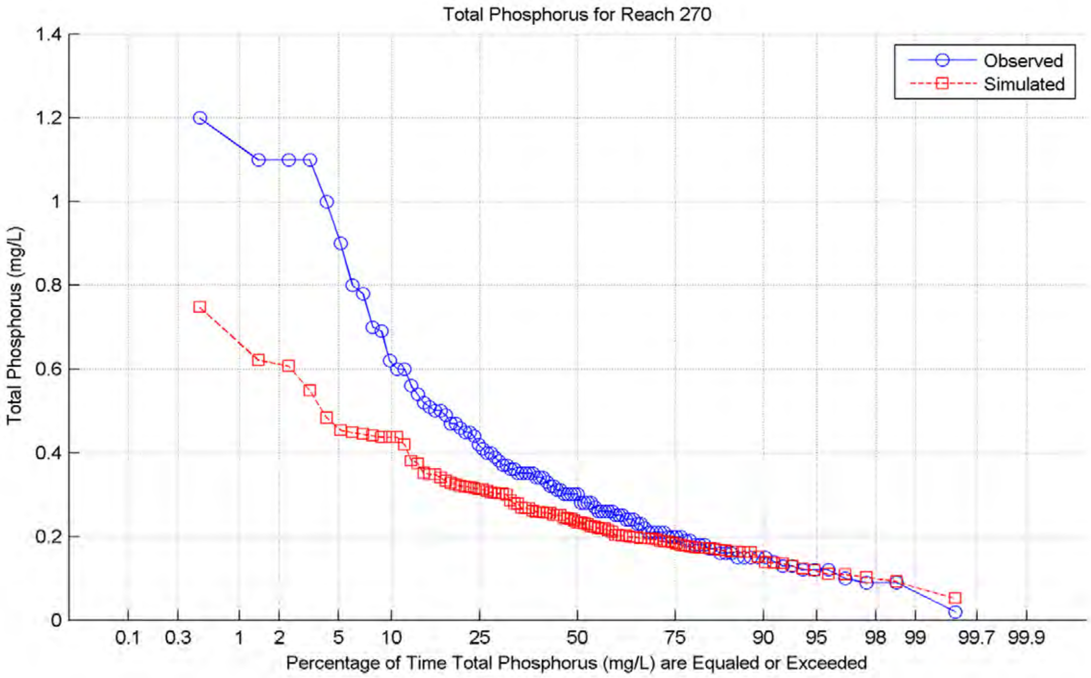

Figure E-46. Total Phosphorus Duration Curve–Little Sioux (Reach 270).

RSI-2279-14-095

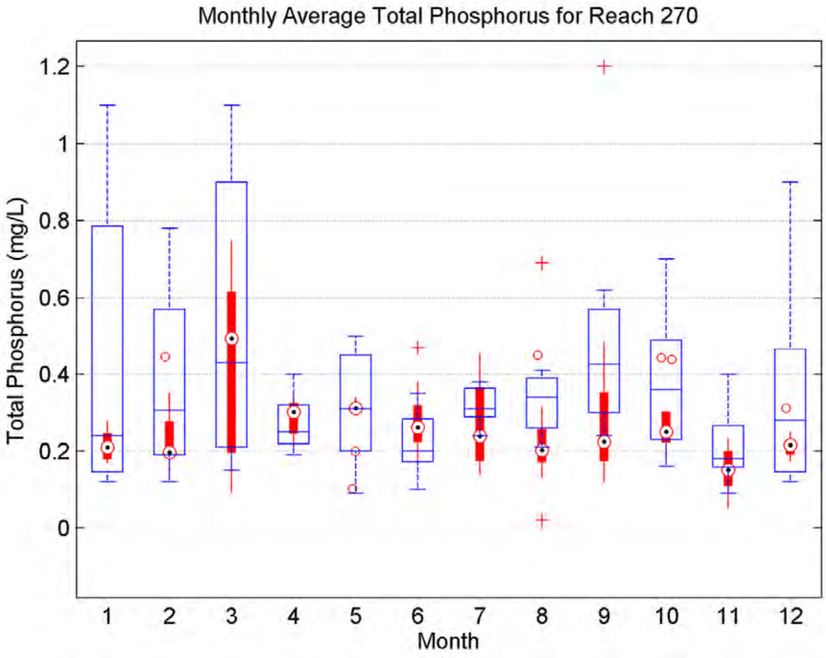

Figure E-47. Total Phosphorus Monthly Averages– Little Sioux (Reach 270).

RSI-2279-14-096

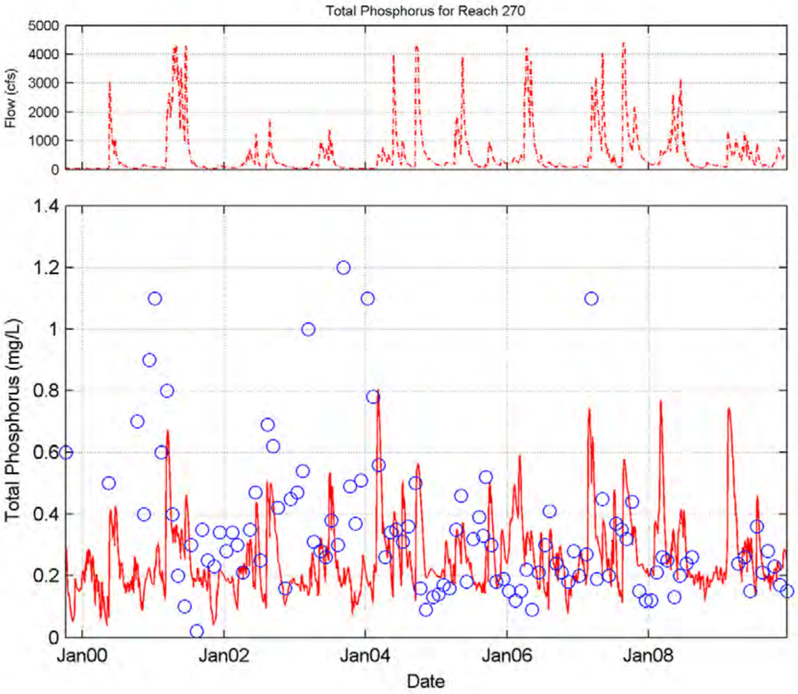

Figure E-48. Total Phosphorus Time Series–Little Sioux (Reach 270).

RSI-2279-14-097

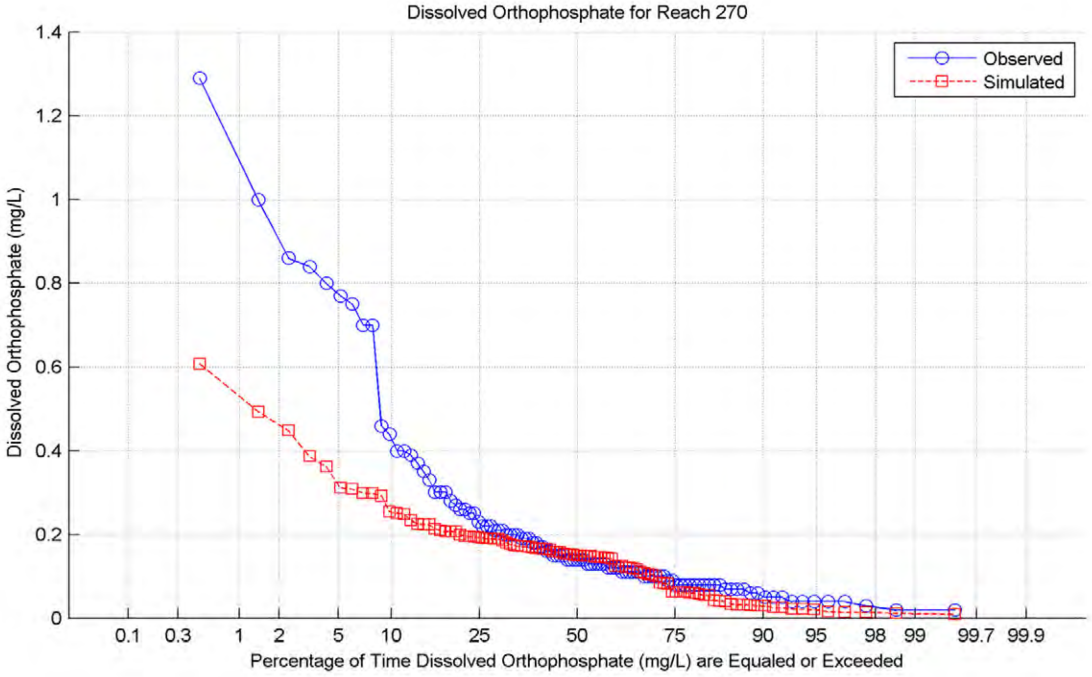

Figure E-49. Orthophosphate Duration Curve–Little Sioux (Reach 270).

RSI-2279-14-098

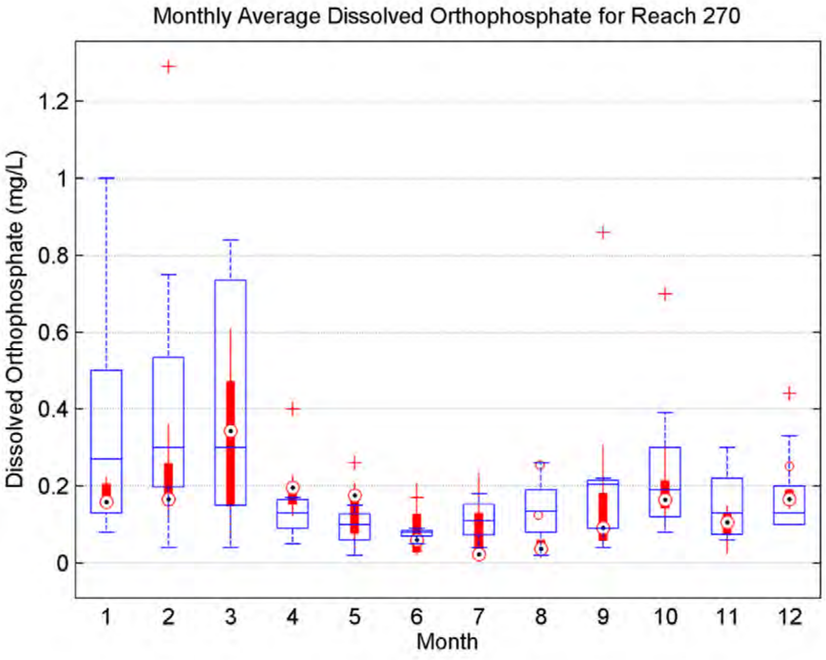

Figure E-50. Orthophosphate Monthly Averages–Little Sioux (Reach 270).

RSI-2279-14-099

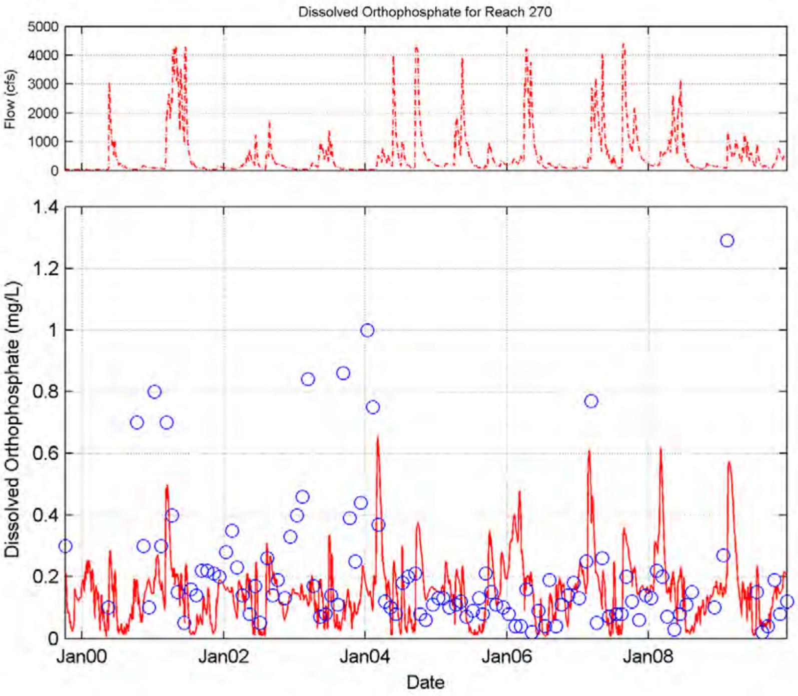

Figure E-51. Orthophosphate Time Series–Little Sioux (Reach 270).

RSI-2279-14-100

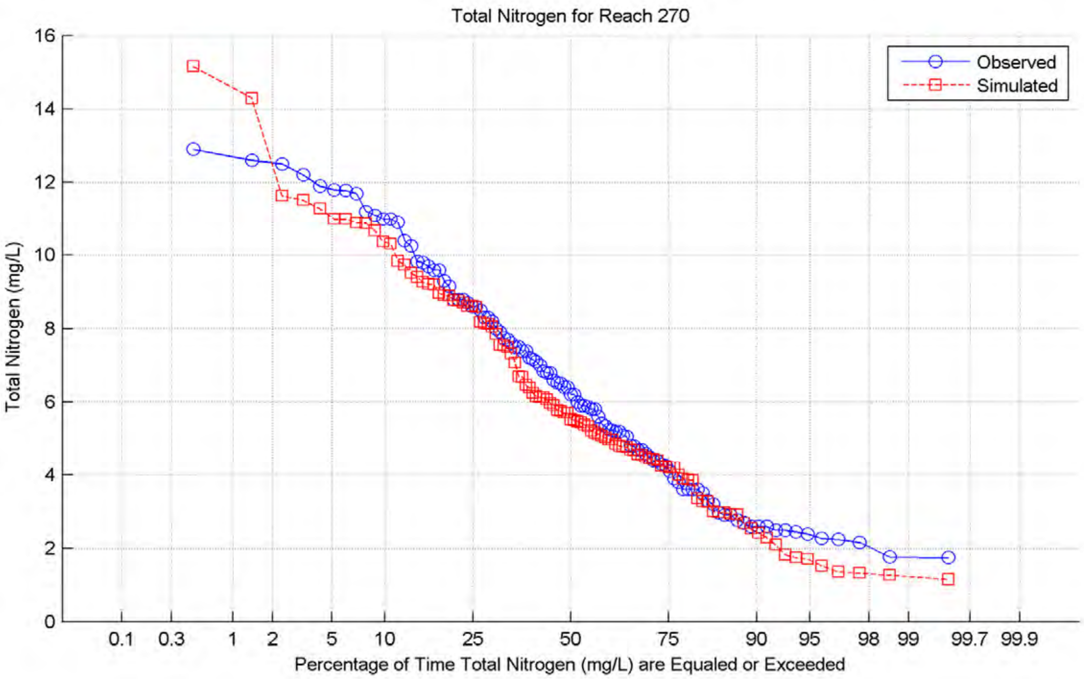

Figure E-52. Total Nitrogen Duration Curve–Little Sioux (Reach 270).

RSI-2279-14-101

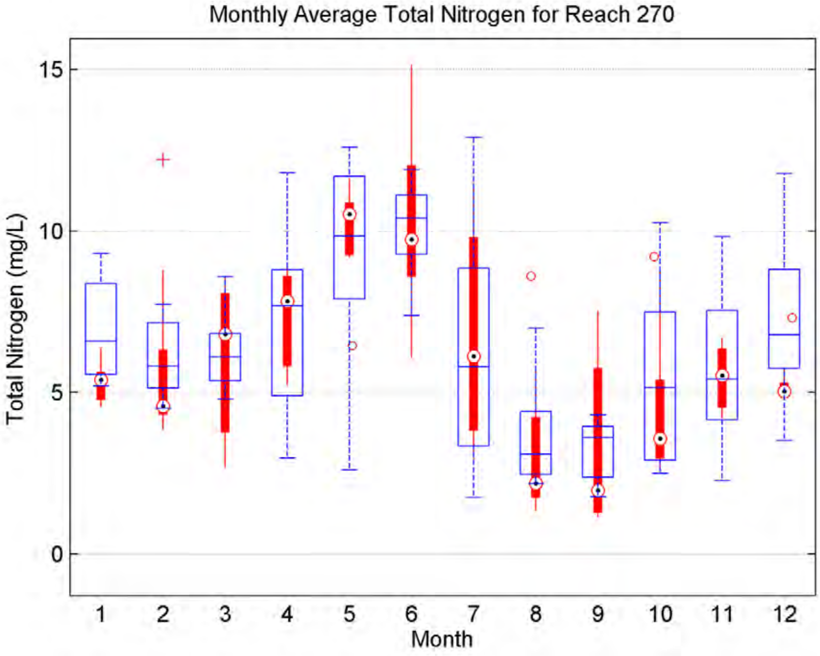

Figure E-53. Total Nitrogen Monthly Averages–Little Sioux (Reach 270).

RSI-2279-14-102

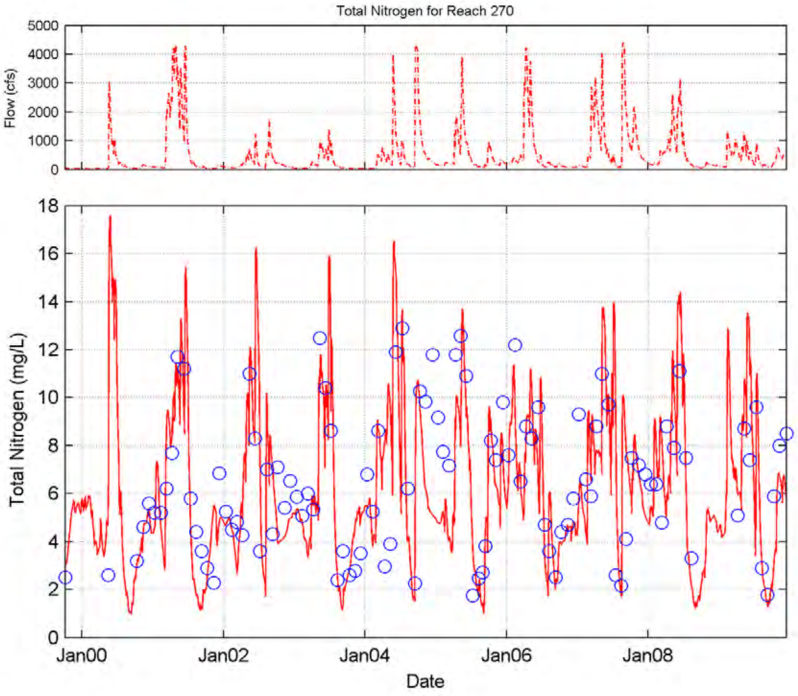

Figure E-54. Total Nitrogen Time Series–Little Sioux (Reach 270).

RSI-2279-14-103

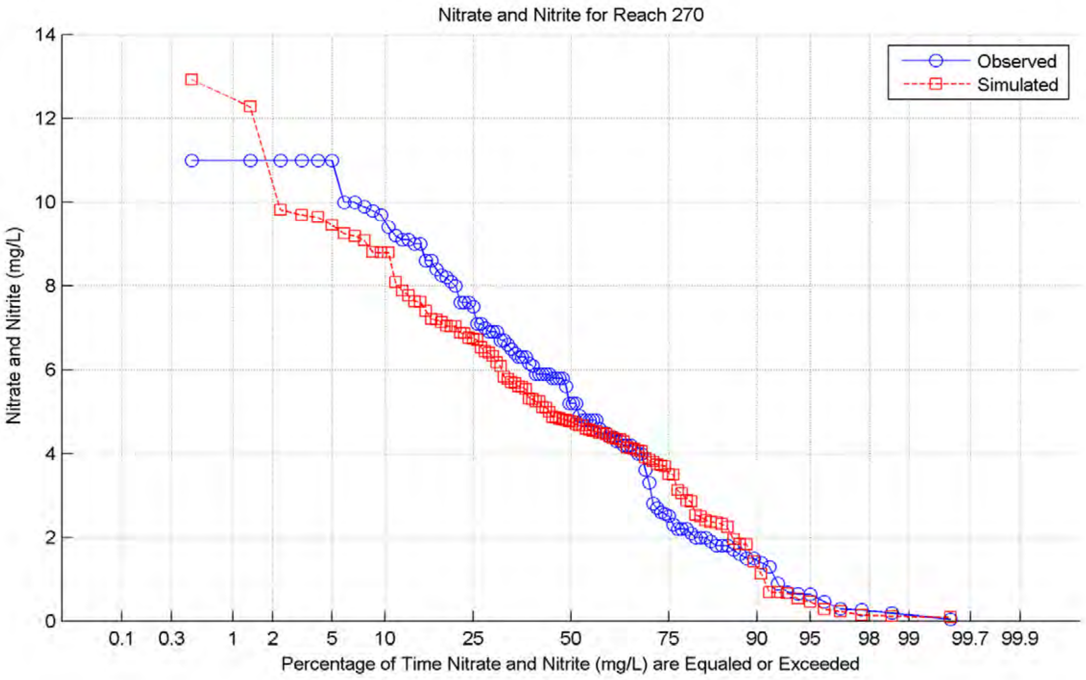

Figure E-55. Nitrate and Nitrite Duration Curve–Little Sioux (Reach 270).

RSI-2279-14-104

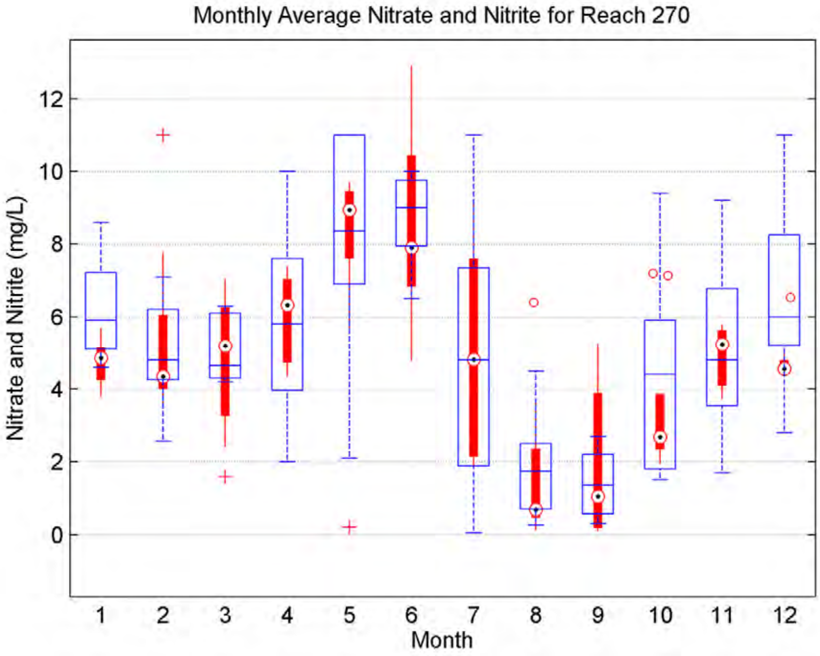

Figure E-56. Nitrate and Nitrite Monthly Averages– Little Sioux (Reach 270).

RSI-2279-14-105

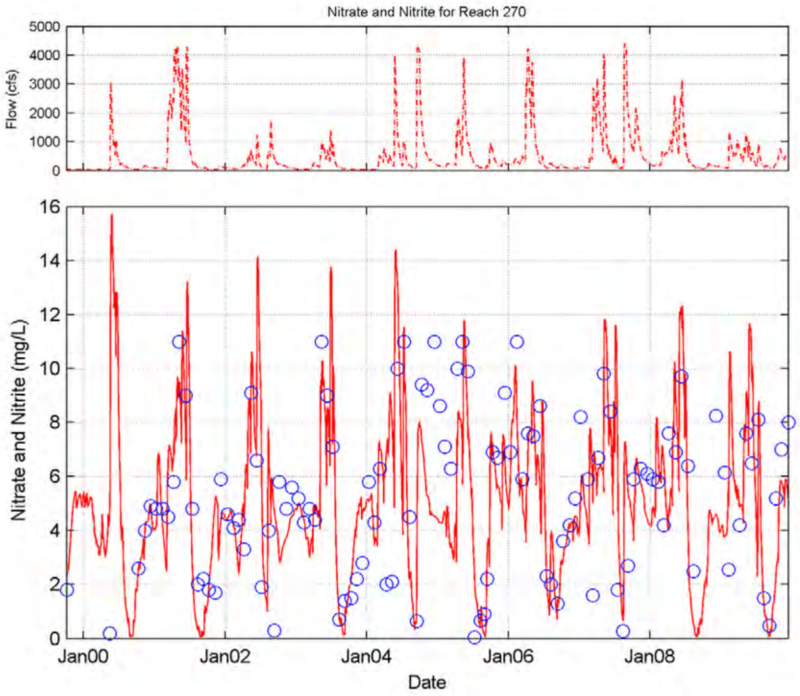

Figure E-57. Nitrate and Nitrite Time Series–Little Sioux (Reach 270).

RSI-2279-14-106

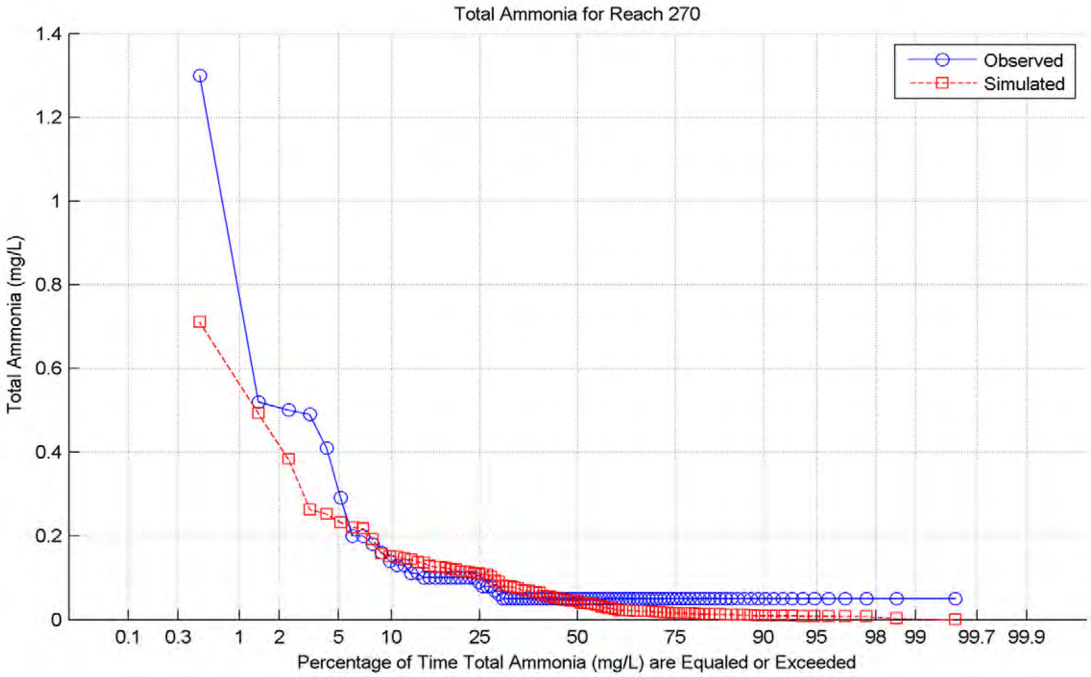

Figure E-58. Total Ammonia Duration Curve–Little Sioux (Reach 270).

RSI-2279-14-107

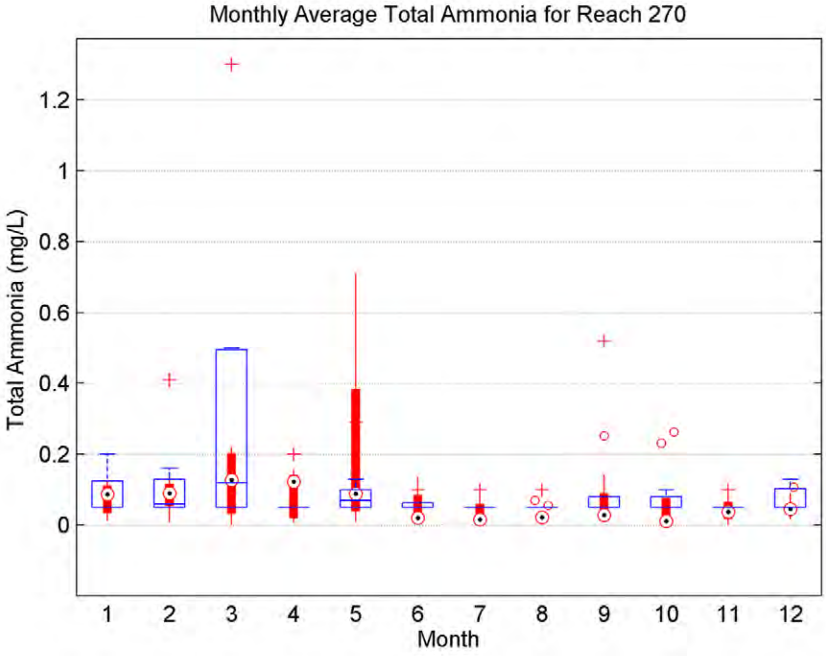

Figure E-59. Total Ammonia Monthly Averages–Little Sioux (Reach 270).

RSI-2279-14-108

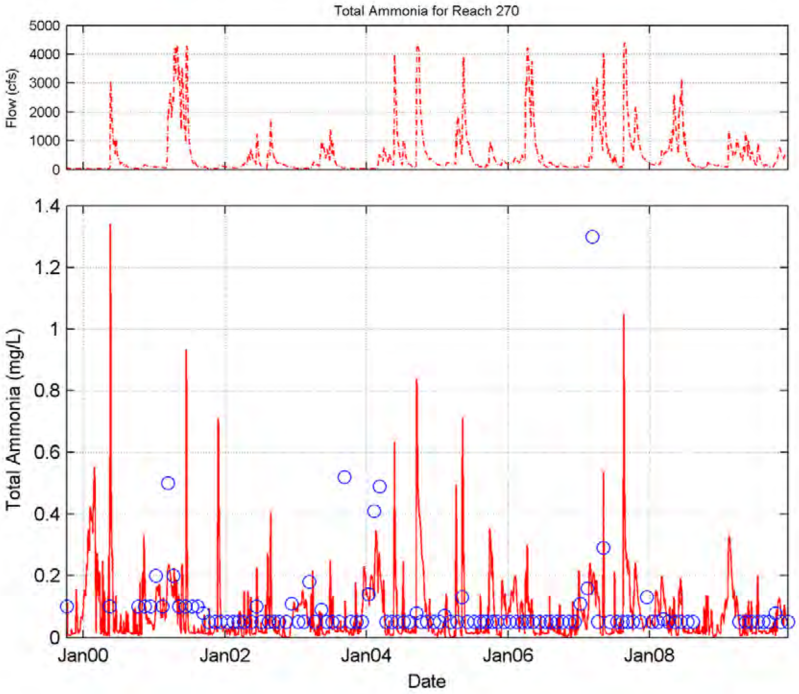

Figure E-60. Total Ammonia Time Series–Little Sioux (Reach 270).

RSI-2279-14-109

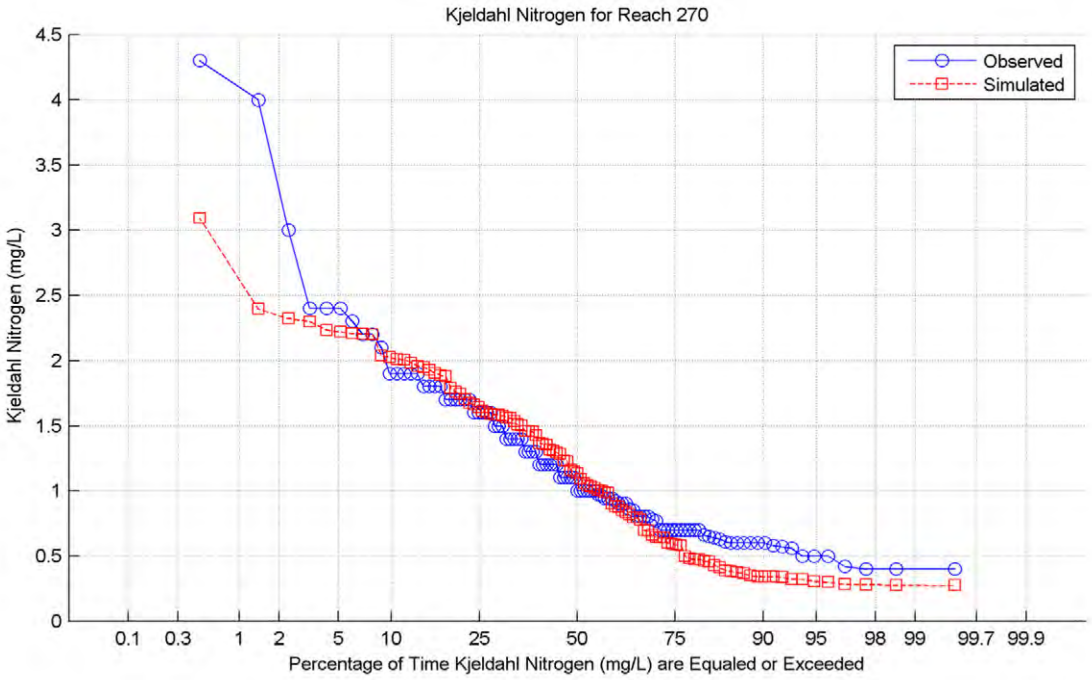

Figure E-61. Kjeldahl Nitrogen Duration Curve– Little Sioux (Reach 270).

RSI-2279-14-110

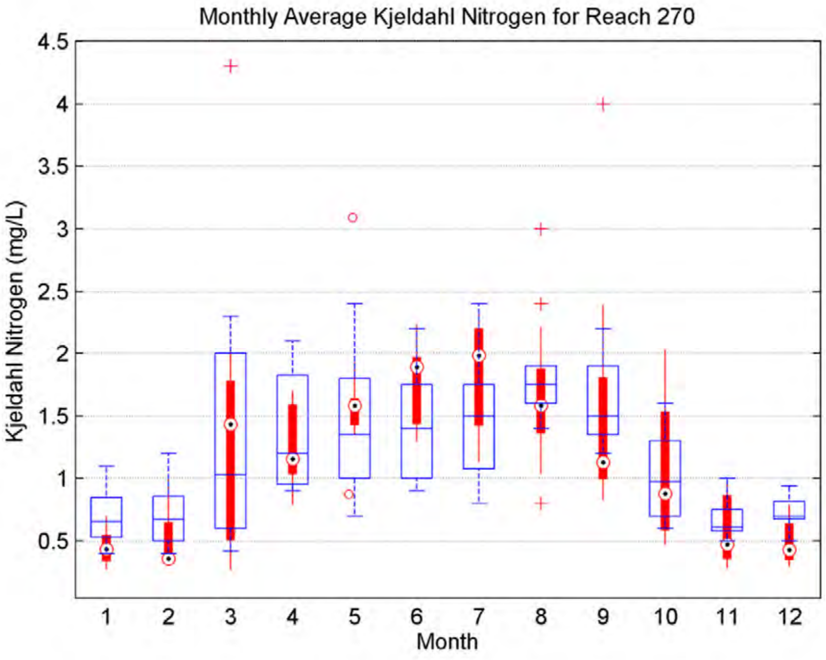

Figure E-62. Kjeldahl Nitrogen Monthly Averages– Little Sioux (Reach 270).

RSI-2279-14-111

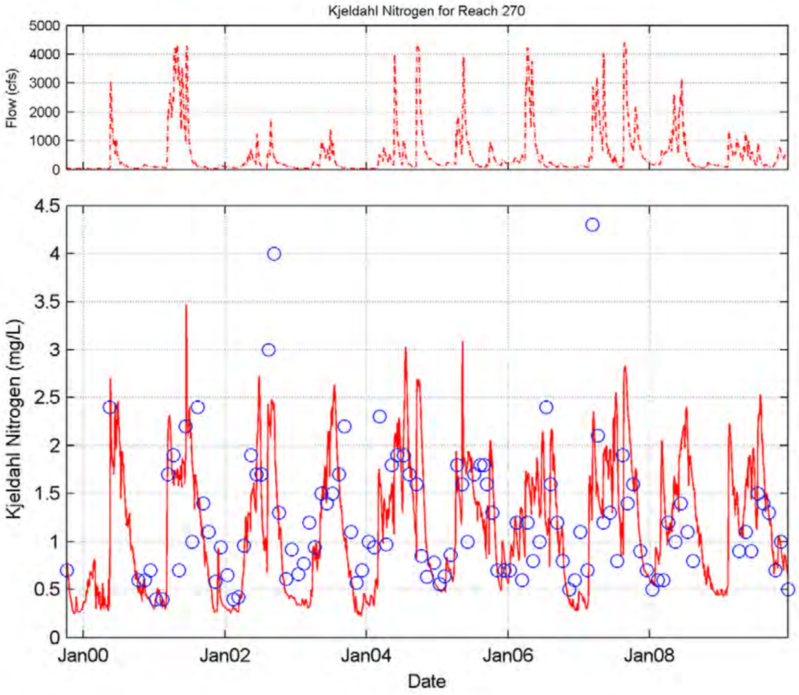

Figure E-63. Kjeldahl Nitrogen Time Series–Little Sioux (Reach 270).

RSI-2279-14-112

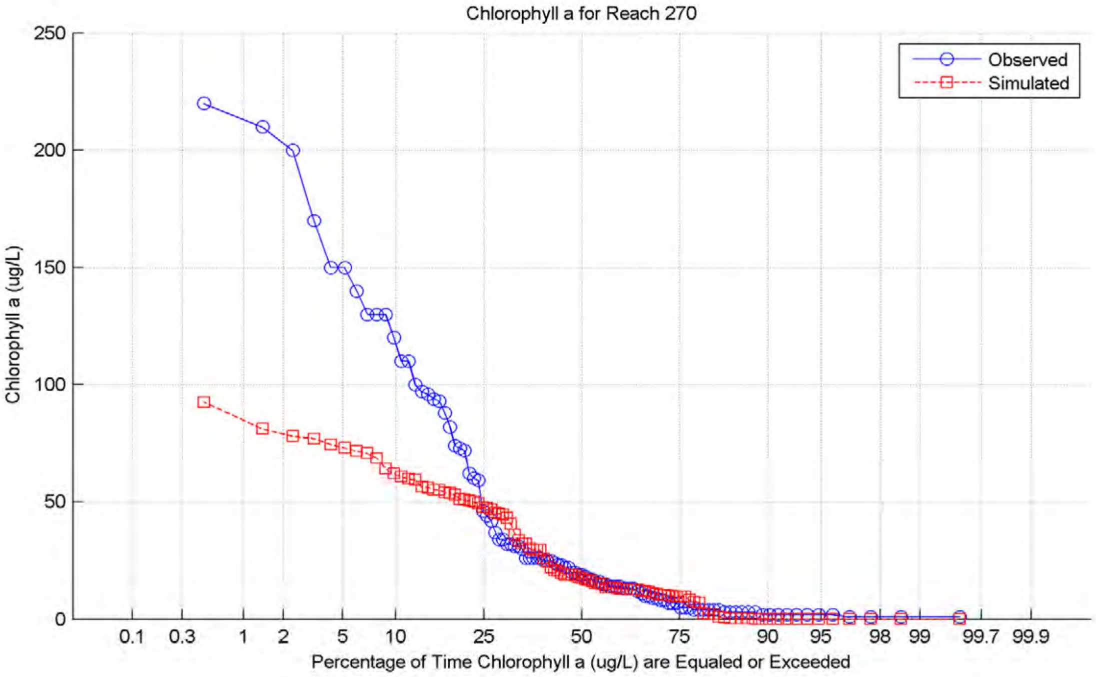

Figure E-64. Chlorophyll *a* Duration Curve–Little Sioux (Reach 270).

RSI-2279-14-113

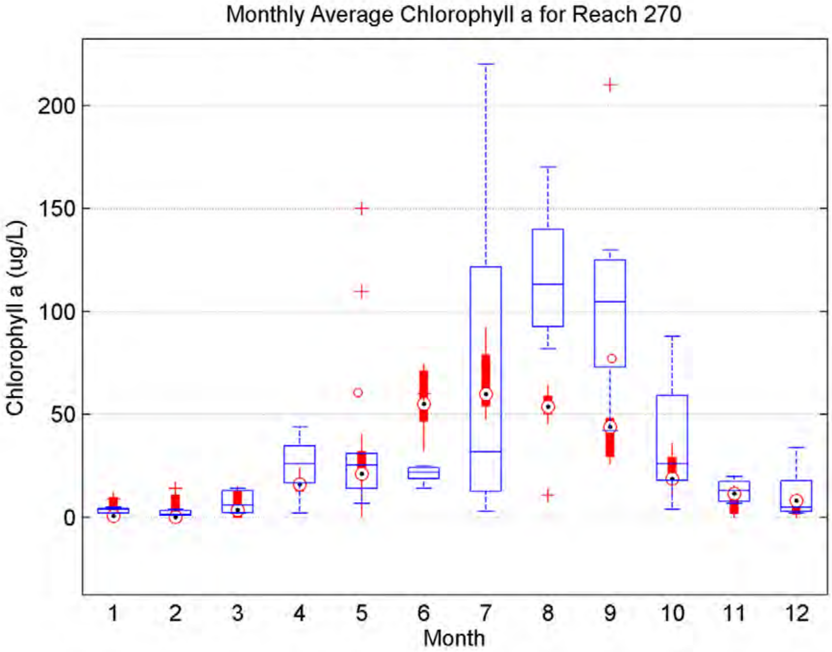

Figure E-65. Chlorophyll *a* Monthly Averages– Little Sioux (Reach 270).

RSI-2279-14-114

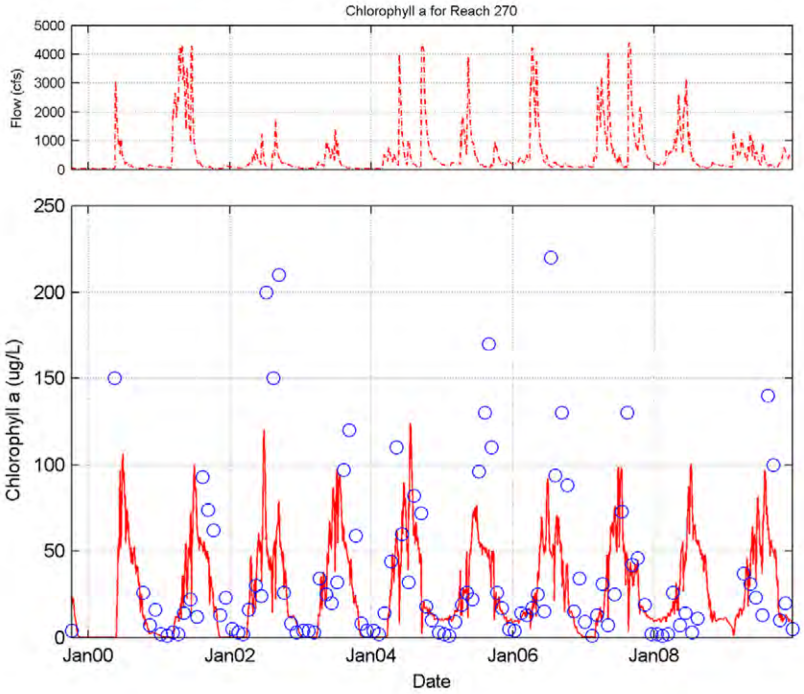

Figure E-66. Chlorophyll *a* Time Series–Little Sioux (Reach 270).

RSI-2279-14-115

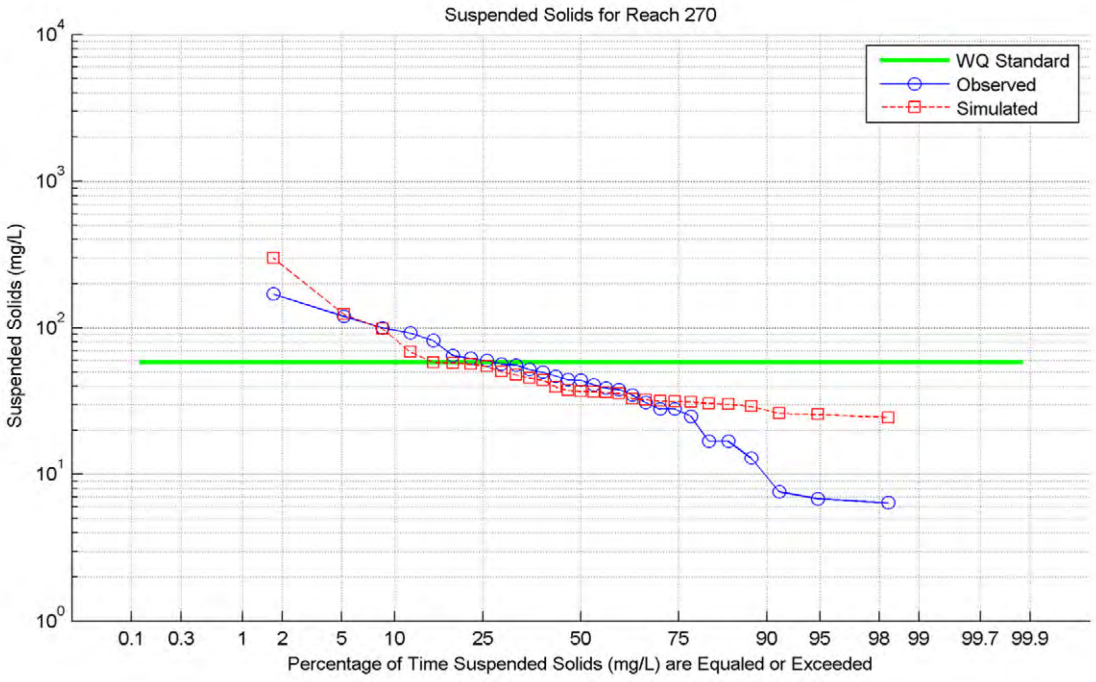

Figure E-67. Suspended Solids Duration Curve–Big Sioux (Reach 270).

RSI-2279-14-116

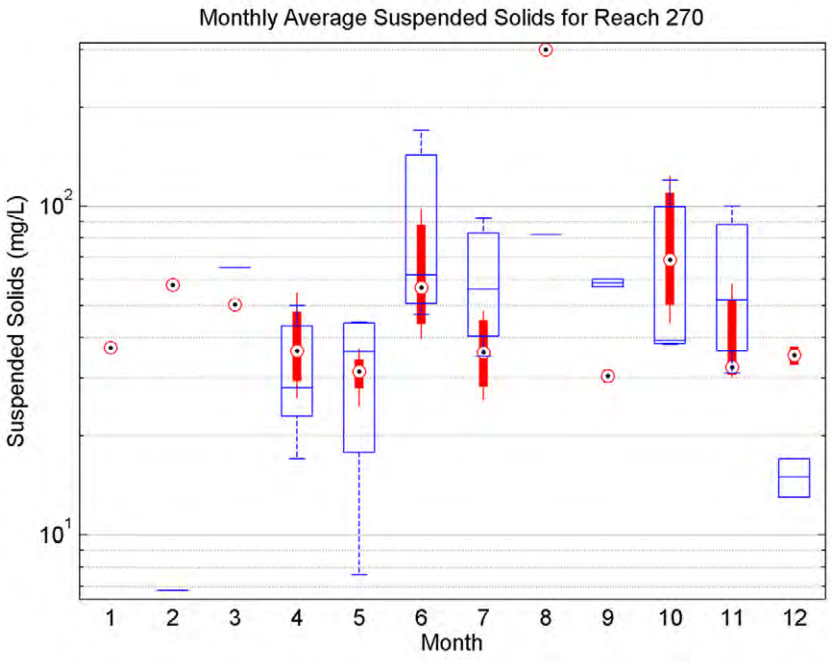

Figure E-68. Suspended Solids Monthly Averages– Big Sioux (Reach 270).

RSI-2279-14-117

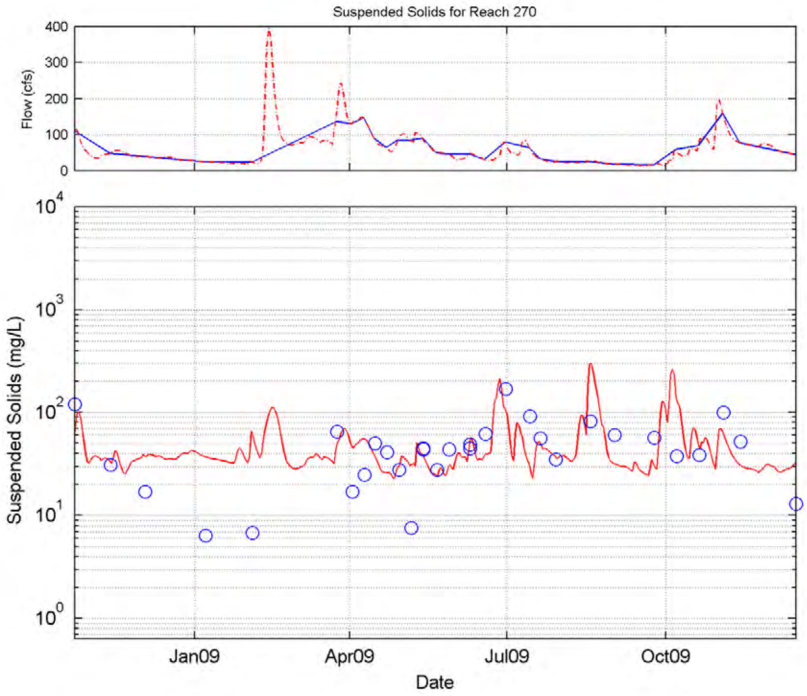

Figure E-69. Suspended Solids Daily Time Series– Big Sioux (Reach 270).

RSI-2279-14-118

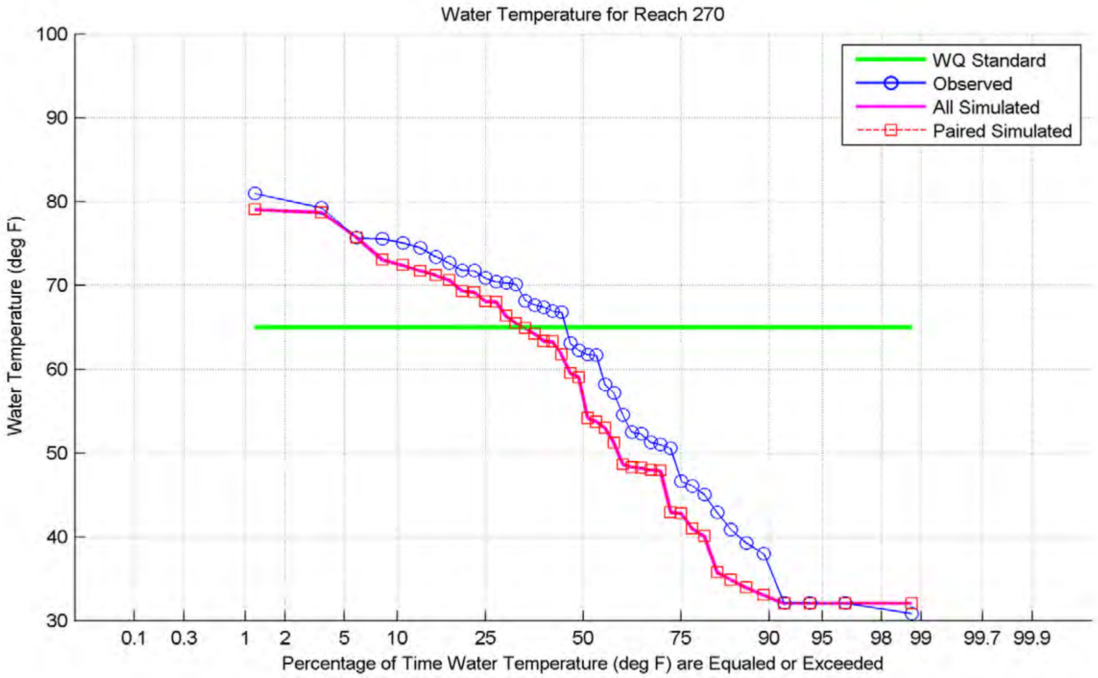

Figure E-70. Water Temperature Duration Curve–Big Sioux (Reach 270).

RSI-2279-14-119

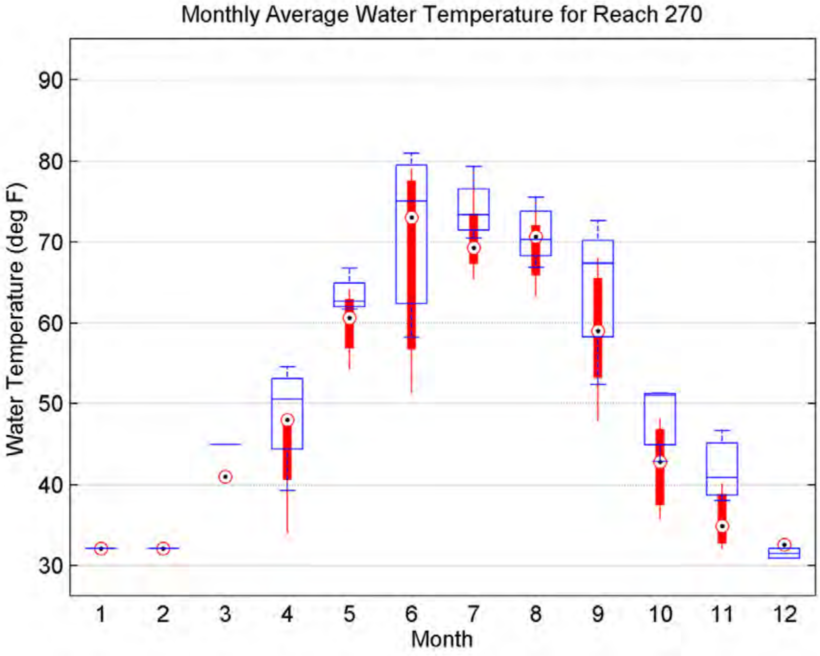

Figure E-71. Water Temperature Monthly Averages–Big Sioux (Reach 270).

RSI-2279-14-120

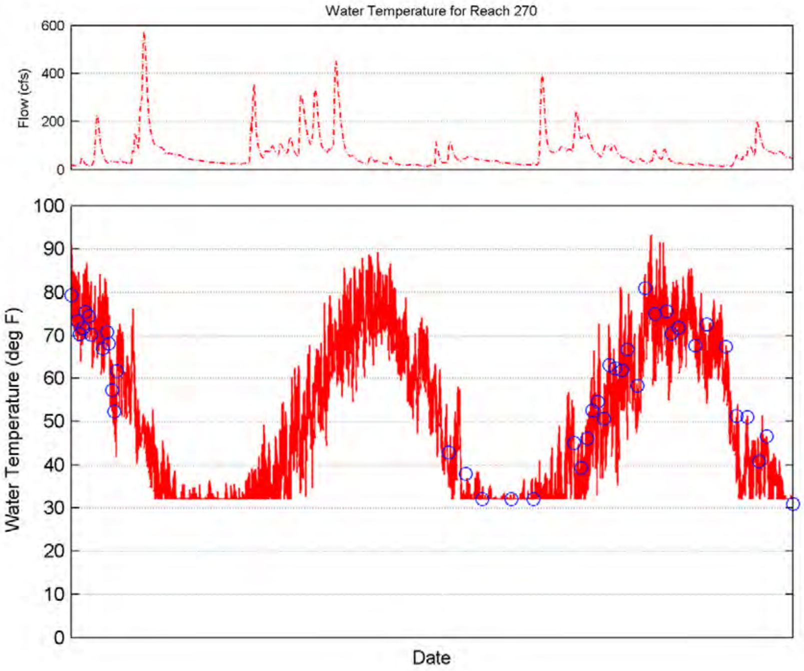

Figure E-72. Water Temperature Daily Time Series–Big Sioux (Reach 270).

RSI-2279-14-121

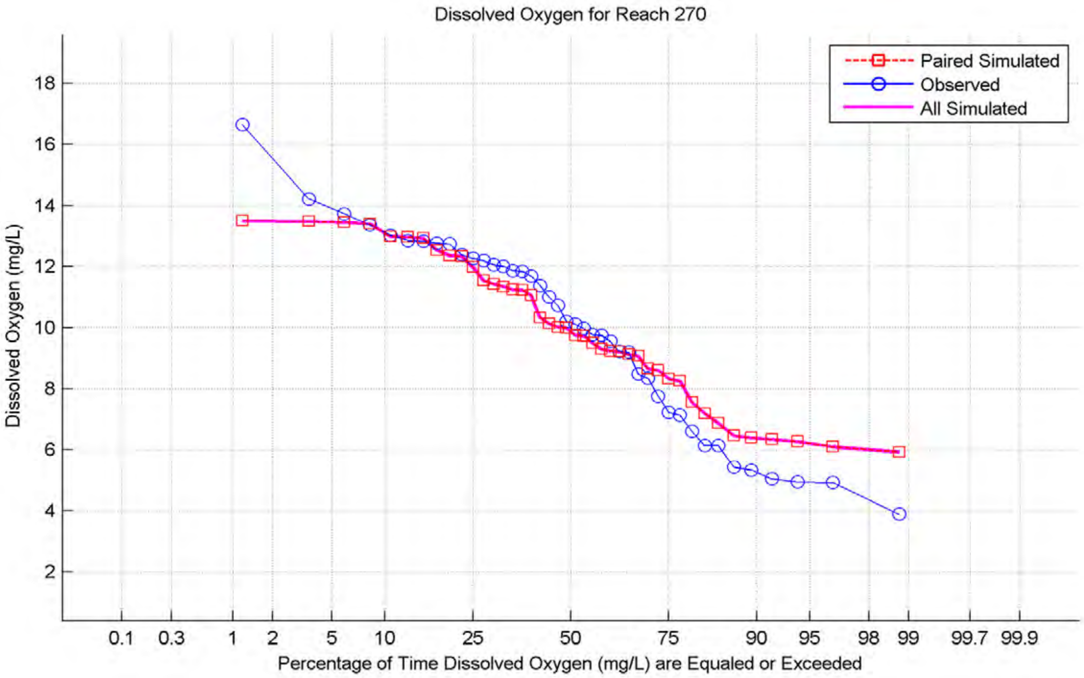

Figure E-73. Dissolved Oxygen Duration Curve– Big Sioux (Reach 270).

RSI-2279-14-122

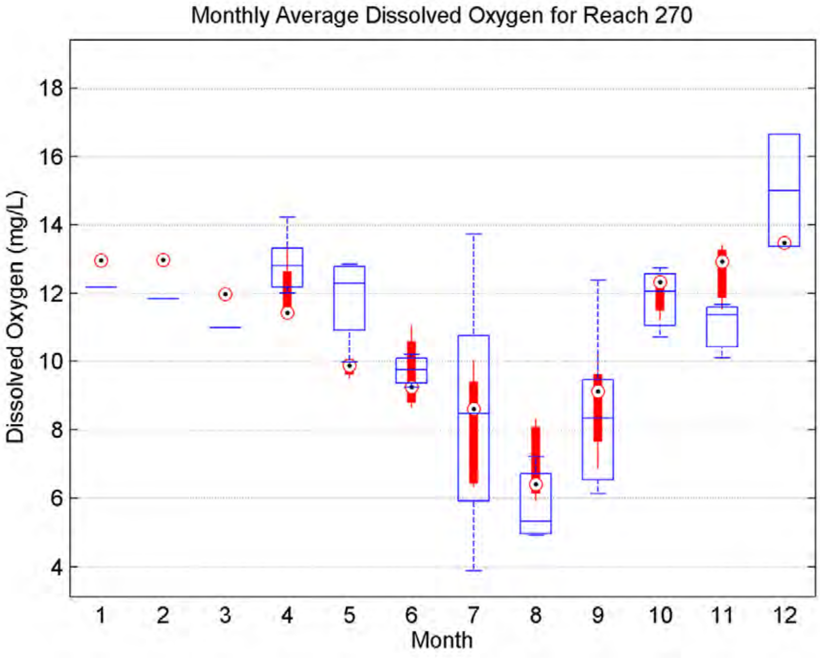

Figure E-74. Dissolved Oxygen Monthly Averages– Big Sioux (Reach 270).

RSI-2279-14-123

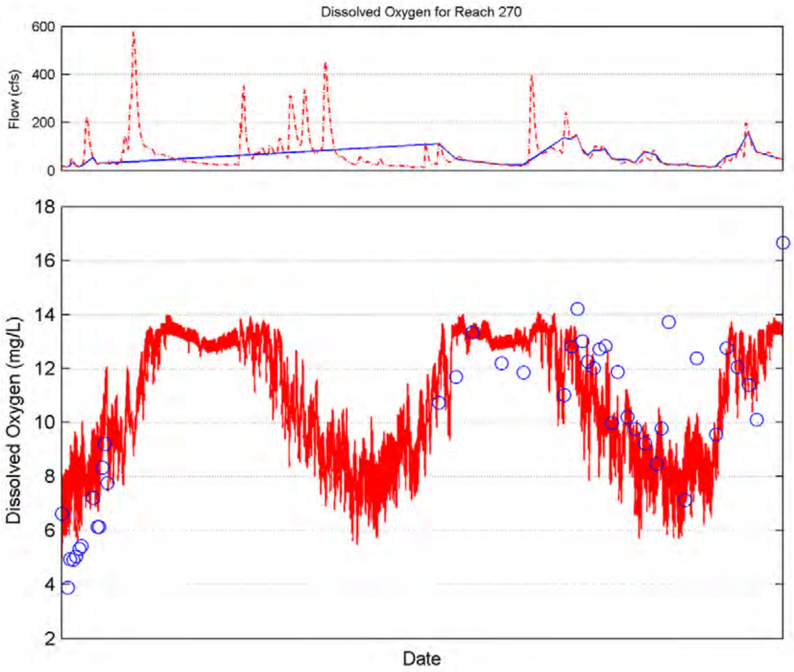

Figure E-75. Dissolved Oxygen Daily Time Series–Big Sioux (Reach 270).

RSI-2279-14-124

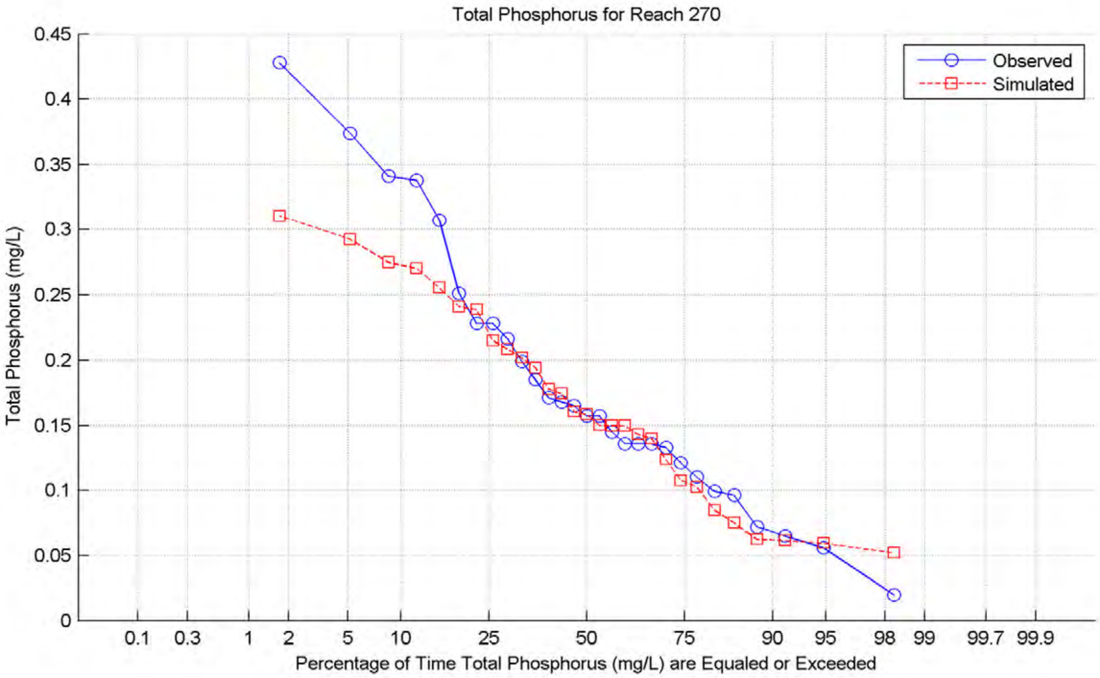

Figure E-76. Total Phosphorus Duration Curve–Big Sioux (Reach 270).

RSI-2279-14-125

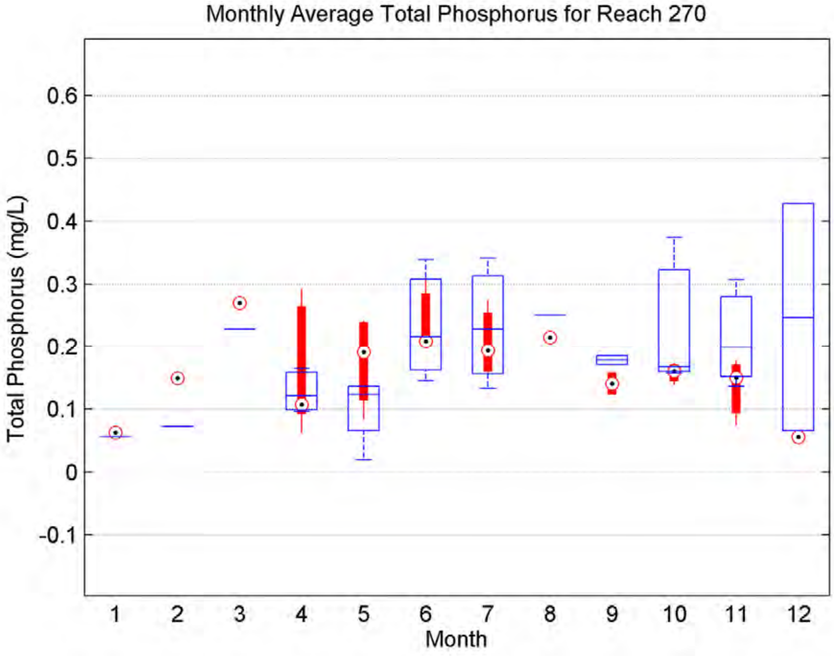

Figure E-77. Total Phosphorus Monthly Averages– Big Sioux (Reach 270).

RSI-2279-14-126

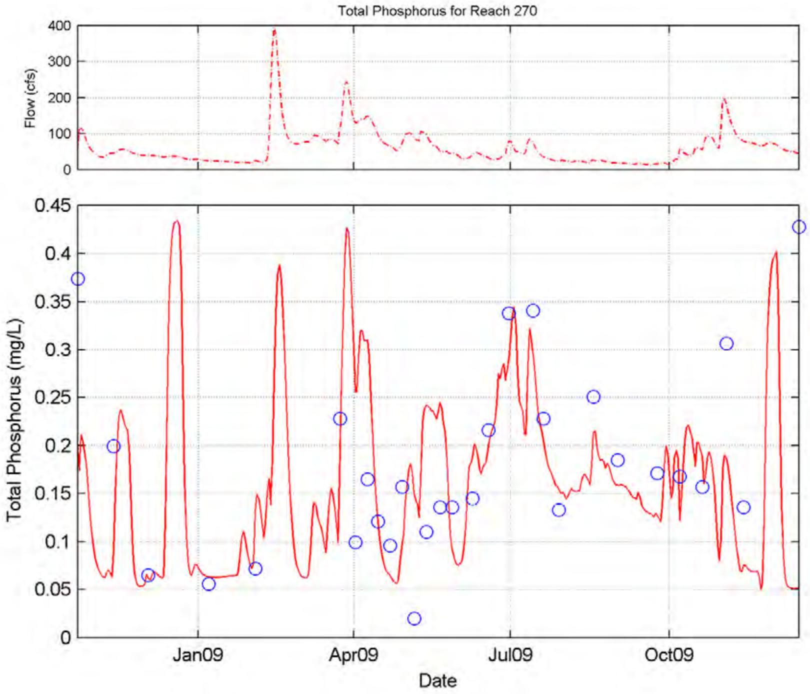

Figure E-78. Total Phosphorus Time Series–Big Sioux (Reach 270).

RSI-2279-14-127

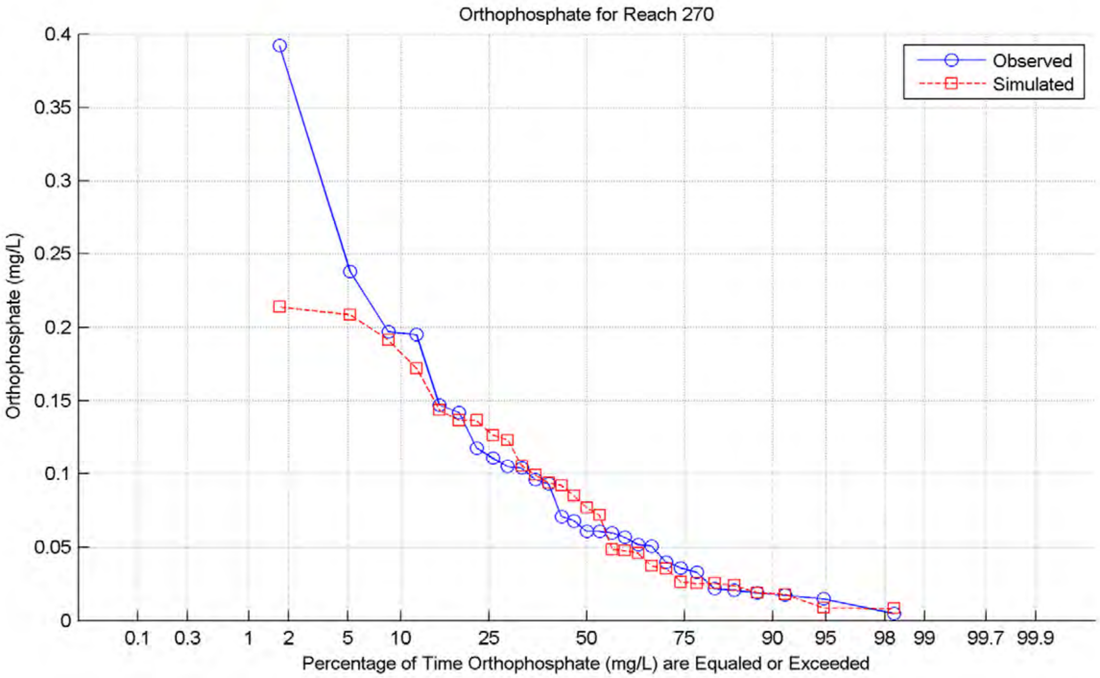

Figure E-79. Orthophosphate Duration Curve–Big Sioux (Reach 270).

RSI-2279-14-128

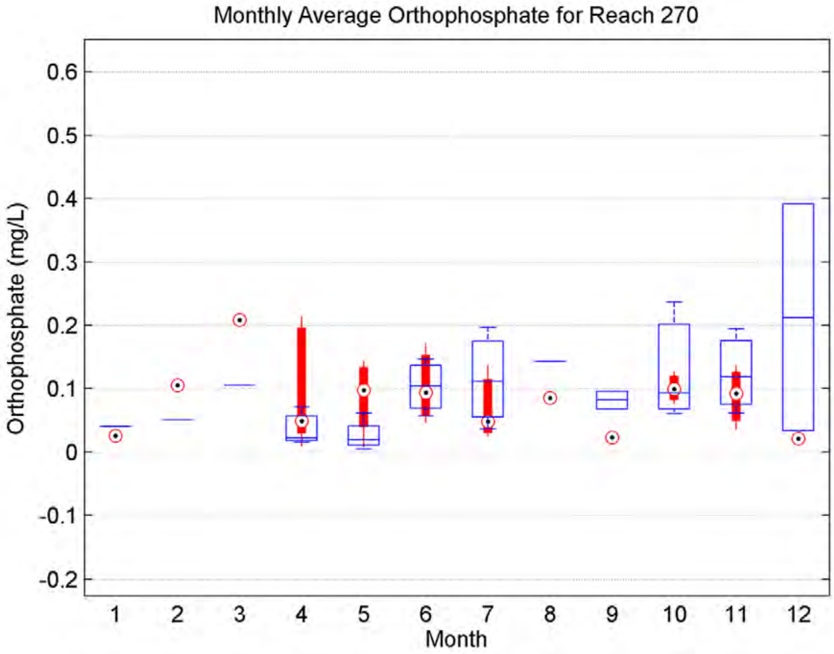

Figure E-80. Orthophosphate Monthly Averages–Big Sioux (Reach 270).

RSI-2279-14-129

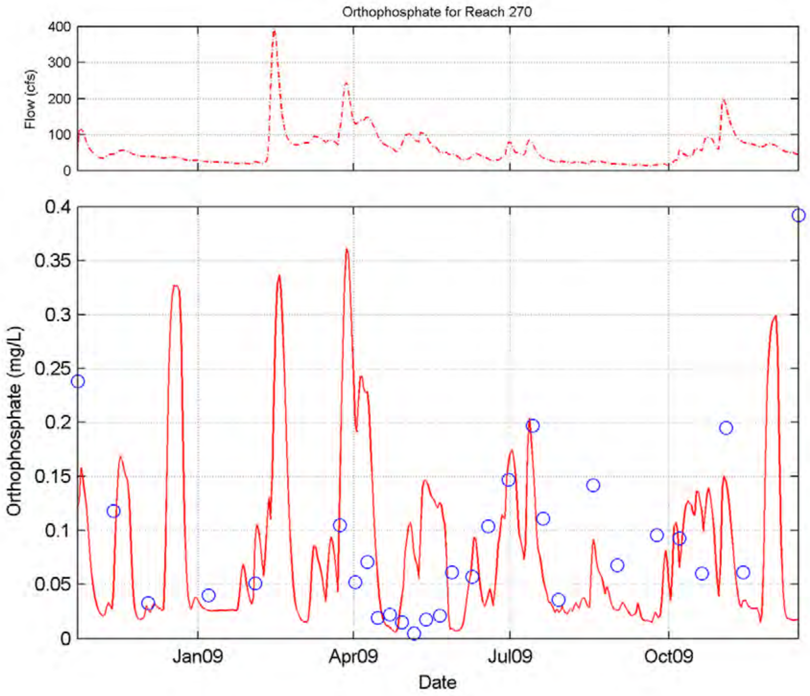

Figure E-81. Orthophosphate Time Series–Big Sioux (Reach 270).

RSI-2279-14-130

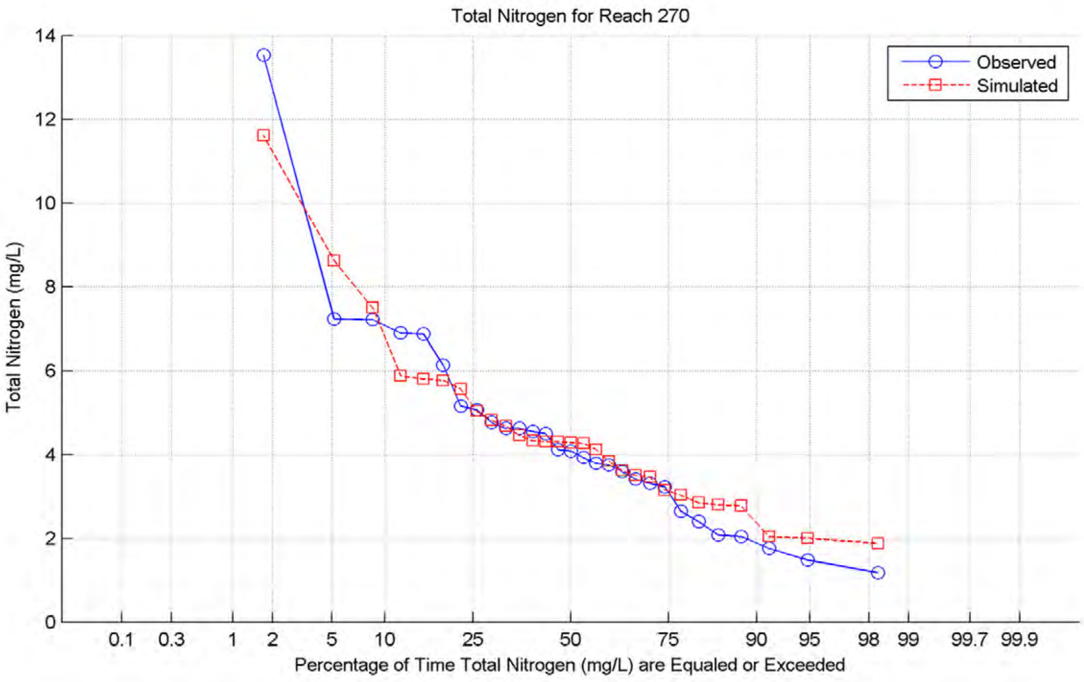

Figure E-82. Total Nitrogen Duration Curve–Big Sioux (Reach 270).

RSI-2279-14-131

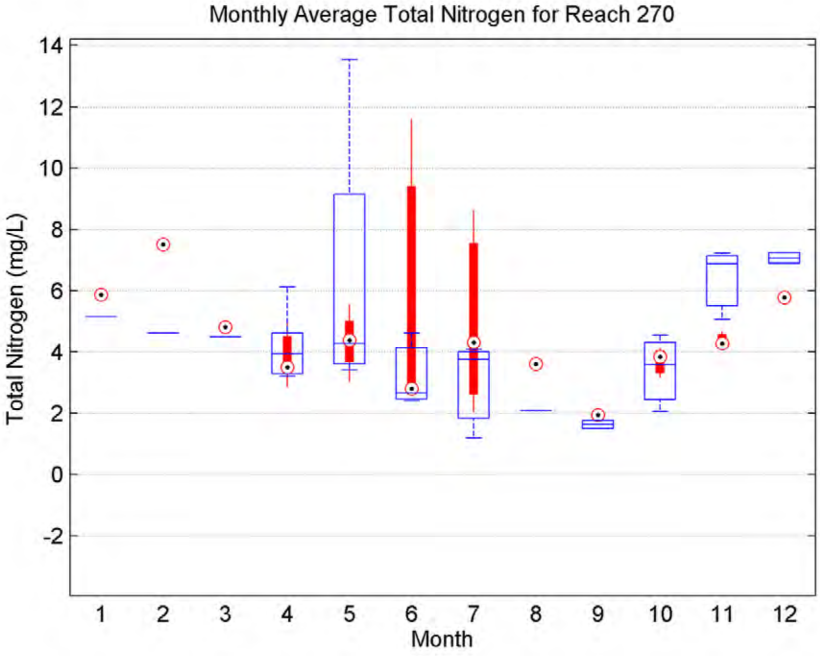

Figure E-83. Total Nitrogen Monthly Averages–Big Sioux (Reach 270).

RSI-2279-14-132

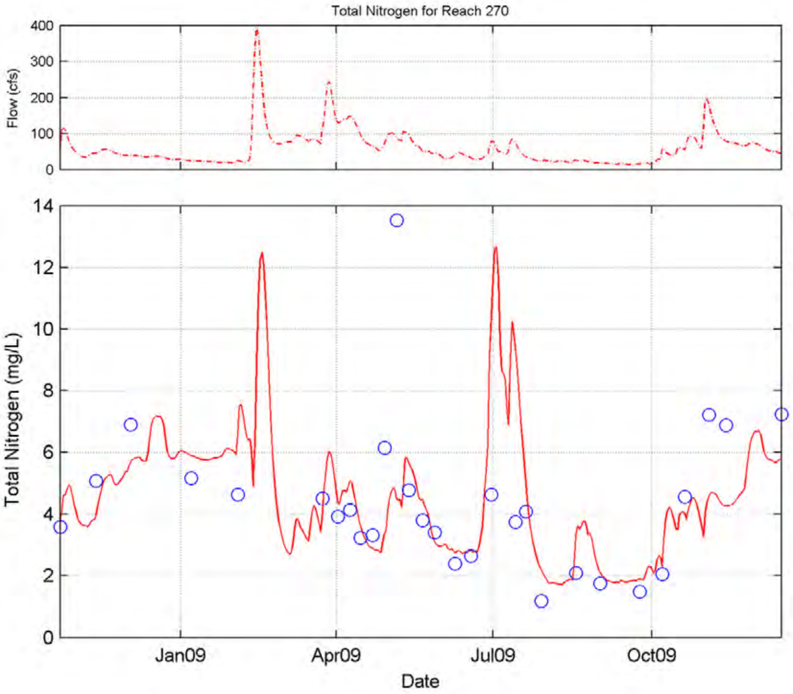

Figure E-84. Total Nitrogen Time Series– Big Sioux (Reach 270).

RSI-2279-14-133

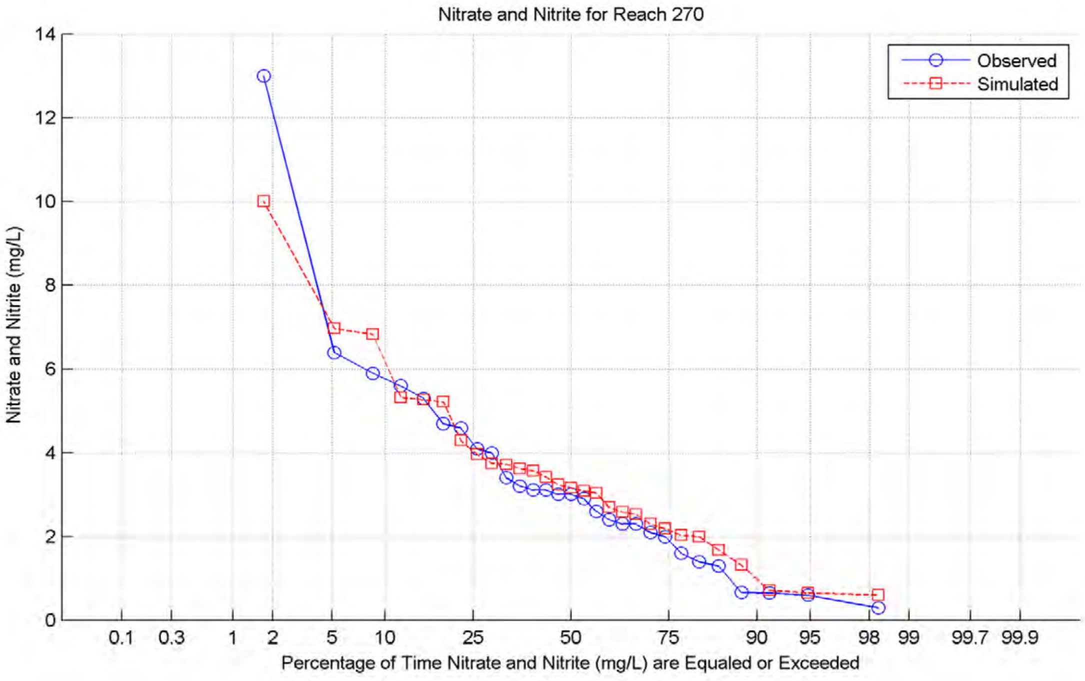

Figure E-85. Nitrate and Nitrite Duration Curve–Big Sioux (Reach 270).

RSI-2279-14-134

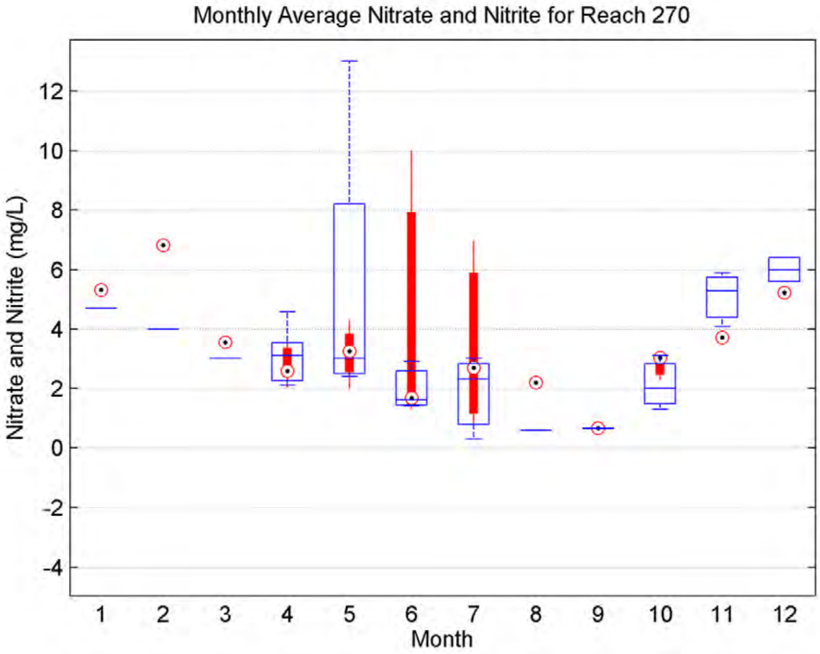

Figure E-86. Nitrate and Nitrite Monthly Averages– Big Sioux (Reach 270).

RSI-2279-14-135

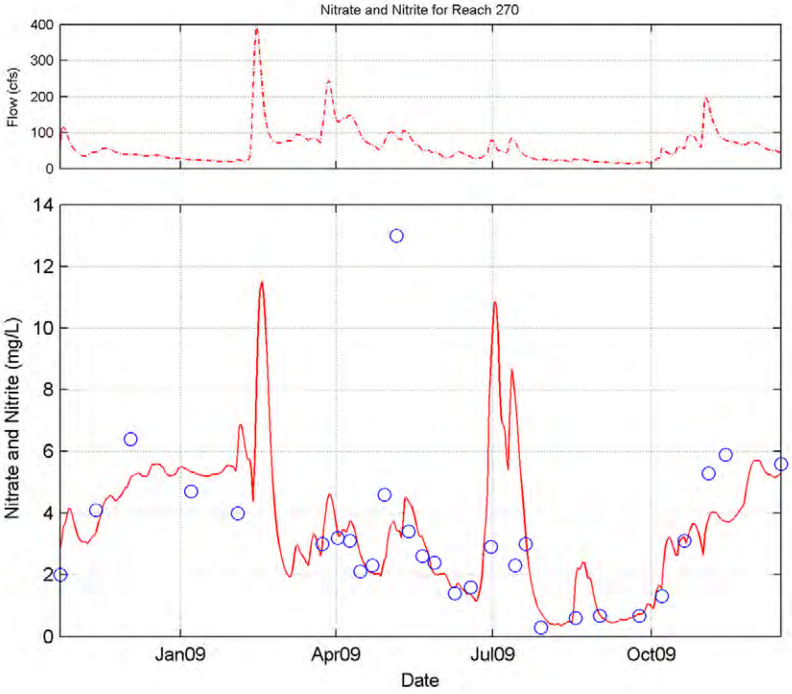

Figure E-87. Nitrate and Nitrite Time Series–Big Sioux (Reach 270).

RSI-2279-14-136

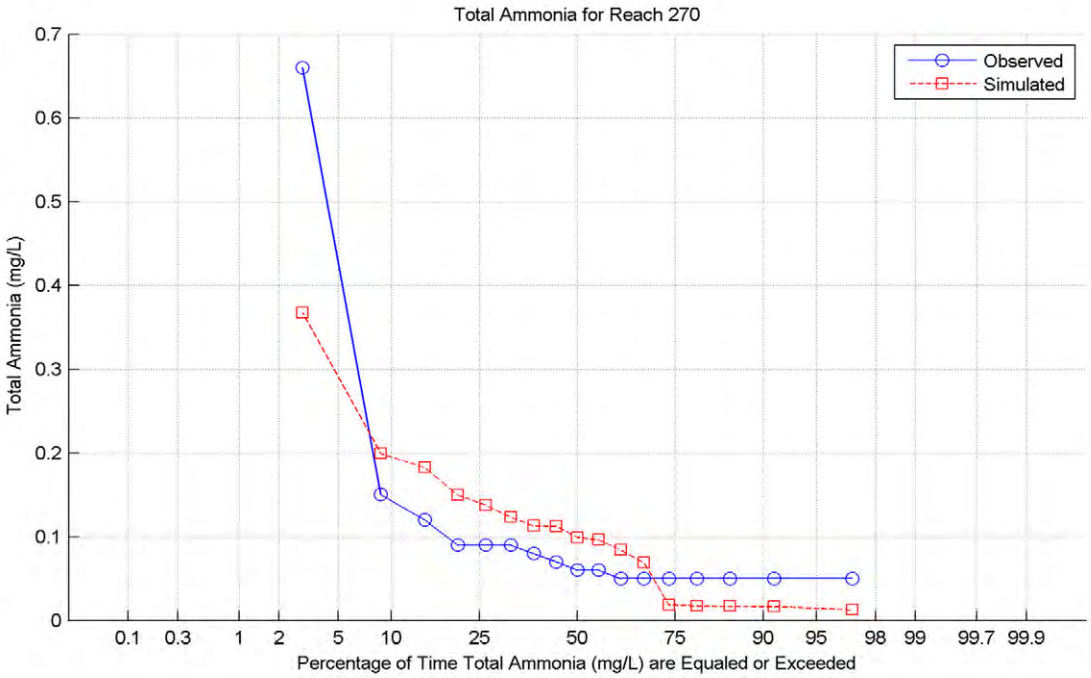

Figure E-88. Total Ammonia Duration Curve– Big Sioux (Reach 270).

RSI-2279-14-137

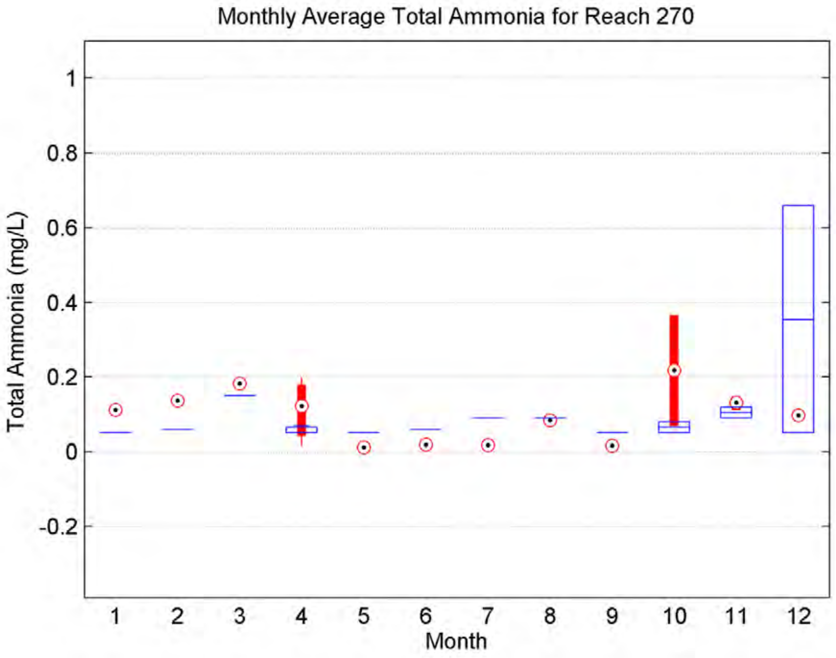

Figure E-89. Total Ammonia Monthly Averages–Big Sioux (Reach 270).

RSI-2279-14-138

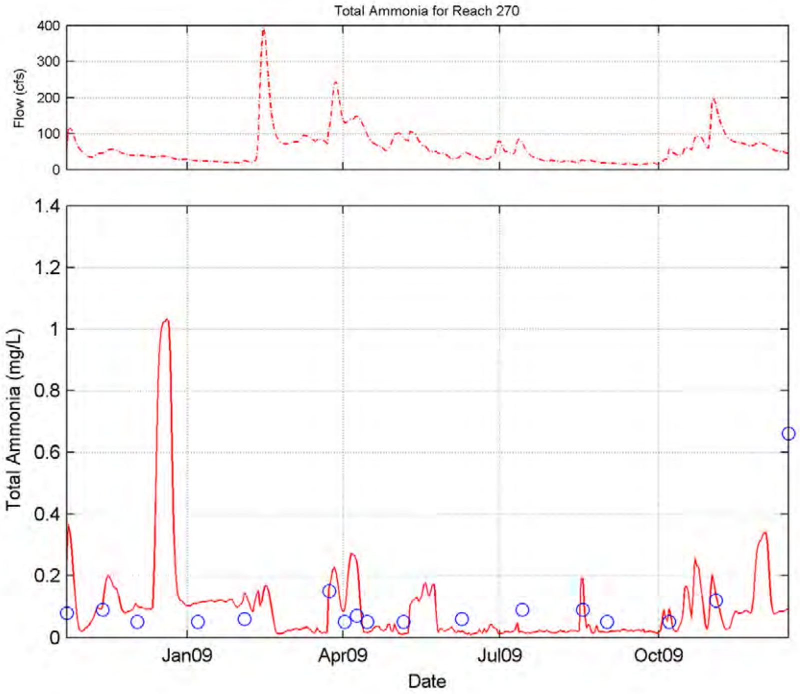

Figure E-90. Total Ammonia Time Series– Big Sioux (Reach 270).

RSI-2279-14-139

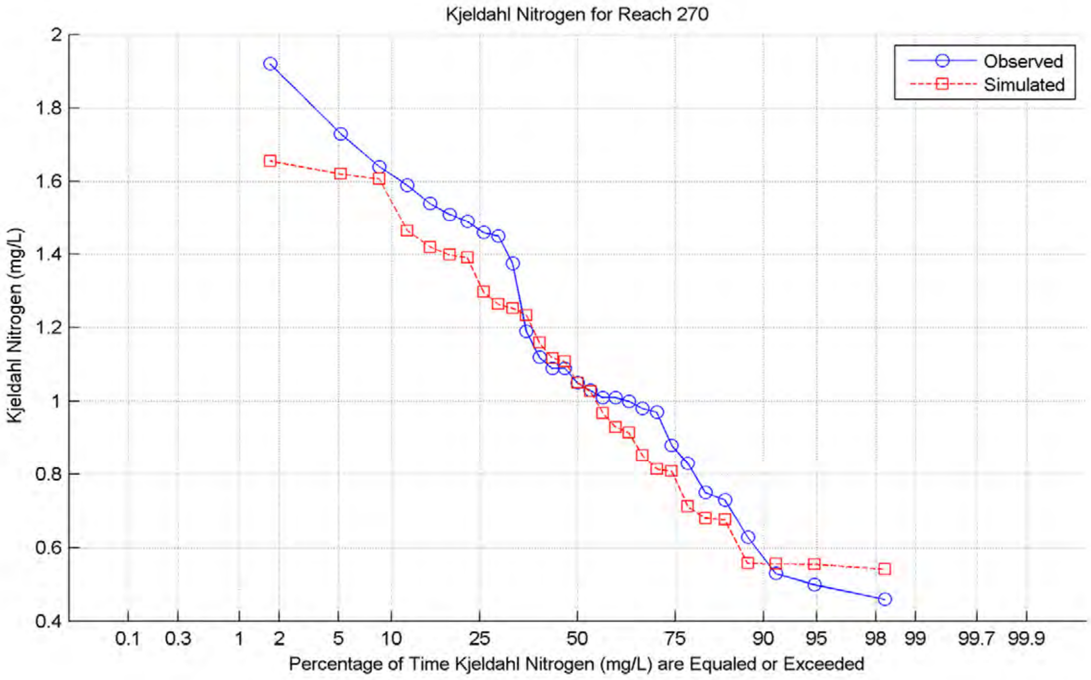

Figure E-91. Kjeldahl Nitrogen Duration Curve–Big Sioux (Reach 270).

RSI-2279-14-140

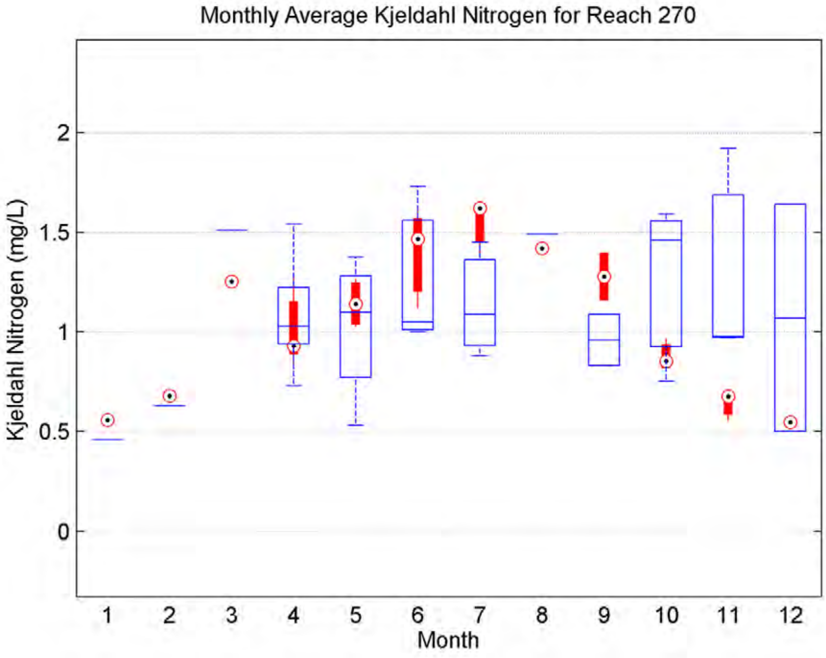

Figure E-92. Kjeldahl Nitrogen Monthly Averages– Big Sioux (Reach 270).

RSI-2279-14-141

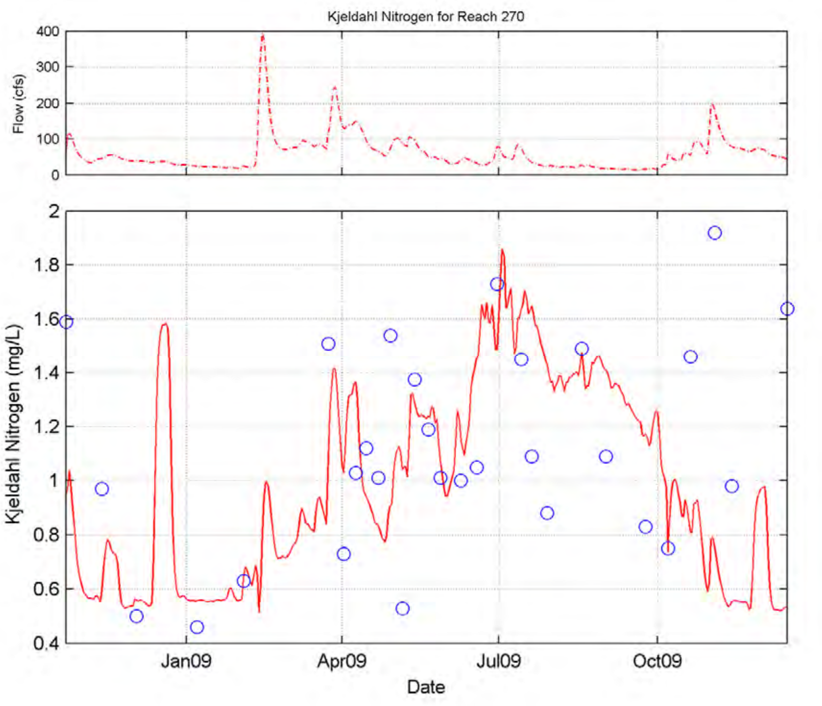

Figure E-93. Kjeldahl Nitrogen Time Series–Big Sioux (Reach 270).

Watershed:	Big Sioux River Watershed (HUC8s 10170202 and 10170203) - One combined model.
Delivery date:	May 30, 2014
Modeler(s):	A. Rutz, C. Lupo
Reviewer(s):	C. Lupo, S. Kenner, M. Burke, C. McCutcheon

The QA/QC procedure outlined below was performed on the HSPF Model Application developed for the above listed watershed(s).
The following components have been reviewed:

Component	Modeler	Reviewer
UCI file	AJR - May 2013	CDL - Mar, 2014
WDM file	AJR - May 2013	CDL - Mar, 2014
Hydro Calibration	AJR - Oct, 2013	CDL - Mar, 2014
WQ Calibration	CDL - Apr, 2014	SJK - May, 2014
GenScn Project	CDL - May, 2014	MPB, CMM - May, 2014
Deliverables	CDL - May, 2014	CMM, TPW - May, 2014

QAQC for UCI and Model Development

Item	Notes
Files	All files called/created correctly, correct HBNs being writing to correct files
Simulation Flags	All correct flags turned on for complete hydro WQ simulation, no lakes
Parameters	All possible PERLNDS, IMPLNDS, RCHRES operations accounted for in all parameter blocks
Opn Sequence	All operations in schematic are called out in opn sequence, rch to rch connections are correct - outlet at 450 to 999
F-Tables	Correct slope used, all Ftable values are consistent and reasonable
SCHEMATIC BLOCK	
Total Area	Less than 0.05% difference between schematic and GIS total areas
Landuse Area	Less than 1% difference for schematic LU and GIS LU
Subwatershed Area	Average 0.03% difference in area from schematic subwatersheds and GIS subwatersheds
LU Area by Sub	Average 0.2% difference - large differences observed due to feedlot classification in GIS - not an issue
Feedlot Areas	Feedlot areas correct. Animal Units > 1000 separated out correctly in the MN portion
Tillage Data	Tillage data applied correctly
MASS LINK BLOCK	
Operations	All valid constituents from Land routed to Reaches

Soils	Not enough difference in soils so only 1 PERLND mass link
Factors	All factors are the standards currently being used
Feedlots	Separate Mass Links for MN Feedlots >1000 AU and Feedlots < 1000
Special cases	No non-contrib area, multiple exits, or MS4 area; no action needed
EXT SOURCES BLOCK	
Met	PEVT was used from BASINS - fixed to use calculated Penman Pan values based on other met data - not an issue
Ag Detached Sed	Detached sediment applied correctly to low and high till cropland
Point Sources	All facilities are Class C, D, or WTP - if no class was given, assumed class was based on description and flow.
	Assumed missing N loads applied correctly; all other factors applied correctly
Atm Deposition	Correct stations used; correct member #s applied to operations
Boundary Condidtions	No boundary condidtions needed

QAQC for Hydrologic and Water Quality Calibration

Item	Notes
Water Balance	All values seem reasonable
Hydro Stats	Ranges "fair" to "good" for primary gages. Flashy response at low flows and snowmelt timing driving the statistics down - product of precip/met data.
Hydro Validation	No change is statistics between 2001 and 2006 landuse.
	Statistics improved to "good" and "great" classification with split sample for both periods at downstream gage - likely due to # of observations
Source Allocation	Loadings values by landuse seem reasonable. Larger per acre loadings for subwatersheds seems to be due to # of feedlots and developed areas
Upstream/Local Conc	Annual local, upstream and outflow concentrations/loads seem reasonable

QAQC for Deliverables

Item	Notes
Model	All models run when coppied from folder to C: drive
GenScn	All projects open and run. All projects' WDMs are linked to features
Memos	Memos reviewed by two people, all maps and wordage match what was actually modeled
Geodatabase	All features used in model development, all features contain metadata

Watershed:	Rock and Little Sioux Watersheds (HUC8s 10170204 & 10230003) - Two separate models
Delivery date:	May 30, 2014
Modeler(s):	A. Rutz, C. Lupo
Reviewer(s):	C. Lupo, S. Kenner, M. Burke, C. McCutcheon

The QA/QC procedure outlined below was performed on the HSPF Model Application developed for the above listed watershed(s).
The following components have been reviewed:

Component	**Modeler**	**Reviewer**
UCI file	AJR - May 2013	CDL - Mar, 2014
WDM file	AJR - May 2013	CDL - Mar, 2014
Hydro Calibration	CDL - Oct, 2013	CDL - Mar, 2014
WQ Calibration	CDL - Apr, 2014	SJK - May, 2014
GenScn Project	CDL - May, 2014	CMM - May, 2014
Deliverables	CDL - May, 2014	CMM, TPW - May, 2014

QAQC for UCI and Model Development

Item	**Notes**
Files	All files called/created correctly, correct HBNs being writing to correct files
Simulation Flags	All correct flags turned on for complete hydro WQ simulation, no lakes
Parameters	All possible PERLNDS, IMPLNDS, RCHRES operations accounted for in all parameter blocks
Opn Sequence	All operations in schematic are called out in opn sequence, rch to rch connections are correct
F-Tables	Correct slope used, all Ftable values are consistent and reasonable
SCHEMATIC BLOCK	
Total Area	Less than 0.001% difference between schematic and GIS total areas
Landuse Area	Less than 2% difference for schematic LU and GIS LU - differences due to feedlots
Subwatershed Area	Average 0.8% difference in area from schematic subwatersheds and GIS subwatersheds
LU Area by Sub	Average 0.8% difference - large differences observed due to feedlot classification in GIS - not an issue
Feedlot Areas	Feedlot areas correct. Animal Units > 1000 separated out correctly
Tillage Data	Tillage data applied correctly
MASS LINK BLOCK	
Operations	All valid constituents from Land routed to Reaches
Soils	Not enough difference in soils so only 1 PERLND mass link

Factors	All factors are the standards currently being used
Feedlots	Separate Mass Links for MN Feedlots >1000 AU and Feedlots < 1000
Special cases	MS4 areas separated and called out correctly. No non-contrib area, multiple exits - no action needed
EXT SOURCES BLOCK	
Met	PEVT was used from BASINS - fixed to use calculated Penman Pan values based on other met data - not an issue
Ag Detached Sed	Detached sediment applied correctly to low and high till cropland
Point Sources	All facilities are Class C, D, or POWER - if no class was given, assumed class was based on description and flow. Assumed missing N loads applied correctly; all other factors applied correctly
Atm Deposition	Correct stations used; correct member #s applied to operations
Boundary Condidtions	No boundary condidtions needed

QAQC for Hydrologic and Water Quality Calibration

Item	Notes
Water Balance	Pasure/Grasslandshigher SURO than Ag low till - most pasture area is in a hydrozone with a slope > 3X that of the average Ag slope - not an issue
Hydro Stats	All daily r^2 range from 0.63 to 0.82 (fair to very good) and monthly from 0.83 to 0.89 (good to very good) for all primary and secondary gages - statistics and duration withing acceptable ranges
Hydro Validation	There was little change in statistics for the 2001 landuse and the split sample periods for all primary and secondary gages
Source Allocation	Loadings values by landuse seem reasonable. Larger per acre loadings for subwatersheds seems to be due to # of feedlots and developed areas
Upstream/Local Conc	Rch 170 Rock (high load - Lavurne WWTP)

QAQC for Deliverables

Item	Notes
Model	All models run when coppied from folder to C: drive
GenScn	All projects open and run. All projects' WDMs are linked to features
Memos	Memos reviewed by two people, all maps and wordage match what was actually modeled
Geodatabase	All features used in model development, all features contain metadata

Appendix F – Okabena Lake Diagnostic Study

WENCK File #0147-280
March 2015

Okabena Lake Diagnostic Study

Prepared for:

OKABENA OCHEDA
WATERSHED DISTRICT

Minnesota Pollution Control Agency

CLEAN
WATER
LAND &
LEGACY
AMENDMENT

WENCK
ASSOCIATES
Responsive partner.
Exceptional outcomes.

Prepared by:

WENCK Associates, Inc.
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Maple Plain, MN 55359
Phone: 763-479-4200
Fax: 763-479-4242

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APPENDICES

1.0 Purpose and Scope

Okabena Lake is a 776-acre water body located in southwestern Minnesota in the City of Worthington. The lake has poor water clarity due to high levels of suspended sediment (TSS), and algae growth caused by excessive nutrients. The purpose of this study is to use historic data along with data collected by the Okabena-Ocheda Watershed District in 2014 to improve the understanding of Lake Okabena's sediment and phosphorus sources. Specifically, this study investigates the following sources of sediment and phosphorus to Okabena Lake: dry and wet deposition on the lake surface; runoff from the City of Worthington; rural runoff from animal agriculture, field erosion and streambank erosion; and internal loading of phosphorus from the lake sediments. These sources were estimated using a combination of monitoring data, literature rates, and modeling exercises. The sediment and phosphorus source assessment presented in this report is intended to support development of the Okabena Lake TMDL and help identify source areas for BMP planning and implementation strategies.

2.0 Site Description

2.1 WATERSHED DESCRIPTION

Okabena Lake (DNR# 53-0028-00) is located entirely within the city limits of Worthington, in southwestern Minnesota. Okabena Lake's drainage area covers approximately 9,437 acres. A majority of the lake's watershed, approximately 7,999 acres (85%), is located outside the City of Worthington municipal boundary in rural portions of Nobles County. There are nine major subwatersheds that discharge to the lake through storm sewer pipes or small ditches and tributary channels (Figure 2-1). The largest surface water inflow to Okabena Lake is Okabena Creek which drains approximately 5,306 acres of land north of the lake. The second largest inflow to the lake is from an unnamed tributary to Sunset Bay that drains 2,628 acres of land west of the lake. The remainder of the watershed is made up of smaller subwatersheds that drain to city stormwater ponds, and direct runoff that enters the lake through overland flow and small storm sewer catchments. Dominant land cover in the Okabena Lake watershed is corn/soybean rotations, which are primarily located in the Okabena Creek and Sunset Bay tributary subwatersheds. The City of Worthington, roadways, and other developed land account for approximately 18% of watershed land cover. Table 2-1 presents current land cover throughout the Okabena Lake watershed.

Table 2-1. Land cover in the Okabena Lake watershed.

Land cover[1]	Acres	Percent
Corn/Soybeans	6,374	67%
Developed	1,698	18%
Grass/Pasture	937	10%
Wetlands	257	3%
Forest	169	2%
Other Crops	2	<1%
Total	**9,437**	**100%**

[1] Land cover calculated using 2013 National Agricultural Statistics Service (NASS) GIS database

There are several unique hydrologic features located throughout the Okabena Lake watershed. One of these features is the Boote-Herlein Marsh located approximately four miles northwest of Okabena Lake that drains approximately 4,200 acres west of Okabena Creek. Prior to 2014, outflow from the marsh was directed toward Okabena Creek through a ditched channel west of Nystrom Avenue. A dam was constructed in early 2014 across the outflow channel and the Boote-Herlein Marsh now outlets to the west and away from Okabena Creek and the Okabena Lake watershed.

Downstream of the Boote-Herlein Marsh, Okabena Creek flows through the Prairie View Golf Links public golf course located approximately one mile northwest of the City of Worthington along County Road 25. During development of the golf course, several large ponds were incorporated into the design to store and treat upstream flow and pollutant loads (Figure 2-2).

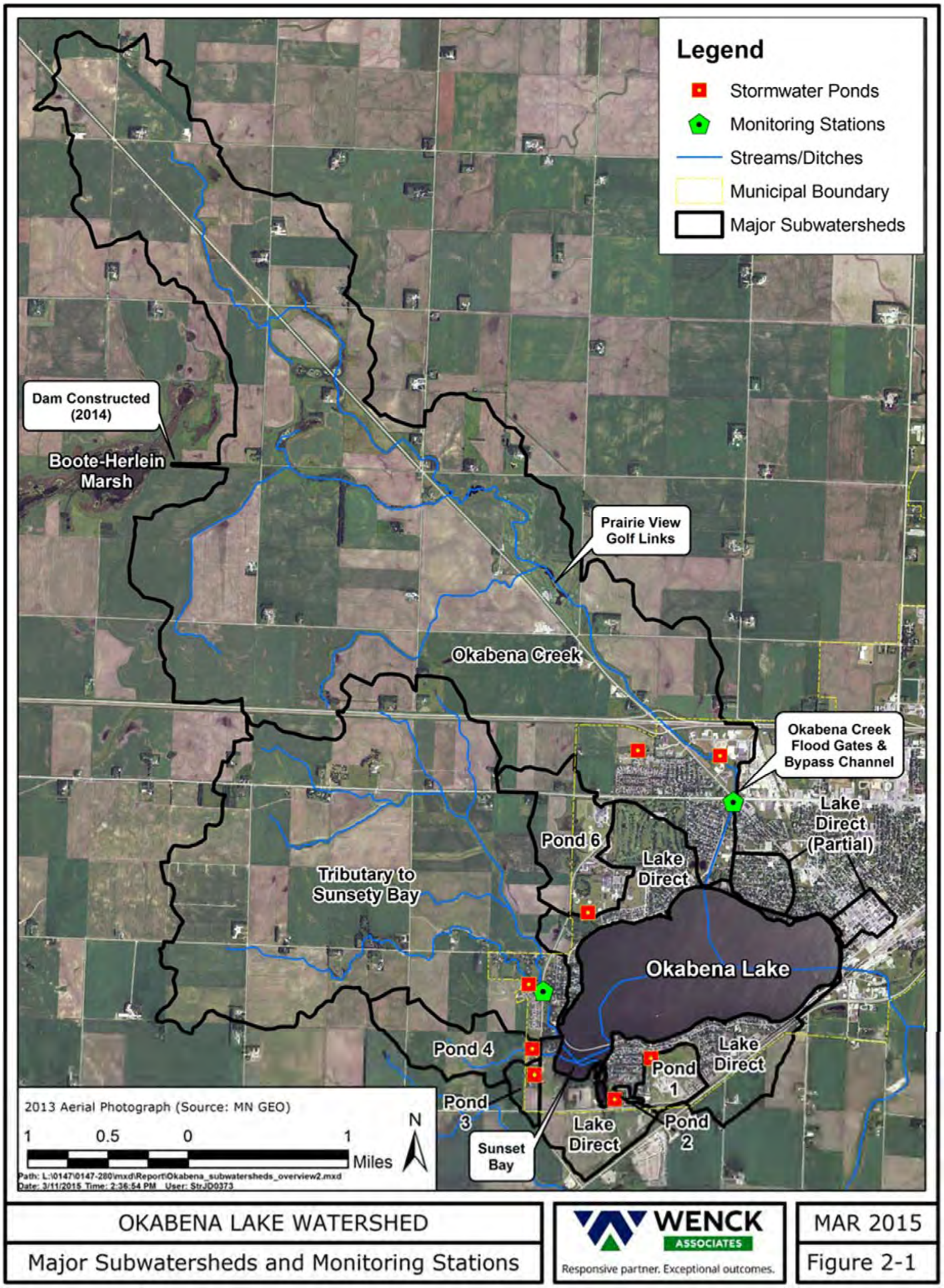


Figure 2-1. Okabena Lake watershed.

In the 1950's a U.S. Army Corp flood control project was completed to upgrade an existing flood diversion of Okabena Creek to Okabena Lake. The Army Corp project increased the capacity of the existing manmade diversion and established a fixed diversion of flows to Okabena Lake with a lesser portion of flows continuing to Okabena Creek (County Ditch 12). At a later date the City of Worthington added flood gates (Figure 2-3) to the Okabena Creek side of the diversion at Oxford Street to allow 100% of the Okabena Creek flow to be routed to Okabena Lake. It should be pointed out that the natural course for Okabena Creek is through Worthington then northeast toward Heron Lake. The portion of Okabena Creek between the Oxford Street flood gates and the lake is referred to as "Whiskey Ditch" and now provides for diversion to Okabena Lake. Historical maps show that the Okabena Lake outlet used to be located at the Whiskey Ditch inlet and flowed northeasterly toward Okabena Creek.

To the west there is a large tributary that drains mostly agricultural land and discharges into Sunset Bay. Sunset Bay is technically a part of Okabena Lake, however it likely acts as a settling basin since it is isolated from the main body of the lake by the South Shore Drive causeway. This basin likely provides some water quality treatment of the western tributary.

Figure 2-2. Okabena Creek ponds located at the Prairie View Golf Links (Image Source: Google Earth)

Figure 2-3. Okabena Creek bypass flood gates at Oxford Street.

2.2 OKABENA LAKE INFORMATION

2.2.1 Lake Morphometry

The Minnesota Department of Natural Resources (DNR) defines the littoral zone as areas of a lake less than 15 feet where light should be able to penetrate to the bottom and plant growth can be expected. With a maximum depth of about 16 feet and littoral area of 97%, Okabena Lake is considered a shallow lake by Minnesota rules and standards (Table 2-2). The lake has approximately 6.5 miles of shoreline that is completely developed. Okabena Lake has a moderate watershed to lake surface area ratio of 12:1 suggesting that the lake is likely sensitive to both external (watershed) and internal nutrient and pollutant sources.

Table 2-2. Physical Features of Okabena Lake.

Parameter	Result
Surface Area (acres)	776
Average Depth (ft)	6.6
Maximum Depth (ft)	16
Volume (acre-feet)	5,129
Littoral Area (acres)	752
Littoral Area (%)	97%
Watershed (acres)	9,437

2.2.2 Water Quality

Lake water quality is typically judged by assessing water clarity during the summer growing season. When excess algae grow in a lake, water clarity is reduced and noxious smells can emit. These are symptoms of lake eutrophication. Water clarity is also affected by the amount of total suspended sediment (TSS) in the water column. High TSS can be the result of excessive algae growth, but can also come from sediment re-suspension from the bottom of the lake caused by wind or fish activity. When lakes become hyper eutrophic (excess nutrients leading to heavy algae growth) or have high levels of TSS, the entire food web is affected. Changes are found in the algal, fish and aquatic plant communities, as well as the overall water quality, including depletion of dissolved oxygen. A healthy lake has good water clarity and a balanced growth of algae supporting the base of the food chain without degrading water quality or harming other biological organisms.

Under Minn. R. 7050.0150 and 7050.0222, subp. 4, Okabena Lake is a shallow lake located within the Western Corn Belt Plain (WCBP) Ecoregion with numeric water quality targets listed in Table 2-3. In addition to meeting phosphorus limits, chlorophyll-a and Secchi depth (water clarity) standards must also be met for the lake to be considered “fully supporting” its designated use. In developing the nutrient standards for Minnesota lakes (Minn. R. 7050), the MPCA evaluated data from a large cross-section of lakes within each of the state’s ecoregions (MPCA, 2005). Relationships were established between the causal factor TP and the response variables chlorophyll-a and Secchi disk.

Table 2-3. Numeric standards for lakes in the WCBP Ecoregion.

Parameters	Western Corn Belt Plain Standards (Shallow Lakes[1])
Total Phosphorus (μg/L)	≤90
Chlorophyll-*a* (μg/L)	≤30
Secchi Disk Transparency (meters)	≥0.7

[1] Shallow lakes are defined as lakes with a maximum depth of 15 feet or less, or with 80% or more of the lake area shallow enough to support emergent and submerged rooted aquatic plants (littoral zone).

Lake water quality samples were collected by Okabena-Ocheda Watershed District staff since 1998. In general, lake monitoring was conducted one time per month from May through October for water clarity (Secchi depth), total phosphorus (TP), chlorophyll-*a* and TSS.

Water Clarity

Water clarity in lakes is typically measured using a Secchi disk. A Secchi disk is a black and white disk that is lowered into the water column until it can no longer be seen. The depth at which the disk disappears is known as the Secchi depth and is considered the depth where 90% of the light is extinguished.

As discussed previously, water clarity in shallow lakes is controlled by several factors including the amount of algae in the water column as well as other suspended particles caused by watershed loading, wind resuspension and bioturbation (such as carp). Since Okabena Lake is a large shallow lake, wind resuspension may be a significant driver of reduced clarity in areas where wind and wave action is able to reach the sediments and stir bottom particles into the water column.

Average summer growing season (June through September) Secchi depth has not met the 0.7 meter water quality standard for shallow lakes in the Western Corn Belt Plain (WCBP) ecoregion in 14 of 17 years since 1998 (Figure 2-4). During this time, mean summer values have ranged from 0.3 meters to 0.8 meters. Below is a more in-depth discussion of the primary factors causing poor water clarity in Okabena Lake, algae (chlorophyll-a) and TSS.

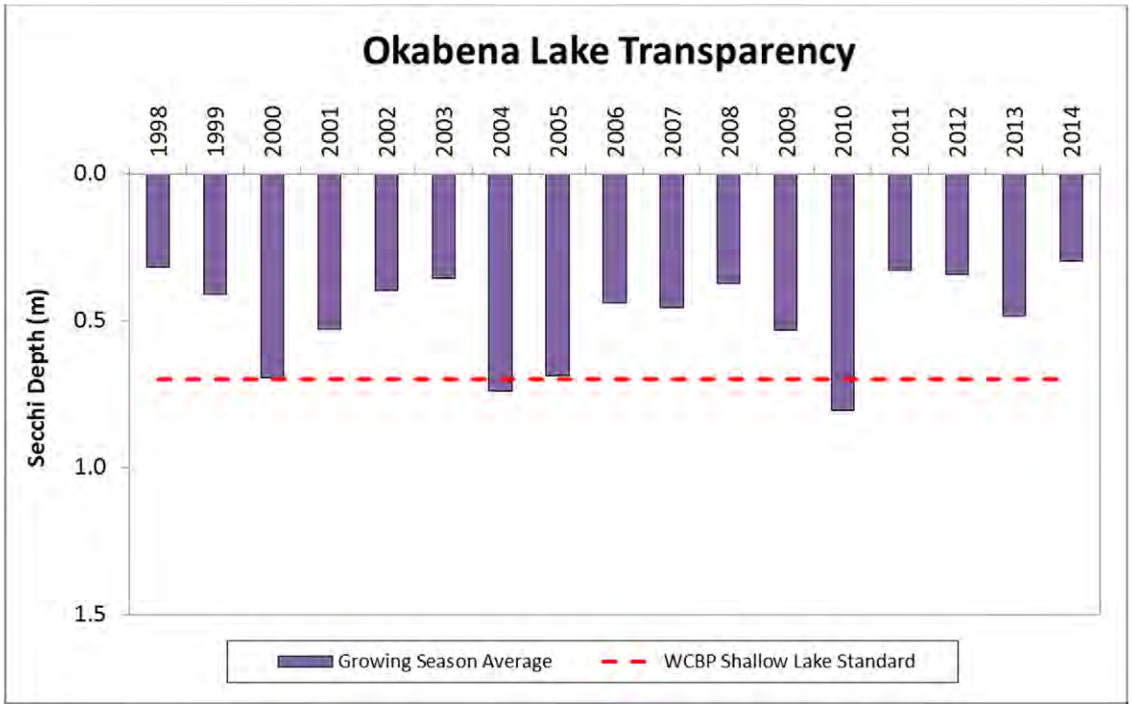


Figure 2-4. Summer average Secchi depth values for Okabena Lake.

Chlorophyll-a and Phosphorus

Chlorophyll-*a* is the primary pigment in aquatic algae and has been shown to have a direct correlation with algal biomass. Chlorophyll-a is a simple measurement and is often used to evaluate algal abundance rather than expensive cell counts. The greater the algal biomass and corresponding chlorophyll-*a* values, the more green and productive a lake appears with worst case scenarios including algal scum and foul odors. These conditions are considered nuisance algal blooms and are both aesthetically unpleasing but also potentially bad for fish and other biological organisms. Nuisance algal blooms cause poor smells and aesthetics and can lead to more severe problems such as summer fish kills. Algal growth (measured as total chlorophyll-*a*) is typically limited by the amount of phosphorus in the water column. Therefore, TP is considered the causative factor for algal growth.

Okabena Lake summer growing season average TP concentrations have ranged from 91-307 µg/L. Average summer TP concentrations have exceeded the WCBP 90 µg/L shallow lake standard every year since 1998 (Figure 2-5). This suggests phosphorus levels are consistently high in Okabena Lake and available to support excessive algae growth. However, Figure 2-6 shows summer average chlorophyll-*a* concentrations in Okabena Lake have ranged from 6 µg/L to as high as 58 µg/L and have exceed WCBP shallow lake water quality standards in only 7 of 17 years since 1998. This indicates nuisance algae blooms do occur in Okabena Lake.

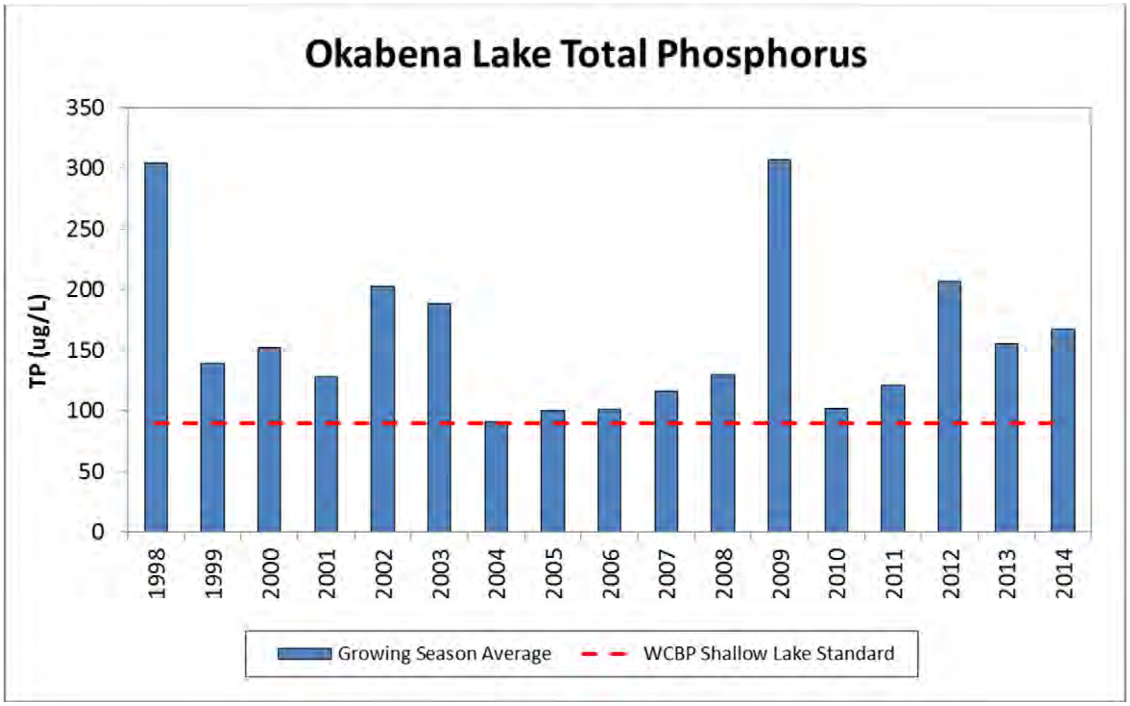


Figure 2-5. Summer average total phosphorus concentrations for Okabena Lake.

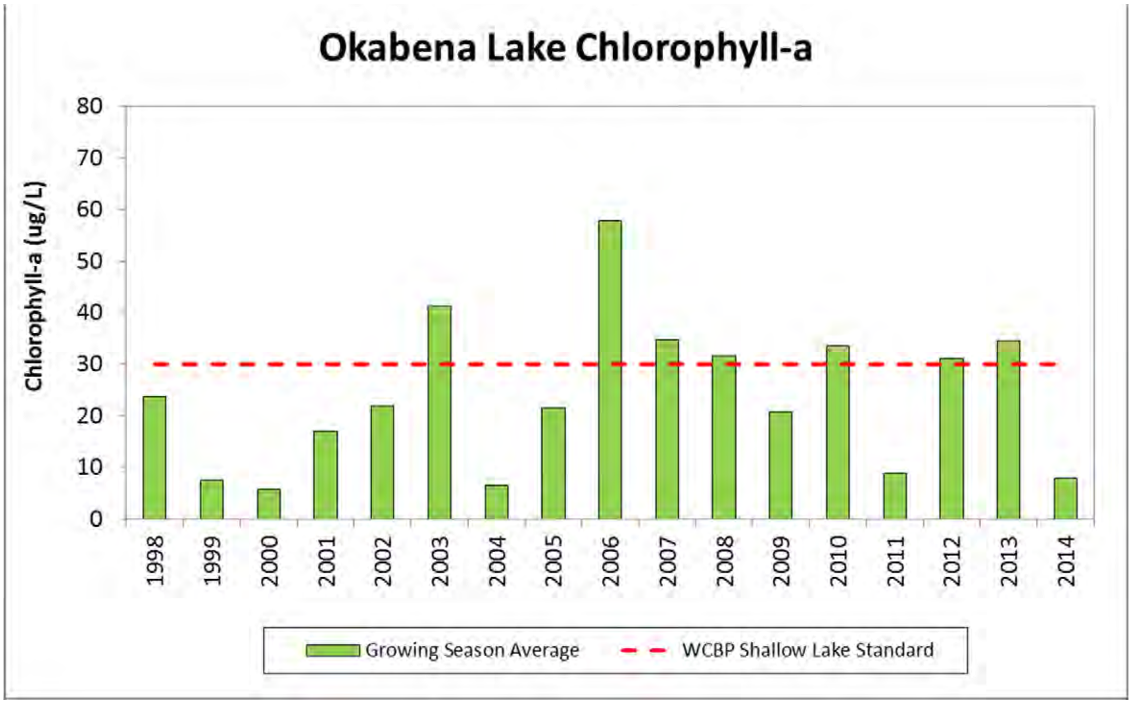


Figure 2-6. Summer average chlorophyll-*a* concentrations for Okabena Lake.

TSS

As discussed previously, TSS measured near the surface of the lake is typically driven by algal biomass and sediment re-suspension from the bottom of the lake. Okabena Lake is a shallow lake with very little submerged vegetation and a large surface area which leaves the lake vulnerable to sediment re-suspension during windy days. Summer average TSS in Okabena Lake has ranged from 9 mg/L to as high as 48 mg/L (Figure 2-7). Comparing Figures 2-4, 2-6 and 2-7 shows that in some years, such as 1999, 2011 and 2014, water clarity was poor even though chlorophyll-*a* levels were very low. In these years, TSS concentrations were high despite low chlorophyll-*a* indicating non-algal sources of turbidity. The high non-algal turbidity is likely a result of wind mixing and/or bioturbation. This suggests non-algal turbidty likely plays as big of a role as algae growth in affecting water clarity in Okabena Lake. Restoring water clarity in Okabena Lake will need to focus on decreasing in-lake sediment resuspension, as well as decreasing phosphorus loading and the potential for nuisance algae blooms. In order to reduce in-lake sediment resuspension, aquatic vegetation in Okabena Lake will need to be re-established. This will be a difficult process that may require drastic measures and in-lake management techniques.

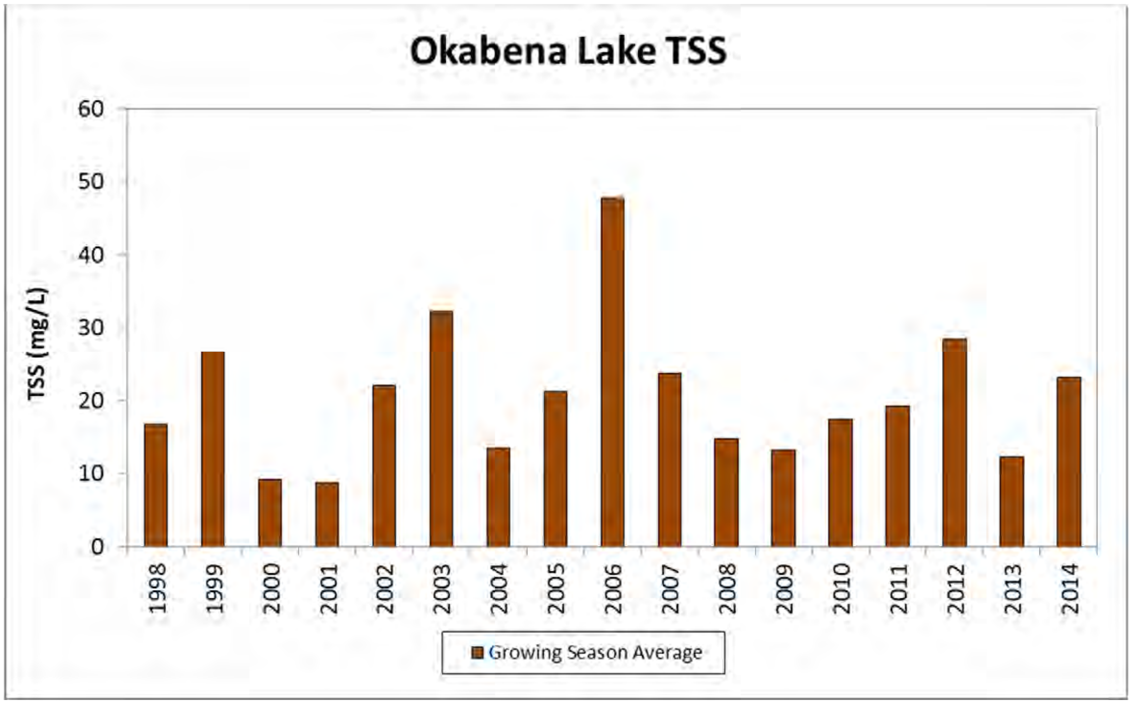


Figure 2-7. Summer average TSS concentrations for Okabena Lake.

3.0 Ecological Review

3.1 VEGETATION

To this point, no formal plant community surveys have been performed on Okabena Lake. Local knowledge has indicated Okabena Lake has very little submerged and emergent plant growth, particularly in late summer when water clarity is poor. With over 97% of the lake considered littoral (15 feet or less), most of Okabena Lake should be able to support aquatic vegetation as water clarity improves.

3.2 FISHERIES

Fish survey reports for Okabena Lake were provided by the DNR Area Fisheries Office in Windom, Minnesota. The first DNR fish survey conducted for Okabena Lake was performed in 1982. Standard survey methods used by the DNR include gill net and trap nets. These sampling methods do have some sampling bias, including focusing on game management species (i.e., northern pike and walleye), under representing small minnow and darter species presence/abundance, and under representing certain management species such as largemouth bass. The current methods also likely under represent carp populations in lakes. However, when carp are present in a lake, the sampling methods do capture some of the population. So, although carp density is likely under represented, the methods do provide a reasonable year to year comparison.

Fish community data for Okabena Lake was summarized by trophic groups (Figures 3-1 and 3-2). Species within a trophic group serve the same ecological process in the lake (i.e., pan fish species feed on zooplankton and invertebrates; may serve as prey for predators). Analyzing all the species as a group is often a more accurate summary of the fish community then analyzing individual species trends. Results indicate pan fish, and in some years rough fish, are the most abundant species in Okabena Lake. Total biomass in Okabena Lake appears to shift year to year between top predators and rough fish, particularly common carp.

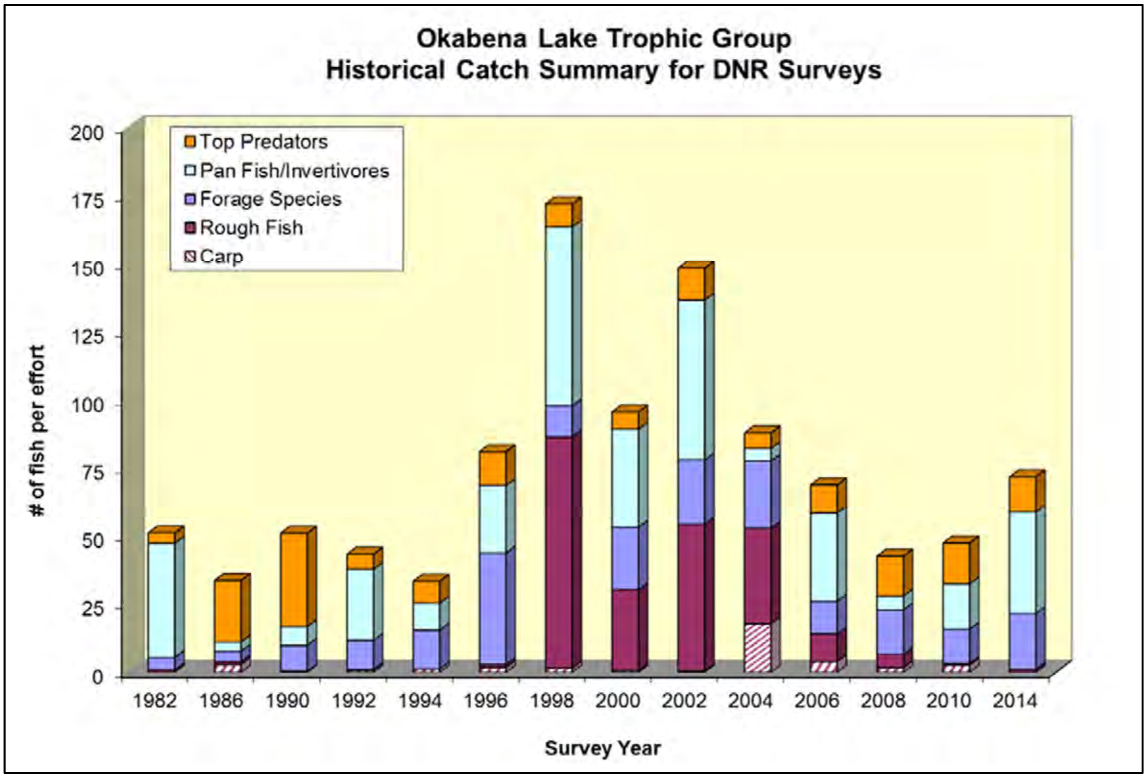


Figure 3-1. Trophic group abundance based on historic MN-DNR fish survey results.

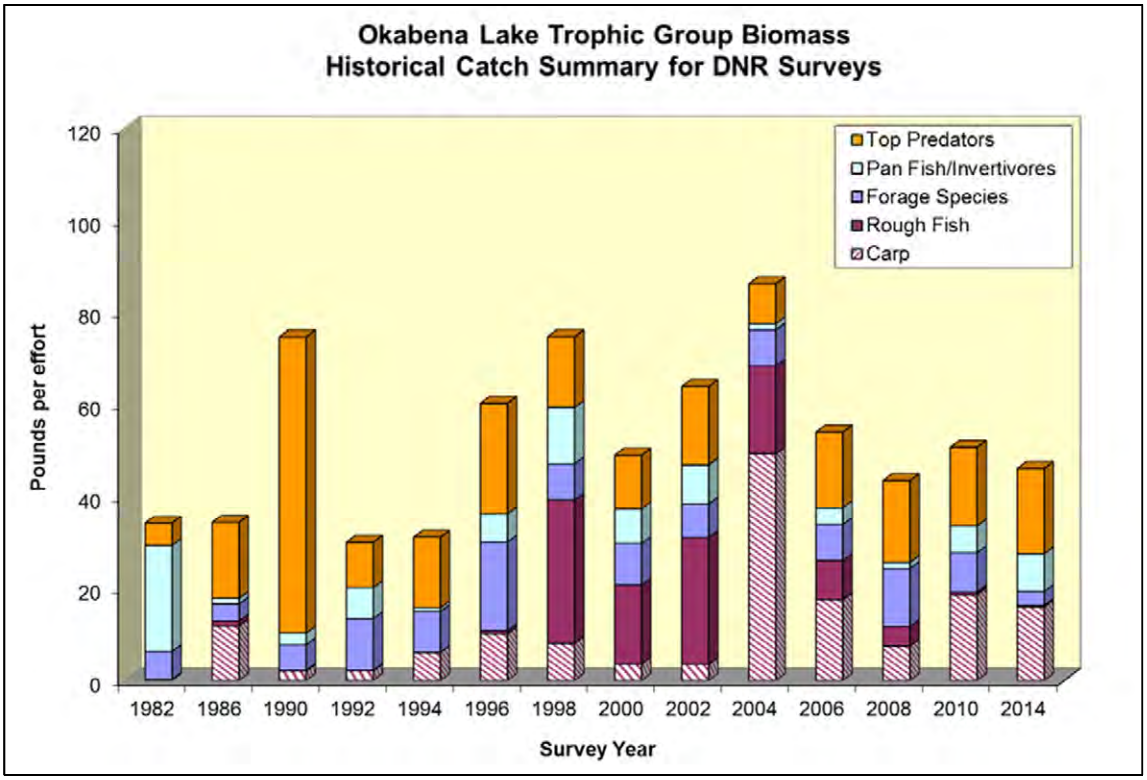


Figure 3-2. Trophic group biomass based on historic MN-DNR fish surveys

Common carp and other rough fish have both direct and indirect effects on aquatic environments. Carp uproot aquatic macrophytes during feeding and spawning and re-suspend bottom sediments and nutrients. These activities can lead to increased nutrients in the water column ultimately resulting in increased nuisance algal blooms. During spring spawning, carp aggressively move into marshes, ponds, wetlands, and other shallow, winterkill prone basins that are connected to the main lake through small streams and waterways. These shallow basins are typically free of predators and therefore allow common carp a reproductive advantage. In lakes with a significant amount of carp, disrupting fish access to potential spawning areas by installing fish barriers and other structures can be effective in limiting reproduction and managing carp populations.

Common carp were present during every survey since 1986 and have typically accounted for a low percent of the total catch count (<1%-20%), but a significant portion of the total catch biomass (3% - 57%). This indicates there are a few large carp present in the lake and their overall presence and relative size could be a factor in the lake's water clarity and re-establishing the plant community. It is difficult to determine the level to which common carp are reproducing in Okabena Lake and its watershed. The Boote-Herlein Marsh may have been one potential common carp spawning habitat, however a dam was built at the outlet of the marsh in 2014 and it is no longer connected to Okabena Creek. Other potential spawning locations include the Okabena Creek ponds located at the Prairie View Golf Links (Figure 2-2) and a small, shallow backwater area connected to Sunset Bay on the southwest corner of the lake (Figure 3-3). There have been several attempts by commercial fisherman dating back to 1926 to harvest and remove carp and other fish, primarily buffalo, bullhead, sucker, and catfish from the lake. However, it is unclear what affect these attempts (Figure 3-4) have had on carp populations and biomass in Okabena Lake.

Figure 3-3. Potential common carp spawning habitat near Sunset Bay (Image Source: Google Earth).

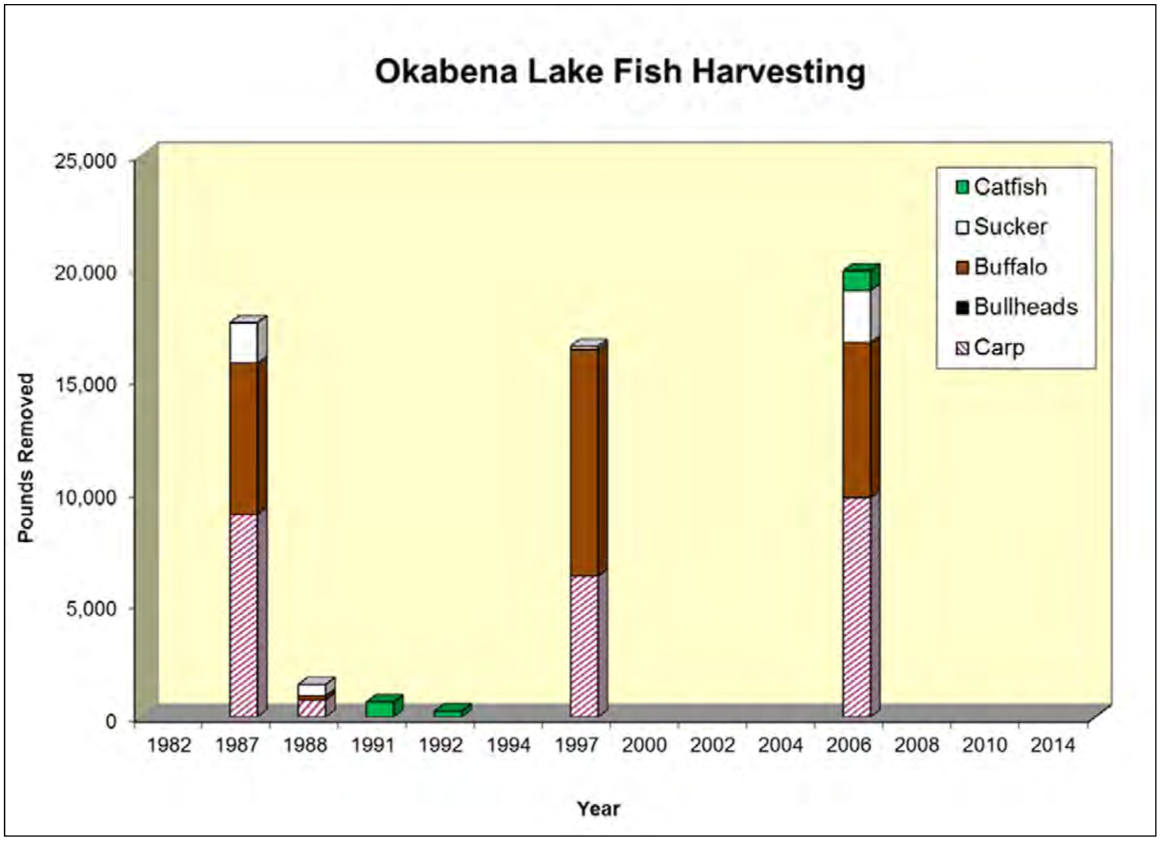


Figure 3-4. Okabena Lake fish harvesting since 1982.

4.0 External Source Assessment

4.1 INTRODUCTION

The primary purpose of this study is to develop a detailed sediment and phosphorus source assessment for Okabena Lake to better understand what is driving lake water quality. Sediment and phosphorus loading to lakes may come from external sources, as well as in-lake sources. This section examines the external sources of sediment and phosphorus to Okabena Lake including dry and wet deposition, and watershed runoff from the urban and rural portions of the watershed.

4.2 LAKE SURFACE DEPOSITION

4.2.1 Dry Deposition

Studies have shown deposition of wind-blown sediment, also referred to as dry deposition, can represent a significant proportion of a lake's total sediment and nutrient load. Dry deposition of sediment and phosphorus are often equal to, and in many cases greater than the sediment and phosphorus delivered from rainwater (wet deposition) via direct precipitation (Hicks et al, 1993). Wind erosion from human activities are often the biggest sources of wind-blown sediment. Some of these include: mining operations, agricultural practices, unpaved roads, aggregate storage piles and heavy construction activities. Depending on wind speed and soil particle size, wind-blown sediment from these sources may travel great distances before being deposited. Land cover in the 5 mile radius surrounding Okabena Lake is dominated by agriculture (85%), suggesting dry deposition of sediment and phosphorus on the lake is likely driven by farming practices. Studies in other agricultural regions have shown strong seasonal patterns of sediment and phosphorus deposition, with highest depositional rates coinciding with spring (April-June) and fall (October-November) planting and harvesting operations (Anderson and Downing, 2006; Cassel et al, 2000).

Estimating the amount of sediment and phosphorus that settles out and is deposited on land and water surfaces is a complex and poorly understood process. To do this for Okabena Lake, literature rates and methodology set forth in an MPCA report (Barr Engineering, 2007) were used that estimate dry deposition throughout different regions of Minnesota (Appendix A). Results of this analysis suggest average annual dry deposition of wind-blown sediment to Okabena Lake is approximately 195.6 tons per year, and dry deposition of phosphorus is 199 pounds per year (Table 4-1). These loading rates are moderately high, but are within the typical range for lakes in southwest Minnesota and agricultural areas throughout the Midwest (Anderson and Downing, 2006; Barr Engineering, 2007).

High potential wind erosion areas near Okabena Lake were identified using the Wind Erosion Prediction System (WEPS) model. WEPS is a process-based, daily time-step model that simulates weather, field conditions, and wind erosion. The model was designed by a multi-agency team of experts and is intended to provide users a tool for inputting initial field conditions to calculate soil loss for conservation planning and designing erosion control systems. WEPS model setup and assumptions for the 5 mile area surrounding Okabena Lake are presented in Appendix A. Model output results indicate wind-blown sediment losses from soybean fields near Okabena Lake ranged from 2.8 to 6.6 tons per acre per year, and were consistently higher than corn fields (1.2 – 3.6 tons per acre per year). Overall, approximately 2.8 tons per acre per year of sediment is potentially lost to wind erosion from the agricultural fields within 5 miles of Okabena Lake. This rate is also moderately high, but is within typical ranges estimated by the Natural Resources Conservation Service (NRCS) for cropland in southwestern Minnesota and other agricultural regions (NRCS, 2000). A map showing potential wind-blown sediment erosion hotspots near Okabena Lake is presented in Appendix A.

4.2.2 Wet Deposition

Wet deposition refers to the amount of sediment and phosphorus delivered to the surface of a lake from direct precipitation. Since phosphorus in rainwater has not been directly measured in or around the Okabena Lake watershed, it was calculated using a regression relationship between calcium and phosphorus concentrations in rainwater developed by the MPCA for Minnesota monitoring stations (Appendix A; Swain, 2003; Barr Engineering, 2007). Applying this regression to Okabena Lake estimates average annual wet deposition of phosphorus to the lake is 185.4 pounds per year, which is approximately 48% of the total dry+wet phosphorus deposition (Table 4-1). It was assumed sediment (TSS) concentrations in rainfall are small and any deposition of sediment during storm events is accounted for in the estimates for dry deposition.

4.2.3 Summary of Wet and Dry Deposition

Table 4-1 summarizes average annual TSS and TP to Okabena Lake from dry deposition and wet deposition sources. Since wind-blown sediment can travel great distances before being deposited, these sources will be difficult to control for Okabena Lake. That said, results of the WEPS model did identify several high potential wind erosion areas near Okabena Lake (Figure A-1 in Appendix A). These areas could be targeted for wind-erosion BMPs such as installing wind breaks/barriers, cover crops, creating soil ridges, and increasing crop residue through conservation tillage. Wet deposition of phosphorus is extremely difficult if not impossible to control and therefore no actions are suggested to manage these sources.

Table 4-1. Dry and wet deposition of sediment and phosphorus on Okabena Lake.

Parameter	Deposition Type	Average Areal Deposition Rate	Average Annual Deposition to Okabena Lake
Sediment (TSS)	dry	0.252 tons/acre/year	195.6 tons/year
Sediment (TSS)	wet	Assumed small or negligible	
Phosphorus (TP)	wet	0.239 lbs/acre/year	185.4 lbs/year
Phosphorus (TP)	dry	0.255 lbs/acre/year	197.9 lbs/year

4.3 WATERSHED SOURCES

Sediment and phosphorus transported by urban stormwater and agricultural runoff represents some of the largest external contributors of these pollutants to surface waters in Minnesota. Ditching through crop and pasture land and storm sewer systems in urban areas improve the efficiency of runoff, sediment and phosphorus moving to streams, wetlands and lakes. Sediment and phosphorus in runoff is a result of leaves and grass clippings, pet waste, excessive lawn watering, automobiles, illicit sanitary sewer connections, crop residue, field erosion, manure and fertilizers, and failing septic systems. The following sections describe the modeling and monitoring data used to estimate watershed runoff, sediment and phosphorus loading to Okabena Lake from urban and rural portions of the watershed.

4.3.1 Urban Sources

Urban land within Worthington's city limits accounts for approximately 15% of Okabena Lake's total watershed area. A P8 model (Program for Predicting Polluting Particles Passage thru Pits, Puddles & Ponds; Walker, 1996) was developed to estimate watershed loading from the City of Worthington. P8 is a public domain (http://wwwalker.net/p8/) industry standard model developed to assess pollutant loading in urban watersheds. P8 was developed using National Urban Runoff Program (NURP) data and provides loading estimates based on data collected as part of the NURP program. The model estimates the build-up and wash-off of particulates from impervious surfaces in the watershed. The NURP 50th percentile particle file was used to estimate watershed pollutant loading for the City of Worthington portion of the Okabena Lake watershed. The P8 model was also setup and used to estimate watershed loading from the rural (non-city) portions of the watersheds. Section 4.4.3 provides a summary and discussion of the rural portion of the P8 model. All inputs, assumptions, and calibration adjustments for the Okabena Lake watershed P8 model are presented in Appendix B.

The City of Worthington P8 model was developed for the most recent ten years (2005-2014) in which lake water quality was monitored. The model predicts 10-year average annual runoff volume, TSS load and TP load for the City of Worthington portion of each major subwatershed (Table 4-2). Appendix B also contains maps showing average annual TSS and TP loading rates by subwatershed. Results indicate the overall load contribution from the City of Worthington is relatively small compared to the rural portion of the watershed. Approximately 20% of the runoff from the City of Worthington is treated by one of eight city stormwater ponds before it enters the lake. Model output suggests these ponds perform relatively well in reducing sediment and phosphorus loads from these portions of the watershed. Currently, runoff from the Lake Direct, Lake Direct (Partial), and portions of the Okabena Creek and Sunset Bay Tributary subwatersheds is not retained or treated by any of the city stormwater ponds before entering the lake. In general, these subwatersheds exhibited higher areal TSS and TP loading rates (Table 4-2 and Appendix B).

Table 4-2. Model predicted average annual flow, TSS and TP loads for the City of Worthington portion of the Okabena Lake watershed.

Subwatershed	City Portion (acres	Flow (acre-	TSS Load		TP Load	
			tons/yr	tons/acre/yr	lbs/yr	lbs/acre/yr
Pond 1	80	45	2.3	0.03	25.1	0.31
Pond 2	7	3	<0.1	0.01	1.1	0.16
Pond 3	18	7	0.4	0.02	5.4	0.30
Pond 4	8	2	0.3	0.03	2.3	0.29
Pond 6	130	79	2.6	0.02	39.2	0.30
Okabena Creek	438	257	39.0	0.09	218.7	0.50
Sunset Bay Tributary	112	44	6.8	0.06	42.3	0.38
Lake Direct (Partial)	126	60	9.4	0.07	48.4	0.38
Lake Direct	520	260	40.0	0.08	215.6	0.41
Totals	**1,439**	**757**	**100.8**	**0.07**	**598.1**	**0.42**

4.3.2 Rural Sources

4.3.2.1 Watershed Monitoring and Modeling

In 2014, Okabena-Ocheda Watershed District staff collected periodic gauged flow measurements and water quality grab samples in Okabena Creek and the Sunset Bay tributary. The monitoring station locations are shown in Figure 2-1 and were selected to characterize the flow and water quality coming from the rural portions of the Okabena Lake watershed. Water quality samples were analyzed for TP, ortho-P, TSS and Volatile Suspended Solids (VSS). Appendix C provides a detailed description of the 2014 sampling results for each monitoring station.

Figures 4-1 and 4-2 show the 2014 TSS and TP sampling results for both monitoring stations and how they relate to average daily flow. Results indicate TSS and TP levels were low and below proposed state standards (TP = 150 ug/L; TSS = 65 mg/L) when stream flow was less than 5 cubic feet per second (cfs). A series of large storm events between June 14 and June 28 delivered over 7 inches of rainfall – about 32% of the total precipitation recorded at the Worthington Municipal Airport in 2014. During this time period, stream flow went from less than 5 cfs to well over 100 cfs in Okabena Creek and the Sunset Bay tributary. Also during this time TSS and TP measurements were very high and well above proposed state standards at both monitoring stations.

TSS, TP and ortho-P loads for 2014 were estimated by calculating each parameter's monitored flow-weighted mean (FWM) concentration and multiplying this by the total annual flow volume. The 2014 FWMs and loading calculations for Okabena Creek and the Sunset Bay Tributary are presented in Appendices B and C. These estimates were used to adjust and calibrate the rural portion of the Okabena watershed P8 model. The TP and ortho-P loading results indicate that only 19%-28% of the TP load from the rural portion of the watershed is in dissolved form (ortho-P). This suggests a majority of the phosphorus delivered to Okabena Lake is in particulate form, likely attached to soil and TSS particles. Thus, targeting BMPs to decrease sediment loading from rural areas should have a significant impact on TP loading as well. Overall, the 2014 loading estimates show that between 56% and 73% of the total flow, TSS load and TP load from Okabena Creek and the Sunset Bay Tributary came during the two week high flow event in late June. This indicates flow and pollutant loading from the rural portions of the watershed are event driven and very sensitive to large, early season storm events.

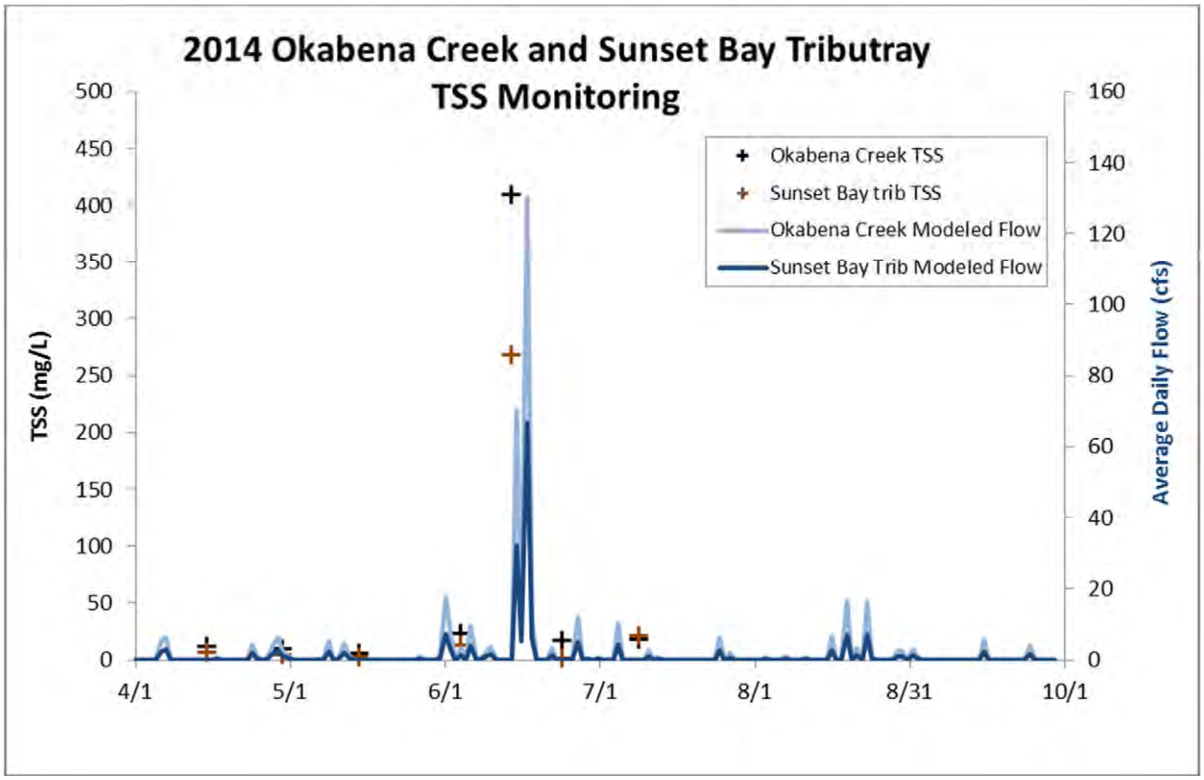


Figure 4-1. Stream TSS monitoring results for 2014.

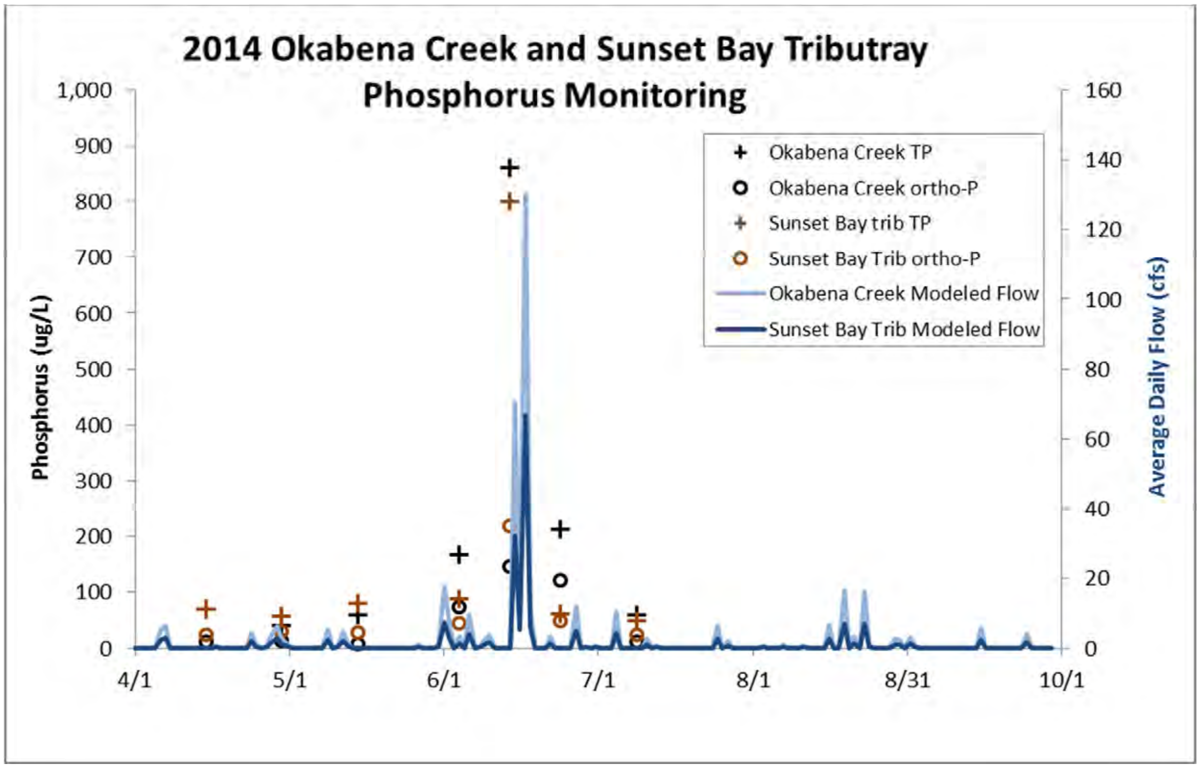


Figure 4-2. Stream TP and ortho-P monitoring results for 2014.

The 2014 monitoring data was used in conjunction with the P8 model to estimate average annual flow, TSS and TP loading from the rural portions of the Okabena Lake watershed. Appendix B provides a complete discussion of the model inputs, assumptions and loading adjustments used for the rural portion of the P8 model. Similar to the urban portion of the model, the rural P8 model was setup and run for the most recent ten years (2005-2014) in which lake water quality was monitored. The model predicted 10-year average annual runoff volume, TSS load and TP load for the rural portion of each major subwatershed are presented in Table 4-3. Appendix B also contains maps showing average annual TSS and TP loading rates by subwatershed.

Model results suggest the total flow, sediment and phosphorus loads from rural areas are significantly greater than loads from the urban portion of the watershed. Overall, approximately 88% of the watershed TSS load comes from rural areas, while city stormwater accounts for 12% of the TSS load. Similarly, 89% and 11% of the watershed TP load comes from rural and city runoff, respectively. Subwatershed loading analyses indicate a majority of the rural watershed TSS and TP load comes from Okabena Creek (61%) and the Sunset Bay Tributary (34%).

Areal loading rates were highest in the Okabena Creek, Sunset Bay Tributary, and Lake Direct subwatersheds. Loading rates for the rural portions of the watershed that flow to city stormwater ponds (Pond 1-4 and 6) were slightly less depending on subwatershed size and treatment efficiency of the pond.

Table 4-3. Model predicted average annual flow, TSS and TP loads for the rural portion of the Okabena Lake watershed.

Subwatershed	Rural Portion (acres	Flow (acre-	TSS Load		TP Load	
			tons/yr	tons/acre/yr	lbs/yr	lbs/acre/yr
Pond 1	<1	1	<0.1	0.03	0.3	0.30
Pond 2*	--	--	--	--	--	--
Pond 3	22	6	0.7	0.03	11.2	0.51
Pond 4	200	53	13.5	0.07	135.5	0.68
Pond 6	149	42	3.1	0.02	57.9	0.39
Okabena Creek	4,868	1,397	472.1	0.10	3,026.5	0.62
Sunset Bay Tributary	2,517	718	259.6	0.10	1,706.4	0.68
Lake Direct (Partial)*	--	--	--	--	--	--
Lake Direct	241	71	23.3	0.10	148.3	0.62
Totals	**7,998**	**2,288**	**772.3**	**0.10**	**5,086.1**	**0.64**

* These subwatersheds do not contain any land outside the City of Worthington municipal boundary

The following sections are intended to provide a better understanding of potential loading from animal agriculture, upland field erosion, and streambank erosion throughout the rural portions of the Okabena Lake watershed.

4.3.2.2 Animal Agriculture

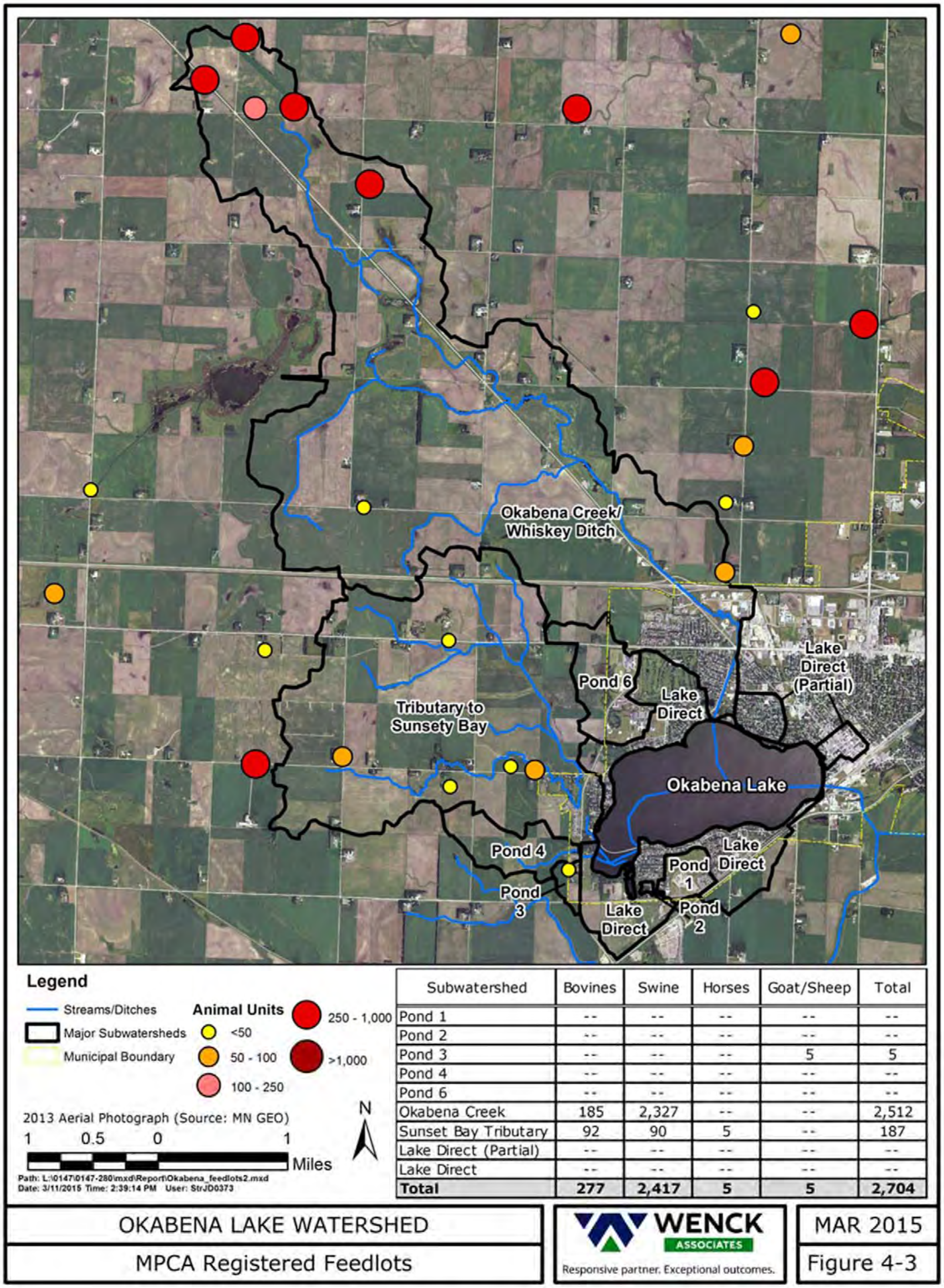
To assess the relative role of manure management on surface water nutrient concentrations and loads, an inventory of all registered agricultural animals in the Okabena Lake watershed was conducted. The MPCA maintains a statewide GIS database of registered feedlots throughout the state of Minnesota. The MPCA categorizes feedlots based on the number of registered animal units, which are the standardized measurement of animals for various agricultural purposes. Figure 4-3 shows all registered feedlots in the Okabena Lake watershed.

There are currently 12 registered feedlot operations and more than 2,700 total animal units throughout the Okabena Lake watershed. It should be pointed out that these numbers reflect each operator's permitted limit, and local knowledge has indicated some of these operations are not currently operating at full capacity. There are several large feedlot operations located just outside the Okabena Lake watershed boundary. A feedlot owner is required to apply for an National Pollutant Discharge Elimination System (NPDES) feedlot permit when a new or expanding facility will have a capacity of 1,000 animal units or more; or if it meets or exceeds the EPA Large Concentrated Animal Feedlot Operation (CAFO) threshold. There is currently one NPDES permitted feedlot operation in the Okabena Lake watershed. This operation contains approximately 3,000 pigs (900 animal units) and is located in the northern portion of the Okabena Creek subwatershed. There are several smaller, non-NPDES registered feedlot operations located throughout the watershed, mostly in the Okabena Creek and Sunset Bay tributary sub watersheds (Figure 4-3). Three operations alone in the Okabena Creek subwatershed account for over 83% of the animal units throughout the watershed.

Manure produced by the animals in the watershed is typically deposited on pasture lands and/or applied to fields for fertilizer as well as general manure management. Manure that is applied to fields during sensitive portions of the year or beyond the nutrient uptake ability of the crops may move easily into the surface waters adding to eutrophication and nutrient loads.

Total mass of phosphorus produced by each animal unit category can be estimated using literature values (Evans et al 2002). Based on these estimates, over 300,000 pounds of phosphorus are potentially applied to land in the form of manure throughout the Okabena Lake watershed (Table 4-4). To put this in perspective, average annual watershed loading to Okabena Lake from rural areas throughout the watershed is typically around 5,086 pounds or approximately 2% of the phosphorus potentially applied to the land throughout the watershed. Only a small proportion of this phosphorus need make its way to the lake to cause serious eutrophication issues.

The Okabena Lake watershed P8 model does not explicitly model phosphorus contributions from manure spreading. The model does, however, implicitly account for animal contributions by calibrating to water quality data collected at the Okabena Creek and Sunset Bay tributary monitoring locations. The watersheds draining to these sites are the largest surface inflows to Okabena Lake and should be representative of the surrounding non-monitored watersheds assuming manure practices are similar and spreading occurs close to where the animals are contained.



Subwatershed	Bovines	Swine	Horses	Goat/Sheep	Total
Pond 1	--	--	--	--	--
Pond 2	--	--	--	--	--
Pond 3	--	--	--	5	5
Pond 4	--	--	--	--	--
Pond 6	--	--	--	--	--
Okabena Creek	185	2,327	--	--	2,512
Sunset Bay Tributary	92	90	5	--	187
Lake Direct (Partial)	--	--	--	--	--
Lake Direct	--	--	--	--	--
Total	**277**	**2,417**	**5**	**5**	**2,704**

Figure 4-3. MPCA registered feedlots and animal units in the OkabenaLake watershed.

Table 4-4. Agriculture animal phosphorus production by subwatershed.

Subwatershed	Agriculture Land (acres)	Total P (lbs/year)	Total P (lbs/acre/yr)
Pond 1	46	--	--
Pond 2	1	--	--
Pond 3	29	361	12.4
Pond 4	199	--	--
Pond 6	169	--	--
Okabena Creek	4,266	293,768	68.9
Sunset Bay Tributary	2,346	17,794	7.6
Lake Direct (Partial)	<1	--	--
Lake Direct	257	--	--
Total	**7,313**	**311,923**	**42.7**

4.3.3 Field Erosion

Average upland soil loss for the rural portions of the Okabena Lake watershed was modeled using the RUSLE. This model provides an assessment of existing soil loss from upland sources and the potential to assess sediment loading through the application of BMPs. RUSLE predicts the long term average annual rate of erosion on a field slope based on rainfall pattern, soil type, topography, land use and management practices. A description of RUSLE model setup and adjustments is provided in Appendix D. Model results predict a watershed-wide gross average annual soil loss of 3,273.4 tons per year (Table 4-5). While this is a significant amount, much of the soil loss occurring on the fields is not fully transported off site to the stream channels as it is trapped by buffers, ditches ponds and wetlands throughout the watershed. Since RUSLE does not take these factors into account, a sediment delivery ratio (Appendix D) was used to estimate the amount of upland soil loss delivered downstream.

After applying this factor, it is estimated about 21% of the gross soil loss, or 700.8 tons is delivered and transported downstream. This value represents approximately 91% of the average annual sediment load from rural areas predicted by the P8 model (772.3 tons/year). Results show Okabena Creek and the Sunset Bay Tributary are responsible for a majority of the TSS delivered to Okabena Lake from field erosion (Table 4-5). However, areal loading rates indicate potential soil loss is also high in the Pond 4 subwatershed. Figure 4-4 shows several modeled erosion hotspots where potential field erosion is greater than 3 tons/acre/year. These hotspots, particularly those in the Okabena Creek and Sunset Bay Tributary subwatersheds, could be targeted to reduce/minimize soil loss. Possible BMPs include increased buffers, grassed waterways, conservation and/or contour tillage, cover crops, and water and sediment control basins.

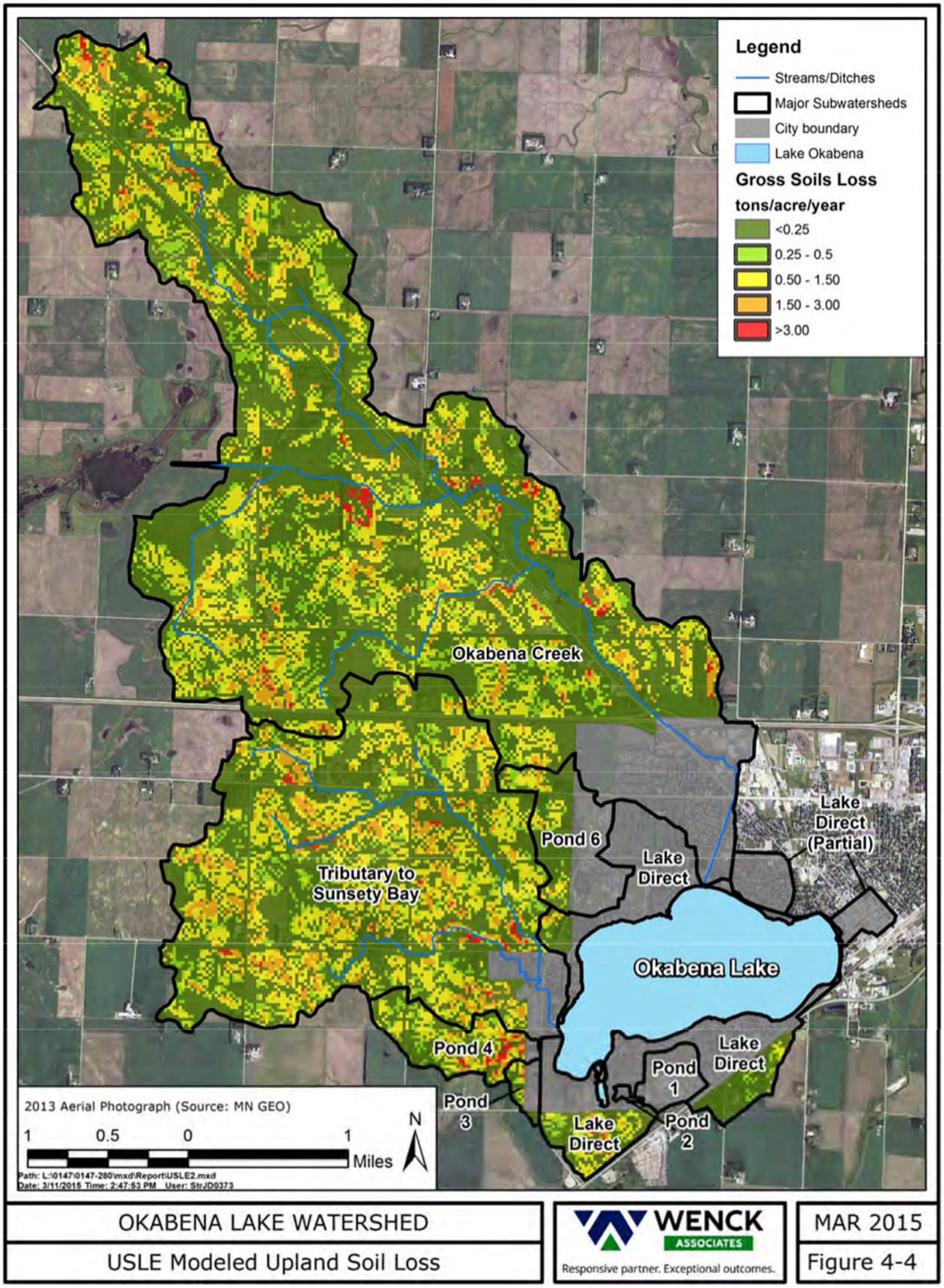


Figure 4-4. Potential rural upland soil loss in the Okabena Lake Watershed.

Table 4-5. Potential soil loss by subwatershed.

Watershed	Rural Portion (acres)	Gross Soil Loss (tons/acre/yr)	Gross Soil Loss (tons/yr)	Soil Loss Delivered to Streams (tons/yr)
Pond 1	<1	<.01	<0.1	<0.1
Pond 2*	--	--	--	--
Pond 3	22	0.37	7.9	2.2
Pond 4	200	0.66	132.0	36.1
Pond 6	149	0.25	37.5	4.1
Okabena Creek	4,868	0.37	1,804.2	334.8
Sunset Bay Tributary	2,517	0.48	1,215.1	278.8
Lake Direct (Partial)*	--	--	--	--
Lake Direct	241	0.32	76.7	44.8
Totals	**7,998**	**0.41**	**3,273.4**	**700.8**

* These subwatersheds do not contain any land outside the City of Worthington municipal boundary

4.3.4 Stream Bank Erosion

Land cover changes in the riparian zone may weaken stream banks by reducing or eliminating long-rooted native vegetation that strengthens and stabilizes the banks. Changes in flow regime may also destabilize stream banks that are exposed to prolonged periods of wetting or wet-dry cycles. A streambank assessment was performed by Okabena-Ocheda Watershed District staff to assess bank conditions as a potential source of sediment to Okabena Lake. Okabena Creek and the major tributary to Sunset Bay were walked, and erosion features were noted and measured (Appendix D).

Streambank conditions were variable, with some banks relatively stable, and others with moderate amounts of slumping and sloughing, especially on outer bends. Along Okabena Creek, the sections demonstrating significant bank erosion were located between Oxford Street and the Prairie View Golf Links (Appendix D). This section of Okabena Creek is situated downstream of the golf course's in-channel treatment ponds and is relatively buffered with some small meanders and channel sinuosity. Upstream of Prairie View Golf Links, Okabena Creek becomes more intermittent and flows through a series of ponded areas and gently sloped ditches buffered by tall grasses and emergent wetland vegetation. This section of Okabena Creek is relatively straight with very few sharp bends that often lead to unstable banks. No major bank erosion features were noted in the upper portions of Okabena Creek during the 2013 survey.

In general, the major tributary to Sunset Bay displays very little streambank erosion. The only section demonstrating significant bank erosion was the tributary's south branch between 260th Street and Oliver Avenue (Appendix D). Similar to Okabena Creek, most of the upper portions of this tributary are comprised of relatively straight, gently sloped ditches or grass waterways that receive intermittent flow.

Stream bottom sediments ranged from very fine muck to small gravel, often within the same sub reach. Some aggradation, deposition, and braiding were observed on the stream walking survey, particularly in areas with either bank sloughing or mass wasting. To evaluate whether soil loss from streambank erosion may be contributing significantly to sediment load, Okabena Creek and the tributary to Sunset Bay were evaluated for stability and amount of observed soil loss. Average annual soil loss for Okabena Creek and the Sunset Bay tributary were estimated using a method developed by the Natural Resources Conservation Service referred to as the "NRCS Direct Volume Method," or the "Wisconsin method," (Wisconsin NRCS 2003). Description of this method and how it was applied to Okabena Creek and the Sunset Bay tributary is discussed in more detail in Appendix D.

During the stream bank survey, watershed district staff noted and measured 15 bank erosion "problem areas" along Okabena Creek, and 4 problem areas along the Sunset Bay tributary (Appendix D). Using the Wisconsin Method, it was estimated these problem areas contribute approximately 31.1 tons of sediment per year to the stream channels. This value is relatively small compared to field erosion (700.8 tons/year) and only about 4% of the average annual sediment load from rural areas predicted by the P8 model (772.3 tons/year). Streams do experience some sediment loss each year from natural processes. According to the Wisconsin NRCS and based on their surveys of a number of streams throughout Wisconsin, a stream that is relatively undisturbed and at low risk for erosion typically experiences lateral recession of 0.01-0.05 feet per year. Therefore, it was assumed the remaining sediment load after the field erosion and problem area bank erosion estimates were subtracted from the total rural sediment load represents "natural background" stream bank erosion. Thus, about 57% (40.4 tons per year) of the sediment load delivered from the stream banks throughout the Okabena Lake watershed could be considered natural background, while 43% (31.1 tons per year) is considered "excess" sediment load. These results suggest that even though there are a few isolated areas of bank erosion occurring throughout the watershed, BMP planning and implementation to address upland field erosion should be a higher priority.

4.4 EXTERNAL LOADING CONCLUSIONS

Table 4-6 below summarizes the average annual external sediment and phosphorus loads to Okabena Lake based on the analyses and modeling presented in this section. Results indicate a majority of external sediment and phosphorus loading to Okabena Lake comes from the rural portions of the Okabena Lake watershed. Upland field erosion was by far the biggest external source of sediment to Okabena Lake, accounting for approximately 65% of the total load. At this time, there is not enough data/information available to estimate the amount of sediment and phosphorus loading from animal agriculture practices. That said, estimates of the average annual phosphorus produced by livestock in the Okabena Lake watershed suggest animal agriculture and manure spreading could be a significant source. While this study was able to quantify sediment loading from field erosion and streambank erosion, the amount of phosphorus associated with these sediment loads was not estimated. 2014 monitoring data showed most of the phosphorus load from the rural portions of the watershed is in particulate form, likely attached to sediment particles that are delivered during large storm events. Thus, it is safe to assume a large portion of the rural phosphorus load also comes from upland field erosion and the greater the amount of manure applied to this soil, the greater the resultant phosphorus load will be.

Table 4-6. External loading summary for Okabena Lake.

Source	Sediment (TSS)		Phosphorus (TP)	
	tons/year	**Percent**	**lbs/year**	**Percent**
Dry Deposition	195.6	18%	197.9	3%
Wet Deposition	0	0%	185.4	3%
City Runoff	100.8	10%	598.1	10%
Rural Runoff (Total)	772.3	72%	5,086.1	84%
- Animal Agriculture	?	?	?	?
- Field Erosion	700.8	65%	?	?
- Streambank Erosion	71.5	7%	?	?
Total	**1,068.7**		**6,067.5**	

5.0 Internal Source Assessment

5.1 SEDIMENT CHEMISTRY

Sediment cores were collected by Okabena-Ocheda Watershed District staff and Wenck Associates at four locations in Okabena Lake on February 19, 2014 (Figure 5-1). The sediment cores were transported to the Discovery Center – Sustainability Sciences Institute Laboratory at the University of Wisconsin – Stout where the top 10 centimeters of each core were analyzed for sediment chemistry. Sediment core chemical analysis included moisture content, organic matter content, sediment density, total iron, and phosphorus (P) content and fractionation. A complete description of the laboratory methodology and results are included in Appendix E (University of Wisconsin – Stout and Wenck Associates, 2014). Sediment chemistry results measured in the top 5 centimeters showed some spatial variability between the four Okabena Lake sampling sites. Moisture and organic matter content were slightly higher and dry bulk density was lower at the Sunset Bay site compared to the three sites located in the lake's main basin. These results suggests Sunset Bay has effectively settled and accumulated more flocculent, fine-grained sediment particles from the tributary that drains the western portion of the lake's watershed. Sites 1, 3 and 4 in the main basin exhibited very low organic matter content (6.9% to 7.5%), moderately low moisture content (64% to 68%) and relatively high sediment dry bulk densities (0.402 g/cm^3 to 0.457 g/cm^3). This suggests the sediment throughout the lake's main basin is relatively compacted and primarily composed of clay and fine silt particles.

The biggest drivers of phosphorus release from lake sediments are the amount of phosphorus in the sediment, and the type of chemical bonds that bind phosphorus to other particles in the sediment. Phosphorus bonds can be very strong and difficult to break, or weak and easy to break depending on conditions within the sediment porewater and overlying water column. For example, phosphorus forms a weak bond with iron that is easily broken when water near the sediment surface is anaerobic (low oxygen and redox potential). When this occurs, phosphorus is released from the sediment in dissolved form to the overlying water column. In lakes, dissolved phosphorus is rapidly taken up by algae which can lead to severe algae blooms. Loosely bound phosphorus and labile organic phosphorus are two other phosphorus fractions that tend to form weak bonds and are easily released from the sediment. In contrast, there are several phosphorus fractions that have stronger chemical bonds that are more difficult to break, such as aluminum and calcium. Collectively, these fractions are often referred to as refractory P and are subject to burial rather than recycling. Quantifying all of the aforementioned forms of phosphorus in lake sediments is an effective way to predict the potential phosphorus release under various conditions.

Sediment core phosphorus analyses indicate Okabena Lake sediment total phosphorus content at all four sites is low and below the 25th percentile measured in lakes throughout Minnesota. Total phosphorus concentration in Sunset Bay was slightly lower than the main basin sites, however Sunset Bay did display higher fractions of iron bound, loosely bound and labile organic phosphorus (Figure 5-2). This suggests Sunset Bay may have a higher potential for sediment phosphorus release compared to the other sites in the main part of the lake. Total iron concentrations in the surface sediment layer at all four sites were near the median compared to other lakes in Minnesota. Okabena Lake iron:phosphorus ratios were high, ranging between 25:1 and 37:1. In general, lakes with iron:phosphorus ratios less than 15:1 tend to display high rates of sediment phosphorus release.

Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

OKABENA LAKE

Sediment Core Locations

WENCK ASSOCIATES

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Figure 5-1

Figure 5-1. Okabena Lake sediment core sites.

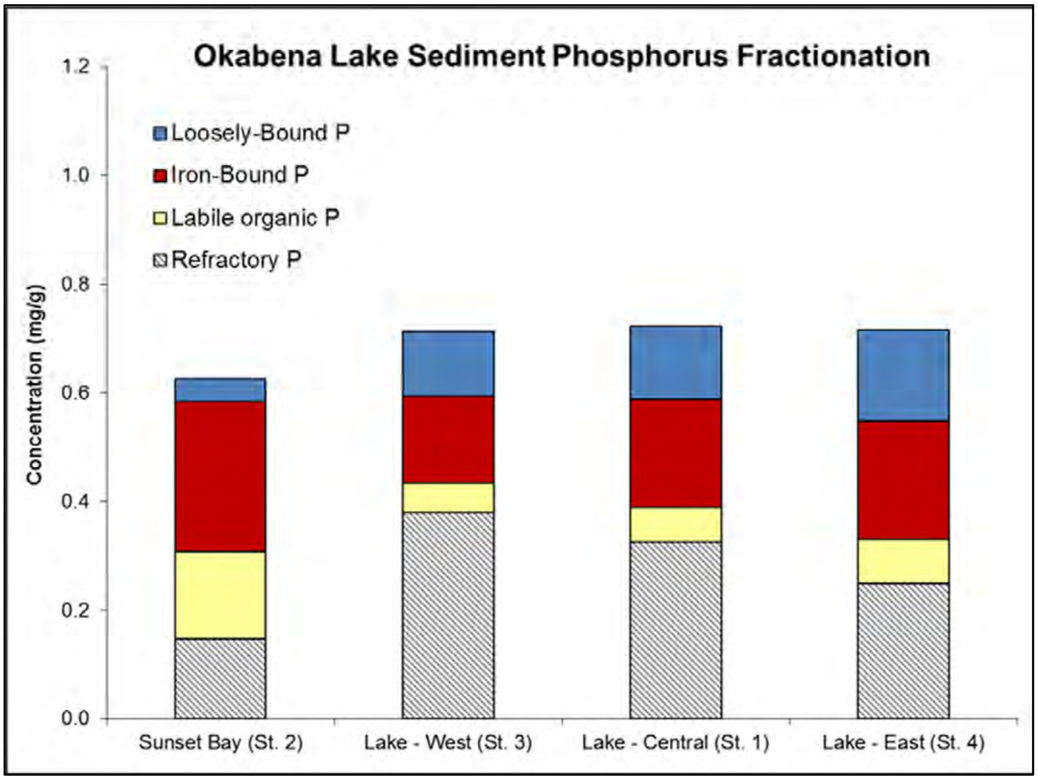

Figure 5-2. Okabena Lake sediment phosphorus fractionation for each monitoring station. Iron-bound P, loosely-bound P, and labile organic P are the fractions most susceptible to recycling and phosphorus release from sediment.

5.1.1 Sediment Phosphorus Release

Internal phosphorus loading from lake sediments can be a major component of a lake's phosphorus budget. In order to estimate internal phosphorus loading in Okabena Lake, sediment from the top 10 centimeters at the central main basin site (Site 1, Figure 5-1) were incubated for approximately 20 days in the lab at 20°C under both anaerobic (low oxygen) and aerobic (oxygenated) conditions. The lab measured phosphorus release rate under anaerobic conditions for Site 1 was 2.7 mg/m^2/day (Appendix E). This rate is moderate compared to other lakes in Minnesota, falling in the lower 25% quartile. The mean phosphorus release rate under aerobic conditions was 0.62 mg/m^2/day. While this rate is lower than the anaerobic release rate, the aerobic release rate is relatively high compared to other lakes in Minnesota (upper 25% quartile). Typically, rates of phosphorus release are higher under anaerobic versus aerobic conditions, due to weak binding of phosphorus to iron in the sediment under aerobic conditions. Since Okabena Lake is shallow and exposed to wind-generated mixing, aerobic conditions likely regulate phosphorus release from sediments throughout much of the year.

Using the lab measured release rates to calculate annual internal loading for the entire lake can be difficult, especially in shallow lakes that mix several times throughout the year. To estimate total internal load, an anoxic factor (Nürnberg 2004) is used which estimates the period where anoxic conditions exist over the sediments. The anoxic factor is expressed in days but is normalized over the area of the lake and is typically calculated using dissolved oxygen (DO) profile data. Bottom water DO measurements were collected by Okabena-Ocheda Watershed District staff at least once per month at three separate Okabena Lake monitoring sites in 2013 and 2014. However; no anoxia (DO less than 2.0 mg/L) was observed at any of the sites during the 2013 and 2014 summer growing season. It is important to note that shallow lakes can often demonstrate short periods of anoxia due to instability of stratification. This instability can last a few days or even a few hours, and are often missed by periodic field measurements. Thus, the following equation was used to estimate the anoxic factor for Okabena Lake (Nürnberg, 2005):

$$AF_{shallow} = -35.4 + 44.2 \log (TP) + 0.95\ z/A^{0.5}$$

Where TP is the average summer phosphorus concentration of the lake, z is the mean depth (m) and A is the lake surface area (km^2). Once the anoxic factor has been calculated, an oxic factor may be estimated which represents the number of days the lake's sediments are well oxygenated (oxygen concentration greater than 2.0 mg/L). For Okabena Lake, the oxic factor was calculated by subtracting the length of the summer growing season (122 days) by the anoxic factor. This calculation assumes the lake's sediments shift between oxic and anoxic conditions throughout the summer growing season. The anoxic and oxic factors are then multiplied by the anaerobic and aerobic sediment release rates and the total area of the lake to estimate gross internal load. The laboratory measured release rates, anoxic and oxic factors, and total estimated internal load for Lake Okabena under both conditions are presented in Table 5-1.

Table 5-1. 2005-2014 average annual internal load estimates for Okabena Lake.

Parameter	**Oxic Release**	**Anoxic Release**
Oxic/Anoxic factor (days)	60	62
Release Rate ($mg/m^2/day$)	0.62	2.7
Total Internal Load (lbs/year)	256	1,157
	1,413 lbs/year	

Figure 5-3 displays all Okabena Lake surface TP measurements since 1998 summarized by month using box plots. In-lake phosphorus is relatively low during the wet months, April and May, and begins steadily increasing from June through October. Typically, by early August watershed inputs to the lake are low and therefore internal load is likely driving high in-lake TP values. So even though the annual internal phosphorus load to Okabena Lake is less than external sources of phosphorus (6,067.5 pounds), it is still an important source during certain times of the year (Aug–Oct) that may need to be addressed.

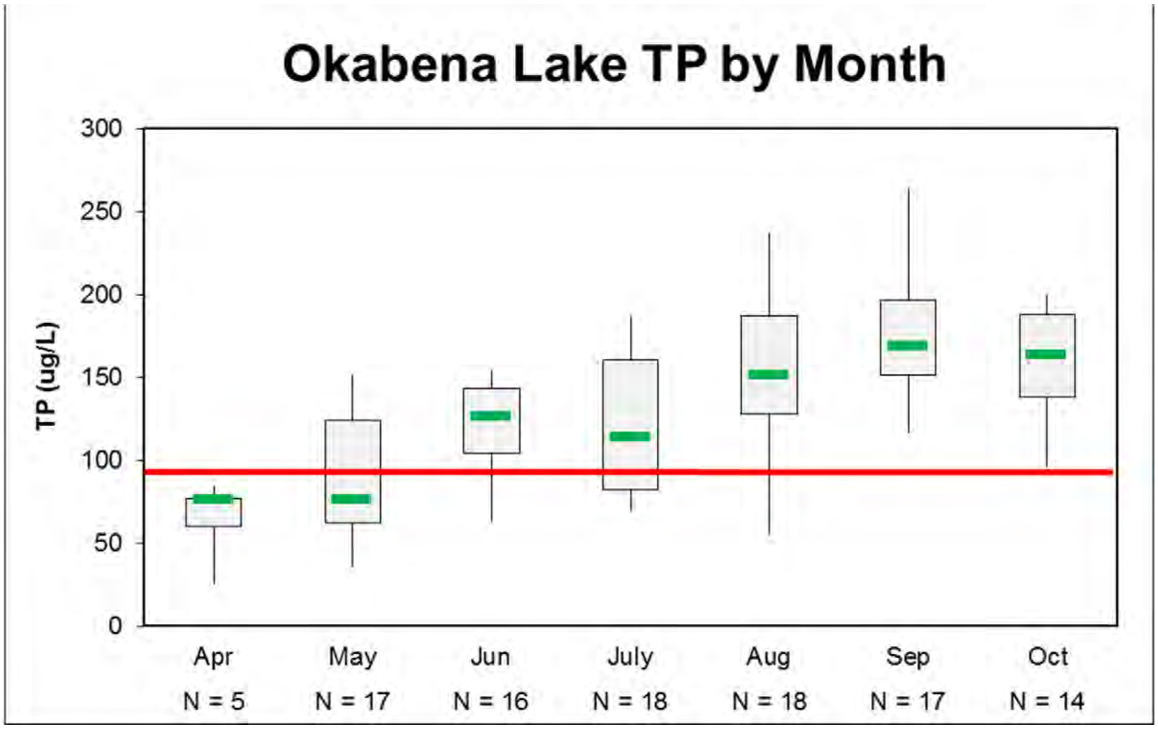

Figure 5-3. Box plots showing monthly surface TP monitoring for Okabena Lake.
Note: The upper and lower edge of each box represent the 75th and 25th percentile of the data range for each month. Error bars above and below each box represent the 95th and 5th percentile of the dataset. The green dash is the median TP concentration of all data collected. The solid red line shows the TP standard (90 µg/L) for shallow lakes in the Western Corn Belt Plains Ecoregion.

6.0 Recommendations and Conclusions

Water quality data for Okabena Lake indicate the lake is currently not meeting state water quality standards for water clarity, TP and chlorophyll-a. These data suggest both excessive algae growth due to high nutrient levels (TP) and sediment (TSS) resuspension are the main factors driving poor water clarity in Okabena Lake. Thus, restoring water quality in Okabena Lake will need to focus on decreasing phosphorus loading to the lake, as well as decreasing external TSS loading and the potential for in-lake sediment resuspension.

The primary purpose of this study was to improve the understanding of Lake Okabena's sediment and phosphorus sources. Specifically, this study investigated the following sources of sediment and phosphorus: dry and wet deposition on the lake surface; runoff from the City of Worthington; rural field erosion, streambank erosion, and animal agriculture; and internal loading of phosphorus from the lake sediments. These sources were estimated using a combination of monitoring data, literature rates, and modeling exercises. Average annual sediment and phosphorus loading to Okabena Lake is presented in Table 6-1 and Figures 6-1 and 6-2. These results support the following conclusions:

- Dry deposition accounts for approximately 18% of the annual sediment load and 3% of the phosphorus load to Okabena Lake. Modeling suggests potential wind erosion rates in areas surrounding Okabena Lake is moderately high, but within typical range for lakes in southwest Minnesota and agricultural areas throughout the Midwest. Dry deposition sources are difficult to control, however areas with high wind-erosion potential could be targeted for BMPs such as wind breaks/barriers, cover crops, soil ridges, and increasing crop residue through conservation tillage.
- It is estimated that only 2% of the phosphorus load comes from wet deposition (rainfall). For this study, it was assumed sediment (TSS) concentrations in rainfall are small and any deposition of sediment during storm events is accounted for in the estimates for dry deposition.
- Sediment and phosphorus loading from the City of Worthington accounts for about 10% and 8% of the total load to Okabena Lake, respectively. There are currently 8 stormwater ponds located throughout the city that provide storage and treatment for some of the city stormwater before entering the lake. Runoff from the Lake Direct, Lake Direct (Partial), and portions of the Okabena Creek and Sunset Bay Tributary subwatersheds is not retained or treated by any of the city stormwater ponds before entering the lake. These subwatersheds exhibited higher areal TSS and TP loading rates and could be assessed and targeted for stormwater BMP retrofit opportunities.
- It is recommended that water quality (TP and ortho-P) be monitored during the summer growing season in at least 2-3 city stormwater ponds for 1-2 years. Priority should be given to constructed ponds with larger drainage areas to validate modeling results and determine pond efficiency, maintenance needs and/or potential improvements.
- Approximately 85% of the Okabena Lake watershed is located outside of the City of Worthington in rural Nobles County. Runoff from rural areas is the largest contributor of sediment and phosphorus to Okabena Lake. The primary rural sources of sediment and phosphorus to Okabena Lake include field erosion, streambank erosion, and animal agriculture.
- Monitoring data collected in 2014 indicate runoff from rural areas is event driven and most of the pollutant load is delivered during large, early season storm events.

Therefore, rural BMP planning and design must focus on treating these high flow conditions. This may require exploring opportunities for additional retention and treatment for Okabena Creek and the Sunset Bay Tributary, along with continuing to implement upland BMPs and responsible farming practices. It is recommended that the 2014 watershed monitoring program be extended for at least 1-2 more years in order to develop a more robust database with multiple years of data to better estimate stream flow, TSS and TP loading from the rural portions of the watershed.

- Upland field erosion accounts for a majority (65%) of the sediment load to Okabena Lake. Most of the upland sediment is delivered by Okabena Creek and the Sunset Bay Tributary during large storm events. Rural areas with high erosion potential should be targeted for BMPs such as increased buffers, grassed waterways, conservation and/or contour tillage, cover crops, and water and sediment control basins.
- Streambank erosion accounts for only 7% of the sediment load to Okabena Lake. While there are a few problem areas throughout the watershed that could be targeted for repairs, it does not appear they are a significant contributor.
- This study did not estimate the exact amount of phosphorus delivered from upland field erosion and streambank erosion. However, 2014 stream monitoring data suggests a majority of the phosphorus from rural areas is attached to sediment particles and therefore most of the rural phosphorus load likely comes from upland field erosion.
- It was estimated that over 300,000 pounds of phosphorus is produced by livestock in the Okabena Lake watershed each year. While this study was not able to determine the exact amount of livestock phosphorus that reaches the lake, these results suggest manure spreading is likely a significant source and local farmers should continue implementing responsible manure management practices.
- In-lake sediment phosphorus fractionation analyses showed Sunset Bay had higher fractions of phosphorus that are susceptible to recycling and phosphorus release from the sediment compared to three sites in the main lake basin. It is recommended that surface water quality samples (TP and ortho-P) be collected in Sunset Bay during the summer growing season to determine if Sunset Bay is experiencing high levels of sediment phosphorus release.
- Phosphorus release from lake sediments represents approximately 19% of the total phosphorus load to Okabena Lake. While Okabena Lake’s lab measured release rates were moderate compared to other lakes, in-lake monitoring data indicates internal phosphorus release likely plays a significant role during the late summer months when TP load from the watershed is low. Additionally, phosphorus loading from sediments is released in dissolved form which is rapidly taken up by algae and can lead to severe algae blooms.

Table 6-1. Average annual sediment and phosphorus loading to Okabena Lake by source.

Source	Sediment (TSS)		Phosphorus (TP)	
	tons/year	**Percent**	**lbs/year**	**Percent**
Dry Deposition	195.6	18%	197.9	3%
Wet Deposition	--	--	185.4	2%
City Runoff	100.8	10%	598.1	8%
Rural Runoff (Total)	772.3	72%	5,086.1	68%
- Animal Agriculture	?	?	?	?
- Field Erosion	700.8	65%	?	?
- Streambank Erosion	71.5	7%	?	?
P Release from Sediments	--	--	1,413.0	19%
Total	**1,068.7**		**7,480.5**	

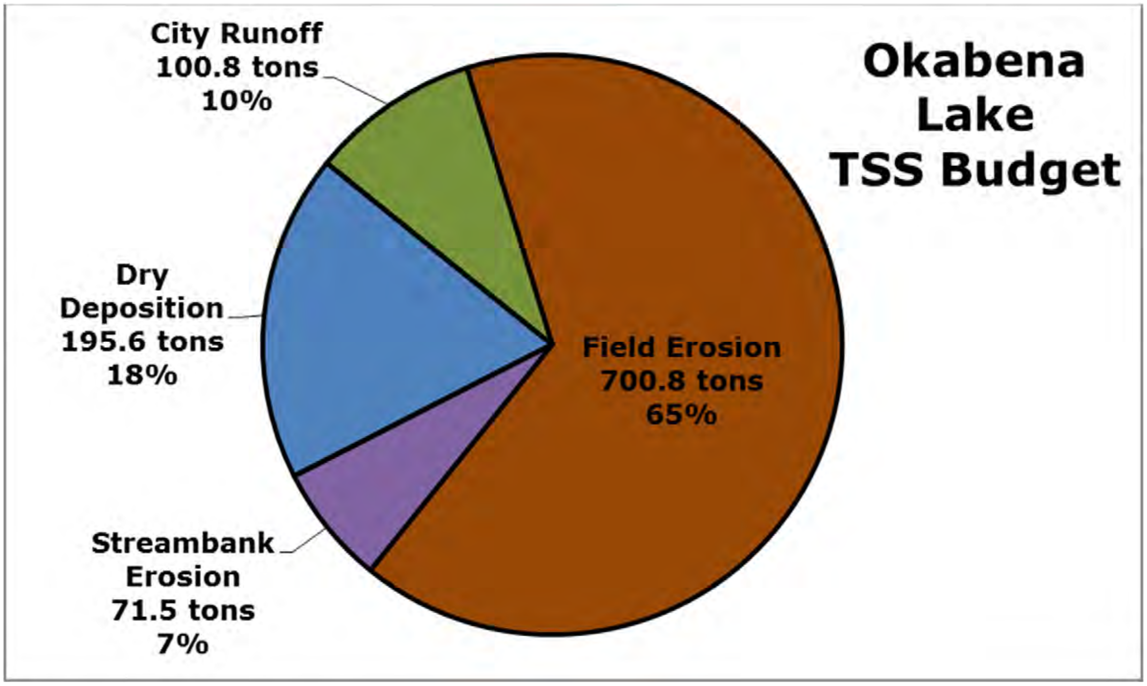

Figure 6-1. Okabena Lake sediment budget

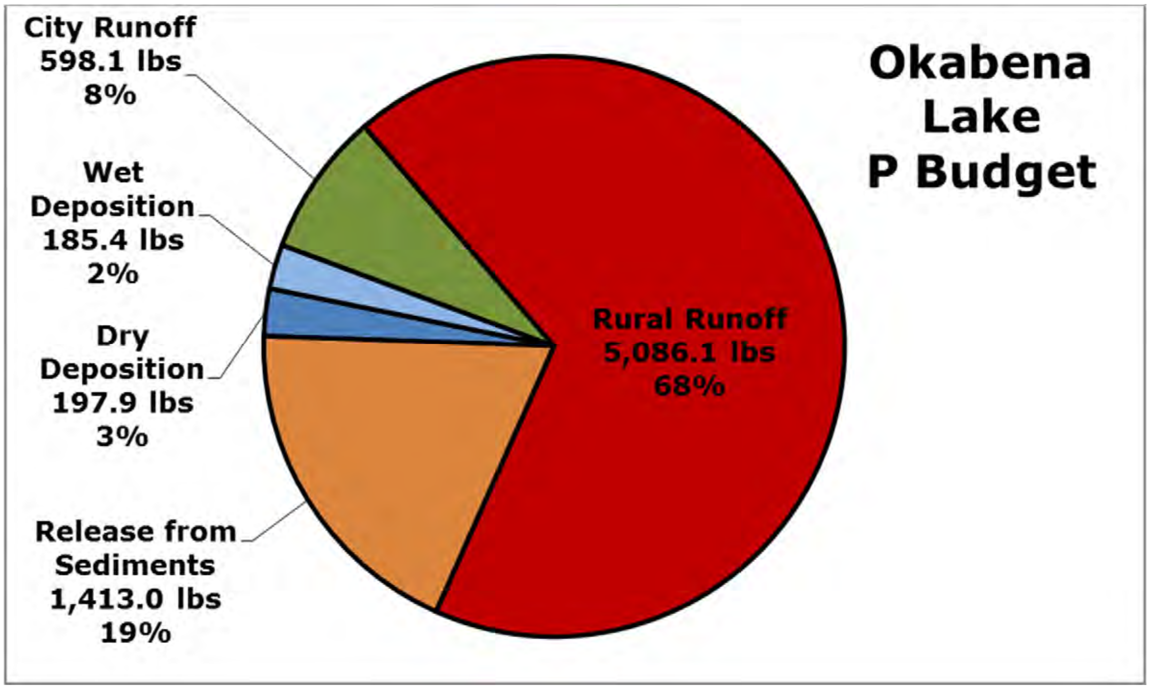

Figure 6-2. Okabena Lake phosphorus budget

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Appendix A

Deposition Modeling

Wind Erosion - WEPS Model Setup and Results

Four main inputs are required to run a simple WEPS model simulation: field size and orientation, latitude and longitude (for weather data/simulation), SSURGO soil type, and a land management scenario. Simple WEPS model simulations were run for all unique NASS (2013) agricultural land cover and SSURGO soil type combinations within a 5 mile radius of Okabena Lake. GIS data limitations and time constraints made it impossible to determine the exact size and orientation of each field within a 5 mile radius of Okabena Lake. So, for this exercise it was assumed each unique land cover-soil type combination is made up of one large (250 acres) square field, positioned perfectly east to west. Since nearly all of the NASS agricultural land cover types were either corn (50%) or soybean (40%), a general corn/soybean crop rotation management file was selected within WEPS that includes spring till and seeding, followed by a fall harvest and plow. Average annual wind-blown sediment erosion rates for the 30 most common agricultural land cover-soil type combinations in the Okabena Lake watershed are presented in Table A-1, and Figure A-1 is a map showing wind-blown sediment loading rates from agricultural areas in a 5 mile radius of Okabena Lake.

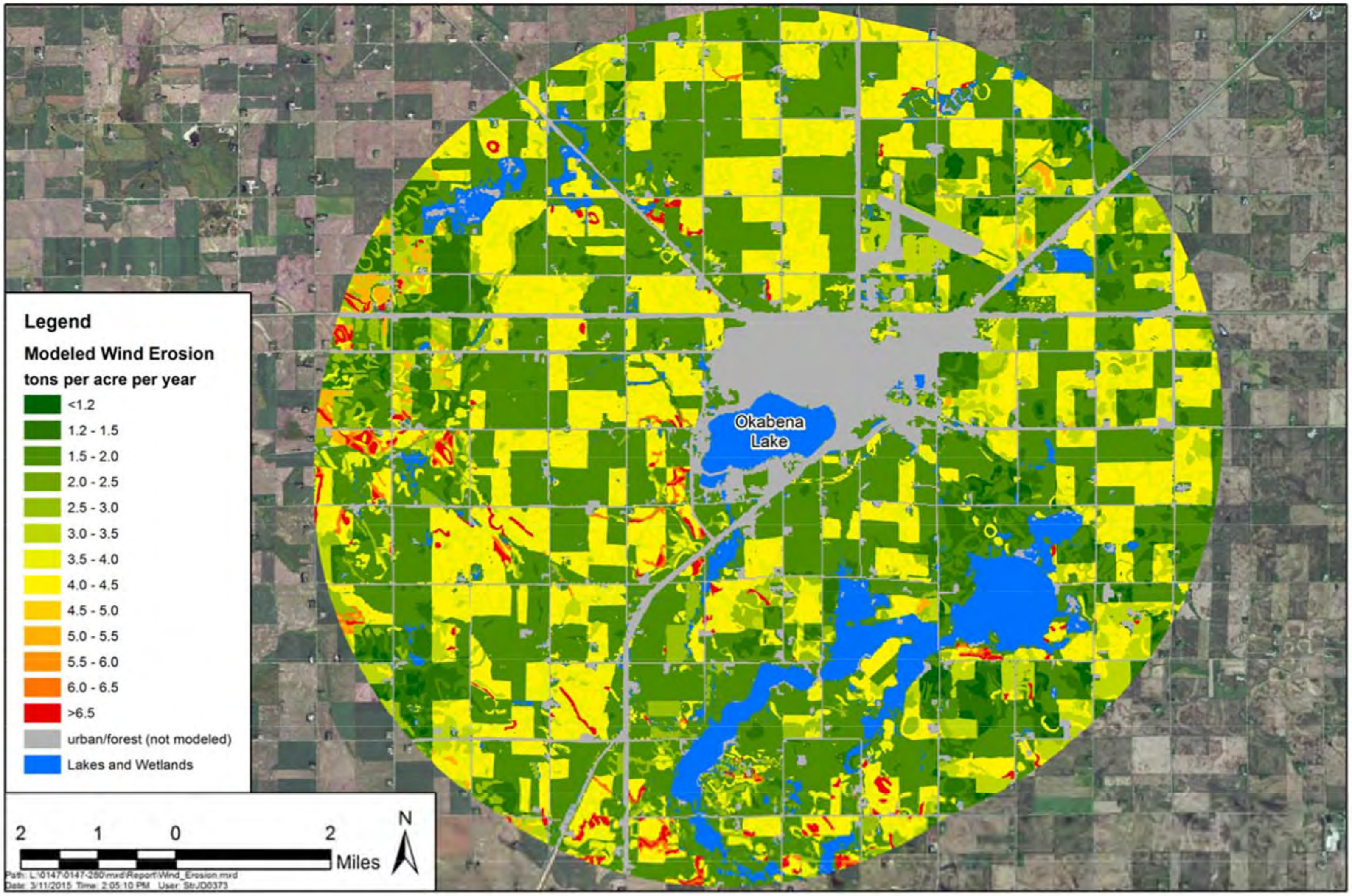
Table A-1. WEPS model predicted wind erosion for the largest landcover-SSURGO soil type combinations surrounding Okabena Lake.

2013 NASS Landcover type	SSURGO Soil Type	Total acres in 5 mile radius of Lake	Wind erosion (tons/acre/year)
soybeans	Omsrud-Storden complex 6-12%	684	6.62
soybeans	Delft, overwash-Delft complex, 1-4%	319	6.06
soybeans	Clarion-Crooks ford complex, 1-5%	356	5.25
soybeans	Canisteo-Glencoe, depressional, complex, 0 to 2 percent slopes	156	4.41
soybeans	Canisteo clay loam, 0-2%	762	4.41
soybeans	Nicollet Clay Loam 1-3%	4,155	4.24
soybeans	Clarion Loam 2-5%	4,876	4.21
soybeans	Webster Cla Loam 0-2%	5024	3.95
soybeans	Webster silty clay loam, 0-2%	359	3.95
corn	Omsrud-Storden complex 6-12%	1000	3.60
soybeans	Okabena silty clay loam, 1-3%	672	3.49
soybeans	Chetomba silty clay loam, 0-2%	303	3.37
soybeans	Waldorf Silt Clay Loam 0-2%	1,076	3.34
soybeans	Ocheda silty clay loam, 1-3%	622	3.15
soybeans	Glencoe silty clay loam, depressional, 0-1%	432	3.10
soybeans	Canisteo silty clay loam, 0-2%	520	2.88
soybeans	Nicollet silty clay loam, 1-3%	652	2.79
corn	Delft, overwash-Delft complex, 1-4%	432	2.76
corn	Clarion-Crooks ford complex, 1-5%	422	2.64

2013 NASS Landcover type	SSURGO Soil Type	Total acres in 5 mile radius of Lake	Wind erosion (tons/acre/year)
corn	Canisteo-Glencoe, depressional, complex, 0 to 2 percent slopes	344	1.93
corn	Canisteo clay loam, 0-2%	838	1.87
corn	Nicollet Clay Loam 1-3%	4,586	1.80
corn	Clarion Loam 2-5%	6,786	1.71
corn	Webster Cla Loam 0-2%	5,677	1.57
corn	Webster silty clay loam, 0-2%	320	1.57
corn	Okabena silty clay loam, 1-3%	902	1.50
corn	Canisteo silty clay loam, 0-2%	905	1.47
corn	Chetomba silty clay loam, 0-2%	509	1.39
corn	Glencoe silty clay loam, depressional, 0-1%	464	1.30
corn	Waldorf Silt Clay Loam 0-2%	1,077	1.27
corn	Nicollet silty clay loam, 1-3%	706	1.24
corn	Ocheda silty clay loam, 1-3%	627	1.19

Dry Deposition Calculations

Sediment and phosphorus deposition near Okabena Lake were estimated using measured 10 micrometer particulate matter (PM_{10}) and 2.5 micrometer particulate matter ($PM_{2.5}$) air quality data downloaded from the nearest Interagency Monitoring of Protected Visual Environments (IMPROVE) monitoring station at Blue Mounds State Park near Luverne, MN (http://vista.cira.colostate.edu/improve/). Phosphorus content of the airborne particulate matter was estimated based on MPCA laboratory phosphorus analyses of PM_{10} filter samples at three air quality monitoring stations with similar land cover characteristics as Okabena Lake watershed (Barr Engineering, 2007). Based on information from Meyers (2003) presented in the MPCA memo (Barr Engineering, 2007), particulate matter dry deposition settling velocities of 0.5 cm/s and 3 cm/s were applied to the fine ($PM_{2.5}$) and coarse ($PM_{10} – PM_{2.5}$) airborne particulate matter data downloaded at Blue Mounds State Park monitoring station. Using the above methodology, average annual dry sediment deposition to Okabena Lake is approximately 196 tons per year and annual phosphorus deposition is 199 pounds per year.



OKABENA LAKE

Modeled Wind Erosion

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Figure A-1

Figure A-1. WEPS model results for the 5 mile radius surrounding Okabena Lake.

Wet Deposition Calculations

Since phosphorus in rainwater has not been directly measured in or around the Okabena Lake watershed, wet deposition of phosphorus on the lake was calculated using the following regression relationship between calcium and phosphorus concentrations in rainwater at several stations throughout Minnesota developed by the MPCA (Swain, 2003; Barr Engineering, 2007):

$y = 0.0671x – 0.4586$
Where:
y = Total phosphorus in µg/L
x = dissolved calcium in rainwater in µg/L

Rainfall dissolved calcium data for the past 10 years was downloaded for the Lamberton, MN station which is the closest National Atmospheric Deposition Program (NADP) monitoring station to Worthington, MN (approximately 50 miles north). The calcium concentrations were used to estimate TP concentrations using the aforementioned equation and were then multiplied by daily rainfall totals in the Okabena Lake watershed recorded at the Worthington Municipal Airport. Results of the 10-year (2005-2014) annual wet deposition of phosphorus to Okabena Lake are presented in Table A-2.

Table A-2. Wet phosphorus deposition estimates to Okabena Lake.

Year	Total Precipitation (inches)	Phosphorus Loading Rate (lbs/acre/year)	Total Phosphorus Load to Lake (lbs/year)
2005	22.3	0.201	156
2006	33.4	0.248	193
2007	37.5	0.228	178
2008	29.6	0.150	117
2009	37.0	0.290	226
2010	29.0	0.309	240
2011	29.7	0.201	156
2012	36.0	0.260	202
2013	29.5	0.356	277
2014	24.1	0.265	206
Average	**29.7**	**0.239**	**186**

Appendix B

P8 Watershed Model

Model Setup

P8 model inputs include watershed characteristics and treatment devices. The Okabena Lake watershed was delineated into several smaller subwatersheds (Figure B-1) using storm sewer information provided by the City of Worthington and two foot LiDAR contours downloaded from the Minnesota Geospatial Information Office. In some cases, the subwatersheds were further divided using the City of Worthington's most recent municipal boundary GIS file in order to separate city and rural portions of the watershed. Overall, there were a total of 28 individual minor subwatersheds delineated for the Okabena Lake watershed P8 model. The 28 minor subwatersheds were then grouped into nine major subwatersheds (Figure B-1) that act as watershed pour points to the lake. The major subwatersheds discharge to the lake through storm sewer pipes or small ditches and tributary channels. The Lake Direct subwatershed represents runoff that enters the lake through overland flow and a few small storm sewer catchments immediately surrounding the lake. There are two small portions of the Lake Direct subwatershed located east and north of Okabena Lake that have interconnected collection systems with gravity outlets that drain away from the lake (toward County Ditch 12) and a storm lift that discharges to the lake. It was assumed approximately 50% of the stormwater runoff and pollutant load from these subwatersheds, referred to as Lake Direct (Partial), makes its way to Okabena Lake.

There are eight stormwater ponds in the Okabena Lake watershed that were included in the model with water quality treatment benefits. Partial as-built design specifications were available for all eight ponds. As-built information included outlet and basin bottom elevations, basin permanent pool and flood pool volumes, and outlet characteristics and dimensions. If basin information was not available, assumptions were made. For unknown outlet characteristics and dimensions, an 18-inch orifice was assumed for modeling purposes. If the outlet elevation and flood pool elevation were unknown, elevations were determined based on LiDAR and/or continuity with available basin information. If basin bottom elevation was unknown, the basin was assumed to have a depth of 7 feet. If the basin permanent pool volume was unknown, the volume was assumed to be the volume of runoff from the 2.5-inch event.

A GIS exercise was executed to intersect 2013 NASS Landcover and Soils Survey Geographic (SSURGO) database soil type information with the delineated subwatershed boundaries. The percent impervious fractions and pervious curve numbers for each subwatershed were estimated using current land cover and soil type information. Each land cover was assigned an impervious percent based on literature values and runoff curve numbers were determined by soil type.

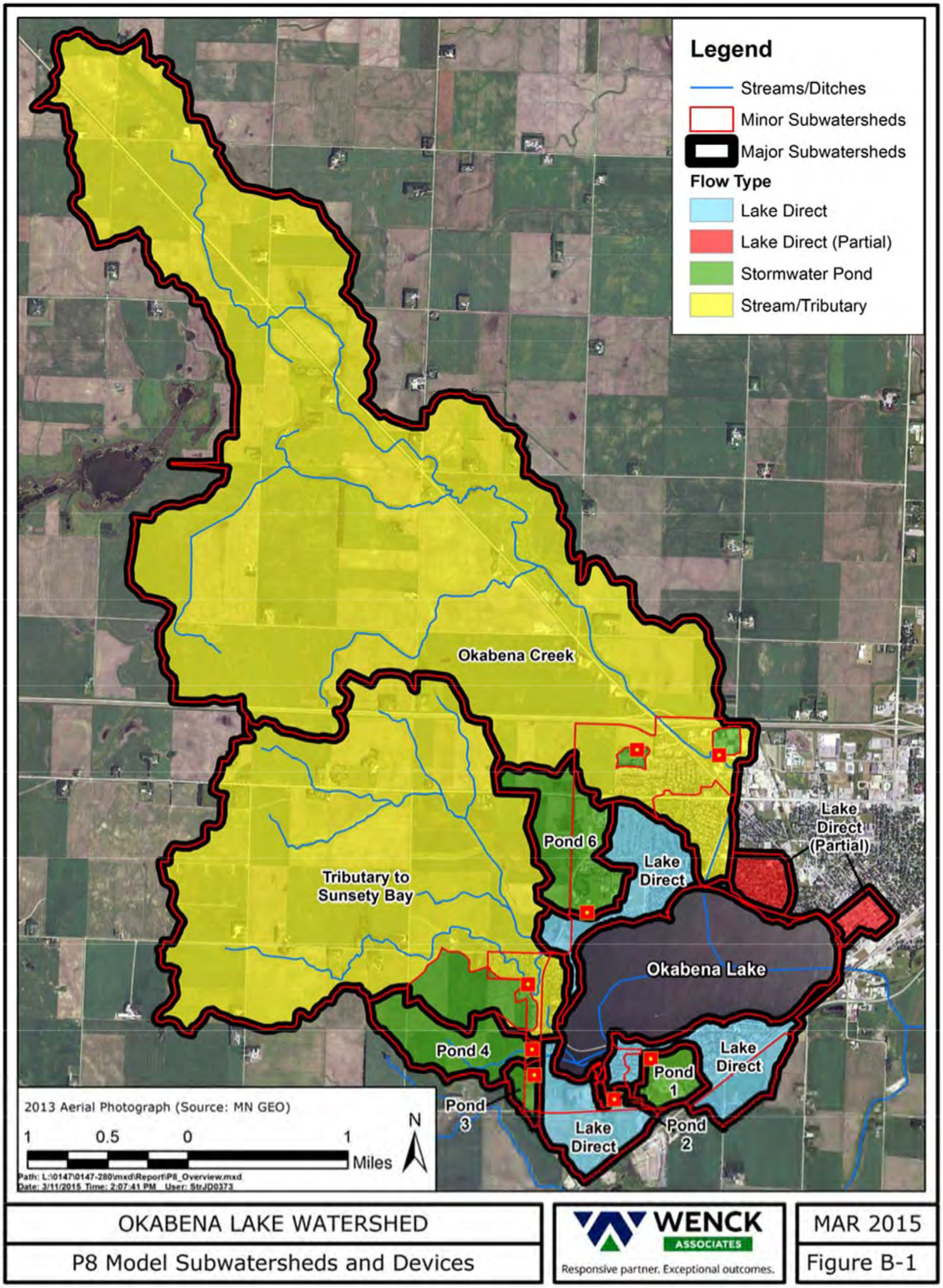


Figure B-1. P8 model major and minor subwatersheds.

Flow Adjustments

Initial runoff curve numbers slightly over-predicted total watershed inflow to Okabena Lake when compared to the 2014 lake inflow estimates (Table C-3) and gauged flow measurements at the Okabena Creek and Sunset Bay tributary monitoring stations. Runoff curve numbers for all subwatersheds were lowered by approximately 25% to match the 2014 data. Final flow calibration is presented in Figures B-2 through B-4.

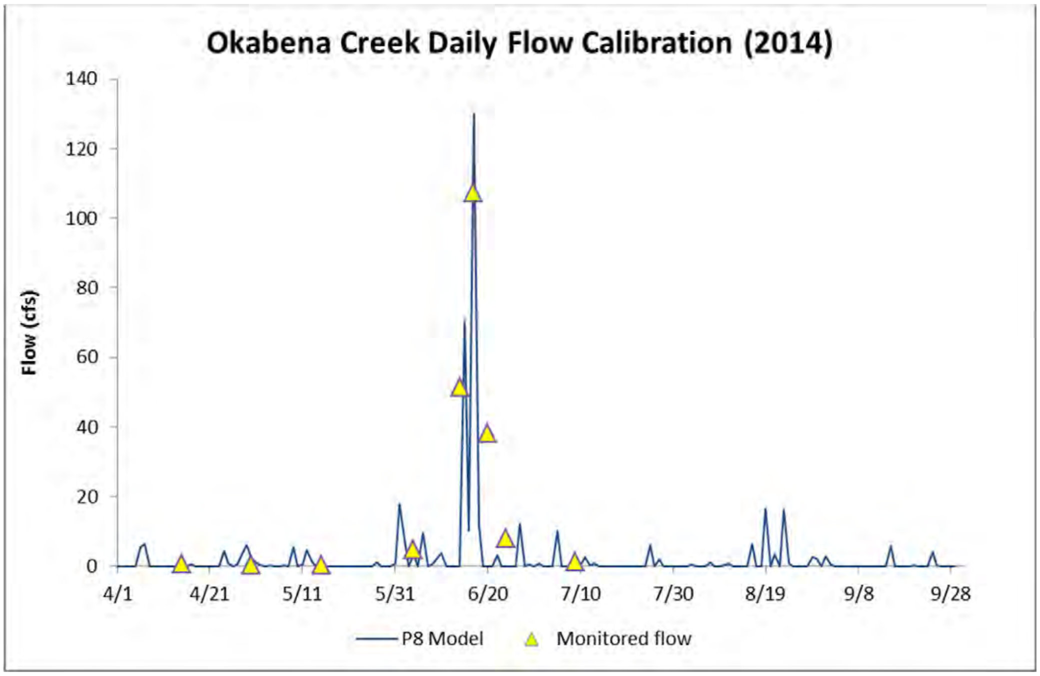


Figure B-2. P8 model average daily flow calibration for Okabena Creek.

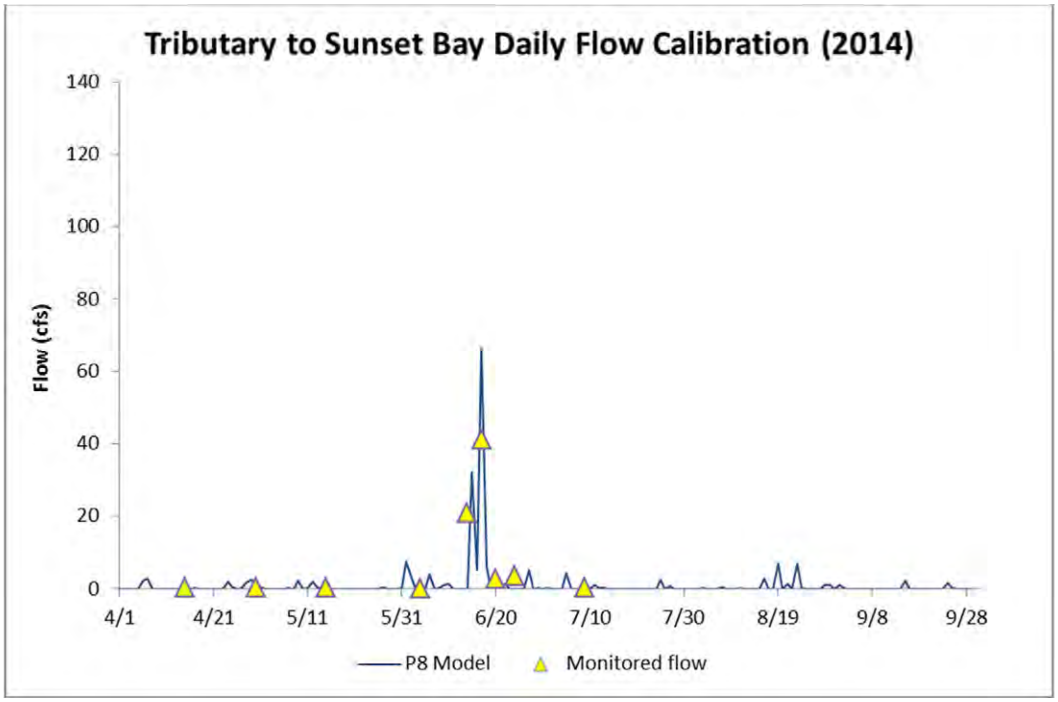


Figure B-3. P8 model average daily flow calibration for Sunset Bay Tributary.

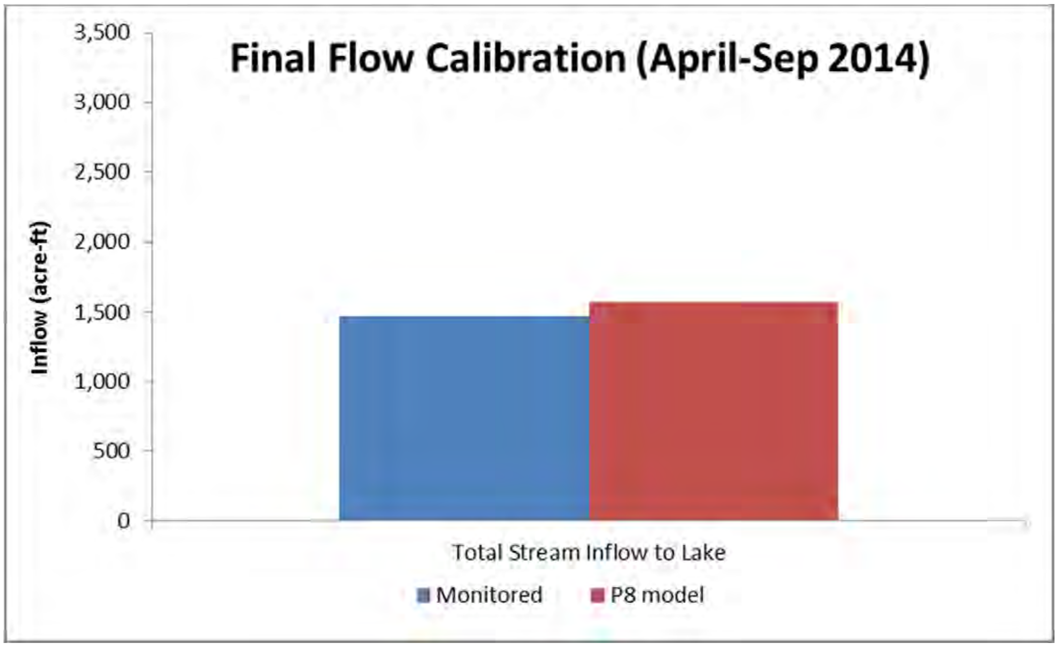


Figure B-4. Final P8 model flow calibration for the entire Okabena Lake watershed.

Water Quality Adjustments

Model predicted sediment and phosphorus concentrations and loads for Okabena Creek and the Sunset Bay tributary were compared to stream water quality data collected in 2014. Initially, the 2014 model predicted TSS and TP flow weighted mean (FWM) concentrations were significantly lower than the monitored FWM concentrations at both monitoring stations (See Appendix C). It should be noted that P8 often struggles to accurately predict pollutant loading from agricultural areas since the model is primarily intended to be used in urban watersheds. Agriculture (row crops and pasture land) is the dominant land cover in the Okabena Creek (80%) and Sunset Bay Tributary (89%) subwatersheds. Thus, Okabena Creek and Sunset Bay Tributary TSS and TP runoff factors had to be increased in P8 in order to bring model predicted FWM concentrations closer to the 2014 monitored values. The runoff factor adjustments applied to both subwatersheds were scaled based on the amount of agricultural land within each watershed and were within the range of published data for agricultural land in Minnesota (Lin 2004; Reckhow et al. 1980). Once it appeared the Okabena Creek and Sunset Bay tributary model predicted FWM TSS and TP concentrations and annual loads matched 2014 monitored values, the agriculture scaled runoff factor adjustments were applied across the entire watershed. Final 2014 model predicted versus monitored FWM concentrations for Okabena Creek and the Sunset Bay tributary are presented in Figures B-5 and B-6. Maps showing average annual TP and TSS loading rates (in lbs/acre/year) by subwatershed are presented in Figure B-7 and B-8.

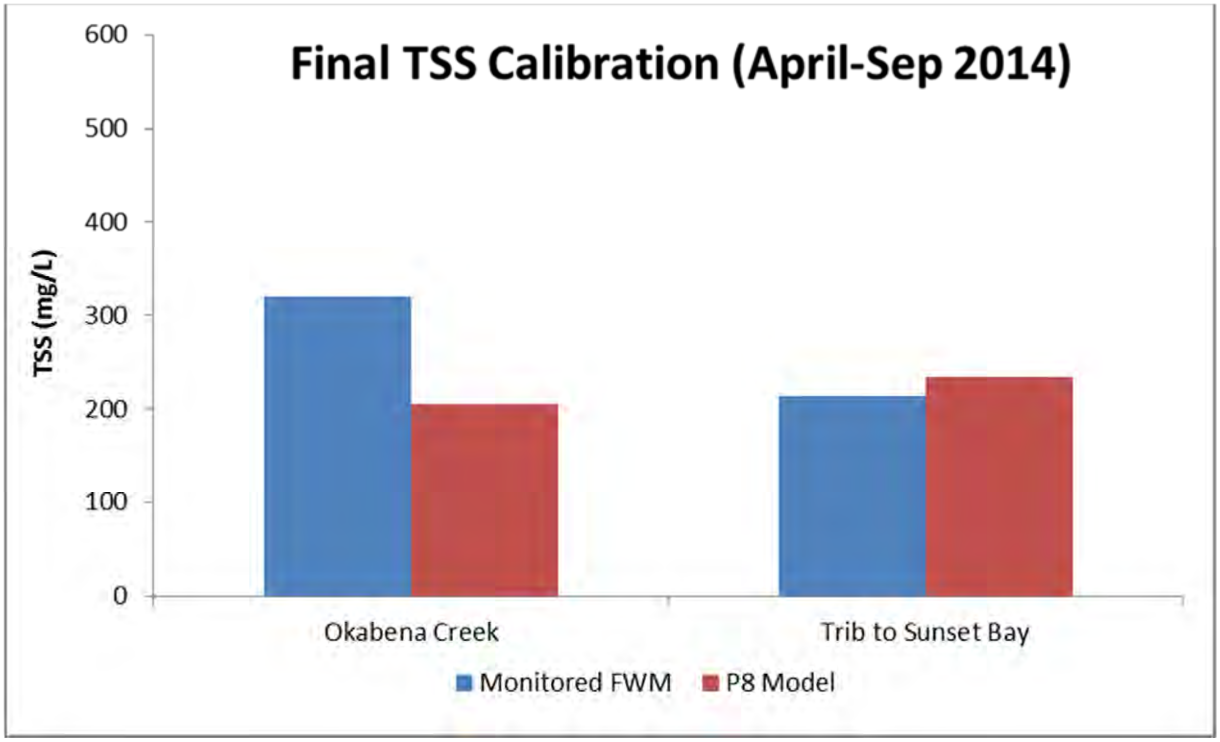


Figure B-5. P8 model TSS calibration.

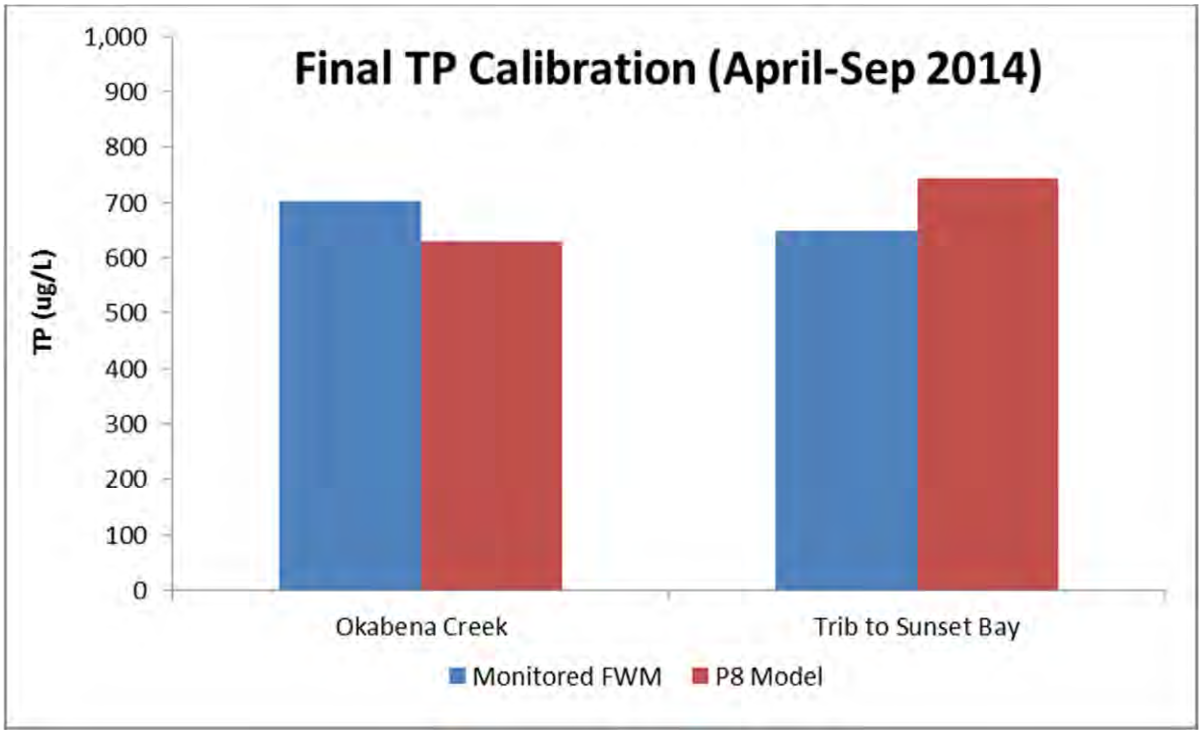
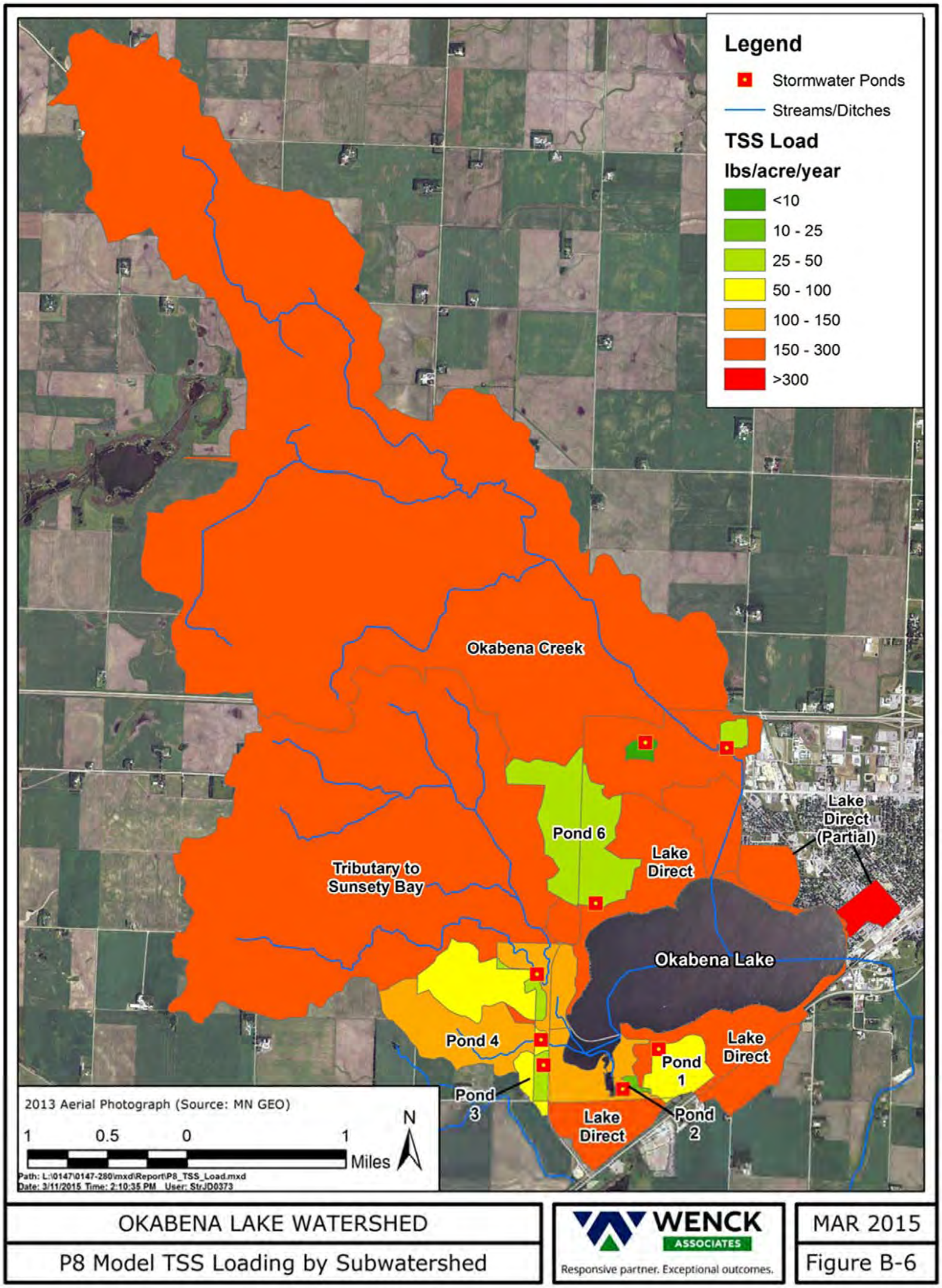


Figure B-6. P8 model TP calibration.



2013 Aerial Photograph (Source: MN GEO)

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Date: 3/11/2015 Time: 2:10:35 PM User: StrJD0373

OKABENA LAKE WATERSHED

P8 Model TSS Loading by Subwatershed

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Figure B-6

Figure B-6. P8 model TSS loading rates by subwatershed.

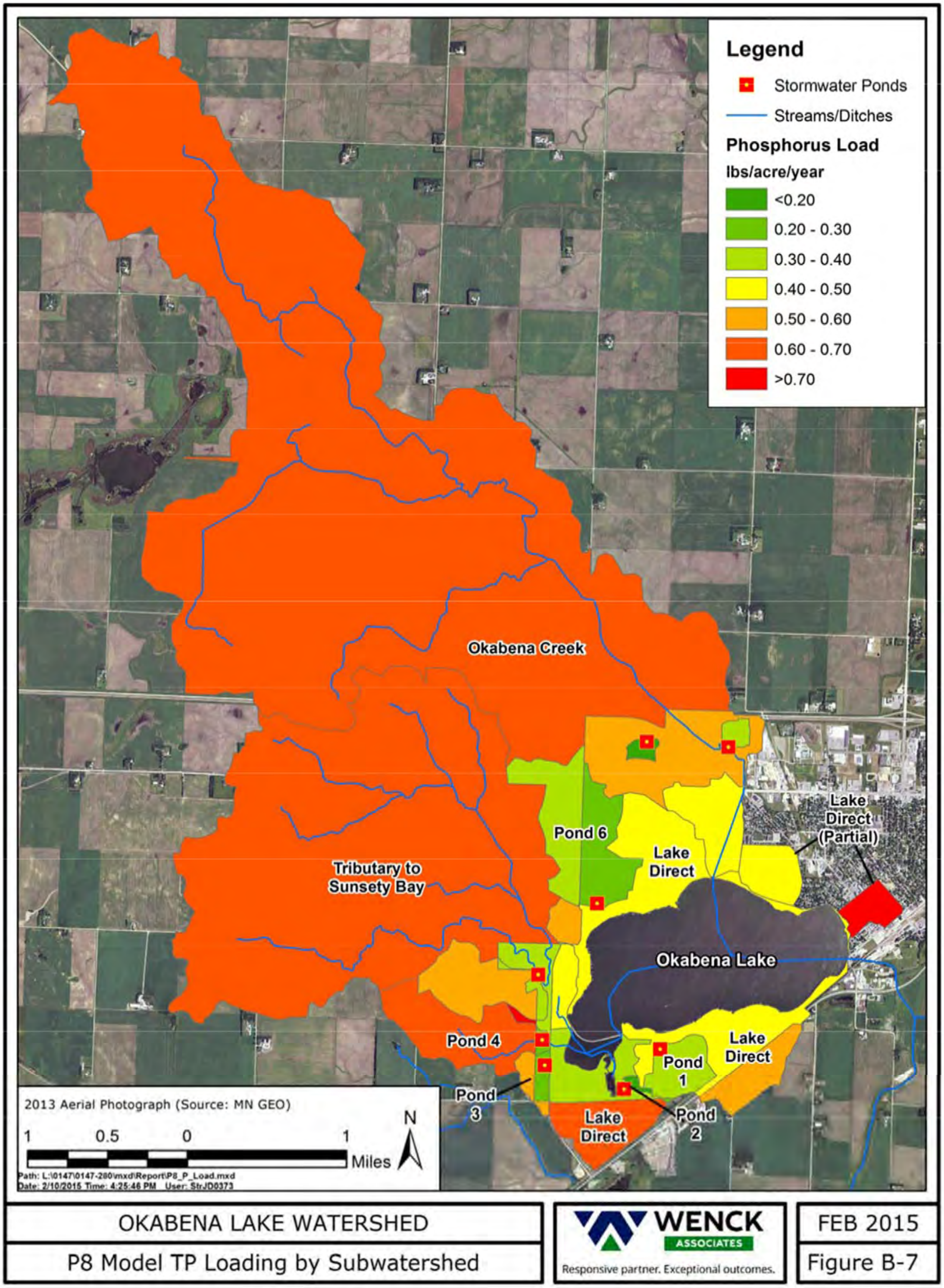

Figure B-7. P8 model TP loading rates by subwatershed.

Appendix C

Water Quality and Lake Level Monitoring

Monitoring Locations and Water Quality Results

Okabena-Ocheda Watershed District staff monitored two stream surface locations in the Okabena watershed in 2014: Okabena Creek/Whiskey Ditch downstream of Oxford Street , and the tributary flowing to Sunset Bay at County Road 10 (Crailsheim Drive) (Figure C-1). Seven water quality samples were collected in 2014 between April and early July (Tables C-1 and C-2). No samples were collected after July 9th due to low-flow and drought conditions. Samples at each site were analyzed for the following lab parameters: total suspended solids (TSS), volatile suspended solids (VSS), total phosphorus (TP), soluble ortho phosphorus (ortho-P), nitrate+nitrite and total Kjeldahl nitrogen (TKN). Additionally, the following field parameters were recorded during each site visit: stream stage (elevation), gauged flow, dissolved oxygen (DO), conductivity and transparency. Gauged flow measurements were made using a Hach FH950 Portable Velocity Meter. Two non-water quality sampling site visits were made during high flow conditions (6/17/2014 and 6/20/2014) to measure stream stage and flow. Results of the stream water quality and flow samples are presented in Tables C-1 and C-2.

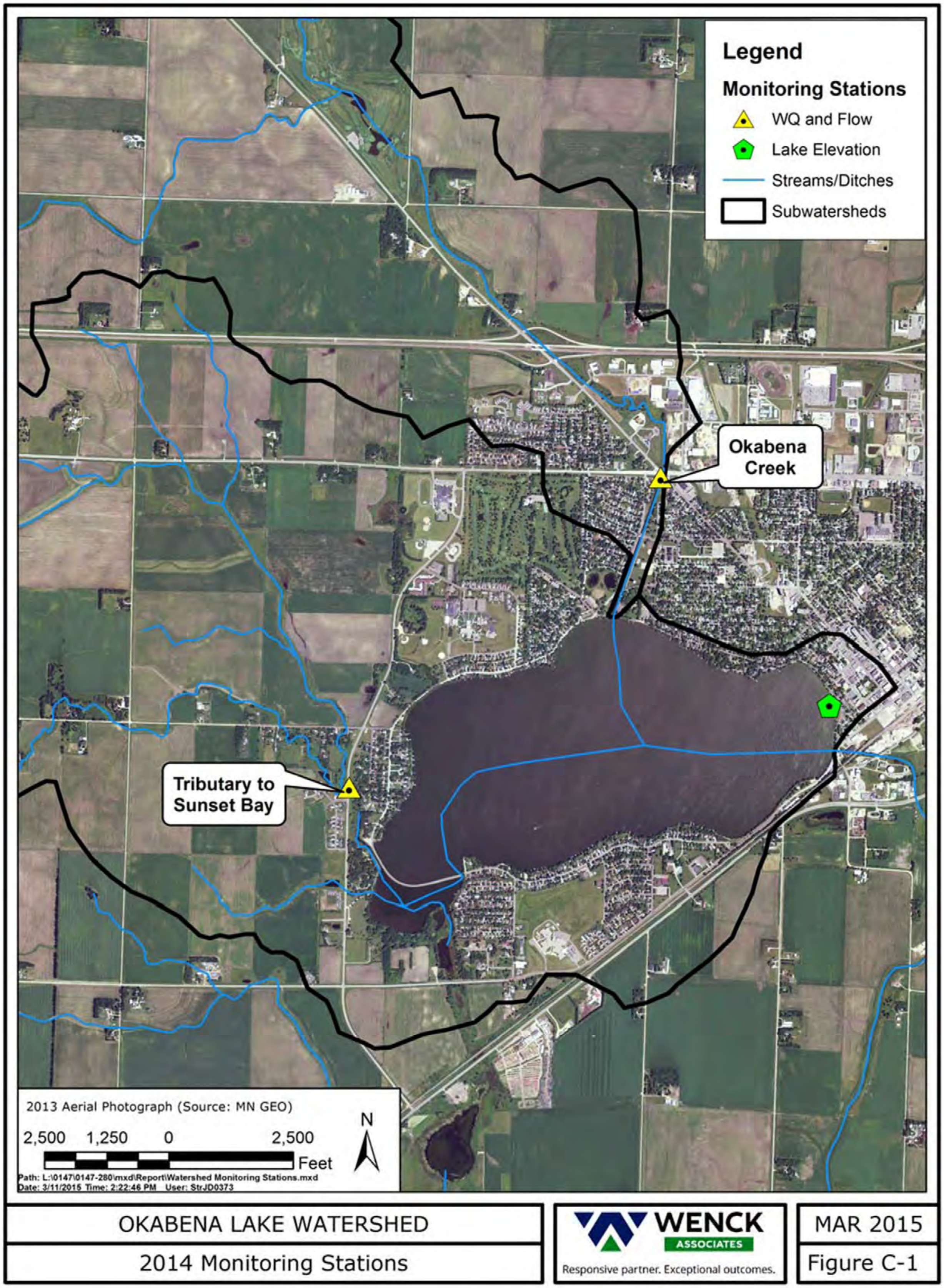

Figure C-1. 2014 Monitoring Stations.

Table C-1. 2014 Okabena Creek flow and water quality monitoring results.

Date	Gauged Flow (cfs)	TSS (mg/L)	VSS (mg/L)	TP (µg/L)	Ortho-P (µg/L)	TKN (mg/L)	Nitrate+Nitrite (mg/L)	DO (mg/L)	Conductivity (µs/cm)	Transparency (cm)
4/15/2014	0.7	12	8	69	11	1.50	1.56	17.45	764	60+
4/30/2014	0.3	10	2	40	13	1.00	0.64	13.47	977	60+
5/15/2014	<0.3	6	6	60	7	1.20	NA	11.36	908	60+
6/4/2014	4.9	23	14	168	74	1.40	2.32	10.58	886	52
6/14/2014	51.5	410	80	860	147	3.20	2.34	7.52	295	4
6/17/2014	107.5	NA	NA	NA	NA	NA	NA	6.72	399	8
6/20/2014	38.2	NA	NA	NA	NA	NA	NA	7.20	568	19
6/24/2014	7.9	122	9	213	122	1.50	7.97	8.41	674	29
7/9/2014	1.3	11	9	60	11	1.10	8.69	7.80	813	44
FWM concentration		**320**	**64**	**702**	**133**	**2.79**	**3.10**			

NA = denotes no water quality sample was collected

Table C-2. 2014 Sunset Bay tributary flow and water quality monitoring results.

Date	Gauged Flow (cfs)	TSS (mg/L)	VSS (mg/L)	TP (µg/L)	Ortho-P (µg/L)	TKN (mg/L)	Nitrate+Nitrite (mg/L)	DO (mg/L)	Conductivity (µs/cm)	Transparency (cm)
4/15/2014	<0.2	6	6	70	25	1.00	0.80	16.58	692	>60
4/30/2014	<0.2	5	5	58	30	1.00	0.65	12.18	807	>60
5/15/2014	<0.2	3	3	81	28	0.60	NA	11.82	970	>60
6/4/2014	0.2	13	12	89	45	1.00	1.53	15.08	896	>60
6/14/2014	20.8	268	52	800	220	3.00	4.05	8.17	236	4
6/17/2014	41.1	NA	NA	NA	NA	NA	NA	6.72	453	13
6/20/2014	2.8	NA	NA	NA	NA	NA	NA	8.17	710	>60
6/24/2014	3.5	2	2	62	49	1.20	15.90	9.25	739	>60
7/9/2014	0.4	21	6	49	25	0.80	13.40	8.37	748	>60
FWM concentration		**218**	**43**	**661**	**187**	**2.64**	**5.71**			

NA = denotes no water quality sample was collected

Lake Elevation Monitoring

Continuous lake elevation measurements were recorded in 2014 at one location from April 15th to September 25th using an In-Situ Rugged Troll 100 pressure transducer with internal logging capabilities. The transducer was housed in a metal pipe that was mounted to a concrete pier north of the lake's outlet near the intersection of Lake Street and 4th Avenue (Figure C-1). The transducer was set using depth to water measurements from a surveyed benchmark at the top of the pier. Site visits were made approximately once every 2-3 weeks to measure depth to water, and download data. Figure C-2 shows results of the 2014 lake elevation measurements.

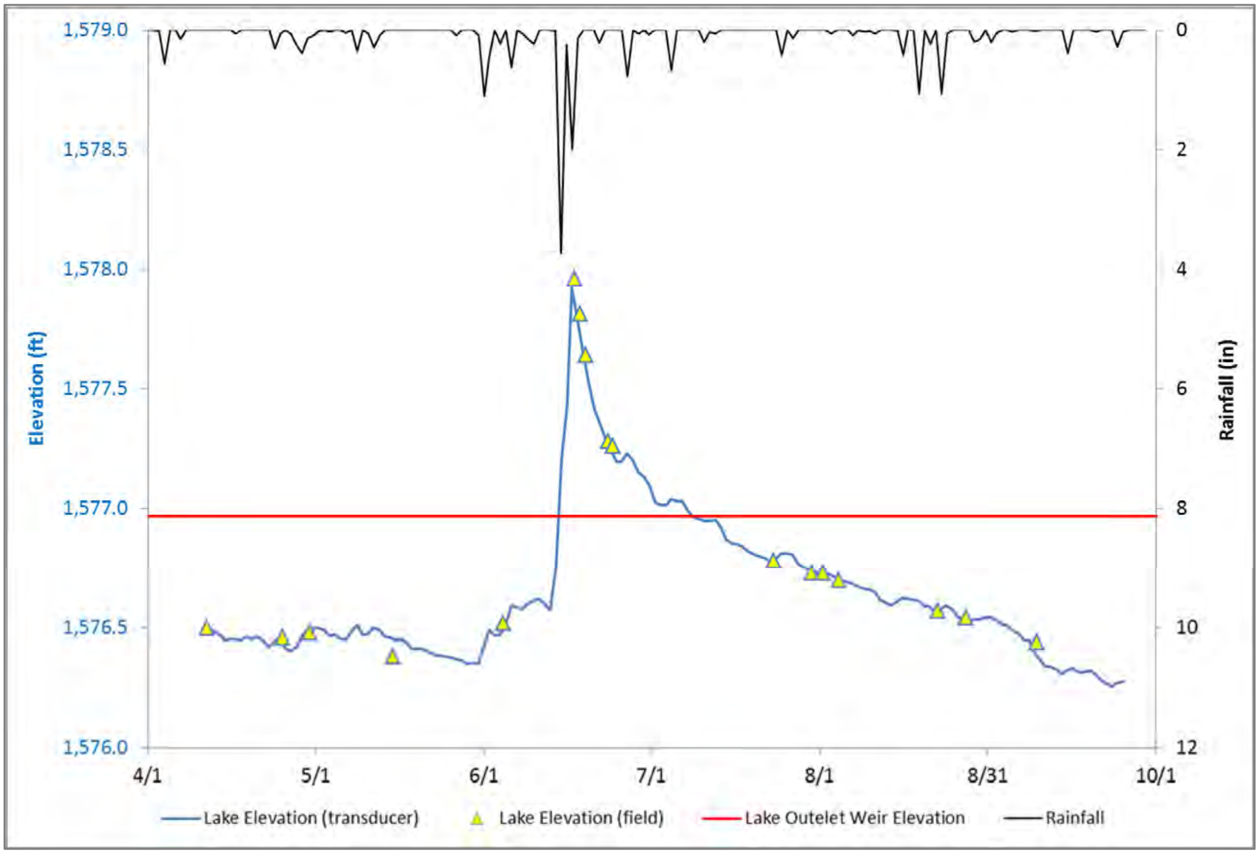

Figure C-2. 2014 Okabena Lake water level monitoring.

Okabena Lake Water Balance

Okabena Lake water budget for the April through September 2014 monitoring period was calculated using the following equation with a daily time step:

$$(1)\ \Delta Lake_{volume} = Inflow_{streams} + Inflow_{precip} - Outflow_{streams} - Outflow_{evaporation}$$

Where $\Delta Lake_{volume}$ represents the average daily change in lake volume which is a function of inflow to the lake from surface water runoff ($Inflow_{streams}$), direct precipitation ($Inflow_{precip}$), evaporation from the lake surface ($Outflow_{evaporation}$) and surface outflow over the lake's outlet weir ($Outflow_{streams}$). This equation assumes all major changes in lake volume are regulated by these four main processes.

Okabena Lake volume was estimated using average daily lake elevation data recorded during the 2014 transducer deployment period (Figure C-2). Okabena Lake direct precipitation during this time period was calculated using Worthington Municipal Airport precipitation data downloaded from the cli-MATE website (http://mrcc.isws.illinois.edu/CLIMATE). Lake evaporation was estimated using the Lamberton, MN weather station weekly pan evaporation rates downloaded from the Minnesota Climatology Working Group website (http://climate.umn.edu). Surface outflow from Okabena Lake was estimated using the following flow equation for rectangular weirs:

(2) $Q = 2/3\ b\ (2g)^{1/2}\ H^{3/2}$

Where:

Q = flow over the weir (cfs)
b = length of Okabena outlet weir (54 ft)
g = acceleration due to gravity (32.2 ft/sec^2)
H = height of surface water above weir (ft)

Height above the weir was calculated based on the difference between the surveyed elevation at the top of the outlet weir (1,577.96 feet) and average daily lake elevation recorded by the pressure transducer. Figure C-2 shows the only time lake elevation exceeded the top of the weir was from June 15 – July 8 which was in response to 6.1 inches of rainfall the week of June 15th.

Once the other parameters were calculated, Equation 1 was solved to determine stream inflow to Okabena Lake. Table C-3 summarizes the lake water balance for the entire 2014 monitoring period. Results indicate total losses slightly exceeded inflows during the April 15th – September 25th monitoring period. Evaporation from the lake surface was the largest loss from the lake and exceeded both surface runoff to the lake and direct precipitation on the lake surface.

Table C-3. Okabena Lake water balance during the 2014 monitoring period.

Water Balance Parameter	Description	Acre-ft
$\text{Inflow}_{\text{streams}}$	Surface water inflow from watershed	(+) 1,467
$\text{Inflow}_{\text{precip}}$	Direct precipitation on lake surface	(+) 1,187
$\text{Outflow}_{\text{streams}}$	Outflow over lake weir	(-) 644
$\text{Outflow}_{\text{evaporation}}$	Evaporation from lake surface	(-) 2,171
$\Delta\text{Lake}_{\text{volume}}$	**Change in total lake volume**	**-161**

Appendix D

Field Erosion and Streambank Assessment Survey

Field Erosion - Universal Soil Loss Equation

Average upland sediment loss in the impaired reach watershed was modeled using the RUSLE. This model provides an assessment of existing soil loss from upland sources and the potential to assess sediment loading through the application of BMPs. RUSLE predicts the long term average annual rate of erosion on a field slope based on rainfall pattern, soil type, topography, land use and management practices. The general form of the RUSLE has been widely used in predicting field erosion and is calculated according to the following equation:

$$A = R \times K \times LS \times C \times P$$

Where A represents the potential long term average soil loss (tons/acre) and is a function of the rainfall erosivity index (R), soil erodibility factor (K), slope-length gradient factor (LS), crop/vegetation management factor (C) and the conservation/support practice factor (P). RUSLE only predicts soil loss from sheet or rill erosion on a single slope as it does not account for potential losses from gully, wind, tillage or streambank erosion.

For this exercise, it was assumed all agricultural practices are subject to maximum soil loss fall plow tillage methods and no support practices (P-factor = 1.00). Raster layers of each RUSLE factor were constructed in ArcGIS for rural areas in the Okabena Lake watershed study area and then multiplied together to estimate the average annual potential soil loss for each grid cell. It is important to note that model results represent the maximum amount of soil loss that could be expected under existing conditions. Thus, results are intended to provide a first cut in identifying potential field erosion hot spots based on slope, landuse and soil attributes. Areas with high potential erosion should be verified in the field prior to BMP planning and targeting.

Since this model does not take into account a stream's ability to transport suspended sediment, a sediment delivery ratio (SDR) (Vanoni 1975) was used to estimate how much upland soil loss may be delivered downstream:

$SDR = 0.451(b)^{-0.298}$
Where b = watershed size in square kilometers

Streambank Assessment Methodology and Results

Annual soil loss from streambank erosion was estimated using field collected data and a method developed by the Natural Resources Conservation Service referred to as the "NRCS Direct Volume Method," or the "Wisconsin method," (Wisconsin NRCS 2003). Soil loss is calculated by:

1. measuring the amount of exposed streambank in a known length of stream;
2. multiplying that by a rate of loss per year;

3. multiplying that volume by soil density to obtain the annual mass for that stream length; then
4. converting that mass into a mass per stream mile.

The Direct Volume Method is summarized in the following equation:

$$\frac{\text{(eroding area) (lateral recession rate) (density)}}{\text{2,000 lbs/ton}} = \text{erosion in tons/year}$$

Data were compiled into a spreadsheet database that summarized stream length, total eroding area, Bank Condition Severity Rating, and soil texture. The estimated recession rate was multiplied by the total eroding area to obtain the estimated total annual volume of soil loss (Table D-1). To convert this soil loss to mass, soil texture was used to establish a volume weight for the soil. The total estimated volume of soil was multiplied by the assumed volume weight and converted into annual tons.

Table D-1. Okabena Creek and Sunset Bay Tributary streambank soil loss per year for identified problem areas.

Reach	Survey Segment	Eroding Bank Length (feet)	Eroding Bank Height (feet)	Area of Eroding Stream-bank (ft^2)	Lateral Recession Rate (Est.) (ft/yr)	Estimated Volume (ft^3) Eroded Annually	Soil Texture	Approx. Pounds of Soil per ft^3	Est. Soil Loss (tons/year)
Okabena Creek	OKA11	70	6.5	455	0.15	68.3	Silt Loam	85	2.9
Okabena Creek	OKA12	66	5.5	363	0.15	54.5	Silt Loam	85	2.3
Okabena Creek	OKA13	97	6.8	660	0.15	98.9	Silt Loam	85	4.2
Okabena Creek	OKA14	27	6.2	167	0.15	25.1	Silt Loam	85	1.1
Okabena Creek	OKA15	22	6.0	132	0.15	19.8	Silt Loam	85	0.8
Okabena Creek	OKA16	34	6.5	221	0.15	33.2	Silt Loam	85	1.4
Okabena Creek	OKA17	33	6.7	221	0.15	33.2	Silt Loam	85	1.4
Okabena Creek	OKA18	38	3.5	133	0.15	20.0	Silt Loam	85	0.8
Okabena Creek	OKA19	38	3.8	144	0.15	21.7	Silt Loam	85	0.9
Okabena Creek	OKA20	59	4.6	271	0.15	40.7	Silt Loam	85	1.7
Okabena Creek	OKA21	33	5.2	172	0.15	25.7	Silt Loam	85	1.1
Okabena Creek	OKA22	37	5.6	207	0.15	31.1	Silt Loam	85	1.3
Okabena Creek	OKA23	30	5.4	162	0.15	24.3	Silt Loam	85	1.0
Okabena Creek	OKA24	29	4.0	116	0.15	17.4	Silt Loam	85	0.7
Okabena Creek	OKA25	88	5.5	484	0.15	72.6	Silt Loam	85	3.1
Sunset Bay Trib	SB1R	13	6.5	85	0.18	15.2	Silt Loam	85	0.6
Sunset Bay Trib	SB2R	49	4.5	221	0.15	33.1	Silt Loam	85	1.4
Sunset Bay Trib	SB3L	12	4.0	48	0.20	9.6	Silt Loam	85	0.4
Sunset Bay Trib	SB4R	70	7.0	490	0.18	88.2	Silt Loam	85	3.7
Total Surveyed		**845**		**4,753**		**732.4**			**31.1**

Surveyed Bank Erosion Sites

The field photos and maps below document the areas that were observed to be actively eroding during the 2013 assessment survey. Table D-1 provides a complete summary of the average annual bank loss occurring at each sites.

Figure D-1. Okabena Creek streambank erosion location OKA11.

Figure D-2. Okabena Creek streambank erosion location OKA12.

Figure D-3. Okabena Creek streambank erosion location OKA13.

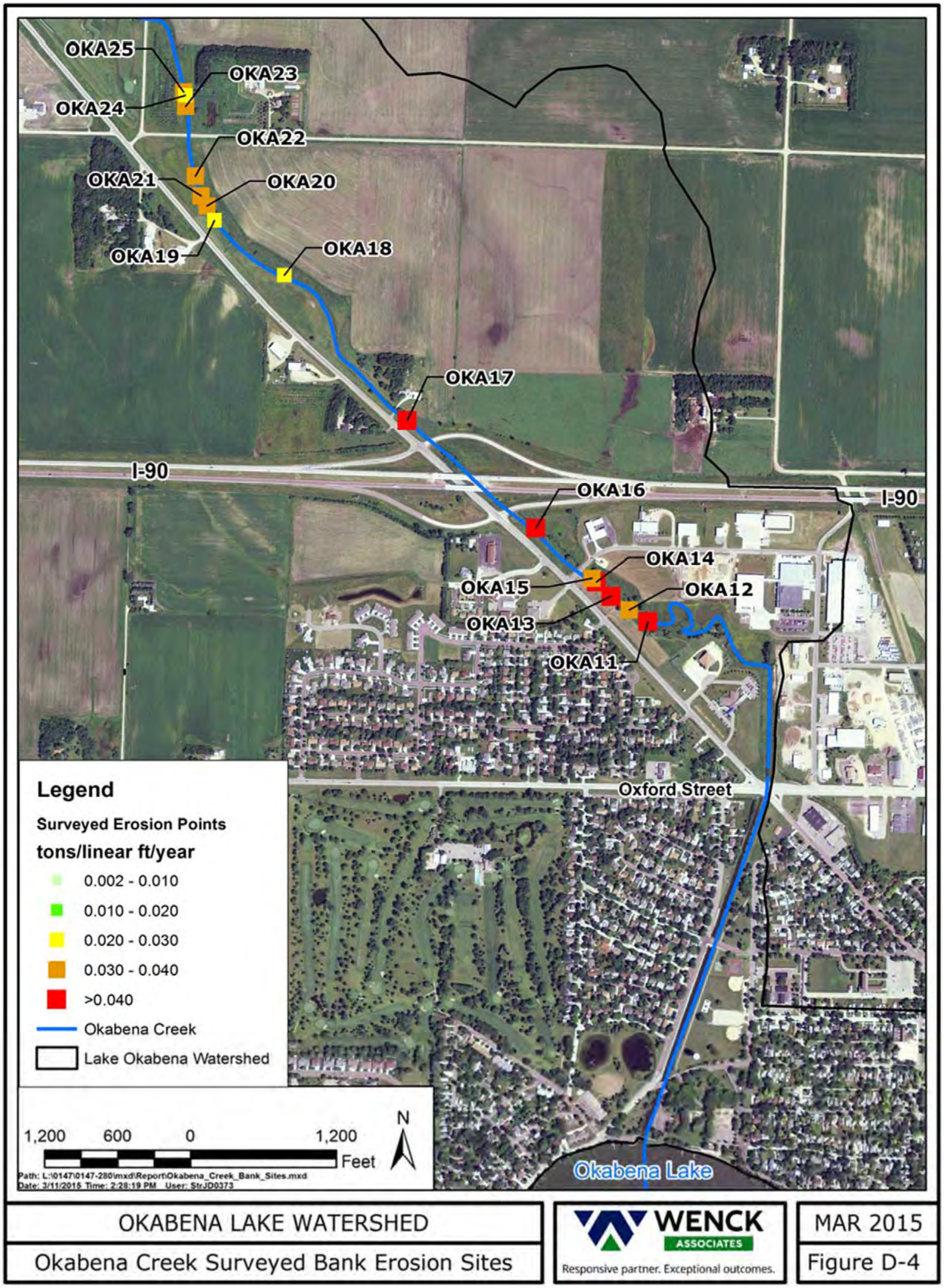

Figure D-4. Okabena Creek surveyed bank erosion locations.

Figure D-5. Sunset Bay tributary streambank erosion location SB1R.

Figure D-6. Sunset Bay tributary streambank erosion location SB2R.

Figure D-7. Sunset Bay tributary streambank erosion location SB3L.

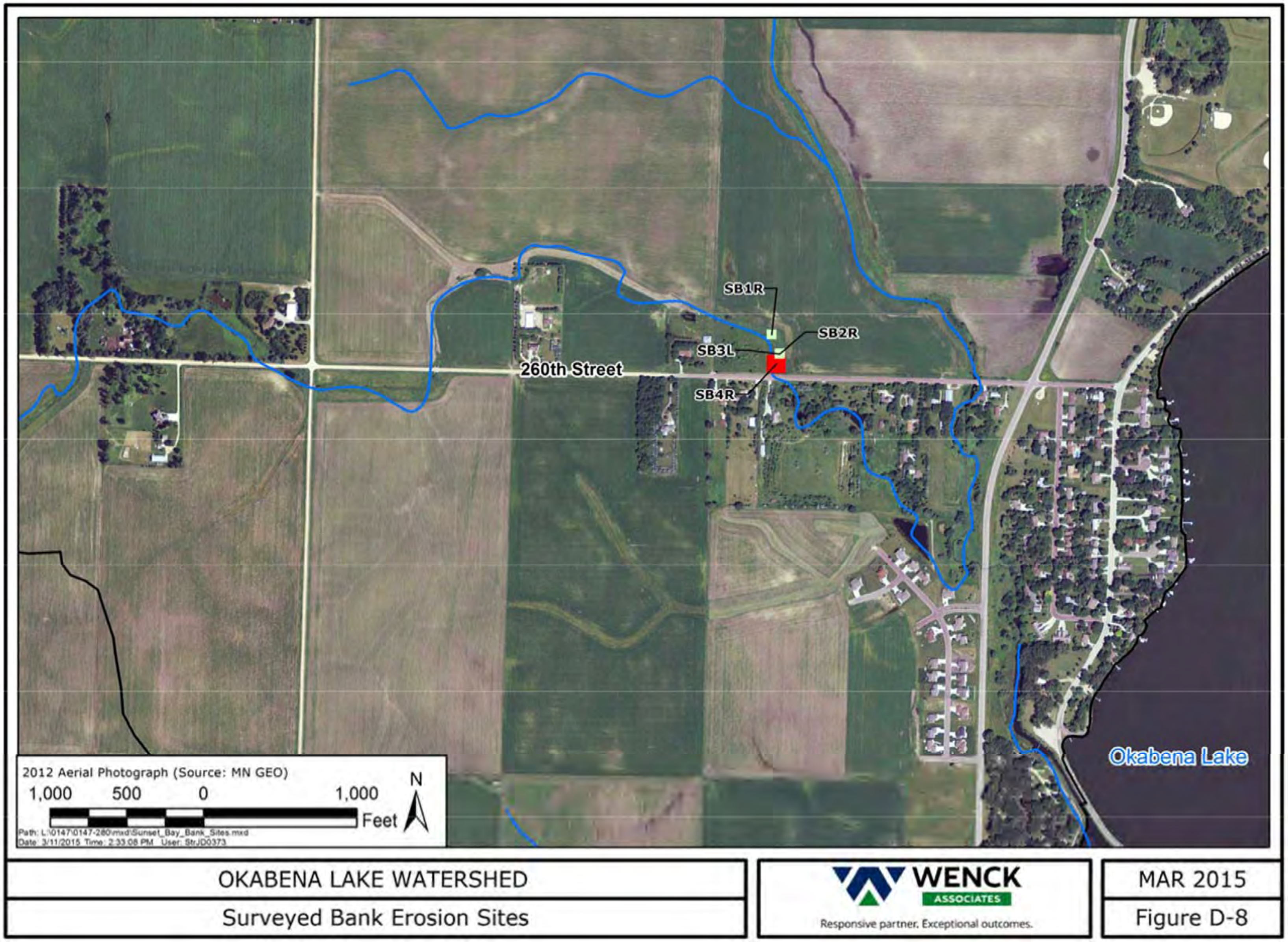

Figure D-8. Sunset Bay tributary surveyed bank erosion locations.

Appendix E

Internal Loading and Sediment Phosphorous Fractionation

Internal Phosphorus Loading and Sediment Phosphorus Fractionation Analysis for Lake Okabena, Minnesota

Google Maps

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10 May, 2014

OBJECTIVES

The objectives of this investigation were to determine rates of phosphorus (P) release from sediments under laboratory-controlled aerobic and anaerobic conditions and to quantify biologically-labile (i.e., subject to recycling) and refractory (i.e., biologically inert and subject to burial) P fractions for sediment collected in Lake Okabena, Minnesota.

APPROACH

Laboratory-derived rates of P release from sediment under anaerobic conditions: Sediment cores were collected by Wenck Associates, Inc. from centrally-located St. 1 in February, 2014, for determination of rates of P release from sediment under aerobic and anaerobic conditions (Figure 1 and Table 1). Cores were drained of overlying water and the upper 10 cm of sediment was transferred intact to a smaller acrylic core liner (6.5-cm dia and 20-cm ht) using a core remover tool. Surface water collected from the lake was filtered through a glass fiber filter (Gelman A-E), with 300 mL then siphoned onto the sediment contained in the small acrylic core liner without causing sediment resuspension. Sediment incubation systems consisted of the upper 10-cm of sediment and filtered overlying water contained in acrylic core liners that were sealed with rubber stoppers. They were placed in a darkened environmental chamber and incubated at a constant temperature (20 ^{o}C). The oxidation-reduction environment in the overlying water was controlled by gently bubbling nitrogen (anaerobic conditions, 3 replicates) or air (aerobic conditions, 3 replicates) through an air stone placed just above the sediment surface in each system. Bubbling action insured complete mixing of the water column but did not disrupt the sediment.

Water samples for soluble reactive P were collected from the center of each system using an acid-washed syringe and filtered through a 0.45 µm membrane syringe filter (Nalge). The water volume removed from each system during sampling was replaced by addition of filtered lake water preadjusted to the proper oxidation-reduction condition. These volumes were accurately measured for determination of dilution effects. Soluble reactive P was measured colorimetrically using the ascorbic acid method (APHA 2005). Rates of P release from the sediment (mg/m^2 d) were calculated as the linear change in mass in the overlying water divided by time (days) and the area (m^2) of the incubation core liner. Regression analysis was used to estimate rates over the linear portion of the data.

Sediment chemistry: In addition to St. 1, sediment cores were also collected in the dredged inlet area (i.e., St. 2; Figure 1) and at stations located in the western and eastern portion of Lake Okabena (Figure 1) for analysis of moisture content (%), sediment density (g/cm^3), loss on ignition (i.e., organic matter content, %), loosely-bound P, iron-bound P, labile organic P, total P, and total iron (Fe; all expressed at mg/g; Table 2). The sediment core collected at the centrally-located St. 1 was sectioned at 2-cm intervals over the upper 10 cm to examine vertical variations in sediment chemistry (Table 1). Sediment cores collected at St. 2, 3, and 4 were sectioned at 5-cm intervals over the upper 10 cm for analysis (Table 1). A known volume of sediment was dried at 105 ^{o}C for determination of moisture content and sediment density and burned at 550 ^{o}C for determination of loss-on-ignition organic matter content (Håkanson and Jansson 2002). Additional sediment was dried to a constant weight, ground, and digested for analysis of total P and Fe using standard methods (Anderson 1976, APHA 2005 method 4500 P.f., EPA method 3050B).

Phosphorus fractionation was conducted according to Hieltjes and Lijklema (1980), Psenner and Puckso (1988), and Nürnberg (1988) for the determination of ammonium-chloride-extractable P (loosely-bound P), bicarbonate-dithionite-extractable P (i.e., iron-bound P), and sodium hydroxide-extractable P (i.e., aluminum-bound P). A subsample of the sodium hydroxide extract was digested with potassium persulfate to determine nonreactive sodium hydroxide-extractable P (Psenner and Puckso 1988). Labile organic P was calculated as the difference between reactive and nonreactive sodium hydroxide-extractable P.

The loosely-bound and iron-bound P fractions are readily mobilized at the sediment-water interface as a result of anaerobic conditions that result in desorption of P from sediment and diffusion into the overlying water column (Mortimer 1971, Boström 1984, Nürnberg 1988). The sum of the loosely-bound and iron-bound P fractions represent redox-sensitive P (i.e., the P fraction that is active in P release under anaerobic and reducing conditions). In addition, labile organic P can be converted to soluble P via bacterial mineralization (Jensen and Andersen 1992) or hydrolysis of bacterial polyphosphates to soluble phosphate under anaerobic conditions (Gächter et al. 1988; Gächter and Meyer 1993; Hupfer et al. 1995). The sum of redox-sensitive P and labile organic P collectively represent biologically-labile P. This fraction is generally active in recycling pathways that result in exchanges of phosphate from the sediment to the overlying water column and potential assimilation by algae. In contrast, aluminum-bound, calcium-bound, and refractory organic P fractions are more chemically inert and subject to burial rather than recycling.

RESULTS AND INTERPRETATION

P mass and concentration increased approximately linearly in the overlying water column of St. 1 sediment systems maintained under anaerobic conditions (Figure 2). Linear increases in P concentration were observed between day 3 and 14. The mean P concentration maximum in the overlying water end of the incubation period was moderate at 0.382 mg/L (± 0.049 standard error; SE; Table 2). The mean rate of P release under anaerobic conditions was also moderate at 2.7 mg/m^2 d (± 0.5 SE; Table 3), but indicative of eutrophic conditions (Nürnberg 1988). Overall, the mean anaerobic P release rate was lower relative to other lakes in the region, and fell in the lower 25% quartile (Figure 3).

Soluble phosphorus accumulation in the overlying water column was lower for sediment cores collected at St. 1 and incubated under aerobic conditions (Figure 4). However, the mean aerobic P release rate was moderately high at 0.62 mg/m^2 d (± 0.03 SE; Table 3) and fell within the upper 25% quartile compared to other lakes in the region (Figure 3). The maximum P concentration attained in the overlying water column toward the end of the incubation period was moderately high at 0.161 mg/L (± 0.014 SE). Typically, rates of P release are higher under anaerobic versus aerobic conditions, due to binding of P onto Fe~(OOH) in the sediment oxidized microzone under the latter condition and suppression of diffusive flux into the overlying water column. Since Lake Okabena is shallow and exposed to wind-generated mixing, aerobic conditions probably regulate P release rates from sediment throughout most if not all of the summer.

At St. 1, sediment moisture content was moderately low (range = 54% to 72%), while dry bulk density was relatively high (range = 0.340 g/cm^3 to 0.640 g/cm^3), suggesting that sediment was composed of compacted clays and fine silts (Table 4). Organic matter content was low at less than 10% (Table 4). Moisture content declined modestly, while sediment dry bulk density increased with increasing sediment depth at St. 1, suggesting compaction of deeper sediment layers (Figure 5). Organic matter content was homogeneous as a function of increasing depth (Figure 5). The surface sediment layer at St. 3 and 4 in the main basin of Lake Okabena exhibited similar patterns of low moisture content (64% to 67%), high sediment dry bulk density (0.42 g/cm^3 to 0.46 g/cm^3), and low organic matter content (7.0%), comparable to St. 1 characteristics. In contrast, St. 2 sediment, located in the dredged area of the lake, exhibited slightly higher moisture content, lower sediment dry bulk density, and higher organic matter content compared to the main basin sites (Table 4). This pattern probably reflected some accumulation of fine-grained, more flocculent, particulate sediment from the watershed drained by the western tributary.

In the main basin (i.e., St. 1, 3, and 4), loosely-bound P concentrations were relatively high, representing ~ 43% of the redox-sensitive P concentration (i.e., the sum of loosely-bound and iron-bound P) in the surface sediment layer (i.e., 0-5 cm; Table 5 and Figure

6). Iron-bound P accounted for ~ 57% of this mobile P fraction at the same main basin stations (Figure 6). Concentrations of loosely-bound P in the main basin were also high, while iron-bound P concentrations were moderate and fell within the lower 25% quartile, relative to other lakes in the region (Figure 7). In contrast, surface sediment in the dredged area of the lake (St. 2), exhibited much lower concentrations of loosely-bound P compared to main basin sediments (Figure 6). Iron-bound P concentrations at this station were moderate and similar to those in the main basin.

Labile organic P concentrations in the main basin surficial sediment layer were low relative to redox-sensitive P concentrations (~ 17% of the biologically labile P; Figure 6). Concentrations also fell below the 25% quartile compared to other lakes in the region (Figure 7), reflecting, perhaps, the overall low organic matter content in the sediment of this shallow lake. Surface sediment concentrations of labile organic P differed in the dredged area versus the main basin (Figure 6). Concentrations of this fraction were much higher at St. 2 compared to other stations, representing ~ 33% of the biologically-labile sediment P concentration. Like other surface sediment characteristics, this pattern coincided with station location near the inflow. Although higher compared to main basin stations, concentrations of labile organic P at St. 2 were moderate relative to other lakes in the region (Figure 7).

Total P concentration in the surface sediment layer was homogeneous for main basin stations and slightly lower at station 2 (Figure 6), ranging between 0.63 mg/g and 0.73 mg/g (Table 5). They were also low relative to other lakes in the region (Figure 8). Total iron concentrations in the surface sediment layer fell near the median compared to other lakes in the region (Figure 8). The Fe:P ratio was high, ranging between 25:1 and 37:1. Ratios greater than 10:1 to 15:1 have been associated with regulation of P release from sediments under oxic (aerobic) conditions due to efficient binding of P onto iron oxyhydroxides in the sediment oxic microzone (Jensen et al. 1992). Complete binding efficiency for P at these higher relative concentrations of Fe are suggested explanations for patterns reported by Jensen et al. At lower Fe:P ratios, Fe binding sites become increasingly saturated with P, allowing for diffusion of excess porewater P into the overlying water column, even in the presence of a sediment oxic microzone. P release rates for Lake Okabena sediments at St. 1 were moderate under aerobic conditions, a pattern that could be attributed to the Jensen et al. model.

Biologically-labile P and total P concentrations were homogeneous over the upper 10-cm sediment layer at St. 1 (Figure 9). In contrast, elevated concentrations in the upper 2- to 4-cm might indicate the accumulation of P in excess of burial, a pattern often associated with eutrophic lake sediments (Carey and Rydin 2012). Lake mixing and frequent periods of sediment resuspension/redeposition may play a role homogenizing the upper sediment layer in the lake.

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Table 1. Station identification labels and numbers of sediment cores collected in Lake Okabena for determination of rates of phosphorus (P) flux under aerobic or anaerobic conditions and biologically-labile and refractory P fractions (see Table 2).

Station	P Flux		P fractions	
	Aerobic	Anaerobic	0- to 5-cm and 5- to 10-cm sections	Vertical profile
1	3	3		1
2			1	
3			1	
4			1	

Table 2. Sediment physical-textural characteristics, phosphorus species, and metals variable list.

Category	Variable
Physical-textural	Moisture content
	Wet and dry sediment bulk density
	Organic matter content
Phosphorus species	Loosely-bound P
	Iron-bound P
	Labile organic P
	Total P
Metals	Total Fe

Table 3. Mean (1 standard error in parentheses; n = 3) rates of phosphorus (P) release under aerobic and anaerobic conditions for sediments collected at station 1 in Lake Okabena.

Station	Diffusive P flux	
	Oxic ($mg\ m^{-2}\ d^{-1}$)	Anoxic ($mg\ m^{-2}\ d^{-1}$)
1	0.62 (0.03)	2.68 (0.47)

Table 4. Textural characteristics in the upper sediment layer for various stations in Lake Okabena.

Station	Section (cm)	Moisture Content (%)	Wet Bulk Density (g/cm^3)	Dry Bulk Density (g/cm^3)	Organic Matter (%)
1	0 - 2	71.8	1.190	0.341	7.9
1	2 - 4	68.0	1.223	0.397	7.4
1	4 - 6	63.6	1.262	0.468	7.4
1	6 - 8	62.5	1.273	0.487	7.2
1	8 - 10	54.0	1.355	0.639	7.5
2	0 - 5	77.7	1.137	0.258	12.3
2	5 - 10	72.7	1.175	0.328	11.5
3	0 - 5	64.3	1.258	0.457	6.9
3	5 - 10	62.4	1.274	0.489	7.0
4	0 - 5	66.8	1.235	0.417	6.9
4	5 - 10	57.9	1.320	0.568	6.4

Table 5. Concentrations of total iron (Fe), total phosphorus (P), the Fe:P ratio, and biologically labile and refractory P for various stations and sediment sections in Lake Okabena. DW = dry mass, FW = fresh mass.

Station	Section	Total Fe	Total P	Fe:P	Redox-sensitive and biologically labile P			
	(cm)	(mg/g DW)	(mg/g DW)		Loosely-bound P (mg/g DW)	Iron-bound P (mg/g DW)	Iron-bound P (ug/g FW)	Labile organic P (mg/g DW)
1	0 - 2	18.60	0.730	25.5	0.150	0.208	59	0.074
1	2 - 4	18.90	0.741	25.5	0.136	0.204	65	0.063
1	4 - 6	18.55	0.695	26.7	0.116	0.183	67	0.055
1	6 - 8	20.71	0.658	31.5	0.133	0.197	74	0.066
1	8 - 10	21.07	0.704	29.9	0.143	0.152	70	0.046
2	0 - 5	22.96	0.626	36.7	0.043	0.276	62	0.159
2	5 - 10	23.56	0.706	33.4	0.035	0.264	75	0.137
3	0 - 5	17.95	0.713	25.2	0.120	0.159	57	0.056
3	5 - 10	17.79	0.700	25.4	0.107	0.162	61	0.049
4	0 - 5	19.38	0.717	27.0	0.170	0.218	73	0.081
4	5 - 10	19.42	0.743	26.1	0.134	0.161	68	0.043

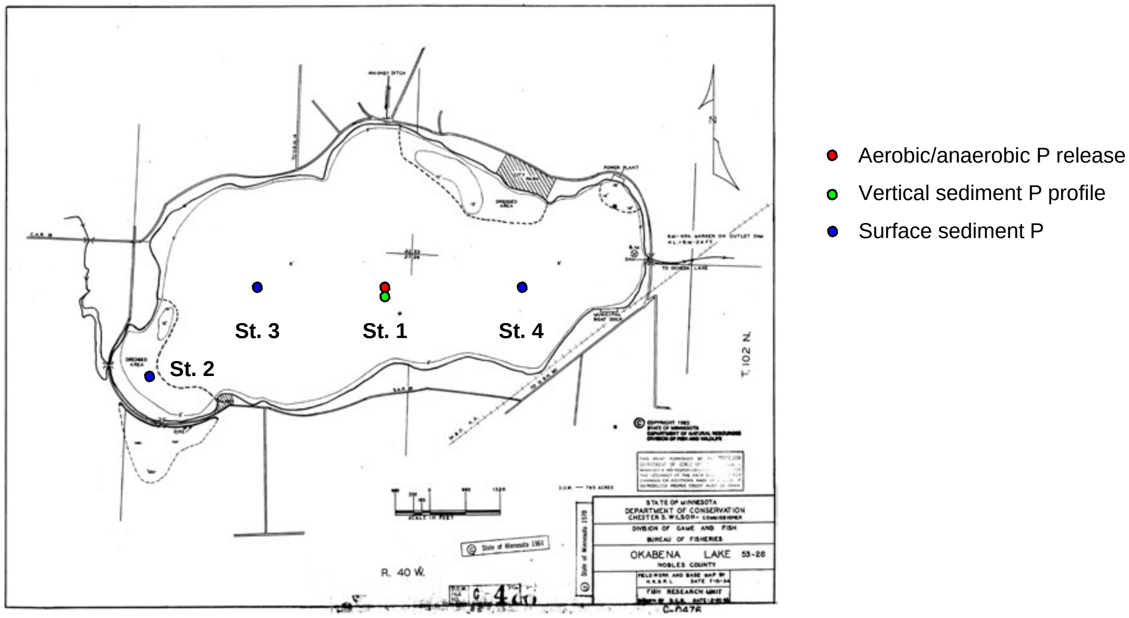

Figure 1. Station locations in Okabena Lake.

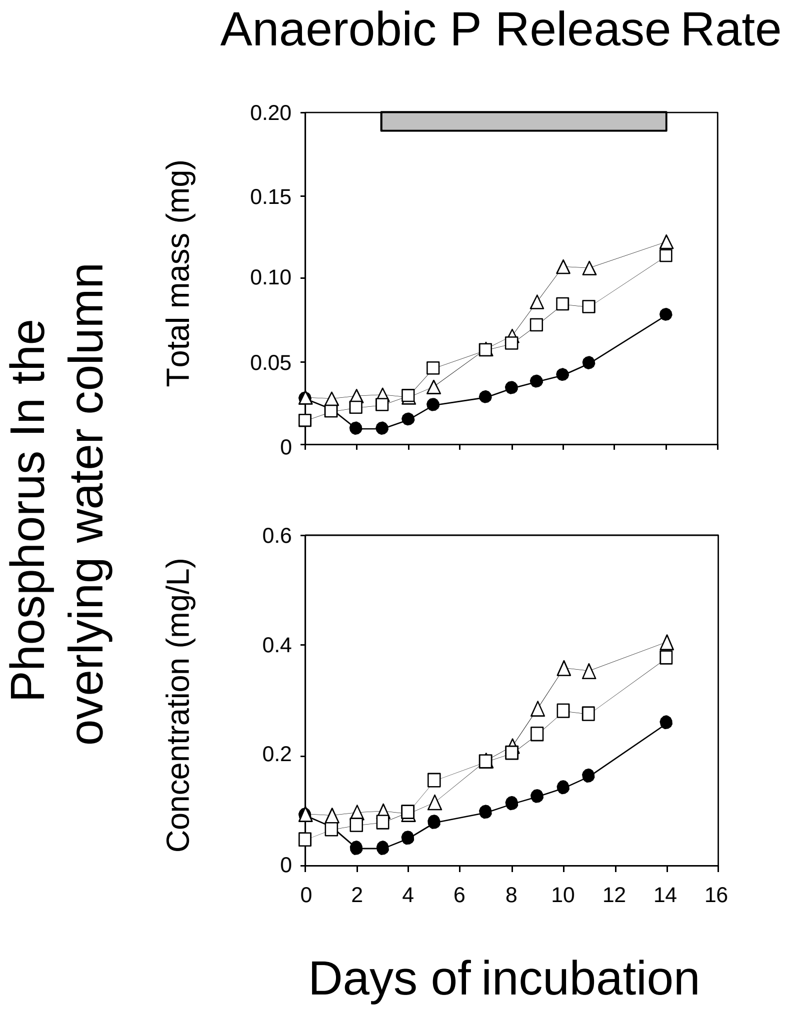

Figure 2. Changes in soluble reactive phosphorus mass (upper panel) and concentration (lower panes) in the overlying water column under anaerobic conditions versus time for sediment cores collected at station 1 in Okabena Lake. Gray horizontal bar denotes the time period used for rate estimation.

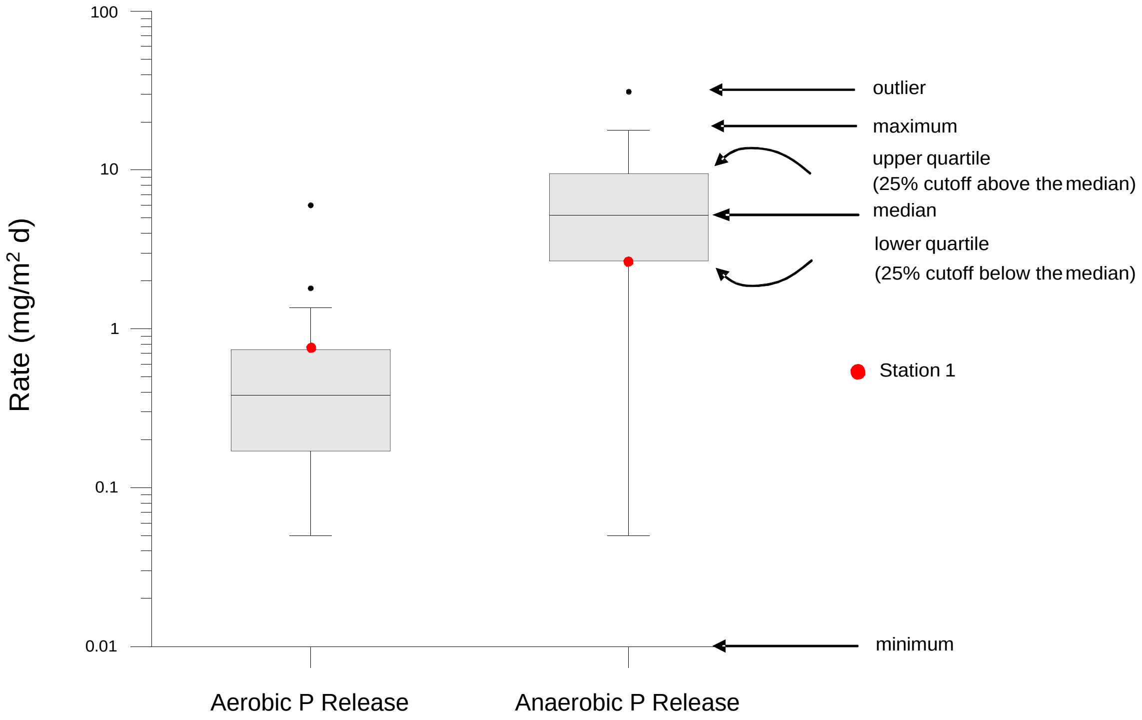

Figure 3. Box and whisker plot comparing the aerobic and anaerobic phosphorus (P) release rates measured for station 1 with statistical ranges for lakes in the region.

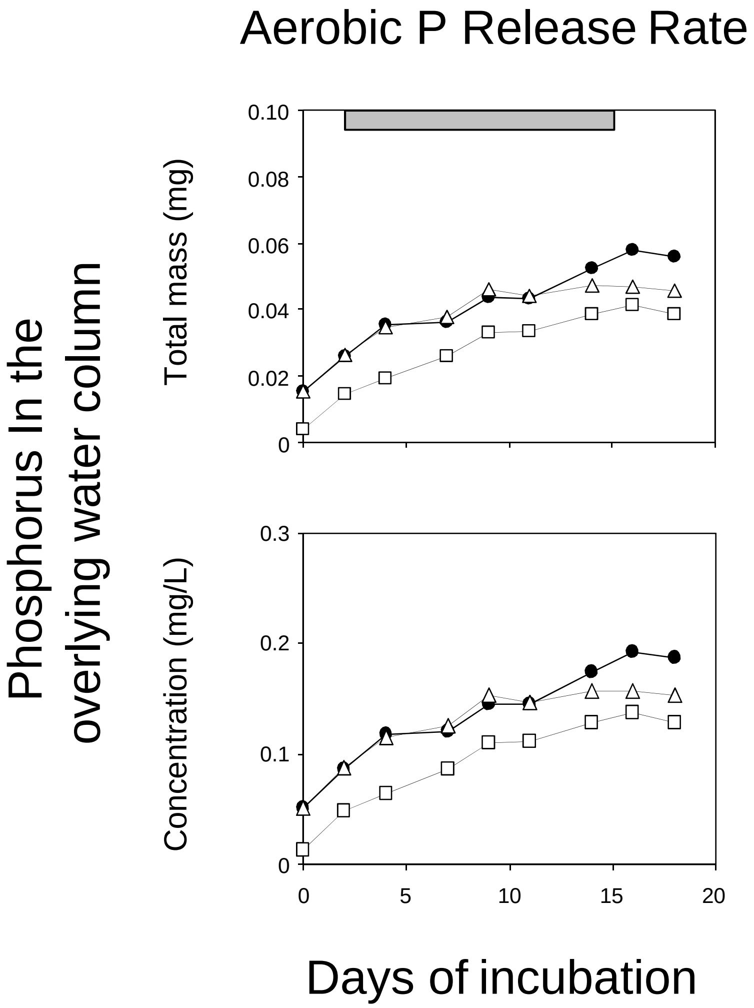

Figure 4. Changes in soluble reactive phosphorus mass (upper panel) and concentration (lower panels) in the overlying water column under aerobic conditions versus time for sediment cores collected from station 1 in Okabena Lake. Gray horizontal bar denotes the time period used for rate estimation.

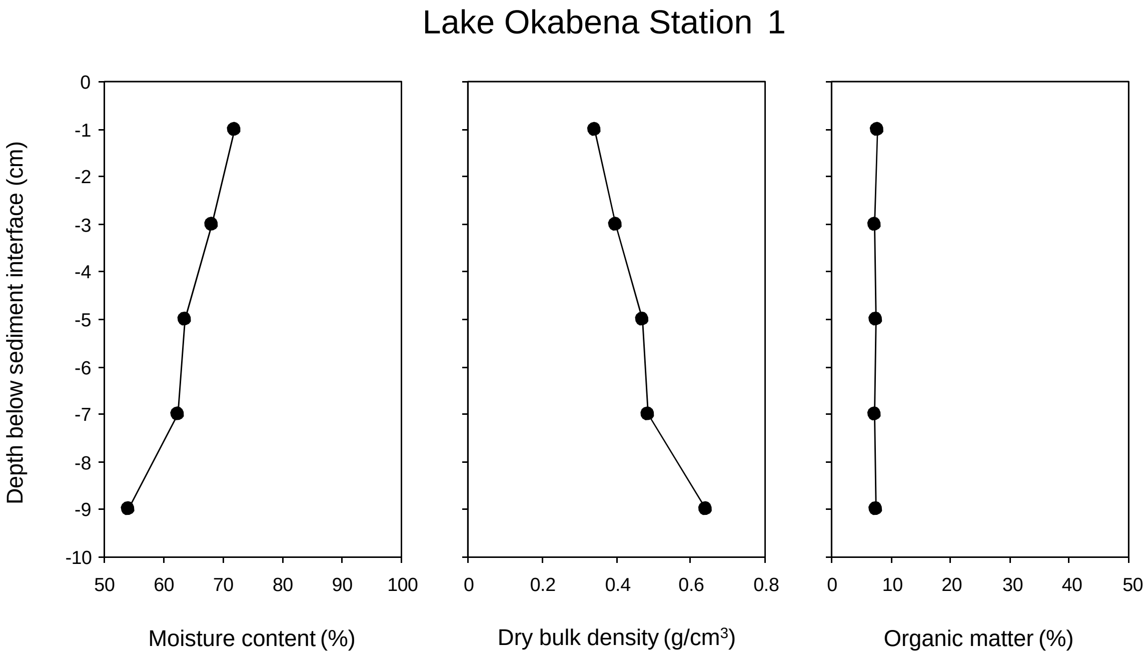

Figure 5. Variations in sediment moisture content, dry bulk density, and organic matter content as a function of depth below the sediment surface for a sediment core collected from station 1 of Okabena Lake.

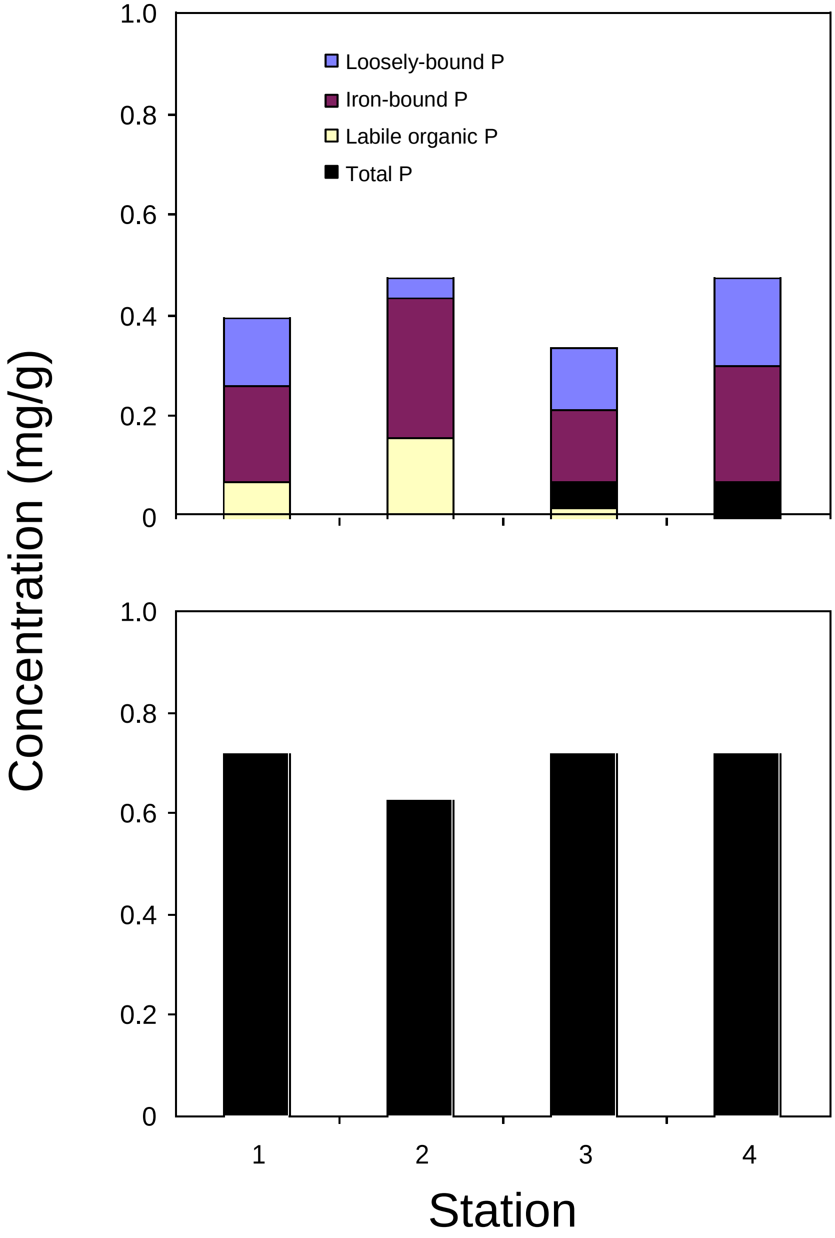

Figure 6. Variations in the concentration of biologically-labile phosphorus (P; i.e., subject to recycling with the overlying water column; sum of the loosely-bound, iron-bound, and labile organic P; upper panel) and total P (lower panel) in the upper 5-cm sediment layer for cores collected in Lake Okabena.

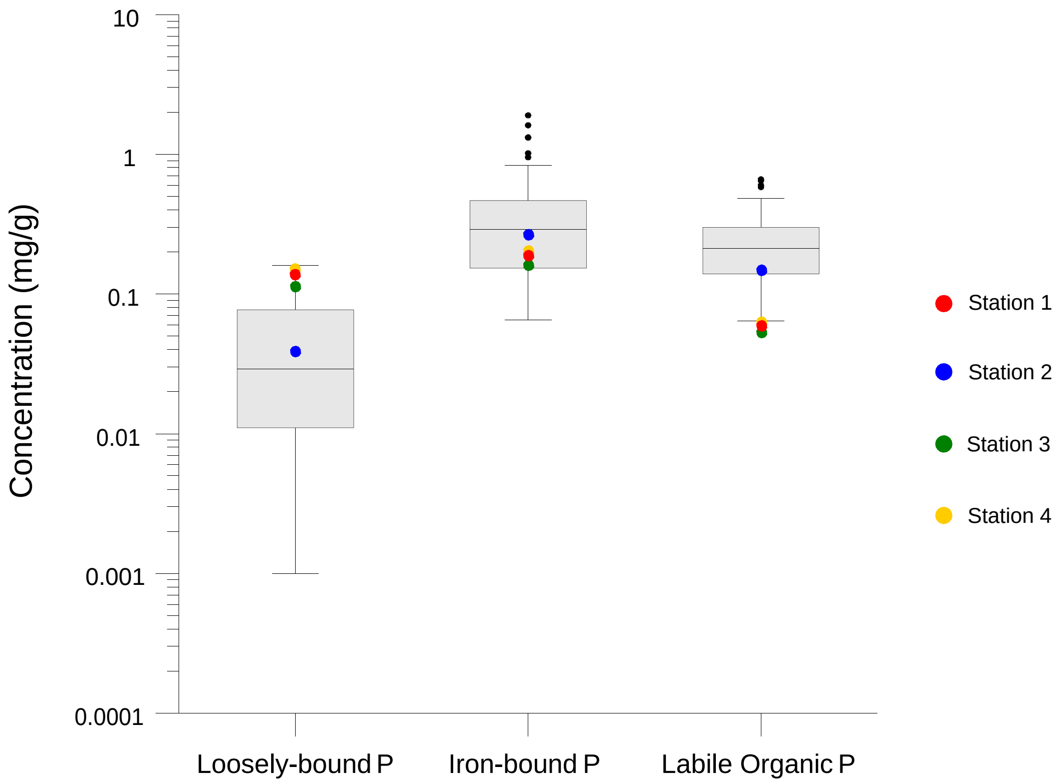

Figure 7. Box and whisker plot comparing various sediment phosphorus (P) fractions measured for various stations in Okabena Lake with statistical ranges for lakes in the region. Loosely-bound, iron-bound, and labile organic P are biologically-labile (i.e., subject to recycling). Please note the logarithmic scale.

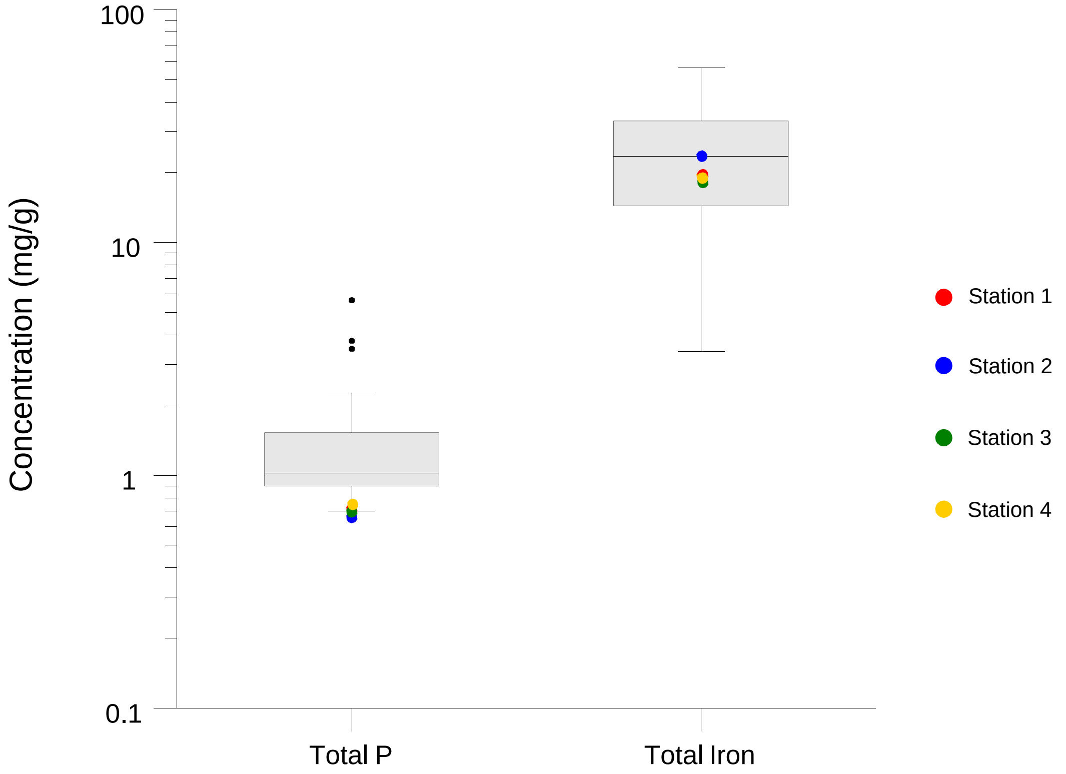

Figure 8. Box and whisker plot comparing total phosphorus (P) and total iron (Fe) measured for various stations in Okabena Lake with statistical ranges for lakes in the region. Please note the logarithmic scale.

Appendix G – Lake Response Models

Table G-1. Okabena Lake Current Conditions Canfield-Bachman Lake Response Model

Average Loading Summary for Okabena

Water Budgets | **Phosphorus Loading**

Inflow from Drainage Areas

	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	MS4s	1,438	5.7	677	275	1.0	507
2	Whiskey Ditch Rural	4,868	3.3	1,355	725.6	1.0	2,674
3	Direct Rural	613	3.3	168	679.8	1.0	311
4	Sunset Bay Rural	2,518	3.3	695	802.0	1.0	1,516
5							
	Summation	*9,437*	*16*	*2,895*			*5,007.4*

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1						1.0	
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation			*0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	Reach 211			0.04634			5.6
2	Reach 213			0.02471			3.0
3	Reach 214			0.01988			2.4
4							
5							
	Summation	*0*	*0*	*0.1*			*10.9*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1					-	1.0	
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*0*

Atmosphere

Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
778	27.6	27.6	0.00	0.49	1.0	378.7

Groundwater

Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
778	0.0		0.00	0	1.0	0

Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
3.15	59.9		Oxic	0.6	1.0	258
3.15	62.1		Anoxic	2.7	1.0	1,155
Summation						1,413
			Net Discharge [ac-ft/yr] =	**2,895**	**Net Load [lb/yr] =**	**6,810**

Average Lake Response Modeling for Okabena

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	[redacted] $P = P_i / \left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)$	C_P =	0.98	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
	W (total P load = inflow + atm.) =		3,089	[kg/yr]
	Q (lake outflow) =		3.6	[10^6 m^3/yr]
	V (modeled lake volume) =		6.3	[10^6 m^3]
		T = V/Q =	1.77	[yr]
		P_i = W/Q =	865	[µg/l]
Model Predicted In-Lake [TP]			**149**	**[ug/l]**
Observed In-Lake [TP]			**149**	**[ug/l]**

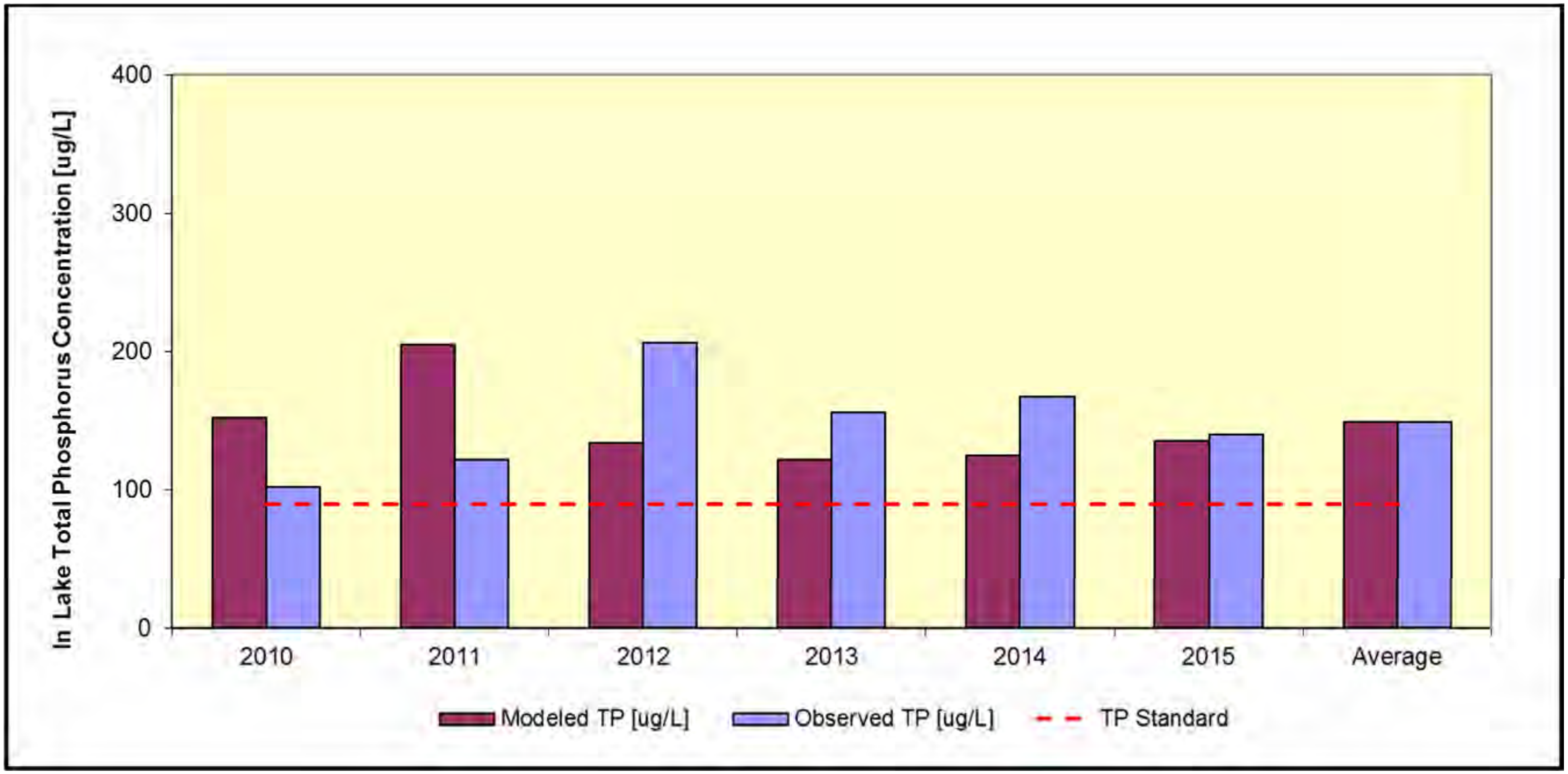

Figure G-1. Okabena Lake Model Calibration.

Table G-2. Okabena Lake TMDL Conditions Canfield-Bachman Lake Response Model

TMDL Loading Summary for Okabena

Water Budgets					Phosphorus Loading		
Inflow from Drainage Areas							
	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [lb/yr]
1	MS4s	1,438	5.7	677	255	0.9	470
2	Whiskey Ditch Ru	4,868	3.3	1,355	255.3	0.4	941
3	Direct Rural	613	3.3	168	255.3	0.4	117
4	Sunset Bay Rural	2,518	3.3	695	255.3	0.3	483
5							
	Summation	*9,437*	*16*	*2,895*			*2,010.5*

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [lb/yr]
1						1.0	
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation			*0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	Reach 211						0
2	Reach 213						0
3	Reach 214						0
4							
5							
	Summation	*0*	*0*	*0.0*			*0.0*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1					-	1.0	
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*0*

Atmosphere

Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
778	27.6	27.6	0.00	0.49	1.0	378.7

Groundwater

Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
778	0.0		0.00	0	1.0	0

Internal

	Lake Area $[km^2]$	Anoxic Factor [days]			Release Rate $[mg/m^2\text{-day}]$	Calibration Factor [--]	Load [lb/yr]
	3.15	59.9		Oxic	0.6	1.0	258
	3.15	62.1		Anoxic	1.0	1.0	432
	Summation						690
		Net Discharge [ac-ft/yr] =		**2,895**	**Net Load [lb/yr] =**		**3,079**

TMDL Lake Response Modeling for Okabena

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$ as f(W,Q,V) from Canfield & Bachmann (1981)	C_P =	0.98	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	1,397	[kg/yr]
		Q (lake outflow) =	3.6	$[10^6 m^3/yr]$
		V (modeled lake volume) =	6.3	$[10^6 m^3]$
		T = V/Q =	1.77	[yr]
		P_i = W/Q =	391	[µg/l]
Model Predicted In-Lake [TP]			**90**	**[ug/l]**
Observed In-Lake [TP]			**149**	**[ug/l]**

Table G-3. Ocheda Lake (West Basin) Average Conditions Canfield-Bachman Lake Response Model

Average Loading Summary for Ocheda

Water Budgets					Phosphorus Loading		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Reach 222 (Direct)	5,074	11.6	4,912	223	1.0	2,986
2	Reach 221	3,915	12.9	4,215	437.1	1.0	5,011
3						1.0	
4						1.0	
5						1.0	
6						1.0	
	Summation	*8,989*	*25*	*9,127*			7997.7
Point Source Dischargers							
				Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1				0		1.0	0
2				0		1.0	0
3				0		1.0	0
4				0		1.0	0
5				0		1.0	0
	Summation			*0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	Reach 221	17					4.3
2	Reach 222	22					5.5
3							
4							
5							
	Summation	*39*	*0*	*0.0*			*9.8*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Ocheda (M) Reach			12,666	271.0	1.0	9,338
2					-	1.0	
3					-	1.0	
	Summation			*12,666*	*271.0*		*9,338*
Atmosphere							
	Lake Area	Precipitation	Evaporation	Net Inflow	Aerial Loading Rate	Calibration Factor	Load
	[acre]	[in/yr]	[in/yr]	[ac-ft/yr]	[lb/ac-yr]	[--]	[lb/yr]
	464	28.4	28.4	0.00	0.49	1.0	228.6
				Dry-year total P deposition =	0.222		
				Average-year total P deposition =	0.239		
				Wet-year total P deposition =	0.259		
				(Barr Engineering 2004)			
Groundwater							
	Lake Area	Groundwater Flux		Net Inflow	Phosphorus Concentration	Calibration Factor	Load
	[acre]	[m/yr]		[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
	464	0.0		0.00	0	1.0	0
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	1.88	51.96288618		Oxic		1.0	
	1.88	70.0		Anoxic	15.8	1.0	4,581
	Summation						4,581
			Net Discharge [ac-ft/yr] =	**21,793**		**Net Load [lb/yr] =**	**22,155**

Average Lake Response Modeling for Ocheda

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.2	[--]
		b =	0.5	[--]
		W (total P load = inflow + atm.) =	10049.3	[kg/yr]
		Q (lake outflow) =	26.9	[10^6 m^3/yr]
		V (modeled lake volume) =	2.3	[10^6 m^3]
		T = V/Q =	0.1	[yr]
		P_i = W/Q =	373.7	[µg/l]
Model Predicted In-Lake [TP]			**227.5**	**[ug/l]**
Observed In-Lake [TP]			**227.5**	**[ug/l]**

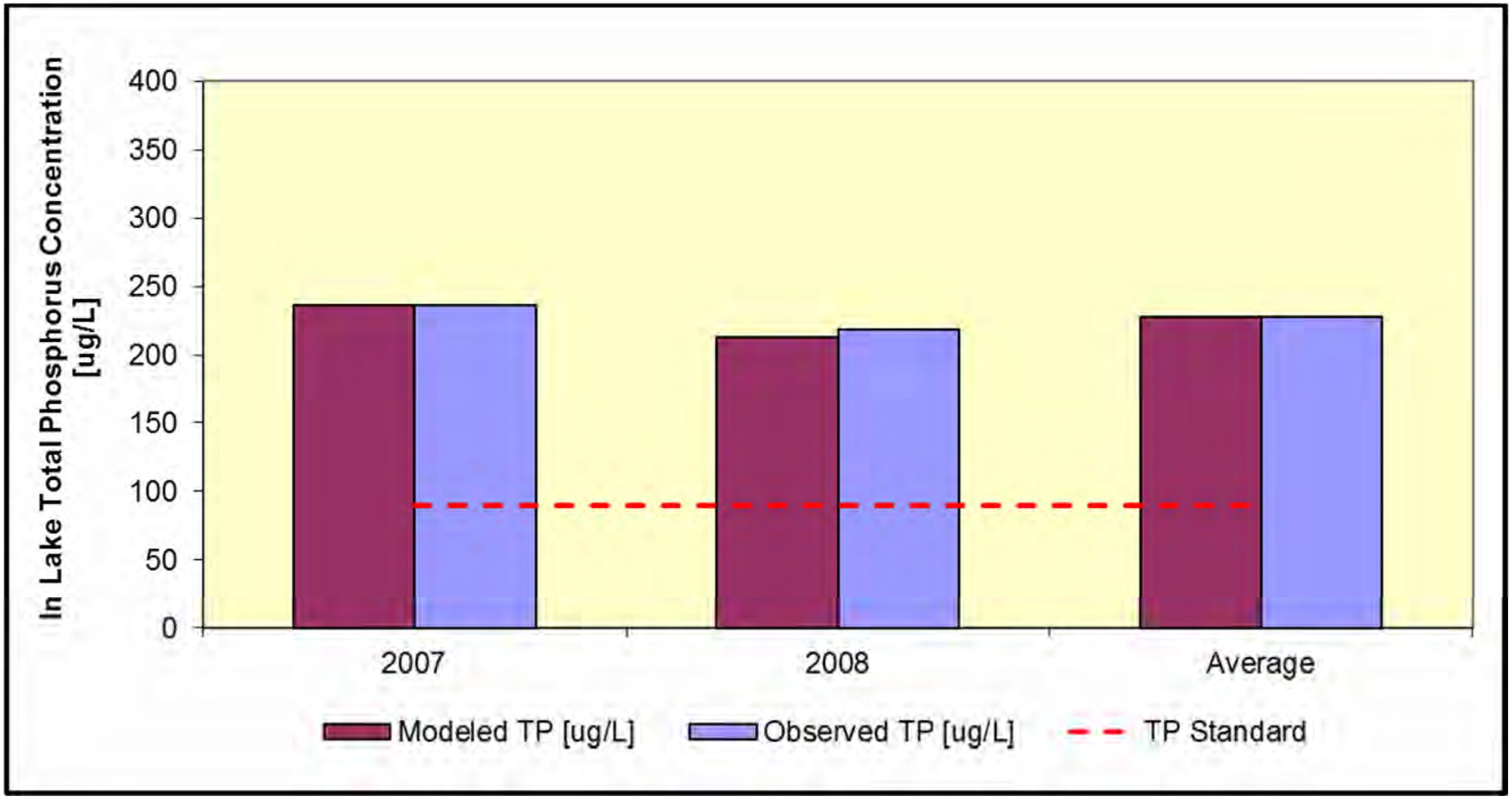

Figure G-2. Ocheda Lake Model Calibration.

Table G-4. Ocheda Lake TMDL Conditions Canfield-Bachman Lake Response Model

TMDL Loading Summary for Ocheda

	Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Reach 222 (Direct)	5,074	11.6	4,912	106	1.0	1,416
2	Reach 221	3,915	12.9	4,215	207.3	1.0	2,376
3						1.0	0
4						1.0	0
5						1.0	0
6						1.0	0
	Summation	*8,989*	*25*	*9,127*			*3,793*
Point Source Dischargers							
				Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1				0		1.0	0
2				0		1.0	0
3				0		1.0	0
4				0		1.0	0
5				0		1.0	0
	Summation			*0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	Reach 221	17					
2	Reach 222	22					
3							
4							
5							
	Summation	*39*	*0*	*0.0*			*0.0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Ocheda (M) Reach 21			12,666	90.0	0.3	3,101
2					-	1.0	
3					-	1.0	
	Summation			*12,666*	*90.0*		*3,101*
Atmosphere							
	Lake Area	Precipitation	Evaporation	Net Inflow	Aerial Loading Rate	Calibration Factor	Load
	[acre]	[in/yr]	[in/yr]	[ac-ft/yr]	[lb/ac-yr]	[--]	[lb/yr]
	464	28.4	28.4	0.00	0.49	1.0	228.6
		Dry-year total P deposition =			0.222		
		Average-year total P deposition =			0.239		
		Wet-year total P deposition =			0.259		
		(Barr Engineering 2004)					
Groundwater							
	Lake Area	Groundwater Flux		Net Inflow	Phosphorus Concentration	Calibration Factor	Load
	[acre]	[m/yr]		[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
	464	0.0		0.00	0	1.0	0
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	1.88	51.96288618		Oxic		1.0	
	1.88	70.0		Anoxic	1.0	1.0	290
	Summation						290
		Net Discharge [ac-ft/yr] =		**21,793**	**Net Load [lb/yr] =**		**7,412**

TMDL Lake Response Modeling for Ocheda

Modeled Parameter — **Equation** — **Parameters** — **Value** — **[Units]**

TOTAL IN-LAKE PHOSPHORUS CONCENTRATION

[redacted]

$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$

Parameters	Value	[Units]
C_P =	1.00	[--]
C_{CB} =	0.162	[--]
b =	0.458	[--]
W (total P load = inflow + atm.) =	3,362	[kg/yr]
Q (lake outflow) =	26.9	[10^6 m^3/yr]
V (modeled lake volume) =	2.3	[10^6 m^3]
T = V/Q =	0.09	[yr]
P_i = W/Q =	125	[µg/l]
Model Predicted In-Lake [TP]	**90.0**	**[ug/l]**
Observed In-Lake [TP]	**227.5**	**[ug/l]**

Table G-5. Bella Lake Average Conditions Canfield-Bachman Lake Response Model

Average Loading Summary for Bella

	Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas							
	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentratio [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Direct (Reach 224)	7,302	5.1	3,112	410	1.0	3,473
2							
3							
4							
5							
6							
	Summation	*7,302*	*5*	*3,112*			3473.3
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentratio [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1				0		1.0	0
2				0		1.0	0
3				0		1.0	0
4				0		1.0	0
5				0		1.0	0
	Summation			*0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	Reach 224	32		0.06671			8.0
2							
3							
4							
5							
	Summation	*32*	*0*	*0.1*			*8.0*
Inflow from Upstream Lakes							
	Name			Discharge [ac-ft/yr]	Estimated P Concentratio [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	Ocheda (W)			16,182	223.2	1.0	9,825
2					-	1.0	
3					-	1.0	
	Summation			*16,182*	*223.2*		*9,825*
Atmosphere							
	Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
	164	33.0	33.0	0.00	0.49	1.0	81.0
				Dry-year total P deposition =	0.222		
				Average-year total P deposition =	0.239		
				Wet-year total P deposition =	0.259		
				(Barr Engineering 2004)			
Groundwater							
	Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentratio [ug/L]	Calibration Factor [--]	Load [lb/yr]
	164	0.0		0.00	0	1.0	0
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	0.66	133		Oxic		1.0	
	0.66	66.0		Anoxic	0.1	1.0	10
	Summation						10
			Net Discharge [ac-ft/yr] =	**19,294**		**Net Load [lb/yr] =**	**13,397**

Average Lake Response Modeling for Bella

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	C_P =	1.22	[--]
		C_{CB} =	0.2	[--]
		b =	0.5	[--]
		W (total P load = inflow + atm.) =	6076.9	[kg/yr]
		Q (lake outflow) =	23.8	[10^6 m^3/yr]
		V (modeled lake volume) =	1.0	[10^6 m^3]
		T = V/Q =	0.04	[yr]
		P_i = W/Q =	255.2	[µg/l]
Model Predicted In-Lake [TP]			**176**	**[ug/l]**
Observed In-Lake [TP]			**176**	**[ug/l]**

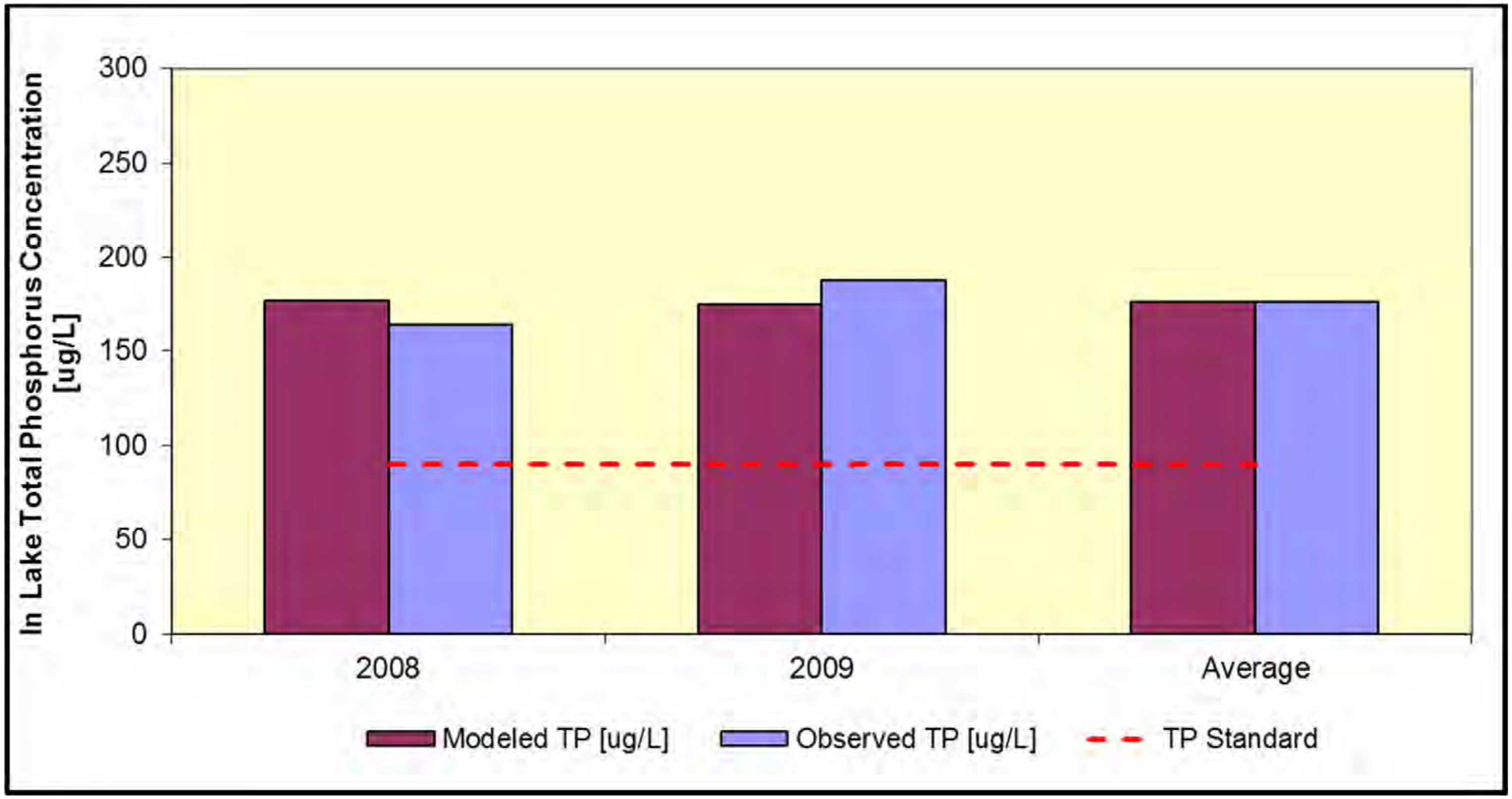

Figure G-3. Bella Lake Model Calibration.

Table G-6. Bella Lake TMDL Conditions Canfield-Bachman Lake Response Model

TMDL Loading Summary for Bella

Water Budgets | **Phosphorus Loading**

Inflow from Drainage Areas

	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Direct (Reach 224)	7,302	5.1	3,112	256	0.6	2,171
2							
3							
4							
5							
6							
	Summation	*7,302*	*5*	*3,112*			2171.2

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1				0		1.0	0
2				0		1.0	0
3				0		1.0	0
4				0		1.0	0
5				0		1.0	0
	Summation			*0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	Reach 224	32					
2							
3							
4							
5							
	Summation	*32*	*0*	*0.0*			*0.0*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	Ocheda (W)			16,182	90.0	0.4	3,962
2					-	1.0	
3					-	1.0	
	Summation			*16,182*	*90.0*		*3,962*

Atmosphere

Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
164	33.0	33.0	0.00	0.49	1.0	81.0
			Dry-year total P deposition =	0.222		
			Average-year total P deposition =	0.239		
			Wet-year total P deposition =	0.259		
			(Barr Engineering 2004)			

Groundwater

Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
164	0.0		0.00	0	1.0	0

Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
0.66	133		Oxic		1.0	
0.66	66.0		Anoxic	0.1	1.0	10
Summation						10

Net Discharge [ac-ft/yr] =	19,294	Net Load [lb/yr] =	6,224

TMDL Lake Response Modeling for Bella

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.22	[--]
		C_{CB} =	0.2	[--]
		b =	0.5	[--]
		W (total P load = inflow + atm.) =	2823.1	[kg/yr]
		Q (lake outflow) =	23.8	[10^6 m^3/yr]
		V (modeled lake volume) =	1.0	[10^6 m^3]
		T = V/Q =	0.04250	[yr]
		P_i = W/Q =	118.6	[µg/l]
Model Predicted In-Lake [TP]			**90**	**[ug/l]**
Observed In-Lake [TP]			**176**	**[ug/l]**

Table G-7. Indian Lake Average Conditions Canfield-Bachman Lake Response Model

Average Loading Summary for Indian

		Water Budgets			Phosphorus Loading		
Inflow from Drainage Areas							
	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [lb/yr]
1	Reach 119	7,724	6.6	4,256	461	1.0	5,338
2							
3							
4							
5							
6							
	Summation	*7,724*	*7*	*4,256*			5338.5
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [lb/yr]
1				0		1.0	0
2				0		1.0	0
3				0		1.0	0
4				0		1.0	0
5				0		1.0	0
	Summation			*0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	Reach 119			0.07007			8.4
2							
3							
4							
5							
	Summation	*0*	*0*	*0.1*			*8.4*
Inflow from Upstream Lakes							
	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	No Upstream Lake				-	1.0	
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*0*
Atmosphere							
	Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
	182	29.7	29.7	0.00	0.44	1.0	79.9
			Dry-year total P deposition =		0.222		
			Average-year total P deposition =		0.239		
			Wet-year total P deposition =		0.259		
			(Barr Engineering 2004)				
Groundwater							
	Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
	182	0.0		0.00	0	1.0	0
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	0.73	52.63215806		Oxic		1.0	
	0.73	69.4		Anoxic	0.1	1.0	11
	Summation						11
			Net Discharge [ac-ft/yr] =	**4,256**		**Net Load [lb/yr] =**	**5,438**

Average Lake Response Modeling for Indian

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)			
		C_P =	1.90	[--]
		C_{CB} =	0.2	[--]
		b =	0.5	[--]
		W (total P load = inflow + atm.) =	2466.2	[kg/yr]
		Q (lake outflow) =	5.3	[10^6 m^3/yr]
		V (modeled lake volume) =	1.0	[10^6 m^3]
		T = V/Q =	0.2	[yr]
		P_i = W/Q =	469.6	[µg/l]
Model Predicted In-Lake [TP]			**154**	**[ug/l]**
Observed In-Lake [TP]			**154**	**[ug/l]**

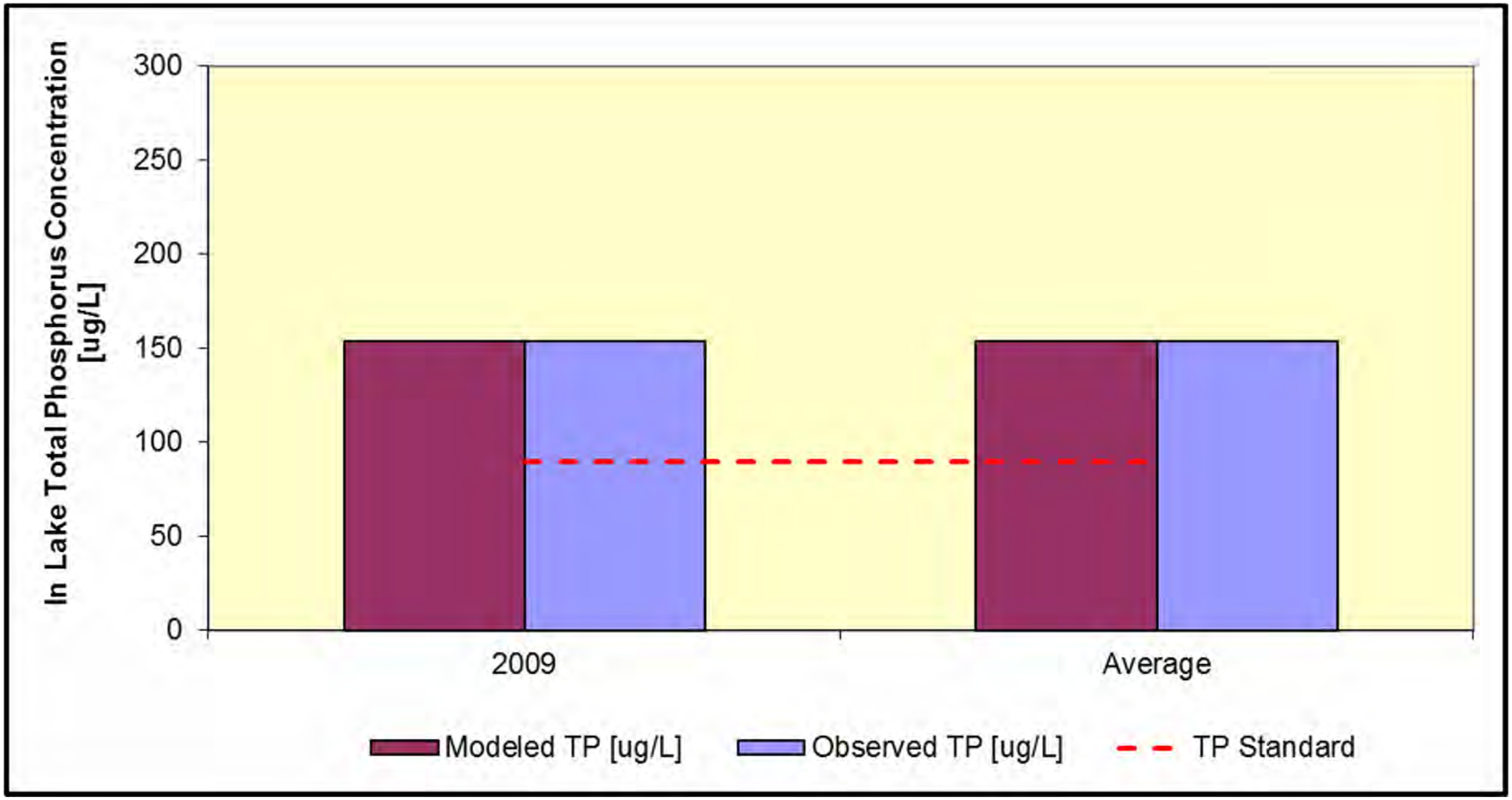

Figure G-4. Indian Lake Model Calibration.

Table G-8. Indian Lake TMDL Conditions Canfield-Bachman Lake Response Model

TMDL Loading Summary for Indian

Water Budgets					Phosphorus Loading		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Reach 119	7,724	6.6	4,256	213	1.0	2,462
2					0.0	1.0	0
3					0.0	1.0	0
4					0.0	1.0	0
5					0.0	1.0	0
6					0.0	1.0	0
	Summation	*7,724*	*7*	*4,256*			2,462
Point Source Dischargers							
				Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1				0		1.0	0
2				0		1.0	0
3				0		1.0	0
4				0		1.0	0
5				0		1.0	0
	Summation			*0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	Reach 119						
2							
3							
4							
5							
	Summation	*0*	*0*	*0.0*			*0.0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	No Upstream Lake				-	1.0	
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*0*
Atmosphere							
	Lake Area	Precipitation	Evaporation	Net Inflow	Aerial Loading Rate	Calibration Factor	Load
	[acre]	[in/yr]	[in/yr]	[ac-ft/yr]	[lb/ac-yr]	[--]	[lb/yr]
	182	29.7	29.7	0.00	0.44	1.0	79.9
				Dry-year total P deposition =	0.222		
				Average-year total P deposition =	0.239		
				Wet-year total P deposition =	0.259		
				(Barr Engineering 2004)			
Groundwater							
	Lake Area	Groundwater Flux		Net Inflow	Phosphorus Concentration	Calibration Factor	Load
	[acre]	[m/yr]		[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
	182	0.0		0.00	0	1.0	0
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	0.73	58.87063443		Oxic		1.0	
	0.73	63.1		Anoxic	0.1	1.0	10
	Summation						10
			Net Discharge [ac-ft/yr] =	**4,256**		**Net Load [lb/yr] =**	**2,552**

TMDL Lake Response Modeling for Indian

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.90	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	1,158	[kg/yr]
		Q (lake outflow) =	5.3	[10^6 m^3/yr]
		V (modeled lake volume) =	1.0	[10^6 m^3]
		T = V/Q =	0.18	[yr]
		P_i = W/Q =	220	[µg/l]
Model Predicted In-Lake [TP]			**90**	**[ug/l]**
Observed In-Lake [TP]			**154**	**[ug/l]**

Table G-9. Iowa Lake Average Conditions Canfield-Bachman Lake Response Model

Average Loading Summary for Iowa

Water Budgets / **Phosphorus Loading**

Inflow from Drainage Areas

	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [lb/yr]
1	Reach 121	4,317	9.4	3,376	431	1.0	3,956
2						1.0	
3						1.0	
4						1.0	
5						1.0	
6						1.0	
	Summation	*4,317*	*9*	*3,376*			3955.8

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [lb/yr]
1				0		1.0	0
2				0		1.0	0
3				0		1.0	0
4				0		1.0	0
5				0		1.0	0
	Summation			*0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	Reach 121			0.04046			4.9
2							
3							
4							
5							
	Summation	*0*	*0*	*0.0*			*4.9*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	No Upstream Lake				-	1.0	
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*0*

Atmosphere

	Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
	220	32.6	32.6	0.00	0.55	1.0	120.2
			Dry-year total P deposition =		0.222		
			Average-year total P deposition =		0.239		
			Wet-year total P deposition =		0.259		
			(Barr Engineering 2004)				

Groundwater

	Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
	220	0.0		0.00	0	1.0	0

Internal

	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	0.89	133		Oxic		1.0	
	0.89	69.6		Anoxic	1.6	1.0	219
	Summation						219
			Net Discharge [ac-ft/yr] =	**3,376**		**Net Load [lb/yr] =**	**4,300**

Average Lake Response Modeling for Iowa

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$$P = \frac{P_i}{1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T}$$	f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.2	[--]
		b =	0.5	[--]
		W (total P load = inflow + atm.) =	1950.6	[kg/yr]
		Q (lake outflow) =	4.2	[10^6 m^3/yr]
		V (modeled lake volume) =	0.8	[10^6 m^3]
		T = V/Q =	0.2	[yr]
		P_i = W/Q =	468.2	[µg/l]
Model Predicted In-Lake [TP]			**221**	**[ug/l]**
Observed In-Lake [TP]			**221**	**[ug/l]**

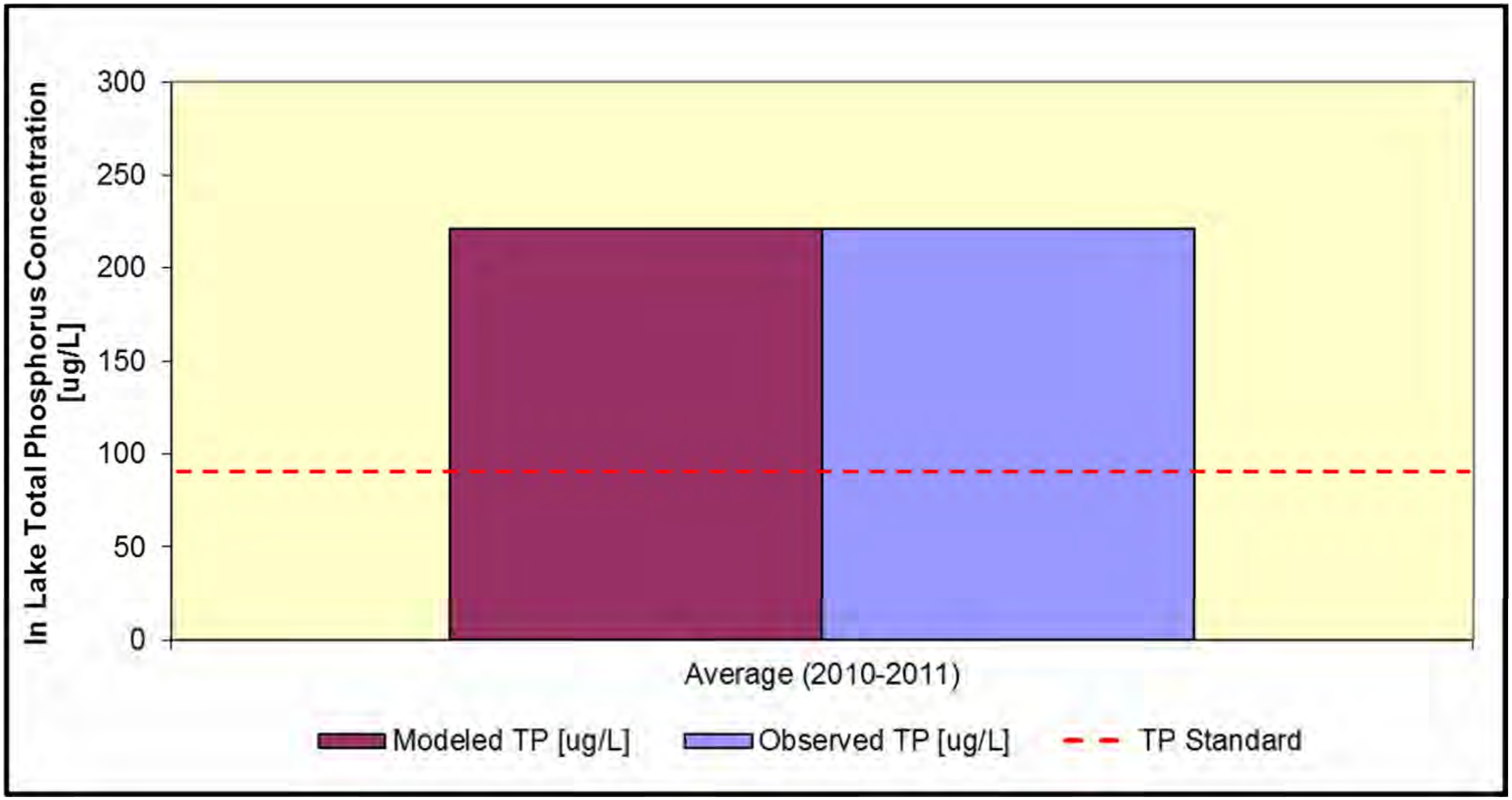

Figure G-5. Iowa Lake Model Calibration.

Table G-10. Iowa Lake TMDL Conditions Canfield-Bachman Lake Response Model

TMDL Loading Summary for Iowa

Water Budgets | **Phosphorus Loading**

Inflow from Drainage Areas

	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Reach 121	4,317	9.4	3,376	122	0.3	1,118
2						1.0	
3						1.0	
4						1.0	
5						1.0	
6						1.0	
	Summation	*4,317*	*9*	*3,376*			1117.8

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1				0		1.0	0
2				0		1.0	0
3				0		1.0	0
4				0		1.0	0
5				0		1.0	0
	Summation			*0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	Reach 121						0
2							
3							
4							
5							
	Summation	*0*	*0*	*0.0*			*0.0*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	No Upstream Lake				-	1.0	
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*0*

Atmosphere

Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
220	32.6	32.6	0.00	0.55	1.0	120.2

Dry-year total P deposition = 0.222
Average-year total P deposition = 0.239
Wet-year total P deposition = 0.259
(Barr Engineering 2004)

Groundwater

Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
220	0.0		0.00	0	1.0	0

Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
0.89	133		Oxic		1.0	
0.89	69.6		Anoxic	1.6	1.0	136
Summation						136

Net Discharge [ac-ft/yr] = 3,376 | **Net Load [lb/yr] = 1,375**

TMDL Lake Response Modeling for Iowa

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \frac{P_i}{1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.2	[--]
		b =	0.5	[--]
		W (total P load = inflow + atm.) =	623.5	[kg/yr]
		Q (lake outflow) =	4.2	[10^6 m^3/yr]
		V (modeled lake volume) =	0.8	[10^6 m^3]
		T = V/Q =	0.2	[yr]
		P_i = W/Q =	149.7	[µg/l]
Model Predicted In-Lake [TP]			**90**	**[ug/l]**
Observed In-Lake [TP]			**221**	**[ug/l]**

Table G-11. Round Lake Average Conditions Canfield-Bachman Lake Response Model

Average Loading Summary for Round

Water Budgets | **Phosphorus Loading**

Inflow from Drainage Areas

	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Reach 124 (Entire Watershed)	5,706	4.7	2,214	593	1.0	3,572
2						1.0	
3						1.0	
4						1.0	
5						1.0	
6						1.0	
	Summation	*5,706*	*5*	*2,214*			3572.2

Point Source Dischargers

	Name			Discharge [ac-ft/yr] 0	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1				0		1.0	0
2				0		1.0	0
3				0		1.0	0
4				0		1.0	0
5				*0*		1.0	0
	Summation						*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	Reach 124	27		0.5705			6.9
2							
3							
4							
5							
	Summation	*27*	*0*	*0.6*			*6.9*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	No Upstream Lakes				-	1.0	
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*0*

Atmosphere

Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
930	23.6	23.6	0.00	0.44	1.0	410.9
			Dry-year total P deposition =	0.222		
			Average-year total P deposition =	0.239		
			Wet-year total P deposition =	0.259		
			(Barr Engineering 2004)			

Groundwater

Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
930	0.0		0.00	0	1.0	0

Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
3.76	63.6		Oxic		1.0	
3.76	58.4		Anoxic	0.6	1.0	276
Summation						276
		Net Discharge [ac-ft/yr] =	**2,215**	**Net Load [lb/yr] =**		**4,266**

Average Lake Response Modeling for Round

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.2	[--]
		b =	0.5	[--]
		W (total P load = inflow + atm.) =	1935.1	[kg/yr]
		Q (lake outflow) =	2.7	[10^6 m^3/yr]
		V (modeled lake volume) =	5.2	[10^6 m^3]
		T = V/Q =	1.9	[yr]
		P_i = W/Q =	708.0	[µg/l]
Model Predicted In-Lake [TP]			**125**	**[ug/l]**
Observed In-Lake [TP]			**125**	**[ug/l]**

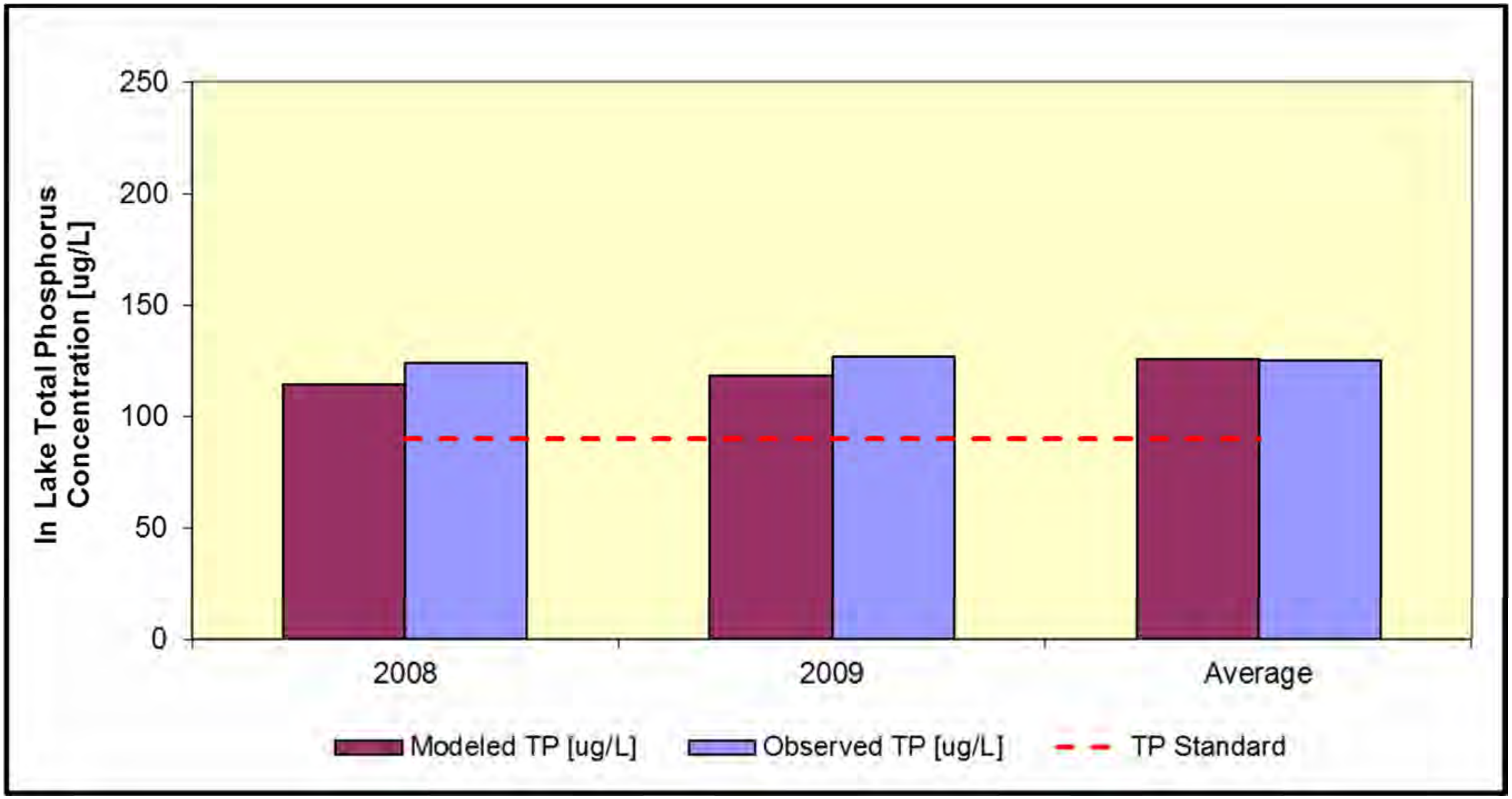

Figure G-6. Round Lake Model Calibration.

Table G-12. Round Lake TMDL Conditions Canfield-Bachman Lake Response Model

	TMDL Loading Summary for Round						
	Water Budgets				**Phosphorus Loading**		
Inflow from Drainage Areas							
	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Reach 124 (Entire Watershed)	5,706	4.7	2,214	305	0.5	1,836
2						1.0	
3						1.0	
4						1.0	
5						1.0	
6						1.0	
	Summation	*5,706*	*5*	*2,214*			1836.0
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1				0		1.0	0
2				0		1.0	0
3				0		1.0	0
4				0		1.0	0
5				0		1.0	0
	Summation			*0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	Reach 124	27					
2							
3							
4							
5							
	Summation	*27*	*0*	*0.0*			*0.0*
Inflow from Upstream Lakes							
	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	No Upstream Lakes				-	1.0	
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*0*
Atmosphere							
	Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
	930	23.6	23.6	0.00	0.44	1.0	410.9
		Dry-year total P deposition =			0.222		
		Average-year total P deposition =			0.239		
		Wet-year total P deposition =			0.259		
		(Barr Engineering 2004)					
Groundwater							
	Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
	930	0.0		0.00	0	1.0	0
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	3.76	63.56912114		Oxic		1.0	
	3.76	58.4		Anoxic	0.6	1.0	276
	Summation						276
		Net Discharge [ac-ft/yr] =		**2,214**	**Net Load [lb/yr] =**		**2,523**

TMDL Lake Response Modeling for Round				
Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	[redacted]			
	$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	C_P =	1.00	[--]
		C_{CB} =	0.2	[--]
		b =	0.5	[--]
		W (total P load = inflow + atm.) =	1144.5	[kg/yr]
		Q (lake outflow) =	2.7	[10^6 m^3/yr]
		V (modeled lake volume) =	5.2	[10^6 m^3]
		T = V/Q =	1.9	[yr]
		P_i = W/Q =	418.7	[µg/l]
Model Predicted In-Lake [TP]			**90**	**[ug/l]**
Observed In-Lake [TP]			**125**	**[ug/l]**

Table G-13. Clear Lake Average Conditions Canfield-Bachman Lake Response Model

Average Loading Summary for Clear

Water Budgets | **Phosphorus Loading**

Inflow from Drainage Areas

	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Total Watershed	1,343	7.0	785	471	1.0	1,006
2				0	0.0	1.0	0
3				0	0.0	1.0	0
4				0	0.0	1.0	0
5				0	0.0	1.0	0
6						1.0	
	Summation	*1,343*	*7*	*785*			1006.4

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1				0		1.0	0
2				0		1.0	0
3				0		1.0	0
4				0		1.0	0
5				0		1.0	0
	Summation			*0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	Reach 152			0.01533			1.8
2							
3							
4							
5							
	Summation	*0*	*0*	*0.0*			*1.8*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	No Upstream Lake				-	1.0	
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*0*

Atmosphere

Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
434	32.6	32.6	0.00	0.47	1.0	206.0
			Dry-year total P deposition =	0.222		
			Average-year total P deposition =	0.239		
			Wet-year total P deposition =	0.259		
			(Barr Engineering 2004)			

Groundwater

Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
434	0.0		0.00	0	1.0	0

Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
1.76	65.24541873		Oxic		1.0	
1.76	56.8		Anoxic	4.1	1.0	910
Summation						910
		Net Discharge [ac-ft/yr] =	**785**		Net Load [lb/yr] =	**2,124**

Average Lake Response Modeling for Clear

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann, (1981)			
		C_P =	1.00	[--]
		C_{CB} =	0.2	[--]
		b =	0.5	[--]
		W (total P load = inflow + atm.) =	963.4	[kg/yr]
		Q (lake outflow) =	1.0	[10^6 m^3/yr]
		V (modeled lake volume) =	3.8	[10^6 m^3]
		T = V/Q =	4.0	[yr]
		P_i = W/Q =	994.3	[µg/l]
Model Predicted In-Lake [TP]			**110**	**[ug/l]**
Observed In-Lake [TP]			**110**	**[ug/l]**

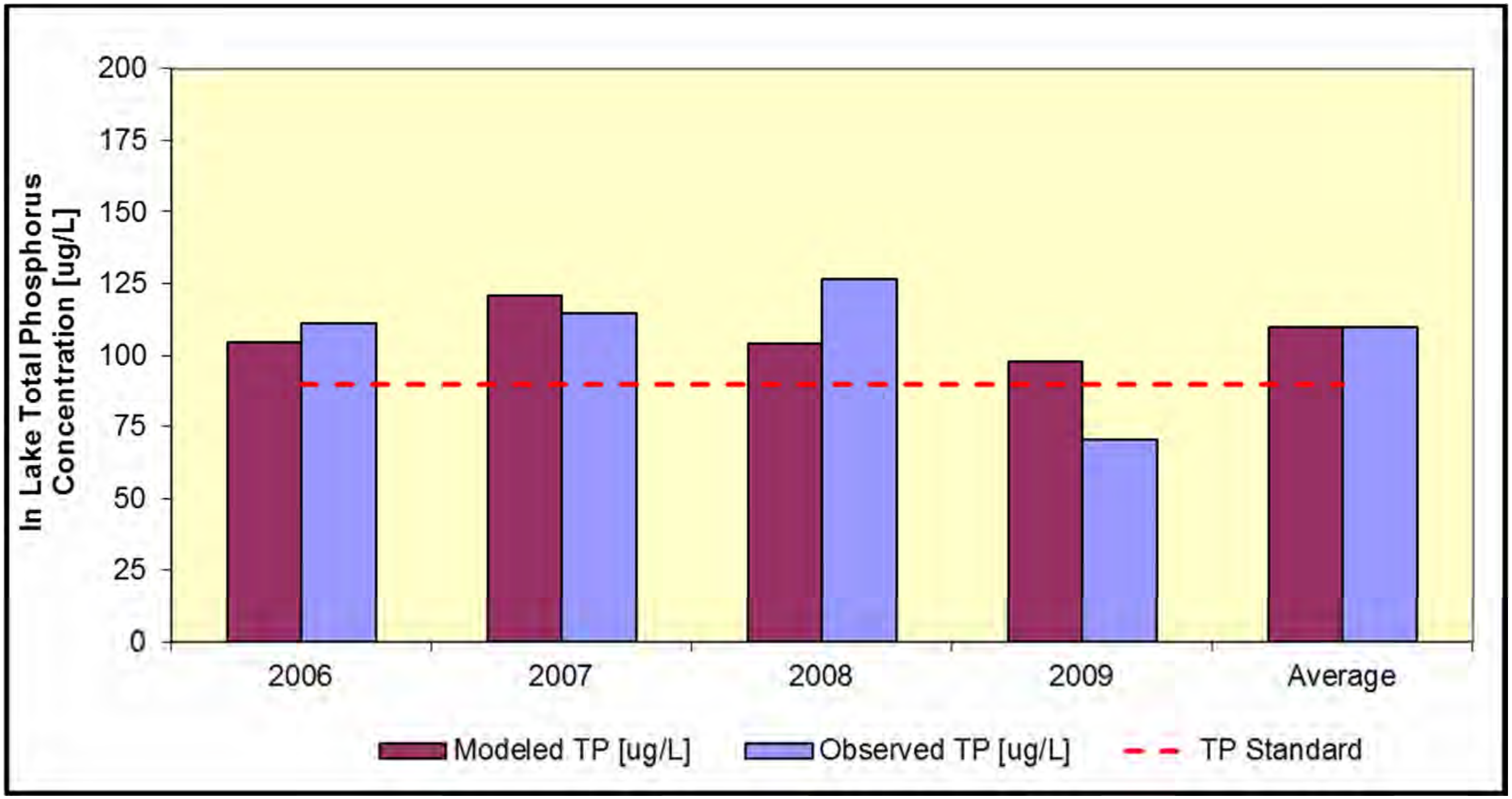

Figure G-7. Clear Lake Model Calibration.

Table G-14. Clear Lake TMDL Conditions Canfield-Bachman Lake Response Model

TMDL Loading Summary for Clear

Water Budgets | **Phosphorus Loading**

Inflow from Drainage Areas

	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Total Watershed	1,343	7.0	785	309	1.0	660
2				0		1.0	0
3				0		1.0	0
4				0		1.0	0
5				0		1.0	0
6						1.0	0
	Summation	*1,343*	*7*	*785*			660

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1				0		1.0	0
2				0		1.0	0
3				0		1.0	0
4				0		1.0	0
5				0		1.0	0
	Summation			*0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	Reach 152						
2							
3							
4							
5							
	Summation	*0*	*0*	*0.0*			*0.0*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	No Upstream Lakes				-	1.0	
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*0*

Atmosphere

Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
434	32.6	32.6	0.00	0.47	1.0	206.0
			Dry-year total P deposition =	0.222		
			Average-year total P deposition =	0.239		
			Wet-year total P deposition =	0.259		
			(Barr Engineering 2004)			

Groundwater

Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
434	0.0		0.00	0	1.0	0

Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
1.76	65.24541873		Oxic		1.0	
1.76	56.8		Anoxic	3.0	1.0	659
Summation						659

Net Discharge [ac-ft/yr] =	**785**	**Net Load [lb/yr] =**	**1,525**

TMDL Lake Response Modeling for Clear

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	[redacted] $P = P_i \Big/ \left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)$	C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	692	[kg/yr]
		Q (lake outflow) =	1.0	[$10^6 m^3/yr$]
		V (modeled lake volume) =	3.8	[$10^6 m^3$]
		T = V/Q =	3.97	[yr]
		P_i = W/Q =	714	[µg/l]
Model Predicted In-Lake [TP]			**90**	**[ug/l]**
Observed In-Lake [TP]			**110**	**[ug/l]**

Table G-15. Loon Lake Average Conditions Canfield-Bachman Lake Response Model

Average Loading Summary for Loon

Water Budgets | **Phosphorus Loading**

Inflow from Drainage Areas

	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Reach 162 (Direct)	2,743	7.2	1,642	407	1.0	1,818
2	Reach 153	6,859	11.2	6,400	408.6	1.0	7,115
3	Reach 159	9,553	10.1	8,048	416.0	1.0	9,108
4						1.0	
5						1.0	
6						1.0	
	Summation	*19,155*	*28*	*16,090*			18041.1

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1				0		1.0	0
2				0		1.0	0
3				0		1.0	0
4				0		1.0	0
5				0		1.0	0
	Summation			*0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-	Failure [%]		Load [lb/yr]
1	Reach 153			0.07826			9.4
2	Reach 159			0.01638			2.0
3	Reach 162			0.03129			3.8
4							
5							
	Summation	*0*	*0*	*0.1*			*15.1*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	Clear			530	105.0	1.0	151
2	Pearl				-	1.0	
3					-	1.0	
	Summation			*530*	*105.0*		*151*

Atmosphere

Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
709	32.6	32.6	0.00	0.47	1.0	336.6
			Dry-year total P deposition =	0.222		
			Average-year total P deposition =	0.239		
			Wet-year total P deposition =	0.259		
			(Barr Engineering 2004)			

Groundwater

Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
709	0.0		0.00	0	1.0	0

Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
2.87	133		Oxic		1.0	
2.87	75.8		Anoxic	20.0	1.0	9,597
Summation						9,597

Net Discharge [ac-ft/yr] =	**16,620**	**Net Load [lb/yr] =**	**28,142**

Average Lake Response Modeling for Loon

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	C_P =	0.74	[--]
		C_{CB} =	0.2	[--]
		b =	0.5	[--]
		W (total P load = inflow + atm.) =	12764.9	[kg/yr]
		Q (lake outflow) =	20.5	[10^6 m^3/yr]
		V (modeled lake volume) =	4.6	[10^6 m^3]
		T = V/Q =	0.2	[yr]
		P_i = W/Q =	622.4	[µg/l]
Model Predicted In-Lake [TP]			**308**	**[ug/l]**
Observed In-Lake [TP]			**308**	**[ug/l]**

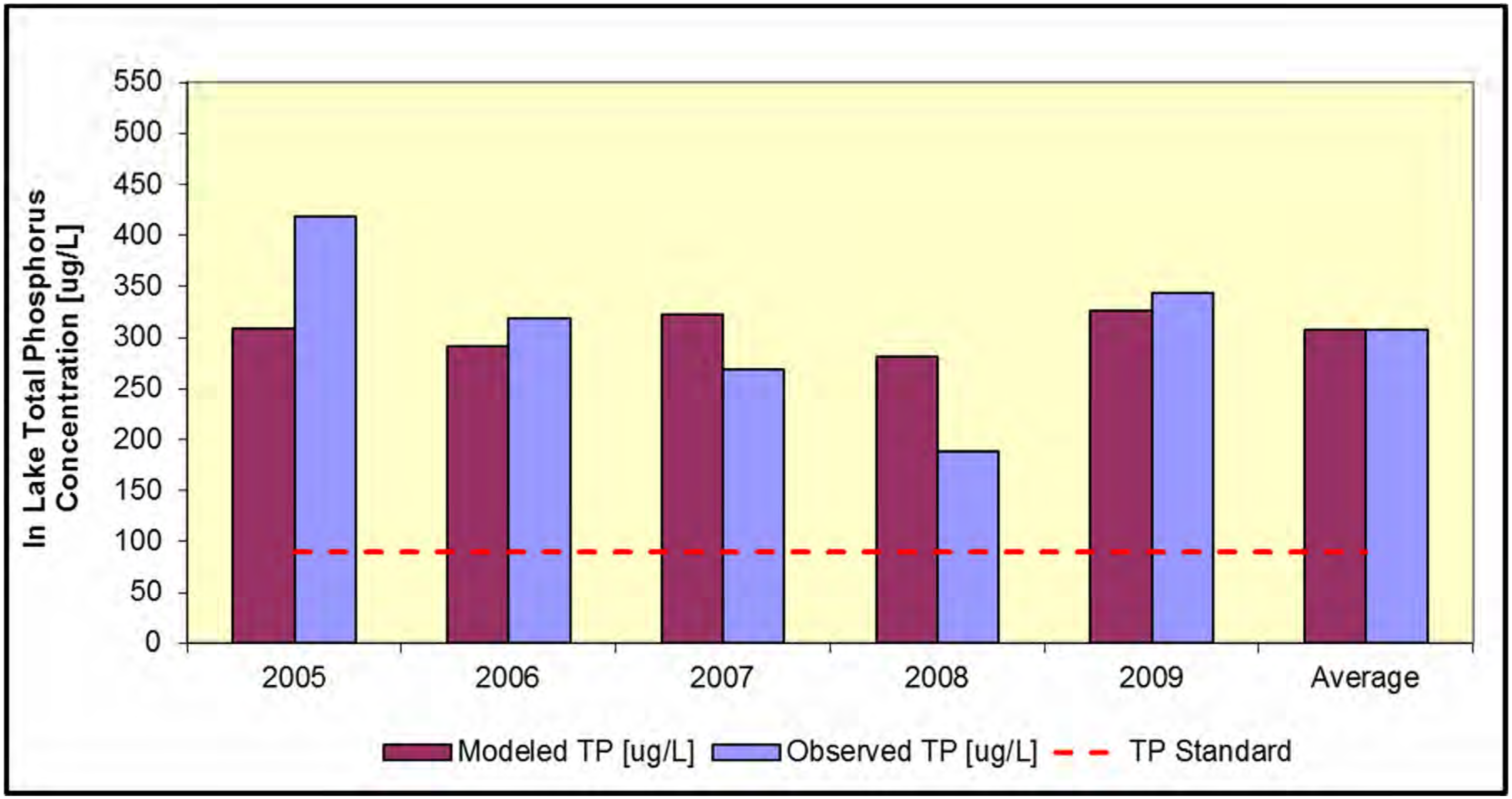

Figure G-8. Loon Lake Model Calibration.

Table G-16. Loon Lake TMDL Conditions Canfield-Bachman Lake Response Model

TMDL Loading Summary for Loon

Water Budgets				Phosphorus Loading			

Inflow from Drainage Areas

	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [lb/yr]
1	Reach 162 (Direct)	2,743	7.2	1,642	117	1.0	524
2	Reach 153	6,859	11.2	6,400	117.8	1.0	2,052
3	Reach 159	9,553	10.1	8,048	120.0	1.0	2,626
4						1.0	0
5						1.0	0
6						1.0	0
	Summatio	*19,155*	*28*	*16,090*			5,202

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [lb/yr]
1				0		1.0	0
2				0		1.0	0
3				0		1.0	0
4				0		1.0	0
5				0		1.0	0
	Summatio			*0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	Reach 153						
2	Reach 159						
3	Reach 162						
4							
5							
	Summatio	*0*	*0*	*0.0*			*0.0*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	Clear			530	90.0	0.9	130
2	Pearl				-	1.0	
3					-	1.0	
	Summatio			*530*	*90.0*		*130*

Atmosphere

	Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
	709	32.6	32.6	0.00	0.47	1.0	336.6
		Dry-year total P deposition =			0.222		
		Average-year total P deposition =			0.239		
		Wet-year total P deposition =			0.259		
		(Barr Engineering 2004)					

Groundwater

	Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
	709	0.0		0.00	0	1.0	0

Internal

	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	2.87	133		Oxic		1.0	
	2.87	75.8		Anoxic		1.0	480
	Summation						480
			Net Discharge [ac-ft/yr] =	**16,620**		**Net Load [lb/yr] =**	**6,149**

TMDL Lake Response Modeling for Loon

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	C_P =	0.74	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	2,789	[kg/yr]
		Q (lake outflow) =	20.5	[10^6 m^3/yr]
		V (modeled lake volume) =	4.6	[10^6 m^3]
		T = V/Q =	0.23	[yr]
		P_i = W/Q =	136	[µg/l]
Model Predicted In-Lake [TP]			**90**	**[ug/l]**
Observed In-Lake [TP]			**308**	**[ug/l]**

Appendix H – Livestock NPDES Permits

Upper Big Sioux River Watershed 10170202		
Facility Name	Permit Number	Animal Units
Christensen Farms F136	MNG440617	936
Christensen Farms Site F064	MNG440666	936
Supreme Pork Inc	MNG440137	1749

Lower Big Sioux River Watershed 10170203		
Facility Name	Permit Number	Animal Units
Anthony Dunn Farm	MNG450101	1500
Blac-X Farms Inc	MNG440842	2959
Blom South	MNG441291	1500
Blue Mound Dairy	MNG440803	1580
Bradley & Eugene Petersen Farm	MNG440828	810
Calumet Pork LLP	MNG440288	4621
Chad Hoff Farm	MNG441325	1080
Christensen Farms Site C012	MNG440056	1200
Christensen Farms Site C018	MNG450067	1200
Christensen Farms Site F061	MNG450062	1248
Craig Otkin Farm	MNG450016	1248
Dave DeBoer Farm	MNG440867	1545
David Wynia Farm	MNG440658	960
Derek Petersen Farm	MNG440434	510
Feikema Farms Home	MNG440434	4010
Fluit Hog Farm - Beaver Creek Site	MNG440995	900
Gray Farms Inc	MNG450150	1590
Heartland Hutterian Brethren Inc	MNG440767	1062
Heartland Hutterian Brethren Inc Site 3	MNG440805	1530
Heartland Hutterian Brethren/Heartland Colonies	MN0070637	3782
Jim Veldkamp Farm - Home Site	MNG440448	810
Jim Veldkamp Farm - Sec 36 Site	MNG440448	1890
Johnson Farms - Pipestone	MNG440294	1140
Josh Fick - Sec 7	MNG441133	2160
Moss Farms Inc	MNG450015	1939
New Horizon Farms - Applewood	MNG440966	1268
New Horizon Farms - BMB	MNG440291	1590
New Horizon Farms - East	MNG440537	1411
New Horizon Farms - North	MNG440477	1699
New Horizon Farms - Research Facilities	MNG440299	1590
New Horizon Farms - Rock Island Finisher	MNG440965	795

Lower Big Sioux River Watershed 10170203		
Facility Name	Permit Number	Animal Units
New Horizon Farms - West	MNG440479	2323
New Horizon Farms - Wheatfield Finishers	MNG440300	1590
Newalta Dairy LLC	MNG441001	6665
Pater Dairy Inc	MNG441272	3612
Robert & Lucinda Penner Farm	MNG440990	795
Rosewood LLP	MNG440912	1948
Schwartz Farms Inc - Blue Mound Site	MNG441182	990
Schwartz Farms Inc - Brandt	MNG440853	900
Schwartz Farms Inc - Feikema Site	MNG440652	900
Schwartz Farms Inc - Fluit	MNG440926	900
Schwartz Farms Inc - Willers	MNG441016	900
Sells Farms Ltd	MNG440612	1500
Spronk Brothers III Real Estate LLLP - Buttercup	MNG440338	1540
Spronk Brothers III Real Estate LLLP - Hiawatha	MNG440289	1728
Stoltzfus Finisher	MNG440768	795
Sweet Finishers II	MNG440818	1125
Sweet Finishers LLP	MNG440818	2070
T&E Pork	MNG440821	900
Tom Baustian Farm	MNG440870	1824
Troy Farms Inc	MNG450149	1590
Twin Rock Family Farms Inc	MNG440302	2330

Rock River Watershed 10170204		
Facility Name	Permit Number	Animal Units
3B Farms LLC	MNG440978	2656
Ahrendt Brothers Feedlot	MNG440916	2292
Alan Baker - Sec 27	MNG441260	1850
Anthony Lonneman Co - Sec 21	MNG441307	1440
Bacon Maker Ltd	MN0069809	1980
Binford Farms - Sec 4	MNG440564	5770
Block Finishers	MNG441275	1080
Brad & Ryan Lonneman	MNG441206	1440
Brent Fluit Farm - Home	MNG441234	1172
Brian Knips - Knips Pork	MNG441573	1440
Bullerman Farms LLC - Sec 5	MNG440996	196
Bullerman Farms LLC - Sec 7	MNG440996	1954
Bullerman Livestock & Grain Inc	MN0070939	2490
Bullerman Livestock & Grain LLC - Leon's Site	MNG440863	890
Craig Stegenga Farm	MNG440851	1440
Curt Schilling - Sec 34	MNG441343	1440
Dale Reverts Farm	MNG441191	1440
Dale-Neuroth Finishers	MNG440350	2223

Rock River Watershed 10170204

Facility Name	Permit Number	Animal Units
DeKam Properties Inc	MNG440272	2553
Diekmann Finisher - Wilmont 18	MNG4412320	990
Donald DeKam Farm - Sec 2	MNG440271	1300
Doug's Farrowing	MNG440348	1599
Elias Brothers LLC - Sec 11	MNG441196	1440
Elias Brothers LLC - Sec 12	MNG441196	600
Faccendiere LLC - Hunter	MNG440657	1320
Faccendiere-Manderscheid	MNG441218	2400
Farm 173 - Engelkes	MNG450029	1320
G&A Farms Inc	MNG440871	990
Gary Overgaard Farm	MNG440613	72
Gary Rodrigue - Hoffman Site	MN440531	900
GPFF Inc - Whitetail Run	MNG440320	1526
Greg Kracht Farm	MNG441104	1830
Hokeness Grain & Livestock Inc	MNG440933	2600
Homeplace Finishers - David's Site	MNG440349	1050
Jeff & Debra Brockberg Farms - Sec 10	MNG440298	1192
Jeff & Debra Brockberg Farms - Sec 9	MNG440298	1656
Jeff Kopplow Farm - Sec 2	MNG440861	1200
Jim Remme Farm	MNG440689	900
Jim Rust Farm - Sec 5	MNG440985	1080
Joe & Chris Wieneke Farm - Sec 22 & 27	MN0070751	3459
Joey Bullerman Farm - Sec 24	MNG441270	1100
Kellenberger Farms	MNG441338	1440
Ken Winsel Farm Sec 22	MNG440823	1610
Kent Lorang Farm - Sec 31	MNG440409	1992
Kluis Farms	MNG441828	1845
Knips Bros Farm - Sec 29	MNG440713	1082
Knips Bros Farm - Sec 31	MNG440713	2118
Knips's Finisher - Sec 7	MN441091	900
Knips Finishers - Sec 6	MN441236	900
Kracht Hill Farm	MNG440873	960
Leon Kracht Farm	MNG440891	990
Lonneman Farms Inc	MNG441190	1440
Malone Finishing Site	MNG440688	1080
Martin Weiss Farm	MNG441186	3916
Merlin Wynia Farm	MNG440609	991
Metz Professional Waste Applicators	MNG440274	1248
Michael Wolf Farm	MNG440277	753
Myron Grussing Farm Sec 34	MNG440862	1320
New Fashion Pork - Farm 172 - Fransen	MNG450025	1320
New Fashion Pork - Farm 186-Nachtigal	MNG440771	990

Rock River Watershed 10170204		
Facility Name	Permit Number	Animal Units
New Horizon Farms - Kas Nursery	MNG441151	700
New Horizon Farms - Whitewood	MNG440966	1268
NUF - Pork Inc	MNG440915	990
Overgaard Pork - Site 1	MNG440607	960
Overgaard Pork - Site 2	MNG440798	900
Overgaard Pork - Site 3	MNG441252	990
Pig City LLP	MNG440835	1440
R & R Thier Feedlot Inc	MNG440351	5475
R & R Thier Feedlot Inc Sec 22	MNG440351	6000
Richard Zebe Farm - Sec 5	MNG440584	884
Rick Bullerman Farm - Sec 25	MNG440826	1150
RJ Pork	MNG441210	1059
Rob VanHill Farm	MN0070971	2093
Robert Wassenaar Farm	MNG440820	960
Roger Talsma Farm	MN0070327	1495
Ross Wiertsema - Sec 32	MNG441295	900
Schwartz Farms Inc - Bush Site	MNG441033	900
Schwartz Farms Inc - Luverne 19 Fick Site	MNG440935	900
Schwartz Farms Inc - Rock River	MNG441215	990
Schwartz Farms Inc - Smith	MNG441015	900
Schwartz Farms Inc - Stagenga Site	MNG440653	900
SFI Heeren Site	MNG441312	990
SFI - Pleasant View	MNG441266	990
Spronk Brothers III Real Estate LLP - Hollyhock	MNG440290	1620
Sy Lonneman & Sons Inc - Grand Prairie 1	MNG441079	1254
Sy Lonneman & Sons Inc - Sec 31	MNG441034	2219
Taylor Brothers LLP	MNG441268	1274
Thier Feedlots Inc	MNG440276	4190
Thompson (Bigelow) Finishers	MNG441046	1440
Todd Wessels Farm	MNG440691	1560
Troy Dykstra Farm - Sec 30	MNG440661	900
Veldhuizen Farms LLC	MNG440303	2340
Verlis Schilling Farm - Sec 18	MNG441739	1350
Versteeg Farms	MNG441866	1440
Weg's Blue & White Dairy	MNG440877	1960
William Tjepkes Farm	MNG440694	990
Wolf Pork LLC	MNG440936	1420

Little Sioux River Watershed 10230003		
Facility Name	Permit Number	Animal Units
Bernell Voss Farm	MNG440053	3580
Bezdicek Finisher	MNG441319	990

Little Sioux River Watershed 10230003

Facility Name	Permit Number	Animal Units
BIL LLC	MNG440547	990
Brandon Ahrenstorff Swine Facility	MNG440910	990
Brent Pohlman Farm	MNG441043	900
Brent Whisney Farm 203	MNG440911	990
Brent Wintz Farm 090	MNG450159	1320
Brogan Farm 239 - Suhr	MNG441198	990
David Vancura Swine Facility	MNG440721	990
Dylan Majerus Farm	MNG440610	1247
Eugene Meyer Farm - Sec 13	MNG441040	1125
Farm 231 - Ashmore	MNG441181	990
Farm 36 - Baumgarn 36	MNG450023	1320
Farm 71 - Freking Research	MNG441249	990
Frank Riley Farm	MNG440511	1200
Ihnen Family Farms - Round Lake 34	MNG440994	940
Janet Fischer East Farm - Sec 36	MNG441141	750
Janet Fischer West Farm - Sec 33	MNG441140	750
Jim Spangler Farm - Sec 24	MNG440822	225
Kayle Koep Farm	MNG440733	990
Kevin Schmid Swine Facility	MNG440687	990
Lakefield Finishers	MNG441166	1980
MANA Pork LLC	MNG440690	900
Mark & Stacy Soleta Farm	MNG440928	936
New Fashion Pork - Farm 25-Baumgarn	MNG440664	990
New Fashion Pork - Farm 27-Baumgarn	MNG440608	990
New Fashion Pork - Farm 903 - Freking Farms	MNG450024	1361
New Fashion Pork - Farm 912-Freking Sow 2	MNG450002	1153
Ocheda Dairy Farm	MN0070769	3234
Paul Hintze Farm Site 097	MNG450127	1320
Randy Wilson Farm	MNG440275	1110
Ryan Meyer Swine Facility	MNG440811	900
Schwartz Farms Inc - Cuperus Site	MNG440654	900
Scott Vancura Farms	MNG440872	990
Scott Vancura Farms - Sec 32	MNG441321	990
Stammer Farms	MNG440655	1008