South Fork Crow River Watershed Total Maximum Daily Load Report

Upper Mississippi Basin

MINNESOTA POLLUTION CONTROL AGENCY

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South Fork Crow River Watershed TMDL

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Contents

Contents ... **3**
List of Tables ... **6**
List of Figures ... **8**
Acronyms ... **10**
Executive Summary ... **11**
1. Project Overview ... **12**
1.1 Purpose ... 12
1.2 Identification of Waterbodies ... 14
1.3 Priority Ranking ... 15
2. Applicable Water Quality Standards and Numeric Water Quality Targets ... **16**
2.1 Turbidity and TSS ... 16
2.2 Dissolved Oxygen ... 17
2.3 Bacteria ... 17
2.4 Nutrients ... 18
3. Watershed and Waterbody Characterization ... **19**
3.1 Streams ... 19
3.2 Lakes ... 20
3.3 Subwatersheds ... 20
3.4 Land Cover ... 20
3.5 Current/Historic Water Quality ... 23
3.5.1 TSS ... 23
3.5.2 DO ... 27
3.5.3 Bacteria ... 31
3.5.4 Nutrients ... 33
3.6 Pollutant Source Summary ... 34
3.6.1 TSS ... 34
3.6.2 Dissolved Oxygen ... 35
3.6.2.1 Potential Drivers ... 36
3.6.2.2 Oxygen Demand ... 39
3.6.3 Bacteria ... 42
3.6.4 Nutrients ... 47
4 TMDL Development ... **50**
4.1 Modeling Approach ... 50
4.2 Gathering and Developing Time-Series Data ... 50

4.3 Segmenting and Characterizing the Watershed ... 50
4.4 Calibrating and Validating the Model ... 51
4.5 Load Duration Curve Approach ... 52
4.6 Natural Background Considerations ... 52
4.7 TSS ... 53
4.7.1 TSS Allocation Methodology ... 53
4.7.2 Loading Capacity Methodology ... 53
4.7.3 Waste Load Allocation Methodology ... 53
4.7.4 Watershed Load Allocation ... 58
4.7.5 Margin of Safety ... 59
4.7.6 Seasonal Variation ... 59
4.7.7 TMDL Summary ... 59
4.8 Dissolved Oxygen ... 65
4.8.1 Loading Capacity Methodology ... 65
4.8.2 Waste Load Allocation Methodology ... 65
4.8.2.1 Permitted Wastewater Dischargers ... 65
4.8.2.2 Permitted MS4s ... 70
4.8.2.3 Construction and Industrial Stormwater ... 70
4.8.3 Watershed Load Allocation ... 71
4.8.4 Margin of Safety ... 71
4.8.5 Seasonal Variation ... 72
4.8.6 TMDL Summary ... 72
4.9 Bacteria ... 72
4.9.1 Loading Capacity Methodology ... 72
4.9.2 Waste Load Allocation Methodology ... 73
4.9.2.1 Permitted Wastewater Dischargers ... 74
4.9.2.2 Permitted MS4s ... 75
4.9.3 Watershed Load Allocation ... 75
4.9.4 Margin of Safety ... 75
4.9.5 Seasonal Variation ... 76
4.9.6 TMDL Summary ... 76
4.10 Nutrients ... 78
4.10.1 Loading Capacity Methodology ... 78
4.10.1.1 Watershed Loading ... 78
4.10.1.2 Septic System Loading ... 78
4.10.1.3 Upstream Lakes ... 79
4.10.1.4 Atmospheric Deposition ... 79

4.10.1.5 Internal Loading ... 79
4.10.1.6 Canfield-Bachman Lake Response Model ... 79
4.10.2 Load Allocation Methodology ... 80
4.10.3 Waste Load Allocation Methodology ... 80
4.10.3.1 Permitted Wastewater Dischargers ... 80
4.10.3.2 Permitted MS4s ... 81
4.10.3.3 Construction and Industrial Stormwater ... 81
4.10.4 Margin of Safety ... 81
4.10.5 Seasonal Variation ... 81
4.10.6 Lake Nutrient Load Allocation Methodology ... 82
4.10.7 TMDL Summary ... 82
5 Future Growth Considerations ... 95
5.1 New or Expanding Permitted MS4 WLA Transfer Process ... 95
5.2 New or Expanding Wastewater (TSS and *E. coli* TMDLs only) ... 95
6 Reasonable Assurance ... 96
6.1 Regulatory Approaches ... 96
6.2 Local Management ... 97
6.2.1 Crow River Organization of Water (CROW) ... 97
6.2.2 Soil and Water Conservation Districts ... 98
6.2.3 Watershed Districts ... 98
7 Monitoring Plan ... 99
8 Implementation Strategy Summary ... 101
8.1 Implementation Framework ... 101
8.2 Sources ... 101
8.2.1 MS4 ... 101
8.2.2 Construction Stormwater ... 102
8.2.3 Industrial Stormwater ... 102
8.2.4 Wastewater ... 102
8.3 Strategies ... 103
8.3.1 TSS ... 103
8.3.2 Dissolved Oxygen ... 104
8.3.3 Bacteria (*E .coli*) ... 104
8.3.4 Nutrients (Phosphorus) ... 105
8.4 Adaptive Management ... 106
8.5 Cost ... 107
9 Public Participation ... 109

10 Literature Cited **110**
Appendices **113**

List of Tables

Table 1-1. Stream impairments addressed in this TMDL, presented upstream to downstream. 14
Table 1-2. Lake impairments addressed in this TMDL study. 15
Table 2-1. Numeric standards for lakes in the NCHF and WCBP Ecoregions. 18
Table 3-1. Impaired reach watershed areas and locations and areas. 19
Table 3-2. Impaired lake location and morphometry. 20
Table 3-3. Land cover in the South Fork Crow River Watershed (Source 2011 NASS). 21
Table 3-4. Observed TSS data summary in the South Fork Crow River Watershed. 24
Table 3-5. Dissolved oxygen observed data summary (07010205-501) (all data from Buffalo Creek portion of the South Fork Crow River Watershed) measured between the months of April and November from 2003 to 2013. 28
Table 3-6. Dissolved oxygen observed data summary (samples before 9:00 a.m. from Buffalo Creek portion of South Fork Crow River Watershed) measured between the months of April and November from 2003 to 2013. 29
Table 3-7. Monthly geometric mean of *E. coli* values for the South Fork Crow River impaired reaches, and major upstream reaches. 32
Table 3-8. Summer growing season averages for each water quality parameter. 33
Table 3-9. Bacteria production in the JD15 bacteria impaired reach (513) watershed. 45
Table 3-10. Bacteria production in the South Fork Crow River Subwatershed that drains directly to reach 508. 46
Table 3-11. Potential permitted sources of phosphorus. 47
Table 3-12. Potential non-permitted sources of phosphorus. 48
Table 3-13. Nutrient source summary for each of the impaired lakes in the South Fork Crow River Watershed. DNR Lake survey reports (if available) were reviewed to assess the vegetation and fish communities for each lake. 49
Table 4-1. Permitted TSS allocations for point sources in the South Fork Crow River Watershed. 55
Table 4-2. Wasteload allocations for all MS4 communities that contribute directly to impaired reaches. 57
Table 4-3. Buffalo Creek (07010205-501) TMDL allocations. 60
Table 4-4. South Fork Crow (07010205-540) TMDL allocations. 61
Table 4-5. South Fork Crow (07010205-510) TMDL allocations. 62
Table 4-6. South Fork Crow (07010205-511 and 07010205-512) TMDL allocations. 63
Table 4-7. South Fork Crow (07010205-508) TMDL allocations. 64

Table 4-8. CBOD concentration and loading assumptions for point sources in the Buffalo Creek Watershed.......... 67

Table 4-9. Ammonia concentration and loading assumptions for point sources in the Buffalo Creek Watershed.......... 68

Table 4-10. Oxygen demand WLAs for individual permitted wastewater dischargers. 69

Table 4-11. Buffalo Creek Dissolved Oxygen Total Maximum Daily Load. 72

Table 4-12. NPDES permitted wastewater dischargers in the bacteria impaired reach watersheds. 74

Table 4-13. Summary of permitted MS4s in the bacteria impaired reach watersheds. 75

Table 4-14. South Fork Crow River reach 508 *E. coli* TMDL. 77

Table 4-15. JD15 reach 513 *E. coli* TMDL summary. 78

Table 4-16. Summary of permitted MS4s in the impaired lake watersheds. 81

Table 4-17. Preston Lake TP TMDL summary (shallow lake, WCBP ecoregion, located in the Judicial Ditch 28A Major Subwatershed) 83

Table 4-18. Marion Lake TP TMDL summary (shallow lake, WCBP ecoregion, located in the Buffalo Creek Major Subwatershed) 83

Table 4-19. Big Kandiyohi Lake TP TMDL summary (shallow lake, WCBP ecoregion, located in the Headwaters – South Fork Crow Major Subwatershed) 84

Table 4-20. Johnson Lake TP TMDL summary (shallow lake, WCBP ecoregion, located in the Headwaters – South Fork Crow Major Subwatershed).......... 84

Table 4-21. Kasota Lake TP TMDL summary (shallow lake, WCBP ecoregion, located in the Headwaters – South Fork Crow Major Subwatershed).......... 85

Table 4-22. Lillian Lake TP TMDL summary (shallow lake, WCBP major subwatershed, located in the Headwaters – South Fork Crow Major Subwatershed) 85

Table 4-23. Little Kandiyohi Lake TP TMDL summary (shallow lake, WCBP ecoregion, located in the Headwaters – South Fork Crow Major Subwatershed) 86

Table 4-24. Minnetaga Lake TP TMDL summary (shallow lake, WCBP ecoregion, located in the Headwaters – South Fork Crow Major Subwatershed) 86

Table 4-25. Thompson Lake TP TMDL summary (shallow lake, WCBP ecoregion, located in the Headwaters – South Fork Crow Major Subwatershed) 87

Table 4-26. Wakanda Lake TP TMDL summary (shallow lake, WCBP ecoregion, located in the Headwaters - South Fork Crow Major Subwatershed) 87

Table 4-27. Cedar Lake TP TMDL summary (shallow lake, NCHF ecoregion, located in the Hutchinson – South Fork Crow Major Subwatershed).......... 88

Table 4-28. Greenleaf Lake TP TMDL summary (shallow lake, NCHF ecoregion, located in the Hutchinson – South Fork Crow Major Subwatershed).......... 88

Table 4-29. Goose Lake TP TMDL summary (shallow lake, WCBP ecoregion, located in the Hutchinson – South Fork Crow Major Subwatershed).......... 89

Table 4-30. Hoff Lake TP TMDL summary (shallow lake, WCBP ecoregion, located in the Hutchinson – South Fork Crow Major Subwatershed).......... 89

Table 4-31. Star Lake TP TMDL summary (shallow lake, WCBP ecoregion, located in the Hutchinson – South Fork Crow Major Subwatershed)(This lake is not on the 2016 303(d) list, however is proposed on the 2018 list.) 90

Table 4-32. Belle Lake TP TMDL summary (deep Lake, NCHF ecoregion, located in the Hutchinson – South Fork Crow Major Subwatershed)..... 90

Table 4-33. Willie Lake TP TMDL summary (shallow lake, NCHF ecoregion, located in the Hutchinson – South Fork Crow Major Subwatershed)..... 91

Table 4-34. Bear Lake TP TMDL summary (shallow lake, NCHF ecoregion, located in the Lester Prairie – South Fork Crow Major Subwatershed)..... 91

Table 4-35. Boon Lake TP TMDL summary (shallow lake, WCBP ecoregion, located in the Lester Prairie – South Fork Crow Major Subwatershed)..... 92

Table 4-36. Silver Lake TP TMDL summary (shallow lake, WCBP ecoregion, located in the Lester Prairie – South Fork Crow Major Subwatershed)..... 92

Table 4-37. Winsted Lake TP TMDL summary (shallow lake, NCHF ecoregion, located in the Lester Prairie – South Fork Crow Major Subwatershed)..... 93

Table 4-38. Mud Lake TP TMDL summary (shallow lake, NCHF ecoregion, located in the South Fork Crow River Major Subwatershed) 93

Table 4-39. Rice Lake TP TMDL summary (shallow lake, NCHF ecoregion, located in the S South Fork Crow Major Subwatershed) 94

Table 7-1. Water monitoring in the South Fork Crow River Watershed by entity 99

Table 8-1. Implementation baseline years. 101

Table 8-2. Potential TSS reduction implementation strategies. 104

Table 8-3. Potential *E. coli* reduction implementation strategies. 105

Table 8-4. Potential nutrient reduction strategies. 105

List of Figures

Figure 1-1. South Fork Crow River Watershed impairments addressed in this TMDL study..... 13

Figure 3-1. Land cover in the South Fork Crow River Watershed..... 22

Figure 3-2. Seasonal variation of TSS at Buffalo Creek 07010205-501. The red dashed line indicates the South River Nutrient Region 65 mg/L TSS standard. 25

Figure 3-3. Seasonal variation of TSS at South Fork Crow River 07010205-540. The red dashed line indicates the South River Nutrient Region 65 mg/L TSS standard..... 25

Figure 3-4. Seasonal variation of TSS at South Fork Crow River 07010205-510. The red dashed line indicates the South River Nutrient Region 65 mg/L TSS standard..... 26

Figure 3-5. Seasonal variation of TSS at South Fork Crow River 07010205-511. The red dashed line indicates the South River Nutrient Region 65 mg/L TSS standard..... 26

Figure 3-6. Seasonal variation of TSS at South Fork Crow River 07010205-508. The red dashed line indicates the South River Nutrient Region 65 mg/L TSS standard.4.3 Total Suspended Solids TMDLs 27

Figure 3-7. Seasonal variation of dissolved oxygen samples in Buffalo Creek (all data). The red dashed line indicates the 5 mg/L DO standard. 30

Figure 3-8. Seasonal variation of dissolved oxygen samples in Buffalo Creek measured before 9:00 a.m. The red dashed line indicates the 5 mg/L DO standard........ 30

Figure 3-9. TSS source assessment modeling results within the South Fork Crow River Watershed impaired reaches. 34

Figure 3-10. All dissolved oxygen samples in Buffalo Creek plotted on flow duration curve. The red dashed line indicates the 5 mg/L DO standard. Simulated DO values represent the daily minimum dissolved oxygen values........ 37

Figure 3-11. Dissolved oxygen samples taken before 9:00 a.m. in Buffalo Creek plotted on flow duration curve. The red dashed line indicates the 5 mg/L DO standard. Simulated DO values represent the daily minimum dissolved oxygen values. 37

Figure 3-12. BOD5 samples in Buffalo Creek plotted on flow duration curve. The red dashed line indicates the 3 mg/L proposed BOD5 standard. Simulated BOD5 represent the daily average values. 38

Figure 3-13. TKN samples in Buffalo Creek plotted on flow duration curve. Simulated TKN values represent the daily average values........ 38

Figure 3-14. TP samples in Buffalo Creek plotted on flow duration curve. The red dashed line indicates the .015 mg/L proposed TP standard. Simulated TP values represent the daily average values.............. 39

Figure 3-15. Chlorophyll-a samples in Buffalo Creek plotted on flow duration curve. The red line indicates the 35 mg/L chlorophyll a standard. Simulated chlorophyll a values represent the daily average values. 39

Figure 3-16. HSPF modeled drivers of dissolved oxygen in Buffalo Creek (AUID 07010205-501)............. 41

Figure 3-17. Oxygen Demand Source Assessment Modeling Results Within the South Fork Crow River Watershed........ 42

Figure 3-18. MPCA registered feedlots in the South Fork Crow River Watershed. 44

Figure 4-1. Buffalo Creek (07010205-501) TSS load duration curve........ 60

Figure 4-2. South Fork Crow (07010205-540) TSS load duration curve........ 61

Figure 4-3. South Fork Crow (07010205-510) TSS load duration curve........ 62

Figure 4-4. South Fork Crow (07010205-511 and 07010205-512) TSS load duration curve. 63

Figure 4-5. South Fork Crow (07010205-508) TSS load duration curve........ 64

Figure 4-6. *E. coli* monitored loads, load standard and load reductions for JD15 reach 513. 73

Figure 4-7. *E. coli* monitored loads, load standard and load reductions for South Fork Crow River reach 508. 73

Figure 8-1. Adaptive management. 107

Acronyms

AF	Anoxic factor
AUID	Assessment Unit ID
BMP	best management practice
CAFO	Concentrated Animal Feeding Operation
cfu	colony-forming unit
Chl-*a*	Chlorophyll-*a*
DNR	Minnesota Department of Natural Resources
EPA	U. S. Environmental Protection Agency
EQuIS	Environmental Quality Information System
GW	Groundwater
HSPF	Hydrologic Simulation Program-Fortran
km^2	square kilometer
LA	Load Allocation
Lb	pound
lb/day	pounds per day
lb/yr	pounds per year
LGU	Local Government Unit
m	meter
mg/L	milligrams per liter
mg/m^2-day	milligram per square meter per day
mL	milliliter
MOS	Margin of Safety
MPCA	Minnesota Pollution Control Agency
MS4	Municipal Separate Storm Sewer Systems
NPDES	National Pollutant Discharge Elimination System
RR	Release rate
SRO	Surface runoff
SONAR	Statement of Need and Reasonableness
SSTS	Subsurface Sewage Treatment Systems
SWPPP	Stormwater Pollution Prevention Plan
TDLC	Total Daily Loading Capacity
TMDL	Total Maximum Daily Load
TP	Total phosphorus
UAL	Unit-area Load
µg/L	microgram per liter
WLA	Wasteload Allocation
WRAPS	Watershed Restoration and Protection Strategy

Executive Summary

This Total Maximum Daily Load (TMDL) study was completed for the South Fork Crow River Watershed (07010205), which is a subwatershed in the Upper Mississippi River Basin. The study addresses 5 river/stream total suspended solids (TSS) impairments; 1 river/stream dissolved oxygen (DO) impairment; 2 river/stream bacteria impairments; and nutrient impairments for 23 lakes. The South Fork Crow River Watershed covers approximately 1,279 square miles across eight counties in west central Minnesota. The watershed drains to the North Fork Crow River and ultimately the Mississippi River near Dayton, Minnesota. The goal of this TMDL is to quantify the pollutant reductions needed to meet state water quality standards for TSS, DO, *E. coli*, and nutrients in the impaired streams and lakes throughout the South Fork Crow River Watershed.

Hydrologic Simulation Program – Fortran (HSPF), a watershed computer model, simulated flow and TSS output were used to establish load duration curves (LDCs) for the five TSS impairments covered in this TMDL study. The curve displays the class 2B TSS numeric standard of 65 milligrams per liter (mg/L) that may not be exceeded more than 10% of the time over a multiyear data window. A TMDL, wasteload allocations (WLAs), and load allocations (LAs) were established for five flow categories along the flow duration curve: very high, high, mid, low, and very low flow conditions.

The HSPF model simulated flow, and monitored bacteria data for the two bacteria impaired reaches were used to establish LDCs. The curves were set up to meet the *E. coli* numeric standard of no more than 126 organisms per 100 mL as a geometric mean within any calendar month. Additionally, no more than 10% of all samples taken during any calendar month may exceed 1,260 organisms per 100 mL. The TMDL WLAs and LAs for each bacteria impaired reach were established for the five flow categories described previously.

Nutrient budgets were developed for all 23 lakes along with lake response models to set the TMDL LAs and WLAs. The HSPF model was used along with in-lake monitoring data to develop nutrient budgets for each lake, and to set up the lake response models and TMDL equations.

1. Project Overview

1.1 Purpose

This TMDL study addresses five TSS impairments, one DO impairment, and two bacteria (fecal coliform and *E. coli*) impairments on several main stem and tributary reaches in the South Fork Crow River Watershed, as shown in Figure 1-1. This TMDL also addresses nutrient (phosphorus) impairments for 23 lakes in the South Fork Crow River Watershed. The watershed boundaries of the impaired streams and lakes cover portions of eight counties in the South Fork Crow River Watershed: Kandiyohi, Wright, Meeker, Hennepin, McLeod, Carver, Renville and Sibley. The western end of the watershed is in Kandiyohi County, the eastern tip in Hennepin, with Wright and Sibley Counties containing only small portions of the watershed to the north and south, respectively. The goal of this TMDL report is to quantify the pollutant reductions needed to meet State water quality standards for TSS, DO, bacteria and phosphorus for the stream reaches and lakes listed in Tables 1-1 and 1-2. This TMDL study is established in accordance with Section 303(d) of the Clean Water Act and provides WLAs and LAs for the watershed areas as appropriate.

There have been three TMDL studies completed in the South Fork Crow River Watershed prior to this study. The Buffalo Creek Bacteria TMDL (Wenck Associates 2013) covered two bacteria impaired reaches (07010205-502 and 501) of Buffalo Creek from its headwaters to its junction with the South Fork Crow River. The Lake Independence (27-0176) Phosphorus TMDL was completed in 2007 as a collaborative effort between the Pioneer-Sarah Creek Watershed Commission and the Three Rivers Park District. The South Fork Crow River Lakes Excess Nutrient TMDL (Carver County Land and Water Services 2010) addresses phosphorus impairments for Eagle (10-0121), Oak (10-0093) and Swede (10-0095) Lakes, which are located in the Carver County portion of the South Fork Crow River Watershed.

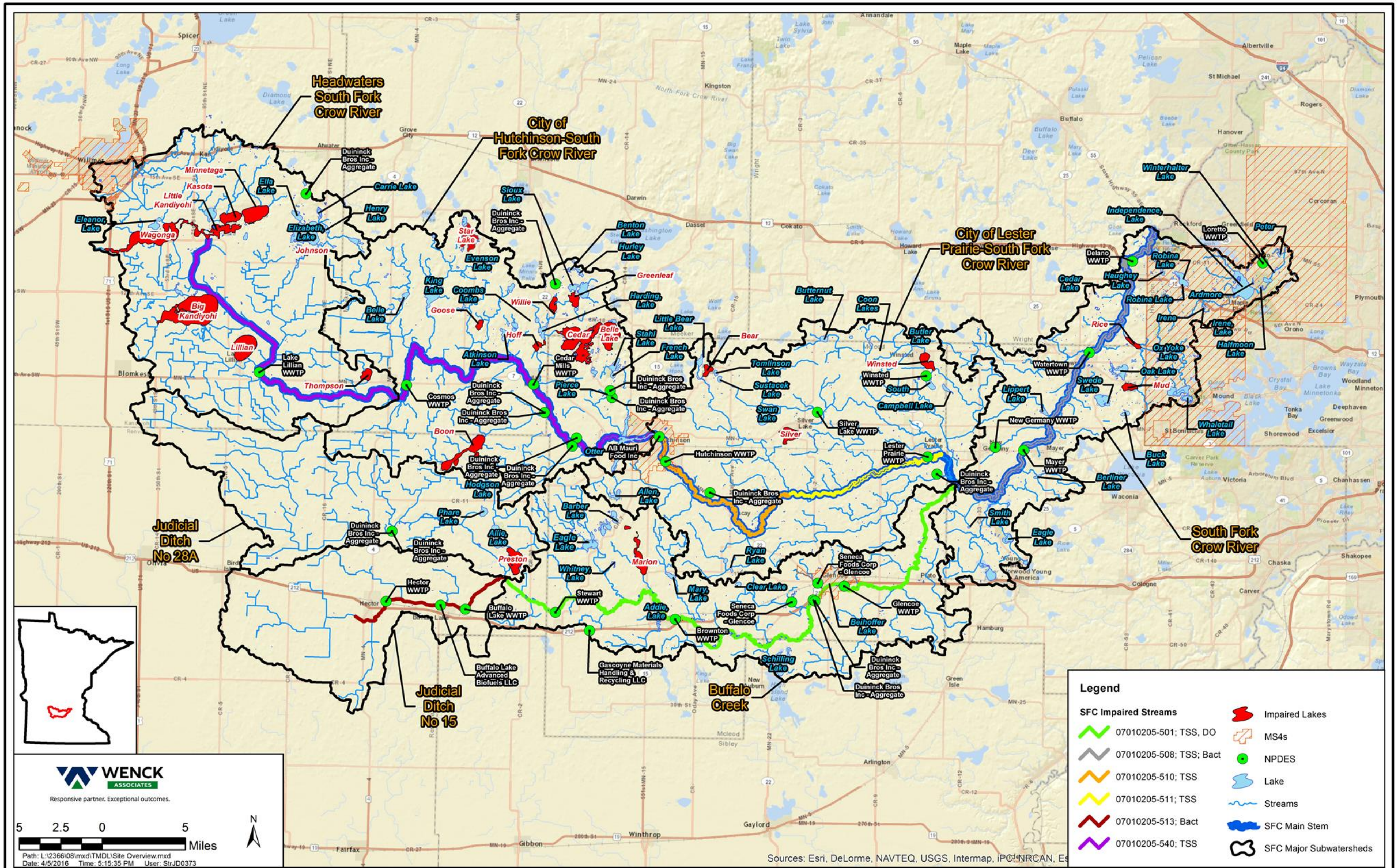

Figure 1-1. South Fork Crow River Watershed impairments addressed in this TMDL study.

1.2 Identification of Waterbodies

The TSS impaired reaches were placed on the State of Minnesota's 303(d) list of impaired waters in 2006 and 2012 as detailed in Table 1-1. The DO impaired reach and the two bacteria impaired reaches were placed on the 303(d) list in 2012. The impaired streams addressed in this TMDL are a mixture of Class 2B (warm water) and Class 7 (limited resource value) waters. In addition to the stream impairments, there are 23 lakes in the South Fork Crow River Watershed that are impaired by nutrients and are addressed in this TMDL study (Table 1-2).

Table 1-1. Stream impairments addressed in this TMDL, presented upstream to downstream.

Reach Name	AUID#	Impairment	Class	Beneficial Use[1]	Year Listed	Target Start / Completion
Judicial Ditch 15	07010205-513	*E. coli*	7	LRV	2010	2012/2018
Buffalo Creek	07010205-501*	DO	2B	AQL	2010	2012/2018
Buffalo Creek	07010205-501*	TSS/Turbidity	2B	AQL	2006	2006/2012
South Fork Crow River	07010205-540**	TSS/Turbidity	2B	AQL	2006	2012/2018
South Fork Crow River	07010205-510***	TSS/Turbidity	2B	AQL	2006	2012/2018
South Fork Crow River	07010205-511	TSS/Turbidity	2B	AQL	2006	2012/2018
South Fork Crow River	07010205-508	Fecal coliform	2B	AQR	2006	2012/2018
South Fork Crow River	07010205-508	TSS/Turbidity	2B	AQL	2004	2012/2018

[1] Beneficial use abbreviations: AQL = aquatic life; AQR = aquatic recreation; LRV = limited resource value

*Note: Reach ID number recently changed from 501 to 638 in the 2016 303(d) list and it is delisted for turbidity on the 2016 303(d) list.

**Note: Reach was split in two and the ID number changed from 540 to 658 and 659 on the 2016 303(d) list.

***Note: Reach ID number 510 is no longer listed for turbidity on the 2016 303(d) list due to new assessment method.

Table 1-2. Lake impairments addressed in this TMDL study.

Lake Name	Lake ID	Impairment	Year Listed	Target Start / Completion
Bear	43-0076-00	Nutrients	2016	2012/2017
Belle	47-0049-01	Nutrients	2016	2012/2017
Big Kandiyohi	34-0086--00	Nutrients	2008	2013/2018
Boon	65-0013-00	Nutrients	2016	2012/2017
Cedar	43-0115-00	Nutrients	2010	2013/2018
Goose	47-0127-00	Nutrients	2016	2012/2017
Green Leaf	47-0062-00	Nutrients	2010	2013/2018
Hoff	47-0106-00	Nutrients	2016	2012/2017
Johnson	34-0012-00	Nutrients	2016	2012/2017
Kasota	34-0105-00	Nutrients	2010	2013/2018
Lillian	34-0072-00	Nutrients	2016	2012/2017
Little Kandiyohi	34-0096-00	Nutrients	2010	2013/2018
Marion	43-0084-00	Nutrients	2010	2013/2018
Minnetaga	34-0076-00	Nutrients	2016	2012/2017
Mud	10-0094-00	Nutrients	2016	2012/2017
Preston	65-0002-00	Nutrients	2016	2012/2017
Rice	86-0032-00	Nutrients	2016	2012/2017
Silver	43-0034-00	Nutrients	2016	2012/2017
Star	47-0129-00	Nutrients	--	--
Thompson	47-0159-00	Nutrients	2016	2012/2017
Wakanda	34-0169-03	Nutrients	2008	2013/2018
Willie	47-0061-00	Nutrients	2016	2012/2017
Winsted	43-0012-00	Nutrients	2016	2012/2017

1.3 Priority Ranking

The Minnesota Pollution Control Agency (MPCA's) schedule for TMDL completions, as indicated on Minnesota's Section 303(d) impaired waters list, reflects Minnesota's priority ranking of this TMDL. The MPCA has aligned our TMDL priorities with the watershed approach and our Watershed Restoration and Protection Strategy (WRAPS) cycle. The schedule for TMDL completion corresponds to the WRAPS report completion on the 10-year cycle. The MPCA developed a state plan Minnesota's TMDL Priority Framework Report to meet the needs of U. S. Environmental Protection Agency (EPA's) national measure (WQ-27) under EPA's Long-Term Vision for Assessment, Restoration and Protection under the Clean Water Act Section 303(d) Program. As part of these efforts, the MPCA identified water quality impaired segments that will be addressed by TMDLs by 2022. The South Fork Crow River Watershed waters addressed by this TMDL are part of that MPCA prioritization plan to meet EPA's national measure.

2. Applicable Water Quality Standards and Numeric Water Quality Targets

2.1 Turbidity and TSS

Turbidity is a measure of the cloudiness or haziness of water caused by suspended and dissolved substances in the water column. Turbidity can be caused by increased suspended soil or sediment particles, phytoplankton growth, and dissolved substances in the water column. Excess turbidity can degrade aesthetic qualities of waterbodies, increase the cost of treatment for drinking water or food processing uses, and harm aquatic life. Adverse ecological impacts caused by excessive turbidity include hampering the ability of aquatic organisms to visually locate food, negative effects on gill function, and smothering of spawning beds and benthic organism habitat.

The four reaches of the South Fork River listed as impaired by turbidity are a class 2B warm water stream. The class 2B turbidity standard (Minn. R. 7050.0222) that was in place at the time of the impairment assessment for these reaches was 25 nephelometeric turbidity units (NTUs). The designated use that this standard protects is the propagation and maintenance of a healthy community of cold water sport or commercial fish and associated aquatic life, and their habitat. Impairment assessment procedures for turbidity are provided in the guidance manual for determination of impairment (MPCA 2007). Impairment listings occur when greater than 10% of data points collected within the previous 10-year period exceed the 25 NTU standard (or equivalent values for TSS or Secchi tube).

The aforementioned 25 NTU turbidity standard had been in place since the late 1960s. However, the standard had several weaknesses, including being a statewide standard and, since turbidity is a measure of light scatter and absorption, it is not a mass unit measurement and therefore not directly amenable to TMDLs and other load-based studies. Other issues with the previous turbidity standard included having too much variation in measurement because of particle composition in water, variation among turbidity meters, and poor quantitative documentation of what a turbidity unit is.

Although recognized earlier, these weaknesses became a significant problem when U.S. Environmental Protection Agency (EPA) and the MPCA TMDL program became fully realized in the early 2000s. Once the TMDL studies began, it became clear that the existing standard was only indirectly related to biotic community health. In addition, TMDL development was challenging because the studies needed to be developed using TSS, which is measured as a mass unit (mg/L).

As a result, a committee of MPCA staff across several divisions met for over a year to develop TSS criteria to replace the current turbidity standards. These TSS criteria are regional in scope and based on a combination of both biotic sensitivity to TSS concentrations and reference streams/least impacted streams as data allow. The results of the TSS criteria development were published by the MPCA in 2011, and proposed a 65 mg/L TSS standard for Class 2B waters in the Southern River Nutrient Region that may not be exceeded more than 10% of the time over a multi-year data window (MPCA 2011). The assessment season is identified as April through September. The TSS standard technical support document was placed on public notice in November 2013, and the rules were adopted at the June 24, 2014, meeting of the MPCA Citizen's Board. The rules were approved by the EPA in January 2015. For the purpose of this TMDL, the newly adopted 65 mg/L TSS standard for Class 2B waters will be used to develop the turbidity TMDL and allocations for the Buffalo Creek and South Fork Crow River turbidity impaired reaches.

2.2 Dissolved Oxygen

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

The South Fork Crow Assessment Unit 07010205–501 (Buffalo Creek) DO impaired reach was designated as impaired under the listing standards in place prior to the 2010 assessment cycle, in which a waterbody was considered impaired for DO if it met the following criteria:

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

2.3 Bacteria

The fecal coliform standard contained in Minn. R. 7050.0222 (5), states that fecal coliform concentrations shall "not exceed 200 organisms per 100 milliliters as a geometric mean of not less than five samples in any calendar month, nor shall more than 10% of all samples taken during any calendar month individually exceed 2000 organisms per 100 milliliters. The standard applies only between April 1 and October 31." Impairment assessment is based on the procedures contained in the Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment (MPCA 2012).

With the revisions of Minnesota's water quality rules in 2008, the state changed to an *E. coli* standard because it is a superior potential illness indicator and costs for lab analysis are less (MPCA 2007). The revised standards now state:

> "*E. coli* concentrations are not to exceed 126 colony forming units per 100 milliliters (cfu/100 ml) as a geometric mean of not less than five samples representative of conditions within any calendar month, nor shall more than 10% of all samples taken during any calendar month individually exceed 1,260 cfu/100 ml. The standard applies only between April 1 and October 31."

The *E. coli* concentration standard of 126 cfu/100 ml was considered reasonably equivalent to the fecal coliform standard of 200 cfu/100 ml from a public health protection standpoint. The SONAR (Statement of Need and Reasonableness) section that supports this rationale uses a log plot that shows a good relationship between these two parameters. The following regression equation was deemed reasonable to convert fecal coliform data to *E. coli* equivalents:

E coli concentration (equivalents) = 1.80 x (Fecal Coliform Concentration)$^{0.81}$

2.4 Nutrients

Under Minn. R. 7050.0150 and 7050.0222, subp. 4, the lakes addressed in this study are shallow and deep lakes located within the North Central Hardwood Forest (NCHF) and the Western Cornbelt Plain (WCBP) Ecoregions, with numeric targets listed in Table 2-1. This TMDL presents load and WLAs and estimated load reductions for each lake assuming end points of the phosphorus criteria listed in Table 2-1.

In addition to meeting phosphorus limits, Chlorophyll-a (Chl-*a*) and Secchi depth standards must also be met for the resource to be considered “fully supporting” its designated use. In developing the nutrient standards for Minnesota lakes (Minn. R. ch. 7050), the MPCA evaluated data from a large cross-section of lakes within each of the state’s ecoregions (MPCA 2005). Clear relationships were established between the causal factor TP and the response variables Chl-*a* and Secchi disk. Based on these relationships, it is expected that by meeting the phosphorus targets, the Chl-*a* and Secchi standards will likewise be met.

Table 2-1. Numeric standards for lakes in the NCHF and WCBP Ecoregions.

Parameter	NCHF Ecoregion Standards (shallow lakes[1])	NCHF Ecoregion Standards (deep lakes)	WCBP Ecoregion Standards (shallow lakes[1])	WCBP Ecoregion Standards (deep lakes)
Total Phosphorus [µg/L]	60	40	90	65
Chlorophyll-a [µg/L]	20	14	30	22
Secchi Disk Transparency [meters]	1.0	1.4	0.7	0.9

[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).

3. Watershed and Waterbody Characterization

The South Fork Crow River Watershed is located in the Upper Mississippi River Basin in central Minnesota, and encompasses all or parts of Kandiyohi, Meeker, Renville, McLeod, Carver, Sibley, Wright, and Hennepin Counties. The headwaters for the South Fork Crow River are located in Kandiyohi County, at Little Kandiyohi Lake. The segment of the South Fork Crow from Little Kandiyohi Lake to Cosmos, Minnesota, has been for the most part, channelized. Buffalo Creek, a major tributary to the South Fork Crow River originates in Renville County and flows east through McLeod County. Similar to the South Fork Crow, most of Buffalo Creek has been channelized. Buffalo Creek joins the South Fork Crow in Carver County, just across the Carver/McLeod County line. The South Fork Crow River then flows northeast approximately 30 miles where it meets the North Fork Crow River in Rockford, Minnesota.

The total watershed area of the South Fork Crow River Watershed is approximately 818,428 acres. The dominant land use within the watershed is agriculture (predominantly row crops), followed to a much lesser extent by grasslands, forests, water, wetlands, and urban. Each impaired waterbody is located in various subwatersheds that discharge to Buffalo Creek and the South Fork Crow River.

3.1 Streams

The most downstream reach of Buffalo Creek, reach 501, is impaired by both TSS and low DO (Figure 1-1, Table 1-1). This reach, along with the adjacent upstream reach (502), are impaired by bacteria; however, TMDLs for these reaches were included as part of the Buffalo Creek TMDL completed in 2013 (Wenck Associates 2013). One tributary to Buffalo Creek, Judicial Ditch #15 (JD15), was assessed as being impaired by bacteria (*E. coli*) in 2010 and is therefore included in this TMDL study. Three of the TSS impairments (540, 510, and 511) are located along the main stem of the South Fork Crow River upstream of its confluence with Buffalo Creek. At this time, no river or stream reaches in the South Fork Crow River Watershed upstream of Buffalo Creek have been listed as impaired due to bacteria. Reach 508 begins at the confluence of Buffalo Creek and the South Fork Crow River, and ends at the confluence of the South Fork Crow and the North Fork Crow Rivers in Rockford, Minnesota. This reach is impaired by both TSS and bacteria and is addressed in this TMDL study. Collectively, the six impaired reaches addressed in this TMDL study span approximately 175 stream miles in all eight counties of the South Fork Crow River Watershed (Table 3-1).

Table 3-1. Impaired reach watershed areas and locations and areas.

Major Subwatershed (HUC 10)	AUID#	Impairment(s)	Reach Length [miles]	Direct Drainage[1] [acres]	Total Drainage[2] [acres]
Judicial Ditch 15	07010205-513	*E. coli*	11	63,673	63,673
Buffalo Creek	07010205-501	TSS, DO	52	121,573	266,822
Headwaters - SFC Hutchinson - SFC	07010205-540	TSS	51	285,239	285,239
Lester Prairie - SFC	07010205-510	TSS	18	42,414	327,654
Lester Prairie - SFC	07010205-511	TSS	14	35,054	362,708
South Fork Crow River	07010205-508	TSS, Fecal Coliform	31	111,775	818,103

[1] Includes only area draining directly to impaired reach
[2] All area draining to impaired

3.2 Lakes

Lake morphometry, ecoregion, and major subwatershed of each impaired lake is presented in Table 3-2.

Table 3-2. Impaired lake location and morphometry.

Lake Name	Ecoregion	Major Subwatershed	Surface Area [acres]	Ave. Depth [ft]	Max Depth [ft]	Volume [acre-ft]	Littoral Area [acres]	Littoral Area [%]
Preston	WCBP	Judicial Ditch 28A	636	6.2	10	3,955	636	100%
Marion	WCBP	Buffalo Creek	532	7.0	15	3,717	532	100%
Big Kandiyohi	WCBP	Headwaters – SFC	2,673	11.5	15	30,735	1,435	100%
Little Kandiyohi	WCBP	Headwaters – SFC	669	5.0	7	3,345	669	100%
Johnson	WCBP	Headwaters – SFC	101	4.0	6	404	101	100%
Kasota	WCBP	Headwaters – SFC	434	5.0	7	2,170	434	100%
Lillian	WCBP	Headwaters – SFC	1,118	4.3	5	4,767	1,118	100%
Minnetaga	WCBP	Headwaters – SFC	766	5.0	8	3,830	766	100%
Thompson	WCBP	Headwaters – SFC	218	5.5	7	1,211	218	100%
Wakanda	WCBP	Headwaters – SFC	1,704	6.5	13	11,138	1,704	100%
Cedar	NCHF	Hutchinson – SFC	1,852	4.0	5	7,342	1,852	100%
Greenleaf	NCHF	Hutchinson – SFC	240	8.7	15	2,078	194	81%
Goose	WCBP	Hutchinson – SFC	105	7.8	12	819	105	100%
Hoff	WCBP	Hutchinson – SFC	151	4.3	7	655	151	100%
Star	NCHF	Hutchinson – SFC	553	8	14	4,428	553	100%
Belle	NCHF	Hutchinson – SFC	918	13.2	20	12,082	436	48%
Willie	NCHF	Hutchinson – SFC	187	8.2	15	1,528	166	89%
Bear	NCHF	Lester Prairie - SFC	169	5.0	9	845	169	100%
Boon	WCBP	Lester Prairie - SFC	763	3.0	6	2,289	763	100%
Silver	WCBP	Lester Prairie - SFC	453	3.8	5	1,713	453	100%
Winsted	NCHF	Lester Prairie - SFC	361	6.5	10	2,333	361	100%
Mud	NCHF	SFC River	221	3.4	7	742	221	100%
Rice	NCHF	SFC River	142	1.0	2	142	142	100%

3.3 Subwatersheds

The major subwatersheds of the South Fork Crow River Watershed are shown in Figure 1-1. Smaller, individual subwatersheds for the impaired reaches and lakes were determined using the Minnesota Department of Natural Resources (DNR) GIS catchment file.

3.4 Land Cover

A broad range of land use and land cover exists within the South Fork Crow River Watershed, which is summarized in Table 3-3 below and illustrated in Figure 3-1. Land cover for the South Fork Crow River Watersheds was calculated using the 2011 National Agricultural Statistics Service (NASS) GIS land cover file. The dominant land use is corn/soybean crops (Table 3-3). The remaining land area is comprised of forest and shrub land, lakes and wetlands, developed land and non-corn/soybean crops.

Table 3-3. Land cover in the South Fork Crow River Watershed (Source 2011 NASS).

Land use	Percent of Total South Fork Crow Watershed
Corn/Soybeans	64.1%
Wetland and Open Water	13.5%
Grains and Other Crops	8.5%
Urban/Roads	6.0%
Forest and Shrubland	5.9%
Hay and Pasture	1.8%
Barren	0.2%

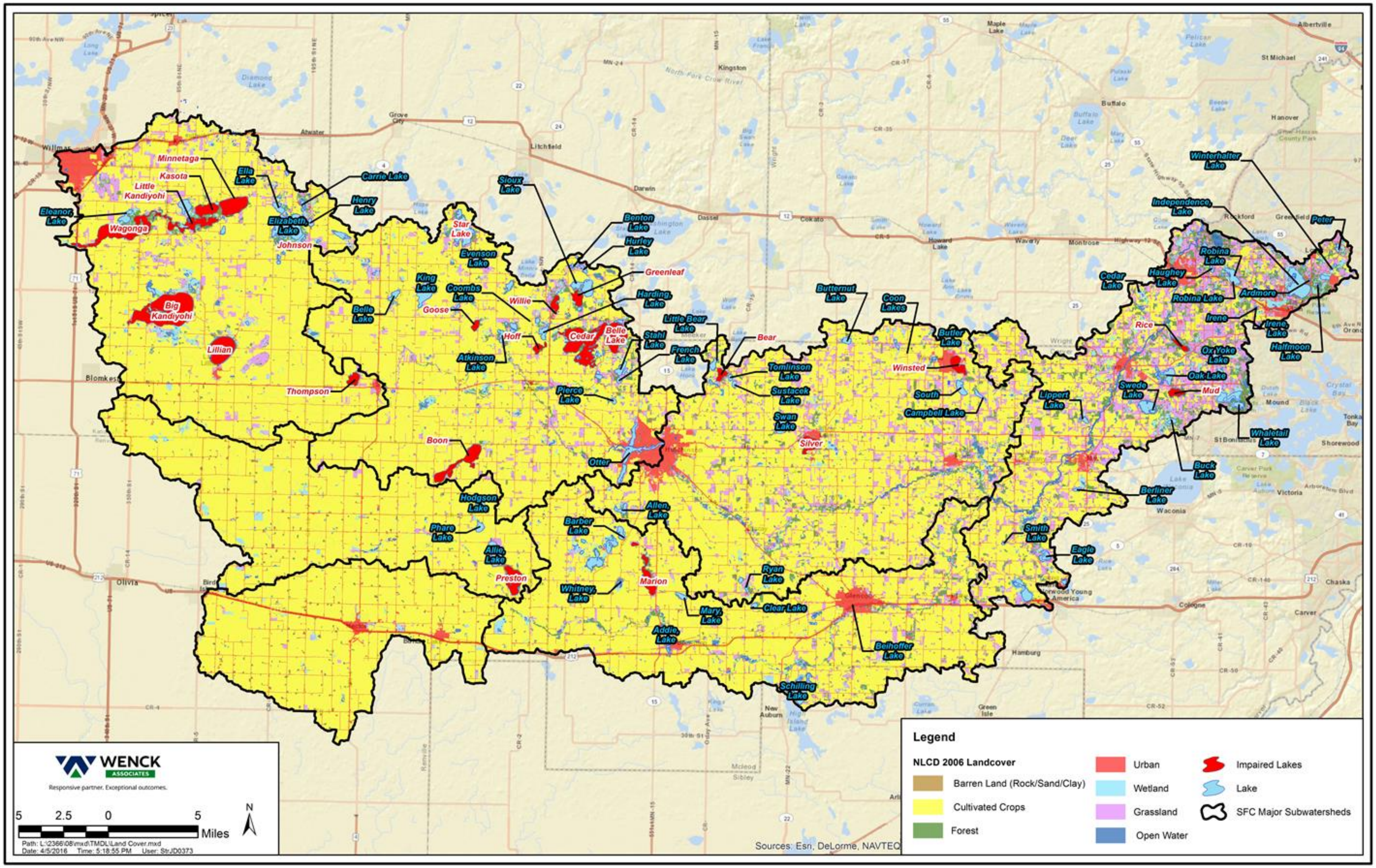

Figure 3-1. Land cover in the South Fork Crow River Watershed.

3.5 Current/Historic Water Quality

All data used in the development of this TMDL were collected between 2000 and 2014 by various agencies and local groups, including the Crow River Organization of Water (CROW), MPCA, and area Soil and Water Conservation Districts (SWCDs). Although data prior to 2000 exists within the watershed, the more recent data better represent current conditions in the watershed. Only data available through the MPCA's Environmental Quality Information System (EQuIS) website, regardless of what organization gathered the data, was used in this TMDL study.

3.5.1 TSS

The TSS data was summarized by site for the entire watershed using all data from 2000 to 2013 (Table 3-4). Figures 3-2 through 3-6 show the seasonal variation of TSS data at each TMDL reach. TSS TMDLs are included for five Assessment Unit ID (AUIDs): 07010205-501 on Buffalo Creek and 07010205-508, 07010205-510, 07010205-511, and 07010205-540 on the South Fork Crow River (Figure 1-1). These TMDLs are based upon the current TSS standard for the Southern River Nutrient Region TSS standard of 65 mg/L, since these reaches were assessed using this criteria. It should be noted that 07010205-508 is located in the Central River Region.

Table 3-4. Observed TSS data summary in the South Fork Crow River Watershed.

Station	TMDL Reach	Number of Samples	Sample Date Range		Minimum (mg/L)	Average (mg/L)	Maximum (mg/L)	Number of Samples Over 65 mg/L	Percent of Samples Over 65 mg/L
05278930	501	1	12/7/2007	12/7/2007	4.0	4.0	4.0	0	0%
S000-460	501	99	3/19/2003	10/9/2013	1.0	29.8	120.0	7	7%
S000-528	501	8	6/10/2007	9/30/2007	14.0	46.5	112.0	2	25%
S000-531	501	8	6/10/2007	9/30/2007	25.0	54.5	104.0	2	25%
S000-582	501	152	3/19/2003	11/8/2013	1.0	32.5	120.0	15	10%
S000-165	508	7	7/10/2006	9/18/2006	26.0	84.0	210.0	3	43%
S001-255	508	197	3/25/2003	11/21/2013	1.2	37.8	320.0	20	10%
S001-731	508	2	6/14/2013	10/3/2013	7.6	68.8	130.0	1	50%
S001-801	508	2	6/14/2013	10/3/2013	35.0	97.5	160.0	1	50%
S001-827	508	4	4/7/2009	8/12/2009	15.0	68.5	153.0	2	50%
S000-395	510	27	3/25/2003	9/22/2009	9.0	36.4	81.0	3	11%
S001-443	511	27	3/19/2003	9/27/2010	10.0	47.0	100.0	5	19%
S000-353	540	13	3/25/2003	6/30/2003	5.0	36.9	104.0	1	8%
34-0096-00	540	5	5/16/2013	9/23/2013	4.0	22.2	37.0	0	0%
43-0085-01	540	22	5/18/2006	9/23/2013	14.0	51.5	130.0	5	23%
S000-575	540	27	5/18/2008	9/21/2009	1.0	34.9	184.0	3	11%
S002-014	540	29	4/22/2009	11/8/2013	5.0	27.1	71.0	1	3%
S002-015	540	30	3/25/2003	11/8/2013	1.0	29.0	102.0	2	7%

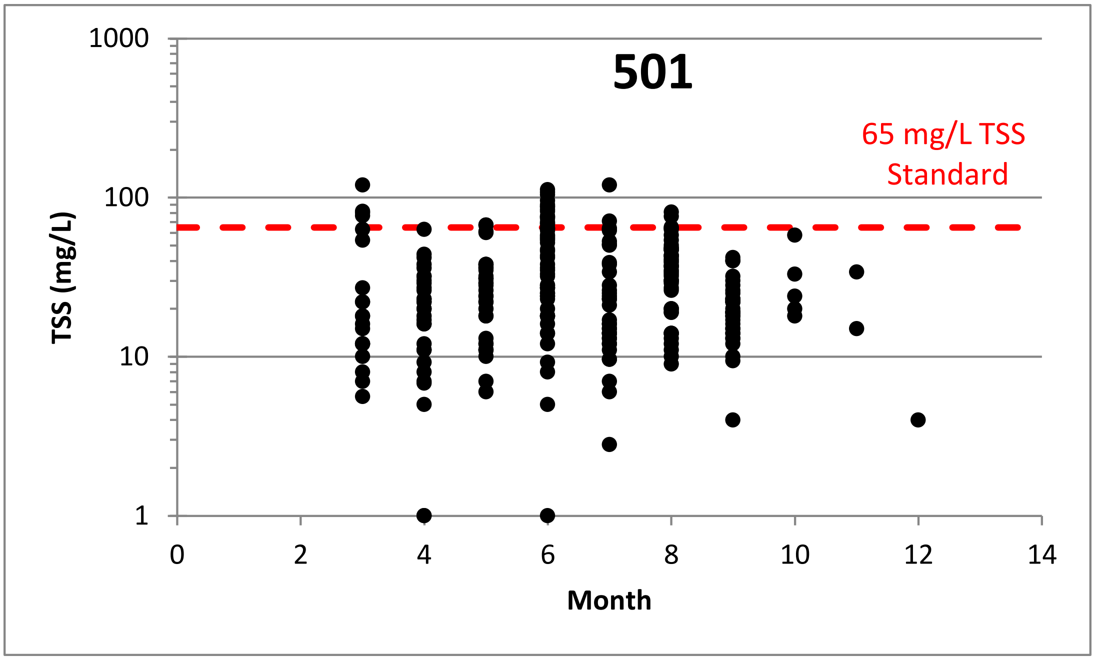

Figure 3-2. Seasonal variation of TSS at Buffalo Creek 07010205-501. The red dashed line indicates the South River Nutrient Region 65 mg/L TSS standard.

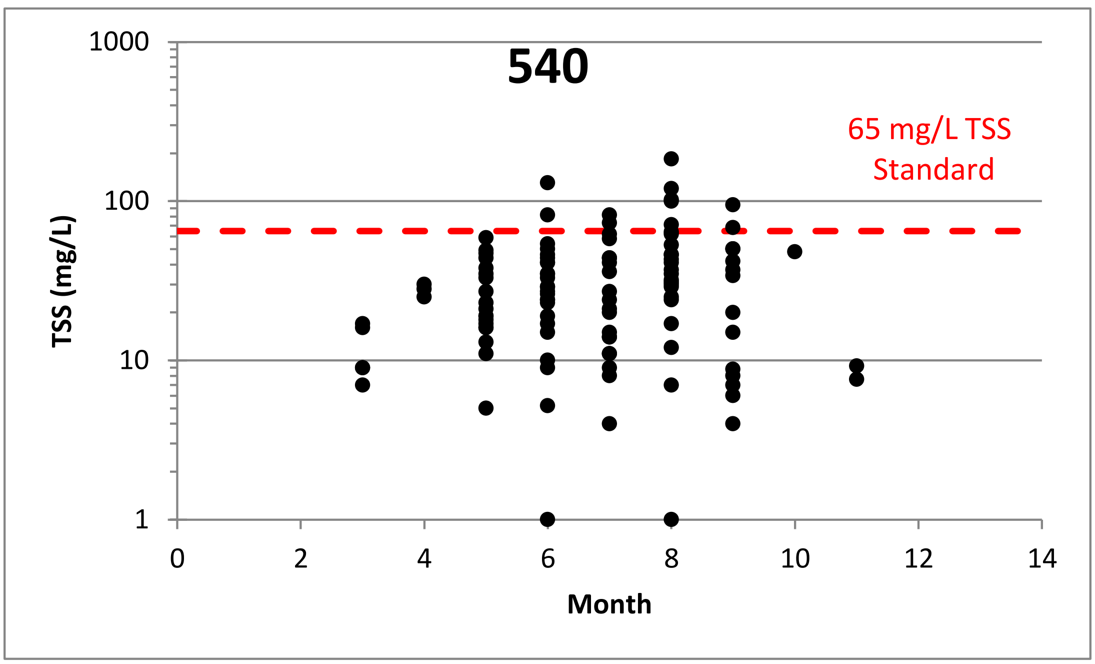

Figure 3-3. Seasonal variation of TSS at South Fork Crow River 07010205-540. The red dashed line indicates the South River Nutrient Region 65 mg/L TSS standard.

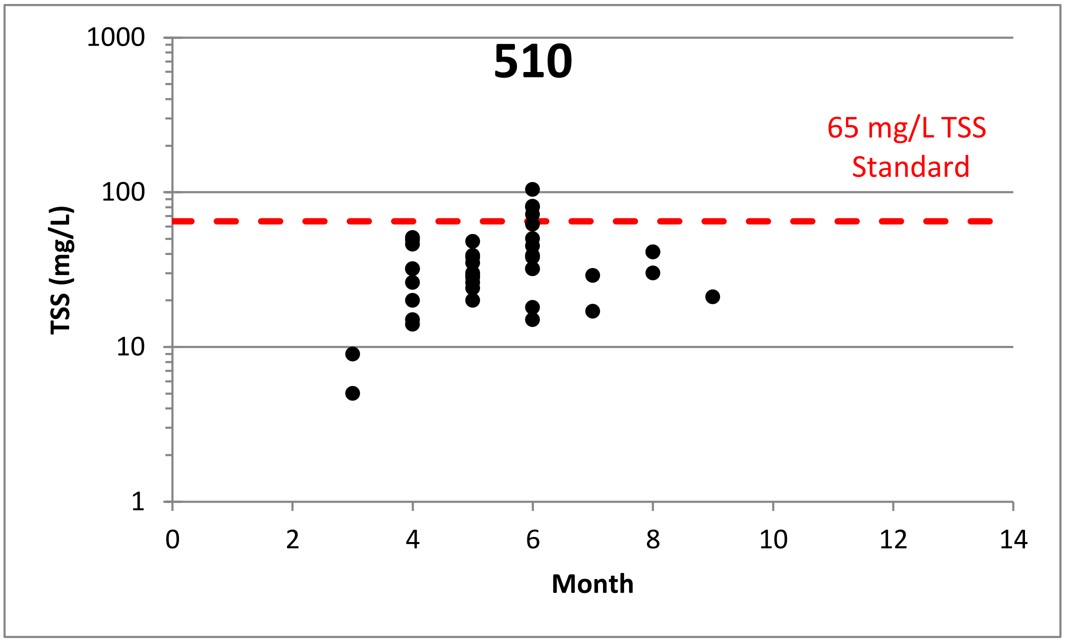

Figure 3-4. Seasonal variation of TSS at South Fork Crow River 07010205-510. The red dashed line indicates the South River Nutrient Region 65 mg/L TSS standard.

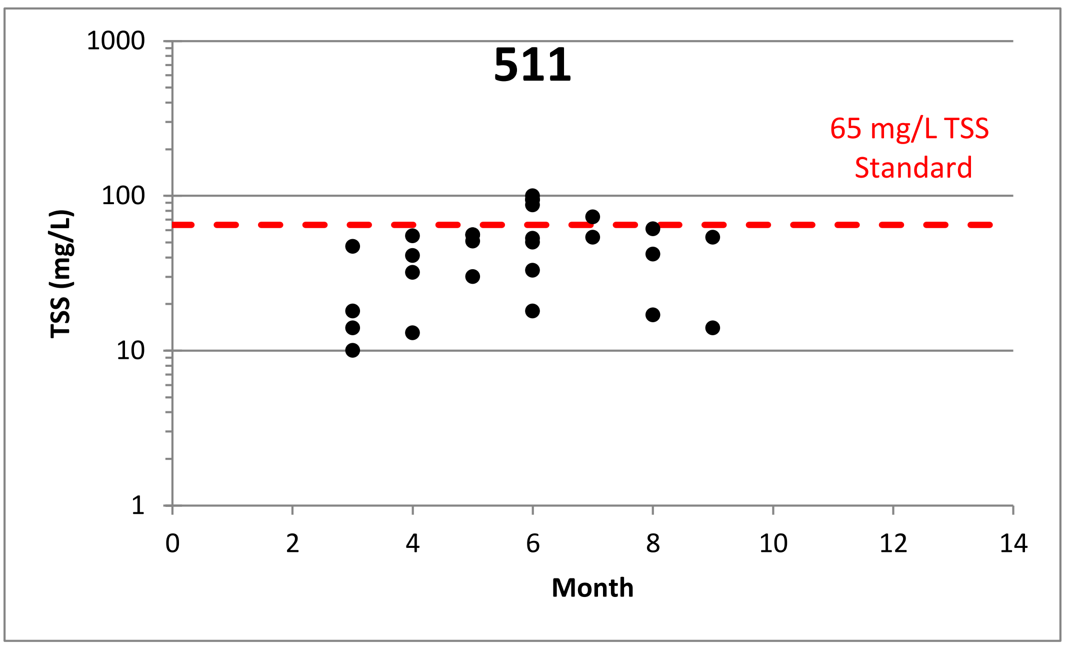

Figure 3-5. Seasonal variation of TSS at South Fork Crow River 07010205-511. The red dashed line indicates the South River Nutrient Region 65 mg/L TSS standard.

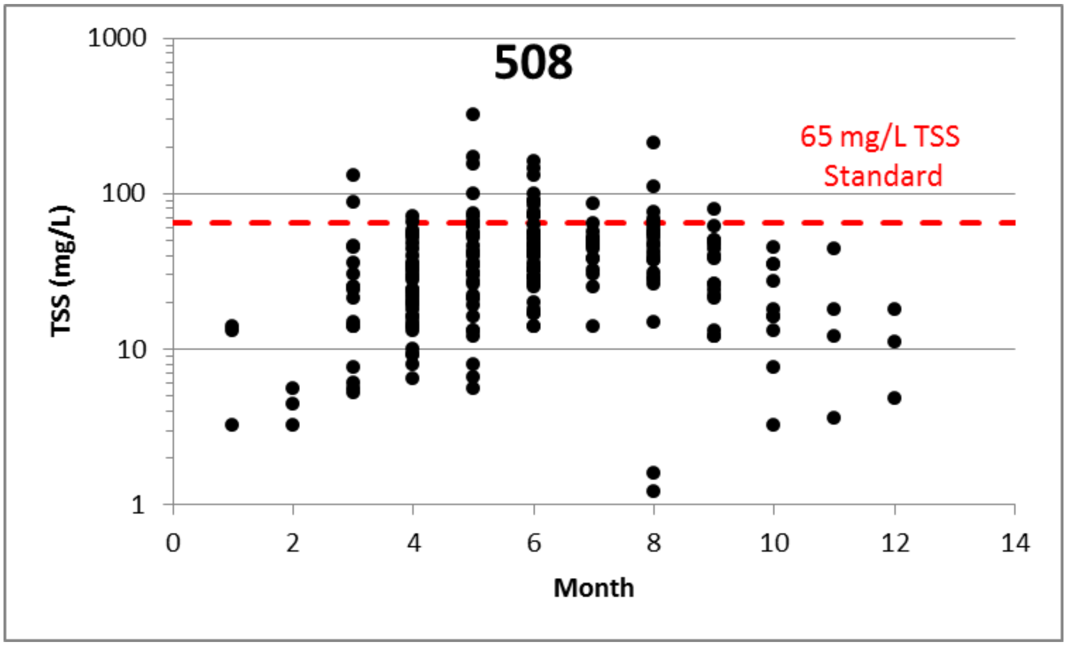

Figure 3-6. Seasonal variation of TSS at South Fork Crow River 07010205-508. The red dashed line indicates the South River Nutrient Region 65 mg/L TSS standard.4.3 Total Suspended Solids TMDLs

3.5.2 DO

The DO data were summarized by site for the Buffalo Creek portion of the watershed (07010205-501) using all data from 2000 to 2014. Table 3-5 shows the summary of all data, and Table 3-6 shows a table of samples occurring before 9:00 a.m. Figures 3-7 and 3-8 show the seasonality of all DO data and DO data measured before 9:00 a.m., respectively.

Table 3-5. Dissolved oxygen observed data summary (07010205-501) (all data from Buffalo Creek portion of the South Fork Crow River Watershed) measured between the months of April and November from 2003 to 2013.

Station	Number of Samples	Sample Date Range		Minimum (mg/L)	Average (mg/L)	Maximum (mg/L)	Number Under 5 mg/L	Percent Under 5 mg/L
S000-457	5	4/13/2010	10/26/2010	1.4	5.7	8.2	1	20%
S000-460	112	4/7/2003	10/9/2013	2.9	8.4	14.4	7	6%
S000-462	1	6/16/2011	6/16/2011	8.1	8.1	8.1	0	0%
S000-466	3	6/21/2013	10/9/2013	7.3	7.8	8.3	0	0%
S000-528	3	6/21/2013	11/8/2013	7.4	8.9	11.4	0	0%
S000-579	22	5/2/2012	9/11/2013	3.3	7.8	10.7	4	18%
S000-580	1	6/21/2013	6/21/2013	7.7	7.7	7.7	0	0%
S000-582	115	4/7/2003	11/8/2013	1.0	8.5	15.7	9	8%
S002-017	122	4/7/2003	10/9/2013	3.7	10.3	20.7	3	2%
S006-986	1	6/16/2011	6/16/2011	8.5	8.5	8.5	0	0%
S006-987	1	6/16/2011	6/16/2011	7.5	7.5	7.5	0	0%
S006-988	1	6/16/2011	6/16/2011	7.3	7.3	7.3	0	0%
S007-617	2	6/21/2013	10/9/2013	7.7	9.4	11.1	0	0%
S007-654	1	7/10/2013	7/10/2013	11.6	11.6	11.6	0	0%
S007-655	1	7/10/2013	7/10/2013	8.9	8.9	8.9	0	0%
S007-709	2	10/9/2013	11/8/2013	9.0	9.3	9.6	0	0%

Table 3-6. Dissolved oxygen observed data summary (samples before 9:00 a.m. from Buffalo Creek portion of South Fork Crow River Watershed) measured between the months of April and November from 2003 to 2013.

Station	Number of Samples	Sample Date Range		Minimum (mg/L)	Average (mg/L)	Maximum (mg/L)	Number Under 5 mg/L	Percent Under 5 mg/L
S000-460	4	4/26/2006	7/29/2010	5.8	9.1	11.3	0	0%
S000-579	1	9/11/2013	9/11/2013	4.9	4.9	4.9	1	100%
S000-582	16	4/26/2006	8/11/2009	3.3	8.0	11.9	2	13%
S002-017	2	5/2/2012	9/11/2013	3.7	4.8	5.8	1	50%
S006-986	1	6/16/2011	6/16/2011	8.5	8.5	8.5	0	0%

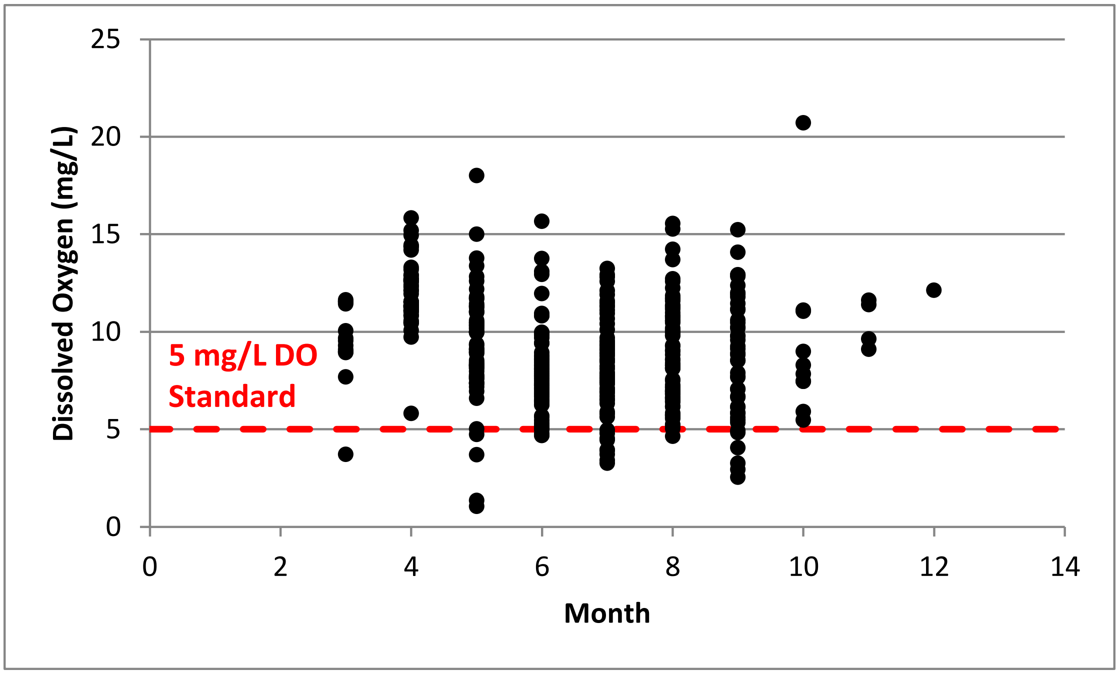

Figure 3-7. Seasonal variation of dissolved oxygen samples in Buffalo Creek (all data). The red dashed line indicates the 5 mg/L DO standard.

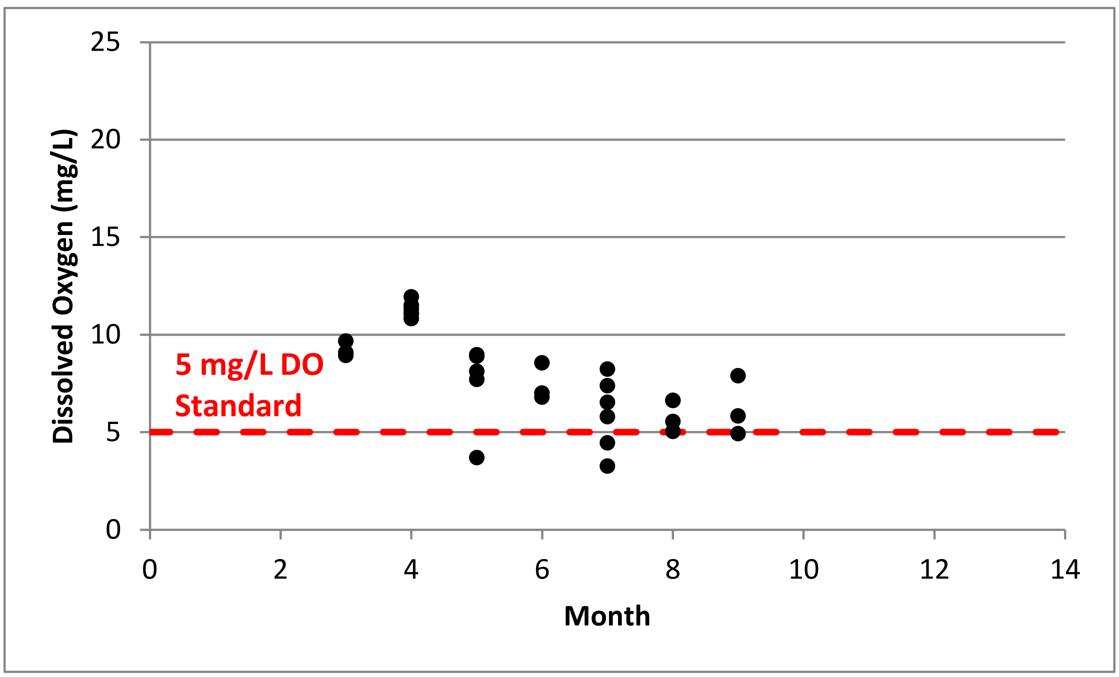

Figure 3-8. Seasonal variation of dissolved oxygen samples in Buffalo Creek measured before 9:00 a.m. The red dashed line indicates the 5 mg/L DO standard.

3.5.3 Bacteria

A stream reach is placed on the 303(d) Impaired Waters List if the geometric mean (or "geomean") of the aggregated monthly *E. coli* concentrations for one or more months exceed the chronic standard of 126 cfu/100 ml. A waterbody is also considered impaired if more than 10% of the individual samples during any calendar year exceed the 1,260 cfu/100 ml acute standard.

Table 3-4 shows April through October monthly *E. coli* geometric means for the two bacteria impaired reaches addressed in this TMDL study. Geometric means are often used to describe bacteria data over arithmetic means as the geometric mean normalizes the ranges being averaged, using the following equation:

$$Geometric\ mean = \sqrt[n]{x_1 * \ x_2 * \ldots .x_n}$$

Bacteria samples in the South Fork Crow River Watershed were analyzed for fecal coliform prior to 2006 and more recently *E. coli*. Fecal coliform data were converted to *E. coli* equivalents using the equation described in Section 2.3. Table 3-7 shows monthly geometric means and acute exceedances for sampling stations located within each impaired reach. Results indicate both impaired reaches exceeded the 126 cfu/100 ml chronic *E. coli* standard for at least one month during the April through October index period. Additionally, individual samples exceed the 1,260 cfu/100 ml acute standard at least 10% of the time in several reaches during the April through October index period.

Table 3-7 also shows monthly geometric means and acute exceedances for one reach of Buffalo Creek (501) and several reaches of the South Fork Crow River (540, 510, and 511) that are located upstream of the South Fork Crow *E. coli* impaired reach (508). Bacteria data from these reaches indicate high levels of *E. coli,* which are likely a significant driver of the high levels observed in reach 508.

Table 3-7. Monthly geometric mean of *E. coli* values for the South Fork Crow River impaired reaches, and major upstream reaches.

			April			May			June			July			August			September			October			All Months		
Reach ID	**EQuIS ID**	**Data Years**	n	Geo	%n > 1,260	n	Geo	%n > 1,260	n	Geo	%n > 1,260	n	Geo	%n > 1,260	n	Geo	%n > 1,260	n	Geo	%n > 1,260	n	Geo	%n > 1,260	n	Geo	%n > 1,260
JD15 (513)	S002-016	2006-2013	10	86	0%	10	122	0%	21	**381**	14%	17	**392**	6%	21	**437**	10%	9	**634**	33%	1	**920**	0%	88	**309**	10%
South Fork Crow River (508)	S001-255	2001-2013	23	47	0%	27	99	0%	13	**231**	23%	--	--	--	--	--	--	--	--	--	--	--	--	63	90	5%
	S001-827	2003-2013	18	45	0%	18	**133**	0%	21	**290**	5%	17	**221**	12%	13	**258**	23%	8	**305**	25%	2	**361**	0%	97	**172**	8%
	S003-629	2010-2013	4	62	0%	8	**161**	0%	9	**441**	44%	9	**236**	0%	9	**495**	22%	3	**737**	33%	1	**1046**	0%	43	**290**	16%
Buffalo Creek (501)*	S000-460	2006-2012	10	28	0%	12	96	0%	19	**320**	16%	15	**318**	20%	19	**416**	11%	12	**298**	0%	1	**330**	0%	88	**216**	9%
	S000-579	2012-2013	--	--	--	--	--	--	5	**308**	20	5	**375**	20	5	**257**	0	--	--	--	--	--	--	15	**309**	13
	S000-582	2006-2012	10	28	0%	12	92	0%	20	**348**	20%	15	**227**	13%	19	**510**	26%	12	**307**	17%	1	**140**	0%	89	**215**	15%
South Fork Crow River (540)**	S002-014	2010-2013	3	7	0%	4	64	0%	8	**358**	25%	10	**144**	0%	10	**128**	0%	3	**199**	0%	--	--	--	39	122	5%
South Fork Crow River (510)**	S000-395	2003-2011	3	15	0%	4	91	0%	5	**453**	40%	4	**235**	0%	3	**435**	33%	3	**149**	0%	--	--	--	23	**155**	13%
South Fork Crow River (511)**	S001-443	2010-2013	3	26	0%	4	75	0%	13	**292**	23%	11	112	0%	13	**186**	0%	4	**206**	0%	--	--	--	48	**155**	6%

Notes:
Red values = monthly geomean values greater than 126 cfu/100ml
n = number of samples
Geo = Geometric mean in cfu/100 ml
%n > 1,260 = Percent of samples greater than 1,260 cfu/100 ml
-- no available data
* Buffalo Creek reach 501 is directly upstream of South Fork Crow reach 508 and was covered in a previous TMDL report
** South Fork Crow River reaches 540, 510 and 511 are upstream of South Fork Crow reach 508 and are not listed as impaired for *E. coli* at this time.

3.5.4 Nutrients

In general, historical in-lake water quality data collected from 2000 to 2013 was reviewed for use in the TMDL study. For the purposes of developing the majority of the nutrient TMDLs, only available data from 2004 to 2013 was used to establish the “average” condition. However, most lakes did not have datasets, which covered the entire 2004 through 2013 period. For lakes without the full data set, available data from 2004 to 2013 was used to establish the “average” condition for those lakes.

Table 3-8 lists the June through September averages of total phosphorus (TP) concentration, Chl-*a* concentration, and Secchi depth for each impaired lake. The table also lists the data years, which were used to calculate the “average” condition for the TMDL study. All lakes indicate average summer TP, Chl-*a*, and/or Secchi depth are not meeting ecoregion-defined state standards.

Table 3-8. Summer growing season averages for each water quality parameter.

		In-Lake "Average" Condition (Calculated June - September)		
Lake Name	**"Average" Condition Calculation Years**	**TP Concentration (µg/L)**	**Chl-*a* Concentration (µg/L)**	**Secchi Depth (m)**
NCHF Ecoregion Deep Lake Standards		**40**	**14**	**1.4**
Belle	2008-2009, 2013	53	27	1.0
NCHF Ecoregion Shallow Lake Standards		**60**	**20**	**1.0**
Cedar	2006, 2008	109	47	0.4
Greenleaf	2007-2008	74	33	0.7
Willie	2010-2011	60	22	0.9
Bear	2011	200	58	1.0
Winsted	2008, 2010	377	71	1.0
Mud	2010-2011	187	137	0.7
Rice	2010-2011	345	82	0.6
WCBP Ecoregion Shallow Lake Standards		**90**	**30**	**0.7**
Preston	2008-2010, 2012	112	47	0.5
Marion	2006, 2008, 2010-2013	93	31	1.0
Big Kandiyohi	2005-2006	165	19	1.0
Little Kandiyohi	2006-2008	319	167	0.2
Johnson	2012-2013	210	66	0.4
Kasota	2006-2007	415	177	0.2
Lillian	2008-2009	101	49	1.2
Minnetaga	2008-2009	270	38	0.3
Thompson	2011	167	15	1.4
Wakanda	2005	155	153	0.2
Goose	2012-2013	436	99	0.9
Hoff	2010-2011	120	62	1.0
Boon	2008-2009	205	114	0.2
Silver	2006, 2011	275	144	1.0
Star	2009-2010	89	42	0.4

3.6 Pollutant Source Summary

3.6.1 TSS

The HSPF model was used to determine the contribution of TSS from identified sources in the South Fork Crow River Watershed. Source assessment modeling results were summarized using the following categories: bed/bank, cropland, pasture/rangeland, urban, and other. The “other” category includes point sources, feedlots, forest, septic, and wetland; it makes up less than 2% of overall sources for all impaired reaches. Pie charts, shown in Figure 3-9, were produced at each of the five TMDL endpoints to show the relative contribution of each source. All impaired reaches showed bed and bank to be the primary source of sediment, followed by cropland. Urban lands contributed 6% or less for all impaired reaches, and pasture/rangeland contributed 5% or less for all impaired reaches. It should be noted that bed/bank sediment can increase from practices that increase “flashiness” of the system, such as straightening of channels (ditches), tile drainage, and runoff from impervious urban land.

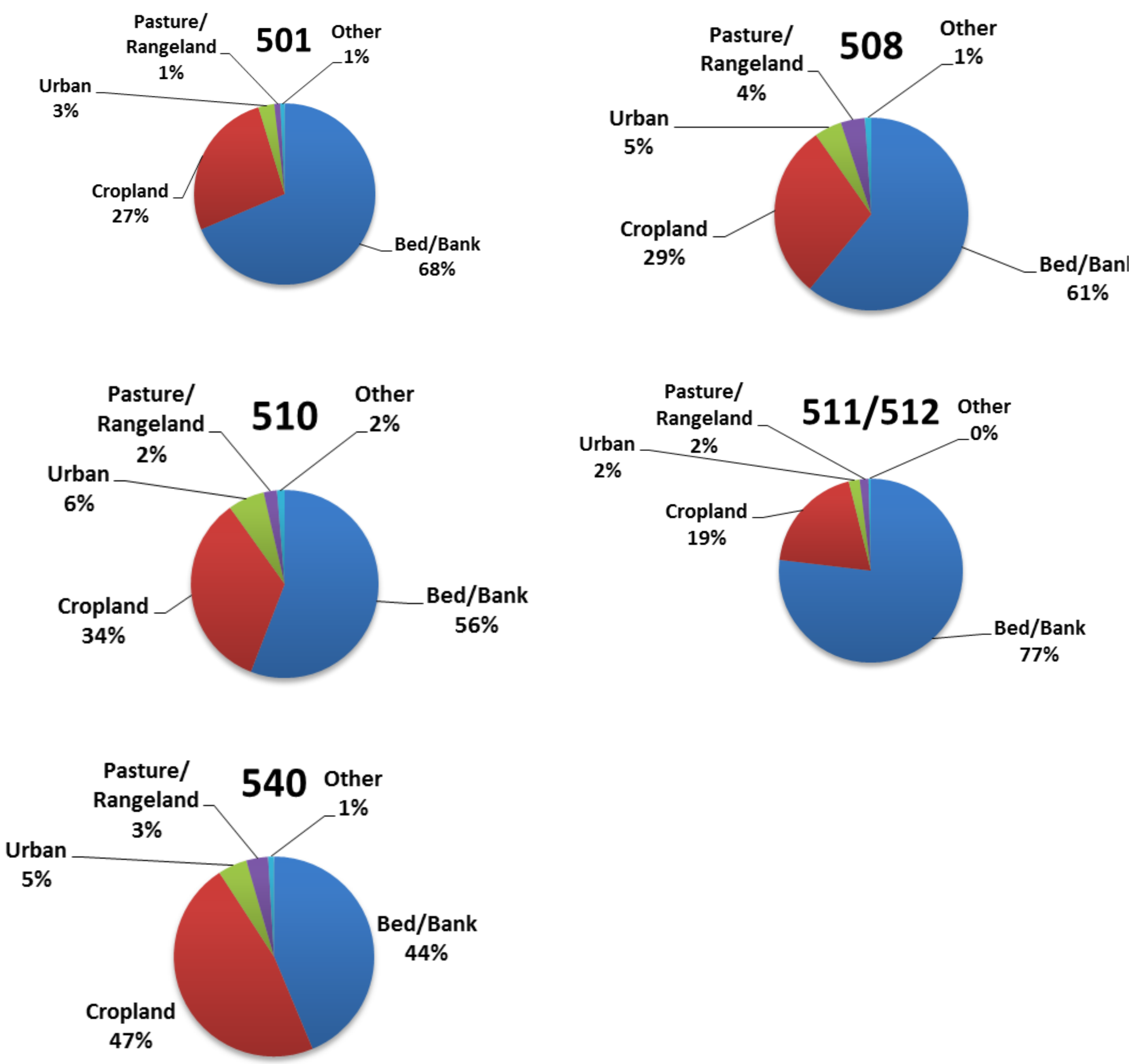

Figure 3-9. TSS source assessment modeling results within the South Fork Crow River Watershed impaired reaches.

3.6.2 Dissolved Oxygen

The Buffalo Creek DO TMDL for AUID 07010205-501 is required due to violations of Minnesota's DO standard of 5 mg/L (daily minimum). Minn. R. 7050.0222, subp. 4, states that compliance with the 5.0 mg/L class 2B DO standard is required 50% of the days at which the flow of the receiving water is equal to the 7Q10 flow condition. For this TMDL, the daily minimum time series from HSPF during open water months (April through November) was used, and the loading capacity was set to achieve the 5 mg/L or higher throughout over 95% of simulation period. The numerical TMDL is the sum of the WLA, the LA, and the MOS.

The water quality target for Buffalo Creek is the DO criteria. The pollutants of concern are constituents that reduce or lead to the reduction of DO in the listed reach. The decomposition of organic matter such as proteins, human and animal waste, and dead plant matter, and the oxidation of inorganic ammonia, consume oxygen. Phosphorus, and, in some cases, nitrogen, can be a limiting nutrient to the production of algae and aquatic macrophytes, which die, decompose, and use oxygen in the water. One of the required elements of a TMDL is the identification of the pollutants of concern. The pollutant of concern for this TMDL is organic matter, which is measured as biochemical oxygen demand (BOD). While nutrients such as phosphorus and nitrogen may contribute to the growth of organic matter within the reach (i.e., algae) and inputs from the watershed (i.e., ammonia and organic-nitrogen), this TMDL is written for oxygen demanding substances. It is assumed that future TMDL efforts will establish appropriate phosphorus and/or nitrogen loading capacities for this reach to meet Minnesota's River Nutrient Eutrophication Criteria and State nitrogen standards when they are developed.

Conventionally, BOD – determined by the test of the same name – is used to combine the oxygen demand of wastes and plant matter. Biochemical oxidation of organic material is a slow process with an infinite timeframe, but usually the process is 95% complete within 20 days. During the initial portion of this period – from 6 to 10 days – oxygen is consumed to oxidize mostly carbonaceous matter. The hydrolysis of proteins in wastewater produces ammonia. After 6 to 10 days, the autotrophic bacteria, which utilize oxygen to oxidize ammonia, are present in sufficient numbers to exert a measureable oxygen demand. These two sources of oxygen demand are referred to as carbonaceous BOD, or CBOD, and nitrogenous BOD, or NBOD. The oxygen demand determined by continuing the BOD test until DO consumption is reduced to a negligible level is the ultimate BOD of the wastewater. Most laboratories limit the BODu test to 20 days or 40 days inhabitation of nitrifying bacteria during the test results in the CBODu of the wastewater. Due to the time requirements of the BODu test, the oxygen demand from the 5-day carbonaceous BOD test is commonly used to evaluate the organic waste load of wastewater.

Another source of oxygen demand in a stream reach can be stream bed itself. Deposition of dead plant matter, including algae and macrophytes, eroded organic soils, wastewater bypasses and historic sludge deposits from old rudimentary wastewater treatment plants (WWTPs) can result in organic benthic deposits. The aerobic decomposition of the surface layer of these deposits can exude an oxygen demand during decomposition. In addition, high spring flow rates in the stream can scour these sediments and reduce the demand in a reach, but may redeposit the sediment in a reduced velocity zone downstream. Sediment oxygen demand (SOD) is best determined using in–situ testing, but can also be approximated with sediment samples in the laboratory. In TMDL analysis, SOD is commonly determined through water quality models to avoid laborious in–situ monitoring.

Living material can also exude an oxygen demand upon the water column. Algae, both suspended in the water (phytoplankton) and attached to rocks and wood debris on the stream bed (periphyton), utilize oxygen during respiration.

In addition to oxygen demanding substances, sources of low oxygen content (anoxic) water, such as groundwater and water draining from wetlands, can also reduce the DO concentration of a stream reach. This source could be classified as background.

A list of sources of low DO may include:

- CBOD
- NBOD
- SOD
- Nitrogen
- Phosphorus
- Anoxic water
- Algal respiration

3.6.2.1 Potential Drivers

The observed DO data in Buffalo Creek suggests that DO was not flow driven, since values below 5 mg/L occurred in all flow zones (Figures 3-10 and 3-11). This indicates that low DO is a chronic condition and driven by a persistent condition in the system. Figure 3-12 shows BOD5 samples plotted in a flow duration curve. These data indicate the BOD5 levels do not appear to significantly increase during higher flow runoff related events. Similarly, total Kjeldahl nitrogen (TKN) and TP samples plotted with the flow duration curve (Figures 3-13 and 3-14) show that TKN and TP also did not consistently increase with high flow. Peak Chl-*a* values were observed in the mid to high flow zone (Figure 3-15).

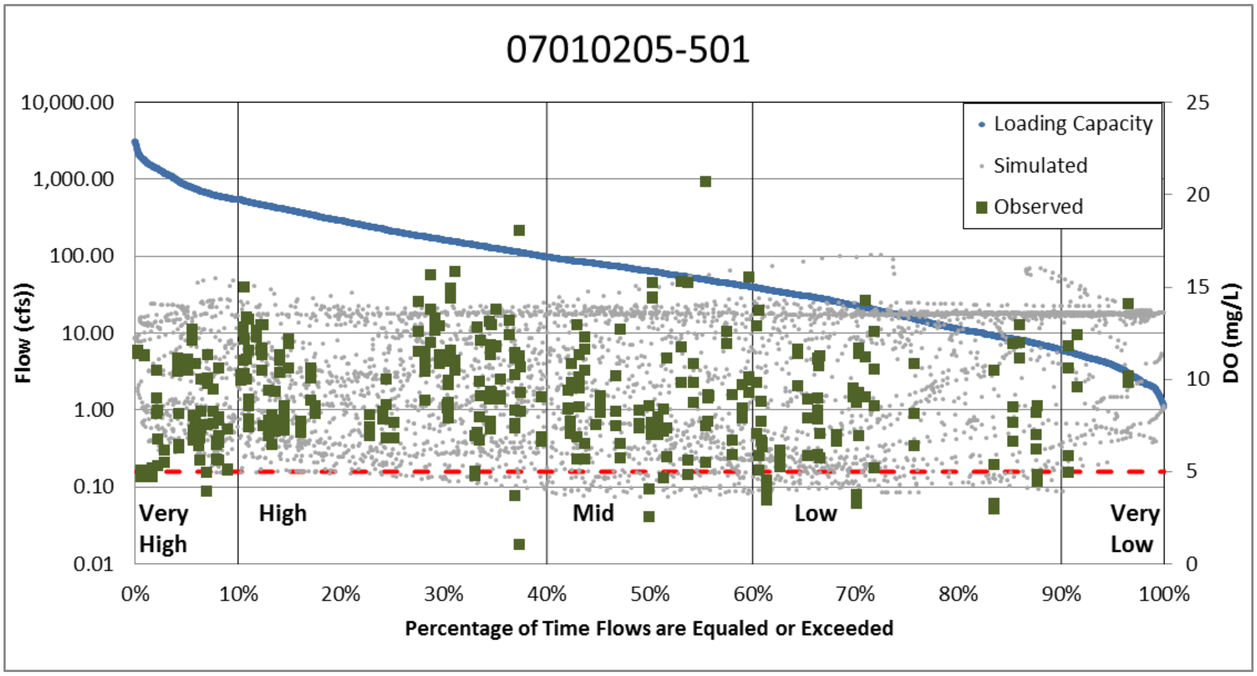

Figure 3-10. All dissolved oxygen samples in Buffalo Creek plotted on flow duration curve. The red dashed line indicates the 5 mg/L DO standard. Simulated DO values represent the daily minimum dissolved oxygen values.

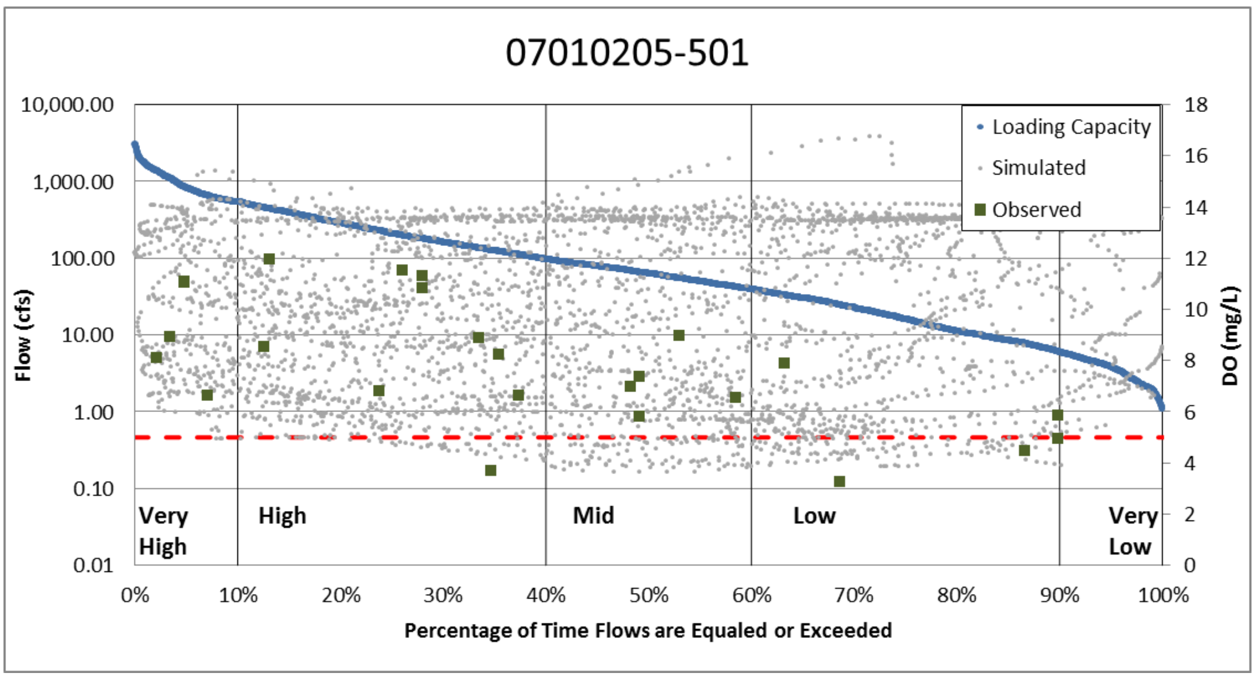

Figure 3-11. Dissolved oxygen samples taken before 9:00 a.m. in Buffalo Creek plotted on flow duration curve. The red dashed line indicates the 5 mg/L DO standard. Simulated DO values represent the daily minimum dissolved oxygen values.

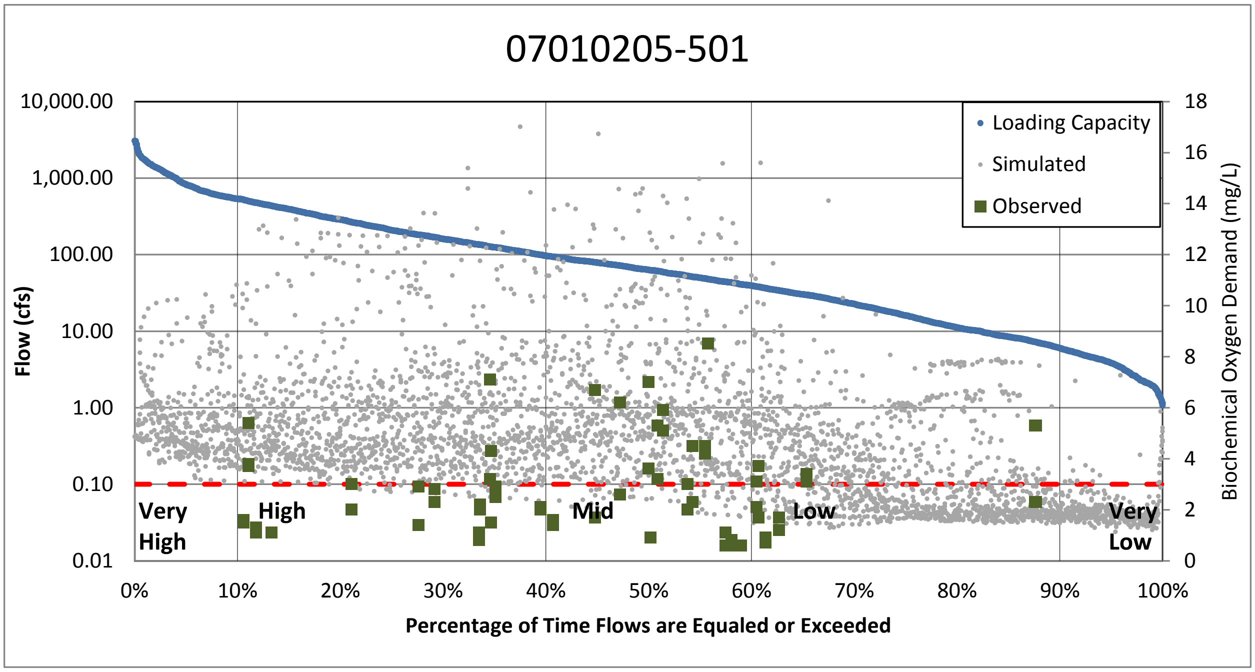

Figure 3-12. BOD5 samples in Buffalo Creek plotted on flow duration curve. The red dashed line indicates the 3 mg/L proposed BOD5 standard. Simulated BOD5 represent the daily average values.

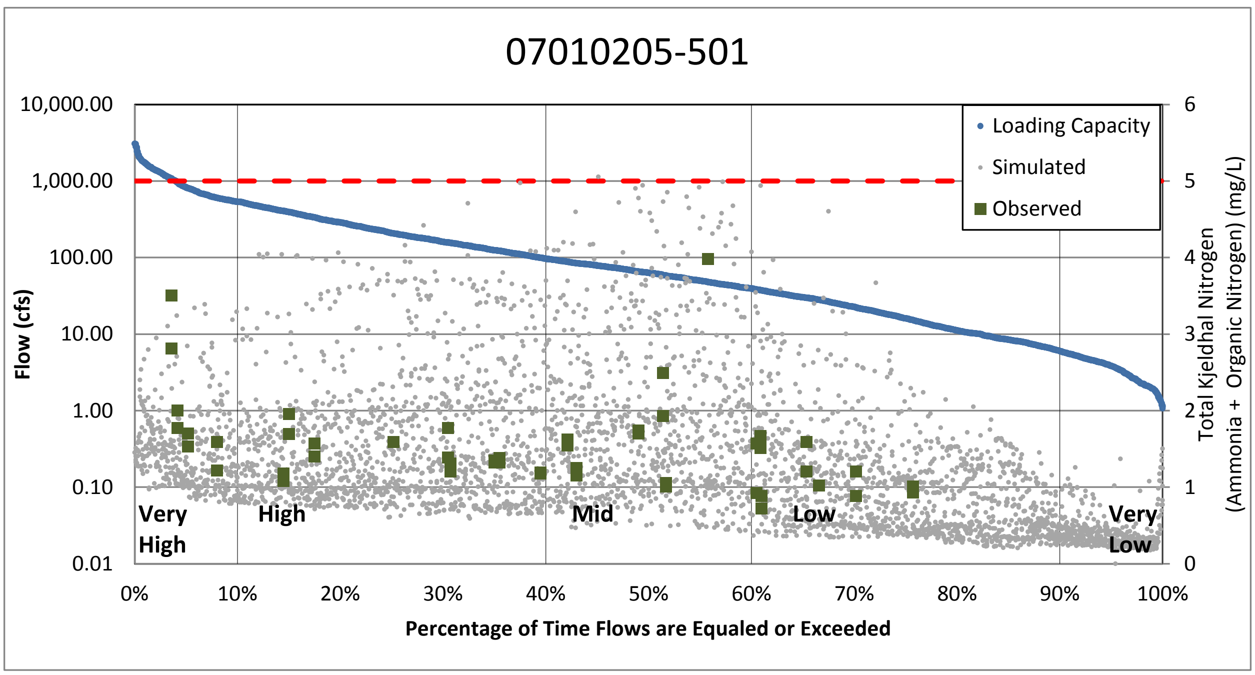

Figure 3-13. TKN samples in Buffalo Creek plotted on flow duration curve. Simulated TKN values represent the daily average values.

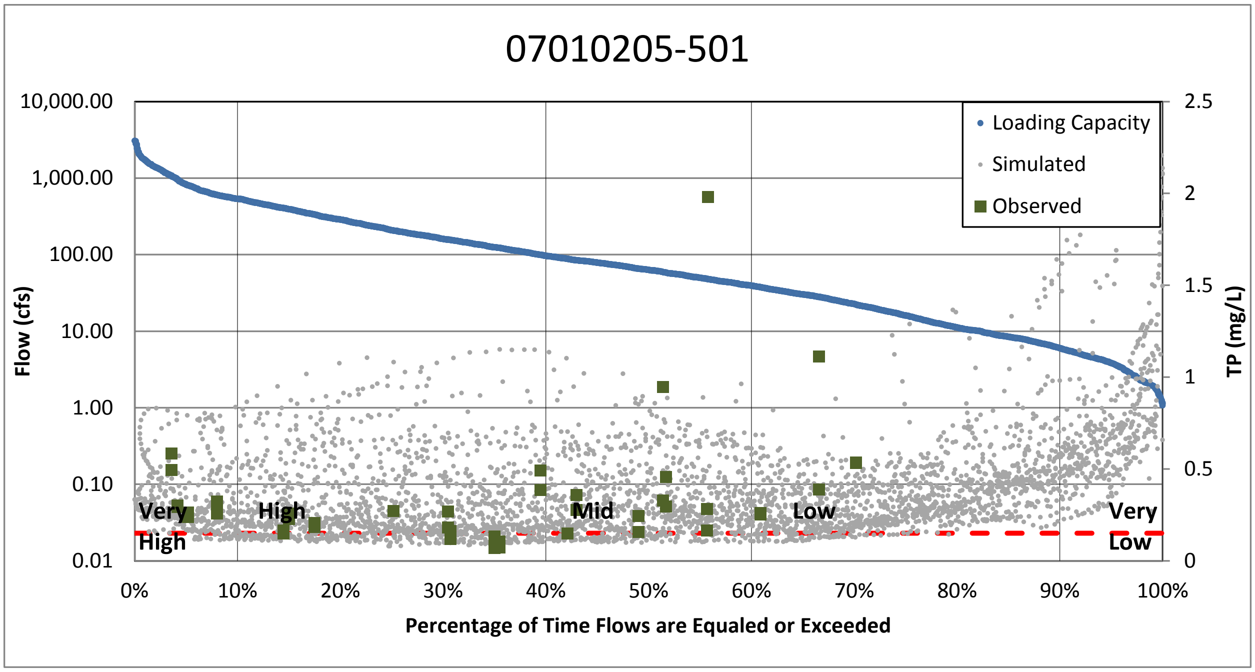

Figure 3-14. TP samples in Buffalo Creek plotted on flow duration curve. The red dashed line indicates the .015 mg/L proposed TP standard. Simulated TP values represent the daily average values.

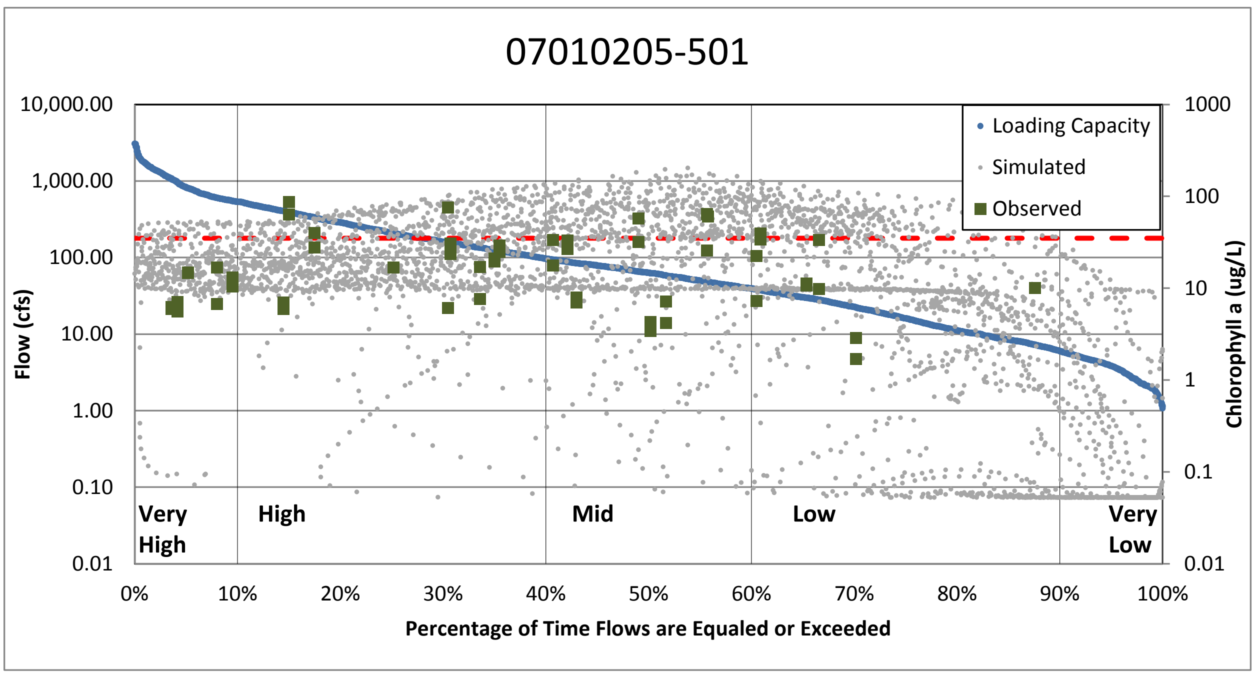

Figure 3-15. Chlorophyll-a samples in Buffalo Creek plotted on flow duration curve. The red line indicates the 35 mg/L chlorophyll a standard. Simulated chlorophyll a values represent the daily average values.

3.6.2.2 Oxygen Demand

For the South Branch Crow River Low DO TMDL, it has been determined that SOD, CBOD, and NBOD are the significant sources contributing to the low DO impairment.

General rules of thumb based on stoichiometry are:

- 2.7 mg of oxygen is required to completely stabilize every mg of carbon

- 3.43 mg of oxygen is required to completely stabilize every mg of ammonia-nitrogen
  - ($NH_4^+ + 3/2O_2 \rightarrow 2H^+ + H_2O + NO_2^-$)
- 1.14 mg of oxygen is required to completely stabilize every mg of nitrate-nitrogen
  - ($NO_2^- + 1/2O_2 \rightarrow NO_3^-$)

The SOD can be a key contributor to low DO concentrations in streams, and results in the removal of oxygen from overlying waters from the decomposition of settled organic matter. As a result, stream SOD is an expression of the watershed loss of oxygen within streams due to aerobic decay of organic materials, enriched organic substrates in ditches/artificial drainage systems and discharges from wetlands and lakes. SOD rates are defined in units of oxygen used per surface area per day ($g\text{-}O_2/m^2/day$). Higher SOD rates are typically associated with eutrophic systems with values exceeding 5 $g\text{-}O_2/m^2/day$. This degradation of organic material can also result in the release of phosphorus into overlying waters (USACE 1994). Extreme oxygen consumption without replacement by reaeration or primary production may create hypoxic or anoxic conditions that can result in fish kills, invertebrate mortality and species displacement. Seasonality has been noted as an important factor affecting SOD rates with warmer temperatures accelerating chemical reaction rates.

Several factors affect SOD. Primary focus is often given to the biological components such as organic content of the benthic sediment and microbial concentrations. Three of the most important parameters affecting SOD, as described in the literature, are temperature near the sediment-water interface, stream depth (Ziadat and Berdanier 2004), and the overlying water velocity (Truax et al. 1995). Specifically, SOD increases linearly with velocity at low velocities (<10 cm/s), but becomes independent at high velocities (Makenthun and Stefan 1998). Ziadat and Berdanier (2004) found that depth was the most important hydrologic variable effecting SOD in Rapid Creek, South Dakota. The base SOD rate changes throughout the year due to multiple factors including: DO concentration in the water column, seasonal benthic population changes, mixing rate of the overlying water, presence of toxic chemicals, and changes in temperature.

Key factors affecting SOD rates in Buffalo Creek are the sediment organic content, temperature at the sediment/water interface, steam depth and velocity. As Buffalo Creek is a shallow system, ambient temperatures increase in the summer growing season where there are low flows with low stream velocities, which can increase the biologic activity and oxygen consumption at the sediment-water interface with minimal reaeration from water movement.

Closely associated with SOD are oxygen demand terms and methodologies borrowed from wastewater treatment for BOD5 or BOD five-day laboratory method, which is represented as the sum of carbonaceous and nitrogenous oxygen demands. CBOD represents the oxygen equivalent (amount of oxygen) that microorganisms require to breakdown and convert organic carbon to CO_2 from carbonaceous organic matter. A second source is NBOD. A wide variety of micro-organisms rapidly transform organic nitrogen (ON) to ammonia nitrogen (NH_3-N). Bacteria then transform NH3-N to nitrate through an oxygen consuming process called nitrification. While these laboratory measures from sampled waters are appropriate, they do not adequately describe the cumulative oxygen depletions from upland ditches, drained wetlands and eutrophic lakes. Hence, a variety of SOD measurement methodologies employ a variety of in-situ and laboratory core measurements. Lacking these assessments, alternative evaluations will be employed to approximate SOD. It is important to note that stream eutrophication standards were recently adopted for TP (150 µg/L), Chl-*a* (seston) (35 µg/L), diel DO flux (4.5 mg/L), and biochemical oxygen demand (BOD_5) (3 mg/L).

Water quality and flow data from the HSPF model were used to evaluate oxygen demands from CBOD, NBOD, and SOD to the DO impaired reach of Buffalo Creek. The impact to DO loads from reaeration, oxygen demand (BOD decay, reach SOD, and NOD), phytoplankton, and benthic algae is shown in Figure 3-16.

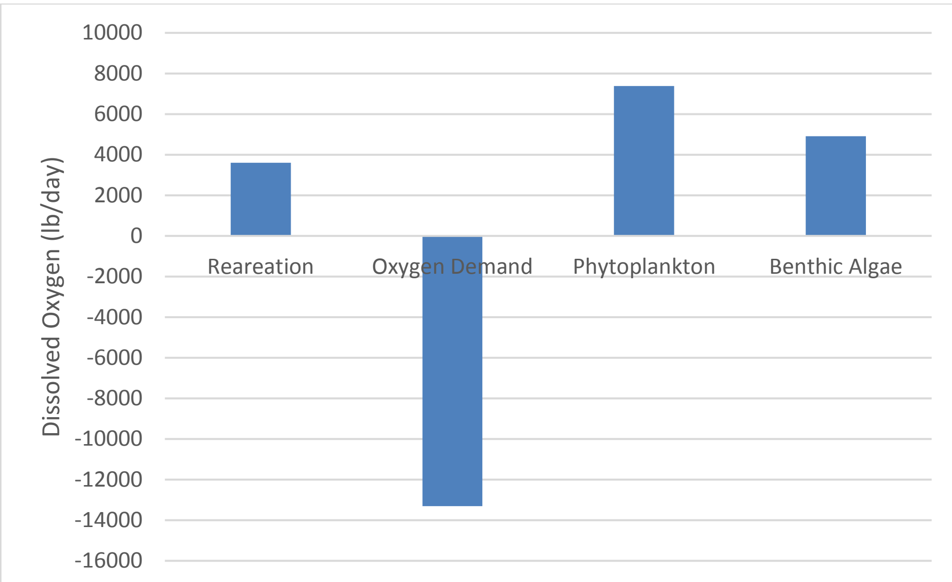

Figure 3-16. HSPF modeled drivers of dissolved oxygen in Buffalo Creek (AUID 07010205-501).

The current oxygen demands (SOD, BOD, and NOD) were calculated within the HSPF model. A model output variable is the total oxygen demand, which was summed for the entire simulation period for the seven listed model reaches within the impaired reach (07010205-501). Total oxygen demand was reduced by 57% in the model until 95% compliance was achieved with the standard of a daily minimum DO concentration of 5 mg/L.

Source assessment modeling results were summarized using the following categories: cropland, point sources, urban, pasture/rangeland, septic, and other. The “other” category includes feedlot, forest, groundwater, and wetland. The “other” category makes up less than 1% of overall sources of TKN and BOD for all impaired reaches. Pie charts, shown in Figure 3-17, were produced at the Buffalo Creek TMDL endpoint for each source. Cropland was the dominant source of both TKN and BOD, as it contributed to approximately 93% of the load of each. All other sources accounted for less than 3% of the total load individually. It is important to note that because much of the feedlot manure is spread on local cropland, feedlot loads in the HSPF model application source pie-charts are accounted for in the cropland category as opposed to the feedlot category. The HSPF model was used to determine the contribution of oxygen demanding substances from identified sources in the South Fork Crow River Watershed.

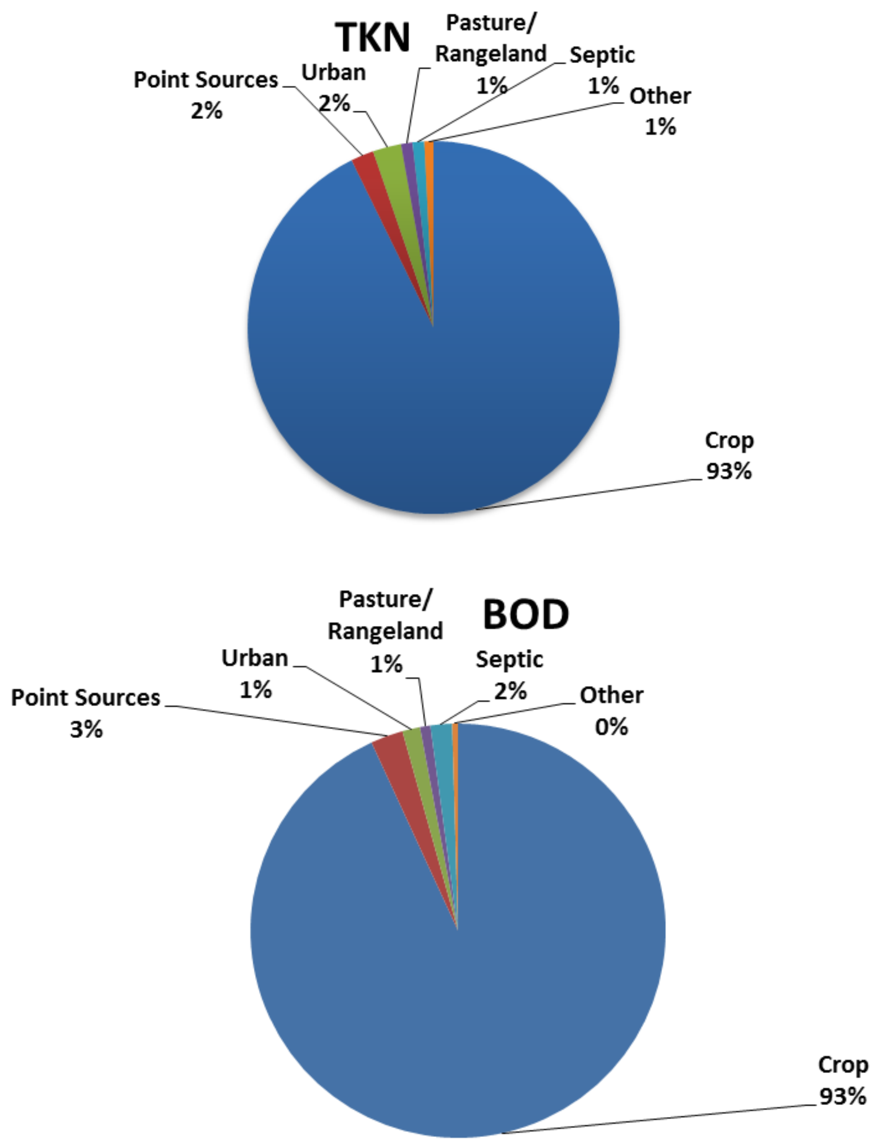

Figure 3-17. Oxygen Demand Source Assessment Modeling Results Within the South Fork Crow River Watershed.

3.6.3 Bacteria

Bacteria loading can occur from both permitted and non-permitted sources. Permitted sources of bacteria can include industrial wastewater effluent, municipal WWTP effluent, and municipal stormwater runoff. Review of the impaired reaches indicates that there are three active permitted wastewater dischargers in the JD15 reach (513) watershed and four active wastewater dischargers in the South Fork Crow River impaired reach (508) watershed (Figure 1-1). There are also eight dischargers in the reach 508 watershed, which are located in the Buffalo Creek Watershed that were addressed and allocated as part of the Buffalo Creek Bacteria TMDL (Wenck Associates 2013). In addition to the permitted wastewater dischargers, there are nine MS4s that have at least a portion of their boundary within the bacteria impaired reach watersheds.

There are currently 15 National Pollutant Discharge Elimination System (NPDES) permitted feedlot operations in the South Fork Crow River Watershed (Figure 3-18). A feedlot owner is required to apply for an NPDES feedlot permit when a new or expanding facility will have a capacity of 1,000 animal unit (AUs) or more; or if it meets or exceeds the EPA Large Concentrated Animal Feeding Operation (CAFO) threshold. There are also several smaller, non-NPDES registered feedlot operations in the South Fork Crow River Watershed.

Runoff from homes, pastures, and other areas has the potential to transport bacteria from pets and livestock animals to surface water. Failing or nonconforming septic systems, or subsurface sewage treatment systems (SSTS) near waterways can also be a source of bacteria to streams, especially during low flow periods when these sources continue to discharge and runoff driven sources are not active. Currently, the exact number and status of SSTSs in the South Fork Crow River Watershed is unknown. The MPCA's 10-year plan to upgrade and maintain Minnesota's On-Site Treatment Systems (MPCA 2013) includes some general information regarding the performance of SSTSs in the South Fork Crow River Watershed. This study provides county annual reports from 2012 that include estimated failure rates for each county in the state of Minnesota. The report differentiates between systems that are generally failing and those that are an imminent threat to public health and safety (ITPHS).

It has been suggested that *E. coli* bacteria has the capability to reproduce naturally in water and sediment, and therefore should be taken into account when identifying bacteria sources. Two Minnesota studies describe the presence and growth of "naturalized" or "indigenous" strains of *E. coli* in watershed soils (Ishii et al. 2006), and ditch sediment and water (Sadowsky et al. 2010). The latter study, supported with Clean Water Land and Legacy funding, was conducted in the Seven Mile Creek Watershed, an agricultural landscape in southwest Minnesota. DNA fingerprinting of *E. coli* from sediment and water samples collected in Seven Mile Creek from 2008 through 2010 resulted in the identification of 1,568 isolates comprised of 452 different *E. coli* strains. Of these strains, 63.5% were represented by a single isolate, suggesting new or transient sources of *E. coli*. The remaining 36.5% of strains were represented by multiple isolates, suggesting persistence of specific *E. coli*. Discussions with the primary author of the Seven Mile Creek study suggest that while 36% might be used as a rough indicator of "background" levels of bacteria at this site during the study period, this percentage is not directly transferable to the concentration and count data of *E. coli* used in water quality standards and TMDLs. Additionally, because the study is not definitive as to the ultimate origins of this bacteria, it would not be appropriate to consider it as "natural" background. Finally, the author cautioned about extrapolating results from the Seven Mile Creek Watershed to other watersheds without further studies.

A bacteria accounting exercise was performed to estimate the total amount of bacteria produced within the direct drainage area of each impaired reach. The accounting exercise uses available livestock, geographic information systems (GIS), human and pet populations, wildlife population, septic data and literature rates from various studies/sources to estimate bacteria production in each watershed. The purpose of this exercise was to compare the number of bacteria generated by each source to aid in focusing implementation activities. A similar inventory was conducted as part of the Buffalo Creek Bacteria TMDL (Wenck Associates 2013) and therefore the inventory for reach 508 does not include this portion of the watershed. The source inventory for reach 508 also does not include the Headwaters, Hutchinson, and Lester Prairie South Fork Crow River Major subwatersheds since there are currently no bacteria impairments in these subwatersheds. Tables 3-9 and 3-10 below provide a general source assessment summary for each reach based on the watershed bacteria accounting exercise.

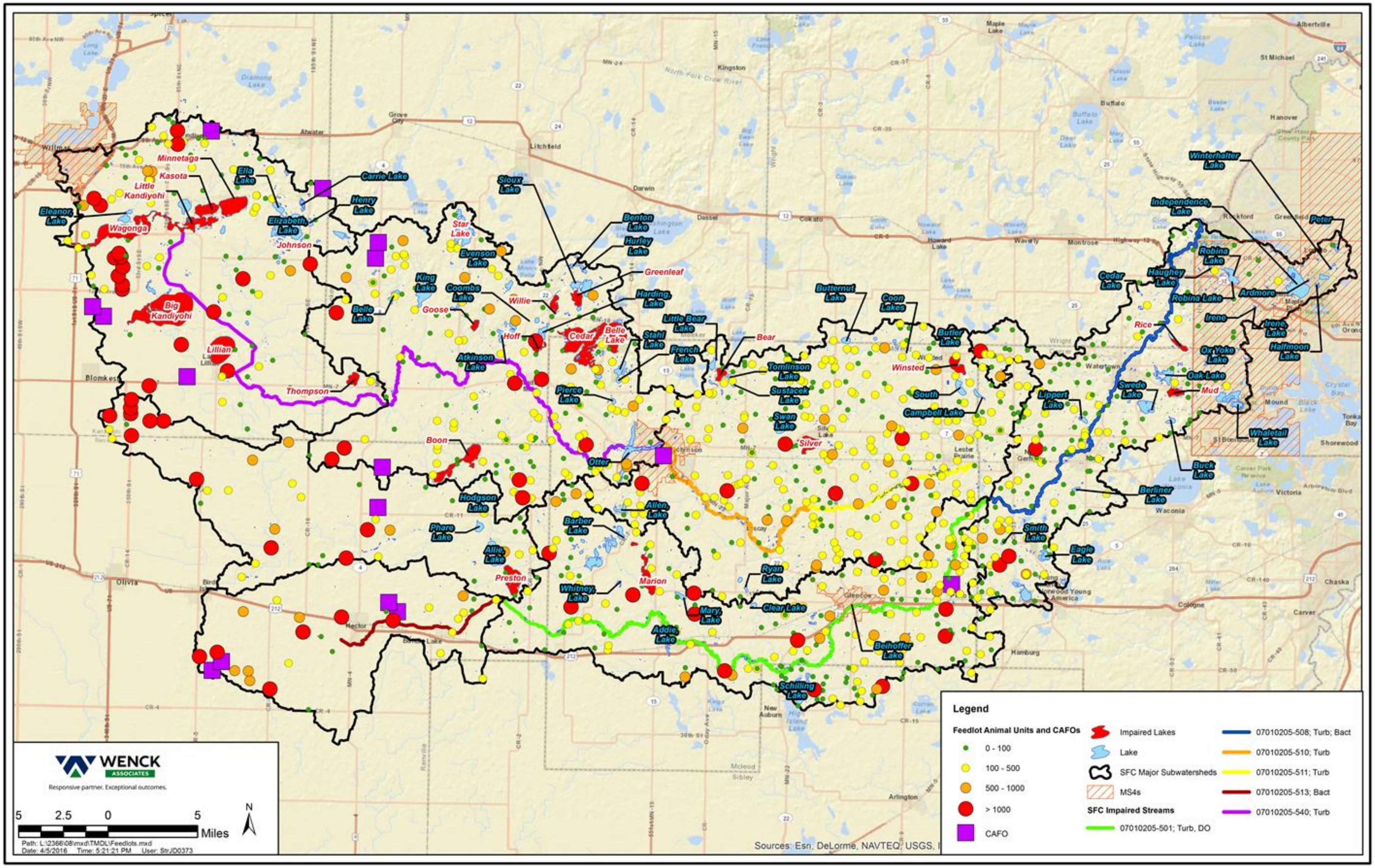

Figure 3-18. MPCA registered feedlots in the South Fork Crow River Watershed.

Table 3-9. Bacteria production in the JD15 bacteria impaired reach (513) 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 Month [Billions of Org.]	Total Bacteria Produced Per Month by Major Category [Billions of Org.]	Percent by Category
Livestock (1)	Horses (Animal Units)	17	58	29,700	12,182,300	99.0%
	Cattle (Animal Units)	1,584	74	4,476,800		
	Chicken/Turkeys (Animal Units)	1,176	21	723,200		
	Swine	7,087	33	6,952,600		
Wildlife	Deer (3)	597	0.5	9,000	12,800	0.1%
	Waterfowl (4)	995	0.4	11,900		
Human	Failing Septic Systems (5)	133	2	7,980	8,160	<0.1%
	WWTP effluent (6)	3	2	180		
Domestic Animals (2)	Improperly Managed Pet Waste (7)	758	4	102,300	102,300	0.8%

(1) Livestock animal units estimated based on MPCA registered feedlot database
(2) Calculated based on # of households in watershed multiplied by 0.58 dogs/ household and 0.73 cates/household according to the Southeast Minnesota Regional TMDL (MPCA, 2012)
(3) Assumes average deer density of 6 deer/mi2 (DNR Willmar Office, personal communication)
(4) Estimated from the DNR and U.S. Fish & Wildlife Service 2011 Waterfowl Breeding Population Survey (Minnesota DNR, 2011)
(5) Based on county SSTS inventory failure rates (MPCA, 2013) and rural population estimates
(6) 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, 2012). Values have been reported to two significant digits.

Table 3-10. Bacteria production in the South Fork Crow River Subwatershed that drains directly to reach 508.

Major Category	Source	Animal Units or Individuals in Subwatershed	Bacteria Organisms Produced Per Unit Per Day [Billions of Org.] (8)	Total Bacteria Produced Per Month [Billions of Org.]	Total Bacteria Produced Per Month by Major Category [Billions of Org.]	Percent by Category
Livestock (1)	Horses (Animal Units)	715	58	1,248,400	28,243,300	93.5%
	Cattle (Animal Units)	11,979	74	25,472,300		
	Chicken/Turkeys (Animal Units)	4	21	2,500		
	Swine	1,550	33	1,520,100		
Wildlife	Deer (3)	1,048	0.5	15,700	36,700	0.1%
	Waterfowl (4)	1,746	0.4	21,000		
Human	Failing Septic Systems (5)	375	2	22,500	22,860	<0.1%
	WWTP effluent (6)	6	2	360		
Domestic Animals (2)	Improperly Managed Pet Waste (7)	14,060	4	1,898,000	1,898,000	6.3%

(1) Livestock animal units estimated based on MPCA registered feedlot database
(2) Calculated based on # of households in watershed multiplied by 0.58 dogs/ household and 0.73 cates/household according to the Southeast Minnesota Regional TMDL (MPCA 2012)
(3) Assumes average deer density of 6 deer/mi2 (DNR Willmar Office, personal communication)
(4) Estimated from the DNR and U.S. Fish & Wildlife Service 2011 Waterfowl Breeding Population Survey (Minnesota DNR 2011)
(5) Based on county SSTS inventory failure rates (MPCA 2013) and rural population estimates
(6) 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 2012). Values have been reported to two significant digits.

3.6.4 Nutrients

A key component to developing a nutrient TMDL is understanding the sources contributing to the impairment. This section provides a brief description of the potential permitted and non-permitted sources contributing to excess nutrients to the impaired lakes in the South Fork Crow River Watershed. Section 4.6 of this report will discuss the major pollutant sources and how they were quantified using monitoring data and water quality modeling. The information presented here and in the upcoming sections together will provide information necessary to both assess the existing contributions of pollutant sources and target pollutant load reductions.

Phosphorus loading from a lake's watershed can come from a variety of sources such as fertilizer, manure, and the decay of organic matter. Wind and water action erode the soil, detaching particles and conveying them in stormwater runoff to nearby waterbodies where the phosphorus that comes with the soil becomes available for algal growth (Table 3-11). Organic material such as leaves and grass clippings can leach dissolved phosphorus into standing water and runoff or be conveyed directly to waterbodies where biological action breaks down the organic matter and releases phosphorus.

Table 3-11. Potential permitted sources of phosphorus.

Permitted Source	Source Description	Phosphorus Loading Potential
Phase II Municipal Stormwater NPDES/SDS General Permit	Municipal Separate Storm Sewer Systems (MS4s)	Potential for runoff to transport sediment, grass clippings, leaves, and other phosphorus-containing materials to surface water through a regulated MS4 conveyance system.
Construction Stormwater NPDES/SDS General Permit	Permits for any construction activities disturbing: 1) One acre or more of soil, 2) Less than one acre of soil if that activity is part of a "larger common plan of development or sale" that is greater than one acre or 3) Less than one acre of soil, but the MPCA determines that the activity poses a risk to water resources.	The EPA estimates a soil loss of 20 to 150 tons per acre per year from stormwater runoff at construction sites. Such sites vary in the number of acres they disturb.
Multi-sector Industrial Stormwater NPDES/SDS General Permit	Applies to facilities with Standard Industrial Classification Codes in ten categories of industrial activity with significant materials and activities exposed to stormwater.	Significant materials include any material handled, used, processed, or generated that when exposed to stormwater may leak, leach, or decompose and be carried offsite.

Table 3-12 describes several phosphorus sources that are not regulated by the NPDES program. For many lakes, especially shallow lakes, internal sources can be a significant portion of the TP load. Under anoxic conditions at the lake bottom, weak iron-phosphorus adsorption bonds on sediment particles break, releasing phosphorus into the water column in a form highly available for algal uptake. In many lakes, high internal loading rates are the result of a large pool of phosphorus in the sediment that has accumulated over several decades of watershed loading to the lake. Thus, even if significant watershed load reductions have been achieved through best management practices (BMPs) and other efforts, internal loading from the sediment can remain high and in-lake water quality may not improve. Carp and other rough fish uproot aquatic macrophytes during feeding and spawning and re-suspend bottom sediments, releasing phosphorus and decreasing water clarity. Some aquatic vegetation species such as invasive curly-leaf pondweed can outcompete and suppress native vegetation species. Curly-leaf begins its growth cycle earlier in the season compared to other species and typically dies back in mid-summer.

As a result, lakes with heavy curly-leaf pondweed infestation can have little or no submerged vegetation by late summer. This can cause lower DO levels, increased sediment re-suspension and phosphorus release from sediment. Eurasian watermilfoil, which is present in many lakes throughout Minnesota, is not a phosphorus source, but is an invasive that can also out-compete native vegetation and negatively impact recreational use of lakes.

Table 3-12. Potential non-permitted sources of phosphorus.

Non-Permitted Source	Source Description
Atmospheric Phosphorus Loading	Precipitation and dryfall (dust particles suspended by winds and later deposited).
Watershed Phosphorus Export	Variety in land use (see Table 3-3) creating both rural and urban stormwater runoff that does not pass through a regulated MS4 conveyance system.
Internal Phosphorus Release	Release from lake bottom sediments during periods of low dissolved oxygen; release from aquatic vegetation during senescence and breakdown.
Failing SSTS	SSTS failures on lakeshore homes can contribute to lake nutrient impairments.

A general summary of the nutrient sources to each impaired lake in the South Fork Crow River Watershed is provided in Table 3-13. Estimates of each source and how they were calculated are discussed in Section 4.6.

Table 3-13. Nutrient source summary for each of the impaired lakes in the South Fork Crow River Watershed. DNR Lake survey reports (if available) were reviewed to assess the vegetation and fish communities for each lake.

		Watershed Sources				Internal Sources					
Major Subwatershed	**Lake Name**	**Agriculture**	**Urban**	**SSTS**	**WWTPs**	**Sediment Release**	**Historic Impacts (i.e. WWTP discharge)**	**Aquatic Vegetation**	**Rough Fish (i.e. Carp) (2)**	**Upstream Lakes**	**Notes**
Lester Prairie - SFC	Bear	●		○		●					
Hutchinson - SFC	Belle	●		○		●			Δ	○	Low amount of carp and black bullhead biomass in most recent fisheries survey
Headwaters - SFC	Big Kandiyohi	○		○		●			Δ	●	Large number of both carp and black bullhead surveyed in most recent fisheries survey
Lester Prairie - SFC	Boon	●		○		●					
Hutchinson - SFC	Cedar	●		○		●		Δ	Δ	○	Large number of both carp and black bullhead surveyed in most recent fisheries survey. Curly-leaf pondweed identified in most recent survey.
Hutchinson - SFC	Greenleaf	●		○		●					Large number of both carp and black bullhead surveyed in most recent fisheries survey
Hutchinson - SFC	Goose	●		○		●					
Hutchinson - SFC	Hoff	●	○	○		○				●	
Headwaters - SFC	Johnson	●		○		●					
Headwaters - SFC	Kasota	●		○		●				●	
Headwaters - SFC	Lillian	○				○				●	Large number of both carp and black bullhead surveyed in most recent fisheries survey
Headwaters - SFC	Little Kandiyohi	○		○		●				●	
Buffalo Creek	Marion	●	○	○		○			Δ		High biomass of carp and black bullhead identified on most recent fisheries survey. No Curly-leaf pondweed identified
Headwaters - SFC	Minnetaga	●				●			Δ		Large number of both carp and black bullhead surveyed in most recent fisheries survey
SFC River	Mud	●	○	○		○				○	
Judicial Ditch 28A	Preston	●		○		○				●	Large number of carp identified in most recent fisheries survey
SFC River	Rice	●	○	○		●				●	
Lester Prairie - SFC	Silver	○	○	○		●					
Hutchinson – SFC	Star										
Headwaters - SFC	Thompson	●		○		○					
Headwaters - SFC	Wakanda	●		○		●					Large number of both carp and black bullhead surveyed in most recent fisheries survey
Hutchinson - SFC	Willie	●		○		○				○	Low amount of carp and black bullhead biomass in most recent fisheries survey
Lester Prairie - SFC	Winsted	●	○	○		●		Δ		○	Large number of both carp and black bullhead surveyed in most recent fisheries survey. Curly-leaf pondweed identified in most recent survey.

● Primary Source ○ Secondary Source Δ Potential Source (Unknown Level of Impact)

4 TMDL Development

4.1 Modeling Approach

The HSPF model was used to develop many of the flow and water quality load estimates used to develop the TMDLs presented in this study. HSPF is a comprehensive watershed model of hydrology and water quality that includes modeling land surface and subsurface hydrologic and water-quality processes, which are linked and closely integrated with corresponding stream, wetland and reservoir processes. The HSPF model applications can be used to determine critical environmental conditions (e.g., low/high flows or seasons) for the impaired segments by providing continuous flow and concentration predictions at any point in the system. Multiple memos are available which discuss modeling methodologies, data used, and calibration results in the South Fork Crow Watershed in great detail [RESPEC, 2011a, 2011b, 2011c, 2011d, 2011e, 2011f, 2012, 2015].

An HSPF basin runoff model was developed in 2011/2012 and updated in 2015 for the Crow River Watershed, including South Fork Crow River. The model application predicts the range of flows that have historically occurred in the modeled area, the load contributions from a variety of point and nonpoint sources in a watershed, and the source contributions when paired flow and concentration data are limited.

The primary components of developing an HSPF model application include:

- gathering and developing time-series data,
- characterizing and segmenting the watershed,
- calibrating and validating the model,
- quality assurance review.

4.2 Gathering and Developing Time-Series Data

Data requirements for developing and calibrating an HSPF model application are both spatially and temporally extensive. The model evaluation period was from 2000 through 2013. Time-series data used in developing the model application included meteorological, atmospheric deposition, and point-source data. Precipitation, potential evapotranspiration, air temperature, wind speed, solar radiation, dew-point temperature, and cloud cover data are used in HSPF to simulate hydrology (including snow processes).

4.3 Segmenting and Characterizing the Watershed

The project area was delineated into 79 subwatersheds to capture hydrologic and water-quality variability. Then, the watershed was segmented into individual land and channel pieces that are based on relatively homogeneous hydrologic, hydraulic, and water-quality characteristics. This segmentation provides the basis for assigning similar inputs and parameter values or functions to portions of a land area or channel length contained in a model segment. The individual land and channel segments are linked together to represent the entire project area.

The watershed land segmentation was defined by land cover, soil class, and slope. Land cover, soil class, and slope affect the hydrologic and water-quality response of a watershed through their impact on infiltration, surface runoff, and water losses from evapotranspiration. Land use affects the rate of the accumulation of pollutants because certain land uses often support different pollutant sources.

Land cover categories (based on the National Land Cover Dataset, NLCD) were aggregated into groups with similar characteristics. The urban categories were divided into pervious and impervious areas based on an estimated percentage of effective impervious area (EIA). The term "effective" implies that the impervious region is directly connected to a local hydraulic conveyance system (e.g., open channel and river), and the resulting overland flow will not run onto pervious areas but will rather directly enter the reach network.

River channel segmentation considers river travel time, riverbed slope continuity, temporal and spatial cross section and morphologic changes or obstructions, tributary confluence, impaired reaches, and locations of flow and water quality calibration and verification gages. After the reach network was segmented, the hydraulic characteristics of each reach were computed and the areas of the land cover categories that drain to each reach were calculated. Reach hydraulics were specified by a reach function table (F-table), which is an expanded rating curve that contains the reach surface area, volume, and discharge as functions of depth. F-tables were developed for each reach segment by using channel cross-sectional data. Unsurveyed tributaries were assigned the geometry of hydraulically similar channels.

4.4 Calibrating and Validating the Model

Hydrologic and water-quality calibrations were performed by comparing observed flow and water-quality data to simulated conditions. Because water-quality simulations were based on watershed hydrology, the hydrology calibration was completed first, followed by sediment, temperature, and finally TP, nitrogen, chlorophyll and DO calibrations. Stream discharge sites with time-series monitoring data were used for calibration and validation. Data from all but the first year of the simulation period were used to calibrate the model. The model simulated the conditions in 1999 (one year prior to the model period) to allow it to adjust to existing conditions. The 13-year simulation period covered a range of dry years (2000, 2003, 2006, and 2008) and wet years (2002, 2005, and 2010). This range improved the model calibration and validation and provided an application that can simulate hydrology and water quality during a broad range of recently observed climatic conditions.

Hydrologic calibration is an iterative process intended to match simulated flow to observed flow by methodically adjusting model parameters. The HSPF hydrologic calibration is divided into four sequential phases of adjusting parameters to improve model performance:

- annual runoff,
- seasonal or monthly runoff,
- low- and high-flow distribution,
- individual storm hydrographs.

By iteratively adjusting calibration parameters within accepted ranges, the simulation results are improved until an acceptable comparison of simulated results and measured data is achieved. The procedures and parameter adjustments involved in these phases are more completely described in Donigian et al. [1984] and Lumb et al. [1994].

The hydrology calibration was evaluated using a weight-of-evidence approach based on a variety of graphical comparisons and statistical tests. The performance criteria are described in more detail in Donigian [2002]. Graphical comparisons included monthly and average flow volume comparisons, daily time-series data comparisons, and flow duration plots. Statistical tests included annual and monthly runoff errors, low-flow and high-flow distribution errors, and storm volume and peak flow errors.

The water quality calibration optimized alignment between the loads from simulated land uses and observed in-stream concentrations. Water-quality data from monitoring sites were used to calibrate the model to observed conditions. To calibrate under baseflow conditions, adjustments are typically made to parameters that represent continuous discharges, not dependent on transport via runoff mechanisms, (i.e., direct sources). To calibrate over the range of wet and dry watershed runoff conditions, parameters that relate to land use build up and washoff processes are adjusted. More detail information on the HSPF model application and model calibration results (hydrology and water quality) can be found in Model Extension and Recalibration for South Fork Crow River Watershed Model Application [RESPEC 2015].

4.5 Load Duration Curve Approach

Pollutant loading capacity for the impaired stream reaches were developed using duration curves. The LDCs incorporate flow and water quality across stream flow regimes and provide loading capacities and a means of estimating load reductions necessary to meet water quality standards. To develop the LDCs, HSPF simulated average daily flow values for each reach from 2000 through 2013 were multiplied by the appropriate water quality standard and converted to daily loads to create “continuous” LDCs. For the purposes of this TMDL, the baseline year for implementation will be 2007, which represents the mid-range year of the HSPF flow record used to construct the LDCs (See section 8.2). The LDCs presented throughout this report were divided into flow zones including very high (0% to 10%), high (10% to 40%), mid (40% to 60%), low (60% to 90%), and very low (90% to 100%) flow conditions. For simplicity, only the median (or midpoint) load of each flow zone is used to show the TMDL equation components in the TMDL tables. However, it should be understood that the entire curve represents the TMDL and is what is ultimately approved by the EPA.

4.6 Natural Background Considerations

Natural background conditions refer to inputs that would be expected under natural, undisturbed conditions. Natural background sources can include inputs from natural geologic processes such as soil loss from upland erosion and stream development, atmospheric deposition, and loading from forested land, wildlife, etc. For each impairment, natural background levels are implicitly incorporated in the water quality standards used by the MPCA to determine/assess impairment and therefore natural background is accounted for and addressed through the MPCA’s waterbody assessment process. Natural background conditions were also evaluated, where possible, within the modeling and source assessment portion (Section 3.6) of this study. These source assessment exercises indicate natural background inputs are generally low compared to livestock, cropland, streambank, urban stormwater, WWTFs, failing SSTSs and other anthropogenic sources.

Based on the MPCA’s waterbody assessment process and the TMDL source assessment exercises, there is no evidence at this time to suggest natural background sources are a major driver of any of the impairments and/or affect their ability to meet state water quality standards. For all impairments addressed in this study, natural background sources are implicitly included in the LA portion of the TMDL allocation tables and TMDL reductions should focus on the major anthropogenic sources identified in the source assessment.

4.7 TSS

4.7.1 TSS Allocation Methodology

The LDCs, which represent the allowable daily load under any given flow condition, were used to represent the loading capacity and allocations of each impaired reach. This approach results in a flow-variable target that considers the entire flow regime within the time period of interest. Five flow intervals were identified for each reach, and the loading capacity and allocations were developed for each flow interval zone. The five flow zones were very high (0% to 10%), high (10% to 40%), mid (40% to 60%), low (60% to 90%), and very low (90% to 100%) in adherence to guidance provided by the EPA [2007]. For this TMDL, loading capacities were evaluated at the median and current loads were evaluated at the 90th percentile within each flow zone to be protective of the environment but not overly constrain the allowable loadings.

4.7.2 Loading Capacity Methodology

The LDC method is based on an analysis that encompasses the cumulative frequency of historic flow data over a specified period. Because this method uses a long-term record of daily average flow, virtually the full spectrum of allowable loading capacities is represented by the resulting curve. In the TMDL tables of this report, only five points on the loading capacity curve are depicted (one for each flow zone). However, it should be understood that the entire curve represents the TMDL. The TMDL is the loading capacity of a reach and is the sum of the LA, the WLA, and a margin of safety (MOS), shown in Equation 1.

$$\text{TMDL} = \text{LA} + \text{WLA} + \text{MOS} \qquad \text{(Equation 1)}$$

The LDCs were used to represent the loading capacity. The flow component of the loading capacity curve is based on the HSPF simulated daily average flows (2003 through 2013), and the concentration component is the TSS concentration criteria of 65 mg/L. The loading capacities presented in the TMDL tables are the products of the median simulated flow in each flow zone, the TSS concentration criterion, and a unit conversion factor. There is a very short assessment reach (07010205-512, 3.16 miles) below reach 07010205-511 that is not listed as impaired. However, no TSS data are available in this reach. At the time the HSPF model for the South Fork Crow River was developed (2010), 07010205-511 was not impaired by any modeled constituents, and therefore a model outlet does not exist at the endpoint of this reach. The HSPF model was calibrated at the outlet of 07010205-512. It is assumed that because the entirety of the South Fork Crow River is impaired except this short, dataless reach, that the reach is in fact impaired. Therefore, the TMDL for 07010205-511 is assumed to also address 07010205-512.

4.7.3 Waste Load Allocation Methodology

The WLAs were divided into five primary categories including NPDES permitted wastewater dischargers, industrial dischargers, MS4 stormwater, and NPDES-permitted construction and industrial stormwater. Following is a description of how each WLA was assigned.

4.7.3.1 Permitted Wastewater Dischargers

There are 27 active regulated NPDES wastewater dischargers in the South Fork Crow Watershed that have been assigned TSS effluent limits. Facility maximum daily effluent TSS loads were established and provided by the MPCA and are a function of the facility design flows and permitted TSS concentration limits (Table 4-1). The WLA was calculated as the product of the TSS effluent limit and permitted facility design flow and a unit conversion factor. Continuously discharging municipal WWTF WLAs were calculated based on the average wet-weather design flow, equivalent to the wettest 30-days of influent flow expected over the course of a year. Controlled municipal pond discharge WWTF WLAs were calculated based on the maximum daily volume that may be discharged in a 24-hour period. The WLAs for the permitted wastewater dischargers in Buffalo Creek (07010205-501) and the two most upstream impaired reaches of the South Fork Crow River (07010205-540 and 07010205-510) are based on facility design flow. In these reaches, the portion of the WLAs from permitted wastewater dischargers exceeded the low flow regimes TDLC (less the MOS).

Table 4-1. Permitted TSS allocations for point sources in the South Fork Crow River Watershed.

Impaired Reach AUID	Facility	Permit	Facility Type	Effluent Design Flow (mgd)	Permitted Concentration (mg/L)	Permitted Load (tons/day)	Impaired Reach Point Source WLA
07010205-501	Brownton WWTP	MN0022951	Continuous	0.196	30	0.025	1.9
	Buffalo Lake Advanced Biofuels LLC	MN0063151	Continuous	0.04	30	0.005	
	Buffalo Lake WWTP	MN0050211	Controlled	1.74	45	0.327	
	Gascoyne Materials Handling & Recycling LLC	MN0069612	Periodic/ Seasonal	0.30	30	0.038	
	Glencoe WWTP	MN0022233	Continuous	2.60	30	0.325	
	Hector WWTP	MN0025445	Continuous	0.66	30	0.083	
	Seneca Foods Corp – Glencoe	MN0001236	Continuous	0.45	15	0.028	
	Seneca Foods Corp – Glencoe	MN0001236	Controlled	5.00	45	0.939	
	Stewart WWTP	MNG580077	Controlled	0.841	45	0.158	
07010205-508	Delano WWTP	MN0051250	Continuous	2.20	30	0.275	0.81
	Loretto WWTP	MN0023990	Controlled	0.80	45	0.150	
	Mayer WWTP	MN0021202	Continuous	0.44	30	0.054	
	New Germany WWTP	MN0024295	Controlled	0.38	45	0.071	
	Watertown WWTP	MN0020940	Continuous	1.26	30	0.158	
	Winsted WWTP	MN0021571	Continuous	0.82	30	0.103	
07010205-510	AB Mauri Food Inc.	MNG250099	Continuous	3.00	30	0.376	1.1
	Hutchinson WWTP	MN0055832	Continuous	5.43	30	0.680	
07010205-512	Silver Lake WWTP	MNG580164	Controlled	1.32	45	0.248	0.25
07010205-540	Cedar Mills WWTP	MN0066605	Controlled	0.20	45	0.037	1.5
	Cosmos WWTP	MNG580056	Controlled	0.45	45	0.084	
	Duininck Bros Inc - Aggregate	MNG490046	Periodic/Seasonal	2.60	30	0.325	

Impaired Reach AUID	Facility	Permit	Facility Type	Effluent Design Flow (mgd)	Permitted Concentration (mg/L)	Permitted Load (tons/day)	Impaired Reach Point Source WLA
	Duininck Bros Inc - Aggregate	MNG490046	Periodic/Seasonal	2.60	30	0.325	
	Duininck Bros Inc - Aggregate	MNG490046	Periodic/Seasonal	2.60	30	0.325	
	Duininck Bros Inc - Aggregate	MNG490046	Periodic/Seasonal	2.60	30	0.325	
	Lake Lillian WWTP	MNG580225	Controlled	0.39	45	0.073	
	Lester Prairie WWTP	MN0023957	Continuous	0.36	30	0.046	

4.7.3.2 Permitted MS4s

Multiple regulated MS4s have portions of their municipal boundaries within the South Fork Crow River Watershed (Table 4-2). The percent flow volume that all MS4s were contributing above the endpoint of each reach was calculated using HSPF. It was assumed that the MS4 areas draining to an upstream reach addressed with a TSS TMDL were in compliance with their respective TMDL, and therefore upstream MS4 loads were not reallocated for downstream TSS TMDLs. The percent flow volume contributing, which was derived from the HSPF model application, was then multiplied by the loading capacity in each flow zone after the MOS and NPDES portion of the WLAs were subtracted. The MS4 portion of the WLA allocations in this TMDL are categorical in nature because the HSPF model estimated the percent of flow volume from the MS4 areas above the impaired reach endpoints.

Table 4-2. Wasteload allocations for all MS4 communities that contribute directly to impaired reaches.

Reach	MS4	Permit #	Area (acres)	TSS Standard (mg/L)	Individual TSS MS4 Allocation (Percent of Allowable Load)
Buffalo Creek (07010205-501)	Glencoe City MS4	MS400252	1,967	65	2.1%
South Fork Crow River (07010205-540)	Willmar City MS4	MS400272	2,693	65	2.4%
	Hutchinson City MS4	MS400248	2,319		
South Fork Crow River (07010205-510)	Hutchinson City MS4	MS400248	3,346	65	7.3%
South Fork Crow River (07010205-508)	Corcoran City MS4	MS400081	164	65	22.8%
	Independence City MS4	MS400095	17,981		
	Loretto City MS4	MS400030	68		
	Maple Plain City MS4	MS400103	485		
	Medina City MS4	MS400105	4,397		
	Minnetrista City MS4	MS400106	7,093		

4.7.3.3 Construction and Industrial Stormwater

Construction stormwater is regulated by NPDES permits for any construction activity disturbing a) one acre or more of soil, b) less than one acre of soil if that activity is part of a "larger common plan of development or sale" that is greater than one acre, or c) less than one acre of soil, but the MPCA determines that the activity poses a risk to water resources. The WLA for stormwater discharges from sites where there is construction activities reflects the number of construction sites less than one acre expected to be active in the impaired reach subwatershed at any one time.

A categorical WLA was assigned to all construction activity in the watershed. The average annual acres under construction in each applicable county were available from 2009 through 2015 from the MPCA Construction Stormwater Permit data. The percent of each county in the South Fork Crow Watershed was multiplied by the average annual construction acres for that county to determine the acres under construction in the South Fork Crow River Watershed. Finally, percent of area under construction was determined by dividing total construction acres over total watershed acres. This percentage was multiplied by the portion of the TMDL LA associated with direct drainage to determine the construction stormwater WLA. Average annual construction acres from 2009 through 2015 were determined to occur on 0.06% of the watershed. This was rounded up to 0.1% to represent the construction stormwater WLA to account for future growth. The LAs were reduced by an amount equivalent to the construction stormwater WLA.

The stormwater WLA includes loads from construction stormwater. Loads from construction stormwater are considered to be a small percent of the total WLA and are difficult to quantify. The WLA for stormwater discharges from sites where there are construction activities reflects the number of construction sites one or more acres expected to be active in the watershed at any one time, and the BMPs and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at construction sites are defined in the State's NPDES/State Disposal System (SDS) General Stormwater Permit for Construction Activity (MNR100001). If a construction site owner/operator obtains coverage under the NPDES/SDS General Stormwater Permit and properly selects, installs and maintains all BMPs required under the permit, including those related to impaired waters discharges and any applicable additional requirements found in Appendix A of the Construction General Permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. All local construction stormwater requirements must also be met.

Industrial stormwater is regulated by NPDES permits if the industrial activity has the potential for significant materials and activities to be exposed to stormwater discharges. The number of acres regulated under 2015 industrial permits was available from MPCA Industrial Stormwater Permit data. The percent of each county in the South Fork Crow Watershed was multiplied by 2015 industrial permitted acres for that county to determine the acres under industrial permits in the South Fork Crow River Watershed. Finally, percent of area with industrial uses was determined by dividing total industrial acres over total watershed acres. Industrial permits in 2015 were determined to occur on 0.06% of the watershed. This was rounded up to 0.1% to represent the industrial stormwater WLA to account for future growth.

The BMPs and other stormwater control measures that should be implemented at the industrial sites are defined in the State’s NPDES/SDS Industrial Stormwater Multi-Sector General Permit (MNR050000) or facility specific Individual Wastewater Permit or NPDES/SDS General Permit for Construction Sand and Gravel, Rock Quarrying and Hot Mix Asphalt Production facilities (MNG490000). If an industrial facility owner/operator obtains stormwater coverage under the appropriate NPDES/SDS Permit and properly selects, installs and maintains all BMPs required under the permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. All local construction and industrial stormwater management requirements must also be met.

To determine the load allowed from construction and industrial stormwater, the loading capacity in each flow zone (minus the MOS and NPDES portion of the WLAs) was multiplied by 0.002 to represent 0.1% from construction stormwater and 0.1% from industrial permits.

4.7.4 Watershed Load Allocation

Once WLAs (regulated point sources, construction and industrial stormwater) and MOS were determined for each reach and flow regime, the remaining loading capacity was considered the LA. The LA includes nonpoint pollution sources that are not subject to NPDES permit requirements such as natural background, wind-blown materials, and soil erosion from stream channel and upland areas. The LA also includes runoff from agricultural lands and non-NPDES stormwater runoff.

4.7.5 Margin of Safety

MOS is a portion of the TMDL that is set aside to account for the uncertainties associated with achieving water quality standards. MOS is usually expressed in terms of percentage of the loading capacity that is set aside as an uncertainty-insurance measure. MOS can be explicitly defined as a set-aside amount. For TSS TMDLs in the South Fork Crow River Watershed, an explicit MOS was calculated as 10% of the loading capacity. Ten percent was considered an appropriate MOS since the LDC approach minimizes a great deal of uncertainty associated with the development of TMDLs, because the calculation of the loading capacity is the product of monitored flow and the TSS target concentration. Most of the uncertainty with this calculation is therefore associated with the flows in the impaired reach that were calculated based on monitored flows at S003-326, which is a well-established continuous flow monitoring station with a long flow record."

4.7.6 Seasonal Variation

Both seasonal variation and critical conditions are accounted for in this TMDL through the application of LDCs. LDCs evaluate water quality conditions across all flow regimes including high flow runoff conditions where sediment transport tends to be greatest. Seasonality is accounted for by addressing all flow conditions in a given reach.

4.7.7 TMDL Summary

To develop a LDC, average daily flow values from the full year were multiplied by the TSS standard and then converted to a daily load to create "continuous" LDCs. The lines one each graph represent the assimilative capacity of the stream for each daily flow. To develop the TMDL, the median load of each flow zone is used to represent the TDLC for that flow zone. The TDLC can also be compared to current conditions by plotting individual load measurements (green squares in LDCs) for each water quality sampling event. Each value that is above the TDLC lines (blue line) represents an exceedance of the standards while those below the lines are below the water quality standards. The difference between the blue line and the green squares provides a general percent reduction in TSS that will be needed to remove each reach from the impaired waters list. Simulated loads are also shown on the LDCs as light grey dots, as these were used to determine exceedances. A simulated load for every day from 2003 through 2013 is shown on the plot. The curves are divided into flow zones including very high (0% to 10%), high (10% to 40%), mid (40% to 60%), low (60% to 90%), and very low (90% to 100%) [EPA 2007].

The TSS LDCs and TMDL Tables by reach are shown for Buffalo Creek, and then from upstream to downstream along the South Fork Crow River in Figures 4-1 through 4-5 and Tables 4-3 through 4-7. Current loads calculated using the 90th percentile of the HSPF simulated TSS loads were used, with loading capacities calculated using median flows in each flow zone to determine required reductions.

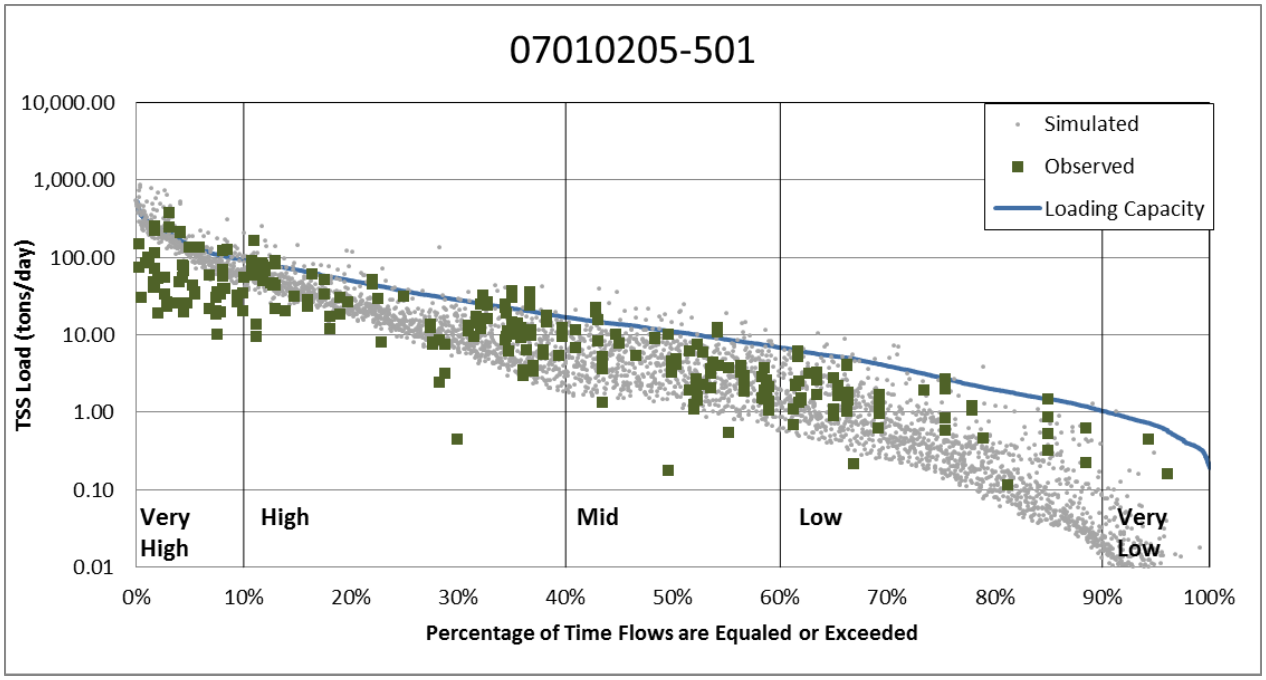

Figure 4-1. Buffalo Creek (07010205-501) TSS load duration curve.

Table 4-3. Buffalo Creek (07010205-501) TMDL allocations.

		Flow Zone*				
		Very High	**High**	**Mid**	**Low**	**Very Low**
		TSS Load (tons/day)				
Wasteload	**Total WLA**	**4.9**	**2.7**	**2.1**	**1.9**	*****
	Permitted Wastewater Dischargers	1.9	1.9	1.9	1.9	*
	MS4 Communities (City of Glencoe)	2.7	0.7	0.2	<0.1	*
	Industrial & Construction Stormwater	0.3	0.1	<0.1	<0.1	*
Load	**Total LA**	**126.0**	**30.3**	**7.8**	**0.6**	*****
	Reach 501 Watershed Nonpoint Source	126.0	30.3	7.8	0.6	*
MOS		**14.6**	**3.7**	**1.1**	**0.3**	**0.1**
TOTAL LOAD (TMDL)		**145.5**	**36.7**	**11.0**	**2.8**	**0.7**
Existing Load (90th percentile of observed data)		324.0	52.1	9.1	1.8	<0.1
Estimated Reduction (%)		55%	30%	0%	0%	0%

* The WLA for the permitted wastewater dischargers are based on facility design flow. The WLA exceeded the low flow regimes total daily loading capacity and is denoted in the table by a “*”. For this flow regime, the WLA and non-point source load allocation is determined by the following formula:

Allocation = (flow contribution from a given source) X (TSS concentration limit or standard)

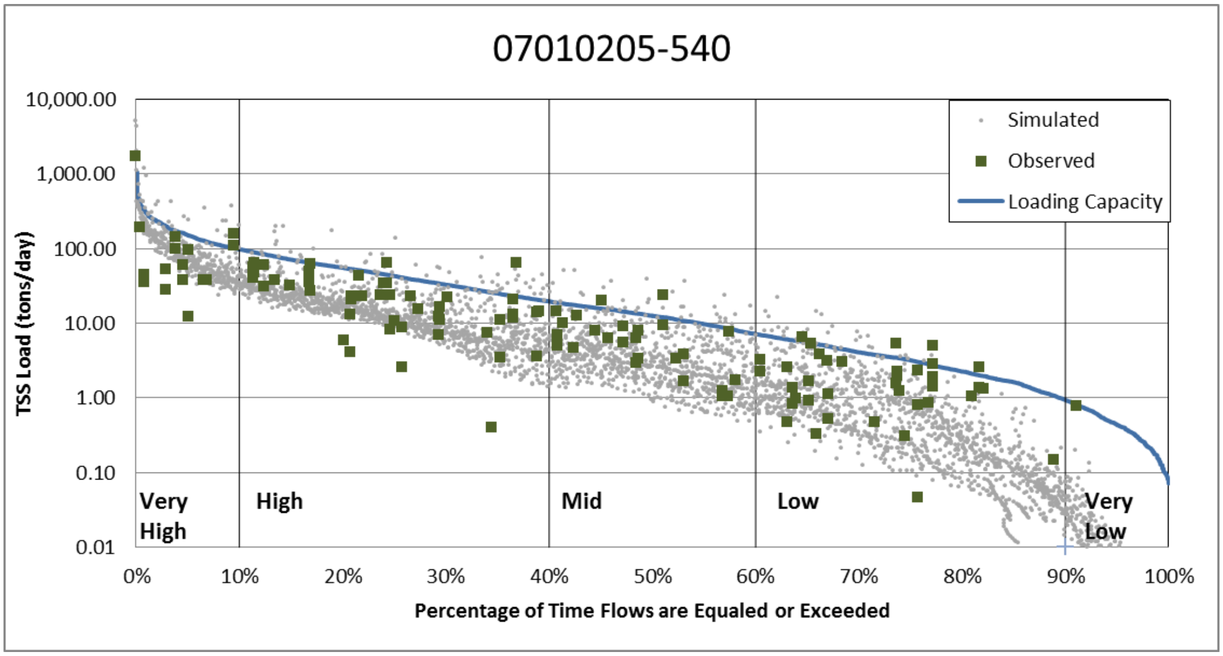

Figure 4-2. South Fork Crow (07010205-540) TSS load duration curve.

Table 4-4. South Fork Crow (07010205-540) TMDL allocations.

		Flow Zone*				
		Very High	High	Mid	Low	Very Low
		TSS Load (tons/day)				
Wasteload	Total WLA	5.1	2.5	1.7	1.5	*
	Permitted Wastewater Dischargers	1.5	1.5	1.5	1.5	*
	MS4 Communities (Cities of Wilmar and Hutchinson)	3.3	0.9	0.2	<0.1	*
	Industrial & Construction Stormwater	0.3	0.1	<0.1	<0.1	*
Load	Total LA	131.3	36.2	9.6	1.4	*
	Reach 540 Watershed Nonpoint Source	131.3	36.2	9.6	1.4	*
MOS		15.2	4.3	1.3	0.3	<0.1
TOTAL LOAD (TMDL)		151.6	43.0	12.6	3.2	0.4
Existing Load		240.1	35.0	9.2	2.2	<0.1
Estimated Reduction (%)		37%	0%	0%	0%	0%

* The WLA for the permitted wastewater dischargers are based on facility design flow. The WLA exceeded the low flow regimes total daily loading capacity and is denoted in the table by a "*". For this flow regime, the WLA and non-point source load allocation is determined by the following formula:
Allocation = (flow contribution from a given source) X (TSS concentration limit or standard)

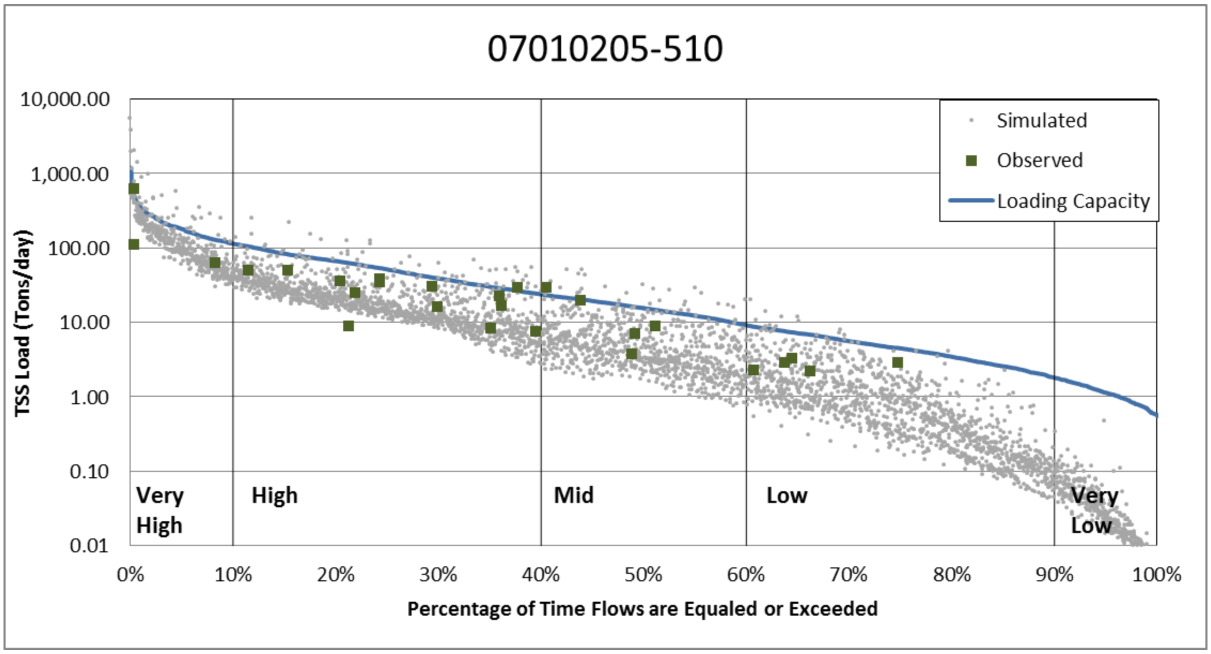

Figure 4-3. South Fork Crow (07010205-510) TSS load duration curve.

Table 4-5. South Fork Crow (07010205-510) TMDL allocations.

		Flow Zone*				
		Very High	**High**	**Mid**	**Low**	**Very Low**
		TSS Load (tons/day)				
Wasteload	**Total WLA**	**2.9**	**1.6**	**1.2**	**1.1**	*****
	Permitted Wastewater Dischargers	1.1	1.1	1.1	1.1	*
	MS4 Communities (City of Hutchinson)	1.8	0.5	0.1	<0.1	*
	Industrial & Construction Stormwater	<0.1	<0.1	<0.1	<0.1	*
Load	**Total LA**	**174.2**	**49.1**	**14.0**	**3.3**	*****
	Upstream Boundary Condition (Reach 540)	151.6	43.0	12.6	3.2	0.4
	Reach 510 Watershed Nonpoint Source	22.6	6.1	1.4	0.1	*
MOS		**2.8**	**0.8**	**0.3**	**0.1**	**0.1**
TOTAL LOAD (TMDL)		**179.9**	**51.5**	**15.5**	**4.5**	*****
Existing Load		310.9	42.9	11.8	2.7	0.1
Estimated Reduction (%)		42%	0%	0%	0%	0%

Reach 510

**The WLA for the permitted wastewater dischargers are based on facility design flow. The WLA exceeded the low flow regimes total daily loading capacity (less the MOS) and is denoted in the table by a "*". For this flow regime, the WLA and non-point source load allocation is determined by the following formula:
Allocation = (flow contribution from a given source) X (TSS concentration limit or standard)

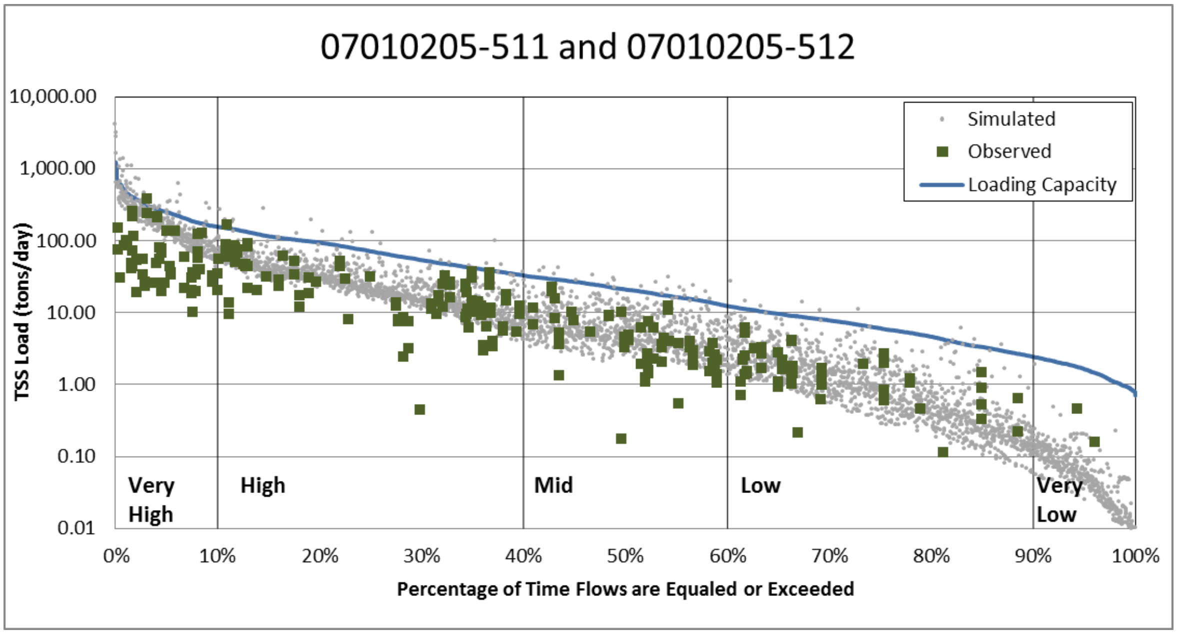

Figure 4-4. South Fork Crow (07010205-511 and 07010205-512) TSS load duration curve.

Table 4-6. South Fork Crow (07010205-511 and 07010205-512) TMDL allocations.

		Flow Zone*				
		Very High	**High**	**Mid**	**Low**	**Very Low**
		TSS Load (tons/day)				
Wasteload	**Total WLA**	**0.3**	**0.2**	**0.2**	**0.2**	**0.2**
	Permitted Wastewater Dischargers	0.2	0.2	0.2	0.2	0.2
	Industrial & Construction Stormwater	0.1	<0.1	<0.1	<0.1	<0.1
Load	**Total LA**	**241.3**	**68.7**	**20.2**	**5.6**	**1.4**
	Upstream Boundary Condition (Reach 510)	179.9	51.5	15.5	4.5	1.1
	Reach 510 Watershed Nonpoint Source	61.4	17.2	4.7	1.1	0.3
MOS		6.9	1.9	0.5	0.2	<0.1
TOTAL LOAD (TMDL)		248.5	70.8	20.9	6.0	1.6
Existing Load		433.9	57.5	12.7	3.3	0.1
Estimated Reduction (%)		43%	0%	0%	0%	0%

**The WLA for the permitted wastewater dischargers are based on facility design flow. The WLA exceeded the low flow regimes total daily loading capacity (less the MOS) and is denoted in the table by a "*". For this flow regime, the WLA and non-point source load allocation is determined by the following formula:
Allocation = (flow contribution from a given source) X (TSS concentration limit or standard)

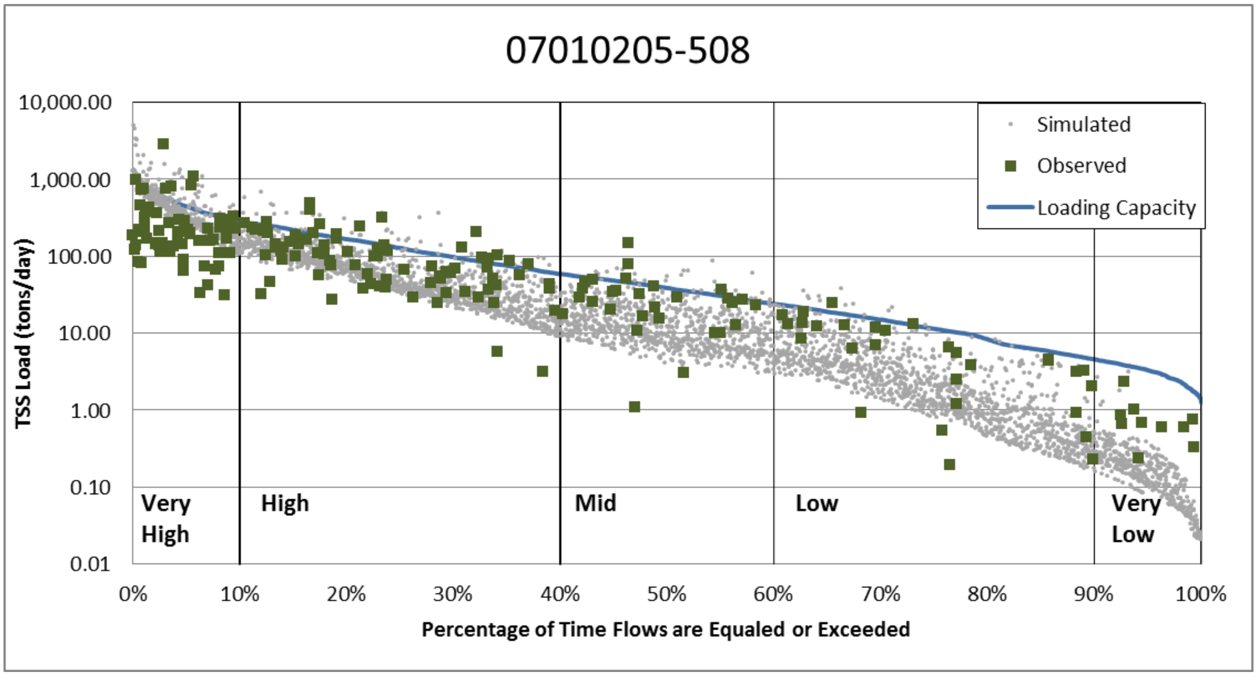

Figure 4-5. South Fork Crow (07010205-508) TSS load duration curve.

Table 4-7. South Fork Crow (07010205-508) TMDL allocations.

		Flow Zone*				
		Very High	**High**	**Mid**	**Low**	**Very Low**
		TSS Load (tons/day)				
Wasteload	**Total WLA**	**11.1**	**4.8**	**2.0**	**1.1**	**0.8**
	Permitted Wastewater Dischargers	0.8	0.8	0.8	0.8	0.8
	MS4 Communities	10.2	4.0	1.2	0.3	<0.1
	Industrial & Construction Stormwater	0.1	<0.1	<0.1	<0.1	<0.1
Load	**Total LA**	**428.3**	**121.2**	**36.0**	**10.0**	**2.4**
	Upstream Boundary Condition (Reaches 501 & 502)	394.0	107.6	31.9	8.8	2.3
	Reach 508 Watershed Nonpoint Source	34.3	13.6	4.1	1.2	0.1
MOS		**5.1**	**2.1**	**0.7**	**0.3**	**0.1**
TOTAL LOAD (TMDL)		**444.5**	**128.1**	**38.7**	**11.4**	**3.3**
Existing Load (90th percentile of observed data)		869.8	140.1	26.6	8.0	0.3
Estimated Reduction (%)		49%	9%	0%	0%	0%

4.8 Dissolved Oxygen

4.8.1 Loading Capacity Methodology

The loading capacity in a DO TMDL is the maximum allowable oxygen demand the stream can withstand and still meet water quality standards. To determine the loading capacity, oxygen demand rates were adjusted in the HSPF model until model-predicted minimum daily DO in the impaired reach was below the 5.0 mg/L standard less than 5% of the open water months (April through November) during the modeled years (2003 through 2013). The oxygen demand calculated using the TMDL scenario was 5,784 lb/day (a reduction of 57% from the current load of 13,312 lb/day).

4.8.2 Waste Load Allocation Methodology

The TMDL WLAs are typically divided into three categories: NPDES point source dischargers, permitted MS4s, and construction and industrial stormwater. The following sections describe how each of these WLAs was estimated.

4.8.2.1 Permitted Wastewater Dischargers

There are nine NPDES wastewater dischargers throughout the Buffalo Creek DO impaired reach, five of which are WWTPs and four of which are more industrial in nature. The WWTPs have permitted CBOD5 effluent limits, which were used for the CBOD5 concentration assumptions. The CBOD5 concentration assumption for Gascoyne Materials Handling & Recycling was set using estimated concentrations from a similar facility [Stahl et al. 1984]. The CBOD concentration assumption for the other facilities without a current effluent limit was set using the highest WWTP concentration (25 mg/L). CBOD5 concentrations were converted to CBODu using the following equation, assuming k was on the low end of effluent from a primary treatment pond or on the high end of activated sludge (0.1) [Chapra 1997]:

$$CBOD_u = \frac{CBOD_5}{1-e^{-k(5)}}$$

Two of the nine wastewater dischargers (Brownton WWTP and Glencoe WWTP) have permitted total ammonia limits. The Browntown WWTP total ammonia limit is 2 mg/L from June to September and 9 mg/L from October to November. The Glencoe WWTP limit is 1 mg/L from June to September, 4.3 mg/L from October to November, 7.7 mg/L from December to March, and 4 mg/L from April to September. These permitted total ammonia effluent limits were developed to protect Buffalo Creek from the short term and near field toxic effects of un-ionized ammonia. The toxic un-ionized ammonia fraction is related to water temperature and pH, resulting in effluent limits that are more restrictive in the summer than winter. The permitted total ammonia effluent limits are not intended to account for the effect of the facility's effluent NOD on the DO in the receiving water. Effluent total ammonia data are available for five of the wastewater dischargers. Based on a frequency distribution of available effluent ammonia data for dischargers in the Buffalo Creek Watershed, 95% of all reported sample results were less than or equal to 6 mg/L. Use of a 6 mg/L total ammonia concentration assumption to estimate the model-based WLA ensures that facilities are able to comply with this TMDLs WLAs. Use of the least restrictive ammonia permit limits as concentration assumptions for TMDL development purposes is not necessary because these limits, which are calculated to protect for the toxic effects of un-ionized ammonia, can be extremely lenient in non-summer months, and their use to calculate oxygen demand characteristics of discharge is unnecessary. Similarly, the Buffalo Creek TMDL is only intended to apply during the open water season of April through November. Approximately 4.33 mg of oxygen are required for complete oxidation of 1 mg of ammonia as N; this estimate is slightly lower than the stoichiometry based theoretical value of 4.57 g as it takes cell synthesis into account, as discussed in the Biological Nitrification Section of Metcalf & Eddy [2003]. Ammonia concentrations can be converted to NOD using the ratio of oxygen demand to ammonia (4.33 mg NOD: 1 mg ammonia nitrogen as N).

The CBOD5 and ammonia load assumptions were calculated as the product of the facility design flows or maximum permitted flow rates, the effluent concentration assumptions in Tables 4-8 for CBOD5 and 4-9 for ammonia, and a unit conversion factor. Continuously discharging municipal WWTF load assumptions were calculated based on the average wet-weather design flow, equivalent to the wettest 30-days of influent flow expected over the course of a year. Controlled municipal pond discharge WWTF load assumptions were calculated based on the maximum daily volume that may be discharged in a 24-hour period.

BOD consists of carbonaceous (CBODu) and nitrogenous (NOD) components. The permitted CBODu load assumptions from Table 4-8, the ammonia load assumptions from Table 4-9, and the design flows were input into the HSPF model as constant loads in place of their observed data. The modeled difference in oxygen demand occurring from this run, and a run with no point sources, was set as the WLA and represents the actual oxygen demand that the permitted wastewater dischargers exert on the TMDL stream segment. The loading assumptions in Tables 4-8 and 4-9 are not comparable to the oxygen demand WLA from wastewater dischargers because the loading assumptions represent the total potential oxygen demand, which is counteracted in-stream by reaeration and other oxygen supplying processes that are simulated in the model application. The “end of pipe” Oxygen Demand wastewater treatment facility WLAs, calculated as the sum of CBODu and NOD loading model inputs are shown in Table 4-10. Due to in-stream reaeration processes, the 8,451.8 lb/day “end of pipe” wastewater WLA results in the 765 lb/day HSP model output Oxygen Demand WLA for wastewater permitted dischargers shown in Table 4-11.

Ammonia-based NOD loading assumptions calculated from the 6 mg/L total ammonia effluent concentration assumptions should not be interpreted to require future NPDES permits to contain 6 mg/L total ammonia effluent limits from April through November. Effluent limit developers should evaluate each discharger’s reasonable potential (RP) to exceed the oxygen demand WLA resulting from the sum of the TMDL’s CBODu and ammonia-based NOD loading assumptions in Table 4-10. Future effluent limit analyses may evaluate potential trade-off between CBODu and ammonia NOD because any summation of the two oxygen demanding characteristics that meets the TMDL’s oxygen demand WLA would be consistent with the WLA assumptions of the TMDL.

Table 4-8. CBOD concentration and loading assumptions for point sources in the Buffalo Creek Watershed.

Facility	Permit	Facility Type	Effluent Design Flow (MGD)	CBOD5 Concentration Assumption (mg/L)	Converted CBODu Concentration Assumption (mg/L)	CBOD5 Load Assumption (lb/day)	Converted CBODu Load Assumption (lb/day)
Brownton WWTP	MN0022951	Continuous	0.196	10	25	16.4	41.6
Buffalo Lake Advanced Biofuels LLC	MN0063151	Continuous	0.040	15	38	5.0	12.7
Buffalo Lake WWTP	MN0050211	Controlled	1.743	25	64	363.7	924.4
Gascoyne Materials Handling & Recycling LLC	MN0069612		0.300	20	51	50.1	127.3
Glencoe WWTP	MN0022233	Continuous	2.600	25	64	542.5	1,378.6
Hector WWTP	MN0025445	Continuous	0.660	15	38	82.6	210.0
Seneca Foods Corp – Glencoe	MN0001236	Continuous	0.450	10	25	37.6	95.4
Seneca Foods Corp – Glencoe	MN0001236	Controlled	5.000	25	64	1,043.2	2,651.2
Stewart WWTP	MNG580077	Controlled	0.841	25	64	175.5	445.9
					Total Loads	2,316.6	5,887.1

Table 4-9. Ammonia concentration and loading assumptions for point sources in the Buffalo Creek Watershed.

Facility	Permit	Facility Type	Effluent Design Flow (MGD)	Ammonia Concentration Assumption (mg/L)	Converted Ammonia NOD Concentration Assumption (mg/L)	Ammonia Load Assumption (lb/day)	Converted Ammonia NOD Load Assumption (lb/day)
Brownton WWTP	MN0022951	Continuous	0.196	6	26.0	9.8	42.4
Buffalo Lake Advanced Biofuels LLC	MN0063151	Continuous	0.040	6	26.0	2.0	8.7
Buffalo Lake WWTP	MN0050211	Controlled	1.743	6	26.0	87.3	378.0
Gascoyne Materials Handling & Recycling LLC	MN0069612		0.300	6	26.0	15.0	65.0
Glencoe WWTP	MN0022233	Continuous	2.600	6	26.0	130.2	563.8
Hector WWTP	MN0025445	Continuous	0.660	6	26.0	33.0	142.9
Seneca Foods Corp – Glencoe	MN0001236	Continuous	0.450	6	26.0	22.5	97.4
Seneca Foods Corp – Glencoe	MN0001236	Controlled	5.000	6	26.0	250.4	1084.2
Stewart WWTP	MNG580077	Controlled	0.841	6	26.0	42.1	182.3
					Total Loads	592.3	2,564.7

Table 4-10. Oxygen demand WLAs for individual permitted wastewater dischargers.

Facility	Permit	Facility Type	Effluent Design Flow (MGD)	Converted CBODu Load Assumption (lbs/day)	Converted Ammonia NOD Load Assumption (lbs/day)	Oxygen Demand WLA (lbs/day)
Brownton WWTP	MN0022951	Continuous	0.196	41.6	42.4	84.0
Buffalo Lake Advanced Biofuels LLC	MN0063151	Continuous	0.040	12.7	8.7	21.4
Buffalo Lake WWTP	MN0050211	Controlled	1.743	924.4	378.0	1,302.4
Gascoyne Materials Handling & Recycling LLC	MN0069612		0.300	127.3	65.0	192.3
Glencoe WWTP	MN0022233	Continuous	2.600	1,378.6	563.8	1,942.4
Hector WWTP	MN0025445	Continuous	0.660	210.0	142.9	352.9
Seneca Foods Corp – Glencoe	MN0001236	Continuous	0.450	95.4	97.4	192.8
Seneca Foods Corp – Glencoe	MN0001236	Controlled	5.000	2,651.2	1,084.2	3,735.4
Stewart WWTP	MNG580077	Controlled	0.841	445.9	182.3	628.2
			Total Loads	5,887.1	2,564.7	8,451.8

4.8.2.2 Permitted MS4s

There is only one MS4, Glencoe City MS4 (MS400252), with a municipal boundary located above the Buffalo Creek outlet. The percent flow volume that the Glencoe City MS4 was contributing above the endpoint of the reach was calculated to be 2.1% using HSPF. The percent flow volume contributing was then multiplied by the loading capacity after the MOS and NPDES portion of the WLAs were subtracted.

4.8.2.3 Construction and Industrial Stormwater

Construction stormwater is regulated by NPDES permits for any construction activity disturbing a) one acre or more of soil, b) less than one acre of soil if that activity is part of a "larger common plan of development or sale" that is greater than one acre, or c) less than one acre of soil, but the MPCA determines that the activity poses a risk to water resources. The WLA for stormwater discharges from sites where there is construction activities reflects the number of construction sites less than one acre expected to be active in the impaired reach subwatershed at any one time.

Industrial stormwater is regulated by NPDES permits if the industrial activity has the potential for significant materials and activities to be exposed to stormwater discharges. The WLA for stormwater discharges from sites where there is industrial activity reflects the number of sites in an impaired lake subwatershed for which NPDES Industrial Stormwater Permit coverage is required. There are no NPDES Industrial Stormwater permitted facilities in the TMDL project area.

A categorical WLA was assigned to all construction activity in the watershed. The average annual acres under construction in each applicable county were available from 2009 through 2015 from MPCA Construction Stormwater Permit data. The percent of each county in the South Fork Crow Watershed was multiplied by the average annual construction acres for that county to determine the acres under construction in the South Fork Crow River Watershed. Finally, percent of area under construction was determined by dividing total construction acres over total watershed acres. This percentage was multiplied by the portion of the TMDL LA associated with direct drainage to determine the construction stormwater WLA. Average annual construction acres from 2009 through 2015 were determined to occur on 0.06% of the watershed. This was rounded up to 0.1% to represent the construction stormwater WLA to account for future growth.

The stormwater WLA includes loads from construction stormwater. Loads from construction stormwater are considered to be a small percent of the total WLA and are difficult to quantify. The WLA for stormwater discharges from sites where there are construction activities reflects the number of construction sites one or more acres expected to be active in the watershed at any one time, and the BMPs and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at construction sites are defined in the state's NPDES/SDS General Stormwater Permit for Construction Activity (MNR100001). If a construction site owner/operator obtains coverage under the NPDES/SDS General Stormwater Permit and properly selects, installs, and maintains all BMPs required under the permit, including those related to impaired waters discharges and any applicable additional requirements found in Appendix A of the Construction General Permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. All local construction stormwater requirements must also be met.

Industrial stormwater is regulated by NPDES permits if the industrial activity has the potential for significant materials and activities to be exposed to stormwater discharges. The number of acres regulated under 2015 industrial permits was available from MPCA Industrial Stormwater Permit data. The percent of each county in the South Fork Crow Watershed was multiplied by 2015 industrial permitted acres for that county to determine the acres under industrial permits in the South Fork Crow River Watershed. Finally, percent of area under construction was determined by dividing total industrial acres over total watershed acres. Industrial permits in 2015 were determined to occur on 0.06% of the watershed. This was rounded up to 0.1% to represent the industrial stormwater WLA to account for future growth.

The BMPs and other stormwater control measures that should be implemented at the industrial sites are defined in the State's NPDES/SDS Industrial Stormwater Multi-Sector General Permit (MNR050000), or facility specific Individual Wastewater Permit, or NPDES/SDS General Permit for Construction Sand and Gravel, Rock Quarrying and Hot Mix Asphalt Production facilities (MNG490000). If an industrial facility owner/operator obtains stormwater coverage under the appropriate NPDES/SDS Permit and properly selects, installs, and maintains all BMPs required under the permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. All local construction and industrial stormwater management requirements must also be met.

To determine the load allowed from industrial and construction stormwater, the oxygen demand loading capacity in each flow zone (minus the MOS and NPDES portion of the WLAs) was multiplied by 0.002% to represent 0.1% from construction stormwater and 0.1% from industrial permits.

4.8.3 Watershed Load Allocation

The LA is oxygen demand from nonpoint sources such as headwater, tributary and groundwater sources and from the sediments. The LA represents the load allowed from nonpoint sources such as direct runoff-related sources as well as organic material and sediment that have settled into the bed and bank and exert oxygen demand. The LA was calculated as the loading capacity minus the MOS and the WLA.

4.8.4 Margin of Safety

MOS is a portion of the TMDL that is set aside to account for the uncertainties associated with achieving water quality standards. MOS is usually expressed in terms of percentage of the loading capacity that is set aside as an uncertainty-insurance measure. The MOS may be implicit, that is, incorporated into the TMDL through conservative assumptions in the analysis. The MOS may also be explicit and expressed in the TMDL as a set aside load. For DO TMDLs, the MOS is typically applied to the oxygen deficit terms that require a measurable reduction to achieve the standard. An explicit 10% MOS was included in TMDLs to provide a reasonable cushion against uncertainties. Oxygen demand for this TMDL was not measured directly as it was calculated using model predicted rates and variables. Thus, a 10% MOS accounts for the uncertainty in model predicted loads and the uncertainty in how the stream may respond to changes in oxygen demand loading. It is also important to note that the TMDL was set to predict the stream meeting the DO standard 95% of the time whereas the standard only requires meeting the DO standard 50% of the time below the 7Q10. Consequently, the current modeling also provides an implicit MOS.

4.8.5 Seasonal Variation

Figure 3-7 in Section 3.5.2 shows that the DO exceedances did not occur during the winter where data were available. Therefore, the critical period for DO was determined to be the open water months, and the TMDL was written for the months of April through November. It was determined that most exceedances occurring during May, June, and early July occurred in the high and very high flow zones and most exceedances occurring during late July, August, and September occurred in the mid, and low, and very low flow zones. For Buffalo Creek, because exceedances occur in all flow zones, as shown in Figure 3-10, it was determined that the critical condition is not flow-related.

4.8.6 TMDL Summary

A scenario was run whereby oxygen demanding pollutants were systematically reduced throughout the impaired reach until the 5.0 mg/L DO standard was achieved (57%). These reductions resulted in the impaired reach meeting the DO standard 95% of the time. Final TMDL allocations for Buffalo Creek are presented in Table 4-11.

Table 4-11. Buffalo Creek Dissolved Oxygen Total Maximum Daily Load.

TMDL Component		HSPF Oxygen Demand* (lbs.'/day)
Total Daily Loading Capacity		5,784
Margin of Safety (MOS)		578
Wasteload Allocations	Permitted Wastewater Dischargers	765
	Glencoe City MS4	95
	Construction and Industrial Stormwater	9
Load Allocation		4,337
Current Load		13,312
Required Reduction		57%

*Oxygen demand accounts for the combination of SOD, NOD, and BOD as discussed in Section 3.6.2.

4.9 Bacteria

4.9.1 Loading Capacity Methodology

The loading capacity for each bacteria impaired reach was developed using LDCs. To develop each *E. coli* LDC, HSPF daily flow values for each reach were multiplied by the 126 cfu/100 mL standard and converted to a daily load to create a "continuous" LDC. *E. coli* LDCs for each impaired reach are shown in Figures 4-6 and 4-7. On these figures, the red curve represents the loading capacity of the stream for each daily flow. The loading capacities were divided into flow zones and the median (or midpoint) load of each flow zone were used in the TMDL equations. Each of the reaches' loading capacity can be compared to current conditions by plotting the measured load during each water quality sampling event (blue circles in Figures 4-6 and 4-7). Each value that is above the curve represents an exceedance of the water quality standard while those below the line meet the water quality standard. Also plotted are the monitored *E. coli* geometric mean concentrations for each flow zone (solid orange circles). The difference between the loading capacity line and monitored geometric means provide a general percent reduction in *E. coli* that will be needed to remove each reach from the impaired waters list. The data shows *E. coli* reductions in both impaired reaches will need to be achieved across all flow regimes.

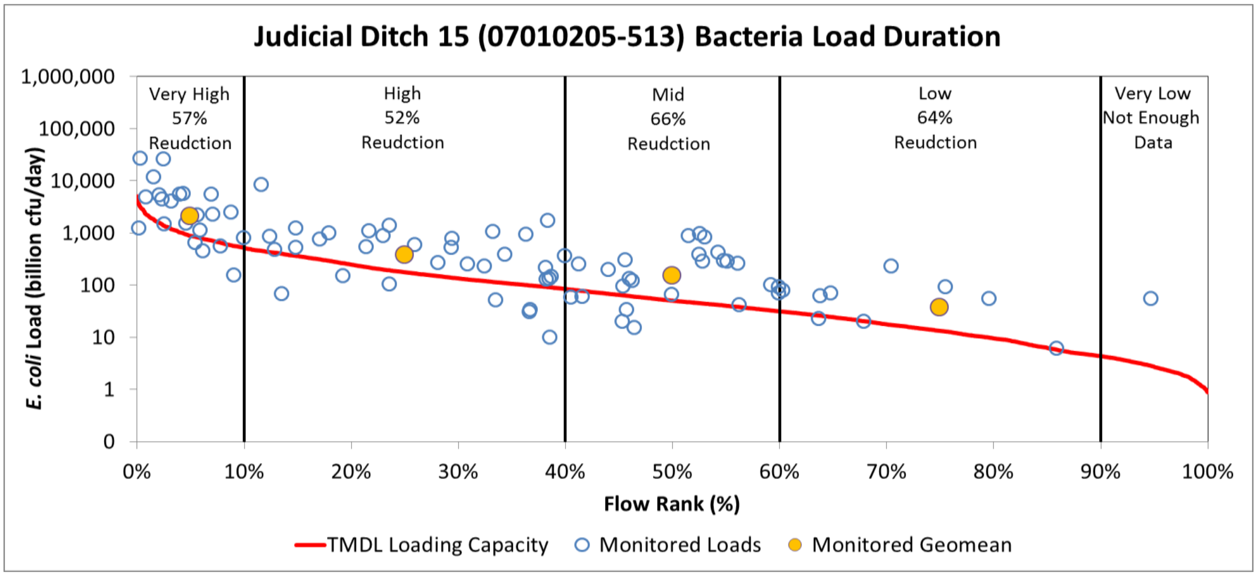

Figure 4-6. *E. coli* monitored loads, load standard and load reductions for JD15 reach 513.

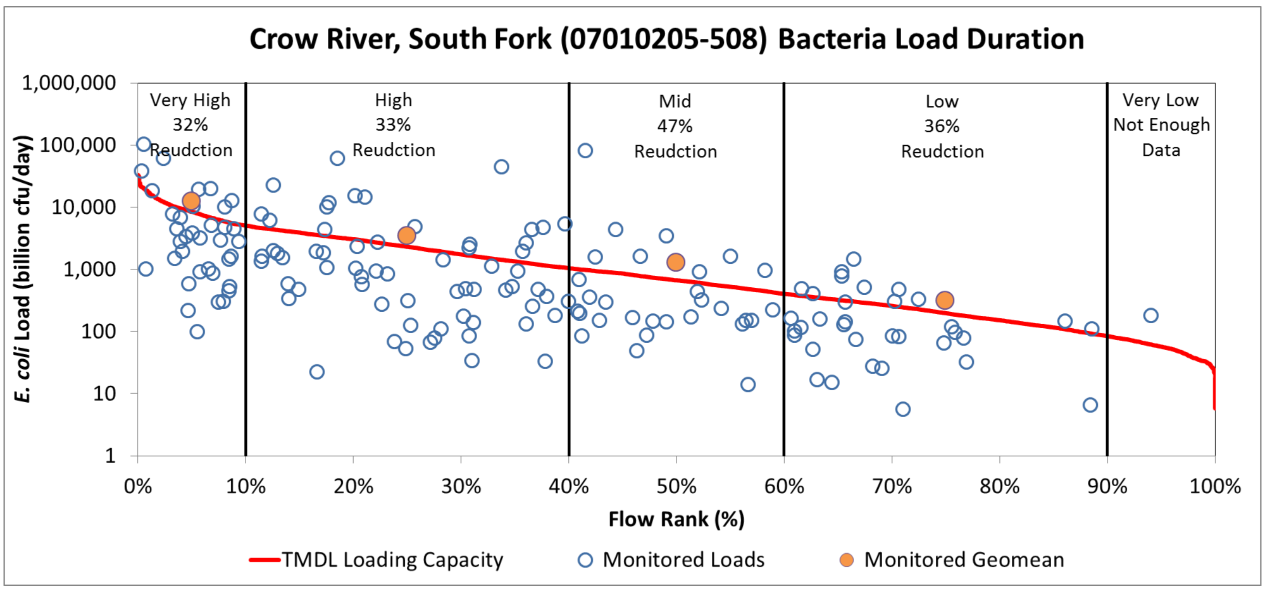

Figure 4-7. *E. coli* monitored loads, load standard and load reductions for South Fork Crow River reach 508.

4.9.2 Waste Load Allocation Methodology

The WLAs for bacteria TMDLs are typically divided into three categories: permitted point source dischargers, permitted MS4s, and construction and industrial stormwater. WLAs for regulated construction stormwater (Permit #MNR100001) were not developed, since *E. coli* is not a typical pollutant from construction sites. The WLAs for regulated industrial stormwater were also not developed. Industrial stormwater must receive a WLA only if the pollutant is part of benchmark monitoring for an industrial site in the watershed of an impaired waterbody. There are no bacteria or *E. coli* benchmarks associated with any of the Industrial Stormwater Permits (Permit #MNR050000). The following sections describe how each of these WLAs was estimated.

4.9.2.1 Permitted Wastewater Dischargers

There are 13 active permitted NPDES surface wastewater dischargers in the impaired reach watersheds that will require *E. coli* allocations (Table 4-12, Figure 1-1). There are eight additional dischargers in the reach 508 watershed not listed in Table 4-12 that are located in the Buffalo Creek Watershed. These facilities were addressed and allocated as part of the Buffalo Creek Bacteria TMDL (Wenck Associates 2013). The LAs for the six facilities were calculated by multiplying the facility's wet weather design flow by the *E. coli* standard (126 cfu/100 mL). Discharge monitoring reports (DMRs) were downloaded to assess the typical monthly discharge values and bacteria concentrations at which each facility discharges. It should be noted that NPDES wastewater permit limits for bacteria are currently expressed in fecal coliform concentrations, not *E. coli*. However, the fecal coliform permit limit for each WWTF (200 organisms/100 mL) is believed to be equivalent to this TMDLs 126 organism/100 mL *E. coli* criterion. The fecal coliform-*E. coli* relationship is documented extensively in the SONAR for the 2007-2008 revisions of Minn. R. ch. 7050. Results of DMRs are presented in Appendix A.

The WLA for permitted wastewater dischargers is based on facility design flow. For both reaches, however, the WLA exceeds the dry flow regimes daily loading capacity because the facilities in these reaches typically discharge less than their design flows. To account for this, the WLA and nonpoint source LA for this flow regime is determined by the following formula:

Allocation = (flow contribution from a given source) X (*E. coli* concentration limit or standard)

Table 4-12. NPDES permitted wastewater dischargers in the bacteria impaired reach watersheds.

Impaired Reach	Facility Name	NPDES ID#	Major Subwatershed	Facility Type	Effluent Design Flow (MGD)	Allocated Load (billions organisms/ day)
513	Buffalo Lake WWTP	MN0050211	Judicial Ditch 15	Controlled	1.74	8.31
513	Hector WWTP	MN0025445	Hector WWTP	Continuous	0.66	3.15
					Reach 513 Total	**11.46**
508	Delano WWTP	MN0051250	SFC River	Continuous	2.20	10.49
508	Mayer WWTP	MN0021202	SFC River	Continuous	0.44	2.07
508	New Germany WWTP	MN0024295	SFC River	Controlled	0.38	1.81
508	Watertown WWTP	MN0020940	SFC River	Continuous	1.26	6.02
508	Cedar Mills WWTP	MN0066605	Hutchinson - SFC	Controlled	0.20	0.93
508	Cosmos WWTP	MNG580056	Hutchinson - SFC	Controlled	0.45	2.14
508	Hutchinson WWTP	MN0055832	Lester Prairie - SFC	Continuous	5.43	25.90
508	Lake Lillian WWTP	MNG580225	Headwaters - SFC	Controlled	0.39	1.87
508	Lester Prairie WWTP	MN0023957	Lester Prairie - SFC	Continuous	0.36	1.74
508	Silver Lake WWTP	MNG580164	Lester Prairie - SFC	Controlled	1.32	6.29
508	Winsted WWTP	MN0021571	Lester Prairie - SFC	Continuous	0.82	3.91
					Reach 508 Total	**63.17**

4.9.2.2 Permitted MS4s

There are eight MS4s that are completely within or have a portion of their municipal boundary in the impaired reach watersheds (Table 4-13; Figure 1-1) and are therefore assigned WLAs. The MPCA defined and supplied a GIS boundary file for all MS4s in the South Fork Crow River Watershed. Individual MS4 allocations were calculated by multiplying each MS4's percent watershed coverage (determined in GIS) by the total watershed loading capacity (determined by LDCs) after the MOS and NPDES point source dischargers were subtracted.

Table 4-13. Summary of permitted MS4s in the bacteria impaired reach watersheds.

TMDL Reach	MS4	Permit #	Area within watershed (acres)	Percent of Watershed
508	Corcoran City MS4	MS400081	164	0.03%
508	Hutchinson City MS4	MS400248	5,665	1.01%
508	Independence City MS4	MS400095	17,981	3.21%
508	Loretto City MS4	MS400030	68	0.01%
508	Maple Plain City MS4	MS400103	485	0.09%
508	Medina City MS4	MS400105	4,397	0.79%
508	Minnetrista City MS4	MS400106	7,093	1.27%
508	Willmar City MS4	MS400272	2,693	0.48%

4.9.3 Watershed Load Allocation

The LA, also referred to as the watershed LA, is the remaining load after the MOS and WLAs are subtracted from the total load capacity of each flow zone. The watershed LA includes all non-permitted sources such as outflow from lakes and wetlands in the watershed and runoff from agricultural land, forested land, and non-regulated MS4 residential areas. For this TMDL, the watershed LAs are primarily comprised of agricultural land outside the MS4 boundaries.

E. coli allocations for Buffalo Creek were established as part of the Buffalo Creek Bacteria TMDL (Wenck Associates 2013). Thus, for the purposes of this TMDL, upstream flow from Buffalo Creek (referred to as the Buffalo Creek Boundary Condition) was included as a separate line item in the LA for reach 508. The Buffalo Creek boundary conditions LA was calculated using HSPF simulated flow data for Buffalo Creek reach 501 directly upstream of reach 508. Since watershed loading capacities for the impaired reach were established using the 126 cfu/100ml *E. coli* standard, the LA for the boundary condition assume flow from Buffalo Creek is allocated to the *E. coli* standard.

4.9.4 Margin of Safety

The MOS accounts for uncertainties in both characterizing current conditions and the relationship between the load, waste load, monitored flows, and in-stream water quality to ensure the TMDL allocations result in attainment of water quality standards. An explicit MOS equal to 5% of the total load was applied, whereby 5% of the loading capacity for each flow regime was subtracted before allocations were made among the waste load and watershed load. Five percent was considered an appropriate MOS since the LDC approach minimizes a great deal of uncertainty associated with the development of TMDLs because the calculation of the loading capacity is the product of monitored flow and the target *E. coli* concentration. Most of the uncertainty with this calculation is associated with the flows in each impaired reach, which were simulated using the HSPF model, which was calibrated using well-established, long term monitored flow data at several stations throughout the South Fork Crow River Watershed.

4.9.5 Seasonal Variation

Monthly geometric means (Table 3-7) and the LDCs (Figures 4-6 and 4-7) indicate bacteria levels are often above the state chronic standard during all flow conditions from April through October. This suggests that the critical time period for bacteria loading/growth/survival in the impaired reaches is the April through October index period, and there is no critical flow condition for bacteria in these reaches. Exceedances of the acute standard are also common in these reaches during this time period. Fecal bacteria are most productive at temperatures similar to their origination environment in animal digestive tracts. Thus, these organisms are expected to be at their highest concentrations during warmer summer months when stream flow is low and water temperatures are high. High *E. coli* concentrations in these reaches continue into the fall, which may be attributed to constant sources of *E. coli* (such as animal access to the stream) and less flow for dilution. However, this data may be skewed as more samples were collected in the summer months than in October. Critical conditions and seasonal and annual variations are accounted for in these TMDLs by setting the TMDL across the entire observed flow record using the load duration method.

4.9.6 TMDL Summary

Tables 4-14 and 4-15 present the existing load, the total loading capacity, MOS, WLA, and LA for each *E. coli* impaired reach. Allocations for these TMDLs were established using the 126 cfu/100 ml *E. coli* standard. All LAs are reported in billions of cfu/day and were rounded to two significant figures to prevent zero load values. The bottom line of the table shows the estimated load reduction for each flow zone. This reduction was calculated based on the difference between the monitored geometric mean *E. coli* concentration of each flow zone and the 126 cfu/100 ml standard. At this time, there is not enough information or data available to estimate or calculate the existing (current conditions) load contribution from each of the WLA and LA sources presented in Tables 4-5 through 4-16. Thus, the estimated load reduction for each flow zone applies to all sources. The South Fork Crow River WRAPS Report will further investigate which sources and geographical locations within the impaired reach watershed should be targeted for bacteria BMPs and restoration strategies.

Table 4-14. South Fork Crow River reach 508 *E. coli* TMDL.

		Flow Regime*				
		Very High	**High**	**Mid**	**Low**	**Very Low**
		***E. coli* in billions of cfu/day**				
Wasteload	**Total WLA**	**613.29**	**213.82**	**106.77**	**76.06**	**
	Corcoran City MS4	*2.34*	*0.64*	*0.19*	*0.05*	**
	Hutchinson City MS4	*80.85*	*22.14*	*6.41*	*1.90*	**
	Independence City MS4	*256.61*	*70.27*	*20.33*	*6.02*	**
	Loretto City MS4	*0.98*	*0.27*	*0.08*	*0.02*	**
	Maple Plain City MS4	*6.92*	*1.90*	*0.55*	*0.16*	**
	Medina City MS4	*62.75*	*17.18*	*4.97*	*1.47*	**
	Minnetrista City MS4	*101.23*	*27.72*	*8.02*	*2.37*	**
	Willmar City MS4	*38.44*	*10.53*	*3.05*	*0.90*	**
	NPDES Wastewater Dischargers (individual allocations summarized in Table 4-1)	*63.17*	*63.17*	*63.17*	*63.17*	**
Load	**Total LA**	**7,373.91**	**1,973.30**	**526.05**	**111.24**	**
	Buffalo Creek Boundary Condition (Reach 501)	*3,909.08*	*965.92*	*275.03*	*70.19*	**
	Watershed LA	*3,464.83*	*1,007,38*	*251.02*	*41.05*	**
MOS		**420.38**	**115.11**	**33.31**	**9.86**	**2.84**
TOTAL LOAD (TMDL)		**8,407.58**	**2,302.23**	**666.13**	**197.16**	**56.89**
Existing Load (geomean of observed data)		12,409.11	3,417.86	1,260.48	306.29	***
Estimated Reduction (%)		32%	33%	47%	36%	***

* HSPF simulated flow was used to develop the flow regimes and loading capacities for this reach
** The WLA for the permitted wastewater dischargers (Table 4-1) are based on facility design flow. The WLA exceeded the dry flow regimes total daily loading capacity and is denoted in the table by "**". For this flow regime, the WLA and LAs are determined by the following formula:
Allocation = (flow contribution from a given source) X (*E. coli* concentration limit or standard)
*** Not enough data at this time to estimate a reduction

Table 4-15. JD15 reach 513 *E. coli* TMDL summary.

		Flow Regime*				
		Very High	High	Mid	Low	Very Low
		E. coli in billions of cfu/day				
Wasteload	**Total WLA**	**11.46**	**11.46**	**11.46**	**11.46**	**
	NPDES Wastewater Dischargers (individual allocations summarized in Table 4-1)	*11.46*	*11.46*	*11.46*	*11.46*	**
Load	**Total LA**	**827.23**	**157.19**	**36.69**	**1.19**	**
	Watershed LA	*827.23*	*157.19*	*36.69*	*1.19*	**
MOS		**44.14**	**8.88**	**2.53**	**0.67**	**0.14**
TOTAL LOAD (TMDL)		**882.83**	**177.53**	**50.68**	**13.32**	**2.73**
Existing Load (geomean of observed data)		2,061.27	371.27	148.91	37.16	***
Estimated Reduction (%)		57%	52%	66%	64%	***

* HSPF simulated flow was used to develop the flow regimes and loading capacities for this reach
** The WLA for the permitted wastewater dischargers (Table 4-1) are based on facility design flow. The WLA exceeded the dry flow regimes total daily loading capacity and is denoted in the table by "**". For this flow regime, the WLA and LAs are determined by the following formula:
Allocation = (flow contribution from a given source) X (*E. coli* concentration limit or standard)
*** Not enough data at this time to estimate a reduction

4.10 Nutrients

4.10.1 Loading Capacity Methodology

The first step in developing excess nutrient TMDLs for lakes is to determine the total nutrient loading capacity for the lake. A key component for this determination is to estimate each source's current phosphorus loading for the lake. Next, lake response to phosphorus loading is modeled using the Canfield-Bachman lake equation for each impaired lake and the final loading capacity is determined. The components of this process are described below.

4.10.1.1 Watershed Loading

The South Fork Crow River HSPF model was used to estimate phosphorus loading from the watershed and failing SSTSs for each impaired lake. Annual flow and phosphorus output from the HSPF models were incorporated into a spreadsheet version of the Canfield-Bachman Lake equation. It is important to note that the HSPF model uses loading rates based on hydrozones and not individual lakesheds, meaning that some resolution is lost for each of the individual lakes.

4.10.1.2 Septic System Loading

Failing or nonconforming SSTSs can be an important source of phosphorus to surface waters. Currently, knowledge of the exact number and status of SSTSs in the South Fork Crow River Watershed is unclear. The MPCA's 10-year Plan to upgrade and maintain Minnesota's On-Site Treatment Systems (MPCA 2013) includes some information regarding the performance of SSTSs in the South Fork Crow River Watershed. To address failing SSTSs and phosphorus loading to impaired lakes, HSPF modeled phosphorus loading from SSTS was used in the BATHTUB lake response models.

4.10.1.3 Upstream Lakes

Some of the lakes addressed in the TMDL have upstream impaired lakes, which are also addressed in this study or previous TMDL studies. Meeting water quality standards in the downstream lakes is contingent on water quality improvements in the impaired upstream lakes. For these situations, lake outflow loads from the upstream lakes were routed in the model directly into the downstream lake, and were estimated using flow results from the HSPF model and monitored lake water quality data.

4.10.1.4 Atmospheric Deposition

The atmospheric load refers to the load applied directly to the surface of the lake through atmospheric deposition. Atmospheric inputs of phosphorus from wet and dry deposition were estimated using published rates based on annual precipitation (Barr Engineering 2004). The atmospheric deposition values used for dry (< 25 inches), average, and wet precipitation years (>38 inches) are 24.9, 26.8, and 29.0 kg/km2-year, respectively. These values are equivalent to 0.22, 0.24, and 0.26 pounds per acre per year for dry, average, and wet years, respectively.

4.10.1.5 Internal Loading

Internal phosphorus loading from lake sediments can be a major component of a lake's phosphorus budget. Internal loading is typically the result of organic sediment releasing phosphorus to the water column. This often occurs when anoxic conditions are present, meaning that the water in and above the sediment is devoid of oxygen. Studies have shown that internal loading occurs even when the overlying water column is well oxygenated; however, release rates are typically an order of magnitude lower. For this reason, it is assumed that in deep lakes the anoxic portions of the lake are the primary source of internal phosphorus relative to the oxic shallow regions. For deep lakes in this study, temperature and DO profiles were used to determine the volume of lake water under anoxic conditions throughout the summer growing season. This volume was then used to calculate an anoxic factor (AF) (Nürnberg 2004) normalized over the lake basin, and reported as number of days.

The AFs are often difficult to measure in shallow lakes since they can have intermittent anoxic periods that are not measured with routine monitoring. For this reason, AFs for shallow lakes are regularly underestimated, which subsequently will result in inaccurate internal release rate calculations. Due to the difficulty of measuring shallow lake anoxia, a shallow lake AF equation was used to calculate AFs for shallow lakes in this study (Nurnberg 2005).

In order to calculate total internal load for a lake, the AF (days) is multiplied by an estimated phosphorus release rate (mg/m^2/day). Release rates can be obtained by collecting sediment cores in the field and incubating them in the lab under oxic and/or anoxic conditions to measure phosphorus release over time. No lab determined release rates were available for any of the lakes in this TMDL study. Instead, model residuals were used to determine appropriate release rates for all the impaired lakes covered in this TMDL study. Selected release rates and calculated AFs are provided in Appendix B.

4.10.1.6 Canfield-Bachman Lake Response Model

Once the nutrient budget for a lake has been developed, the response of the lake to those nutrient loads must be established. Lake response was modeled using the Canfield-Bachman lake equation (Canfield and Bachman 1981). This equation estimates the lake phosphorus sedimentation rate, which is needed to predict the relationship between in-lake phosphorus concentrations and phosphorus load inputs. The phosphorus sedimentation rate is an estimate of net phosphorus loss from the water column through sedimentation to the lake bottom, and is used in concert with lake-specific characteristics such as annual phosphorus loading, mean depth, and hydraulic flushing rate to predict in-lake phosphorus concentrations. These model predictions are compared to measured data to evaluate how well the model describes the lake system. If necessary, the model parameters are adjusted appropriately to achieve an approximate match to monitored data. Once a model is calibrated, the resulting relationship between phosphorus load and in-lake water quality is used to determine the assimilative capacity.

To set the TMDL for each impaired lake, the nutrient inputs partitioned between sources in the lake response models were systematically reduced until the model predicted that each lake met their current ecoregion TP standard. Construction, calibration, and results of the Canfield-Bachman lake response models for each lake are presented in Appendix B.

Since atmospheric load is extremely difficult to control, no reduction in this source is assumed for the TMDLs. Any upstream lakes are assumed to meet water quality standards, and the resultant reductions are applied to the lake being evaluated. If these reductions result in the lake meeting water quality standards, then the TMDL allocations are done. If more reductions are required, then the internal and external loads are evaluated simultaneously.

The capacity for watershed load reductions is considered first by looking at watershed loading rates and runoff concentrations compared to literature values. For example, phosphorus concentrations and export rates from certain subwatersheds are already low which would make large reductions extremely difficult.

The general approach to internal load reductions is based on review of the existing sediment release rates and the lake morphometry. This is accomplished by reviewing the release rates versus literature values of healthy lakes. If the release rates are high, then they are reduced systematically until either a minimum of 1 $mg/m^2/day$ is reached or the lakes meet TMDL requirements. In a few cases, internal release rates less than 1 $mg/m^2/day$ were required in order for the lake to meet state water quality standards.

4.10.2 Load Allocation Methodology

The LA includes all non-permitted sources, including: atmospheric deposition, septic systems, discharge from upstream lakes, watershed loading from non-regulated areas, and internal loading. Some discharges from areas geographically located in a regulated MS4 community that do not drain through a conveyance system (and therefore are not regulated sources) are also included in the LA (determined as described in the following section).

4.10.3 Waste Load Allocation Methodology

The WLA were divided into four primary categories including NPDES permitted wastewater dischargers, MS4 permits, and NPDES-permitted construction and industrial stormwater. The following sections describe how each permitted source was calculated for the impaired lakes covered in this TMDL study.

4.10.3.1 Permitted Wastewater Dischargers

There is currently no permitted wastewater dischargers located in the impaired lake watersheds.

4.10.3.2 Permitted MS4s

There are four MS4s that are completely within or have a portion of their municipal boundary in at least one of the impaired lake watersheds (Table 4-16). These MS4 communities were assigned WLAs by multiplying the percent area of each MS4 by the total annual watershed phosphorus load to each lake. Figure 1-1 shows general boundaries of the MS4s in the South Fork Crow River Watershed.

Table 4-16. Summary of permitted MS4s in the impaired lake watersheds.

Lake	MS4	Permit #	Area within watershed (acres)*	Percent of Watershed*
Mud	Minnetrista City	MS400106	783	16%
Rice	Minnetrista City	MS400106	3,975	25%
	Maple Plain City	MS400103	485	3%
	Independence City	MS400095	8,282	53%
Wakanda	Willmar City	MS400272	9533	41%

*Does not include upstream lake boundary condition MS4 area

4.10.3.3 Construction and Industrial Stormwater

Construction and industrial stormwater WLAs were established based on estimated percentage of land in the watershed that is currently under construction or permitted for industrial use. A recent permit review across the South Fork Crow River Watershed (see section 4.6.3.3) showed minimal construction (0.06% of watershed area) and industrial activities (also 0.06% of the watershed). To account for future growth (reserve capacity), allocations in the TMDL were rounded up to 0.1% of the total watershed load for construction stormwater, and 0.1% for industrial stormwater.

4.10.4 Margin of Safety

An explicit MOS has been included in this TMDL. Ten percent of the load has been set aside to account for any uncertainty in the lake response models. The 10% MOS was considered reasonable for all of the modeled lakes due to uncertainties in the HSPF model and the quantity of watershed and in-lake monitoring data available. Watershed modeling results over a 10-year period (2004 to 2013) were used for the majority of the lake modeling. In-lake monitoring data collected during the same 10-year period was also available for the majority of the lakes. However, if monitoring data was not available for the most recent 10-year period, modeling results were used from the same years in which monitoring data was available. For example, if a given lake only had monitoring data for 2008 to 2012, model years 2008 to 2012 were used in the TMDL process.

4.10.5 Seasonal Variation

Seasonal variation is accounted for through the use of annual loads and developing targets for the summer period, where the frequency and severity of nuisance algal growth will be the greatest. Although the critical period is the summer, lakes are not sensitive to short term changes in water quality, rather lakes respond to long-term changes such as changes in the annual load. Therefore, seasonal variation is accounted for in the annual loads. By setting the TMDL to meet targets established for the most critical period (summer), the TMDL will inherently be protective of water quality during the other seasons.

4.10.6 Lake Nutrient Load Allocation Methodology

Nutrient reduction strategies must be developed for each lake, which must be tailored to watershed conditions, internal loading, septic loading, biologic conditions, and upstream lakes. The magnitude of phosphorus loading in each lake was assessed in Table 3-13. A uniform methodology was established to assign load reductions to each phosphorus source. The steps for phosphorus reductions are as follows:

- Loading from septic systems is reduced to zero since properly functioning septic systems should have zero phosphorus export.
- If there is an upstream lake that is currently not meeting phosphorus standards, phosphorus concentrations will be reduced to the lake eutrophication standards. If there are no upstream lakes exceeding Minnesota eutrophication standards this step is skipped.
- Watershed loading will ideally be reduced until the lake response model indicates the lake is meeting lake eutrophication water quality standards. Watershed loading will be incrementally reduced until watershed TP concentrations meet river/stream eutrophication standards. If the lake is still not meeting water quality standards and watershed phosphorus concentrations have been reduced to meet the river/stream eutrophication standards, the remaining phosphorus reduction will be taken from internal loading.
- Internal phosphorus loading is the final reduction source. Internal phosphorus release will be reduced for a given lake until lake phosphorus eutrophication standard is met or until phosphorus release rates reach 0.1 mg/m^2/day. If in-lake phosphorus eutrophication standards are not met after this step, further phosphorus reduction will be achieved by reducing watershed runoff concentrations beyond the river eutrophication standards.

4.10.7 TMDL Summary

The allowable TP load (TMDL) for each lake was divided among the WLA, LA, and the MOS as described in the preceding sections. The following tables summarize the existing and allowable TP loads, the TMDL allocations, and required reductions for each lake. In these tables the total load reduction is the sum of the required WLA reductions plus the required LA reductions; this is not the same as the net difference between the existing and allowable total loads, however, because the WLA and LA reductions must accommodate the MOS.

The following rounding conventions were used in the TMDL tables:

- Values ≥0.1 reported in lbs/yr have been rounded to the nearest tenth of a pound.
- Values <0.1 reported in lbs/yr have been rounded to enough significant digits so that the value is greater than zero and a number is displayed in the table.
- Values ≥0.01 reported in lbs/day have been rounded to the nearest hundredth of a pound.
- Values <0.01 reported in lbs/day have been rounded to enough significant digits so that the value is greater than zero and a number is displayed in the table.
- While some of the numbers in the tables show multiple digits, they are not intended to imply great precision; this is done primarily to make the arithmetic accurate.

Tables 4-17 through 4-39 present the allocations for the impaired lakes in the South Fork Crow River Watershed.

Table 4-17. Preston Lake TP TMDL summary (shallow lake, WCBP ecoregion, located in the Judicial Ditch 28A Major Subwatershed)

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr[1]	%
Wasteload	**Total WLA**	3.5	0.01	3.5	0.01	0.0	**0%**
	Construction and Industrial Stormwater	3.5	0.01	3.5	0.01	0.0	**0%**
Load	**Total LA**	4,603.5	12.60	3,000.6	8.22	1,602.9	**35%**
	Drainage Areas	2,456.3	6.72	1,415.7	3.88	1040.6	**42%**
	Upstream Lake (Allie)	1,818.0	4.98	1,272.0	3.48	546.0	**30%**
	Atmosphere	152.1	0.42	152.1	0.42	0.0	**0%**
	Internal Load	160.8	0.44	160.8	0.44	0.0	**0%**
	SSTS	16.3	0.04	0.0	0.00	16.3	**100%**
MOS				333.8	0.91		
Total Load		**4,607.0**	**12.61**	**3,337.9**	**9.14**	**1,602.9**	35%

[1] Net reduction from current load to TMDL is 1,269.1 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 1,269.1 + 333.8 = 1,602.9 lbs/yr.
Model Calibration Years: 2008, 2009, 2010, and 2012

Table 4-18. Marion Lake TP TMDL summary (shallow lake, WCBP ecoregion, located in the Buffalo Creek Major Subwatershed)

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr[1]	%
Wasteload	**Total WLA**	5.8	0.02	5.8	0.02	0.0	**0%**
	Construction and Industrial Stormwater	5.8	0.02	5.8	0.02	0.0	**0%**
Load	**Total LA**	3,244.8	8.89	2,756.3	7.55	488.5	**15%**
	Drainage Areas	3,070.0	8.41	2603.8	7.13	466.2	**15%**
	Atmosphere	127.1	0.35	127.1	0.35	0.0	**0%**
	Internal Load	25.4	0.07	25.4	0.07	0.0	**0%**
	SSTS	22.3	0.06	0.0	0.00	22.3	**100%**
MOS				306.9	0.84		
Total Load		**3,250.6**	**8.91**	**3,069.0**	**8.41**	**488.5**	15%

[1] Net reduction from current load to TMDL is 181.6 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 181.6 + 306.9 = 488.5 lbs/yr.
Model Calibration Years: 2006, 2008, 2010, 2011, 2012, and 2013

Table 4-19. Big Kandiyohi Lake TP TMDL summary (shallow lake, WCBP ecoregion, located in the Headwaters – South Fork Crow Major Subwatershed)

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr[1]	%
Wasteload	**Total WLA**	1.9	0.005	1.9	0.005	0.0	**0%**
	Construction and Industrial Stormwater	1.9	0.005	1.9	0.005	0.0	**0%**
Load	**Total LA**	29,686.2	81.27	8,909.7	24.40	20,776.6	**70%**
	Drainage Areas	1,706.2	4.67	449.0	1.23	1,257.3	**74%**
	Upstream Lake (Wakanda)	9,124.6	24.98	1,204.6	3.30	7,920.0	**87%**
	Atmosphere	639.0	1.75	639.0	1.75	0.0	**0%**
	Internal Load	18,193.3	49.81	6,617.1	18.12	11,576.2	**64%**
	SSTS	23.1	0.06	0.0	0.00	23.1	**100%**
MOS				990.2	2.71		
Total Load		**29,688.1**	**81.28**	**9,901.8**	**27.12**	**20,776.6**	**70%**

[1] Net reduction from current load to TMDL is 19,786.4 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 19,786.4 + 990.2 = 20,776.6 lbs/yr.
Model Calibration Years: 2005 and 2006

Table 4-20. Johnson Lake TP TMDL summary (shallow lake, WCBP ecoregion, located in the Headwaters – South Fork Crow Major Subwatershed)

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr[1]	%
Wasteload	**Total WLA**	0.2	0.0005	0.2	0.0005	0.0	**0%**
	Construction and Industrial Stormwater	0.2	0.0005	0.2	0.0005	0.0	**0%**
Load	**Total LA**	493.7	1.35	127.1	0.35	366.7	**74%**
	Drainage Areas	205.9	0.56	77.4	0.21	128.6	**62%**
	Atmosphere	24.2	0.07	24.2	0.07	0.0	**0%**
	Internal Load	263.0	0.72	25.5	0.07	237.5	**90%**
	SSTS	0.6	0.002	0.0	0.00	0.6	**100%**
MOS				14.1	0.04		
Total Load		**493.9**	**1.35**	**141.4**	**0.39**	**366.7**	**74%**

[1] Net reduction from current load to TMDL is 352.4 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 352.4 + 14.1 = 366.7 lbs/yr.
Model Calibration Years: 2005 and 2006

Table 4-21. Kasota Lake TP TMDL summary (shallow lake, WCBP ecoregion, located in the Headwaters – South Fork Crow Major Subwatershed)

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr[1]	%
Wasteload	**Total WLA**	1.4	0.004	1.4	0.004	0.0	**0%**
	Construction and Industrial Stormwater	1.4	0.004	1.4	0.004	0.0	**0%**
Load	**Total LA**	13,748.5	37.63	1,571.0	4.30	12,177.5	**89%**
	Drainage Areas	2,491.7	6.82	612.1	1.68	1,879.6	**75%**
	Upstream Lake (Minnetaga)	1,625.6	4.45	541.9	1.48	1,083.7	**67%**
	Atmosphere	103.8	0.28	103.8	0.28	0.0	**0%**
	Internal Load	9,505.4	26.02	313.2	0.86	9,192.2	**97%**
	SSTS	22.0	0.06	0.0	0.00	22.0	**100%**
MOS				174.7	0.48		
Total Load		**13,749.9**	**37.63**	**1,747.1**	**4.78**	**12,177.5**	**89%**

[1] Net reduction from current load to TMDL is 12,002.7 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 12,002.7 + 174.7 = 12,177.5 lbs/yr.
Model Calibration Years: 2006 and 2007

Table 4-22. Lillian Lake TP TMDL summary (shallow lake, WCBP major subwatershed, located in the Headwaters – South Fork Crow Major Subwatershed)

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr[1]	%
Wasteload	**Total WLA**	1.8	0.005	1.8	0.005	0.0	**0%**
	Construction and Industrial Stormwater	1.8	0.005	1.8	0.005	0.0	**0%**
Load	**Total LA**	8,112.3	22.20	4,749.7	13.00	3,362.7	**41%**
	Drainage Areas	888.5	2.43	888.5	2.43	0.0	**0%**
	Upstream Lakes	6,213.8	17.01	2,851.2	7.81	3,362.6	**54%**
	Atmosphere	267.4	0.73	267.4	0.73	0	**0%**
	Internal Load	742.6	2.03	742.6	2.03	0	**0%**
MOS				527.9	1.45		
Total Load		**8,114.1**	**22.21**	**5,279.4**	**14.45**	**3,362.7**	**41%**

[1] Net reduction from current load to TMDL is 2,834.7 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 2,834.7 + 527.9 = 3,362.7 lbs/yr.
Model Calibration Years: 2008 and 2009

Table 4-23. Little Kandiyohi Lake TP TMDL summary (shallow lake, WCBP ecoregion, located in the Headwaters – South Fork Crow Major Subwatershed)

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr[1]	%
Wasteload	Total WLA	1.6	0.005	1.6	0.005	0.0	**0%**
	Construction and Industrial Stormwater	1.6	0.005	1.6	0.005	0.0	**0%**
Load	Total LA	12,267.5	33.59	2,328.1	6.73	9,939.4	**81%**
	Drainage Areas	1,458.4	3.99	692.0	1.89	766.4	**53%**
	Upstream Lakes (Kasota)	5,772.9	15.81	1,252.7	3.43	4,520.2	**78%**
	Atmosphere	160.0	0.44	160.0	0.44	0.0	**0%**
	Internal Load	4,568.9	12.51	223.4	0.61	4,345.5	**95%**
	SSTS	307.3	0.84	0.0	0.00	307.3	**100%**
MOS				258.9	0.71		
Total Load		**12,269.1**	**33.60**	**2,588.6**	**7.08**	**9,939.4**	**81%**

[1] Net reduction from current load to TMDL is 9,680.6 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 9,680.6 + 258.9 = 9,680.5 lbs/yr.
Model Calibration Years: 2006, 2007 and 2008

Table 4-24. Minnetaga Lake TP TMDL summary (shallow lake, WCBP ecoregion, located in the Headwaters – South Fork Crow Major Subwatershed)

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr[1]	%
Wasteload	Total WLA	3.2	0.01	3.2	0.01	0.0	**0%**
	Construction and Industrial Stormwater	3.2	0.01	3.2	0.01	0.0	**0%**
Load	Total LA	10,237.3	28.03	1,949.9	5.34	8,287.3	**81%**
	Drainage Areas	3,744.0	10.25	1,499.6	4.11	2,244.4	**60%**
	Atmosphere	183.1	0.50	183.1	0.50	0.0	**0%**
	Internal Load	6,310.2	17.28	267.2	0.73	6,042.9	**96%**
MOS				217.0	0.59		
Total Load		**10,240.5**	**28.04**	**2,170.1**	**5.94**	**8,287.3**	**81%**

[1] Net reduction from current load to TMDL is 8,070.3 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 8,070.3 + 217.0 = 8,287.3 lbs/yr.
Model Calibration Years: 2008 and 2009

Table 4-25. Thompson Lake TP TMDL summary (shallow lake, WCBP ecoregion, located in the Headwaters – South Fork Crow Major Subwatershed)

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr[1]	%
Wasteload	Total WLA	1.1	0.003	1.1	0.003	0.0	**0%**
	Construction and Industrial Stormwater	1.1	0.003	1.1	0.003	0.0	**0%**
Load	Total LA	1,796.1	4.91	675.9	1.84	1,120.2	**62%**
	Drainage Areas	1,381.3	3.78	487.4	1.33	893.9	**65%**
	Atmosphere	52.2	0.14	52.2	0.14	0.0	**0%**
	Internal Load	337.9	0.92	136.3	0.37	201.6	**60%**
	SSTS	24.74	0.07	0.0	0.00	24.7	**100%**
MOS				75.2	0.21		
Total Load		**1,797.2**	**4.91**	**752.2**	**2.05**	**1,120.2**	**62%**

[1] Net reduction from current load to TMDL is 1,045.0 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 1,045.0 + 75.2 = 1,120.2 lbs/yr.
Model Calibration Years: 2009 and 2010

Table 4-26. Wakanda Lake TP TMDL summary (shallow lake, WCBP ecoregion, located in the Headwaters - South Fork Crow Major Subwatershed)

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr[1]	%
Wasteload	Total WLA	4,014.0	10.99	2,515.1	6.89	1,498.8	**37%**
	Construction and Industrial Stormwater	12.9	0.04	12.9	0.04	0.0	**0%**
	Willmar City MS4	4,001.1	10.95	2,502.2	6.85	1,498.8	**37%**
Load	Total LA	11,998.4	32.85	4,496.7	12.32	7,501.8	**63%**
	Drainage Areas	5,699.0	15.60	3,564.2	9.76	2,134.9	**37%**
	Atmosphere	441.0	1.21	441.0	1.21	0.0	**0%**
	Internal Load	5,801.3	15.88	491.5	1.35	5,309.8	**92%**
	SSTS	57.1	0.16	0.0	0.00	57.1	**100%**
MOS				779.1	2.13		
Total Load		**16,012.4**	**43.84**	**7,790.9**	**21.34**	**9,000.6**	**56%**

[1] Net reduction from current load to TMDL is 8,221.5 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 8,221.5.0 + 779.1 = 9,000.6lbs/yr.
Model Calibration Years: 2005

Table 4-27. Cedar Lake TP TMDL summary (shallow lake, NCHF ecoregion, located in the Hutchinson – South Fork Crow Major Subwatershed)

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr[1]	%
Wasteload	**Total WLA**	2.1	0.01	2.1	0.01	0.0	**0%**
	Construction and Industrial Stormwater	2.1	0.01	2.1	0.01	0.0	**0%**
Load	**Total LA**	5,964.1	16.32	2,231.9	6.12	3,732.2	**63%**
	Drainage Areas	2,779.3	7.61	929.7	2.55	1,849.6	**67%**
	Upstream Lakes	175.8	0.48	162.8	0.45	13.0	**7%**
	Atmosphere	442.9	1.21	442.9	1.21	0.0	**0%**
	Internal Load	2,521.5	6.90	696.5	1.91	1,825.0	**72%**
	SSTS	44.6	0.12	0.0	0.00	44.6	**100%**
MOS				248.2	0.68		
Total Load		**5,966.2**	**16.33**	**2,482.2**	**6.81**	**3,732.2**	**63%**

[1] Net reduction from current load to TMDL is 3,484.0 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 3,484.0 + 248.2 = 3,732.2 lbs/yr.
Model Calibration Years: 2006 and 2008

Table 4-28. Greenleaf Lake TP TMDL summary (shallow lake, NCHF ecoregion, located in the Hutchinson – South Fork Crow Major Subwatershed)

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr[1]	%
Wasteload	**Total WLA**	0.2	0.001	0.2	0.001	0.0	**0%**
	Construction and Industrial Stormwater	0.2	0.001	0.2	0.001	0.0	**0%**
Load	**Total LA**	693.2	1.90	439.4	1.21	253.8	**37%**
	Drainage Areas	172.8	0.47	83.5	0.23	89.3	**52%**
	Atmosphere	57.3	0.16	57.3	0.16	0.0	**0%**
	Internal Load	451.5	1.24	298.6	0.82	152.9	**34%**
	SSTS	11.6	0.03	0.0	0.00	11.6	**100%**
MOS				48.9	0.13		
Total Load		**693.4**	**3.77**	**488.5**	**1.34**	**253.8**	**37%**

[1] Net reduction from current load to TMDL is 204.9 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 204.9 + 48.9 = 253.8lbs/yr. Model Calibration Years: 2007 and 2008

Table 4-29. Goose Lake TP TMDL summary (shallow lake, WCBP ecoregion, located in the Hutchinson – South Fork Crow Major Subwatershed)

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr[1]	%
Wasteload	**Total WLA**	0.2	0.0005	0.2	0.0005	0.0	**0%**
	Construction and Industrial Stormwater	0.2	0.0005	0.2	0.0005	0.0	**0%**
Load	**Total LA**	2,260.7	6.19	162.3	0.44	2,098.4	**93%**
	Drainage Areas	411.5	1.13	76.2	0.21	335.3	**81%**
	Atmosphere	23.4	0.06	23.4	0.06	0.0	**0%**
	Internal Load	1,822.2	4.99	62.7	0.17	1,759.5	**97%**
	SSTS	3.6	0.01	0.0	0.00	3.6	**100%**
MOS				18.1	0.05		
Total Load		2,260.9	6.19	180.6	0.49	2,089.4	**93%**

[1] Net reduction from current load to TMDL is 2,071.3 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 2,071.3+ 18.1 = 2,089.4 lbs/yr.
Model Calibration Years: 2012 and 2013

Table 4-30. Hoff Lake TP TMDL summary (shallow lake, WCBP ecoregion, located in the Hutchinson – South Fork Crow Major Subwatershed)

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr[1]	%
Wasteload	**Total WLA**	4.8	0.01	4.8	0.01	0.0	**0%**
	Construction and Industrial Stormwater	4.8	0.01	4.8	0.01	0.0	**0%**
Load	**Total LA**	7,910.8	21.66	5,296.2	14.51	2,614.6	**33%**
	Drainage Areas	3,025.2	8.28	1,808.2	4.95	1,217.0	**40%**
	Upstream Lakes	4,391.1	12.02	2,997.0	8.21	1,394.1	**32%**
	Atmosphere	36.1	0.10	36.1	0.10	0.0	**0%**
	Internal Load	454.9	1.25	454.9	1.25	0.0	**0%**
	SSTS	3.5	0.01	0.0	0.00	3.5	**100%**
MOS				589.0	1.61		
Total Load		**7,915.6**	**21.67**	**5,890.0**	**16.13**	**2,614.6**	**33%**

[1] Net reduction from current load to TMDL is 2,025.6 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 2,025.6 + 589.0 = 2,614.6 lbs/yr.
Model Calibration Years: 2010 and 2011

Table 4-31. Star Lake TP TMDL summary (shallow lake, WCBP ecoregion, located in the Hutchinson – South Fork Crow Major Subwatershed)(This lake is not on the 2016 303(d) list, however is proposed on the 2018 list.)

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr[1]	%
Wasteload	**Total WLA**	0.7	0.002	0.7	0.002	0.0	**67%**
	Construction and Industrial Stormwater	0.7	0.002	0.7	0.002	0.0	**0%**
Load	**Total LA**	2,196.7	6.01	1,113.9	3.05	1,082.8	**49%**
	Drainage Areas	1,040.2	2.85	306.1	0.84	734.1	71%
	Atmosphere	132.2	0.36	132.2	0.36	0.0	0%
	Internal Load	1,024.3	2.80	675.6	1.85	348.7	34%
MOS				34.0	0.09		
Total Load		2,197.4	6.01	1,148.6	3.14	1,082.8	**49%**

[1] Net reduction from current load to TMDL is 1,048.8 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 1,048.8 + 34.0 = 1,082.8 lbs/yr.
Model Calibration Years: 2009 and 2010

Table 4-32. Belle Lake TP TMDL summary (deep Lake, NCHF ecoregion, located in the Hutchinson – South Fork Crow Major Subwatershed)

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr[1]	%
Wasteload	**Total WLA**	0.05	0.0001	0.05	0.0001	0.0	**0%**
	Construction and Industrial Stormwater	0.05	0.0001	0.05	0.0001	0.0	**0%**
Load	**Total LA**	2,035.4	5.56	1,038.4	2.84	997.0	**49%**
	Drainage Areas	490.6	1.34	25.2	0.07	465.4	**95%**
	Upstream Lakes	77.1	0.21	77.1	0.21	0.0	**0%**
	Atmosphere	219.6	0.60	219.6	0.60	0.0	**0%**
	Internal Load	1,228.3	3.36	716.5	1.96	511.8	**42%**
	SSTS	19.8	0.05	0	0	19.8	**100%**
MOS				115.4	0.32		
Total Load		**2,035.5**	**5.56**	**1,153.9**	**3.16**	**997.0**	49%

[1] Net reduction from current load to TMDL is 881.6 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 881.6 + 115.4 = 997.0 lbs/yr.
Model Calibration Years: 2008, 2009, and 2013

Table 4-33. Willie Lake TP TMDL summary (shallow lake, NCHF ecoregion, located in the Hutchinson – South Fork Crow Major Subwatershed)

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr[1]	%
Wasteload	**Total WLA**	4.7	0.01	4.7	0.01	0.0	**0%**
	Construction and Industrial Stormwater	4.7	0.01	4.7	0.01	0.0	**0%**
Load	**Total LA**	2,623.9	7.18	2,302.7	6.30	321.1	**12%**
	Drainage Areas	2,335.5	6.39	2,079.1	5.69	256.4	**11%**
	Upstream Lake (Greenleaf)	211.2	0.58	171.2	0.47	39.9	**19%**
	Atmosphere	44.7	0.12	44.7	0.12	0.0	**0%**
	Internal Load	7.7	0.02	7.7	0.02	0	**0%**
	SSTS	24.8	0.07	0.0	0.00	24.8	**100%**
MOS				256.4	0.70		
Total Load		**2,628.6**	**7.19**	**2,563.8**	**7.01**	**321.1**	**12%**

[1] Net reduction from current load to TMDL is 64.8 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 64.8 + 256.4 = 321.1 lbs/yr.
Model Calibration Years: 2010 and 2011

Table 4-34. Bear Lake TP TMDL summary (shallow lake, NCHF ecoregion, located in the Lester Prairie – South Fork Crow Major Subwatershed)

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/da y	lbs/yr	lbs/day	lbs/yr[1]	%
Wasteload	**Total WLA**	0.2	0.001	0.2	0.001	0.0	**0%**
	Construction and Industrial Stormwater	0.2	0.001	0.2	0.001	0.0	**0%**
Load	**Total LA**	1,622.1	4.44	219.9	0.60	1,402.2	**86%**
	Drainage Areas	272.8	0.75	91.3	0.25	181.5	**67%**
	Atmosphere	37.6	0.10	37.6	0.10	0.0	**0%**
	Internal Load	1,311.3	3.59	91.0	0.25	1,220.3	**93%**
	SSTS	0.4	0.001	0.0	0.00	0.4	**100%**
MOS				24.5	0.07		
Total Load		**1,622.3**	**4.44**	**244.6**	**0.67**	**1,402.2**	**86%**

[1] Net reduction from current load to TMDL is 1,377.7 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 1,377.7 + 24.5 = 1,402.2 lbs/yr.
Model Calibration Years: 2011

Table 4-35. Boon Lake TP TMDL summary (shallow lake, WCBP ecoregion, located in the Lester Prairie – South Fork Crow Major Subwatershed)

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr[1]	%
Wasteload	Total WLA	2.2	0.01	2.2	0.01	0.0	**0%**
	Construction and Industrial Stormwater	2.2	0.01	2.2	0.01	0.0	**0%**
Load	Total LA	6,356.0	17.41	1,700.2	4.66	4.655.8	**73%**
	Drainage Areas	1,590.7	4.36	978.4	2.68	612.3	**38%**
	Atmosphere	182.5	0.50	182.5	0.50	0.0	**0%**
	Internal Load	4,556.9	12.48	539.3	1.48	4,017.6	**88%**
	SSTS	25.9	0.07	0.0	0.00	25.9	**100%**
MOS				189.2	0.52		
Total Load		**6,358.2**	**17.42**	**1,891.6**	**5.19**	**4,655.8**	**73%**

[1] Net reduction from current load to TMDL is 4,466.6 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 4,466.6 +189.2= 4,655.8 lbs/yr.
Model Calibration Years: 2008 and 2009

Table 4-36. Silver Lake TP TMDL summary (shallow lake, WCBP ecoregion, located in the Lester Prairie – South Fork Crow Major Subwatershed)

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr[1]	%
Wasteload	Total WLA	0.8	0.002	0.8	0.002	0.0	**0%**
	Construction and Industrial Stormwater	0.8	0.002	0.8	0.002	0.0	**0%**
Load	Total LA	6,108.3	16.73	874.2	2.4	5,234.2	**86%**
	Drainage Areas	519.8	1.42	334.3	0.92	185.5	**36%**
	Atmosphere	100.6	0.28	100.6	0.28	0.0	**0%**
	Internal Load	5,484.9	15.02	439.3	1.20	5045.7	**92%**
	SSTS	3.0	0.008	0.0	0.00	3.0	**100%**
MOS				97.2	0.27		
Total Load		**6,109.1**	**16.73**	**972.2**	**2.67**	**5,234.2**	**86%**

[1] Net reduction from current load to TMDL is 5,137.0 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 5,137.0 + 97.2 = 5,234.2 lbs/yr.
Model Calibration Years: 2006 and 2011

Table 4-37. Winsted Lake TP TMDL summary (shallow lake, NCHF ecoregion, located in the Lester Prairie – South Fork Crow Major Subwatershed)

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr[1]	%
Wasteload	Total WLA	3.9	0.01	3.9	0.01	0.0	**0%**
	Construction and Industrial Stormwater	3.9	0.01	3.9	0.01	0.0	**0%**
Load	Total LA	15,448.0	42.29	1,950.4	5.35	13,497.6	**87%**
	Drainage Areas	10,812.8	29.60	1,744.3	4.78	9,068.5	**84%**
	Upstream Lake (South)	901.1	2.47	93.8	0.26	807.3	**90%**
	Atmosphere	86.4	0.24	86.4	0.24	0.0	**0%**
	Internal Load	3,628.1	9.93	25.9	0.07	3,602.2	**99%**
	SSTS	19.6	0.05	0.0	0.00	19.6	**100%**
MOS				217.1	0.59		
Total Load		**15,451.9**	**42.30**	**2,171.4**	**5.95**	**13,497.6**	**87%**

[1] Net reduction from current load to TMDL is 13,280.5 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 13,280.5 + 217.1 = 13,497.6 lbs/yr.
Model Calibration Years: 2008 and 2010

Table 4-38. Mud Lake TP TMDL summary (shallow lake, NCHF ecoregion, located in the South Fork Crow River Major Subwatershed)

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr[1]	%
Wasteload	Total WLA	331.0	0.90	91.9	0.25	239.1	**72%**
	Construction and Industrial Stormwater	1.3	0.003	1.3	0.003	0.0	**0%**
	Minnetrista City MS4	329.7	0.90	90.6	0.25	239.1	**73%**
Load	Total LA	2,342.8	6.42	573.6	1.57	1,769.1	**76%**
	Drainage Areas	1,700.8	4.66	467.8	1.28	1,233.0	**72%**
	Upstream Lakes	221.5	0.61	39.8	0.11	181.7	**82%**
	Atmosphere	52.9	0.14	52.9	0.14	0.0	**0%**
	Internal Load	367.3	1.01	13.1	0.04	354.1	**96%**
	SSTS	0.3	0.0007	0.0	0.00	0.3	**100%**
MOS				73.9	0.20		
Total Load		**2,673.8**	**7.32**	**739.4**	**2.02**	**2,008.2**	**75%**

[1] Net reduction from current load to TMDL is 1,934.3 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 1,934.3 + 73.9 = 2,008.2 lbs/yr.
Model Calibration Years: 2010 and 2011

Table 4-39. Rice Lake TP TMDL summary (shallow lake, NCHF ecoregion, located in the S South Fork Crow Major Subwatershed)

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	**lbs/day**	**lbs/yr**	**lbs/day**	**lbs/yr[1]**	**%**
Wasteload	**Total WLA**	1,162.1	318	214.0	0.58	948.0	**82%**
	Construction and Industrial Stormwater	0.6	0.002	0.6	0.002	0.0	**0%**
	Independence City MS4	755.5	2.07	138.7	0.38	616.8	**82%**
	Maple Plain City MS4	43.7	0.12	8.1	0.02	35.5	**82%**
	Minnetrista City MS4	362.3	0.99	66.6	0.18	295.7	**82%**
Load	**Total LA**	2,578.0	7.06	274.5	0.75	2,303.5	**89%**
	Drainage Areas (Non-MS4)	263.0	0.72	48.2	0.13	214.8	**82%**
	Upstream Lakes[2]	484.4	1.33	182.6	0.50	301.8	**62%**
	Atmosphere	33.9	0.09	33.9	0.09	0.0	**0%**
	Internal Load	1,743.2	4.77	9.8	0.03	1,733.4	**99%**
	SSTS	53.5	0.15	0.0	0.00	53.5	**100%**
MOS				54.3	0.15		
Total Load		3,740.0	10.23	542.8	1.49	**3,251.5**	87%

[1] Net reduction from current load to TMDL is 3,197.2 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 3,197.2 + 54.3 = 3,251.5 lbs/yr.
[2] Upstream lakes incorporated in the model include Independence, Oak, Mud, Irene, Robina, Whaletail (North)
Model Calibration Years: 2010 and 2011

5 Future Growth Considerations

5.1 New or Expanding Permitted MS4 WLA Transfer Process

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

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

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

5.2 New or Expanding Wastewater (TSS and *E. coli* TMDLs only)

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

For more information on the overall process, visit the MPCA’s TMDL Policy and Guidance webpage.

6 Reasonable Assurance

Reasonable assurance (RA) activities are programs that are in place to assist in attaining the TMDL allocations and applicable water quality standards. The development of a rigorous RA demonstration includes both state and local regulatory oversight, funding, implementation strategies, follow-up monitoring, progress tracking, and adaptive management. (Note: Some of these elements are described in Sections 6.0 and 7.0.)

The goals outlined in this TMDL study are consistent with and inform objectives outlined in the local county water management plans. These plans have the objective of implementing strategies called for in WRAPS/TMDLs through targeted actions to bring impaired waters into compliance with appropriate water quality standards, and thereby establish the basis for removing those impaired waters from the 303(d) Impaired Waters List. These plans provide the watershed management framework for addressing water quality issues. In addition, the stakeholder processes associated with this TMDL effort, as well as the broader planning efforts mentioned previously, have generated commitment and support from the local government units (LGUs) affected by this TMDL, and will help ensure that this TMDL project is carried successfully through implementation.

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

- Federal Section 319 Grants for watershed improvements (These will, after 2020, be available only to a small group of HUC 10 or HUC 12 subwatersheds).
- Funds ear-marked to support TMDL implementation from the Clean Water, Land, and Legacy constitutional amendment, approved by the state's citizens in November 2008.
- Watershed District cost-share funds
- Local government funds
- SWCD cost-share funds
- NRCS cost-share funds
- Local Lake Association funds

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

6.1 Regulatory Approaches

NPDES Phase II MS4 Stormwater Permits are in place for some of the cities in the South Fork Crow River Watershed. Under the stormwater program, permit holders are required to develop and implement a Stormwater Pollution Prevention Plan (SWPPP; MPCA 2004). The SWPPP must cover six minimum control measures:

- Public education and outreach;

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

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

The MPCA's MS4 General Permit requires MS4 permittees to provide reasonable assurances that progress is being made toward achieving all WLAs in TMDLs approved by the EPA prior to the effective date of the permit. The current permit was made effective August 1, 2013, meaning regulatory requirements resulting from the South Fork Crow River Watershed TMDLs will not be enforced until the subsequent permit term. In doing so, they must determine if they are currently meeting their WLA(s). If the WLA is not being achieved at the time of application, a compliance schedule is required that includes interim milestones, expressed as BMPs, that will be implemented over the current five-year permit term to reduce loading of the pollutant of concern in the TMDL. Additionally, a long-term implementation strategy and target date for fully meeting the WLA must be included.

6.2 Local Management

6.2.1 Crow River Organization of Water (CROW)

Portions of 10 counties in Central Minnesota make up the Crow River Watershed, which includes both the South Fork and North Fork Crow Rivers. From the perspective of the Upper Mississippi River Basin, the Crow River is one of the major tributaries to the Mississippi River. The effects of rapid urban growth, new and expanding wastewater facilities, and erosion from agricultural lands have been common concerns of many citizens, and local, state, and regional governments in Central Minnesota. As a result, many parties began meeting in 1998 to discuss management of the Crow River sub-basin consisting of the South Fork and North Fork Crow River Watersheds. The CROW was formed in 1999 as a result of heightened interest in the Crow River. A Joint Powers Agreement was signed by all 10 of the counties with land in the Crow River Watersheds. The CROW Joint Powers Board is made up of one representative from each of the county boards who signed the agreement. The counties involved in the CROW Joint Powers Board include Carver, Hennepin, Kandiyohi, McLeod, Meeker, Pope, Renville, Sibley, Stearns and Wright. The CROW currently focuses on identifying and promoting the following:

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

In the fall of 2011, the CROW and local partners began working with the MPCA's new WRAPS approach in the South Fork Crow River Watershed. See the WRAPS report developed concurrently with this TMDL report for more details.

Specific practices that can be successfully implemented to address the loading reductions required for these TMDLs are identified in Sections 8.3.1-8.3.4 of this document. The organizations listed below have the technical expertise to identify and implement the correct BMPs for each parameter.

6.2.2 Soil and Water Conservation Districts

SWCDs plan and execute policies, programs, and projects, which conserve the soil and water resources within their jurisdictions. They are particularly concerned with erosion of soil due to wind and water. The SWCDs are heavily involved in the implementation of practices that effectively reduce or prevent erosion, sedimentation, siltation, and agricultural-related pollution in order to preserve water and soil as resources. The Districts frequently act as local sponsors for many types of agricultural BMP projects, including grassed waterways, on-farm terracing, erosion control structures, and flow control structures. The CROW has established close working relationships with the SWCDs on a variety of projects. One example is a conservation buffer strip cash incentive program that provided cash incentives to create permanent grass buffer strips adjacent to waterbodies and water courses on land in agricultural use. SWCDs are key organizations providing local capacity to ensure implementation actions are taken. SWCDs that are active in the South Fork Crow River watershed and can provide the technical expertise necessary to identify potential projects and implement them include Carver SWCD, Kandiyohi SWCD, McLeod SWCD, Renville SWCD, Sibley SWCD, and Wright SWCD. Additional personnel with technical expertise include staff from the City of Hutchinson, the City of Winsted, the City of Glencoe, Kandiyohi County, McLeod County, Renville County, and Wright County.

6.2.3 Watershed Districts

The South Fork Crow River Basin has one watershed district, the Buffalo Creek Watershed District. Goals for the district include: help alleviate water problems, enhance the living conditions of the area, and maintain or improve the economic wellbeing of the residents of the District. CROW works with the Buffalo Creek Watershed District to implement conservation programs and educational outreach. Buffalo Creek Watershed District has a management plan to address drainage and water quality concerns.

7 Monitoring Plan

Two types of monitoring are necessary to track progress toward achieving the load reduction required in the TMDL and the attainment of water quality standards. The first type of monitoring is tracking implementation of BMPs on the ground. The CROW, SWCDs, and Buffalo Creek Watershed District will track the implementation of these projects annually. The second type of monitoring is physical and chemical monitoring of the resource. The CROW plans to monitor the affected resources on a 10-year cycle.

This type of effectiveness monitoring is critical in the adaptive management approach. Results of the monitoring identify progress toward benchmarks, as well as shape the next course of action for implementation. Adaptive management combined with obtainable benchmark goals and monitoring is the best approach for implementing TMDLs.

Funding mechanisms for effectiveness monitoring are limited, and compete against other funding priorities. However, there are a number of local entities that conduct monitoring in the South Fork Crow River Watershed including but not limited to the CROW, Buffalo Creek Watershed District, local SWCDs, cities, and counties. Local entities will continue to pursue funding to assess and monitor water quality in the South Fork Crow River Watershed to fill identified data gaps, measure progress toward implementation goals for both protection and restoration, and provide the basis for future planning and adaptive management. Some of the tools used by the local entities to measure implementation progress are:

- Annual local monitoring reports showing trends (if appropriate) and progress are produced, posted on websites, and distributed by the CROW, BCWD, and counties.
- Numbers of BMPs funded by state/federal funds are reported and tracked annually through the BWSR eLINK reporting system, which also calculates pollutant reductions.
- Annual reports and open houses highlight BMP protection and restoration projects.

Current Water Monitoring Efforts

Table 7-1 below depicts the ongoing water monitoring by entity in the South Fork Crow River Watershed.

Table 7-1. Water monitoring in the South Fork Crow River Watershed by entity

ENTITY	BASELINE	IMPLEMENTATION	FLOW	EFFECTIVENESS	TREND	VALIDATION
CROW	X					X
SWCD	X				X	X
DNR			X			
MPCA	X		X		X	

CROW: The CROW will continue to seek funding to help on-going monitoring for baseline conditions and validation of TMDL allocations. CROW will collaborate with local partners and the MPCA on large scale effectiveness monitoring.

DNR: The DNR will be collecting additional geomorphology data relating the pattern and profile of the main stem of the South Fork Crow River and many of the major tributaries. The preliminary plan includes data collection on at least two reaches of the main stem South Fork Crow River and data collection on the following major tributaries:

<u>Main stem</u>

- SFC at Cosmos
- SFC at Mayer

<u>Tributaries</u>

- J.D. 15 at Hector
- Cedar Creek at T.H. 7
- Otter Creek at CSAH 1
- Buffalo Creek at Buffalo Creek County Park

MPCA: Large scale effectiveness monitoring will be provided by the MPCA through on-going monitoring in the watershed, including the Watershed Pollutant Load Monitoring Network and the Intensive Watershed Monitoring (IWM) associated with the Watershed Approach. As part of the 10-year monitoring cycle, monitoring in the South Fork Crow Watershed will begin again in 2022, which will allow another round of watershed-wide data collection of biology, hydrology, and chemistry data that will be used for comparison with current conditions.

8 Implementation Strategy Summary

8.1 Implementation Framework

This section describes strategies and potential actions to reduce TSS, oxygen demanding substances, bacteria, and nutrient loads (TP) in the South Fork Crow River Watershed. These strategies are further developed in a separate, more detailed WRAPS report. The CROW and local water resource managers will coordinate on the selection, prioritization, and incorporation of implementation actions into local water plans, based on strategies identified in this TMDL and the WRAPS report, and implementation of those plans. The MPCA will work with regulated entities on meeting permit requirements based on the TMDLs.

8.2 Sources

8.2.1 MS4

The NPDES Permit requirements must be consistent with the assumptions and requirements of an approved TMDL and associated WLAs. For the purposes of this TMDL, the baseline year for implementation will be the mid-range year of the data years used for the lake response modeling (Table 8-1), the DO model, and development of the TSS and bacteria LDCs. Since the DO model and the TSS and bacteria LDCs were developed using the South Fork Crow River Watershed HSPF model, the baseline year will coincide with the mid-range year of the HSPF model simulation. The rationale for developing a baseline year is that projects undertaken recently may take a few years to influence water quality. Any waste load-reducing BMP implemented since the baseline year will be eligible to “count” toward an MS4’s load reductions. If a BMP was implemented during or just prior to the baseline year, the MPCA is open to presentation of evidence by the MS4 Permit holder to demonstrate that it should be considered as a credit. The WRAPS report for the South Fork Crow River Watershed was developed with input from stakeholders to determine the appropriate BMPs and implementation strategies to meet the MS4 goals for all the TMDLs presented in this report.

Table 8-1. Implementation baseline years.

Impairment	Data Years Used for TMDL Development	Baseline Year
TSS Impairments (HSPF)	2000 - 2013	2007
DO Impairment (HSPF)	2000 – 2013	2007
Bacteria Impairments (HSPF)	2000 – 2013	2007
Bear	2011	2011
Belle	2008-2009, 2013	2009
Big Kandiyohi	2005-2006	2006
Boon	2008-2009	2009
Cedar	2006, 2008	2008
Goose	2012-2013	2013
Greenleaf	2007-2008	2008
Hoff	2010-2011	2011
Johnson	2012-2013	2013
Kasota	2006-2007	2007
Lillian	2008-2009	2009
Little Kandiyohi	2006-2008	2007

Impairment	Data Years Used for TMDL Development	Baseline Year
Marion	2006, 2008, 2010-2013	2011
Minnetaga	2008-2009	2009
Mud	2010-2011	2011
Preston	2008-2010, 2012	2010
Rice	2010-2011	2011
Silver	2006, 2011	2011
Star	2009-2010	2009
Thompson	2011	2011
Wakanda	2005	2005
Willie	2010-2011	2011
Winsted	2008, 2010	2010

8.2.2 Construction Stormwater

The WLAs for stormwater discharges from sites where there is construction activity reflects the number of construction sites greater than one acre expected to be active in the watershed at any one time, and the BMPs and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at construction sites are defined in the State's NPDES/SDS General Stormwater Permit for Construction Activity (MNR100001). If a construction site owner/operator obtains coverage under the NPDES/SDS General Stormwater Permit and properly selects, installs, and maintains all BMPs required under the permit, including those related to impaired waters discharges and any applicable additional requirements found in Appendix A of the Construction General Permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. All local construction stormwater requirements must also be met.

8.2.3 Industrial Stormwater

The WLAs for stormwater discharges from sites where there is industrial activity reflects the number of sites in the watershed for which NPDES Industrial Stormwater Permit coverage is required, and the BMPs and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at the industrial sites are defined in the State's NPDES/SDS Industrial Stormwater Multi-Sector General Permit (MNR050000) or NPDES/SDS General Permit for Construction Sand and Gravel, Rock Quarrying and Hot Mix Asphalt Production facilities (MNG490000). If a facility owner/operator obtains stormwater coverage under the appropriate NPDES/SDS Permit and properly selects, installs, and maintains all BMPs required under the permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. All local stormwater management requirements must also be met.

8.2.4 Wastewater

There are several NPDES permitted wastewater dischargers located within the *E. coli* impaired reach watersheds. The DMRs for each facility were downloaded from the MPCA database to assess effluent bacteria levels. By rule, these facilities cannot discharge treated wastewater with fecal coliform concentrations that exceed 200 cfu/100 ml. DMR records show all facilities are currently meeting their effluent permit limits and state water quality standards for bacteria (Appendix A). Thus, no bacteria reductions or changes are needed for these facilities as long as they continue to employ their current treatment technologies to control bacteria in their effluent waters.

The Winsted WWTP (MN0021571) is located in the South Lake Watershed and is currently the only active permitted wastewater facility that discharges upstream of the impaired lakes in this study. Due to recent phosphorus discharge limits, the Winsted WWTP has decided to begin discharging to Crane Creek (07010205-646) downstream of South Lake. This strategy will decrease phosphorus loading to South Lake by approximately 795 pounds per year.

A TSS effluent evaluation was completed for the facilities with monthly average DMR monitoring data (January 2010 through March 2015) for sites included in Table 4-1. The monitoring data shows all facilities typically discharge at TSS concentrations below their permit limits. Less than 0.4% of the samples evaluated throughout the watershed exceeded the listed permit limit. Additionally, daily TSS data was evaluated at the major facilities (Delano, Hutchinson, and Glencoe). Less than 1% of all available samples were over the required 30 mg/L at the major facilities.

An effluent evaluation was also completed for ammonia and CBOD5 for the facilities with available monthly average DMR monitoring data included in Table 4-8 and Table 4-9. Permit limits for ammonia and CBOD5 varied by effluent stream, and therefore the data used for the effluent evaluation was only that where a limit was listed. The monitoring data shows all facilities typically discharge at ammonia and CBOD5 concentrations below the permit limits when permit limits were applicable. None of the monthly average CBOD5 samples evaluated (January 2010 through March 2015) in the Buffalo Creek Watershed were over their listed permit limit, and approximately 7% of the monthly average ammonia concentrations were greater than 1 mg/L. Daily CBOD5 and ammonia were evaluated at Glencoe, the major facility in the Buffalo Creek Watershed. Approximately 19% of the daily ammonia samples at Glencoe were above the ammonia concentration assumption of 1 mg/L. But, less than 1% of the daily CBOD5 samples at Glencoe were above the permitted concentration of 25 mg/L. Thus, no ammonia reductions or changes are needed for these facilities as long as they continue to employ their current treatment technologies to control ammonia in their effluent waters.

8.3 Strategies

8.3.1 TSS

Potential BMPs to reduce TSS loads to the South Fork Crow River Watershed impaired reaches are presented in Table 8-2. These potential BMPs, along with cost estimates, will be explored more thoroughly in the South Fork Crow River WRAPS Report. Please note that loading reduced from some of the implementation actions listed in Table 8-2 is creditable to the LA and some to the WLA. The strategy table does not specify the applicable allocation categories.

Table 8-2. Potential TSS reduction implementation strategies.

Potential BMP/Reduction Strategy
Streambank Stabilization/Buffer Enhancement – *Repair and stabilize degraded banks throughout the impaired reach. Establish vegetation (preferably native) to filter runoff from urban areas, cropland and pastures adjacent to the stream. All reaches should have at least 50 feet of buffer on both sides of the stream.*
Vegetative Practices – *Reduce sediment generation and transport through vegetative practices focusing on the establishment and protection of crop and non-crop vegetation to minimize sediment mobilization and transport. Recommended vegetative practices include grassed waterways and grass filter strips, alternative crop rotations, forest management, field windbreaks, rotational grazing, contour farming, strip cropping, cover crops, and others.*
Primary Tillage Practices – *Promote conservation tillage practices to reduce the generation and transport of soil from fields. Conservation tillage techniques emphasize the practice of leaving at least some vegetation cover or crop residue on fields as a means of reducing the exposure of the underlying soil to wind and water, which leads to erosion. If managed properly, conservation tillage can reduce soil erosion on active fields by up to two-thirds (Randall et. al. 2008).*
Urban BMPs – *promote urban BMPs such as infiltration, bioretention, increased street sweeping and others to reduce sediment runoff and transport.*
Education – *Provide educational and outreach opportunities about responsible tillage practice, vegetative management practices, and other BMPs to encourage good individual property management practices to reduce soil loss and upland erosion.*
Control Animal Access to the Stream – *Control and/or limit animal access to streambanks and areas near streams and rivers by installing fencing in pastures where access is unimpeded and installing buffer vegetation where existing fencing is directly adjacent to the stream bank.*

8.3.2 Dissolved Oxygen

As the CROW coordinates with its stakeholders on the details of this TMDL, some of the following BMPs may be selected to reduce oxygen demand in order achieve the Buffalo Creek DO TMDL:

- Targeted monitoring to further identify high loading areas and sources of low DO
- Channel morphology alteration
- Lake restorations
- Watershed nutrient reduction strategies
- Urban BMPs

These possible actions are further developed in the South Fork Crow WRAPS Report.

8.3.3 Bacteria (*E .coli*)

Table 8-3 lists BMPs that may be successful in reducing bacteria loads in the South Fork Crow River Watershed. These potential BMPs are explored more thoroughly in the accompanying WRAPS Report. Please note that loading reduced from some implementation actions listed in Table 8-3 is creditable to LA and some to the WLA. The strategy table does not specify the applicable allocation categories.

Table 8-3. Potential *E. coli* reduction implementation strategies.

Potential BMP/Reduction Strategy
Streambank Stabilization/Buffer Enhancement – *Stabilize vegetation to filter runoff from pastures adjacent to the stream. Enhancements should include at least 50 feet of buffer on both sides of the stream.*
Education – *Provide educational and outreach opportunities about proper manure management, grazing management, proper pet waste disposal, and other topics to encourage good individual property management practices.*
Pasture Management –*create alternate livestock watering systems, rotational grazing, and vegetated buffer strips between grazing land and surface water bodies.*
Manure Management – *Reduction of winter spreading, eliminate spreading near open inlets, apply at agronomic rates, erosion control practices, and manure stockpile runoff controls.*
Septic System Inspection Program Review - *Although not always a significant source of bacteria, counties should continue to inspect and order upgrades of existing septic systems, prioritizing properties near the impaired reaches and its tributaries.*
Control Animal Access to the Stream – *Control and/or limit animal access to streambanks and areas near streams and rivers, by installing fencing in pastures where access is unimpeded and installing buffer vegetation where existing fencing is directly adjacent to the stream bank.*
Pet Waste Management – *Review local ordinances and associated enforcement and fines for residents who do not clean up pet waste. Increase enforcement and education about compliance with such an ordinance.*

8.3.4 Nutrients (Phosphorus)

Table 8-4 lists BMPs that may be successful in reducing nutrient loads and managing lake water quality. Not all BMPs are necessarily appropriate or feasible for each lake covered in this TMDL report. These potential BMPs are explored more thoroughly, including costs and targeting the most appropriate BMPs for each waterbody, in the accompanying WRAPS Report. The CROW and the MS4s have been and will continue to implement BMPs, and have already undertaken similar projects in the lakesheds since the TMDL baseline year. Please note that loading reduced from some implementation actions listed in Table 8-4 is creditable to the LA and some to the WLA. The strategy table does not specify the applicable allocation categories.

Table 8-4. Potential nutrient reduction strategies.

Reduction Target	Potential BMP/Reduction Strategy
Watershed Load	**Education Programs –** *Provide education and outreach on low-impact lawn care practices, proper yard waste removal, and other topics to increase awareness of sources of pollutants.*
	Shoreline Restoration – *Encourage property owners to restore their shoreline with native plants and install/enhance shoreline buffers.*
	Raingarden/Bio-filtration Basins – *Encourage the use of rain gardens and similar features as a means of increasing infiltration and evapotranspiration. Opportunities may range from a single property owner to parks and open spaces.*
	Stormwater Pond Retrofits/Installation - *As opportunities arise, retrofit stormwater treatment through a variety of BMPs. Pond expansion and pre-treatment of water before it reaches the ponds may be beneficial dependent on drainage area. Also, identify target areas for new stormwater pond installation.*

Reduction Target	Potential BMP/Reduction Strategy
	Street Sweeping Program Review/Implementation *Identify target areas for increased frequency of street sweeping and consider upgrades to traditional street sweeping equipment.*
	Agricultural BMP Implementation – *Encourage property owners to implement agricultural BMPs for nutrient load reduction. The Agricultural BMP Handbook for Minnesota (MDA 2012) provides an inventory of agricultural BMPs that address water quality in Minnesota. Several examples include conservation cover, buffer strips, grade stabilization, controlled drainage, rotational grazing, and irrigation management, among many other practices.*
Internal Load	**Technical Review –** *Prior to internal load reduction strategy implementation, a technical review is recommended to evaluate the cost and feasibility of lake management techniques such as hypolimnetic withdrawal, alum treatment, and hypolimnetic aeration to manage internal nutrient sources.*
	In-lake chemical treatment – *If determined feasible based on technical review, chemically treat with alum or other means to remove phosphorus from the water column as well as bind it in sediments.*
	Hypolimnetic Withdrawal or Aeration – *If determined feasible based on technical review, pump nutrient-rich water from the hypolimnion to an external location for phosphorus treatment and discharge treated water back into the lake. Or as an alternate option, aerate the hypolimnetic waters to maintain oxic conditions (the anoxic condition of the hypolimnetic sediments is the contributor to the internal phosphorus load).*
	Aquatic Plant Surveys/Vegetation Management – *Conduct periodic aquatic plant surveys and prepare and implement vegetation management plans.*
	Rough Fish Surveys/Management – *Consider partnership with the DNR to monitor and manage the fish population. Evaluate options to reduce rough fish populations such as installation of fish barriers and carp removal to reduce rough fish access and migration.*

8.4 Adaptive Management

A list of implementation strategies in the WRAPS Report prepared in conjunction with this TMDL assessment should be viewed and used in the context of adaptive management (Figure 8-1). Continued monitoring and "course corrections" responding to monitoring results are the most appropriate long-term strategy for attaining the water quality goals established in this TMDL. Management activities will be changed or refined over time through local water planning and management efforts to efficiently meet the TMDL and lay the groundwork for de-listing the impaired waterbodies.

Adaptive management is an iterative implementation process that makes progress toward achieving water quality goals while using new data and information to reduce uncertainty and adjust implementation activities. The State of Minnesota has a unique opportunity to adaptively manage water resource plans and implementation activities every 10 years. This opportunity resulted from a voter-approved tax increase to improve state waters. The resulting interagency coordination effort is referred to as the Minnesota Water Quality Framework, which works to monitor and assess Minnesota's major watersheds every 10 years. This Framework supports ongoing implementation and adaptive management of conservation activities and watershed-based local planning efforts utilizing regulatory and non-regulatory means to achieve water quality standards.

Implementation of TMDL related activities can take many years, and water quality benefits associated with these activities can also take many years to accrue. As the pollutant source dynamics within the watershed are better understood, implementation strategies and activities will be adjusted and refined to efficiently meet the TMDL and lay the groundwork for de-listing the impaired reaches and lakes. The follow up water monitoring program outlined in Section 6 will be integral to the adaptive management approach, providing assurance that implementation measures are succeeding in attaining water quality standards. Adaptive management does not include changes to water quality standards or LCs. Any changes to water quality standards or LCs must be preceded by appropriate administrative processes, including public notice and an opportunity for public review and comment.

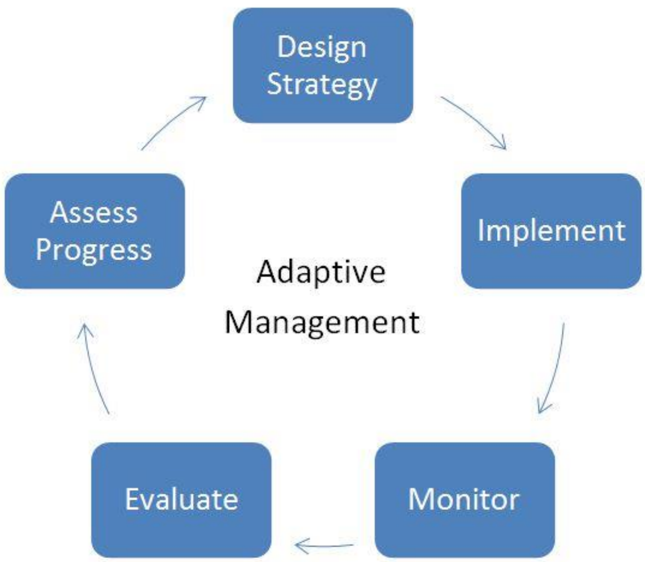

Figure 8-1. Adaptive management.

8.5 Cost

The CWLA requires that a TMDL include an overall approximation of the cost to implement a TMDL [Minn. Stat. 2007 § 114D.25].

Nutrients (Phosphorus)

A detailed analysis of the cost to implement the nutrient TMDLs was not conducted. However, as a rough approximation one can use some general results from BMP cost studies across the U.S. for example, an EPA summary of several studies showed a median life cycle cost of approximately $2,200 per pound TP removed for watershed BMPs (Foraste et al. 2012). Another recent review (Macbeth et al. 2015) of lake restoration projects performed throughout the State of Minnesota suggests a median life cycle cost of approximately $500 per pound of TP removed for internal load BMPs such as aluminum sulfate. Multiplying these rates by the needed watershed (29,941 pounds per year) and internal (57,477 pounds per year), TP reductions needed for the 23 lake basins in this TMDL provides a total cost of approximately $4.1 million per basin per year. This cost estimate assumes a 20-year life cycle for watershed and internal load BMPs.

Bacteria

The cost estimate for bacteria load reduction is based on unit costs for the two major sources of bacteria: livestock and failing SSTSs. The unit cost for bringing AUs under manure management plans and feedlot lot runoff controls is $350 per AU. This value is based on USDA EQIP payment history and includes buffers, livestock access control, manure management plans, waste storage structures, and clean water diversions. Repair or replacement of failing SSTSs was estimated at $7,500 per system. Multiplying those unit costs by an estimated 508 failing SSTSs and 138,768 AU in the South Fork Crow River bacteria impaired reach watersheds provides a total cost of approximately $52 million. The MPCA staff calculates that approximately 30% these AUs currently have controls or management plans in place, thus reducing this estimate by around a third.

TSS

Utilizing estimates developed by an interagency work group (BWSR, USDA, MPCA, Minnesota Association of SWCDs, Minnesota Association of Watershed Districts, NRCS) who assessed restoration costs for several TMDLs throughout the State, it was determined that implementing the South Fork Crow River TSS TMDLs will cost approximately $149.6 million over 10 years. This was based on total area of the watershed (1,279 square miles) multiplied by the cost estimate of $117,000 per square mile for a watershed based treatment approach.

Dissolved Oxygen

Section 8.3.2 of this document references the Watershed Restoration and Protection Strategies (WRAPS) report recommendations for this parameter. The WRAPS report indicates that to meet the reduction goal in current oxygen demand of 57% (5,784 pounds per year to 2047), that the following must occur:

- ID and implement urban urban BMPs throughout City of Glencoe MS4 to reduce sediment, oxygen demand, and bacterial loads to the South Fork Crow River
- Evaluate infrastructure, drainage, and storage in central and eastern portions of the city of Glencoe to reduce flooding and peak flows
- ID and implement urban BMPs in non-MS4 communities (Stewart, Plato, and Brownton) throughout the subwatershed

The Buffalo Creek Watershed District, as part of their 10 year “Overall Plan” (http://bcwatershed.org/pdf/BCWD%20Overall%20Plan%202014-2023%20[with%20%20Appendix%20D%20Amendment%208-5-2015].pdf) prepared in May of 2014, identified a number of studies and practices that they would need to implement by 2023 to meet water quality goals in the watershed. Many of these projects have not been implemented yet and overlap with the BMPs identified in the WRAPS document to meet the DO targets moving forward. Based on the estimates provided in the Buffalo Creek plan, the costs associated with meeting the goals described in the WRAPS would start at roughly 1.5 million dollars, although the WRAPS goals are estimated over 20 years whereas the Buffalo creek plan is projected through 2023, so actual costs are likely to be significantly more.

9 Public Participation

A stakeholder participation process was undertaken for this TMDL to obtain input from, review results with, and take comments from the public and interested and affected agencies regarding the development of and conclusions of the TMDL. The CROW board and Local Partner Technical Team convened multiple times to discuss and review TMDL results. The Technical Team consists of the CROW and stakeholders from local county government departments, SWCDs, cities, state and regional agencies, consultants, and others. Monthly CROW board meetings allowed for the general public and staff from various agencies to be advised on the progress and results of the TMDL study.

The stakeholder process involved meetings and other communications as tabulated below.

Date(s)	Description
12/19/2012	Consulting firm proposals and work plans for the South Fork Crow TMDL were reviewed and discussed at the Buffalo Creek Watershed District's Board meeting
11/30/2013 12/10/2014	Public and stakeholder meeting to kickoff TMDLs and provide background
12/15/2015	Meeting with MS4s and waste water treatment plant operators to discuss wasteload allocations
9/13/2016	Local Partner Technical Team meeting to discuss TMDL and WRAPS
1/31/2017	Public meeting to discuss final TMDL and WRAPS results
10/22/2014	Public open house to discuss Lake Wakanda Implementation Project and issues associated with the TMDLs for the South Fork Crow headwaters
1/27/2015 2/17/2015 6/9/2015	Workgroup, County Board, and public hearing meetings to review public comments and discuss Lake Wakanda restoration strategies
2/2/2012 4/5/2012 9/6/2012 11/8/2012 12/6/2012 2/6/2013 11/6/2013 11/5/2014 2/4/2015 4/14/2015 6/3/2015 10/7/2015 1/6/2016 2/10/2016 3/2/2016 8/3/2016 9/7/2016 11/2/2016	CROW Joint Powers Board Meetings in which progress/updates on the South Fork Crow TMDL were presented and/or preliminary results were discussed. Board Meetings are open to the public

Public Notice for Comments

An opportunity for public comment on the draft TMDL report was provided via a public notice in the *State Register* from April 16, 2018, to May 16, 2018.

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Appendices

Appendix A: NPDES Wastewater Discharger Fecal Coliform DMR Summary

Appendix B: Lake Response Models

Appendix C: HSPF Documentation

Appendix A: NPDES Wastewater Discharger Fecal Coliform DMR Summary

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]
Buffalo Lake WWTP	MN0050211	25	1	100	0	24
Cedar Mills WWTP	MN0066605	15	10	184	0	41
Cosmos WWTP	MNG580056	39	0	105	0	22
Delano WWTP	MN0051250	71	1	19	0	2
Hector WWTP	MN0025445	60	10	72	0	17
Hutchinson WWTP	MN0055832	69	2	137	0	33
Lake Lillian WWTP	MNG580225	26	1	158	0	26
Lester Prairie WWTP	MN0023957	71	1	199	0	13
Mayer WWTP	MN0021202	71	1	127	0	26
New Germany WWTP	MN0024295	37	1	379	1	41
Silver Lake WWTP	MNG580164	17	10	100	0	22
Watertown WWTP	MN0020940	71	10	313	3	50
Winsted WWTP	MN0021571	71	1	65	0	14

Appendix B: Lake Response Models

Ardmore Lake Current Conditions Canfield-Bachman Lake Response Model

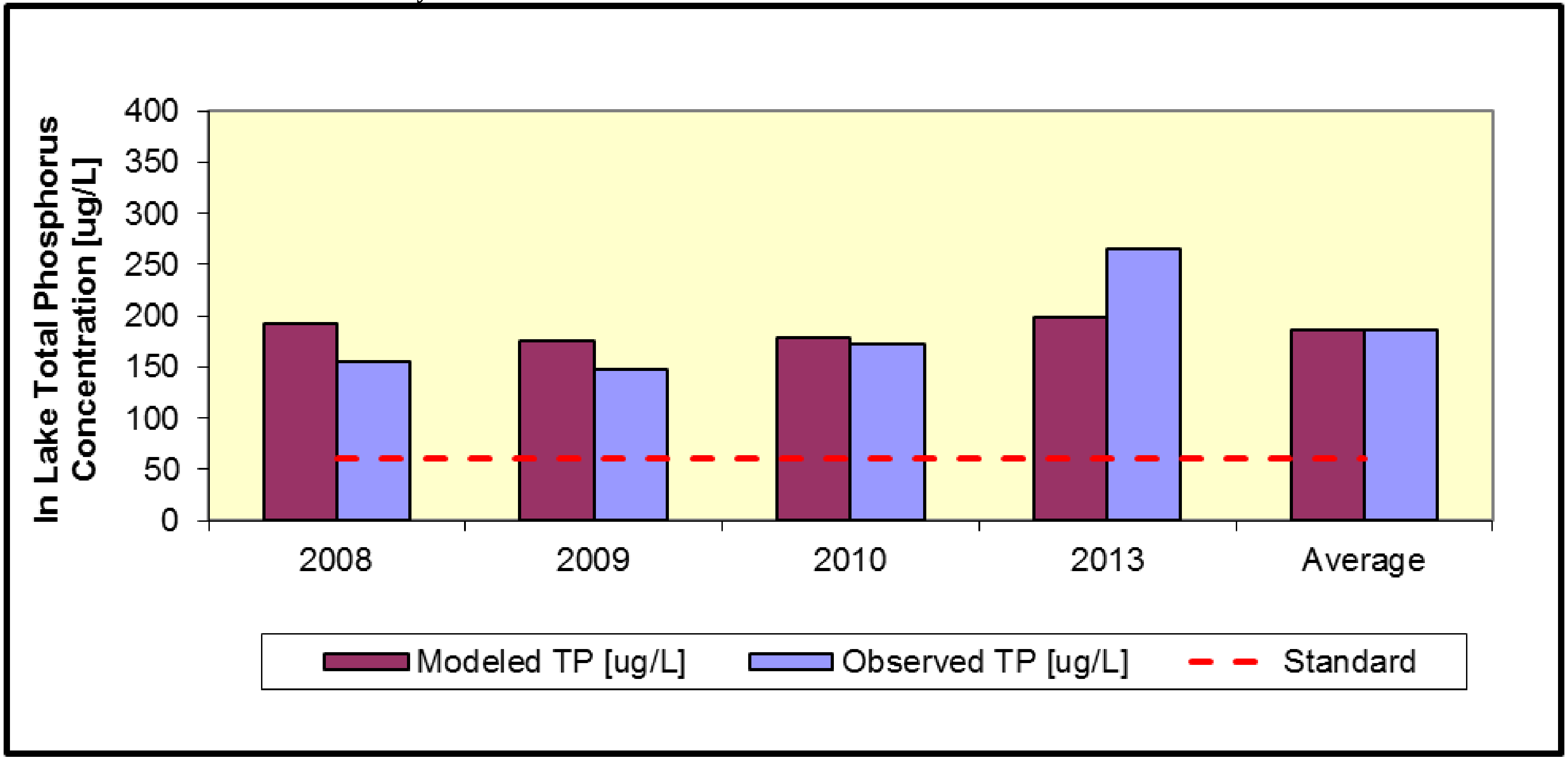
Average Loading Summary for Ardmore

	Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0	Direct Watershed	500.0	4.8	198.9	128.9	1.3	69.8
2.0							
3.0							
4.0							
5.0							
	Summation	*500.0*	*4.8*	*198.9*			*69.8*
Point Source Dischargers							
				Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0						1.0	
2.0						1.0	
3.0						1.0	
4.0						1.0	
5.0						1.0	
	Summation			*0.0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0	Reach 902						3.8
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*0.0*	*0.0*			*3.8*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0					-	1.0	
2.0					-	1.0	
3.0					-	1.0	
	Summation			*0.0*	-		*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]
	10.1	28.9	28.9	0.0	0.2	1.0	2.4
		Dry-year total P deposition =			0.2		
		Average-year total P deposition =			0.2		
		Wet-year total P deposition =			0.3		
		(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]
	10.1	0.0		0.0	0.0	1.0	0.0
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	0.0			Oxic		1.0	
	0.0	76.6		Anoxic	10.0	1.0	69.0
	Summation						69.0
		Net Discharge [ac-ft/yr] =		**198.9**	**Net Load [lb/yr] =**		**145.0**

Average Lake Response Modeling for Ardmore

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION		as f(W,Q,V) from Canfield & Bachmann (1981)		
$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$		C_P =	0.35	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	66	[kg/yr]
		Q (lake outflow) =	0.2	[10^6 m^3/yr]
		V (modeled lake volume) =	0.1	[10^6 m^3]
		T = V/Q =	0.40	[yr]
		P_i = W/Q =	268	[µg/l]
Model Predicted In-Lake [TP]			**185.8**	**[ug/l]**
Observed In-Lake [TP]			**185.8**	**[ug/l]**

Ardmore Lake Calibration Summary



Ardmore Lake TMDL Conditions Canfield-Bachman Lake Response Model

TMDL Loading Summary for Ardmore

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) [--]	Load [lb/yr]
1.0	Direct Watershed	500.0	4.8	198.9	69.0	0.7	37.3
2.0				0.0	0.0		0.0
3.0				0.0	0.0		0.0
4.0				0.0	0.0		0.0
5.0				0.0	0.0		0.0
	Summation	*500.0*	*4.8*	*198.9*			*37.3*

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF) [--]	Load [lb/yr]
1.0				0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0	Reach 902						0.0
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*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]
1.0					-	1.0	
2.0					-	1.0	
3.0					-	1.0	
	Summation			*0.0*	-		*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]
10.1	28.9	28.9	0.0	0.2	1.0	2.4
		Dry-year total P deposition =		0.2		
		Average-year total P deposition =		0.2		
		Wet-year total P deposition =		0.3		
		(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]
10.1	0.0		0.0	0.0	1.0	0.0

Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
0.0			Oxic		1.0	
0.0	76.6		Anoxic	0.1	0.0	0.7
Summation						0.7
		Net Discharge [ac-ft/yr] =	**198.9**		**Net Load [lb/yr] =**	**40.4**

TMDL Lake Response Modeling for Ardmore

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
$P = \dfrac{P_i}{1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T}$	as f(W,Q,V) from Canfield & Bachmann (1981)			
		C_P =	0.35	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	18	[kg/yr]
		Q (lake outflow) =	0.2	[10^6 m^3/yr]
		V (modeled lake volume) =	0.1	[10^6 m^3]
		T = V/Q =	0.40	[yr]
		P_i = W/Q =	75	[µg/l]
Model Predicted In-Lake [TP]			**60.0**	**[ug/l]**
Observed In-Lake [TP]			**60.0**	**[ug/l]**

Bear Lake Current Conditions Canfield-Bachman Lake Response Model

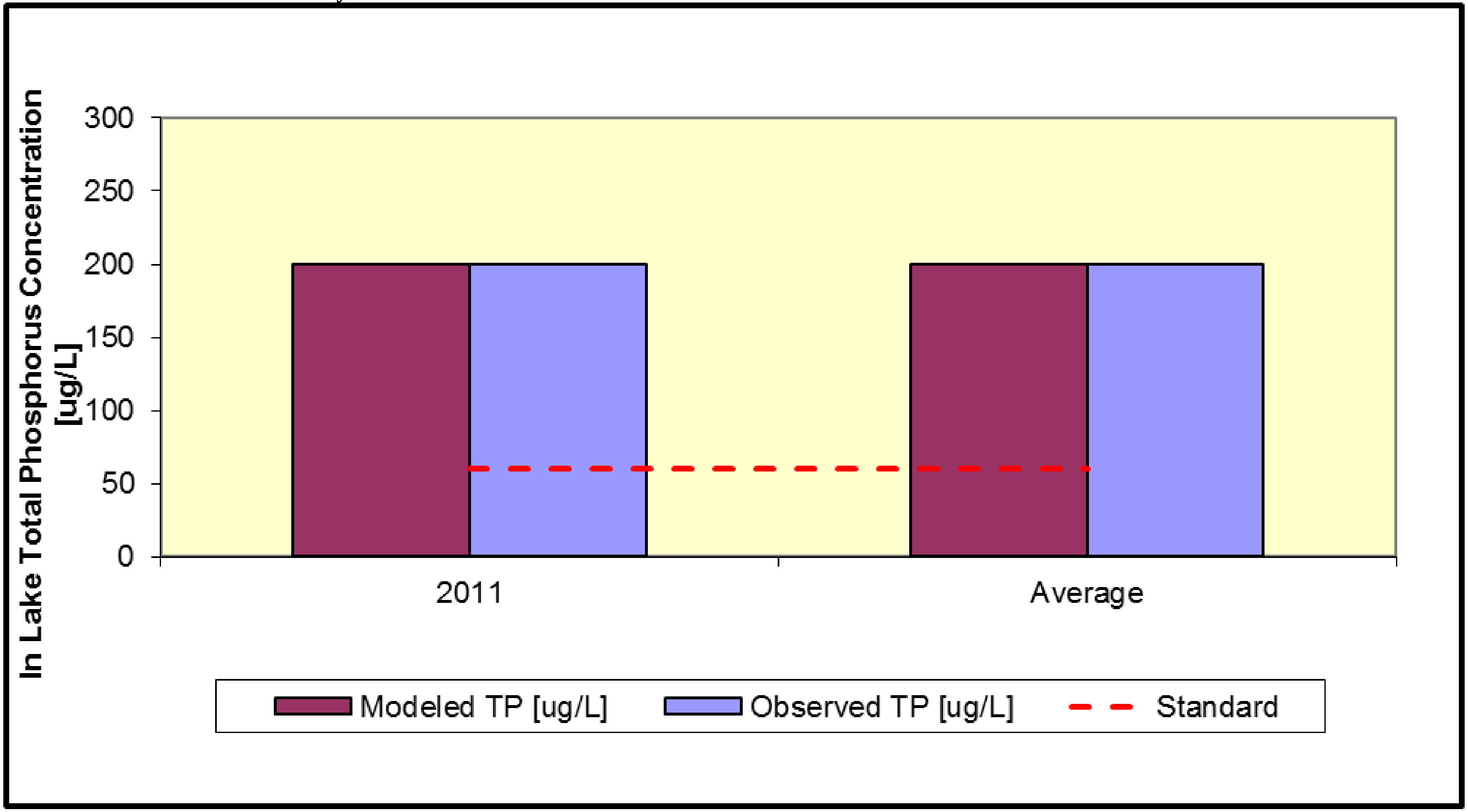
Average Loading Summary for Bear

	Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0	Direct	248.0	21.3	440.5	227.8	1.0	273.0
2.0							
3.0							
4.0							
5.0							
	Summation	*248.0*	*21.3*	*440.5*			*273.0*
Point Source Dischargers							
				Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0						1.0	
2.0						1.0	
3.0						1.0	
4.0						1.0	
5.0						1.0	
	Summation			*0.0*			
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							0.4
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*0.0*	*0.0*			*0.4*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0					-	1.0	
2.0					-	1.0	
3.0					-	1.0	
	Summation			*0.0*	-		*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]
	169.4	24.3	24.3	0.0	0.2	1.0	37.6
				Dry-year total P deposition =	0.2		
				Average-year total P deposition =	0.2		
				Wet-year total P deposition =	0.3		
				(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]
	169.4	0.0		0.0	0.0	1.0	0.0
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	0.7			Oxic		1.0	
	0.7	68.5		Anoxic	12.7	1.0	1,311.3
	Summation						1,311.3
		Net Discharge [ac-ft/yr] =		**440.5**	**Net Load [lb/yr] =**		**1,622.3**

Average Lake Response Modeling for Bear

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 =	0.92	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	736	[kg/yr]
		Q (lake outflow) =	0.5	[10^6 m^3/yr]
		V (modeled lake volume) =	1.0	[10^6 m^3]
		T = V/Q =	1.92	[yr]
		P_i = W/Q =	1354	[µg/l]
Model Predicted In-Lake [TP]			**200**	**[ug/l]**
Observed In-Lake [TP]			**200**	**[ug/l]**

Bear Lake Calibration Summary



Bear Lake TMDL Conditions Canfield-Bachman Lake Response Model

	TMDL Loading Summary for	*Bear*					
Water Budgets				**Phosphorus Loading**			
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0	Direct	248.0	21.3	440.5	86.6	0.4	103.7
2.0				0.0	0.0		0.0
3.0				0.0	0.0		0.0
4.0				0.0	0.0		0.0
5.0				0.0	0.0		0.0
	Summation	*248.0*	*21.3*	*440.5*			*103.7*
Point Source Dischargers							
				Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0				0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							0.0
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*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]
1.0					-	1.0	
2.0					-	1.0	
3.0					-	1.0	
	Summation			*0.0*	-		*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]
	169.4	24.3	24.3	0.0	0.2	1.0	37.6
			Dry-year total P deposition =		0.2		
			Average-year total P deposition =		0.2		
			Wet-year total P deposition =		0.3		
			(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]
	169.4	0.0		0.0	0.0	1.0	0.0
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	0.7			Oxic		1.0	
	0.7	68.5		Anoxic	1.0	1.0	103.2
	Summation						103.2
		Net Discharge [ac-ft/yr] =		**440.5**	**Net Load [lb/yr] =**		**244.6**

TMDL Lake Response Modeling for Bear

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 =	0.92	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	111	[kg/yr]
		Q (lake outflow) =	0.5	[10^6 m^3/yr]
		V (modeled lake volume) =	1.0	[10^6 m^3]
		T = V/Q =	1.92	[yr]
		P_i = W/Q =	204	[µg/l]
Model Predicted In-Lake [TP]			**60**	**[ug/l]**
Observed In-Lake [TP]			**200**	**[ug/l]**

Belle Lake Current Conditions Canfield-Bachman Lake Response Model

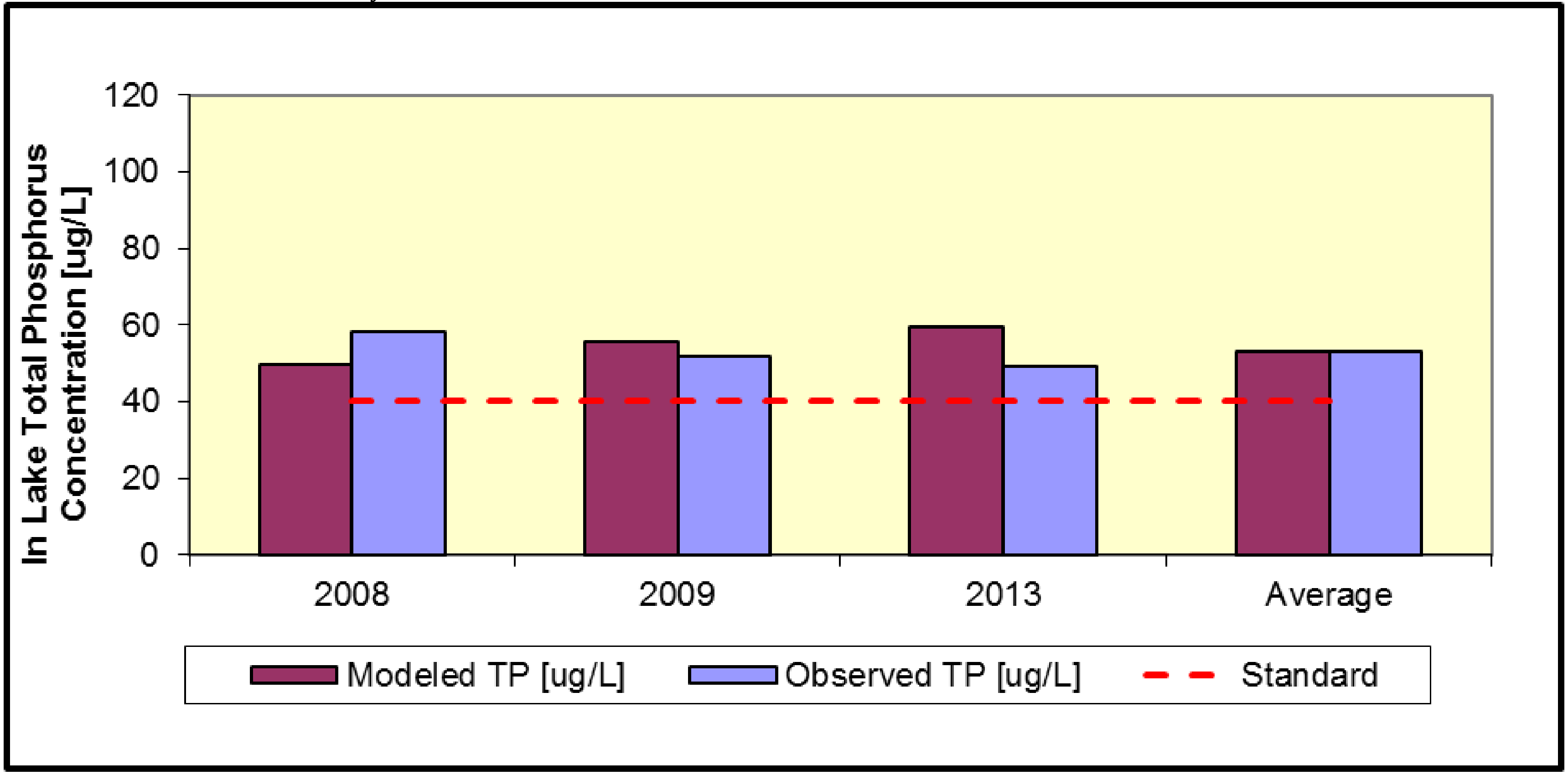
Average Loading Summary for Belle

	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) [--]	Load [lb/yr]
1.0	Watershed	4,351.8	1.1	409.8	440.1	1.0	490.6
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*4,351.8*	*1.1*	*409.8*			*490.6*
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF) [--]	Load [lb/yr]
1.0	No WWTF			0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							19.8
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*0.0*	*0.0*			*19.8*
Inflow from Upstream Lakes							
	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1.0	Stahls			782.6	36.2	1.0	77.1
2.0					-	1.0	
3.0					-	1.0	
	Summation			*782.6*	*36.2*		*77.1*
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]
	918.4	29.2	29.2	0.0	0.2	1.0	219.6
				Dry-year total P deposition =	0.2		
				Average-year total P deposition =	0.2		
				Wet-year total P deposition =	0.3		
				(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]
	918.4	0.0		0.0	0.0	1.0	0.0
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	3.7			Oxic		1.0	
	3.7	43.2		Anoxic	3.5	1.0	1,228.3
	Summation						1,228.3
			Net Discharge [ac-ft/yr] =	**1,192.4**		**Net Load [lb/yr] =**	**2,035.5**

Average Lake Response Modeling for Belle

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} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	923	[kg/yr]
		Q (lake outflow) =	1.5	[10^6 m^3/yr]
		V (modeled lake volume) =	14.9	[10^6 m^3]
		T = V/Q =	10.13	[yr]
		P_i = W/Q =	627	[μg/l]
Model Predicted In-Lake [TP]			**53**	**[ug/l]**
Observed In-Lake [TP]			**53**	**[ug/l]**

Belle Lake Calibration Summary



Belle Lake TMDL Conditions Canfield-Bachman Lake Response Model

TMDL Loading Summary for Belle

	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) [--]	Load [lb/yr]
1.0	Watershed	4,351.8	1.1	409.8	99.9	0.2	25.3
2.0						1.0	
3.0						1.0	
4.0						1.0	
5.0						1.0	
	Summation	*4,351.8*	*1.1*	*409.8*			*25.3*

Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF) [--]	Load [lb/yr]
1.0	No WWTF			0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*

Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							0.0
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*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]
1.0	Stahls			782.6	36.2	1.0	77.1
2.0					-	1.0	
3.0					-	1.0	
	Summation			*782.6*	*36.2*		*77.1*

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]
	918.4	29.2	29.2	0.0	0.2	1.0	219.6
		Dry-year total P deposition =			0.2		
		Average-year total P deposition =			0.2		
		Wet-year total P deposition =			0.3		
		(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]
	918.4	0.0		0.0	0.0	1.0	0.0

Internal							
	Lake Area [km²]	Anoxic Factor [days]			Release Rate [mg/m²-day]	Calibration Factor [--]	Load [lb/yr]
	3.7			Oxic		1.0	
	3.7	43.2		Anoxic	2.4	1.0	831.8
	Summation						831.8
		Net Discharge [ac-ft/yr] =		**1,192.4**	**Net Load [lb/yr] =**		**1,153.8**

TMDL Lake Response Modeling for Belle

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	as f(W,Q,V) from Canfield & Bachmann (1981)			
$P = \frac{P_i}{1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T}$		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	562	[kg/yr]
		Q (lake outflow) =	1.5	[10^6 m^3/yr]
		V (modeled lake volume) =	14.9	[10^6 m^3]
		T = V/Q =	10.13	[yr]
		P_i = W/Q =	382	[µg/l]
Model Predicted In-Lake [TP]			**40**	**[ug/l]**
Observed In-Lake [TP]			**53**	**[ug/l]**

Big Kandiyohi Lake Current Conditions Canfield-Bachman Lake Response Model

Average Loading Summary for Big Kandiyohi

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) [--]	Load [lb/yr]
1.0	Direct	4,051.2	6.9	2,318.1	270.9	1.0	1,708.1
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*4,051.2*	*6.9*	*2,318.1*			*1,708.1*

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF) [--]	Load [lb/yr]
1.0				0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							23.1
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*0.0*	*0.0*			*23.1*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1.0	Wakanda			13,540.6	247.7	1.0	9,124.6
2.0					-	1.0	
3.0					-	1.0	
	Summation			*13,540.6*	*247.7*		*9,124.6*

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]
	2,672.6	28.6	28.6	0.0	0.2	1.0	639.0
		Dry-year total P deposition =			0.2		
		Average-year total P deposition =			0.2		
		Wet-year total P deposition =			0.3		
		(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]
	2,672.6	0.0		0.0	0.0	1.0	0.0

Internal

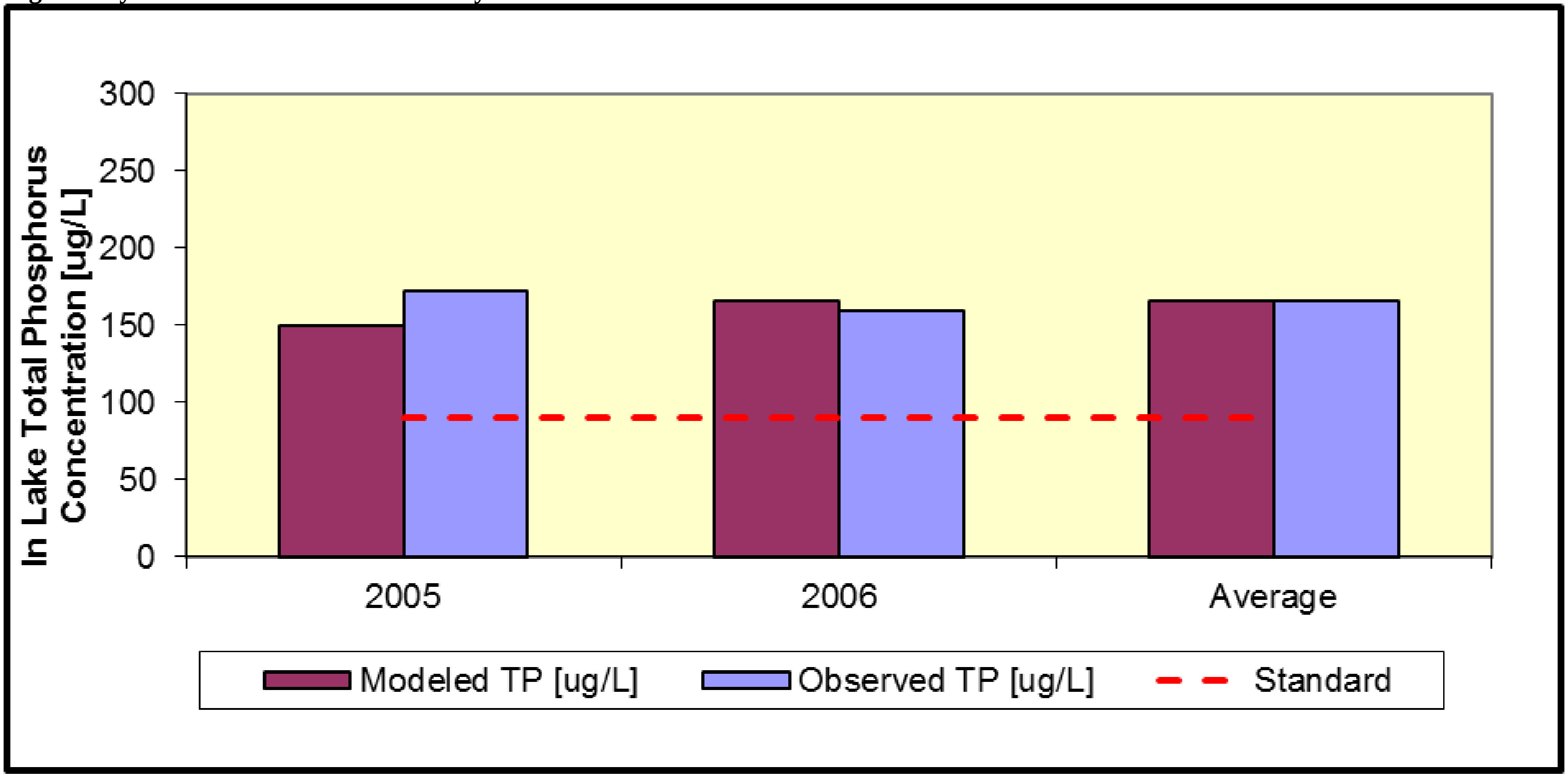
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	10.8	122.0		Oxic	1.0	1.0	2,909.0
	10.8	64.1		Anoxic	10.0	1.0	15,284.3
	Summation						18,193.3

Net Discharge [ac-ft/yr] = 15,858.7 **Net Load [lb/yr] = 29,688.1**

Average Lake Response Modeling for Big Kandiyohi

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 =	0.69	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	13,507	[kg/yr]
		Q (lake outflow) =	19.6	[10^6 m^3/yr]
		V (modeled lake volume) =	37.9	[10^6 m^3]
		T = V/Q =	1.94	[yr]
		P_i = W/Q =	690	[µg/l]
Model Predicted In-Lake [TP]			**165**	**[ug/l]**
Observed In-Lake [TP]			**165**	**[ug/l]**

Big Kandiyohi Lake Calibration Summary



Big Kandiyohi Lake TMDL Conditions Canfield-Bachman Lake Response Model

TMDL Loading Summary for Big Kandiyohi

	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) [--]	Load [lb/yr]
1.0	Direct	4,051.2	6.9	2,318.1	150.0	0.6	945.9
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*4,051.2*	*6.9*	*2,318.1*			*945.9*
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF) [--]	Load [lb/yr]
1.0				0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							0.0
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*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]
1.0	Wakanda			13,540.6	90.0	0.4	1,204.6
2.0					-	1.0	
3.0					-	1.0	
	Summation			*13,540.6*	*90.0*		*1,204.6*
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]
	2,672.6	28.6	28.6	0.0	0.2	1.0	639.0
		Dry-year total P deposition =			0.2		
		Average-year total P deposition =			0.2		
		Wet-year total P deposition =			0.3		
		(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]
	2,672.6	0.0		0.0	0.0	1.0	0.0
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	10.8	122.0		Oxic	1.0	1.0	2,909.0
	10.8	64.1		Anoxic	2.8	1.0	4,203.2
	Summation						7,112.2
		Net Discharge [ac-ft/yr] =		**15,858.7**	**Net Load [lb/yr] =**		**9,901.7**

TMDL Lake Response Modeling for Big Kandiyohi

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 =	0.69	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	5,449	[kg/yr]
		Q (lake outflow) =	19.6	[10^6 m^3/yr]
		V (modeled lake volume) =	37.9	[10^6 m^3]
		T = V/Q =	1.94	[yr]
		P_i = W/Q =	278	[µg/l]
Model Predicted In-Lake [TP]			**90**	**[ug/l]**
Observed In-Lake [TP]			**90**	**[ug/l]**

Boon Lake Current Conditions Canfield-Bachman Lake Response Model

Average Loading Summary for Boon

	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) [--]	Load [lb/yr]
1.0	Watershed	7,703.3	4.1	2,642.2	221.6	1.6	1,592.9
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*7,703.3*	*4.1*	*2,642.2*			*1,592.9*

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF) [--]	Load [lb/yr]
1.0				0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							25.9
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*0.0*	*0.0*			*25.9*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1.0	no upstream lake				-	1.0	
2.0					-	1.0	
3.0					-	1.0	
	Summation			*0.0*	-		*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]
	763.4	31.0	31.0	0.0	0.2	1.0	182.5
			Dry-year total P deposition =		0.2		
			Average-year total P deposition =		0.2		
			Wet-year total P deposition =		0.3		
			(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]
	763.4	0.0		0.0	0.0	1.0	0.0

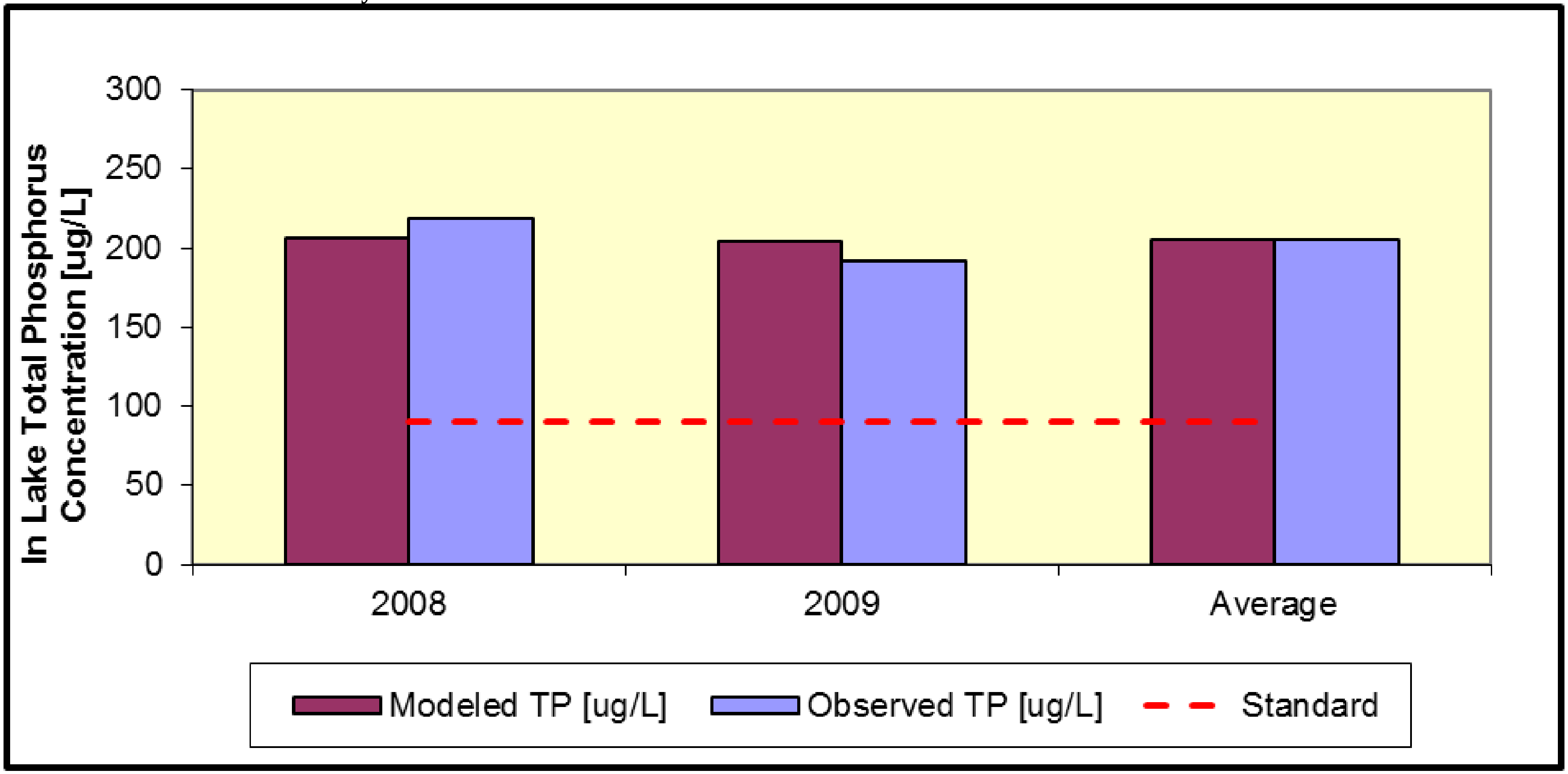
Internal

	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	3.1			Oxic		1.0	
	3.1	67.7		Anoxic	9.9	1.0	4,556.9
	Summation						4,556.9
		Net Discharge [ac-ft/yr] =		**2,642.2**	**Net Load [lb/yr] =**		**6,358.2**

Average Lake Response Modeling for Boon

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION		as f(W,Q,V) from Canfield & Bachmann (1981)		
$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	2,929	[kg/yr]
		Q (lake outflow) =	3.3	[10^6 m^3/yr]
		V (modeled lake volume) =	2.8	[10^6 m^3]
		T = V/Q =	0.87	[yr]
		P_i = W/Q =	898	[µg/l]
Model Predicted In-Lake [TP]			**205**	**[ug/l]**
Observed In-Lake [TP]			**205**	**[ug/l]**

Boon Lake Calibration Summary



Boon Lake TMDL Conditions Canfield-Bachman Lake Response Model

TMDL Loading Summary for Boon

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) [--]	Load [lb/yr]
1.0	Watershed	7,703.3	4.1	2,642.2	149.6	1.1	1,075.2
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*7,703.3*	*4.1*	*2,642.2*			*1,075.2*
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF) [--]	Load [lb/yr]
1.0				0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							0.0
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*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]
1.0	no upstream lake				-	1.0	
2.0					-	1.0	
3.0					-	1.0	
	Summation			*0.0*	-		*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]
	763.4	31.0	31.0	0.0	0.2	1.0	182.5
			Dry-year total P deposition =		0.2		
			Average-year total P deposition =		0.2		
			Wet-year total P deposition =		0.3		
			(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]
	763.4	0.0		0.0	0.0	1.0	0.0
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	3.1			Oxic		1.0	
	3.1	67.7		Anoxic	1.4	1.0	633.9
	Summation						633.9
			Net Discharge [ac-ft/yr] =	**2,642.2**		**Net Load [lb/yr] =**	**1,891.6**

TMDL Lake Response Modeling for Boon

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} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	858	[kg/yr]
		Q (lake outflow) =	3.3	[10^6 m^3/yr]
		V (modeled lake volume) =	2.8	[10^6 m^3]
		T = V/Q =	0.87	[yr]
		P_i = W/Q =	263	[µg/l]
Model Predicted In-Lake [TP]			**90**	**[ug/l]**
Observed In-Lake [TP]			**90**	**[ug/l]**

Cedar Lake Current Conditions Canfield-Bachman Lake Response Model

Average Loading Summary for Cedar

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) [--]	Load [lb/yr]
1.0	Direct Watershed	9,793.4	5.2	4,280.0	238.9	1.0	2,781.4
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*9,793.4*	*5.2*	*4,280.0*			*2,781.4*

Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF) [--]	Load [lb/yr]
1.0				0.0	0.0		0.0
2.0				0.0	0.0		0.0
3.0				0.0	0.0		0.0
4.0				0.0	0.0		0.0
5.0				0.0	0.0		0.0
	Summation			*0.0*			*0.0*

Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							44.6
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*0.0*	*0.0*			*44.6*

Inflow from Upstream Lakes							
	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1.0	Belle			997.5	64.8	1.0	175.8
2.0					-	1.0	
3.0					-	1.0	
	Summation			*997.5*	*64.8*		*175.8*

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]
	1,852.2	28.3	28.3	0.0	0.2	1.0	442.9
		Dry-year total P deposition =			0.2		
		Average-year total P deposition =			0.2		
		Wet-year total P deposition =			0.3		
		(Barr Engineering 2004)					

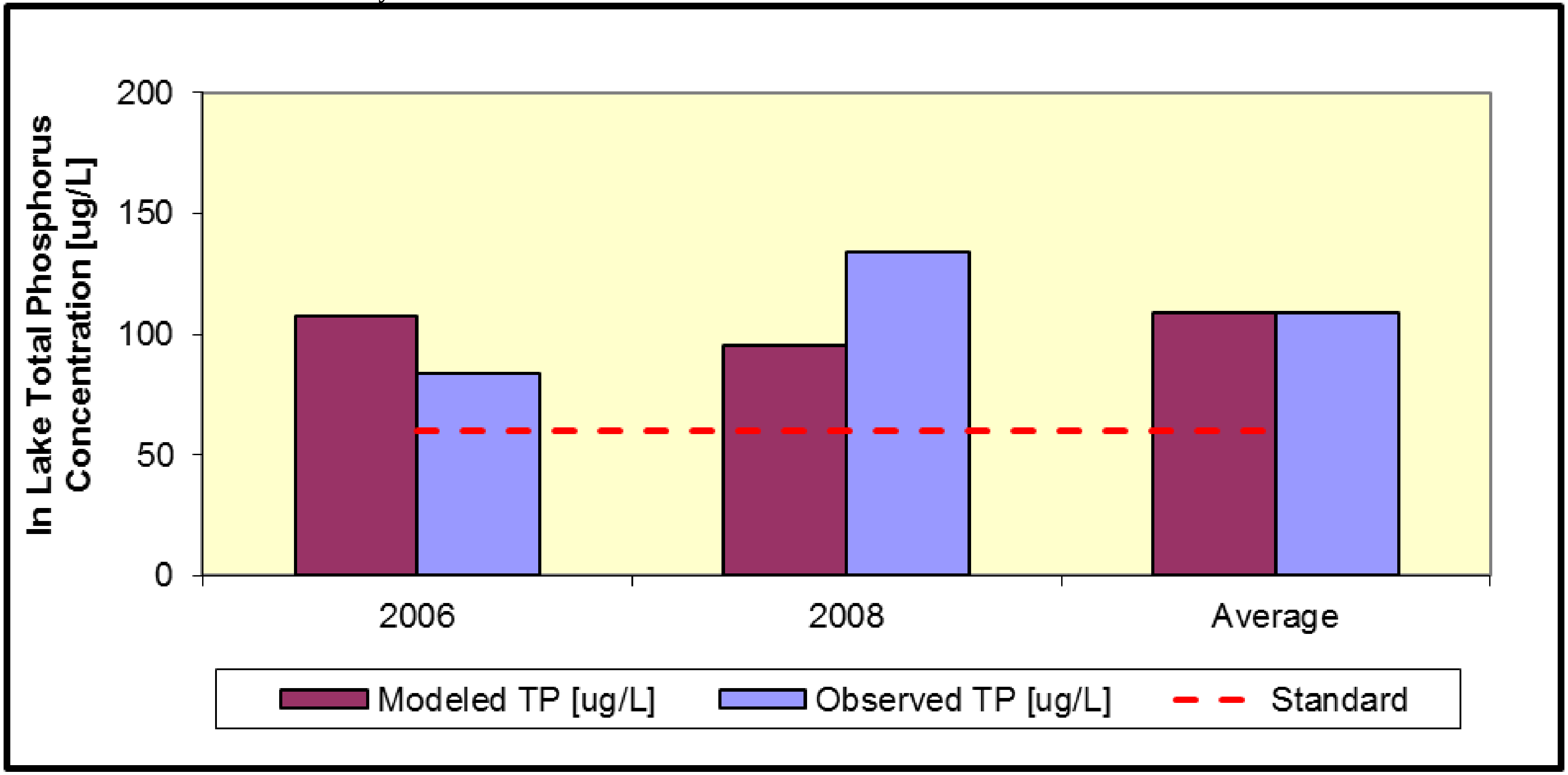
Groundwater							
	Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
	1,852.2	0.0		0.0	0.0	1.0	0.0

Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	7.5			Oxic		1.0	
	7.5	55.5		Anoxic	2.8	1.0	2,521.5
	Summation						2,521.5
		Net Discharge [ac-ft/yr] =		**5,277.5**	**Net Load [lb/yr] =**		**5,966.2**

Average Lake Response Modeling for Cedar

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 =	0.92	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	2,706	[kg/yr]
		Q (lake outflow) =	6.5	[10^6 m^3/yr]
		V (modeled lake volume) =	9.1	[10^6 m^3]
		T = V/Q =	1.39	[yr]
		P_i = W/Q =	416	[µg/l]
Model Predicted In-Lake [TP]			**109**	**[ug/l]**
Observed In-Lake [TP]			**109**	**[ug/l]**

Cedar Lake Calibration Summary



Cedar Lake TMDL Conditions Canfield-Bachman Lake Response Model

TMDL Loading Summary for Cedar

		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) [--]	Load [lb/yr]
1.0	Direct Watershed	9,793.4	5.2	4,280.0	90.7	0.4	1,055.9
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*9,793.4*	*5.2*	*4,280.0*			*1,055.9*
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF) [--]	Load [lb/yr]
1.0				0.0	0.0		0.0
2.0				0.0	0.0		0.0
3.0				0.0	0.0		0.0
4.0				0.0	0.0		0.0
5.0				0.0	0.0		0.0
	Summation			*0.0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							0.0
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*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]
1.0	Belle			997.5	60.0	0.9	162.8
2.0					-	1.0	
3.0					-	1.0	
	Summation			*997.5*	*60.0*		*162.8*
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]
	1,852.2	28.3	28.3	0.0	0.2	1.0	442.9
		Dry-year total P deposition =			0.2		
		Average-year total P deposition =			0.2		
		Wet-year total P deposition =			0.3		
		(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]
	1,852.2	0.0		0.0	0.0	1.0	0.0
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	7.5			Oxic		1.0	
	7.5	55.5		Anoxic	0.9	1.0	820.6
	Summation						820.6
		Net Discharge [ac-ft/yr] =		**5,277.5**	**Net Load [lb/yr] =**		**2,482.2**

TMDL Lake Response Modeling for Cedar

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 =	0.92	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	1,126	[kg/yr]
		Q (lake outflow) =	6.5	[10^6 m^3/yr]
		V (modeled lake volume) =	9.1	[10^6 m^3]
		T = V/Q =	1.39	[yr]
		P_i = W/Q =	173	[µg/l]
Model Predicted In-Lake [TP]			**60**	**[ug/l]**
Observed In-Lake [TP]			**60**	**[ug/l]**

Goose Lake Current Conditions Canfield-Bachman Lake Response Model

Average Loading Summary for Goose

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) [--]	Load [lb/yr]
1.0	Direct	319.3	7.8	208.6	725.2	2.0	411.6
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*319.3*	*7.8*	*208.6*			*411.6*

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF) [--]	Load [lb/yr]
1.0				0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							3.6
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*0.0*	*0.0*			*3.6*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1.0					-	1.0	
2.0					-	1.0	
3.0					-	1.0	
	Summation			*0.0*	-		*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]
105.3	24.6	24.6	0.0	0.2	1.0	23.4
	Dry-year total P deposition =			0.2		
	Average-year total P deposition =			0.2		
	Wet-year total P deposition =			0.3		
	(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]
105.3	0.0		0.0	0.0	1.0	0.0

Internal

Lake Area [km²]	Anoxic Factor [days]			Release Rate [mg/m²-day]	Calibration Factor [--]	Load [lb/yr]
0.4			Oxic		1.0	
0.4	85.2		Anoxic	22.8	1.0	1,822.2
Summation						1,822.2

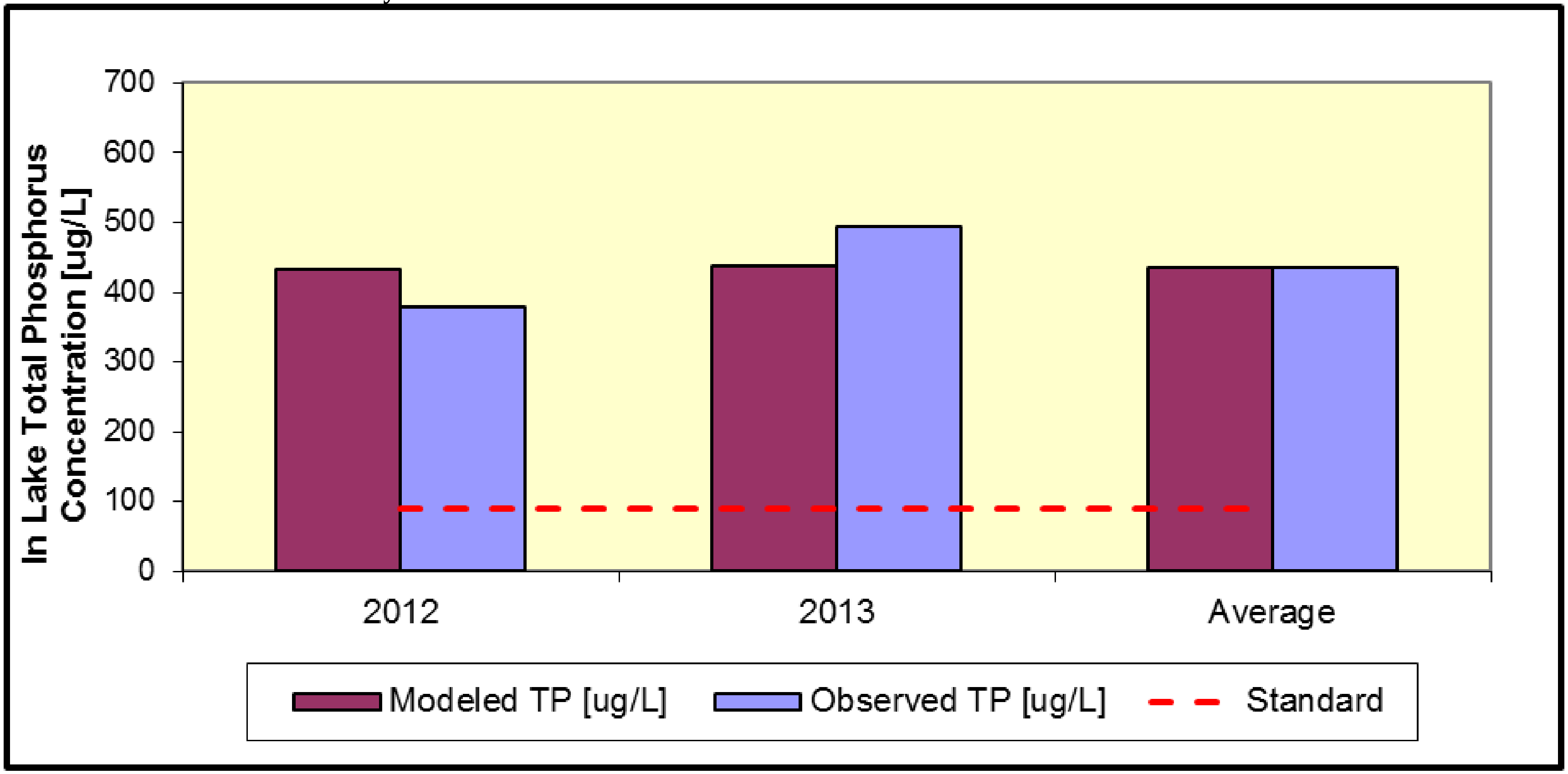
	Net Discharge [ac-ft/yr] =		**208.6**	**Net Load [lb/yr] =**		**2,260.8**

Average Lake Response Modeling for Goose

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION		as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	0.54	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	1,025	[kg/yr]
		Q (lake outflow) =	0.3	[10^6 m³/yr]
		V (modeled lake volume) =	1.0	[10^6 m³]
		T = V/Q =	3.93	[yr]
		P_i = W/Q =	3983	[µg/l]
Model Predicted In-Lake [TP]			**436**	**[ug/l]**
Observed In-Lake [TP]			**436**	**[ug/l]**

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

Goose Lake Calibration Summary



Goose Lake TMDL Conditions Canfield-Bachman Lake Response Model

TMDL Loading Summary for Goose

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) [--]	Load [lb/yr]
1.0	Direct	319.3	7.8	208.6	150.5	0.4	85.4
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*319.3*	*7.8*	*208.6*			*85.4*

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF) [--]	Load [lb/yr]
1.0				0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							0.0
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*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]
1.0					-	1.0	
2.0					-	1.0	
3.0					-	1.0	
	Summation			*0.0*	-		*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]
105.3	24.6	24.6	0.0	0.2	1.0	23.4
		Dry-year total P deposition =		0.2		
		Average-year total P deposition =		0.2		
		Wet-year total P deposition =		0.3		
		(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]
105.3	0.0		0.0	0.0	1.0	0.0

Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
0.4			Oxic		1.0	
0.4	85.2		Anoxic	0.9	1.0	71.7
Summation						71.7
	Net Discharge [ac-ft/yr] =		**208.6**	**Net Load [lb/yr] =**		**180.5**

TMDL Lake Response Modeling for Goose

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 =	0.54	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	82	[kg/yr]
		Q (lake outflow) =	0.3	[10^6 m^3/yr]
		V (modeled lake volume) =	1.0	[10^6 m^3]
		T = V/Q =	3.93	[yr]
		P_i = W/Q =	318	[µg/l]
Model Predicted In-Lake [TP]			**89**	**[ug/l]**
Observed In-Lake [TP]			**436**	**[ug/l]**

Greenleaf Lake Current Conditions Canfield-Bachman Lake Response Model

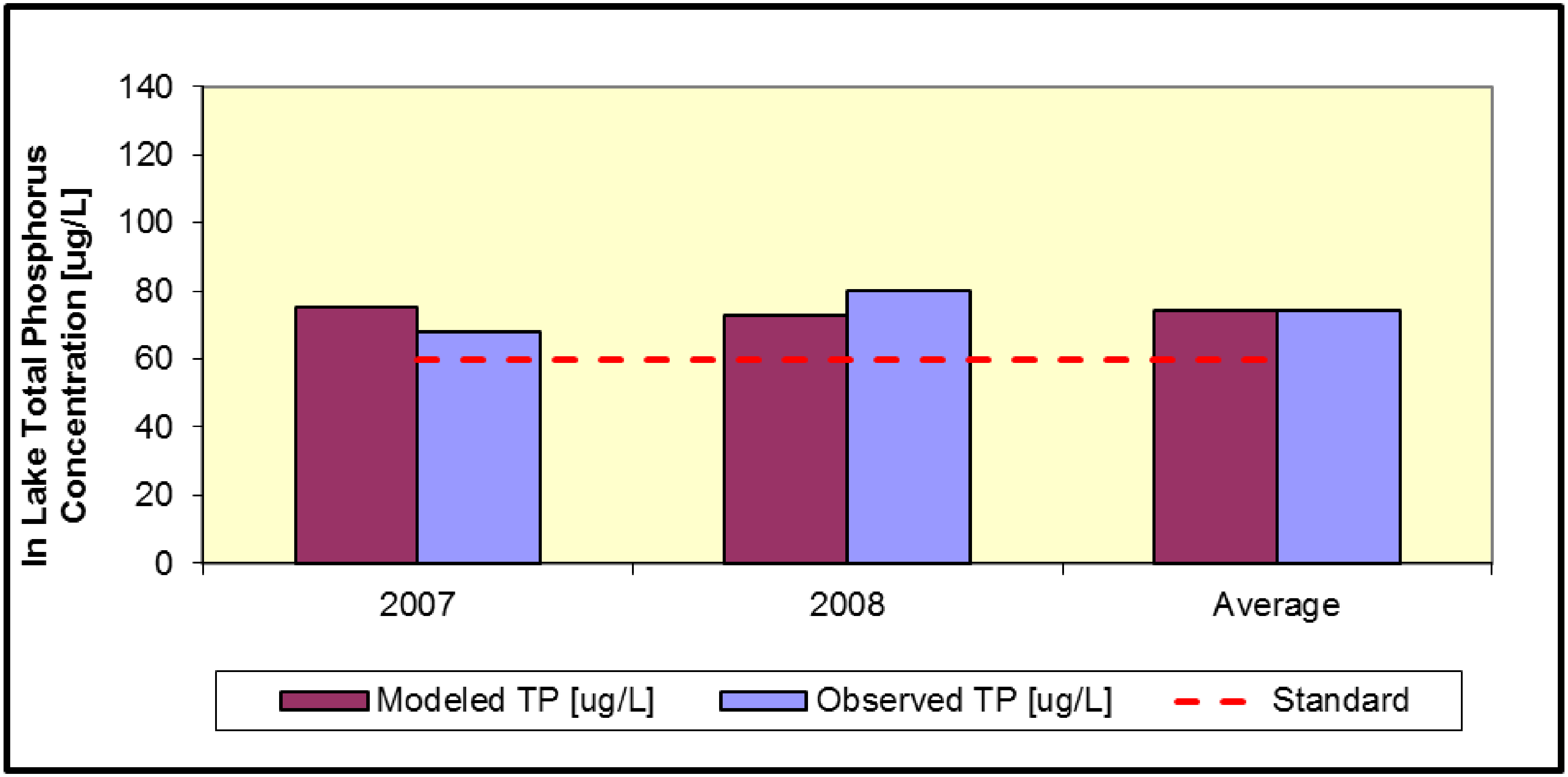
Average Loading Summary for Greenleaf

		Water Budgets			Phosphorus Loading		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0	Watershed	1,219.5	3.9	397.6	159.9	1.0	173.0
2.0				0.0	0.0	1.0	0.0
3.0				0.0	0.0	1.0	0.0
4.0				0.0	0.0	1.0	0.0
5.0				0.0	0.0	1.0	0.0
	Summation	*1,219.5*	*3.9*	*397.6*			*173.0*
Point Source Dischargers							
				Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0				0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							11.6
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*0.0*	*0.0*			*11.6*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0	Sioux				-	1.0	
2.0					-	1.0	
3.0					-	1.0	
	Summation			*0.0*	-		*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]
	239.8	28.9	28.9	0.0	0.2	1.0	57.3
		Dry-year total P deposition =			0.2		
		Average-year total P deposition =			0.2		
		Wet-year total P deposition =			0.3		
		(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]
	239.8	0.0		0.0	0.0	1.0	0.0
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	1.0			Oxic		1.0	
	1.0	50.2		Anoxic	4.2	1.0	451.5
	Summation						451.5
		Net Discharge [ac-ft/yr] =		**397.6**	**Net Load [lb/yr] =**		**693.4**

Average Lake Response Modeling for Greenleaf

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} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	315	[kg/yr]
		Q (lake outflow) =	0.5	[10^6 m^3/yr]
		V (modeled lake volume) =	2.6	[10^6 m^3]
		T = V/Q =	5.23	[yr]
		P_i = W/Q =	641	[µg/l]
Model Predicted In-Lake [TP]			**74**	**[ug/l]**
Observed In-Lake [TP]			**74**	**[ug/l]**

Greenleaf Lake Calibration Summary



Greenleaf Lake TMDL Conditions Canfield-Bachman Lake Response Model

TMDL Loading Summary for Greenleaf

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) [--]	Load [lb/yr]
1.0	Watershed	1,219.5	3.9	397.6	100.0	0.6	108.2
2.0				0.0	0.0	1.0	0.0
3.0				0.0	0.0	1.0	0.0
4.0				0.0	0.0	1.0	0.0
5.0				0.0	0.0	1.0	0.0
	Summation	*1,219.5*	*3.9*	*397.6*			*108.2*
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF) [--]	Load [lb/yr]
1.0				0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							0.0
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*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]
1.0	Sioux				-	1.0	
2.0					-	1.0	
3.0					-	1.0	
	Summation			*0.0*	-		*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]
	239.8	28.9	28.9	0.0	0.2	1.0	57.3
		Dry-year total P deposition =			0.2		
		Average-year total P deposition =			0.2		
		Wet-year total P deposition =			0.3		
		(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]
	239.8	0.0		0.0	0.0	1.0	0.0
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	1.0			Oxic		1.0	
	1.0	50.2		Anoxic	3.0	1.0	323.0
	Summation						323.0
		Net Discharge [ac-ft/yr] =		**397.6**	**Net Load [lb/yr] =**		**488.5**

TMDL Lake Response Modeling for Greenleaf

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
		as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	222	[kg/yr]
		Q (lake outflow) =	0.5	[10^6 m^3/yr]
		V (modeled lake volume) =	2.6	[10^6 m^3]
		T = V/Q =	5.23	[yr]
		P_i = W/Q =	452	[µg/l]
Model Predicted In-Lake [TP]			**60**	**[ug/l]**
Observed In-Lake [TP]			**60**	**[ug/l]**

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

Hoff Lake Current Conditions Canfield-Bachman Lake Response Model

Average Loading Summary for Hoff

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) [--]	Load [lb/yr]
1.0	Direct Watershed	646.3	10.8	581.6	379.0	1.0	599.7
2.0	Upstream Watersh	3,141.0	13.4	3,519.0	253.9	1.0	2,430.3
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*3,787.3*	*24.3*	*4,100.5*			*3,030.0*

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF) [--]	Load [lb/yr]
1.0				0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							3.5
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*0.0*	*0.0*			*3.5*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1.0	Cedar			10,376.8	109.0	1.0	3,077.1
2.0	Willie			7,983.8	60.5	1.0	1,314.1
3.0					-	1.0	
	Summation			*18,360.6*	*84.8*		*4,391.1*

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]
150.8	35.4	35.4	0.0	0.2	1.0	36.1
			Dry-year total P deposition =	0.2		
			Average-year total P deposition =	0.2		
			Wet-year total P deposition =	0.3		
			(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]
150.8	0.0		0.0	0.0	1.0	0.0

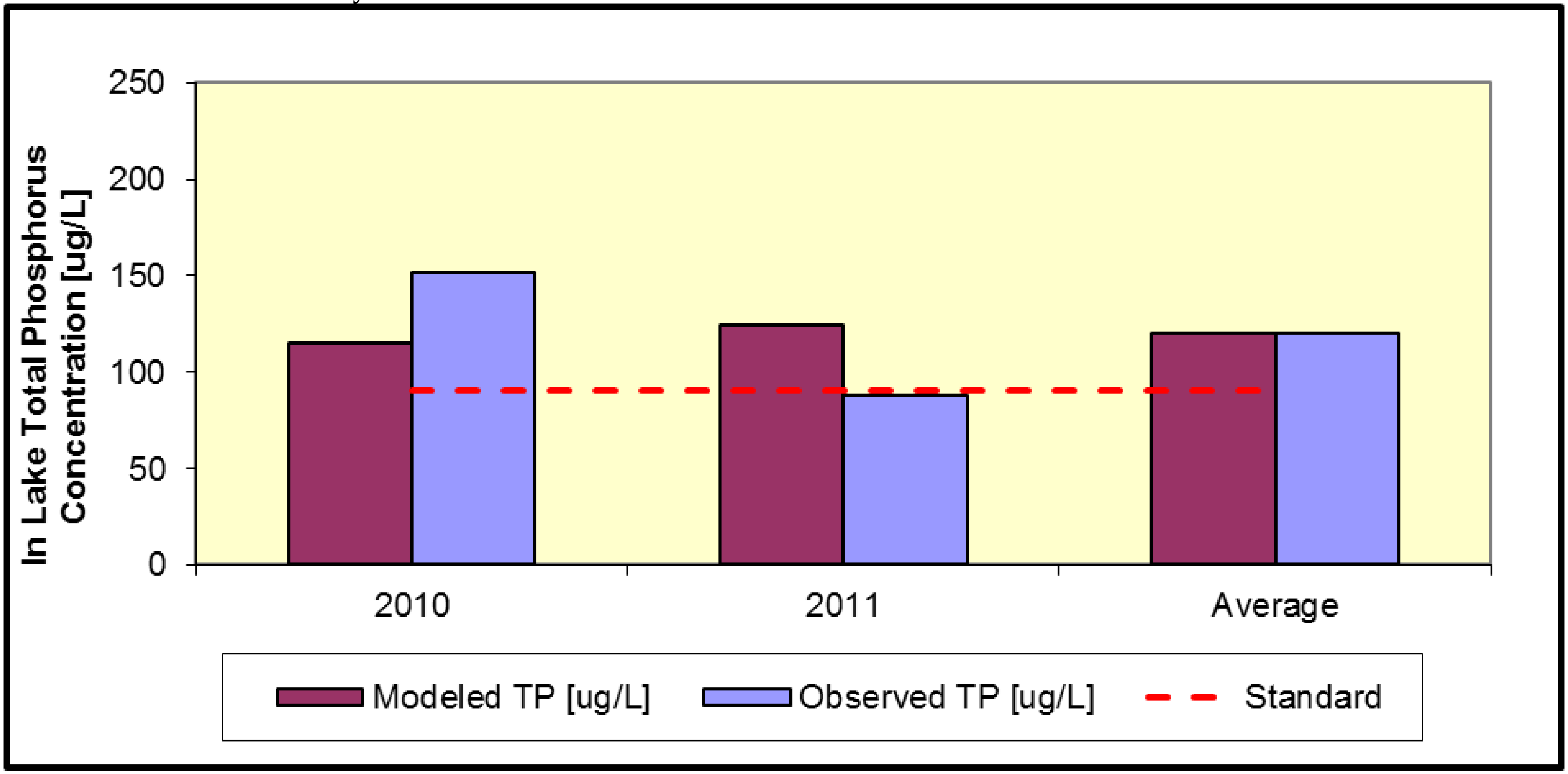
Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
0.6			Oxic		1.0	
0.6	58.5		Anoxic	5.8	1.0	454.9
Summation						454.9
		Net Discharge [ac-ft/yr] =	**22,461.2**		**Net Load [lb/yr] =**	**7,915.5**

Average Lake Response Modeling for Hoff

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 =	0.37	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	3,590	[kg/yr]
		Q (lake outflow) =	27.7	[10^6 m^3/yr]
		V (modeled lake volume) =	0.8	[10^6 m^3]
		T = V/Q =	0.03	[yr]
		P_i = W/Q =	130	[µg/l]
Model Predicted In-Lake [TP]			**120**	**[ug/l]**
Observed In-Lake [TP]			**120**	**[ug/l]**

Hoff Lake Calibration Summary



Hoff Lake TMDL Conditions Canfield-Bachman Lake Response Model

TMDL Loading Summary for Hoff

	Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0	Direct Watershed	646.3	10.8	581.6	150.0	0.4	237.3
2.0	Upstream Watersh	3,141.0	13.4	3,519.0	226.1	0.9	2,164.7
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*3,787.3*	*24.3*	*4,100.5*			*2,402.0*
Point Source Dischargers							
				Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0				0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							0.0
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*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]
1.0	Cedar			10,376.8	60.0	0.6	1,693.8
2.0	Willie			7,983.8	60.0	1.0	1,303.2
3.0					-	1.0	
	Summation			*18,360.6*	*60.0*		*2,997.0*
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]
	150.8	35.4	35.4	0.0	0.2	1.0	36.1
		Dry-year total P deposition =			0.2		
		Average-year total P deposition =			0.2		
		Wet-year total P deposition =			0.3		
		(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]
	150.8	0.0		0.0	0.0	1.0	0.0
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	0.6			Oxic		1.0	
	0.6	58.5		Anoxic	5.8	1.0	454.9
	Summation						454.9
		Net Discharge [ac-ft/yr] =		**22,461.2**	**Net Load [lb/yr] =**		**5,890.0**

TMDL Lake Response Modeling for Hoff

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 =	0.37	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	2,672	[kg/yr]
		Q (lake outflow) =	27.7	[10^6 m^3/yr]
		V (modeled lake volume) =	0.8	[10^6 m^3]
		T = V/Q =	0.03	[yr]
		P_i = W/Q =	96	[µg/l]
Model Predicted In-Lake [TP]			**90**	**[ug/l]**
Observed In-Lake [TP]			**120**	**[ug/l]**

Irene Lake Current Conditions Canfield-Bachman Lake Response Model

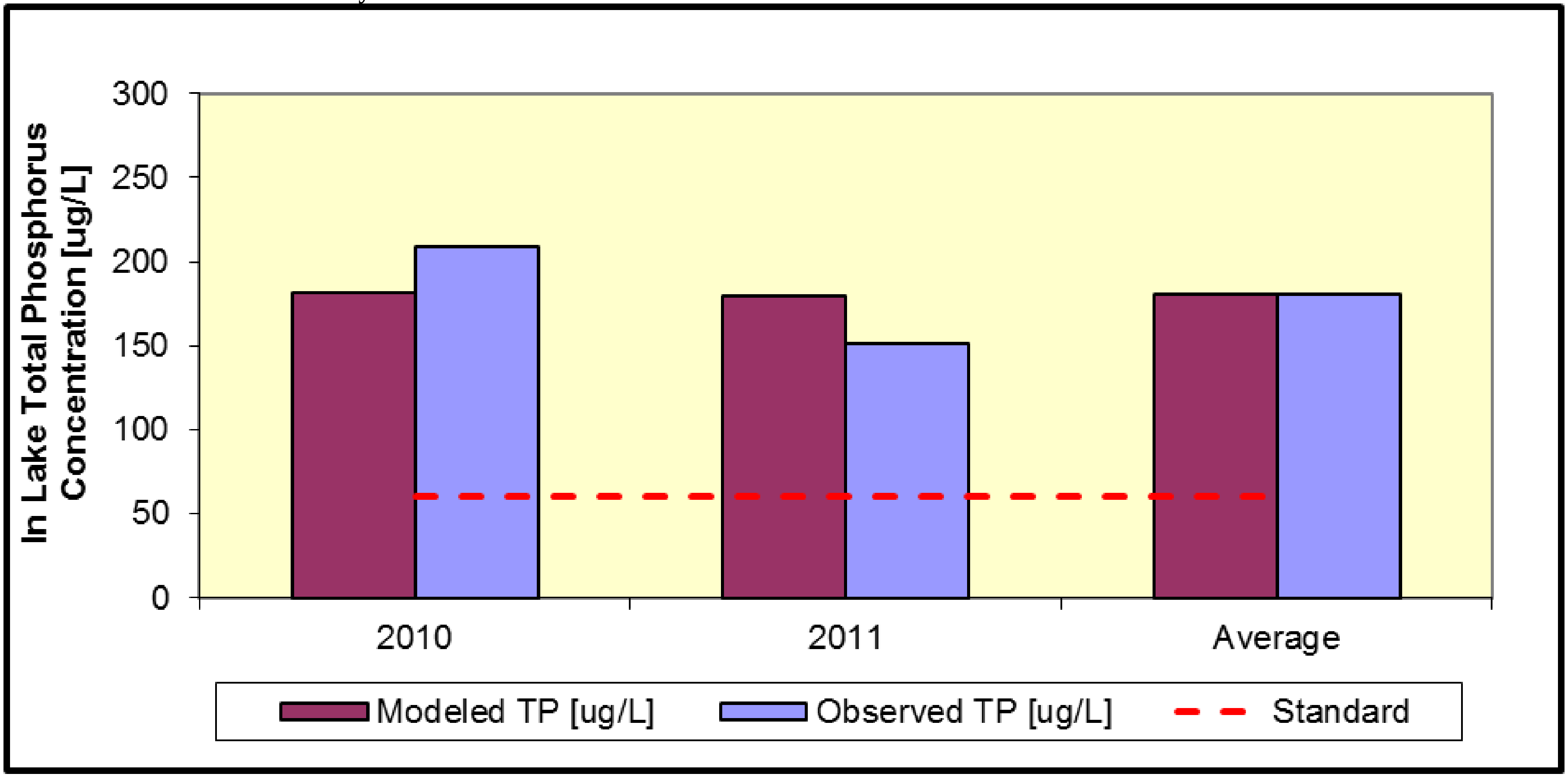
Average Loading Summary for Irene

	Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0	Direct	608.0	8.0	405.2	322.9	1.0	355.9
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*608.0*	*8.0*	*405.2*			*355.9*
Point Source Dischargers							
				Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0				0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							1.4
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*0.0*	*0.0*			*1.4*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0					-	1.0	
2.0					-	1.0	
3.0					-	1.0	
	Summation			*0.0*	-		*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]
	19.0	28.3	28.3	0.0	0.2	1.0	4.5
		Dry-year total P deposition =			0.2		
		Average-year total P deposition =			0.2		
		Wet-year total P deposition =			0.3		
		(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]
	19.0	0.0		0.0	0.0	1.0	0.0
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	0.1			Oxic		1.0	
	0.1	73.2		Anoxic	5.2	1.0	64.5
	Summation						64.5
		Net Discharge [ac-ft/yr] =		**405.2**	**Net Load [lb/yr] =**		**426.4**

Average Lake Response Modeling for Irene

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 =	0.79	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	193	[kg/yr]
		Q (lake outflow) =	0.5	[10^6 m^3/yr]
		V (modeled lake volume) =	0.2	[10^6 m^3]
		T = V/Q =	0.38	[yr]
		P_i = W/Q =	387	[µg/l]
Model Predicted In-Lake [TP]			**180**	**[ug/l]**
Observed In-Lake [TP]			**180**	**[ug/l]**

Irene Lake Calibration Summary



Irene Lake TMDL Conditions Canfield-Bachman Lake Response Model

TMDL Loading Summary for Irene

Water Budgets					**Phosphorus Loading**		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0	Direct	608.0	8.0	405.2	80.7	0.3	89.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*608.0*	*8.0*	*405.2*			*89.0*
Point Source Dischargers							
				Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0				0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							0.0
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*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]
1.0					-	1.0	
2.0					-	1.0	
3.0					-	1.0	
	Summation			*0.0*	-		*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]
	19.0	28.3	28.3	0.0	0.2	1.0	4.5
		Dry-year total P deposition =			0.2		
		Average-year total P deposition =			0.2		
		Wet-year total P deposition =			0.3		
		(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]
	19.0	0.0		0.0	0.0	1.0	0.0
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	0.1			Oxic		1.0	
	0.1	73.2		Anoxic	1.0	1.0	12.7
	Summation						*12.7*
		Net Discharge [ac-ft/yr] =		**405.2**	**Net Load [lb/yr] =**		**106.3**

TMDL Lake Response Modeling for Irene

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 =	0.79	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	48	[kg/yr]
		Q (lake outflow) =	0.5	[10^6 m^3/yr]
		V (modeled lake volume) =	0.2	[10^6 m^3]
		T = V/Q =	0.38	[yr]
		P_i = W/Q =	96	[µg/l]
Model Predicted In-Lake [TP]			**60**	**[ug/l]**
Observed In-Lake [TP]			**60**	**[ug/l]**

Johnson Lake Current Conditions Canfield-Bachman Lake Response Model

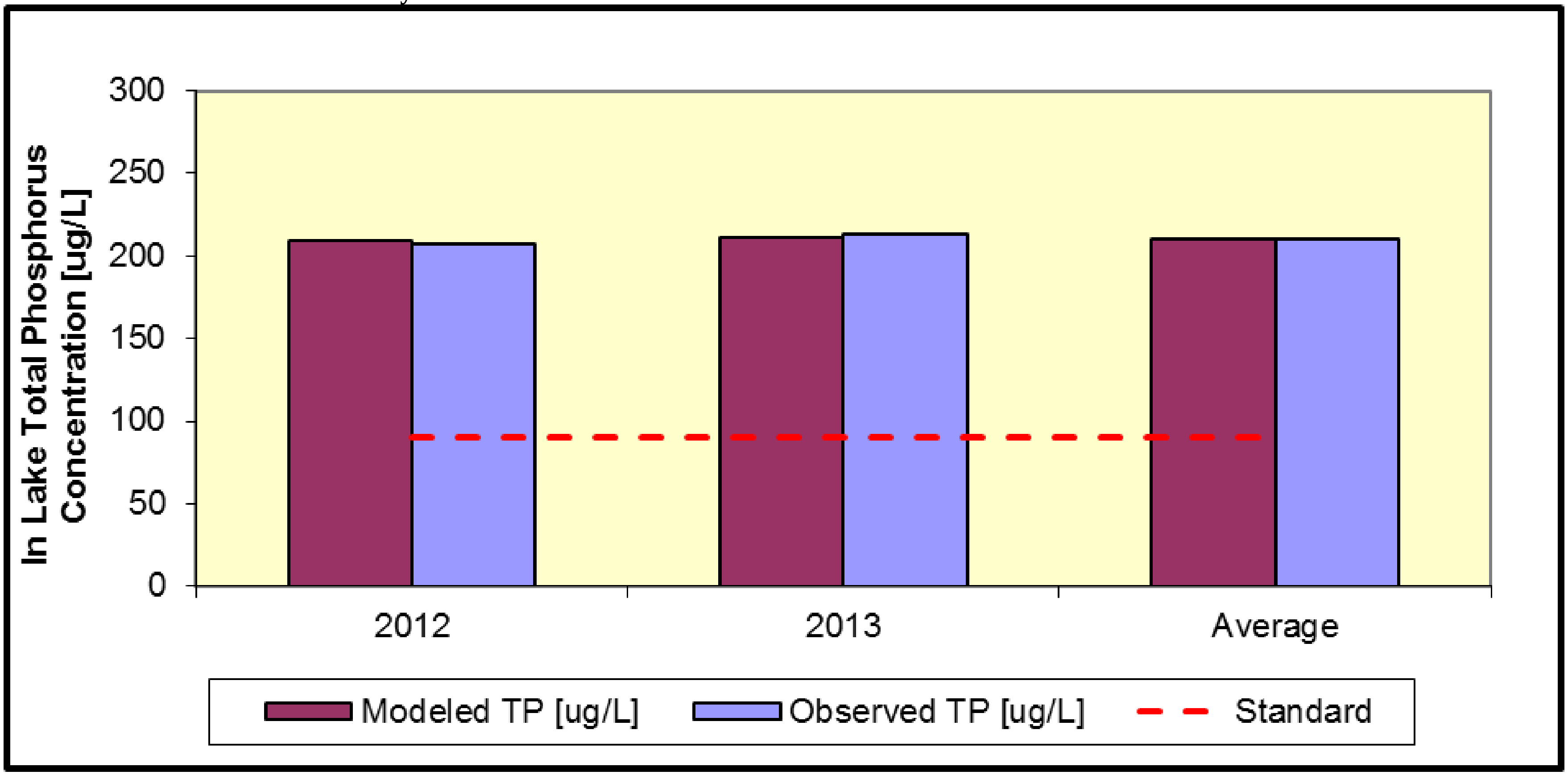
Average Loading Summary for Johnson

	Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0	Direct	689.5	3.6	207.4	365.3	1.0	206.1
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*689.5*	*3.6*	*207.4*			*206.1*
Point Source Dischargers							
				Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0				0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							0.6
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*0.0*	*0.0*			*0.6*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0					-	1.0	
2.0					-	1.0	
3.0					-	1.0	
	Summation			*0.0*	-		*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]
	101.0	26.5	26.5	0.0	0.2	1.0	24.2
				Dry-year total P deposition =	0.2		
				Average-year total P deposition =	0.2		
				Wet-year total P deposition =	0.3		
				(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]
	101.0	0.0		0.0	0.0	1.0	0.0
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	0.4			Oxic		1.0	
	0.4	69.5		Anoxic	4.2	1.0	263.0
	Summation						263.0
		Net Discharge [ac-ft/yr] =		**207.4**	**Net Load [lb/yr] =**		**493.9**

Average Lake Response Modeling for Johnson

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \dfrac{P_i}{1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	0.61	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	224	[kg/yr]
		Q (lake outflow) =	0.3	[10^6 m^3/yr]
		V (modeled lake volume) =	0.5	[10^6 m^3]
		T = V/Q =	1.95	[yr]
		P_i = W/Q =	875	[µg/l]
Model Predicted In-Lake [TP]			**210**	**[ug/l]**
Observed In-Lake [TP]			**210**	**[ug/l]**

Johnson Lake Calibration Summary



Johnson Lake TMDL Conditions Canfield-Bachman Lake Response Model

TMDL Loading Summary for Johnson

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) [--]	Load [lb/yr]
1.0	Direct	689.5	3.6	207.4	150.0	0.4	84.6
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*689.5*	*3.6*	*207.4*			*84.6*

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF) [--]	Load [lb/yr]
1.0				0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							0.0
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*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]
1.0					-	1.0	
2.0					-	1.0	
3.0					-	1.0	
	Summation			*0.0*	-		*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]
	101.0	26.5	26.5	0.0	0.2	1.0	24.2
				Dry-year total P deposition =	0.2		
				Average-year total P deposition =	0.2		
				Wet-year total P deposition =	0.3		
				(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]
	101.0	0.0		0.0	0.0	1.0	0.0

Internal

	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	0.4			Oxic		1.0	
	0.4	69.5		Anoxic	0.5	1.0	32.6
	Summation						32.6
			Net Discharge [ac-ft/yr] =	**207.4**		**Net Load [lb/yr] =**	**141.4**

TMDL Lake Response Modeling for Johnson

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 =	0.61	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	64	[kg/yr]
		Q (lake outflow) =	0.3	[10^6 m^3/yr]
		V (modeled lake volume) =	0.5	[10^6 m^3]
		T = V/Q =	1.95	[yr]
		P_i = W/Q =	251	[µg/l]
Model Predicted In-Lake [TP]			**90**	**[ug/l]**
Observed In-Lake [TP]			**210**	**[ug/l]**

Kasota Lake Current Conditions Canfield-Bachman Lake Response Model

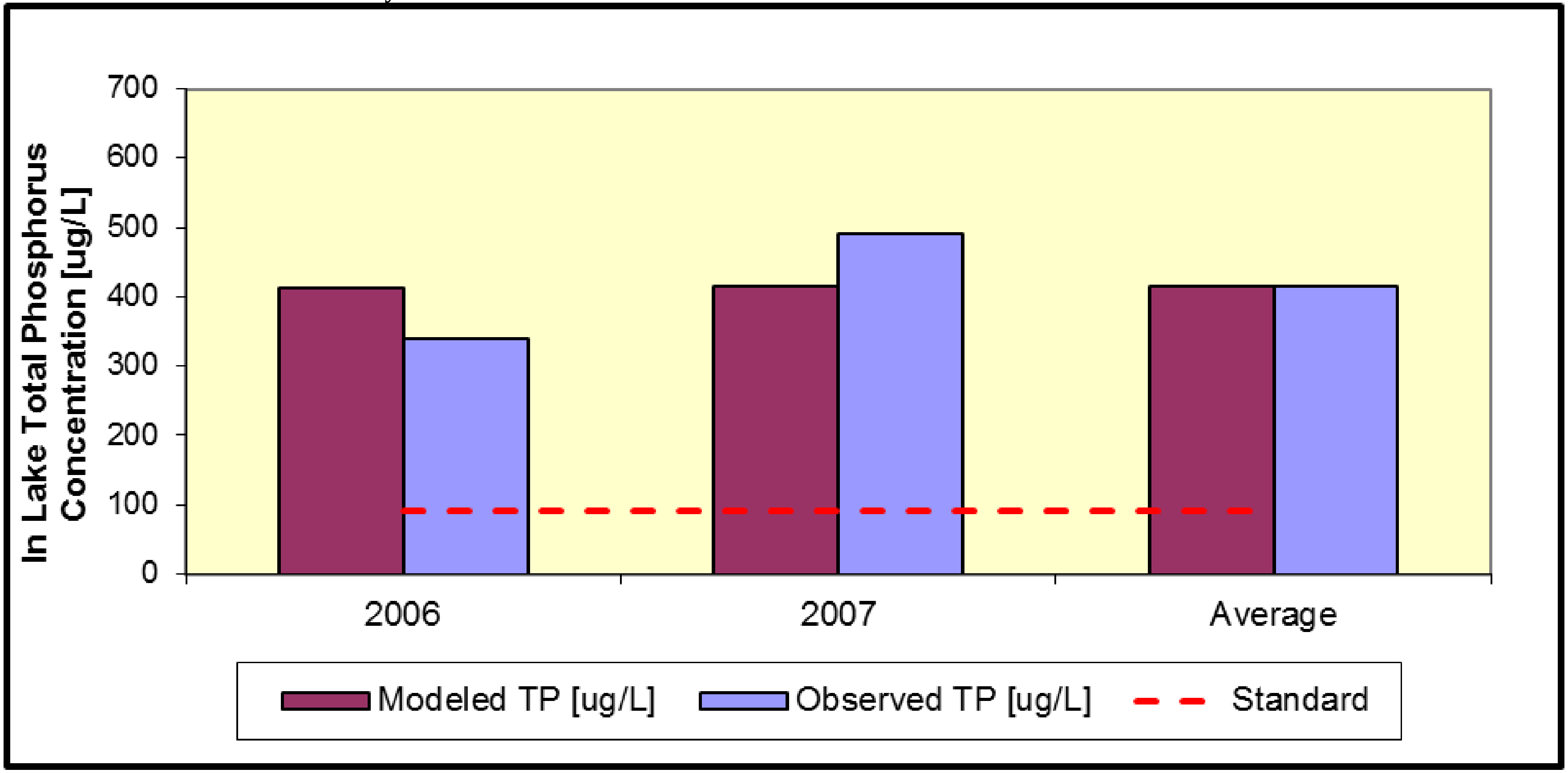
Average Loading Summary for Kasota

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) [--]	Load [lb/yr]
1.0		4,557.8	4.5	1,717.5	533.6	2.0	2,493.1
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*4,557.8*	*4.5*	*1,717.5*			*2,493.1*
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF) [--]	Load [lb/yr]
1.0				0.0	0.0		0.0
2.0				0.0	0.0		0.0
3.0				0.0	0.0		0.0
4.0				0.0	0.0		0.0
5.0				0.0	0.0		0.0
	Summation			*0.0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							22.0
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*0.0*	*0.0*			*22.0*
Inflow from Upstream Lakes							
	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1.0	Minnetaga			2,213.1	270.0	1.0	1,625.6
2.0					-	1.0	
3.0					-	1.0	
	Summation			*2,213.1*	*270.0*		*1,625.6*
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]
	434.0	25.1	25.1	0.0	0.2	1.0	103.8
		Dry-year total P deposition =			0.2		
		Average-year total P deposition =			0.2		
		Wet-year total P deposition =			0.3		
		(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		0.0	0.0	1.0	0.0
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	1.8			Oxic		1.0	
	1.8	81.8		Anoxic	30.0	1.0	9,505.4
	Summation						9,505.4
		Net Discharge [ac-ft/yr] =		**3,930.7**	**Net Load [lb/yr] =**		**13,749.9**

Average Lake Response Modeling for Kasota

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 =	0.67	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	6,236	[kg/yr]
		Q (lake outflow) =	4.9	[10^6 m^3/yr]
		V (modeled lake volume) =	2.7	[10^6 m^3]
		T = V/Q =	0.55	[yr]
		P_i = W/Q =	1286	[µg/l]
Model Predicted In-Lake [TP]			**415**	**[ug/l]**
Observed In-Lake [TP]			**415**	**[ug/l]**

Kasota Lake Calibration Summary



Kasota Lake TMDL Conditions Canfield-Bachman Lake Response Model

TMDL Loading Summary for Kasota

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) [--]	Load [lb/yr]
1.0		4,557.8	4.5	1,717.5	150.0	0.6	700.9
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*4,557.8*	*4.5*	*1,717.5*			*700.9*
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF) [--]	Load [lb/yr]
1.0				0.0	0.0		0.0
2.0				0.0	0.0		0.0
3.0				0.0	0.0		0.0
4.0				0.0	0.0		0.0
5.0				0.0	0.0		0.0
	Summation			*0.0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							0.0
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*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]
1.0	Minnetaga			2,213.1	90.0	0.3	541.9
2.0					-	1.0	
3.0					-	1.0	
	Summation			*2,213.1*	*90.0*		*541.9*
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]
	434.0	25.1	25.1	0.0	0.2	1.0	103.8
			Dry-year total P deposition =		0.2		
			Average-year total P deposition =		0.2		
			Wet-year total P deposition =		0.3		
			(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		0.0	0.0	1.0	0.0
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	1.8			Oxic		1.0	
	1.8	81.8		Anoxic	30.0	1.0	400.6
	Summation						400.6
			Net Discharge [ac-ft/yr] =	**3,930.7**		**Net Load [lb/yr] =**	**1,747.1**

TMDL Lake Response Modeling for Kasota

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 =	0.67	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	792	[kg/yr]
		Q (lake outflow) =	4.9	[10^6 m^3/yr]
		V (modeled lake volume) =	2.7	[10^6 m^3]
		T = V/Q =	0.55	[yr]
		P_i = W/Q =	163	[µg/l]
Model Predicted In-Lake [TP]			**90**	**[ug/l]**
Observed In-Lake [TP]			**415**	**[ug/l]**

Irene Lake Current Conditions Canfield-Bachman Lake Response Model

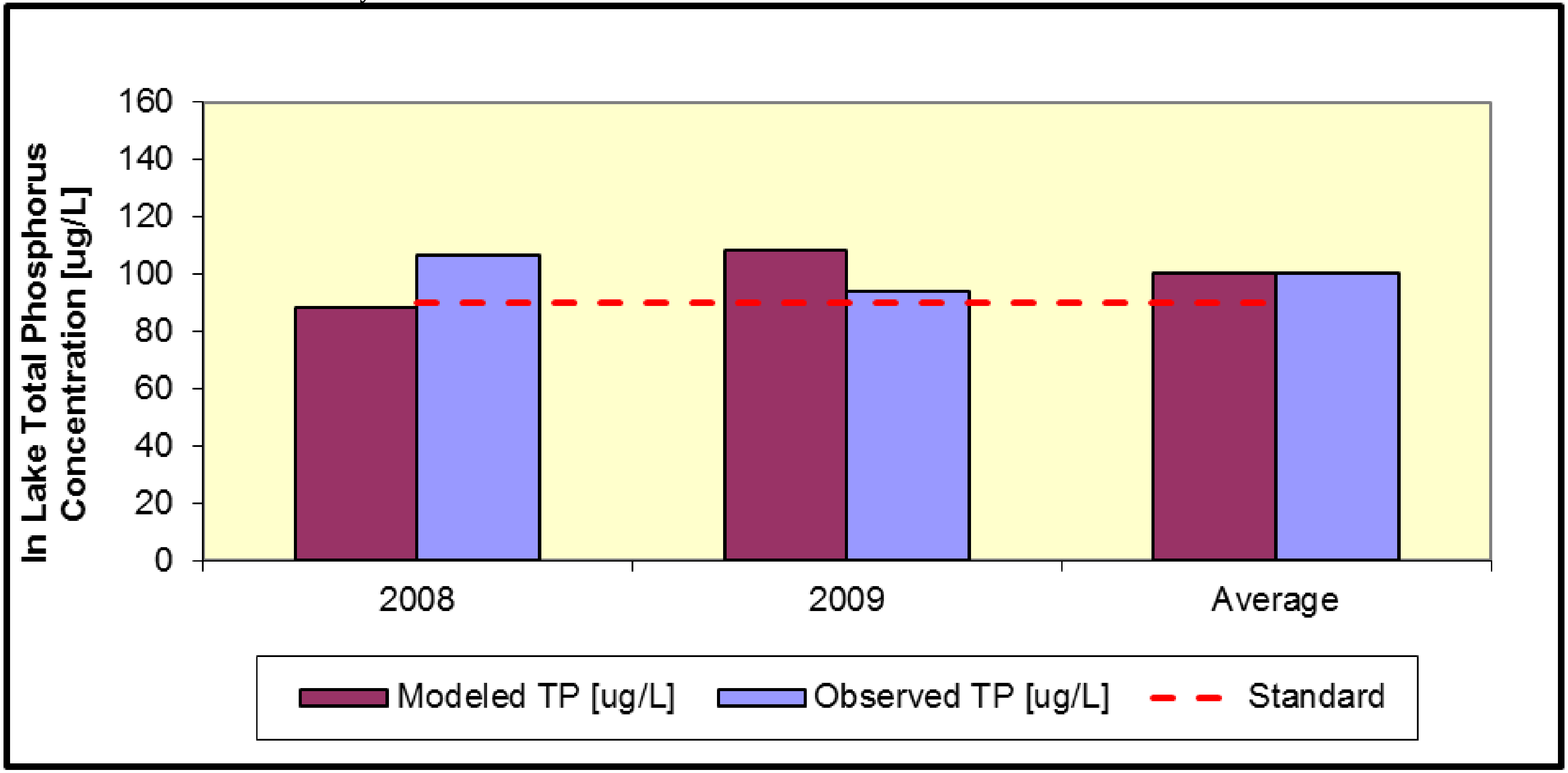
Average Loading Summary for Lillian

	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) [--]	Load [lb/yr]
1.0	Direct runoff	4,007.1	4.0	1,324.2	247.1	1.0	890.2
2.0				0.0		1.0	0.0
3.0				0.0	0.0	1.0	0.0
4.0				0.0	0.0	1.0	0.0
5.0				0.0	0.0	1.0	0.0
	Summation	*4,007.1*	*4.0*	*1,324.2*			*890.2*
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF) [--]	Load [lb/yr]
1.0				0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0	No HSPF Septics						
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*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]
1.0	Big Kandiyohi			13,800.9	165.5	1.0	6,213.8
2.0					-	1.0	
3.0					-	1.0	
	Summation			*13,800.9*	*165.5*		*6,213.8*
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]
	1,118.2	27.4	27.4	0.0	0.2	1.0	267.4
		Dry-year total P deposition =			0.2		
		Average-year total P deposition =			0.2		
		Wet-year total P deposition =			0.3		
		(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]
	1,118.2	0.0		0.0	0.0	1.0	0.0
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	4.5			Oxic		1.0	
	4.5	54.1		Anoxic	1.4	1.0	742.6
	Summation						742.6
		Net Discharge [ac-ft/yr] =		**15,125.1**	**Net Load [lb/yr] =**		**8,114.0**

Average Lake Response Modeling for Lillian

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 =	0.99	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	3,680	[kg/yr]
		Q (lake outflow) =	18.7	[10^6 m^3/yr]
		V (modeled lake volume) =	5.9	[10^6 m^3]
		T = V/Q =	0.32	[yr]
		P_i = W/Q =	197	[µg/l]
Model Predicted In-Lake [TP]			**100.5**	**[ug/l]**
Observed In-Lake [TP]			**100.5**	**[ug/l]**

Irene Lake Calibration Summary



Irene Lake TMDL Conditions Canfield-Bachman Lake Response Model

TMDL Loading Summary for Lillian

		Water Budgets			Phosphorus Loading		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Direct runoff	4,007	4.0	1,324	247	1.0	890
2				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
	Summation	*4,007*	*4*	*1,324*			*890.2*
Point Source Dischargers							
				Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	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	No HSPF Septics						
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	Big Kandiyohi			13,801	90.0	0.5	3,379
2					-	1.0	
3					-	1.0	
	Summation			*13,801*	*90.0*		*3,379*
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]
	1118	27.4	27.4	0.00	0.24	1.0	267.4
		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]
	1118	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]
	4.53			Oxic		1.0	
	4.53	54.1		Anoxic	1.4	1.0	743
	Summation						743
		Net Discharge [ac-ft/yr] =		**15,125**	**Net Load [lb/yr] =**		**5,279**

TMDL Lake Response Modeling for Lillian

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 =	0.99	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	2,395	[kg/yr]
		Q (lake outflow) =	18.7	[10^6 m^3/yr]
		V (modeled lake volume) =	5.9	[10^6 m^3]
		T = V/Q =	0.32	[yr]
		P_i = W/Q =	128	[µg/l]
Model Predicted In-Lake [TP]			**72**	**[ug/l]**
Observed In-Lake [TP]			**101**	**[ug/l]**

Little Kandiyohi Lake Current Conditions Canfield-Bachman Lake Response Model

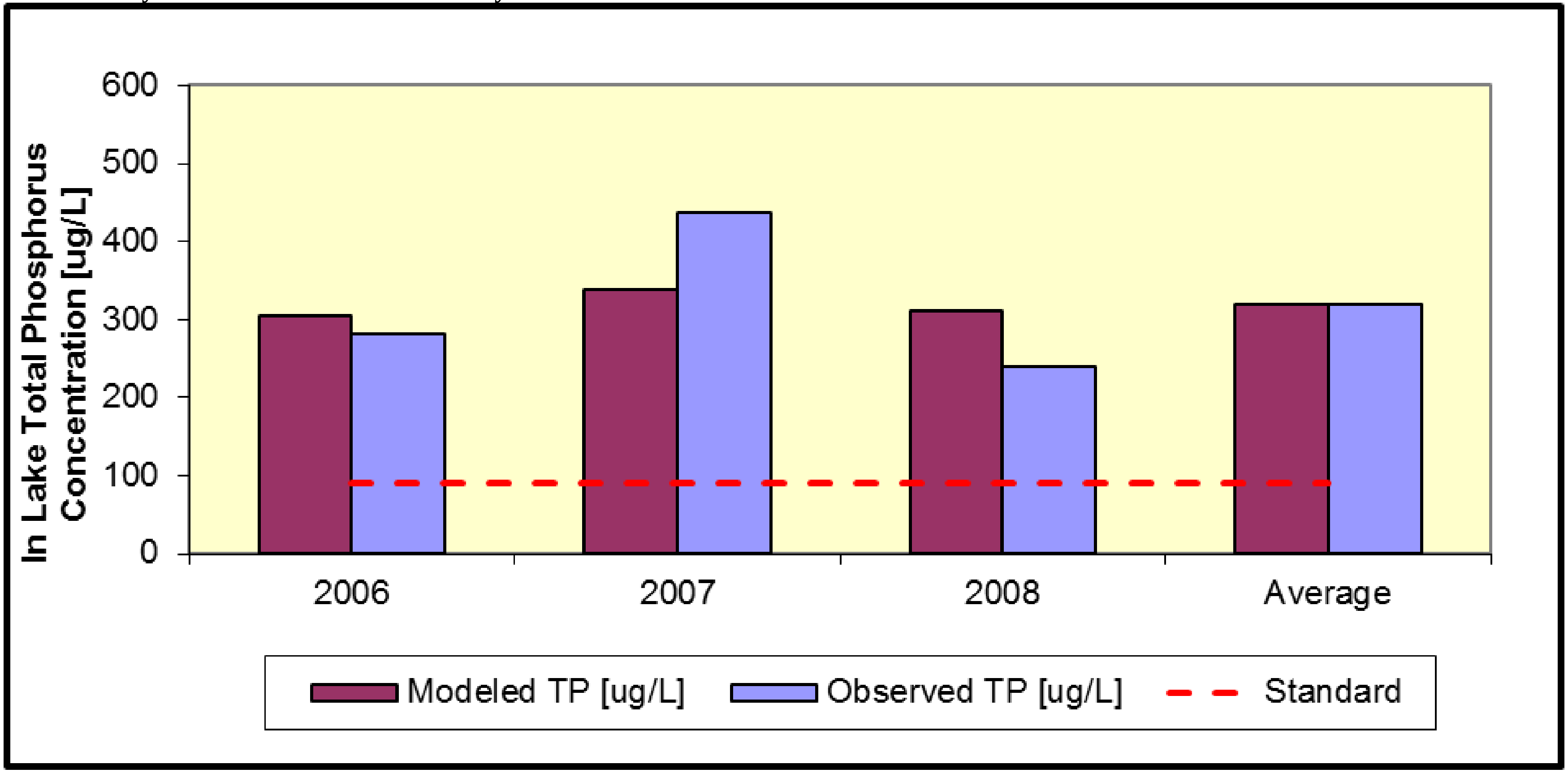
Average Loading Summary for Little Kandiyohi

	Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0	Direct Watershed	6,267.2	3.9	2,016.9	266.1	1.0	1,460.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*6,267.2*	*3.9*	*2,016.9*			*1,460.0*
Point Source Dischargers							
				Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0				0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							307.3
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*0.0*	*0.0*			*307.3*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0	Kasota			5,116.3	414.8	1.0	5,772.9
2.0					-	1.0	
3.0					-	1.0	
	Summation			*5,116.3*	*414.8*		*5,772.9*
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]
	669.0	25.3	25.3	0.0	0.2	1.0	160.0
		Dry-year total P deposition =			0.2		
		Average-year total P deposition =			0.2		
		Wet-year total P deposition =			0.3		
		(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]
	669.0	0.0		0.0	0.0	1.0	0.0
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	2.7			Oxic		1.0	
	2.7	76.5		Anoxic	10.0	1.0	4,568.9
	Summation						4,568.9
		Net Discharge [ac-ft/yr] =		**7,133.1**	**Net Load [lb/yr] =**		**12,269.1**

Average Lake Response Modeling for Little Kandiyohi

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 =	0.48	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	5,565	[kg/yr]
		Q (lake outflow) =	8.8	[10^6 m^3/yr]
		V (modeled lake volume) =	4.1	[10^6 m^3]
		T = V/Q =	0.47	[yr]
		P_i = W/Q =	632	[µg/l]
Model Predicted In-Lake [TP]			**319**	**[ug/l]**
Observed In-Lake [TP]			**319**	**[ug/l]**

Little Kandiyohi Lake Calibration Summary



Little Kandiyohi Lake TMDL Conditions Canfield-Bachman Lake Response Model

TMDL Loading Summary for Little Kandiyohi

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) [--]	Load [lb/yr]
1.0	Direct Watershed	6,267.2	3.9	2,016.9	150.0	0.6	823.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*6,267.2*	*3.9*	*2,016.9*			*823.0*

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF) [--]	Load [lb/yr]
1.0				0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							0.0
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*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]
1.0	Kasota			5,116.3	90.0	0.2	1,252.7
2.0					-	1.0	
3.0					-	1.0	
	Summation			*5,116.3*	*90.0*		*1,252.7*

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]
	669.0	25.3	25.3	0.0	0.2	1.0	160.0
		Dry-year total P deposition =			0.2		
		Average-year total P deposition =			0.2		
		Wet-year total P deposition =			0.3		
		(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]
	669.0	0.0		0.0	0.0	1.0	0.0

Internal

	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	2.7			Oxic		1.0	
	2.7	76.5		Anoxic	0.8	1.0	352.8
	Summation						352.8
		Net Discharge [ac-ft/yr] =		**7,133.1**	**Net Load [lb/yr] =**		**2,588.5**

TMDL Lake Response Modeling for Little Kandiyohi

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 =	0.48	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
	W (total P load = inflow + atm.) =		1,174	[kg/yr]
		Q (lake outflow) =	8.8	[10^6 m^3/yr]
		V (modeled lake volume) =	4.1	[10^6 m^3]
		T = V/Q =	0.47	[yr]
		P_i = W/Q =	133	[µg/l]
Model Predicted In-Lake [TP]			**90**	**[ug/l]**
Observed In-Lake [TP]			**319**	**[ug/l]**

Marion Lake Current Conditions Canfield-Bachman Lake Response Model

Average Loading Summary for Marion

Water Budgets					Phosphorus Loading		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0	Direct Watershed	4,045.1	8.4	2,847.0	397.1	1.0	3,075.9
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*4,045.1*	*8.4*	*2,847.0*			*3,075.9*

Point Source Dischargers

				Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0				0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							22.3
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*0.0*	*0.0*			*22.3*

Inflow from Upstream Lakes

				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0					-	1.0	
2.0					-	1.0	
3.0					-	1.0	
	Summation			*0.0*	-		*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]
	531.7	30.3	30.3	0.0	0.2	1.0	127.1
		Dry-year total P deposition =			0.2		
		Average-year total P deposition =			0.2		
		Wet-year total P deposition =			0.3		
		(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]
	531.7	0.0		0.0	0.0	1.0	0.0

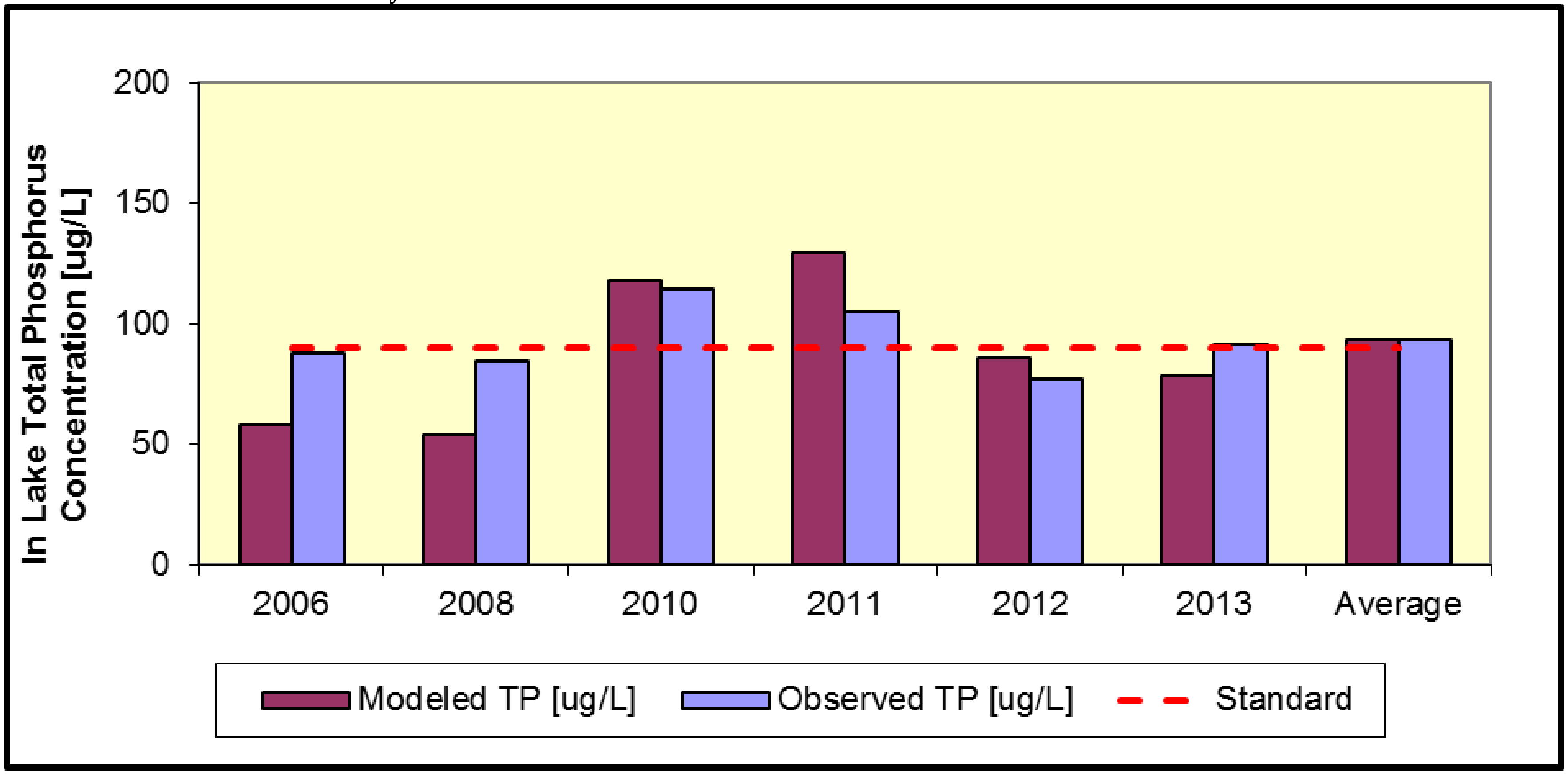
Internal

	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	2.2			Oxic		1.0	
	2.2	53.5		Anoxic	0.1	1.0	25.4
	Summation						25.4
		Net Discharge [ac-ft/yr] =		**2,847.0**	**Net Load [lb/yr] =**		**3,250.7**

Average Lake Response Modeling for Marion

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 =	1.17	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	1,474	[kg/yr]
		Q (lake outflow) =	3.5	[10^6 m^3/yr]
		V (modeled lake volume) =	4.6	[10^6 m^3]
		T = V/Q =	1.31	[yr]
		P_i = W/Q =	420	[µg/l]
Model Predicted In-Lake [TP]			**93**	**[ug/l]**
Observed In-Lake [TP]			**93**	**[ug/l]**

Marion Lake Calibration Summary



Marion Lake TMDL Conditions Canfield-Bachman Lake Response Model

TMDL Loading Summary for Marion

		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) [--]	Load [lb/yr]
1.0	Direct Watershed	4,045.1	8.4	2,847.0	376.6	0.9	2,916.5
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*4,045.1*	*8.4*	*2,847.0*			*2,916.5*

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF) [--]	Load [lb/yr]
1.0				0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							0.0
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*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]
1.0					-	1.0	
2.0					-	1.0	
3.0					-	1.0	
	Summation			*0.0*	-		*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]
531.7	30.3	30.3	0.0	0.2	1.0	127.1
			Dry-year total P deposition =	0.2		
			Average-year total P deposition =	0.2		
			Wet-year total P deposition =	0.3		
			(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]
531.7	0.0		0.0	0.0	1.0	0.0

Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
2.2			Oxic		1.0	
2.2	53.5		Anoxic	0.1	1.0	25.4
Summation						25.4
		Net Discharge [ac-ft/yr] =	2,847.0		Net Load [lb/yr] =	3,069.0

TMDL Lake Response Modeling for Marion

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
		as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.17	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	1,392	[kg/yr]
		Q (lake outflow) =	3.5	[10^6 m^3/yr]
		V (modeled lake volume) =	4.6	[10^6 m^3]
		T = V/Q =	1.31	[yr]
		P_i = W/Q =	396	[µg/l]
Model Predicted In-Lake [TP]			**90**	**[ug/l]**
Observed In-Lake [TP]			**93**	**[ug/l]**

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

Minnetaga Lake Current Conditions Canfield-Bachman Lake Response Model

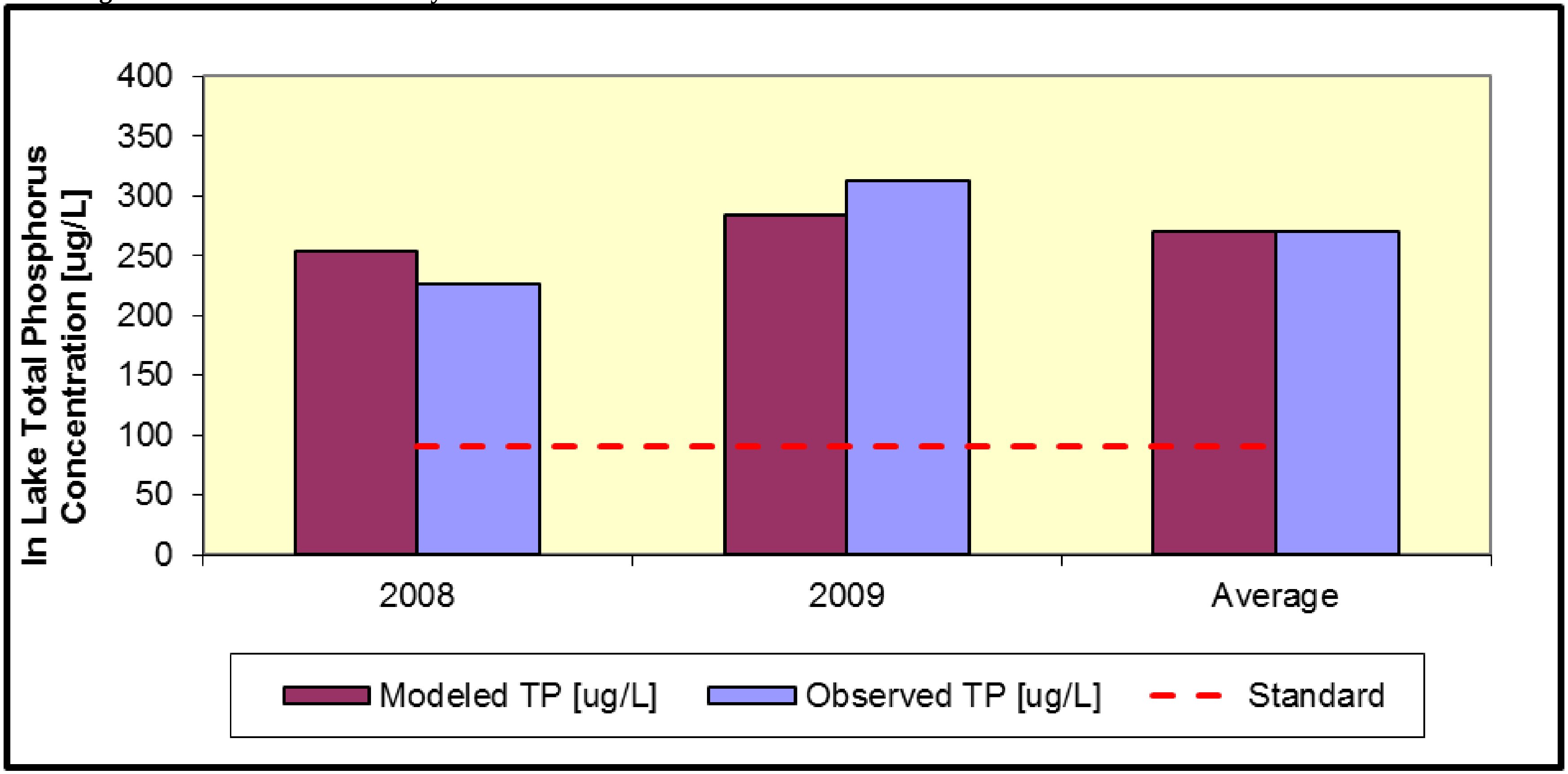
Average Loading Summary for Minnetage

		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) [--]	Load [lb/yr]
1	Direct Watershed	8,172	5.8	3,949	349	1.0	3,747
2				0		1.0	0
3				0		1.0	0
4				0		1.0	0
5				0		1.0	0
	Summation	*8,172*	*6*	*3,949*			*3,747.2*
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF) [--]	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	No septics						
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]
	766	27.4	27.4	0.00	0.24	1.0	183.1
		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]
	766	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]
	3.10			Oxic		1.0	
	3.10	73.3		Anoxic	12.6	1.0	6,310
	Summation						6,310
		Net Discharge [ac-ft/yr] =		**3,949**	**Net Load [lb/yr] =**		**10,240**

Average Lake Response Modeling for Minnetage

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 =	0.69	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	4,645	[kg/yr]
		Q (lake outflow) =	4.9	[10^6 m^3/yr]
		V (modeled lake volume) =	4.7	[10^6 m^3]
		T = V/Q =	0.97	[yr]
		P_i = W/Q =	953	[µg/l]
Model Predicted In-Lake [TP]			**270**	**[ug/l]**
Observed In-Lake [TP]			**270**	**[ug/l]**

Minnetaga Lake Calibration Summary



Minnetaga Lake TMDL Conditions Canfield-Bachman Lake Response Model

TMDL Loading Summary for Minnetage

	Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Direct Watershed	8,172	5.8	3,949	150	0.4	1,611
2				0		1.0	0
3				0		1.0	0
4				0		1.0	0
5				0		1.0	0
	Summation	*8,172*	*6*	*3,949*			*1,611.3*
Point Source Dischargers							
				Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	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	No septics						
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]
	766	27.4	27.4	0.00	0.24	1.0	183.1
		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]
	766	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]
	3.10			Oxic		1.0	
	3.10	73.3		Anoxic	0.8	1.0	376
	Summation						376
		Net Discharge [ac-ft/yr] =		**3,949**	**Net Load [lb/yr] =**		**2,170**

TMDL Lake Response Modeling for Minnetage

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 =	0.69	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	984	[kg/yr]
		Q (lake outflow) =	4.9	[10^6 m^3/yr]
		V (modeled lake volume) =	4.7	[10^6 m^3]
		T = V/Q =	0.97	[yr]
		P_i = W/Q =	202	[µg/l]
Model Predicted In-Lake [TP]			**90**	**[ug/l]**
Observed In-Lake [TP]			**270**	**[ug/l]**

Mud Lake Current Conditions Canfield-Bachman Lake Response Model

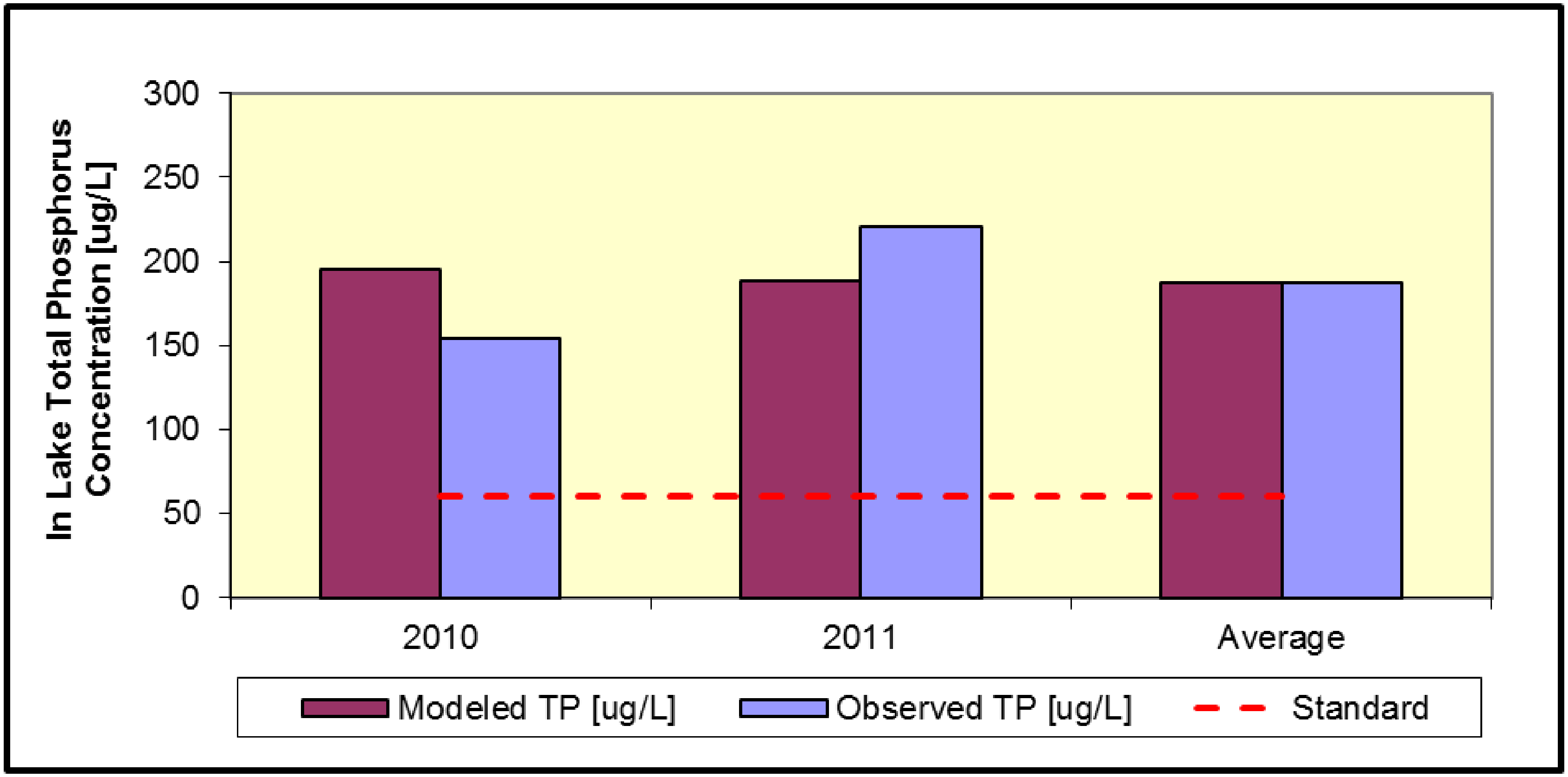
Average Loading Summary for Mud

	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) [--]	Load [lb/yr]
1.0	Entire watershed	4,826.6	8.0	3,215.0	232.3	1.0	2,031.8
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*4,826.6*	*8.0*	*3,215.0*			*2,031.8*
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF) [--]	Load [lb/yr]
1.0				0.0	0.0		0.0
2.0				0.0	0.0		0.0
3.0				0.0	0.0		0.0
4.0				0.0	0.0		0.0
5.0				0.0	0.0		0.0
	Summation			*0.0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							0.3
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*0.0*	*0.0*			*0.3*
Inflow from Upstream Lakes							
	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1.0	Swede			244.0	333.7	1.0	221.5
2.0					-	1.0	
3.0					-	1.0	
	Summation			*244.0*	*333.7*		*221.5*
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]
	221.1	28.5	28.5	0.0	0.2	1.0	52.9
			Dry-year total P deposition =		0.2		
			Average-year total P deposition =		0.2		
			Wet-year total P deposition =		0.3		
			(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]
	221.1	0.0		0.0	0.0	1.0	0.0
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	0.9			Oxic		1.0	
	0.9	66.5		Anoxic	2.8	1.0	367.3
	Summation						367.3
		Net Discharge [ac-ft/yr] =		**3,458.9**	**Net Load [lb/yr] =**		**2,673.7**

Average Lake Response Modeling for Mud

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION		as f(W,Q,V) from Canfield & Bachmann (1981)		
	$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$	C_P =	0.55	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	1,213	[kg/yr]
		Q (lake outflow) =	4.3	[10^6 m^3/yr]
		V (modeled lake volume) =	0.9	[10^6 m^3]
		T = V/Q =	0.21	[yr]
		P_i = W/Q =	284	[µg/l]
Model Predicted In-Lake [TP]			**187**	**[ug/l]**
Observed In-Lake [TP]			**187**	**[ug/l]**

Mud Lake Calibration Summary



Mud Lake TMDL Conditions Canfield-Bachman Lake Response Model

TMDL Loading Summary for Mud

	Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0	Entire watershed	4,826.6	8.0	3,215.0	72.4	0.3	633.7
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*4,826.6*	*8.0*	*3,215.0*			*633.7*
Point Source Dischargers							
				Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0				0.0	0.0		0.0
2.0				0.0	0.0		0.0
3.0				0.0	0.0		0.0
4.0				0.0	0.0		0.0
5.0				0.0	0.0		0.0
	Summation			*0.0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							0.0
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*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]
1.0	Swede			244.0	60.0	0.2	39.8
2.0					-	1.0	
3.0					-	1.0	
	Summation			*244.0*	*60.0*		*39.8*
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]
	221.1	28.5	28.5	0.0	0.2	1.0	52.9
				Dry-year total P deposition =	0.2		
				Average-year total P deposition =	0.2		
				Wet-year total P deposition =	0.3		
				(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]
	221.1	0.0		0.0	0.0	1.0	0.0
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	0.9			Oxic		1.0	
	0.9	66.5		Anoxic	0.1	1.0	13.1
	Summation						13.1
			Net Discharge [ac-ft/yr] =	**3,458.9**		**Net Load [lb/yr] =**	**739.5**

TMDL Lake Response Modeling for Mud

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 =	0.60	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	335	[kg/yr]
		Q (lake outflow) =	4.3	[10^6 m^3/yr]
		V (modeled lake volume) =	0.9	[10^6 m^3]
		T = V/Q =	0.21	[yr]
		P_i = W/Q =	79	[µg/l]
Model Predicted In-Lake [TP]			**60**	**[ug/l]**
Observed In-Lake [TP]			**187**	**[ug/l]**

Peter (N Bay) Lake Current Conditions Canfield-Bachman Lake Response Model

Average Loading Summary for Peter N Bay

		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) [--]	Load [lb/yr]
1.0		2,996.3	0.8	190.5	158.1	1.0	82.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*2,996.3*	*0.8*	*190.5*			*82.0*

Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF) [--]	Load [lb/yr]
1.0				0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*

Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							4.5
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*0.0*	*0.0*			*4.5*

Inflow from Upstream Lakes							
	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1.0					-	1.0	
2.0					-	1.0	
3.0					-	1.0	
	Summation			*0.0*	-		*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]
14.0	30.6	30.6	0.0	0.2	1.0	3.3
	Dry-year total P deposition =			0.2		
	Average-year total P deposition =			0.2		
	Wet-year total P deposition =			0.3		
	(Barr Engineering 2004)					

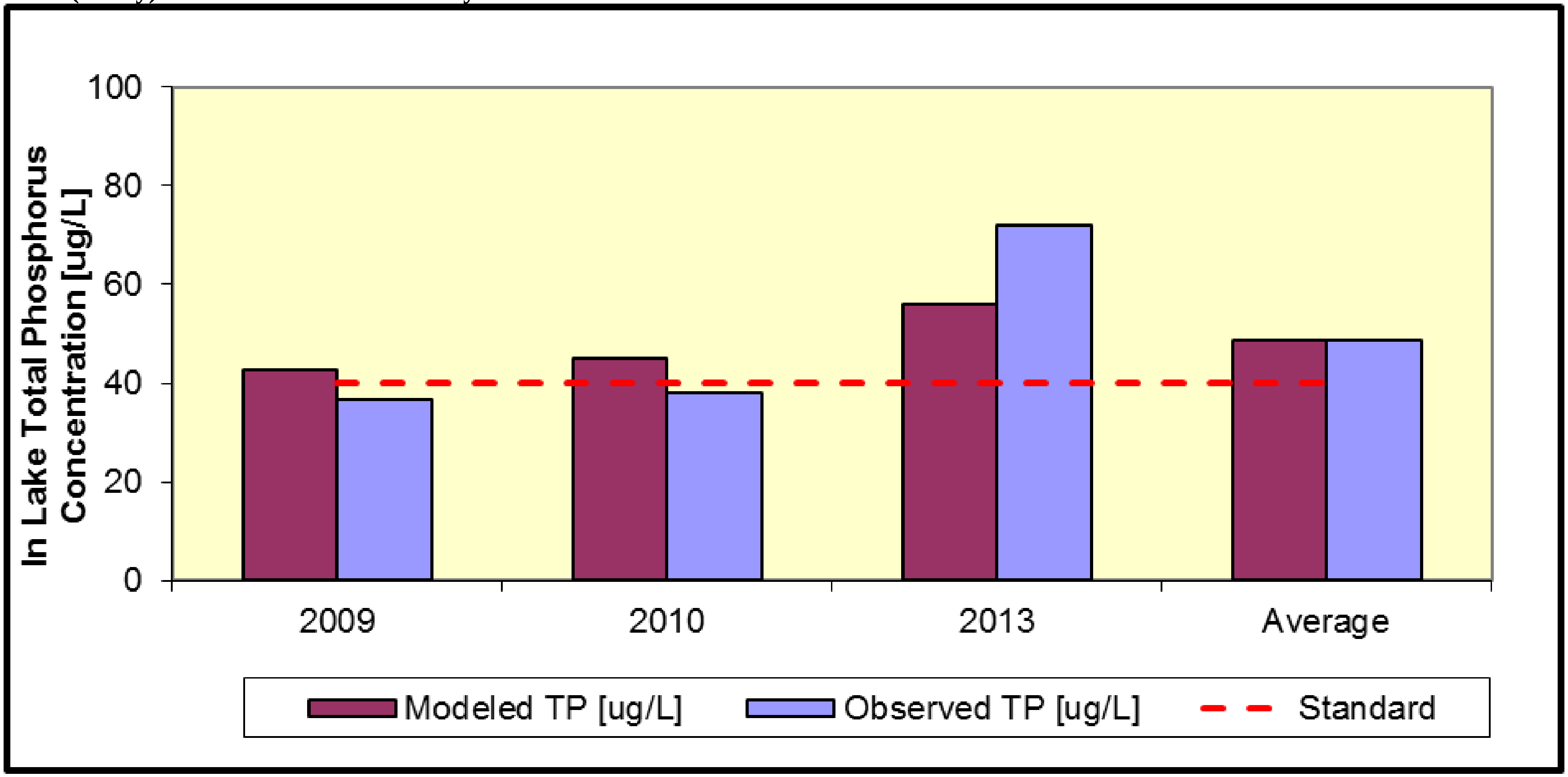
Groundwater						
Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
14.0	0.0		0.0	0.0	1.0	0.0

Internal						
Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
0.1			Oxic		1.0	
0.1	53.4		Anoxic	3.2	1.0	21.3
Summation						21.3
	Net Discharge [ac-ft/yr] =		**190.5**		**Net Load [lb/yr] =**	**111.1**

Average Lake Response Modeling for Peter N Bay

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	as f(W,Q,V) from Canfield & Bachmann (1981)			
	$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$	C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	50	[kg/yr]
		Q (lake outflow) =	0.2	[10^6 m^3/yr]
		V (modeled lake volume) =	0.7	[10^6 m^3]
		T = V/Q =	2.94	[yr]
		P_i = W/Q =	214	[µg/l]
Model Predicted In-Lake [TP]			**49**	**[ug/l]**
Observed In-Lake [TP]			**49**	**[ug/l]**

Peter (N Bay) Lake Calibration Summary



Peter (N Bay) Lake TMDL Conditions Canfield-Bachman Lake Response Model

TMDL Loading Summary for Peter N Bay

		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]
1.0		2,996.3	0.8	190.5	110.7	0.7	57.4
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*2,996.3*	*0.8*	*190.5*			*57.4*
Point Source Dischargers							
				Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0				0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							0.0
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*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]
1.0					-	1.0	
2.0					-	1.0	
3.0					-	1.0	
	Summation			*0.0*	-		*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]
	14.0	30.6	30.6	0.0	0.2	1.0	3.3
		Dry-year total P deposition =			0.2		
		Average-year total P deposition =			0.2		
		Wet-year total P deposition =			0.3		
		(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]
	14.0	0.0		0.0	0.0	1.0	0.0
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km²]	[days]			[mg/m²-day]	[--]	[lb/yr]
	0.1			Oxic		1.0	
	0.1	53.4		Anoxic	3.2	1.0	21.3
	Summation						21.3
		Net Discharge [ac-ft/yr] =		**190.5**	**Net Load [lb/yr] =**		**82.1**

TMDL Lake Response Modeling for Peter N Bay

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION		as f(W,Q,V) from Canfield & Bachmann (1981)		
$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	37	[kg/yr]
		Q (lake outflow) =	0.2	[10^6 m³/yr]
		V (modeled lake volume) =	0.7	[10^6 m³]
		T = V/Q =	2.94	[yr]
		P_i = W/Q =	158	[µg/l]
Model Predicted In-Lake [TP]			**40**	**[ug/l]**
Observed In-Lake [TP]			**49**	**[ug/l]**

Preston Lake Current Conditions Canfield-Bachman Lake Response Model

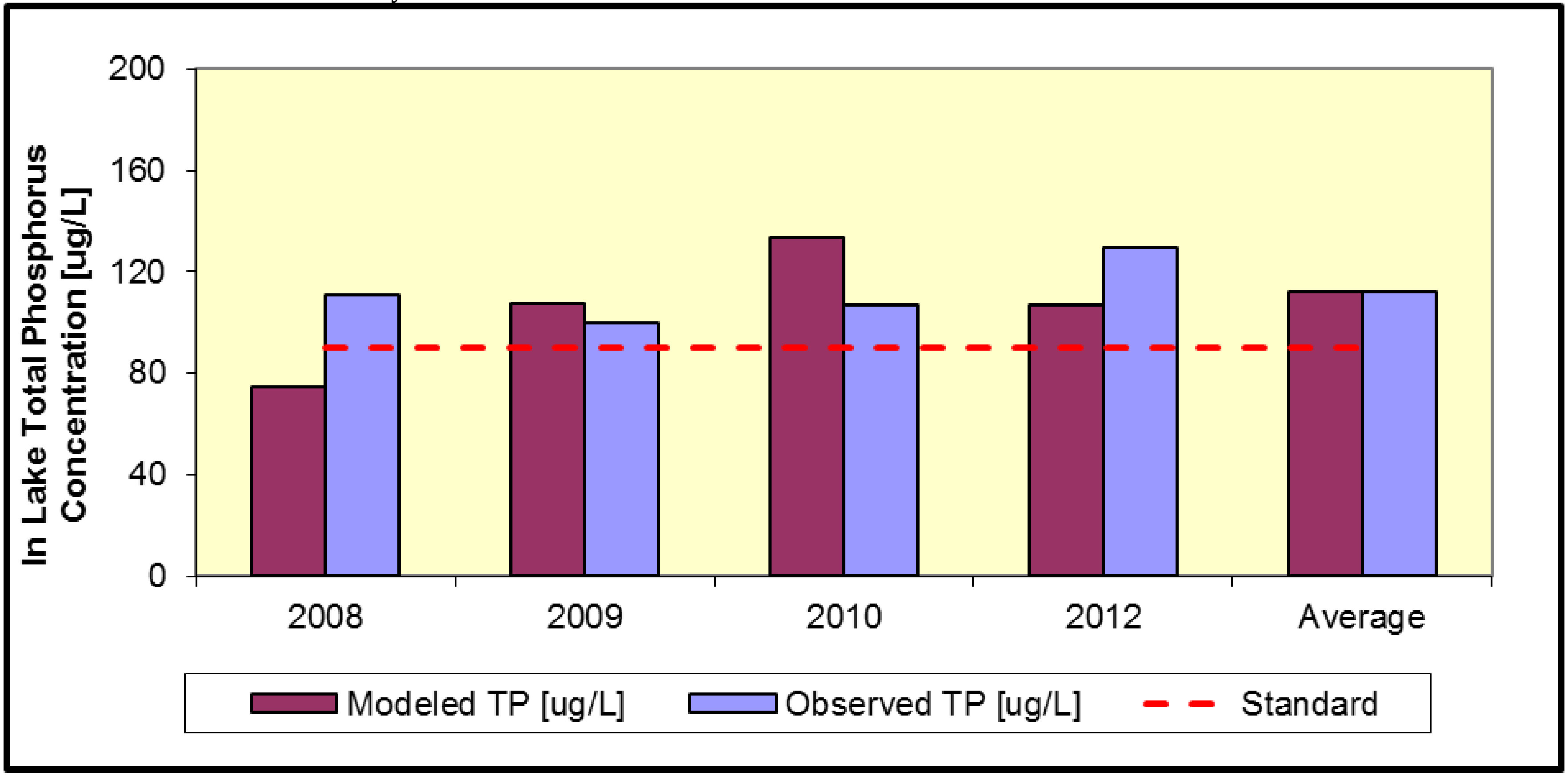
Average Loading Summary for Preston

		Water Budgets			Phosphorus Loading		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0	Direct	4,043.4	4.6	1,539.8	587.2	1.0	2,459.8
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*4,043.4*	*4.6*	*1,539.8*			*2,459.8*
Point Source Dischargers							
				Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0				0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							16.3
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*0.0*	*0.0*			*16.3*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0	Allie			2,570.3	260.0	1.0	1,818.0
2.0					-	1.0	
3.0					-	1.0	
	Summation			*2,570.3*	*260.0*		*1,818.0*
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]
	636.1	34.0	34.0	0.0	0.2	1.0	152.1
			Dry-year total P deposition =		0.2		
			Average-year total P deposition =		0.2		
			Wet-year total P deposition =		0.3		
			(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]
	636.1	0.0		0.0	0.0	1.0	0.0
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	2.6			Oxic		1.0	
	2.6	56.7		Anoxic	0.5	1.0	160.8
	Summation						160.8
			Net Discharge [ac-ft/yr] =	**4,110.0**		**Net Load [lb/yr] =**	**4,607.1**

Average Lake Response Modeling for Preston

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 =	1.07	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	2,090	[kg/yr]
		Q (lake outflow) =	5.1	[10^6 m^3/yr]
		V (modeled lake volume) =	4.9	[10^6 m^3]
		T = V/Q =	0.96	[yr]
		P_i = W/Q =	412	[µg/l]
Model Predicted In-Lake [TP]			**112**	**[ug/l]**
Observed In-Lake [TP]			**112**	**[ug/l]**

Preston Lake Calibration Summary



Preston Lake TMDL Conditions Canfield-Bachman Lake Response Model

TMDL Loading Summary for Preston

	Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0	Direct	4,043.4	4.6	1,539.8	418.5	0.7	1,753.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*4,043.4*	*4.6*	*1,539.8*			*1,753.0*
Point Source Dischargers							
				Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0				0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							0.0
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*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]
1.0	Allie			2,570.3	181.9	0.7	1,272.0
2.0					-	1.0	
3.0					-	1.0	
	Summation			*2,570.3*	*181.9*		*1,272.0*
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]
	636.1	34.0	34.0	0.0	0.2	1.0	152.1
			Dry-year total P deposition =		0.2		
			Average-year total P deposition =		0.2		
			Wet-year total P deposition =		0.3		
			(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]
	636.1	0.0		0.0	0.0	1.0	0.0
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	2.6			Oxic		1.0	
	2.6	56.7		Anoxic	0.5	1.0	160.8
	Summation						160.8
			Net Discharge [ac-ft/yr] =	**4,110.0**		**Net Load [lb/yr] =**	**3,337.9**

TMDL Lake Response Modeling for Preston

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 =	1.07	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	1,514	[kg/yr]
		Q (lake outflow) =	5.1	[10^6 m^3/yr]
		V (modeled lake volume) =	4.9	[10^6 m^3]
		T = V/Q =	0.96	[yr]
		P_i = W/Q =	299	[µg/l]
Model Predicted In-Lake [TP]			**90**	**[ug/l]**
Observed In-Lake [TP]			**112**	**[ug/l]**

Rice Lake Current Conditions Canfield-Bachman Lake Response Model

Average Loading Summary for Rice

	Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0	Entire Watershed	5,345.4	3.6	1,610.8	325.5	1.0	1,426.3
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*5,345.4*	*3.6*	*1,610.8*			*1,426.3*

Point Source Dischargers							
				Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0				0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*

Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0	Reach 903						22.8
2.0	Reach 895						0.2
3.0	Reach 905						30.6
4.0							
5.0							
	Summation	*0.0*	*0.0*	*0.0*			*53.5*

Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0	Independence			387.8	53.9	1.0	56.8
2.0	Oak			43.0	123.7	1.0	14.5
3.0	Mud			267.9	187.5	1.0	136.6
4.0	Irene			405.5	180.0	1.0	198.6
5.0	Robina			75.2	134.2	1.0	27.5
6.0	Whaletail (N)			68.7	269.8	1.0	50.4
	Summation			*1,248.1*	*158.2*		*484.4*

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]
	141.7	28.3	28.3	0.0	0.2	1.0	33.9
				Dry-year total P deposition =	0.2		
				Average-year total P deposition =	0.2		
				Wet-year total P deposition =	0.3		
				(Barr Engineering 2004)			

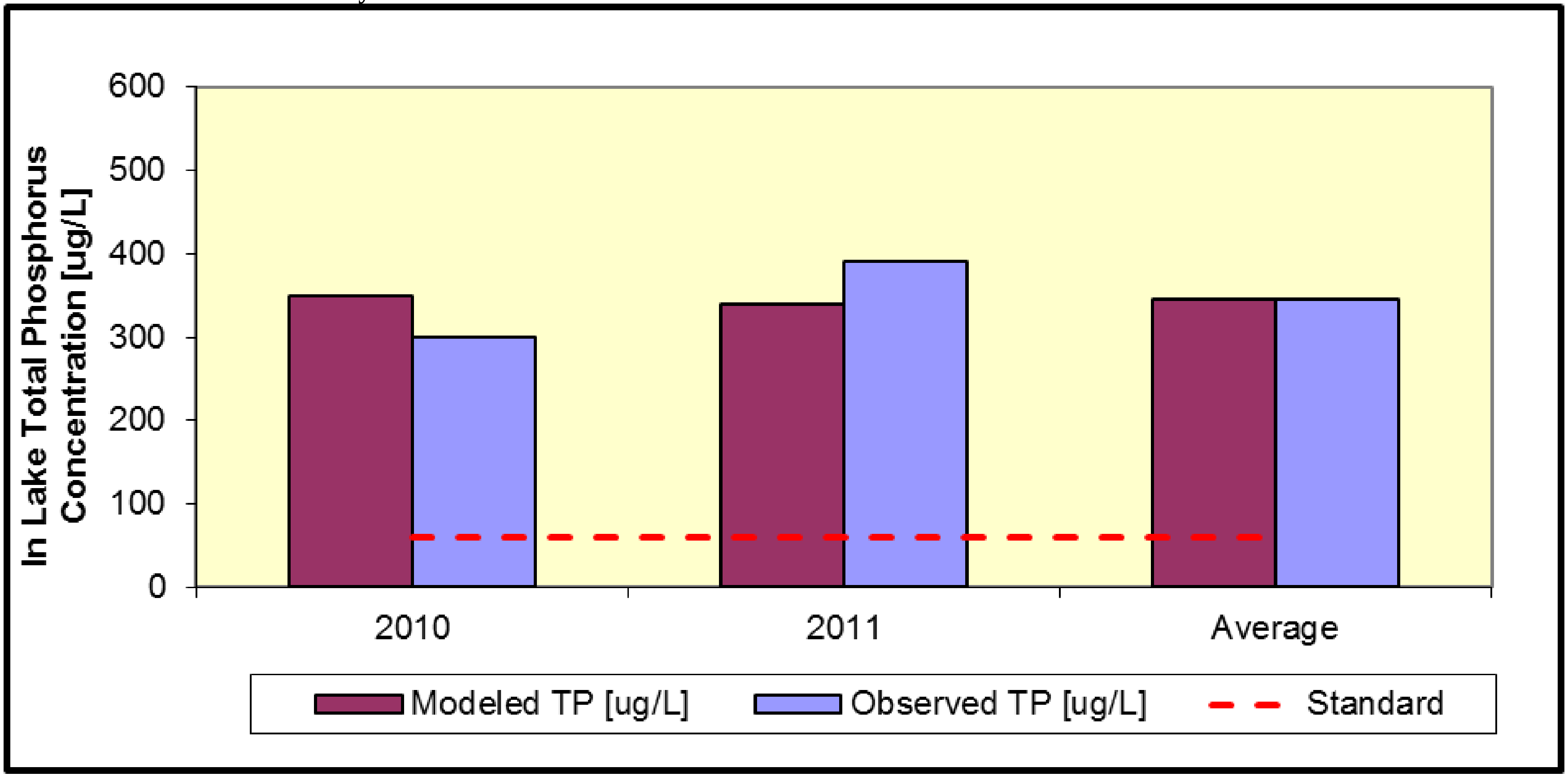
Groundwater							
	Lake Area	Groundwater Flux		Net Inflow	Phosphorus Concentration	Calibration Factor	Load
	[acre]	[m/yr]		[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
	141.7	0.0		0.0	0.0	1.0	0.0

Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	0.6			Oxic		1.0	
	0.6	77.5		Anoxic	17.8	1.0	1,743.2
	Summation						1,743.2
			Net Discharge [ac-ft/yr] =	**2,858.9**		Net Load [lb/yr] =	**3,741.3**

Average Lake Response Modeling for Rice

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 =	0.73	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	1,697	[kg/yr]
		Q (lake outflow) =	3.5	[10^6 m^3/yr]
		V (modeled lake volume) =	0.2	[10^6 m^3]
		T = V/Q =	0.05	[yr]
		P_i = W/Q =	481	[µg/l]
Model Predicted In-Lake [TP]			**345**	**[ug/l]**
Observed In-Lake [TP]			**345**	**[ug/l]**

Rice Lake Calibration Summary



Rice Lake TMDL Conditions Canfield-Bachman Lake Response Model

TMDL Loading Summary for Rice

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) [--]	Load [lb/yr]
1	Entire Watershed	5,345	3.6	1,611	72	0.2	317
2				0		1.0	0
3				0		1.0	0
4				0		1.0	0
5				0		1.0	0
	Summation	*5,345*	*4*	*1,611*			*316.5*

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF) [--]	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 903						0
2	Reach 895						0
3	Reach 905						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	Independence			388	40.0	0.7	42
2	Oak			43	60.0	0.5	7
3	Mud			268	60.0	0.3	44
4	Irene			406	60.0	0.3	66
5	Robina			75	60.0	0.4	12
6	Whaletail (N)			69	60.0	0.2	11
	Summation			*1,248*	*56.7*		*183*

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]
142	28.3	28.3	0.00	0.24	1.0	33.9
			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]
142	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]
0.57			Oxic		1.0	
0.57	77.5		Anoxic	17.8	1.0	10
Summation						10
	Net Discharge [ac-ft/yr] =		**2,859**		**Net Load [lb/yr] =**	**543**

TMDL Lake Response Modeling for Rice

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 =	0.73	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	246	[kg/yr]
		Q (lake outflow) =	3.5	[10^6 m^3/yr]
		V (modeled lake volume) =	0.2	[10^6 m^3]
		T = V/Q =	0.05	[yr]
		P_i = W/Q =	70	[µg/l]
Model Predicted In-Lake [TP]			**60**	**[ug/l]**
Observed In-Lake [TP]			**345**	**[ug/l]**

Silver Lake Current Conditions Canfield-Bachman Lake Response Model

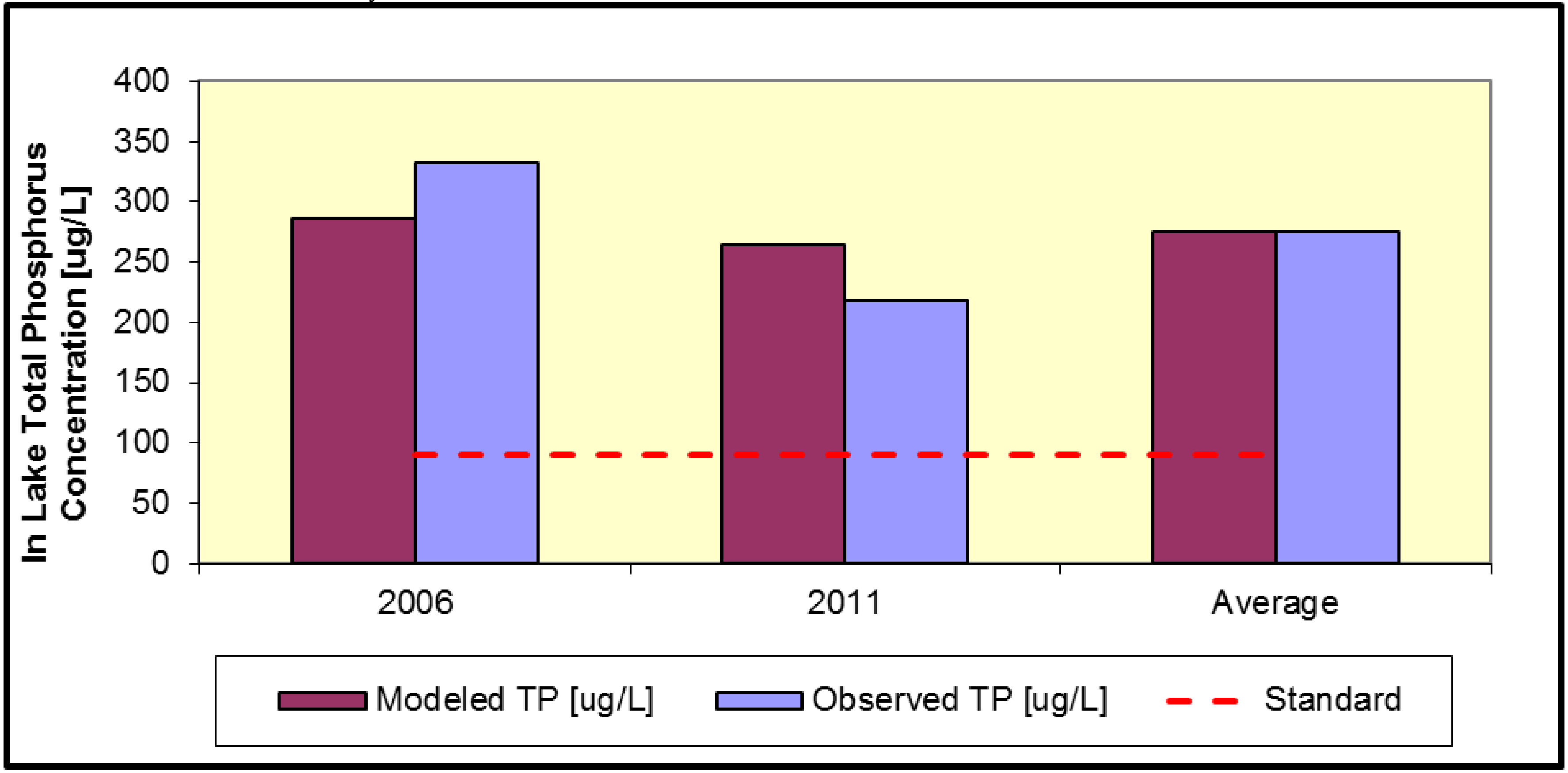
Average Loading Summary for Silver

	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) [--]	Load [lb/yr]
1.0	Direct Watershed	1,319.6	7.2	793.2	241.2	1.0	520.6
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*1,319.6*	*7.2*	*793.2*			*520.6*
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF) [--]	Load [lb/yr]
1.0				0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							3.0
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*0.0*	*0.0*			*3.0*
Inflow from Upstream Lakes							
	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1.0	no upstream lake				-	1.0	
2.0					-	1.0	
3.0					-	1.0	
	Summation			*0.0*	-		*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]
	452.7	22.4	22.4	0.0	0.2	1.0	100.6
				Dry-year total P deposition =	0.2		
				Average-year total P deposition =	0.2		
				Wet-year total P deposition =	0.3		
				(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]
	452.7	0.0		0.0	0.0	1.0	0.0
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	1.8			Oxic		1.0	
	1.8	73.7		Anoxic	18.4	1.0	5,484.9
	Summation						5,484.9
		Net Discharge [ac-ft/yr] =		**793.2**	**Net Load [lb/yr] =**		**6,109.1**

Average Lake Response Modeling for Silver

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 =	0.99	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	2,771	[kg/yr]
		Q (lake outflow) =	1.0	[10^6 m^3/yr]
		V (modeled lake volume) =	2.1	[10^6 m^3]
		T = V/Q =	2.16	[yr]
		P_i = W/Q =	2831	[µg/l]
Model Predicted In-Lake [TP]			**275**	**[ug/l]**
Observed In-Lake [TP]			**275**	**[ug/l]**

Silver Lake Calibration Summary



Silver Lake TMDL Conditions Canfield-Bachman Lake Response Model

TMDL Loading Summary for Silver

		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) [--]	Load [lb/yr]
1.0	Direct Watershed	1,319.6	7.2	793.2	177.8	0.7	383.7
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*1,319.6*	*7.2*	*793.2*			*383.7*
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF) [--]	Load [lb/yr]
1.0				0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							0.0
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*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]
1.0	no upstream lake				-	1.0	
2.0					-	1.0	
3.0					-	1.0	
	Summation			*0.0*	-		*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]
	452.7	22.4	22.4	0.0	0.2	1.0	100.6
		Dry-year total P deposition =			0.2		
		Average-year total P deposition =			0.2		
		Wet-year total P deposition =			0.3		
		(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]
	452.7	0.0		0.0	0.0	1.0	0.0
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	1.8			Oxic		1.0	
	1.8	73.7		Anoxic	1.6	1.0	487.9
	Summation						487.9
		Net Discharge [ac-ft/yr] =		**793.2**		**Net Load [lb/yr] =**	**972.1**

TMDL Lake Response Modeling for Silver

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 =	0.99	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	441	[kg/yr]
		Q (lake outflow) =	1.0	[10^6 m^3/yr]
		V (modeled lake volume) =	2.1	[10^6 m^3]
		T = V/Q =	2.16	[yr]
		P_i = W/Q =	450	[µg/l]
Model Predicted In-Lake [TP]			**90**	**[ug/l]**
Observed In-Lake [TP]			**275**	**[ug/l]**

South Lake Current Conditions Canfield-Bachman Lake Response Model

Average Loading Summary for South

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) [--]	Load [lb/yr]
1.0	Direct Watershed	685.8	8.1	461.3	276.2	1.0	346.6
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*685.8*	*8.1*	*461.3*			*346.6*

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF) [--]	Load [lb/yr]
1.0	Winsted WWTP			213.4	1,368.6	1.0	794.5
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*213.4*			*794.5*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							11.8
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*0.0*	*0.0*			*11.8*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1.0	no upstream lake				-	1.0	
2.0					-	1.0	
3.0					-	1.0	
	Summation			*0.0*	-		*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]
	178.0	34.0	34.0	0.0	0.2	1.0	42.6
		Dry-year total P deposition =			0.2		
		Average-year total P deposition =			0.2		
		Wet-year total P deposition =			0.3		
		(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]
	178.0	0.0		0.0	0.0	1.0	0.0

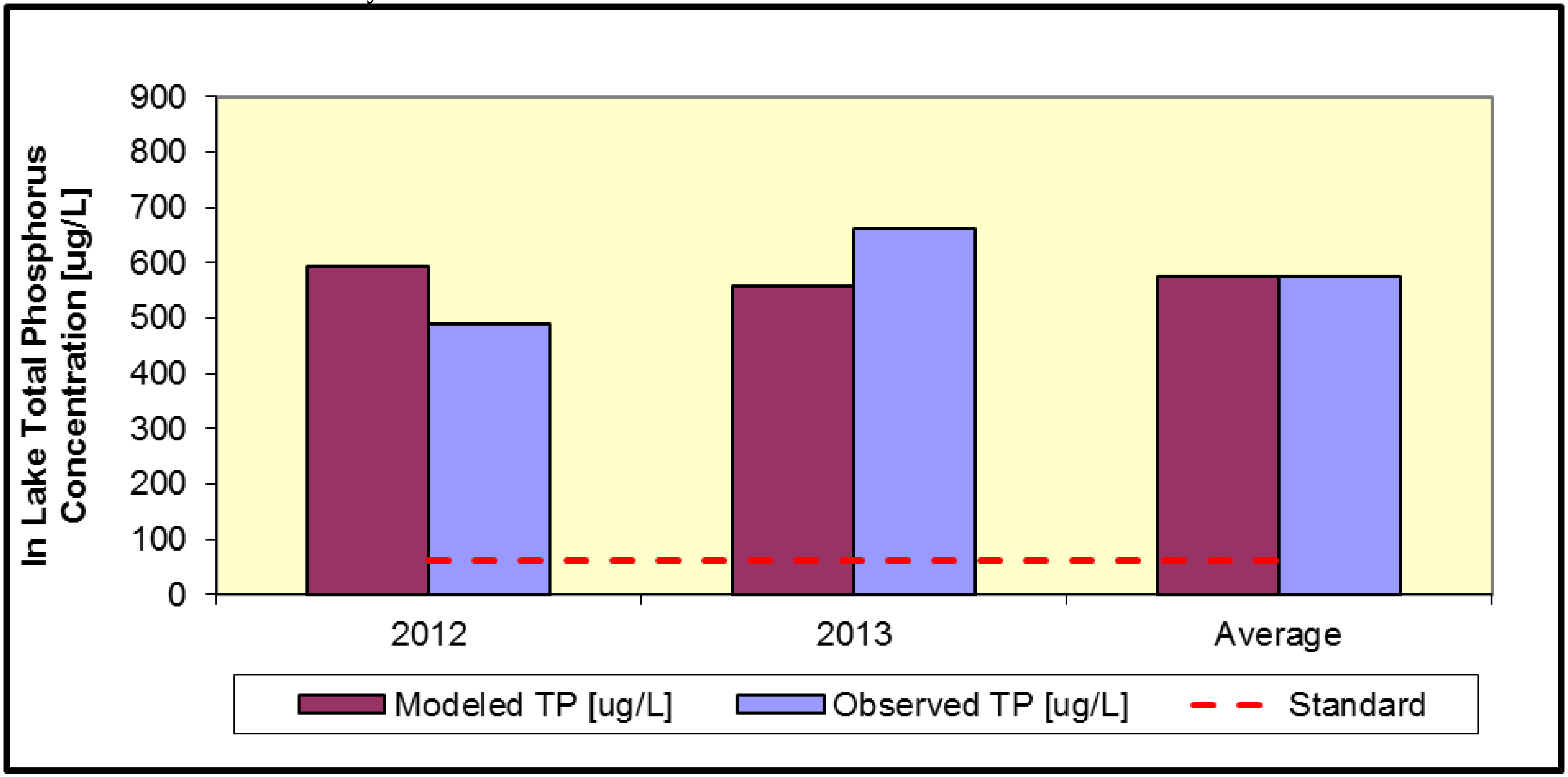
Internal

	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	0.7			Oxic		1.0	
	0.7	89.1		Anoxic	19.2	1.0	2,712.8
	Summation						2,712.8
		Net Discharge [ac-ft/yr] =		**674.7**	Net Load [lb/yr] =		**3,908.2**

Average Lake Response Modeling for South

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 =	0.39	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	1,773	[kg/yr]
		Q (lake outflow) =	0.8	[10^6 m^3/yr]
		V (modeled lake volume) =	1.3	[10^6 m^3]
		T = V/Q =	1.58	[yr]
		P_i = W/Q =	2129	[µg/l]
Model Predicted In-Lake [TP]			**576.5**	**[ug/l]**
Observed In-Lake [TP]			**576.5**	**[ug/l]**

South Lake Calibration Summary



South Lake TMDL Conditions Canfield-Bachman Lake Response Model

TMDL Loading Summary for South

	Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0	Direct Watershed	685.8	8.1	461.3	71.9	0.3	90.2
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*685.8*	*8.1*	*461.3*			*90.2*
Point Source Dischargers							
				Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0	Winsted WWTP			0.0	0.0	1.0	0.0
2.0							
3.0							
4.0							
5.0							
	Summation			*0.0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							0.0
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*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]
1.0	no upstream lake				-	1.0	
2.0					-	1.0	
3.0					-	1.0	
	Summation			*0.0*	-		*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]
	178.0	34.0	34.0	0.0	0.2	1.0	42.6
			Dry-year total P deposition =		0.2		
			Average-year total P deposition =		0.2		
			Wet-year total P deposition =		0.3		
			(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]
	178.0	0.0		0.0	0.0	1.0	0.0
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	0.7			Oxic		1.0	
	0.7	89.1		Anoxic	0.1	1.0	7.1
	Summation						7.1
			Net Discharge [ac-ft/yr] =	**461.3**		**Net Load [lb/yr] =**	**139.8**

TMDL Lake Response Modeling for South

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 =	0.39	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	63	[kg/yr]
		Q (lake outflow) =	0.6	[10^6 m^3/yr]
		V (modeled lake volume) =	1.3	[10^6 m^3]
		T = V/Q =	2.32	[yr]
		P_i = W/Q =	111	[µg/l]
Model Predicted In-Lake [TP]			**60**	**[ug/l]**
Observed In-Lake [TP]			**577**	**[ug/l]**

Thompson Lake Current Conditions Canfield-Bachman Lake Response Model

Average Loading Summary for Thompson

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) [--]	Load [lb/yr]
1.0		1,019.8	15.0	1,270.1	400.1	1.0	1,382.3
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*1,019.8*	*15.0*	*1,270.1*			*1,382.3*

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF) [--]	Load [lb/yr]
1.0				0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							1.9
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*0.0*	*0.0*			*1.9*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1.0					-	1.0	
2.0					-	1.0	
3.0					-	1.0	
	Summation			*0.0*	-		*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]
	218.3	33.8	33.8	0.0	0.2	1.0	52.2
		Dry-year total P deposition =			0.2		
		Average-year total P deposition =			0.2		
		Wet-year total P deposition =			0.3		
		(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]
218.3	0.0		0.0	0.0	1.0	0.0

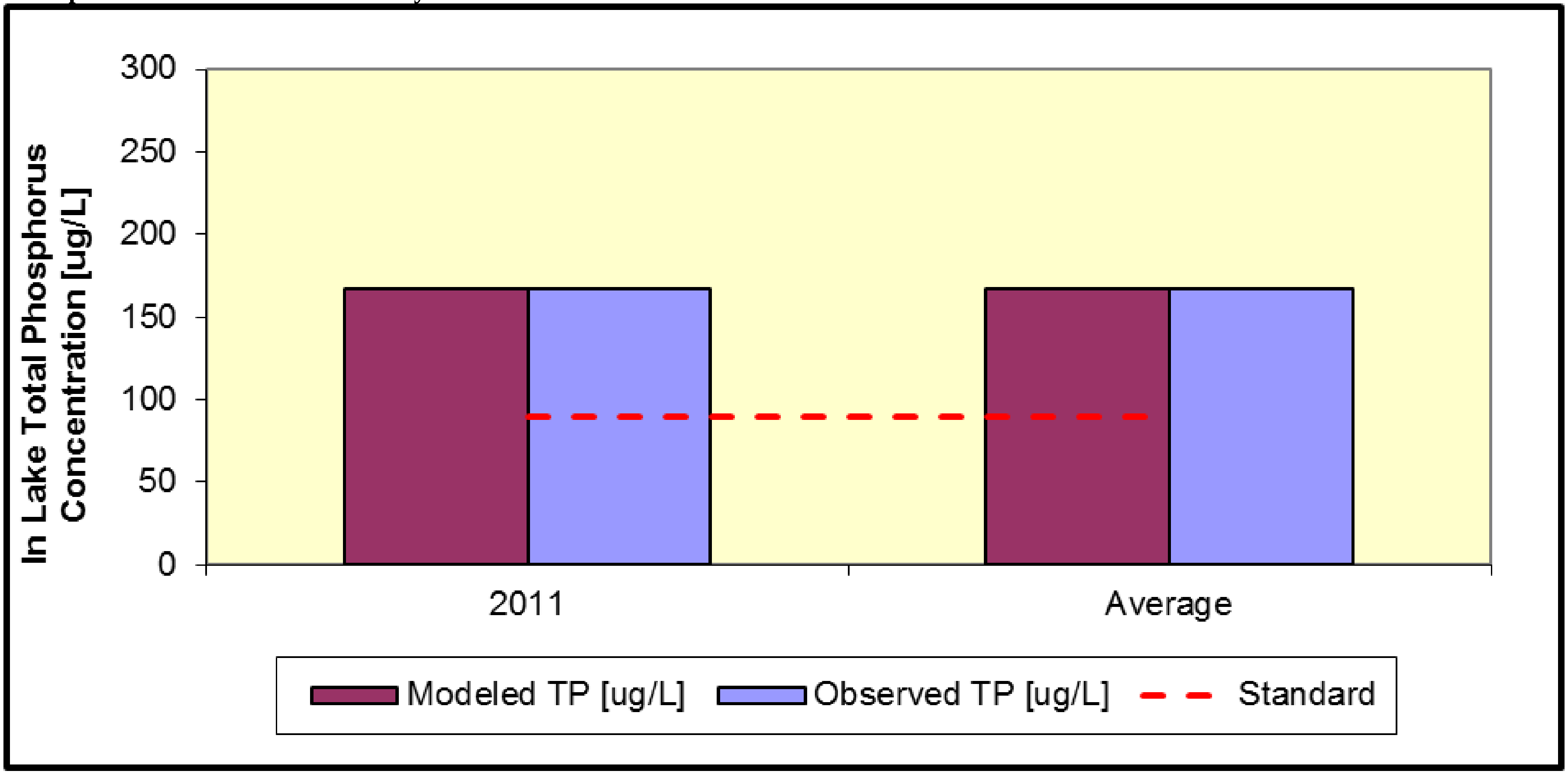
Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
0.9			Oxic		1.0	
0.9	65.0		Anoxic	2.7	1.0	337.9
Summation						337.9
	Net Discharge [ac-ft/yr] =		**1,270.1**	**Net Load [lb/yr] =**		**1,774.3**

Average Lake Response Modeling for Thompson

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 =	0.75	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	805	[kg/yr]
		Q (lake outflow) =	1.6	[10^6 m^3/yr]
		V (modeled lake volume) =	1.5	[10^6 m^3]
		T = V/Q =	0.95	[yr]
		P_i = W/Q =	513	[µg/l]
Model Predicted In-Lake [TP]			**167**	**[ug/l]**
Observed In-Lake [TP]			**167**	**[ug/l]**

Thompson Lake Calibration Summary



Thompson Lake TMDL Conditions Canfield-Bachman Lake Response Model

TMDL Loading Summary for Thompson

	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		1,020	15.0	1,270	150	0.4	518
2				0		1.0	0
3				0		1.0	0
4				0		1.0	0
5				0		1.0	0
	Summation	*1,020*	*15*	*1,270*			*518.3*
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							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					-	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]
	218	33.8	33.8	0.00	0.24	1.0	52.2
		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]
	218	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]
	0.88			Oxic		1.0	
	0.88	65.0		Anoxic	1.4	1.0	174
	Summation						174
		Net Discharge [ac-ft/yr] =		**1,270**		**Net Load [lb/yr] =**	**744.5**

TMDL Lake Response Modeling for Thompson

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)			
		C_P =	0.75	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	338	[kg/yr]
		Q (lake outflow) =	1.6	[10^6 m^3/yr]
		V (modeled lake volume) =	1.5	[10^6 m^3]
		T = V/Q =	0.95	[yr]
		P_i = W/Q =	215	[µg/l]
Model Predicted In-Lake [TP]			**90**	**[ug/l]**
Observed In-Lake [TP]			**167**	**[ug/l]**

Wakanda Lake Current Conditions Canfield-Bachman Lake Response Model

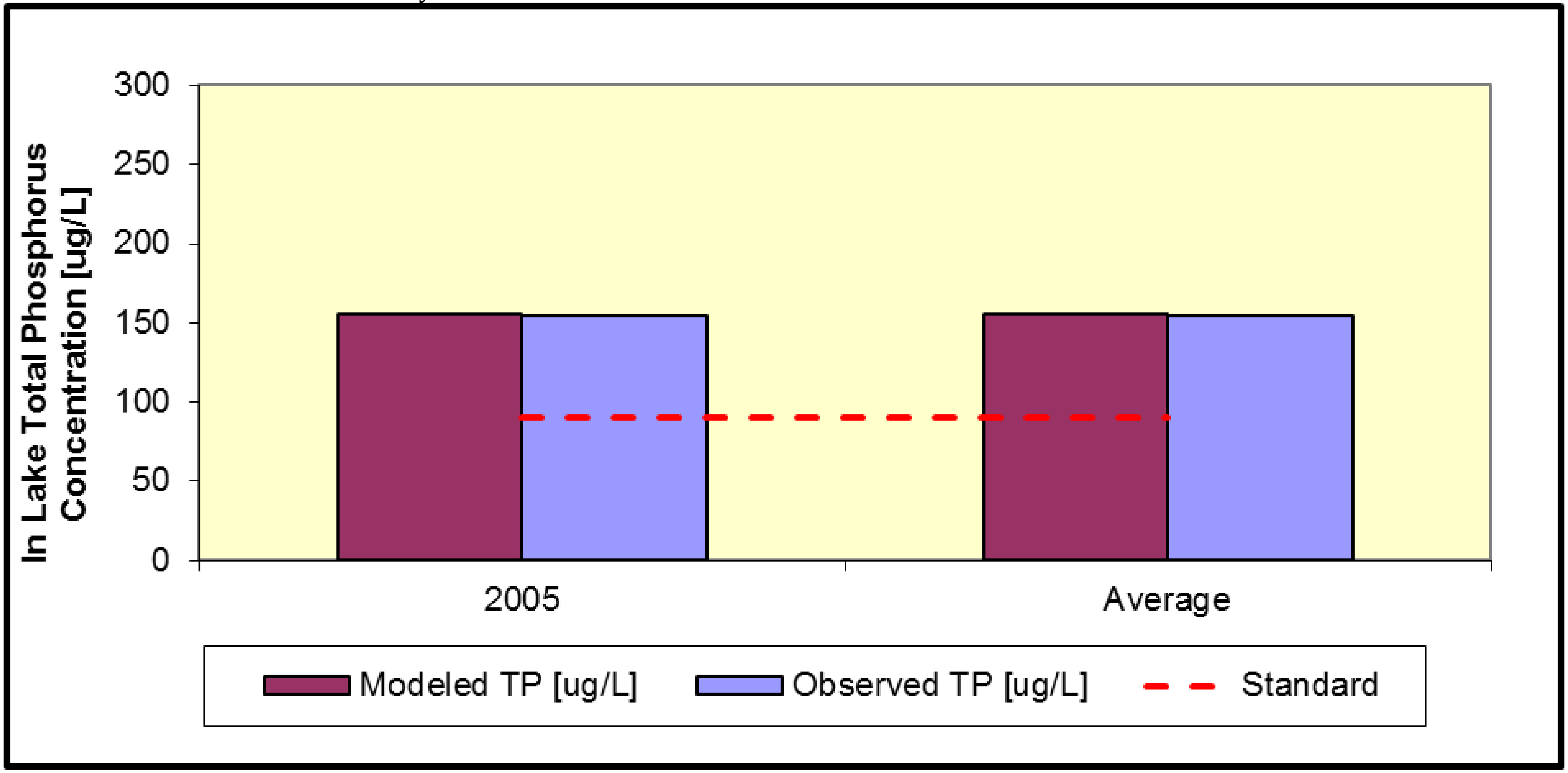
Average Loading Summary for Wakanda

Water Budgets					Phosphorus Loading		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0	Direct Watershed	5,503.0	7.4	3,376.1	273.9	1.0	2,515.6
2.0	Upstream Watersh	17,780.2	8.4	12,476.1	212.1	1.0	7,197.4
3.0				0.0	0.0	1.0	0.0
4.0				0.0	0.0	1.0	0.0
5.0				0.0	0.0	1.0	0.0
	Summation	*23,283.2*	*15.8*	*15,852.2*			*9,713.0*
Point Source Dischargers							
				Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0				0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0	Reach 535						30.2
2.0	Reach 536						26.8
3.0							
4.0							
5.0							
	Summation	*0.0*	*0.0*	*0.0*			*57.1*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0					-	1.0	
2.0					-	1.0	
3.0					-	1.0	
	Summation			*0.0*	-		*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]
	1,704.4	38.6	38.6	0.0	0.3	1.0	441.0
		Dry-year total P deposition =			0.2		
		Average-year total P deposition =			0.2		
		Wet-year total P deposition =			0.3		
		(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]
	1,704.4	0.0		0.0	0.0	1.0	0.0
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	6.9			Oxic		1.0	
	6.9	62.5		Anoxic	6.1	1.0	5,801.3
	Summation						5,801.3
		Net Discharge [ac-ft/yr] =		**15,852.2**	**Net Load [lb/yr] =**		**16,012.4**

Average Lake Response Modeling for Wakanda

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 =	0.69	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	7,263	[kg/yr]
		Q (lake outflow) =	19.6	[10^6 m^3/yr]
		V (modeled lake volume) =	13.7	[10^6 m^3]
		T = V/Q =	0.70	[yr]
		P_i = W/Q =	371	[µg/l]
Model Predicted In-Lake [TP]			**155**	**[ug/l]**
Observed In-Lake [TP]			**155**	**[ug/l]**

Wakanda Lake Calibration Summary



Wakanda Lake TMDL Conditions Canfield-Bachman Lake Response Model

TMDL Loading Summary for Wakanda

		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) [--]	Load [lb/yr]
1.0	Direct Watershed	5,503.0	7.4	3,376.1	150.0	0.5	1,377.7
2.0	Upstream Watersh	17,780.2	8.4	12,476.1	150.0	0.7	5,091.2
3.0				0.0	0.0	1.0	0.0
4.0				0.0	0.0	1.0	0.0
5.0				0.0	0.0	1.0	0.0
	Summation	*23,283.2*	*15.8*	*15,852.2*			*6,468.9*
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF) [--]	Load [lb/yr]
1.0				0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0	Reach 535						0.0
2.0	Reach 536						0.0
3.0							
4.0							
5.0							
	Summation	*0.0*	*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]
1.0					-	1.0	
2.0					-	1.0	
3.0					-	1.0	
	Summation			*0.0*	-		*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]
	1,704.4	38.6	38.6	0.0	0.3	1.0	441.0
				Dry-year total P deposition =	0.2		
				Average-year total P deposition =	0.2		
				Wet-year total P deposition =	0.3		
				(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]
	1,704.4	0.0		0.0	0.0	1.0	0.0
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	6.9			Oxic		1.0	
	6.9	62.5		Anoxic	0.9	1.0	881.1
	Summation						881.1
			Net Discharge [ac-ft/yr] =	**15,852.2**		**Net Load [lb/yr] =**	**7,790.9**

TMDL Lake Response Modeling for Wakanda

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 =	0.69	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	3,534	[kg/yr]
		Q (lake outflow) =	19.6	[10^6 m^3/yr]
		V (modeled lake volume) =	13.7	[10^6 m^3]
		T = V/Q =	0.70	[yr]
		P_i = W/Q =	181	[µg/l]
Model Predicted In-Lake [TP]			**90**	**[ug/l]**
Observed In-Lake [TP]			**155**	**[ug/l]**

Willie Lake Current Conditions Canfield-Bachman Lake Response Model

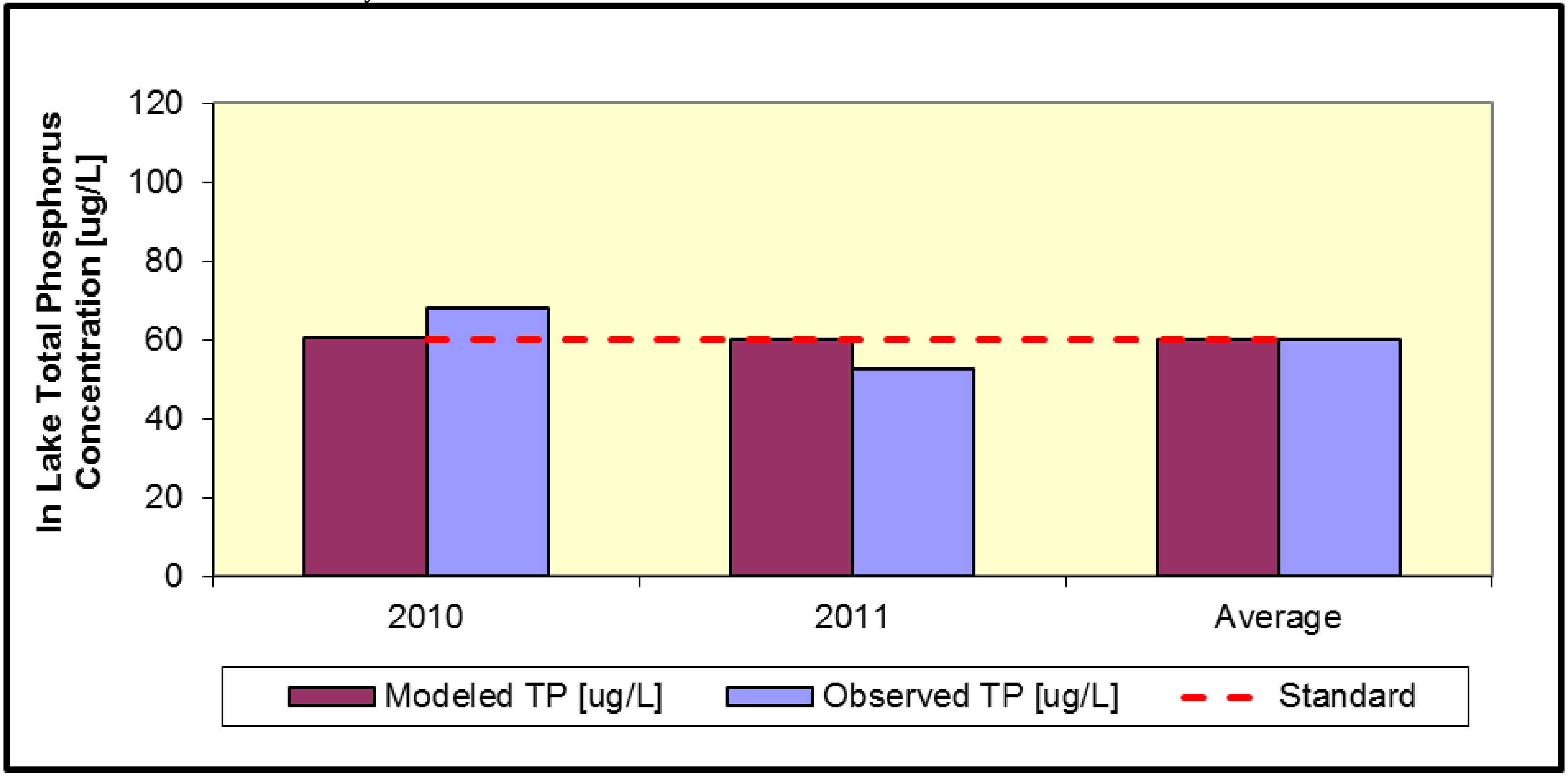
Average Loading Summary for Willie

		Water Budgets			Phosphorus Loading		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0	Direct Watershed	6,504.4	12.9	6,981.8	123.2	0.4	2,340.2
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*6,504.4*	*12.9*	*6,981.8*			*2,340.2*
Point Source Dischargers							
				Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0				0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							24.8
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*0.0*	*0.0*			*24.8*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1.0	Greenleaf			1,048.9	74.0	1.0	211.2
2.0					-	1.0	
3.0					-	1.0	
	Summation			*1,048.9*	*74.0*		*211.2*
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]
	187.1	34.9	34.9	0.0	0.2	1.0	44.7
		Dry-year total P deposition =			0.2		
		Average-year total P deposition =			0.2		
		Wet-year total P deposition =			0.3		
		(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]
	187.1	0.0		0.0	0.0	1.0	0.0
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	0.8			Oxic		1.0	
	0.8	46.4		Anoxic	0.1	1.0	7.7
	Summation						7.7
		Net Discharge [ac-ft/yr] =		**8,030.7**	**Net Load [lb/yr] =**		**2,628.6**

Average Lake Response Modeling for Willie

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 =	1.69	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	1,192	[kg/yr]
		Q (lake outflow) =	9.9	[10^6 m^3/yr]
		V (modeled lake volume) =	1.9	[10^6 m^3]
		T = V/Q =	0.19	[yr]
		P_i = W/Q =	120	[µg/l]
Model Predicted In-Lake [TP]			**60**	**[ug/l]**
Observed In-Lake [TP]			**60**	**[ug/l]**

Willie Lake Calibration Summary



Willie Lake TMDL Conditions Canfield-Bachman Lake Response Model

TMDL Loading Summary for Willie

	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) [--]	Load [lb/yr]
1.0	Direct Watershed	6,504.4	12.9	6,981.8	123.2	0.4	2,340.2
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*6,504.4*	*12.9*	*6,981.8*			*2,340.2*
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF) [--]	Load [lb/yr]
1.0				0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0							0.0
2.0							
3.0							
4.0							
5.0							
	Summation	*0.0*	*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]
1.0	Greenleaf			1,048.9	60.0	0.8	171.2
2.0					-	1.0	
3.0					-	1.0	
	Summation			*1,048.9*	*60.0*		*171.2*
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]
	187.1	34.9	34.9	0.0	0.2	1.0	44.7
				Dry-year total P deposition =	0.2		
				Average-year total P deposition =	0.2		
				Wet-year total P deposition =	0.3		
				(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]
	187.1	0.0		0.0	0.0	1.0	0.0
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	0.8			Oxic		1.0	
	0.8	46.4		Anoxic	0.1	1.0	7.7
	Summation						7.7
		Net Discharge [ac-ft/yr] =		**8,030.7**	**Net Load [lb/yr] =**		**2,563.8**

TMDL Lake Response Modeling for Willie

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 =	1.69	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	1,163	[kg/yr]
		Q (lake outflow) =	9.9	[10^6 m^3/yr]
		V (modeled lake volume) =	1.9	[10^6 m^3]
		T = V/Q =	0.19	[yr]
		P_i = W/Q =	117	[µg/l]
Model Predicted In-Lake [TP]			**59**	**[ug/l]**
Observed In-Lake [TP]			**60**	**[ug/l]**

Winsted Lake Current Conditions Canfield-Bachman Lake Response Model

Average Loading Summary for Winsted

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) [--]	Load [lb/yr]
1.0	Reach 742	1,165.6	16.0	1,553.8	206.7	1.0	873.6
2.0	Reach 741	14,827.3	8.1	9,950.9	367.3	1.0	9,943.1
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*15,992.9*	*24.1*	*11,504.7*			*10,816.7*

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF) [--]	Load [lb/yr]
1.0				0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0	Reach 742						11.8
2.0	Reach 741						7.8
3.0							
4.0							
5.0							
	Summation	*0.0*	*0.0*	*0.0*			*19.6*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1.0	South			574.6	576.5	1.0	901.1
2.0					-	1.0	
3.0					-	1.0	
	Summation			*574.6*	*576.5*		*901.1*

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]
361.4	31.5	31.5	0.0	0.2	1.0	86.4
		Dry-year total P deposition =		0.2		
		Average-year total P deposition =		0.2		
		Wet-year total P deposition =		0.3		
		(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]
361.4	0.0		0.0	0.0	1.0	0.0

Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
1.5			Oxic		1.0	
1.5	80.4		Anoxic	14.0	1.0	3,628.1
Summation						3,628.1

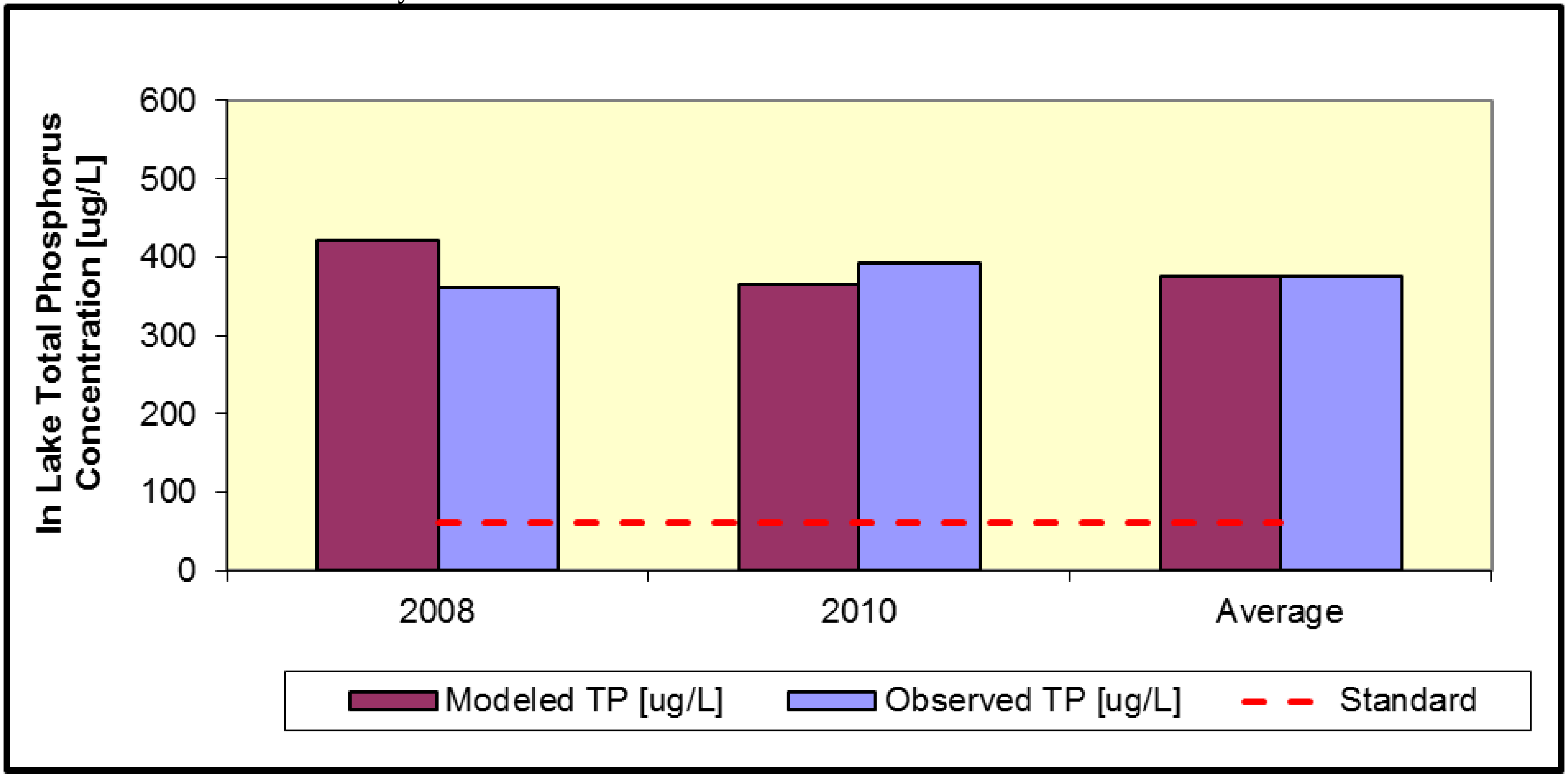
Net Discharge [ac-ft/yr] = 12,079.3 | **Net Load [lb/yr] = 15,452.0**

Average Lake Response Modeling for Winsted

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	as f(W,Q,V) from Canfield & Bachmann (1981)			
		C_P =	0.22	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	7,009	[kg/yr]
		Q (lake outflow) =	14.9	[10^6 m^3/yr]
		V (modeled lake volume) =	2.9	[10^6 m^3]
		T = V/Q =	0.19	[yr]
		P_i = W/Q =	470	[µg/l]
Model Predicted In-Lake [TP]			**376.5**	**[ug/l]**
Observed In-Lake [TP]			**376.5**	**[ug/l]**

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

Winsted Lake Calibration Summary



Winsted Lake TMDL Conditions Canfield-Bachman Lake Response Model

TMDL Loading Summary for Winsted

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) [--]	Load [lb/yr]
1.0	Reach 742	1,165.6	16.0	1,553.8	69.1	0.3	292.0
2.0	Reach 741	14,827.3	8.1	9,950.9	61.8	0.2	1,673.4
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation	*15,992.9*	*24.1*	*11,504.7*			*1,965.3*

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF) [--]	Load [lb/yr]
1.0				0.0		1.0	0.0
2.0				0.0		1.0	0.0
3.0				0.0		1.0	0.0
4.0				0.0		1.0	0.0
5.0				0.0		1.0	0.0
	Summation			*0.0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1.0	Reach 742						0.0
2.0	Reach 741						0.0
3.0							
4.0							
5.0							
	Summation	*0.0*	*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]
1.0	South			574.6	60.0	0.1	93.8
2.0					-	1.0	
3.0					-	1.0	
	Summation			*574.6*	*60.0*		*93.8*

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]
361.4	31.5	31.5	0.0	0.2	1.0	86.4
			Dry-year total P deposition =	0.2		
			Average-year total P deposition =	0.2		
			Wet-year total P deposition =	0.3		
			(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]
361.4	0.0		0.0	0.0	1.0	0.0

Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
1.5			Oxic		1.0	
1.5	80.4		Anoxic	0.1	1.0	25.9
Summation						25.9

	Net Discharge [ac-ft/yr] =		**12,079.3**		**Net Load [lb/yr] =**	**2,171.5**

TMDL Lake Response Modeling for Winsted

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	as f(W,Q,V) from Canfield & Bachmann (1981)			
$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$		C_P =	0.22	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	985	[kg/yr]
		Q (lake outflow) =	14.9	[10^6 m^3/yr]
		V (modeled lake volume) =	2.9	[10^6 m^3]
		T = V/Q =	0.19	[yr]
		P_i = W/Q =	66	[µg/l]
Model Predicted In-Lake [TP]			**60**	**[ug/l]**
Observed In-Lake [TP]			**377**	**[ug/l]**

Appendix C: HSPF Documentation

March 17, 2011

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

Dear Mr. Regan:

RE: Lake Selection for Sauk, North Crow, and South Crow Watersheds

Please review the following proposed methodology for the selection of lakes to model explicitly within the Minnesota watersheds noted above. RESPEC prepared a draft methodology for the lakes selection procedure, discussed it with AQUA TERRA (Mr. Donigian, Mr. Bicknell, and Mr. Mishra) on a conference call, and subsequently enhanced the procedures based on that discussion. AQUA TERRA is proceeding with an initial application of these procedures to their watersheds for selection of their lakes to be modeled.

The analysis begins with the 2008 Minnesota Pollution Control Agency (MPCA) Assessment Lake Layer downloaded at the MPCA 305b Assessments of Lake Conditions in Minnesota's Major River Basins. This layer was supplemented with the lake features in National Hydrography Dataset (NHD) waterbodies having surface areas greater than 200 acres and any 2009/2010 Total Maximum Daily Load (TMDL) lakes that were not included in the 2008 305b Assessment. The total number of lakes for this analysis was 192 for the Sauk, North Crow, and South Crow Watersheds. Table 1 shows the frequency distribution of surface area of lakes in NHD waterbodies not included in the Minnesota 2008 Assessment layer.

The flow chart shown in Figure 1 shows key decision processes used in the selection of lakes to explicitly represent in the **HSPF** models for the Sauk, North Crow, and South Crow Watersheds. The first decision point was whether the lake had a nonmercury impairment; 75 of the 192 lakes met this classification. We suggest this approach to exclude mercury-impaired lakes since the dominant source (99 percent) for mercury is atmospheric deposition [Minnesota Pollution Control Agency, 2007][1] (i.e., not watershed-related).

Final decisions at this point need to be made regarding the following:

- Do you prefer we only include TMDL lakes that require a TMDL (i.e., Category 5) or include all impaired lakes even if a TMDL is already approved (i.e., Categories 4 and 5 Lakes)?
- Do you prefer we include lakes impaired for only Hg? If so, then we need to discuss/investigate the data available for the mercury deposition sources.

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

Table 1. Frequency Distribution of Surface Area of Lakes in NHD Waterbodies not included in the Minnesota 2008 Assessment Layer

Number of Lakes in NHD Waterbodies not Included in 2008 Assessment	Surface Area (Acres)
1	> 1,000
1	> 800
4	> 600
5	> 500
6	> 400
13	> 300
26	> 200

The second decision point was two part, requiring any lakes not selected in the TMDL decision point to (1) intersect a primary reach and (2) be greater than 350 acres. These two criteria are a surrogate for assessing whether a lake is likely to have a significant hydrologic impact on the watershed. The size of 350 acres was the approximate inflection point of a graph, shown in Figure 2, of the number of non-Hg TMDL lakes above specified surface areas. This step added 26 of the remaining 117 non-Hg TMDL lakes to be explicitly modeled and left 91 lakes to be a part of a third decision process. A final decision is needed regarding the following:

- What size of reach-intersecting lakes would be the most likely to affect the watershed hydrology?

The third decision point ensures that large lakes that are not TMDL lakes and do not intersect a primary reach are explicitly modeled. Contours are available for all lakes above 600 acres, as shown in the Figure 3 graph of the number of non-Hg TMDL lakes not intersecting a primary reach and specified surface areas. Because contour availability decreases time required for F-table creation, lakes which are less than 600 acres and do not intersect a primary reach will not be explicitly modeled. Also, lakes not intersecting a primary reach can be more efficiently represented as wetlands. This step added five of the remaining 91 lakes to the list of lakes to be explicitly modeled, setting the number of lakes to be explicitly modeled to 106. A final decision is required regarding the following:

- Although this method is watershed specific, do you believe that 600 acres is a reasonable cutoff for nonreach-intersecting lakes to be explicitly modeled in these three watersheds?

Note that AQUA TERRA is currently applying this lake selection flow chart to the lakes in their three watersheds—Crow Wing, Red Eye, and Long Prairie—to determine if these same surface area thresholds make sense in those watersheds.

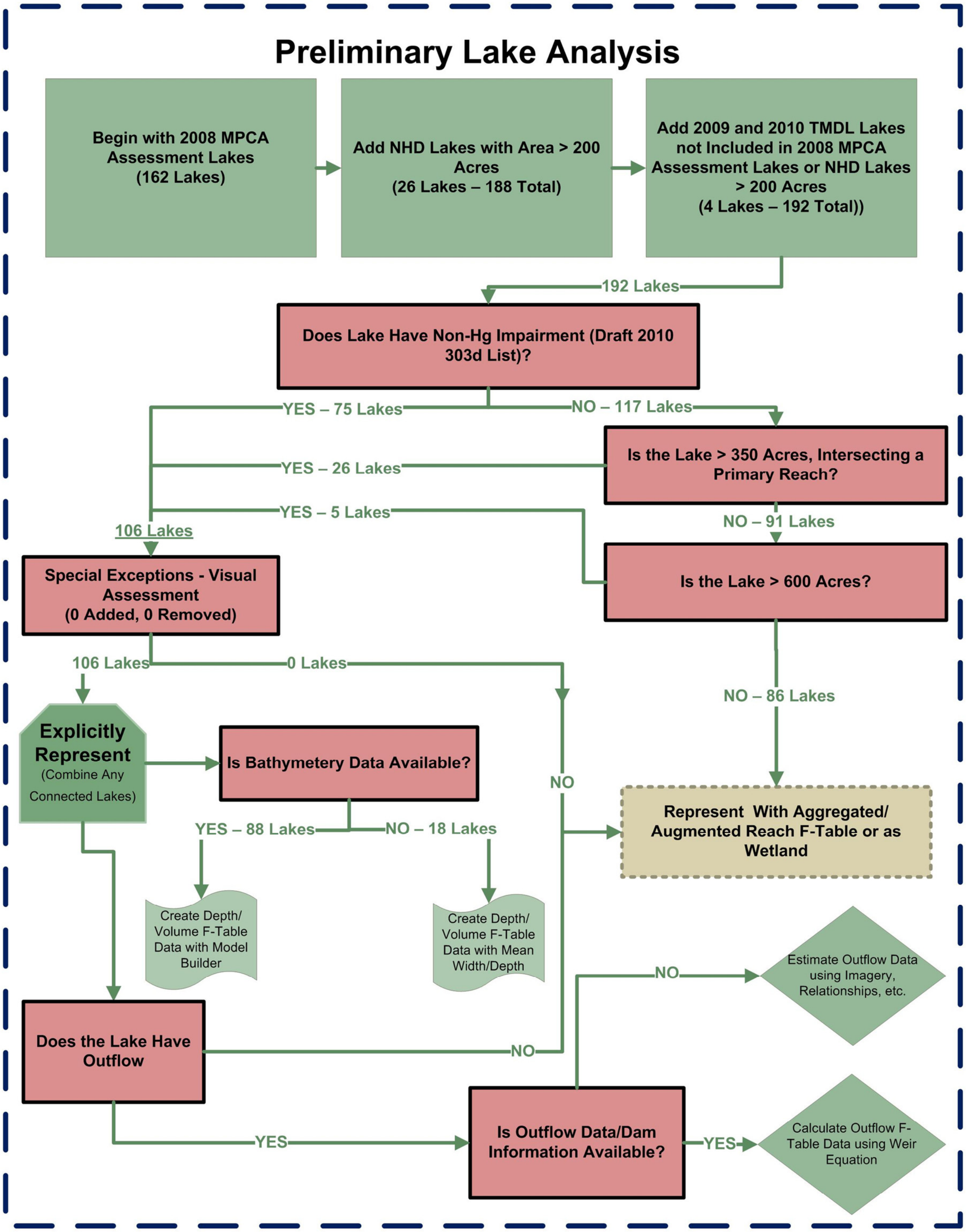


Figure 1. Lake Selection Schematic for Sauk, North Crow, and South Crow Watersheds.

RSI-1953-11-002

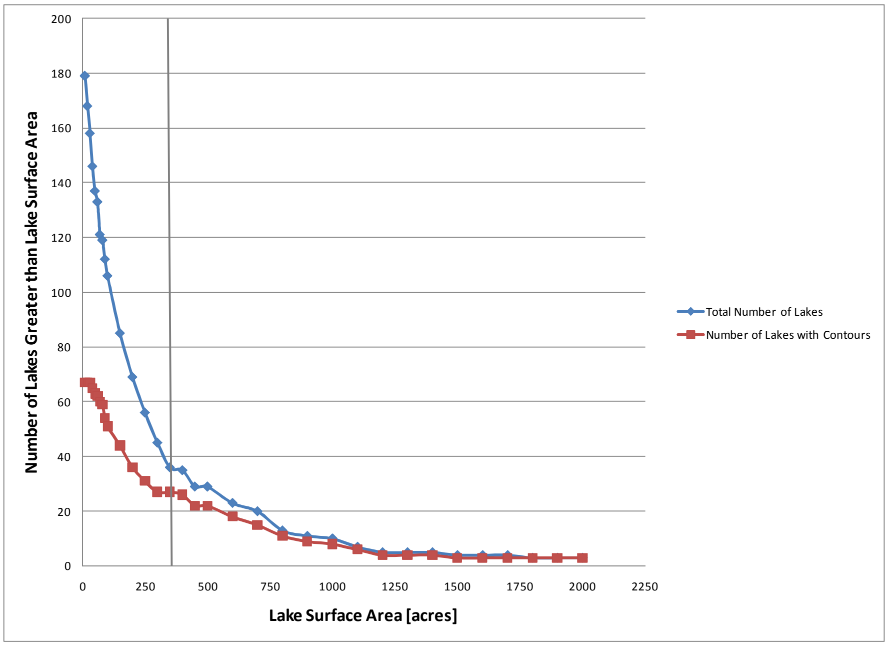


Figure 2. Graph of Cumulative Surface Area and Lake Count for non-Hg Total Maximum Daily Load Lakes.

RSI-1953-11-003

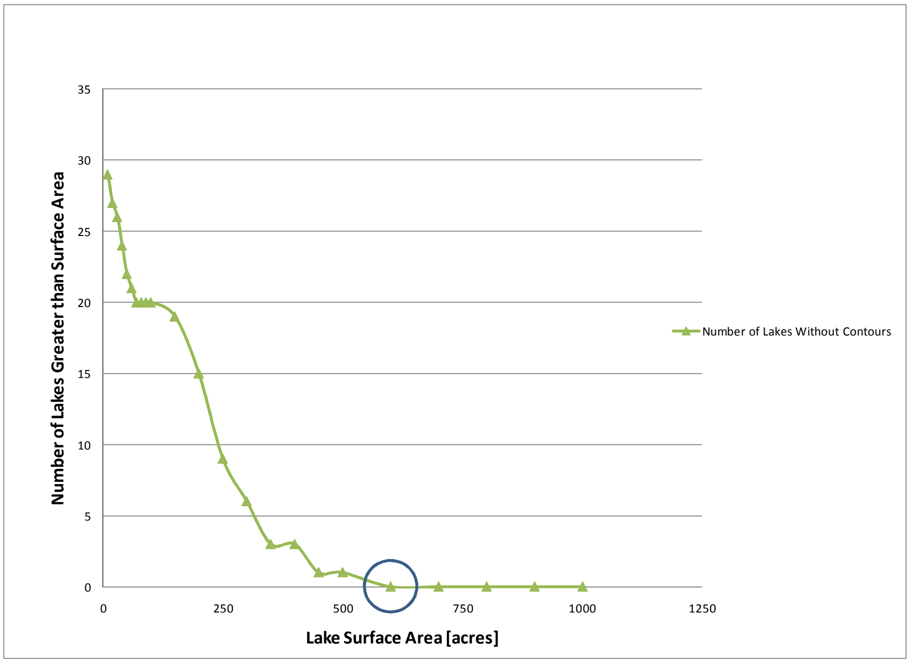


Figure 3. Graph of Cumulative Surface Area and Lake Count for non-Total Maximum Daily Load Lakes Intersecting a Primary Reach.

At this point of the decision-making process, special exception lakes should be added to and/or removed from the list. These might be lakes of special value or concern to the local stakeholders or any lakes with specific ecological value and/or issues

Once all lakes to be explicitly modeled are chosen, lakes having different names and identifications which are connected and within a Level 7 Minor are proposed to be merged and represented as one lake. From this point, bathymetric data and hydraulic data availability for lakes to be explicitly modeled will be examined, and final decisions are required regarding the following:

- If bathymetric data are unavailable, would you prefer we:

    1. Use the surface area and a mean watershed lake depth value to develop geometric values (i.e., depth, surface area, and volume relationships) for F-Tables or
    2. Not explicitly represent the lake?

- If hydraulic data are unavailable, would you prefer we:

    1. Use imagery to measure widths/depths of any existing weirs to assess outflow information or
    2. Not explicitly represent the lake?

    At this time, our recommendation is to NOT explicitly model lakes without bathymetry data unless they fall into the "Special" category or there is some other reason/rationale that demands their explicit representation.

- How would you prefer we include lakes that are not explicitly represented in the model? Recall that these are likely to be small, non-TMDL, non-Hg, and nonreach-intersecting lakes without any "special" significance or ecological value:

    1. Represent using aggregated or augmented reach F-tables for each watershed or subwatershed
    2. Represent the lakes as wetlands
    3. Use a combination of these methods.

We would be happy to discuss these issues with you and hear any feedback you may have regarding the selection of lakes to explicitly model within the Sauk, North Crow, and South Crow Watersheds.

Sincerely,

Jason T. Love
Vice President, Water & Natural Resources

JTL:llf

cc: Project Central File 1953 — Category A

RSI(RCO)-1953/4-11/24

April 28, 2011

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

Dear Mr. Regan:

RE: Primary Reach Selection, Reach/Subwatershed Numbering Scheme Development, and F-Table Development for Sauk, North Crow, and South Crow Watersheds

Please review the following proposed methodology for primary reach selection, reach/subwatershed numbering scheme development, and F-table development for Sauk, North Fork Crow, and South Fork Crow Watersheds.

PRIMARY REACH SELECTION

The Minnesota Department of Natural Resources' (MN DNR) Level 7 watersheds were used as the basis for model subwatersheds. Level 7 watersheds were used as opposed to the Hydrologic Unit Code (HUC) 12 watersheds since they provided more detailed breaks, minimizing further processing. Thus the further processing of the Level 7 watershed was minimal. Level 7 subwatersheds were split using detailed elevation grid processing when a discharge data station or a Total Maximum Daily Load (TMDL) endpoint occurred without a Level 7 subwatershed split.

Multiple guidelines were followed for the selection of the primary reaches to be used in the HSPF model. A Geographic Information System (GIS) map was created containing the following layers: National Hydrography Dataset (NHD) flowlines and waterbodies, 2009 TMDL streams and waterbodies, 2010 TMDL streams and waterbodies, 2008 Minnesota assessment streams and waterbodies, monitoring sites, model subwatersheds from Level 7 subwatersheds, an elevation grid, and an imagery basemap. The NHD flowline shapefile was used as the basis of the reaches file and was edited as needed using imagery and elevation.

In general, a continuous reach connecting the upstream and downstream subwatersheds was chosen as the primary reach. This clearly includes mainstem reaches to be modeled (i.e., the Sauk River, North Fork Crow River, and South Fork Crow River). Thus if the stream passed through only the corner of the subwatershed, as shown in Figure 1, but influenced upstream and downstream connectivity, it was selected as the primary reach. In headwater subwatersheds, the longest continuous NHD flowline connected to the downstream subwatershed was selected as the primary reach. Because they are assumed to be the highest priority, TMDL streams took precedence over 2008 assessment streams regardless of length. Similarly, 2008 assessment streams took precedence to all non-TMDL streams regardless of length. Finally, if the subwatershed appeared to be created as a lakeshed for a TMDL lake, the stream flow through the lake was selected as the primary reach.

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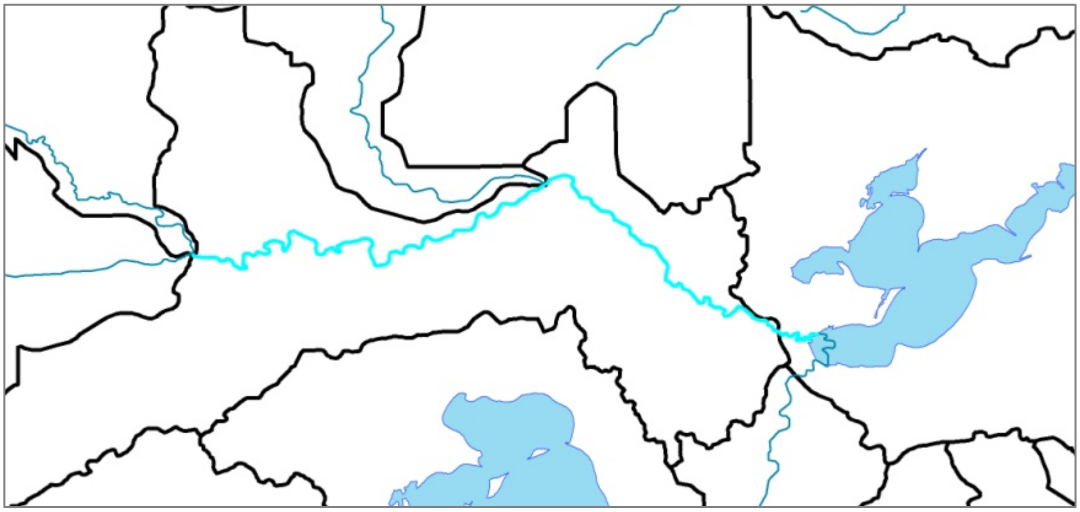

Figure 1. Reach Passing Through Small Portion (Circled) of Subwatershed and Extended Reach in a Lakeshed (Arrow).

Generally, if a reach upstream or downstream of a lake crossed a subwatershed by a substantial distance (greater than approximately 0.1 mile), that reach was extended into that upstream or downstream subwatershed as shown in Figures 1 and 2 to avoid stream-length misrepresentation. Reach length and slope were calculated for all nonlake reaches. Reaches representing a modeled lake were given a length of zero and a slope of one. Currently, all lakes to be modeled are assumed to have an outflow, but this can be easily changed for select lakes during calibration if those lakes are determined to have an isolated drainage area.

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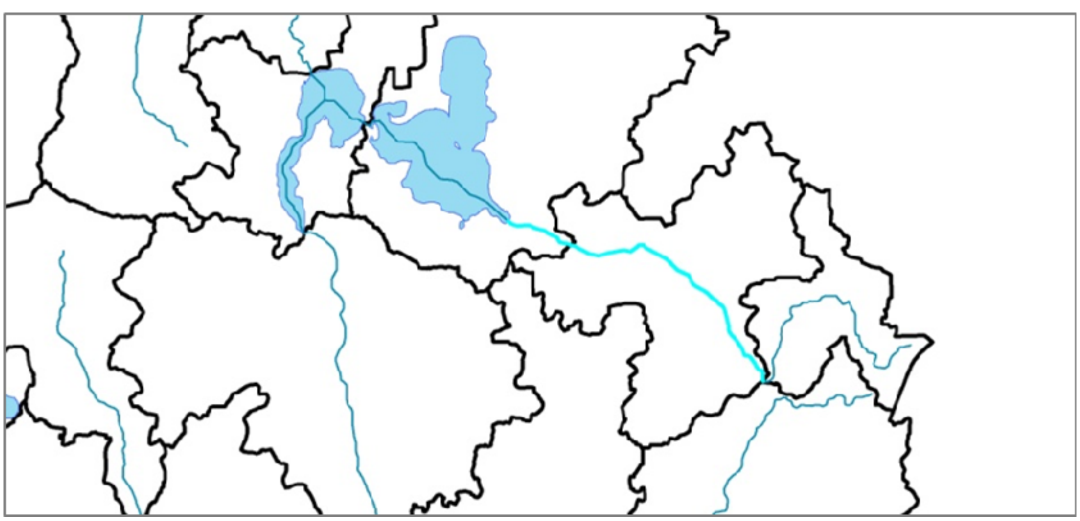

Figure 2. Extended Reach in a Lakeshed.

REACH/SUBWATERSHED NUMBERING SCHEME

The numbering scheme used for the watershed drainage network is described in this paragraph. A Reach I.D. numbering schematic is included in Figure 3. Each reach in the diagram represents one subwatershed. Reach I.D.s consist of one to three numeric digits. Mainstem reaches include the Sauk River, the North Fork Crow River, the South Fork Crow River, and the Crow River. Mainstem Reach I.D.s always end in zero (##0) and were assigned an odd 10s digit (middle number) if they represent a reach (e.g., 110, 130, 150, and 190 in the schematic) and an even 10s digit if they represent a lake (e.g., 120 and 160 in the schematic). Tributaries were assigned an odd Reach I.D. for the 1s digit (end number) if they represent a reach (e.g., 141, 143, and 153 in the schematic) and an even number if they represent a reservoir (e.g., 142 in the schematic). The 10s digit of the tributary Reach I.D.s represents the downstream mainstem Reach I.D. (e.g., 111 and 113 flow into 120). If the logical next down mainstem Reach I.D. was not used (e.g., 170 for reach 160), then the reach would flow into the next largest mainstem Reach I.D. (e.g., 190), which occurred when a combination of reaches, such as five nonlake tributary reaches, flowed into a mainstem reach.

Subwatersheds that will be modeled with both a reach and a reservoir were given the Reach I.D. of the dominant feature as shown in reaches 102 and 151 of the schematic. If the dominant feature is a reach (e.g., 151), then all of the overland flow from that subwatershed is routed into the reach and then into the downstream lake. If the dominant feature is a lake (e.g., 102), then all of the overland flow is routed into the lake and then into the downstream waterbody.

Reaches were given the same I.D. as the subwatershed within which they are located except when a reach and a lake were located in the same subwatershed (denoted by starred subwatersheds 102 and 151 in the schematic); in which case, the dominant upstream waterbody (reach or lake) was given the corresponding subwatershed's Reach I.D. and the downstream waterbody was given the corresponding subwatershed next down number. The Sauk and Crow Subwatersheds and reaches were numbered separately, both beginning with Reach 1. Overall, subwatersheds and reaches are numbered in order, beginning with low I.D. numbers upstream and ending with high I.D. numbers downstream, except when a mainstem reach has more than one branch (e.g., 210 through 290), which occurs for the North and South Fork Crow Rivers.

LAKE F-TABLES

An F-table is required for each modeled reach (lake or stream). The methodology used to select lakes to explicitly model in Sauk, North Fork Crow, and South Fork Crow Subwatersheds was discussed in the previous Lake Selection letter.[1] Data necessary for F-table calculation include volume and area at a variety of depths or water elevations, overflow information (such as spillway width and runout elevation if applicable), and discharge information (if applicable). Because overflow information is unavailable for many of the lakes and because no specific relations exist between such parameters as surface area, depth, and weir length, Phase 1 of the

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[1] **Love, J. T., 2011.** *Lake Selection for Sauk, North Crow, and South Crow Watersheds*, letter RSI(RCO)-1953/3-11/26, prepared by RESPEC, Rapid City, SD, for C. Regan, Minnesota Pollution Control Agency, St. Paul, MN, March 17.

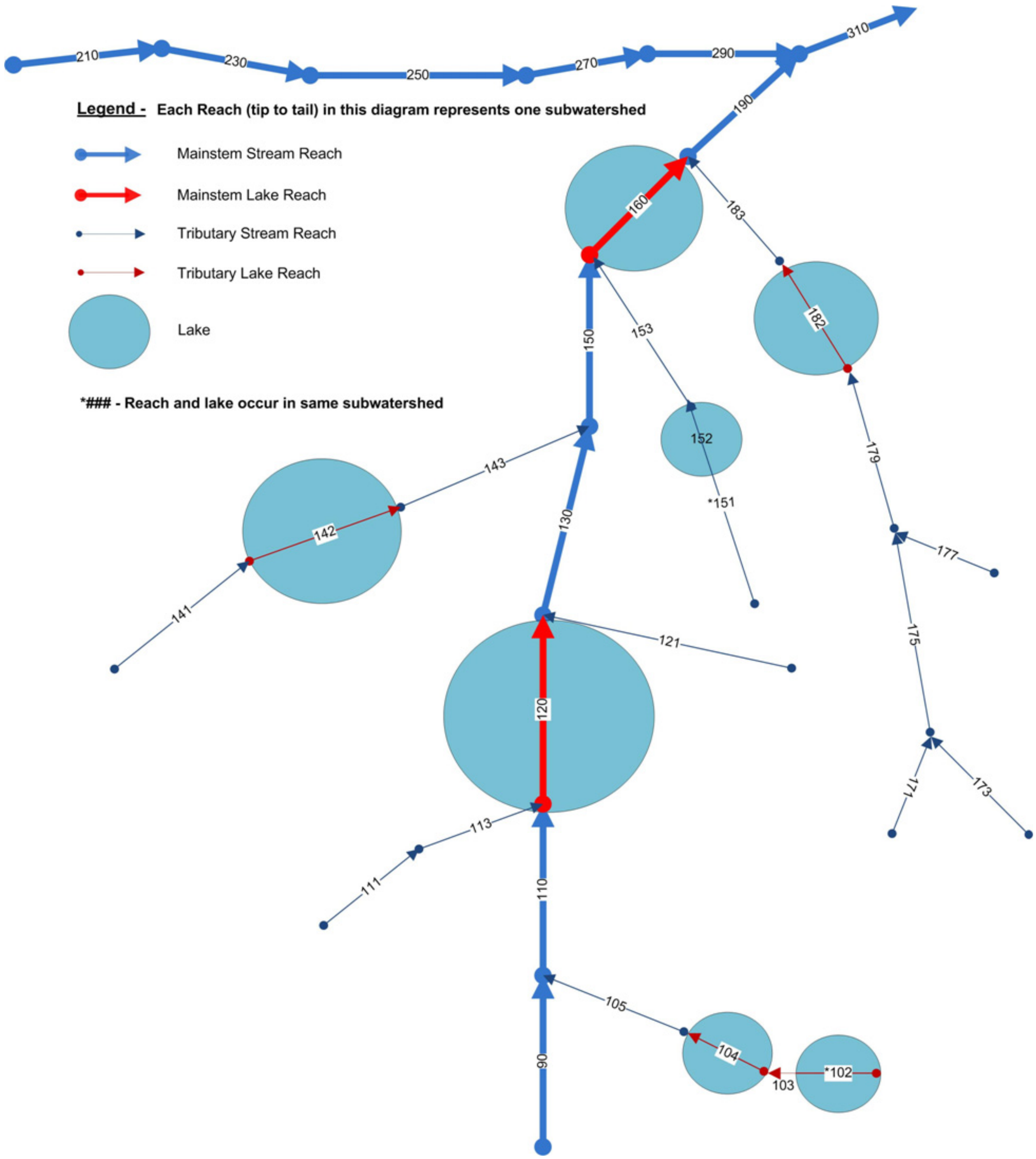

Figure 3. Reach Numbering Schematic.

project (model setup) will use average values for depths and overflow information when no reference data are available. This level of detail will be sufficient for the purposes of this model. If additional data become available, it will be incorporated into the existing model application. Lakes for which we do not have a maximum depth are shown in Table 1. Spillway lengths are available for 14 of our 96 lakes, and thus, are not included in Table 1. Please review Table 1 and provide any additional data you may have.

Table 1. Lakes Missing Maximum Depth Data

Lake Name	Lake I.D.	County
Boon	65001300	Renville
Campbell	10012700	Carver
Clifford	21000300	Douglas
Cowley	27016900	Hennepin
Faille[(a)]	77019500	Todd
Fountain	86008600	Wright
Kasota	34010500	Kandiyohi
King	00000000	Meeker
Little Kandiyohi	34009600	Kandiyohi
McCormic[(a)]	73027300	Stearns
Woodland/Mud	86008500	Wright

(a) Have a maximum contour depth to substitute for maximum depth.

The equations used to calculate flows from lakes at different water elevations as well as any assumptions made are discussed below. For simplicity and because of the lack of overflow data, the equation of discharge for overflow spillways from Gupta's Hydrology and Hydraulic Systems[2] was used to calculate discharge from lakes without coefficient correction factors for all overflow calculations. Because of the large scale of this project, side contractions of the overflow as well as velocity of approach were neglected.

$$Q = C \times L_e \times H^{1.5} \quad (1)$$

2 **Gupta, R. S., 2001.** *Hydrology and Hydraulic Systems*, Second Edition, Waveland Press, Inc., Long Grove, IL.

where:

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

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

L_e = effective length of crest (feet)

C = variable coeffient of discharge.

The total head (H) used in the equation was calculated at variable water levels as the difference between the water surface and the outlet. The outlet was assumed to be the highest contour where contours were available or the maximum depth where contours were unavailable. Effective length of the crest (L_e) was derived from both the National Inventory of Dams dataset or the MN DNR State Dam Inventory. When an effective length was not available for a lake, the mean length of all available sites was assumed. At lake depths above the outlet, the effective length of the crest was variable as a function of depth. The length of the crest increased, assuming a 0.02 flood plain slope at each end of the crest. The distance below abutment was available from the MN DNR dam dataset. For the purpose of this project, the distance below the abutment was assumed to be the crest height (P), and the design head (H_d) was variable with the water surface. When the distance below abutment was unavailable, the mean value from all available sites was assumed. Crest height and variable head values were used to calculate variable coefficients of discharge as shown in Equation 2 for input into Equation 1 for each site. Similarly, the variable head values were used as the F-Table depths above outlets. Equation 2 was derived using Microsoft Excel 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.[3]

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

where:

P = crest height (feet)

H = head (feet).

A similar data-compilation process was completed for reach-intersecting lakes that were not chosen to be explicitly modeled or to be represented as wetlands. The description of their inclusion in an F-table is discussed in the stream F-tables section.

Once all available data were collected and combined, an F-table was developed for each lake by calculating the surface area, volume, and discharge over a range of depths. Surface areas and volumes at different depths were calculated for lakes having contour data using a batch tool created in GIS **ModelBuilder**. This tool created a separate triangulated area network (TIN) for each lake on which a “Surface Volume” tool is used to calculate the area and volume below

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

specified depths. F-tables for lakes with contour data were created using the depths, surface areas, and volumes calculated with the **Bathymetry Volume and Surface Area ArcGIS ModelBuilder** tool. F-tables for lakes without contour data were estimated using maximum surface area and depth data. For these lakes, the volume and surface area at incremental depths were estimated using conical geometry and assuming a flat bottom for an inner circle with half the radius of the maximum surface area. As mentioned above, the highest contour, if available, or maximum depth was assumed to be the outlet. Depths were added incrementally above the outlet until the F-table discharge exceeded 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 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.

STREAM F-TABLES

Data were available throughout the Sauk, North Fork Crow, and South Fork Crow River Watersheds for stream F-tables and included MPCA and MN DNR cross section measurements at Hydstra Sites, MPCA cross section measurements at non-Hydstra sites, and width and area at U.S. Geological Survey (USGS) sites. Where cross-section data were unavailable, USGS maximum width and depth data were used to calculate cross sections assuming a trapezoidal channel and a bank slope of 1/3; however, USGS-calculated cross sections were not assigned to mainstem reaches, even if they occurred within the reach, because they only represent a maximum depth and width instead of an actual cross section. All available cross sections are shown in Figure 4. MPCA also provided flow and rating curve data for multiple Hydstra sites throughout the watersheds. When only one cross section occurred in a reach, that cross section was assign to that reach. If multiple cross sections occurred within a single reach, the following ranking was used to select the single primary cross section that was assigned to that reach:

1. MPCA or MN DNR cross section at Hydstra site with a paired flow rating curve.
2. MPCA or MN DNR cross section at Hydstra site with no paired rating curve.
3. MPCA or MN DNR cross section at non-Hydstra site (no rating curves were available for these).
4. USGS maximum width and area calculated cross section (no rating curves were available for these).

If sites could not be narrowed down to one cross section per reach using the ranking process (i.e., if two sites of the same ranking were located in one reach), the furthest downstream site was assigned. The cross sections selected using the above ranking process are included in Figure 5. Mainstem reaches for which cross-section data were unavailable were then assigned using best engineering judgment a representative cross section based on the available downstream mainstem cross section, where cross section area generally will increase 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. USGS-calculated cross sections were assigned to only those tributary reaches within which they actually occur.

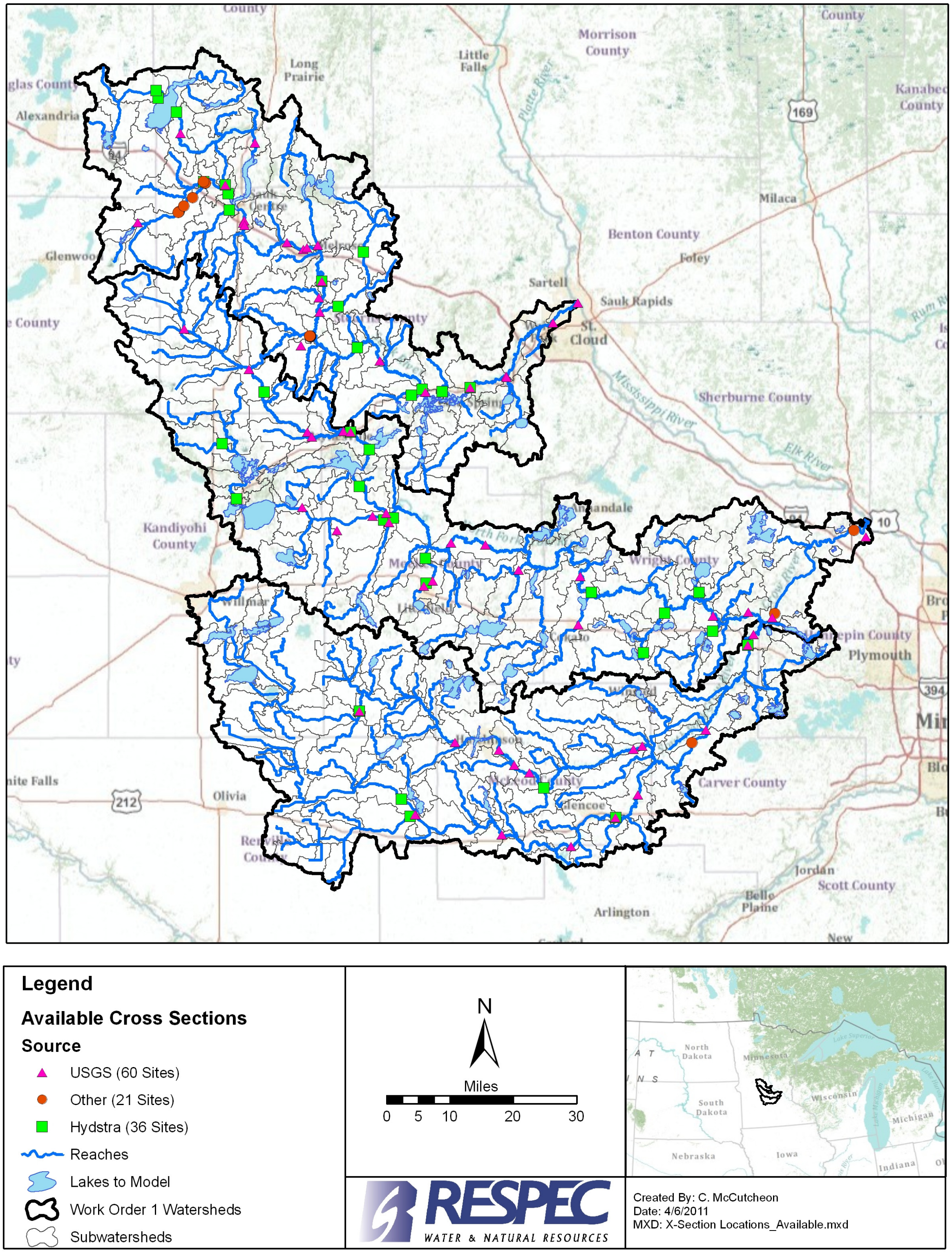

Figure 4. All Available Cross Sections Within the Sauk and Crow Watersheds.

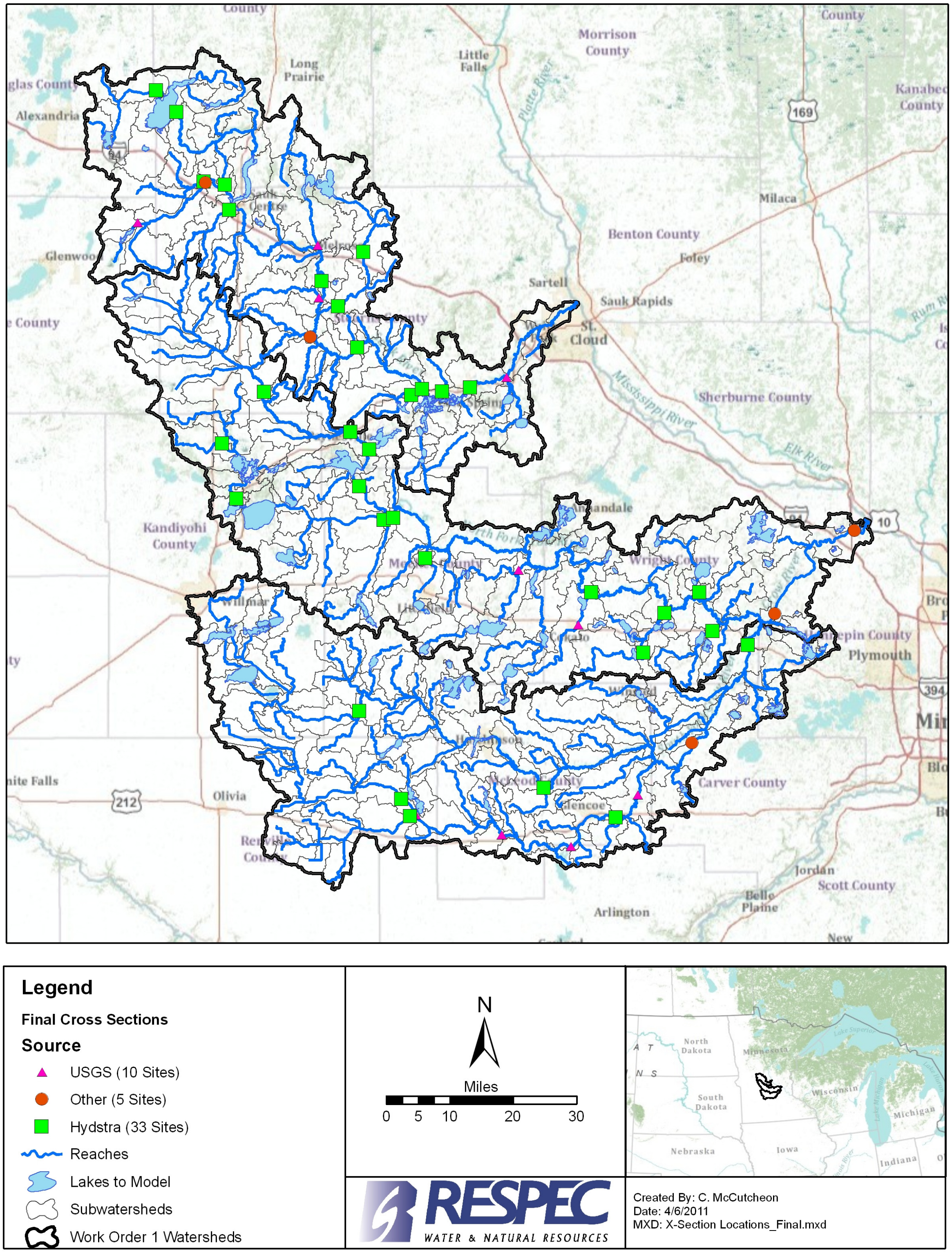

Figure 5. Cross Sections Selected Using Rating Process to Attain One per Reach.

Once all reaches were assigned, their most fitting cross sections according to location and drainage area, an F-table was developed for each stream segment by calculating the surface area, volume, and discharge over a range of depths. To allow the F-table to handle large storm flows, the cross section was extended 1,000 feet horizontally beyond each bank. The floodplain slope was assumed to be 0.02. The volume and surface area were calculated with the cross sections and stream segment lengths. The discharge was calculated 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 (f^2))

R = hydraulic radius (feet)

S = channel slope.

Manning's roughness coefficient was 0.035 for the channel and 0.045 for the floodplain. The values for the floodplain slope, channel slope, Manning's roughness coefficient, and horizontal bank extension length were set using best engineering judgment and can be easily adjusted during the calibration process.

Reach-intersecting lakes that were not chosen to be explicitly modeled or to be represented as wetlands were assigned volume and surface area data using the same methods as lakes to be explicitly modeled. The total surface area and volume at specified depths for these lakes were then added to the surface area and volume of the corresponding reach F-tables.

We would be happy to discuss the contents of this memorandum with you and appreciate any feedback you may have regarding F-table development within the Sauk, North Fork Crow, and South Fork Crow Watersheds.

Sincerely,

Jason T. Love
Vice President, Water & Natural Resources

JTL:llf

cc: Project Central File 1953 — Category A

April 28, 2011

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

Dear Mr. Regan:

RE: Time-Series Development for Sauk, North Fork Crow, and South Fork Crow Watersheds

Please review the following methodology for the development of meteorological and water use input time-series for the external sources of the **HSPF** model applications.

METEOROLOGICAL DATA

Precipitation (PREC) and potential evapotranspiration (PEVT) are the minimum requirements that drive the internal water balance. However, the watersheds of interest are greatly influenced by the accumulation and melting of snow. Air temperature (ATEM), wind speed (WIND), solar radiation (SOLR), dew point temperature (DEWP), and cloud cover (CLOU) are needed for **HSPF** to calculate snow processes using an energy balance method. Although there is an option to compute snow processes based on temperature alone, the data needed for the more accurate energy balance method were available and complete for the simulation time period. The **BASINS** system provides all the previously mentioned time-series data already preprocessed in a watershed data management (WDM) file. The WDM file is accessed directly by **HSPF** during a simulation. In addition to the precipitation data from **BASINS**, extensive supplementary daily precipitation data were provided by the Minnesota Pollution Control Agency (MPCA).

METEOROLOGICAL STATION SELECTION

Stations from **BASINS** were selected based on the availability of the required meteorological data and their proximity to the watersheds of interest. For example, data from a station that are farther from the watershed than another station may be included if that station has available data for parameters that the closer station does not. Stations with supplementary daily precipitation data from MPCA were selected based on their spatial distribution and period of record. MPCA stations were chosen to fill in spatial precipitation data gaps from the **BASINS** stations. Stations with a more complete period of record were chosen when there were high densities of stations. The percent of missing data was generally ignored because of the assumption that the high density of stations within close proximity of each other should have data to fill in the missing data of the selected station. Justification for this assumption will be

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discussed in the precipitation processing section. The meteorological zones for the land segment classification were based on Thiessan polygons developed from the locations of the selected MPCA and **BASINS** precipitation stations. Figure 1 shows the stations and available parameters from **BASINS** and MPCA that were directly used for the meteorological time-series development.

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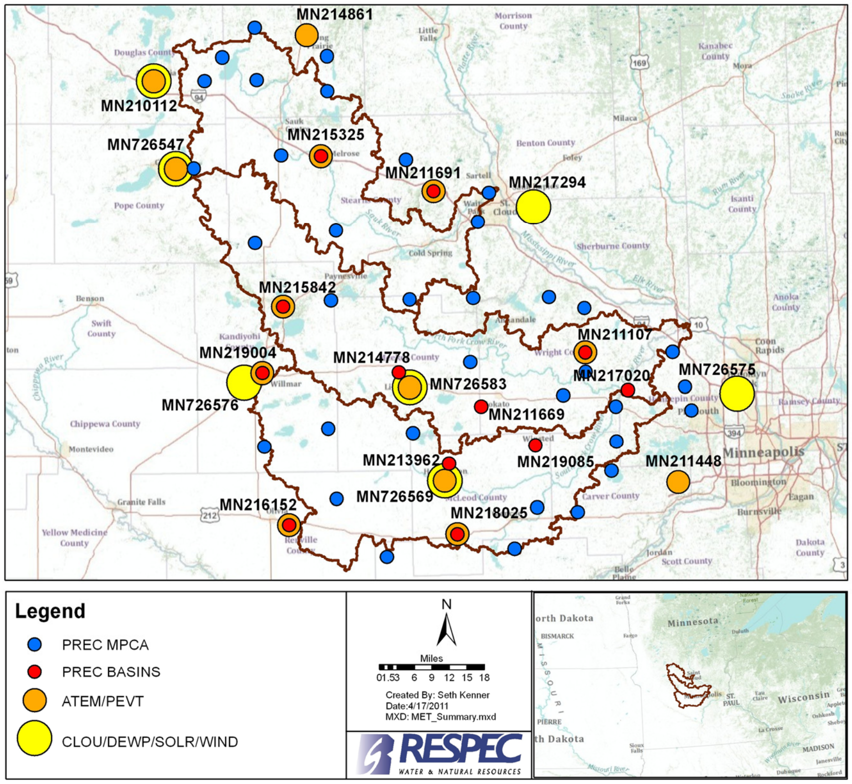

Figure 1. **BASINS** and MPCA Meteorological Stations and Available Parameters.

METEOROLOGICAL DATA PROCESSING

PREC, PEVT, ATEM, SOLR, WIND, DEWP, and CLOU are all available through the **BASINS** system from the National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center. Data from these stations were preprocessed into hourly time-series by AQUA TERRA Consultants. Some stations were incomplete for the modeling period and were extended with available data from the closest station. **BASINS** PEVT data were calculated using Hamon's equation and is typically available wherever ATEM are available. However, the work plan requests that the potential evapotranspiration be represented with Penman Pan evaporation. **WDMutil** calculates Penman Pan evaporation using daily time-series of maximum and minimum temperature, dew point temperature, wind movement, and solar radiation. Penman Pan was calculated for the seven **BASINS** stations having all the required data. Table 1 shows the calculated total annual Penman Pan evaporation at each of the seven stations. The pan evaporation is converted to potential evapotranspiration in the external sources block of the UCI using a factor of 0.79 which was derived from the NOAA Evaporation Atlas.

Table 1. Total Annual Penman Pan Evaporation for Applicable Stations

Year/Station	MN210112	MN217294	MN726547	MN726569	MN726575	MN726576	MN726583
1995	48.1	53.2	43.2	46	48.5	53.5	47.3
1996	55.2	53.3	49.6	47	54.1	49.9	45.4
1997	58.7	53.6	51.3	51.6	50.3	55.6	52.4
1998	60.7	58.5	64.7	55.2	58.6	59.2	58.1
1999	61.9	58.9	66.5	58.6	60.1	65.5	59.6
2000	59	57.2	59.6	58.1	59.2	60.7	54.6
2001	60.1	56.1	59.4	60.1	56.7	61.2	59
2002	59.8	55.4	57.7	58.7	50.4	60.9	56.9
2003	63.1	59.4	61.8	57.1	53.4	63.4	58.6
2004	58.3	54.6	55.9	56.3	50	57.1	54.3
2005	60	59.1	57	60.8	64.2	58.9	56.5
2006	65.8	62.3	62.2	58.8	67	60.7	57.1
2007	65	62.6	67.5	58.6	68.4	64.4	62.8
2008	57.6	57.5	62.8	55.4	63.7	58.7	57.6
2009	56.6	56	63.4	56	61.8	56.3	54.7
Minimum	**48.1**	**53.2**	**43.2**	**46**	**48.5**	**49.9**	**45.4**
Maximum	**65.8**	**62.6**	**67.5**	**60.8**	**68.4**	**65.5**	**62.8**
Average	**59.3**	**57.2**	**58.8**	**55.9**	**57.8**	**59.1**	**55.7**

PRECIPITATION DATA PROCESSING

The MPCA supplementary precipitation stations are spatially extensive and dense; however, the data for individual stations had significant amounts of missing data for the modeling period. The objective is to compile the sporadic data from a large number of stations into a set of base stations that are evenly distributed spatially with complete precipitation time-series for the modeling period. The base MPCA stations were selected based on their spatial distribution within the spatial data gaps of the **BASINS** precipitation stations and the extent of their available data through the modeling period. Percent missing was mostly disregarded but was used to choose between stations that were within the same data gap. It was assumed that the missing data could be filled with data from stations within a close proximity. This method will maximize the use of the supplementary MPCA daily precipitation data.

The missing data and accumulated values from the base MPCA stations were filled or distributed using data from the closest station available, including the **BASINS** stations. Table 2 shows the base MPCA stations with the number of missing days of data filled and the average and maximum distance from a station used to fill in the missing data. The overall average distance from a station used to fill missing data was around 6 miles while the maximum distance was generally below 14 miles. This table indicates that missing data were primarily filled with stations within a distance that was less than the average distances between centroids of neighboring meteorological zones which were approximately 15 to 20 miles. Figures 2, 3, and 4 show the filled average annual total precipitation, average monthly total precipitation, and precipitation mass curve, respectively, of the selected stations. The mass curve is the total accumulated precipitation over the modeling period in days. Figure 5 shows the location of the **BASINS** stations, base MPCA stations, and the stations with data used to fill in missing data. **BASINS** and base MPCA stations are labeled with a processing I.D., and the stations used for filling include both **BASINS** and supplementary MPCA stations.

The daily filled precipitation data from the base MPCA stations were loaded into a WDM file. Each daily precipitation time-series was disaggregated into hourly time-series with **WDMutil** using the five closest **BASINS** stations with hourly precipitation data. The data tolerance used for the precipitation disaggregation was 50 percent. A data tolerance of 50 percent means that if none of the daily totals of the hourly precipitation are within 50 percent of the daily precipitation on a given day then the daily precipitation is disaggregated into hourly precipitation using a triangular distribution with the peak in the middle of the day. The data tolerance used is high to maximize the use of available hourly precipitation data because of the inaccuracy of the triangular distribution method.

WATER USE DATA APPLICATION

Water use **ArcGIS** point layers were retrieved from the Minnesota Department of Natural Resources for the locations of withdrawals for managed water use categories. These layers included water withdrawals from surface water and groundwater and included abandoned and terminated sites. Of the 1,427 withdrawal sites, 1,267 were from groundwater sources and 159 were from surface water sources. Surface water sources included lakes (21 sites), streams or rivers (33 sites), and wetlands (4 sites) as well as ditches (5 sites), dug pits (58 sites), and quarries or gravel pits (38 sites). Figure 6 shows the site distribution of major water use categories for the 1,427 sites that had any activity during the modeling period.

Each withdrawal site was paired with a subwatershed. When a source name was available from a surface water site, the source name was compared with the actual location, and adjustments were made if the source was located in a different subwatershed than the site location. This occurred for three of the surface water sites. The initial approach is to represent the inflow from irrigation categories and disregard the withdrawal from groundwater and surface water. The assumption is that point sources will account for the inflow of water from nonirrigation categories into the system.

Water appropriation uses that will be modeled as irrigation include major crop irrigation, wild rice irrigation, temporary agriculture irrigation, and noncrop irrigation such as golf course

Table 2. Summary Stations With Missing Data Filled

Processing I.D.	Meteorological Zone	Count of Missing Days	Average Distance From Filling Station (Miles)	Maximum Distance From Filling Station (Miles)
9	83	2,723	5.34	8.00
21	85	295	3.21	6.36
32	67	265	4.88	5.08
81	3	3,052	5.12	7.10
85	1	533	2.38	5.07
195	71	3,611	1.30	8.07
208	45	3,580	1.88	6.33
223	47	70	12.52	12.62
225	49	3,649	10.16	11.43
239	31	2,681	8.12	13.56
272	81	190	4.29	6.37
286	51	1,196	8.23	10.15
293	41	2,150	5.07	7.19
296	33	492	1.11	2.92
403	11	3,103	2.87	3.08
442	61	4,127	9.13	9.31
600	79	69	4.50	5.01
604	75	1,039	4.38	12.66
607	35	2,856	18.24	18.24
623	21	3,131	11.84	11.99
624	19	3,196	10.97	11.89
626	27	2,576	1.94	3.19
628	25	343	4.78	5.38
633	17	1,403	7.03	7.05
655	13	685	1.39	6.01
678	9	304	6.30	9.41
683	7	337	6.17	7.10
689	5	31	6.45	7.29
706	69	532	3.59	5.98
716	57	2	3.34	3.34
720	55	3,046	8.58	8.85

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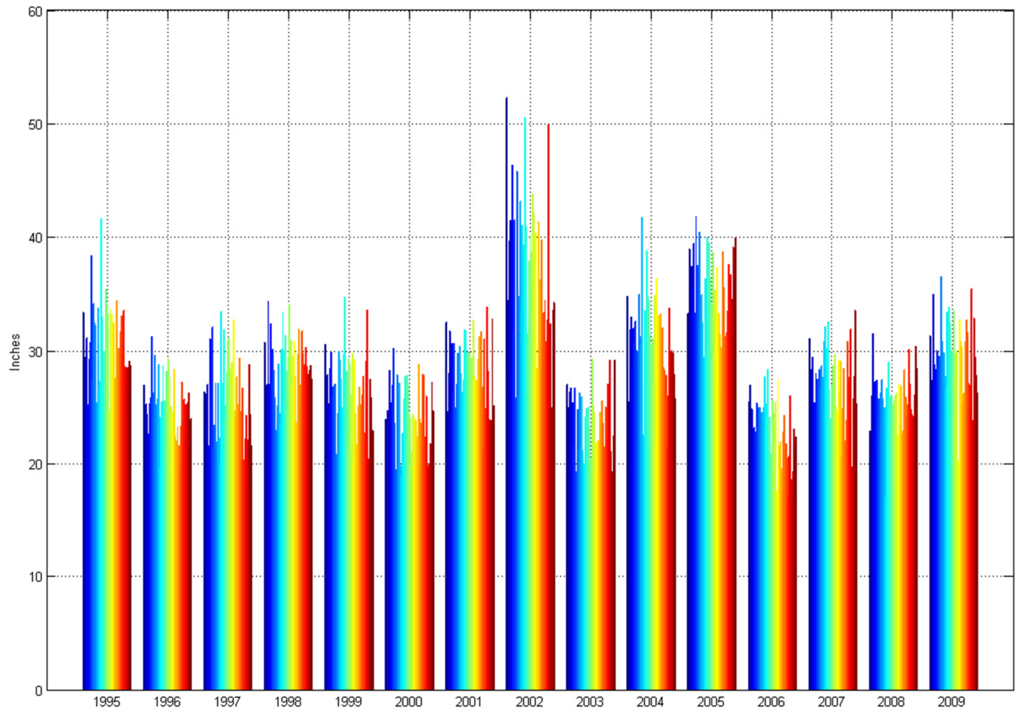

Figure 2. Average Annual Total Precipitation for Selected Stations.

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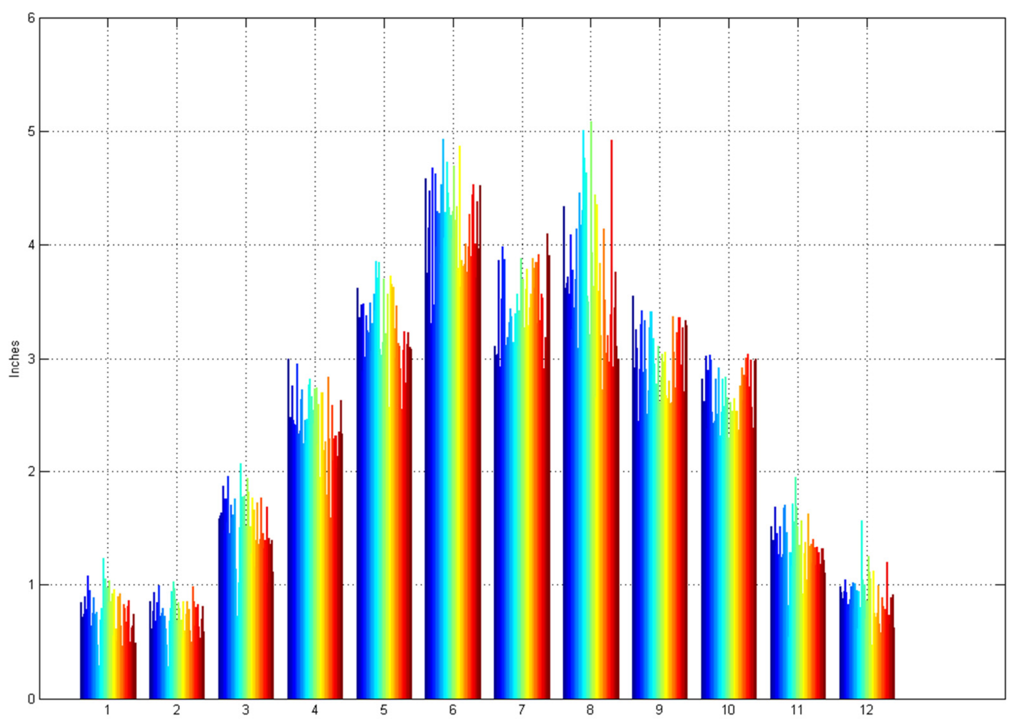

Figure 3. Average Monthly Total Precipitation for Selected Stations.

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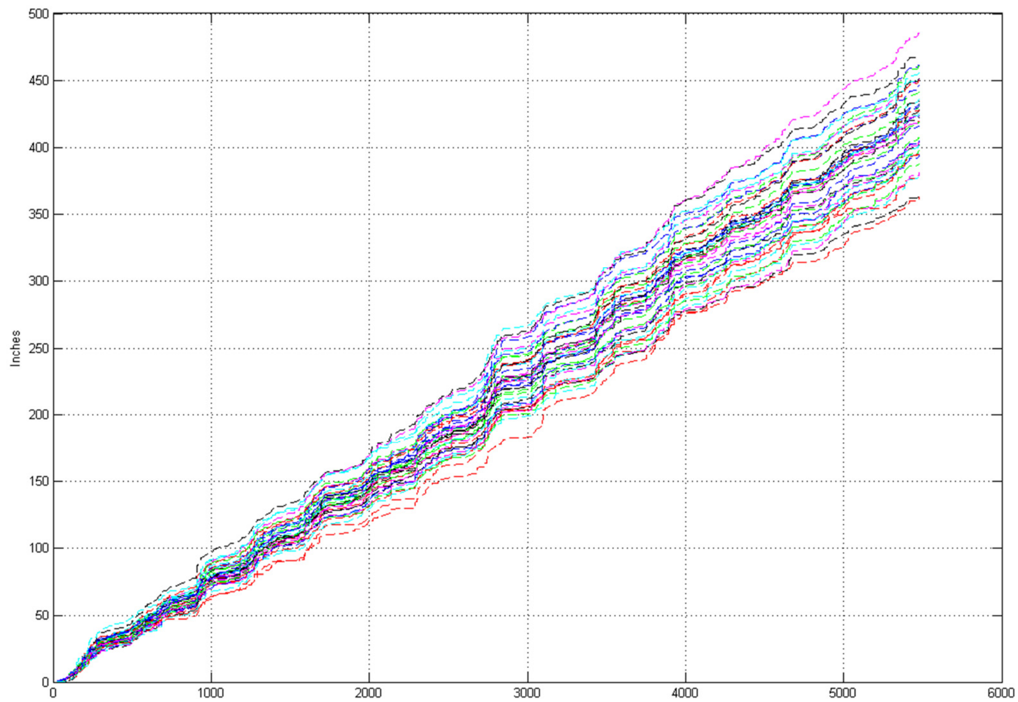

Figure 4. Mass Curve of Accumulated Precipitation Over Modeling Period in Days.

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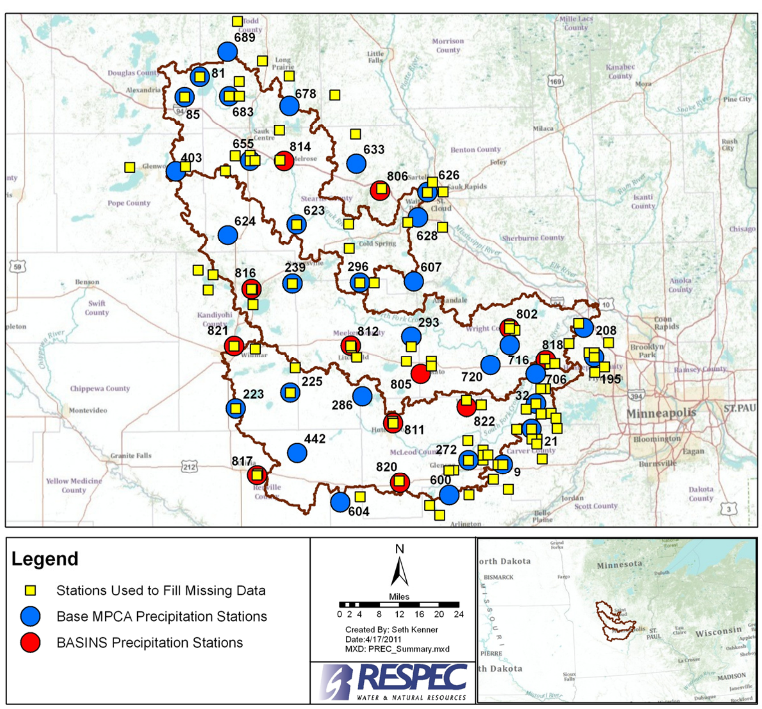

Figure 5. Map of Precipitation Stations With Missing Data Filled.

irrigation, cemetery irrigation, landscaping, sod farms, nurseries, orchards, landscape watering, snow making, peat fire control. The major crop irrigation and rice irrigation are applied to the cropland land use class while the other categories are applied to the pasture class. Golf course irrigation represents the majority of the noncrop irrigation water use and golf courses are primarily classified as pasture in the model application. The monthly total volumes summed for each cropland or pasture PERLND class will be applied as precipitation and surface lateral inflow. The precipitation application represents pivot or sprinkle irrigation and the surface lateral inflow represents flood irrigation. The fraction of the total that goes to each application will be determined through calibration if it is determined to be significant to the hydrology.

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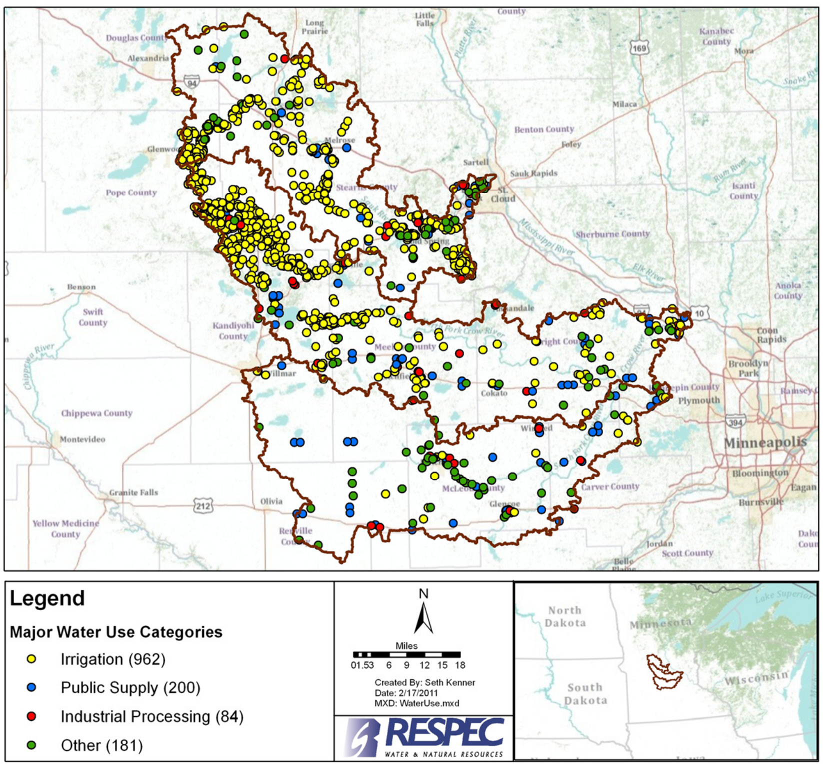

Figure 6. Site Distribution of Major Water Use Categories Active During the Modeling Period.

Table 3 is a summary by meteorological zone of the volume of water applied to crop and pasture or consumed. Crop and pasture columns represent the amount applied to the cropland or pasture in a meteorological zone. The total column represents the total volume removed from the source over the total area of the meteorological zone. Currently, only irrigation is applied as inflow to the model, but each monthly time-series representing outflow or consumption are in the WDM file to be used if necessary during calibration. For example, with surface water sources, water could be removed from the reach or lake on which the source is located unless the source is not located on a modeled reach or lake. If the surface water source is not located on a modeled reach or lake, it could be taken out of a PERLND storage component (e.g., UZS or LZS).

Table 3. Summary of Water Use Application and Consumption by Meteorological Zone (Page 1 of 2)

Major	Meteorological Zone	Source	Crop (acre-in)	Pasture (acre-in)	Consumed (acre-in)	Crop (in/yr)	Past (in/yr)	Total (in/yr)
Sauk	1	Ground	22,992	2,183	2,023	2.2	4.4	0.03
Sauk	3	Ground	9,657	0	27,876	1.7	0.0	0.10
Sauk	7	Surface	107,771	22,152	5,036	3.9	5.3	0.11
Sauk	9	Surface	134,929	0	0	3.7	0.0	0.20
Sauk	11	Ground	581,794	0	1,035	4.6	0.0	1.25
Sauk	13	Ground	275,824	8,693	113,963	3.0	3.9	0.38
Sauk	15	Ground	87,922	11,469	394,309	2.1	8.0	0.38
Sauk	21	Ground	271,493	0	13,972	1.8	0.0	0.18
Sauk	23	Ground	130,415	11,953	283,400	3.3	12.3	1.20
Sauk	25	Ground	58,826	3,181	29,659	3.6	5.3	0.22
Sauk	27	Ground	0	4,456	428,720	0.0	10.6	3.46
Sauk	33	Ground	23,198	24,258	95,018	1.4	3.6	0.17
Sauk	35	Surface	200,852	0	4,862	3.6	0.0	0.84
Crow	11	Ground	114,060	0	0	3.5	0.0	0.41
Crow	19	Ground	2,388,952	10,203	61,462	4.1	14.2	1.51
Crow	21	Ground	17,823	0	0	3.3	0.0	0.05
Crow	29	Ground	329,573	21,187	349,935	3.7	3.1	0.59
Crow	31	Ground	453,844	27,593	200,487	3.2	4.4	0.42
Crow	33	Ground	30,618	0	571	3.5	0.0	0.06
Crow	35	Surface	0	0	28,559	0.0	0.0	0.24
Crow	37	Ground	12,711	3,247	37,228	2.4	4.5	0.06
Crow	39	345	163,971	5,696	268,004	3.7	4.7	0.34
Crow	41	Ground	48,246	0	8,845	3.5	0.0	0.04
Crow	43	Surface	26,145	40,484	314,357	3.0	4.9	0.39
Crow	45	Ground	1,402	69,099	367,932	0.8	10.3	1.20
Crow	47	Ground	0	0	9,105	0.0	0.0	0.01
Crow	49	Ground	0	0	11,539	0.0	0.0	0.01
Crow	51	Surface	20,289	0	6,633	3.4	0.0	0.02

Table 3. Summary of Water Use Application and Consumption by Meteorological Zone (Page 2 of 2)

Major	Meteorological Zone	Source	Crop (acre-in)	Pasture (acre-in)	Consumed (acre-in)	Crop (in/yr)	Past (in/yr)	Total (in/yr)
Crow	53	Surface	0	3,489	117,927	0.0	11.6	0.10
Crow	55	Ground	558	5593	86536	0.6	14.3	0.09
Crow	57	505	1,1561	0	45	1.8	0.0	0.03
Crow	59	Ground	0	3,323	107,910	0.0	1.1	0.15
Crow	61	765	0	5,886	31,333	0.0	3.9	0.03
Crow	63	Surface	1,147	12,094	902,623	0.4	4.9	0.55
Crow	65	Surface	0	18,197	97,955	0.0	7.9	0.08
Crow	67	Ground	0	9,538	60,653	0.0	0.0	0.18
Crow	69	Ground	6,674	17,334	138,274	4.0	2.2	0.32
Crow	71	Ground	0	12,686	687	0.0	6.0	0.24
Crow	73	761	0	0	14,769	0.0	0.0	0.03
Crow	75	Ground	0	0	68,156	0.0	0.0	0.14
Crow	77	701	828	0	16,416	0.7	0.0	0.02
Crow	81	815	0	13,909	250,250	0.0	5.9	0.32
Crow	83	Ground	0	0	33,821	0.0	0.0	0.13
Crow	85	Surface	0	0	23,002	0.0	0.0	0.07

We would be happy to discuss these issues with you and hear any feedback you may have regarding time-series development within the Sauk, North Fork Crow, and South Fork Crow Watersheds.

Sincerely,

Jason Love

Jason T. Love
Vice President, Water & Natural Resources

JTL:llf

cc: Project Central File 1953 — Category A

RSI(RCO)-1953/4-11/5

April 7, 2011

Mr. Chuck Reagan
Minnesota Pollution Control Agency
520 Lafayette Road
St. Paul, MN 55155

Dear Mr. Reagan:

RE: Pervious (PERLND) and Impervious Land (IMPLND) Category Development (Revision 1)

Please review the following methodology for the development of pervious and impervious land segment categories for the Sauk, North Crow, and South Crow River Watersheds. The primary 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. Watershed characteristics selected for categorization of the land segments include meteorological variability, drainage patterns, land use distribution, hydrologic soil classification, artificial drainage, animal feedlot operations, and percent impervious area. These characteristics were selected based on the significance of their influence on hydrologic processes and water-quality constituents of interest as well as the quality and availability of spatial data associated with the characteristics. The selected characteristics were systematically classified and combined to create unique pervious and impervious land segment categories to diversify and manage model parameterization.

METEOROLOGICAL VARIABILITY

The watershed was first segmented into subwatersheds to refine the drainage patterns based on the Level 7 minor watersheds. The subwatersheds shown in Figure 1 represent the drainage network, and their boundaries will determine the area of each unique land segment that contributes to each individual subwatershed reach section. Figure 2 shows how the subwatersheds were aggregated into meteorological zones based on their proximity to a selected meteorological station using the Thiessen polygon approach. Meteorological stations were selected based on the quality and availability of meteorological data from **BASINS** or supplementary Minnesota Pollution Control Agency (MPCA) precipitation stations. The high density of stations available more than adequately captures the meteorological variability and topography of the watershed. The meteorological zones were involved in the classification of the pervious and impervious land segments.

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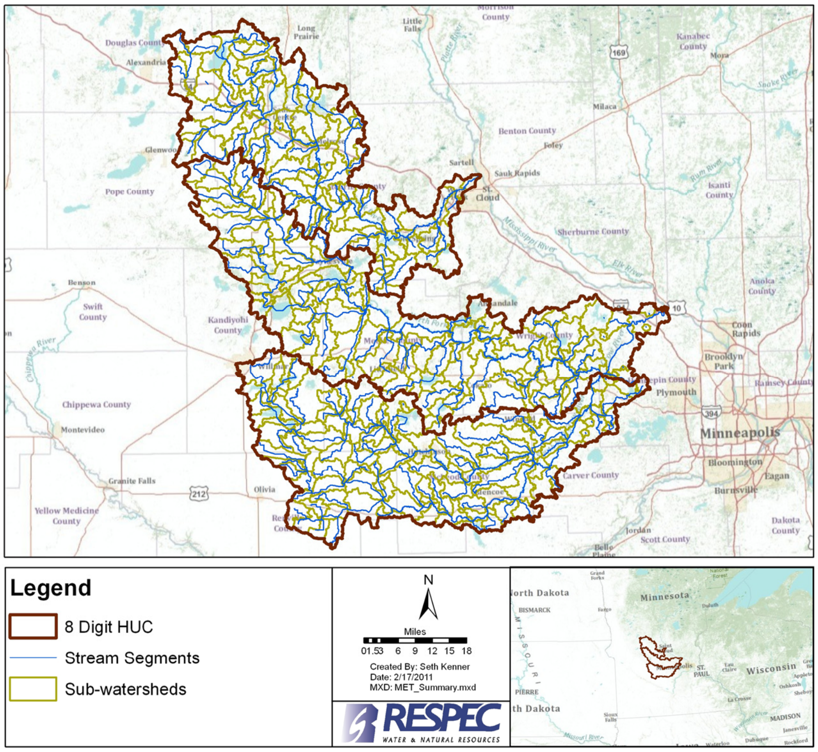

Figure 1. Subwatershed Stream Segmentation Refined From Level 7 Minor Watersheds.

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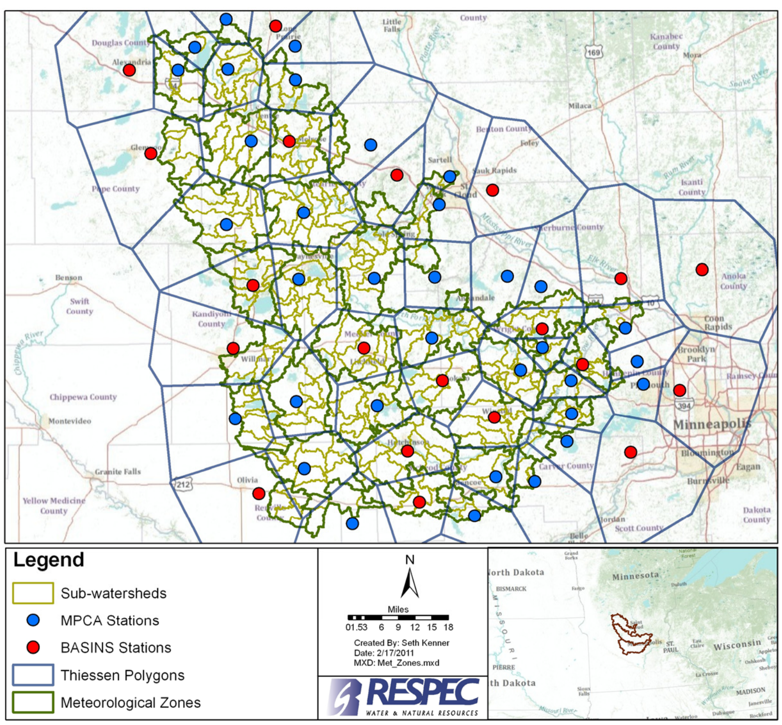

Figure 2. Aggregation of Subwatersheds Into Meteorological Zones Using the Thiessen Polygon Approach.

LAND USE DISTRIBUTION

Land use provides a comprehensive representation of the diverse hydrologic and water-quality responses within a watershed system. Land use affects infiltration, surface runoff, and water losses from evaporation or transpiration by vegetation. The movement of water through the system is affected significantly by the vegetation (e.g., crops, grass, and forest) and associated characteristics. Land use categories also represent characteristics such as manure application and other anthropogenic practices which clearly impact the accumulation of pollutants such as sediment, bacteria, and nutrients.

The National Land Cover Dataset (NLCD) was the source of the land use distribution used for this modeling effort. Because of the length of the simulation period (1995 through 2009), it is desirable to represent the changes in land use over time. The updated NCLD 2001 version 2 and NLCD 2006 will be used to represent land use changes. NLCD 1992 was disregarded because it was based on Landsat images from years outside of the simulation period, and the Multi-Resolution Land Characteristics Consortium (MLRC) recommends not comparing NLCD 1992 to NLCD 2001 on a direct, pixel-to-pixel basis for the following reasons:

1. NLCD 1992 was based on an unsupervised classification algorithm; whereas, NLCD 2001 and 2006 were based on a supervised classification and regression tree algorithm.
2. Terrain corrections were based on digital elevation models (DEMs) with a 90-meter spatial resolution for NLCD 1992; whereas, terrain correction for NLCD 2001 and 2006 used 30-meter DEMs.
3. The impervious surface mapping that is part of NLCD 2001 resulted in the identification of many more roads than could be identified in NLCD 1992; however, most of these roads were present in 1992.
4. NLCD 2001 and 2006 imagery was corrected for atmospheric effects before classification; whereas, NLCD 1992 imagery was not.

The current plan is to use the NLCD 2001 for a portion of the simulation period from 1995 through 2003 and use NLCD 2006 for the remaining portion from 2004 through 2009. Figure 3 shows a map of the percent of total land use area that changed from NLCD 2001 to NLCD 2006 calculated for each Level 7 minor watershed. The more predominate land use changes were from agriculture to another land use in Figure 4 and from another land use to urban in Figure 5.

There are limited number of operations (e.g., PERLND, IMPLND, RCHRES, PLTGEN, and COPY) allowed in one **HSPF** model application. Consequently, the 15 categories represented in the NCLD 2001 and 2006 were aggregated into relatively homogeneous model categories. Figure 6 is a map of the distribution of the model categories for the major watersheds of interest. Tables 1 and 2 have the percent area of each NCLD category in each model category as well as the percent of each model category in the major watersheds of interest for the 2001 and 2006 NLCD, respectively. As a result of the lake selection process, a number of lakes that were not explicitly modeled as reservoirs or joined to reach geometry were selected to be modeled with the wetland land use category. Table 3 shows the original and adjusted area of open water and wetland land use categories in each watershed for each NLCD year.

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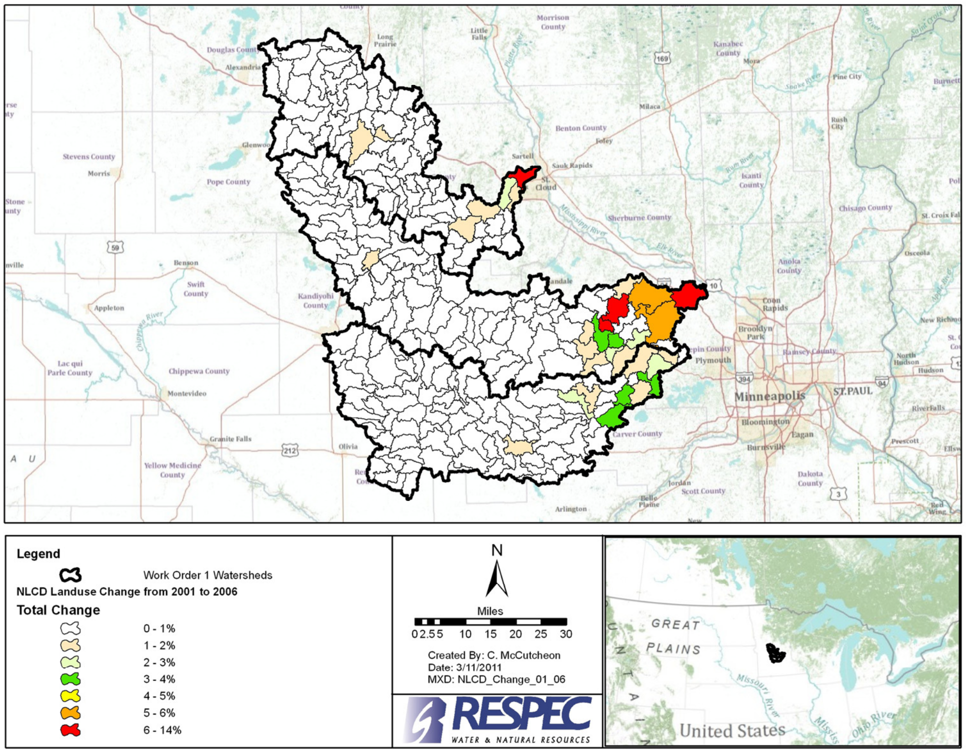

Figure 3. Overall Percent of Land Use Change in Level 7 Minor Watersheds.

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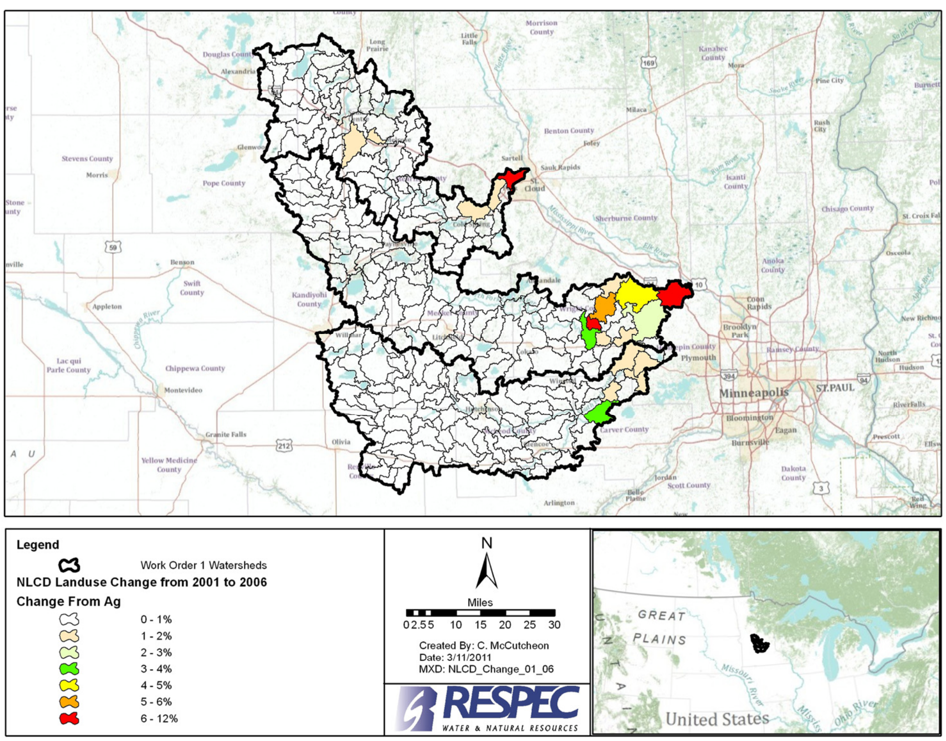

Figure 4. Percent of Land Use Change in Level 7 Watersheds from Agriculture to Another Land Use.

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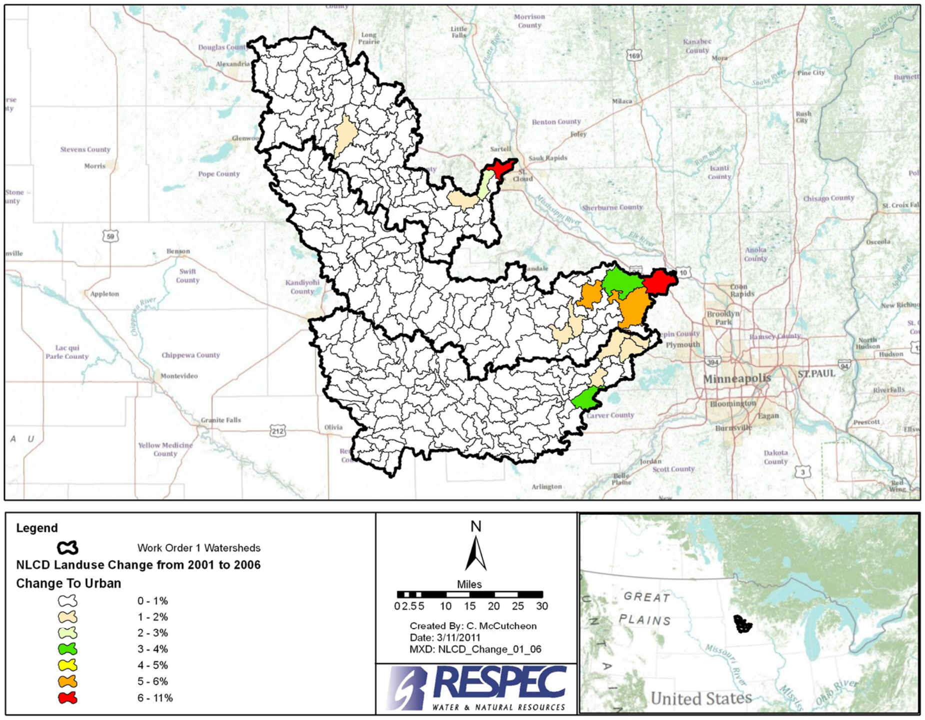

Figure 5. Percent of Land Use Change in Level 7 Watersheds to Urban From Another Land Use.

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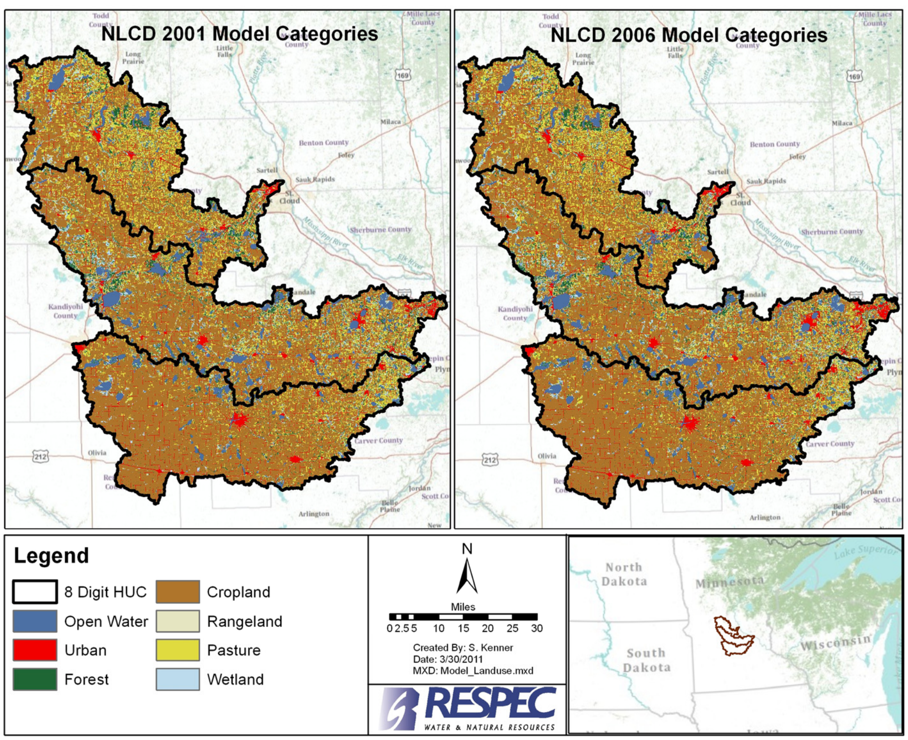

Figure 6. Model Category Distribution Developed From National Land Cover Dataset 2001 and 2006 Land Use Categories.

Table 1. Summary of 2001 National Land Cover Datasets Land Use Categories Aggregated Into Model Categories

2001 NLCD Categories	Percent of Model Category			Model Categories	Percent of Watershed		
	Sauk	North Crow	South Crow		Sauk	North Crow	South Crow
Open Water	100%	100%	100%	Open Water	4.6%	6.8%	3.7%
Developed, Open Space	74.0%	57.3%	47.2%	Urban	5.9%	6.1%	5.8%
Developed, Low Intensity	18.2%	32.5%	41.3%				
Developed, Medium Intensity	5.1%	7.9%	8.7%				
Developed, High Intensity	2.6%	2.3%	2.8%				
Deciduous Forest	96.5%	97.0%	97.2%	Forest	8.4%	8.0%	4.2%
Evergreen Forest	3.3%	2.6%	2.4%				
Mixed Forest	0.2%	0.4%	0.4%				
Cultivated Crops	100%	100%	100%	Cropland	50.2%	56.0%	72.6%
Shrub/Scrub	0.7%	36.9%	61.3%	Grassland	2.6%	3.9%	1.3%
Barren Land (Rock/Sand/Clay)	0.5%	0.4%	2.0%				
Grassland/Herbaceous	98.9%	62.7%	36.7%				
Pasture/Hay	100%	100%	100%	Pasture	24.3%	14.4%	9.7%
Woody Wetlands	15.5%	11.0%	6.5%	Wetland	3.9%	4.7%	2.8%
Emergent Herbaceous Wetlands	84.5%	89.0%	93.5%				

HYDROLOGIC SOIL CLASSIFICATION

Soil properties have a significant effect on hydrologic processes and can also provide an adequate representation of surface geology. Hydrologic variables influenced by soil type include infiltration, surface runoff, interflow, groundwater storage, and deep groundwater losses. Soil types were classified with the hydrologic soil group for the watershed using the Soil Survey Geographic (SSURGO) database. Figure 7 is a map of the distribution of hydrologic soil groups in the major watersheds of interest. The primary hydrologic soil groups, A, B, C, and D, were aggregated into two categories: low runoff potential and high runoff potential. This was practical to reduce PERLND combinations because Groups B and D soils represent, on average, 95 percent of the individual Level 7 watersheds. Group A soils were combined with Group B soils to define the low runoff potential soils, and Group C soils were combined with Group D soils to define the high runoff potential soils. Table 4 has the percent of each hydrologic soil group in the two aggregated categories as well as the percent of the aggregated categories in the major watersheds. Soils that were classified as not rated were grouped with the high runoff potential soils because they typically represent open water or urban areas. Soils with a dual classification (e.g., A/D, B/D, or C/D) were given the class of the higher runoff potential soil (e.g., Group D) because of the inclusion of the artificial drainage characteristic which is discussed in the next section. A dual classification implies that the soil will respond like the low runoff potential group if it is adequately drained. The hydrologic soil classification will be applied to the forest, cropland, grassland, and pasture land use areas. An assumption will be made that wetland and barren areas will only represent high runoff potential soil. Urban areas will disregard soil classification because there is not a diverse distribution of developed categories present.

Table 2. Summary of 2006 National Land Cover Datasets Land Use Categories Aggregated Into Model Categories

2006 NLCD Categories	Percent of Model Category			Model Categories	Percent of Watershed		
	Sauk	North Crow	South Crow		Sauk	North Crow	South Crow
Open Water	100%	100%	100%	Open Water	4.6%	6.9%	3.8%
Developed, Open Space	72.3%	56.8%	47.4%	Urban	6.2%	6.6%	5.9%
Developed, Low Intensity	18.7%	32.1%	41.0%				
Developed, Medium Intensity	6.3%	8.7%	8.9%				
Developed, High Intensity	2.7%	2.4%	2.8%				
Deciduous Forest	96.5%	97.1%	97.2%	Forest	8.4%	8.0%	4.3%
Evergreen Forest	3.3%	2.6%	2.3%				
Mixed Forest	0.2%	0.4%	0.4%				
Cultivated Crops	100%	100%	100%	Cropland	50.0%	55.6%	72.4%
Shrub/Scrub	0.4%	0.7%	2.6%	Grassland	2.7%	3.9%	1.2%
Barren Land (Rock/Sand/Clay)	2.2%	37.6%	61.1%				
Grassland/Herbaceous	97.4%	61.7%	36.4%				
Pasture/Hay	100%	100%	100%	Pasture	24.2%	14.2%	9.6%
Woody Wetlands	15.6%	10.9%	6.5%	Wetland	3.9%	4.8%	2.8%
Emergent Herbaceous Wetlands	84.5%	89.1%	93.5%				

Table 3. Original and Adjusted Area in Acres of Open Water and Wetland Land Use Categories for Each Watershed and National Land Cover Dataset Year

Model Categories (Areas in Acres)	NLCD 2001			NLCD 2006		
	Sauk	North Crow	South Crow	Sauk	North Crow	South Crow
Open Water	30,790	64,023	30,444	30,870	65,105	31,319
Wetland	26,294	44,779	22,948	26,305	45,222	22,901
Open Water to Wetland Adjustment	6,407	17,206	10,165	6,488	18,288	11,040
Adjusted Open Water	24,382	46,817	20,279	243,82	46,817	20,279
Adjusted Wetland	32,702	61,985	33,113	32,702	61,985	33,113

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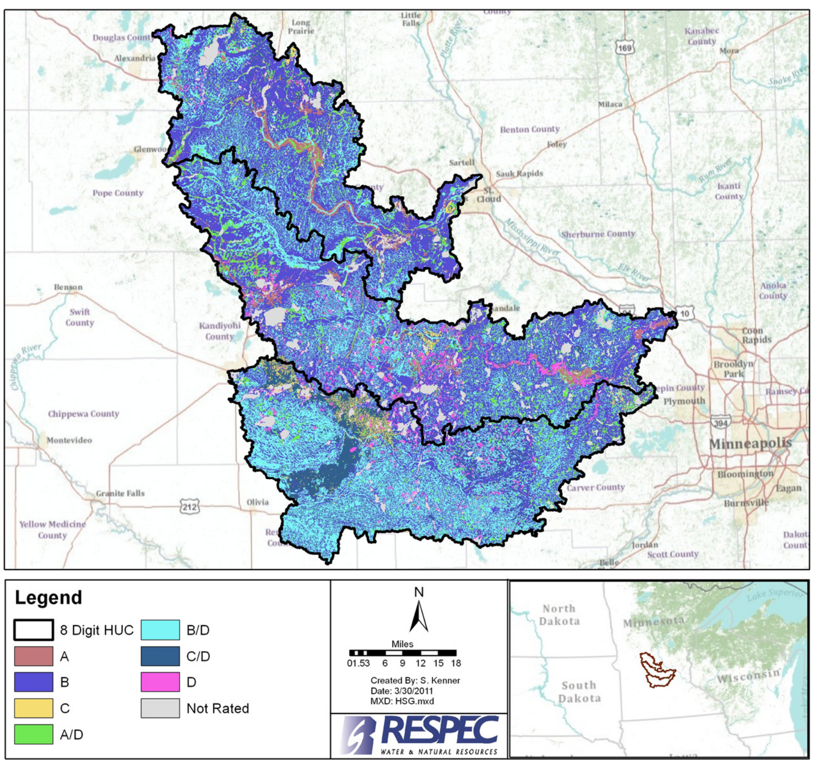

Figure 7. Hydrologic Soil Group Distribution in the Major Watersheds of Interest.

ARTIFICIAL DRAINAGE

Artificial drainage practices on agricultural lands can significantly influence hydrology and water-quality processes. The inclusion of the artificial drainage category allows potentially poorly drained soils to be parameterized in the model as well drained as soils based on estimated areas where artificial drainage is likely to be present. The artificially drained category is not combined with the low runoff potential category even though artificial drainage may decrease the surface runoff potential of the soil if the soil is drained, as in the case of the dual hydrologic soil group. The subsurface processes involved in artificial drainage practices present a much different hydrologic response. Artificial drainage practices are typically drained with channel networks that can shorten travel times and increase runoff volumes. Consequently, the water interacts less with the mineral and organic components of the soil profile and there are less opportunities for biological and chemical interactions to process dissolved nutrients carried with the drainage water to the streams [Fausey et al., 2008][1].

Table 4. Hydrologic Soil Group Watershed Area and Classification Summary

Hydrologic Soil Group	Percent of Model Classification			Model Classification	Percent of Watershed		
	Sauk	North Crow	South Crow		Sauk	North Crow	South Crow
A	9%	6%	1%	Low Runoff Potential	63%	57%	36%
B	91%	94%	99%				
C	2%	2%	4%	High Runoff Potential	37%	43%	64%
A/D	22%	17%	7%				
B/D	55%	53%	60%				
C/D	4%	2%	19%				
D	3%	10%	5%				
Not Rated	14%	16%	6%				

The Geographic Information System (GIS) methodology used to calculate the drained cropland in the Sauk and Crow Watersheds was derived from Sugg [2007][2]. The GIS methodology from the paper is "based on the simple idea that if row crops are cultivated on a poorly drained soil, then an artificial drainage improvement likely exists on that soil." For the Sauk and Crow analysis, SSURGO was used as opposed to the U.S. Department of Agriculture (USDA)/Natural Resources Conservation Service (NRCS) State Soil Geographic Database (STATSGO) used in Sugg's study because it has higher resolution, more detailed information. The ArcGIS Soil Data Viewer was used to query the soil drainage classifications throughout each county. These classifications included excessively drained, somewhat excessively drained, well drained, moderately well drained, somewhat poorly drained, poorly drained, and very poorly drained soil. The soil drainage classification layer was intersected with the NLCD land use layers. Figure 8 is a map of the areas where cultivated crops were present on poorly drained or very poorly drained soils that were classified as likely drained and very likely drained.

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1 **Fausey, N. R., D. Pitts, and D. B. Jaynes, 2008.** *Agricultural Drainage Water Management in the Upper Mississippi River Basin: Potential Impact and Implementation Strategies*, Nonpoint Source Water Quality Monitoring Results Workshop, Meeting Abstract.

2 **Sugg, Z., 2007.** *Assessing U.S. Farm Drainage: Can GIS Lead to Better Estimates of Subsurface Drainage Extent?*, World Resources Institute, Washington, DC, August.

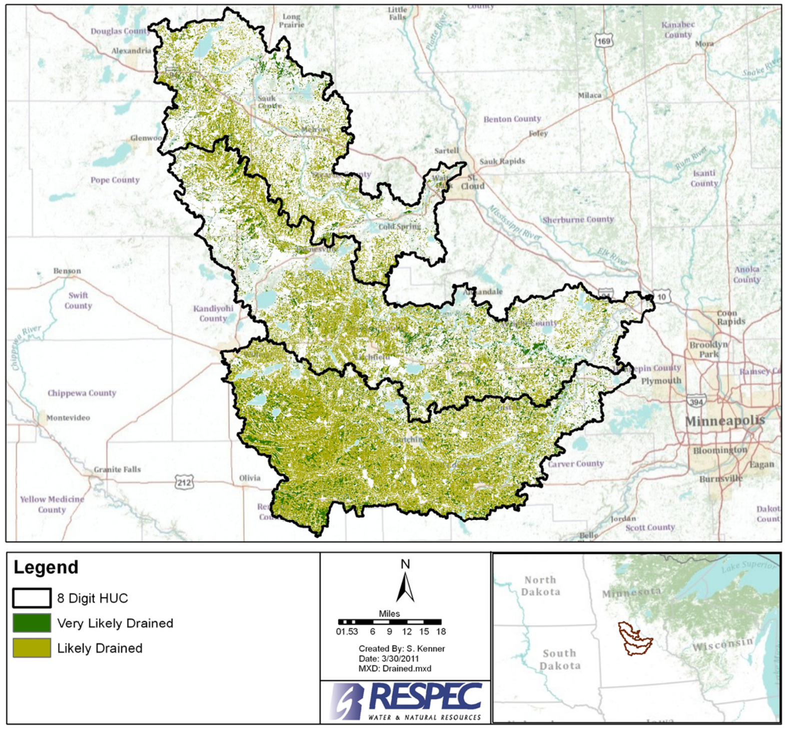

Figure 8. Cultivated Cropland Areas Most Likely to Be Drained With Artificial Drainage.

This analysis located poorly and very poorly drained cultivated cropland that would benefit most from installation of artificial drainage. It is possible that the somewhat poorly drained soil, which was included in Sugg's analysis, could also be drained. However, the purpose of this analysis is to estimate areas of cultivated crops in the Sauk and Crow Watersheds that presently have subsurface drainage. Thus the somewhat poorly drained soil was excluded from this analysis. Approximately 35 percent, 48 percent, and 65 percent of cultivated cropland were estimated to be drained in the Sauk Watershed, North Fork Crow Watershed, and South Fork Crow Watershed, respectively. Although this analysis did not include somewhat poorly drained soils, it concludes that a larger percentage of poorly drained row crops exist than the Sugg analysis estimated. This is likely because the acres of row crops increased by an average of 13 percent for counties overlaying the Sauk and Crow Watersheds and because the SSURGO data is far more detailed than the STATSGO data.

ANIMAL FEEDLOT OPERATIONS

The primary source of pollution from animal feedlot operations (AFOs) is manure. Manure introduces oxygen-demanding substances, ammonia, nutrients, solids, and bacteria into the surrounding water sources through accumulation and wash-off processes. These are all pollutants impairing water-quality in the major watersheds of interest. Also, reduction in vegetation and densely packed subsurface soils resulting from concentrated animal grazing can lower infiltration rates and increase sediment erosion. There are an estimated 1,664, 1,133, and 824 AFOs in the Sauk, North Crow, and South Crow River Watersheds respectively. Figure 9 shows the distribution of AFOs in the major watersheds.

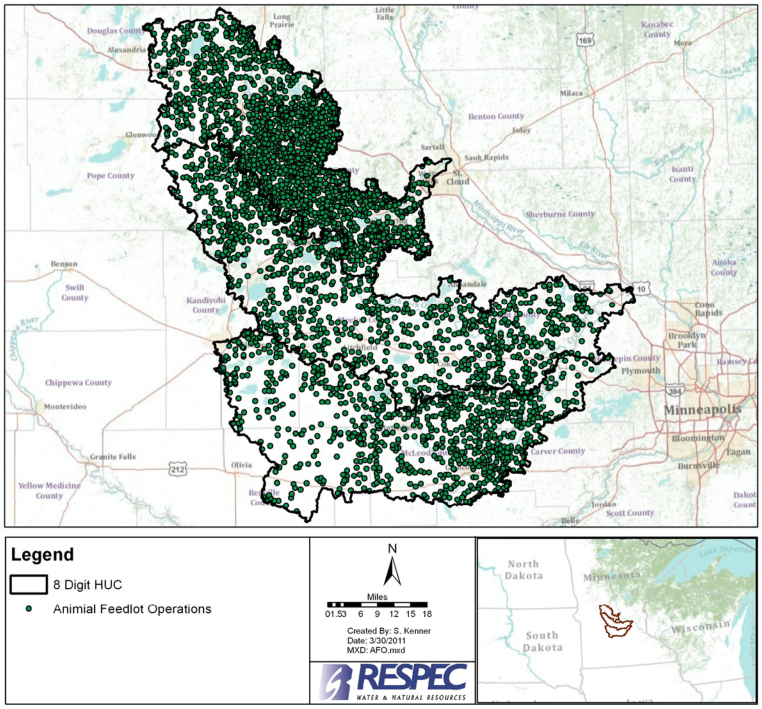

Figure 9. Distribution of Animal Feedlot Operations in the Major Watersheds of Interest.

The spatial location and animal data of the AFOs are known but the area information has not been collected. To create a feedlot land segment category for modeling purposes, an area for each AFO has been estimated. The typical design specification of 300 square feet per animal unit was used to calculate an area for each AFO [Murphy and Harner][3]. The individual calculated areas will be shifted from the land category where each AFO is located to the feedlot category. Table 5 has a summary of the animal data and estimated areas for the AFOs. No discharge is allowed from any feedlot operation with 1,000 animal units or more according to Minnesota Administrative Rule 7020.2003. Area associated with feedlots that are not allowed to discharge will be routed though representative detention ponds with a separate mass link connection.

Table 5. Summary of Animal Feedlot Operations Data and Estimated Area Calculations

Major Watershed	AFOs	Animal Counts	Animal Units	Estimated Area (acres)
Sauk River	1,664	470,2486	249,376	1,717
North Crow River	1,133	626,9390	175,788	1,211
South Crow River	824	189,2380	140,844	970

[3] **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.

PERCENT IMPERVIOUS AREA

In congruence with the land use representation, the imperious area will be represented using the NLCD 2001 version 2 and 2006 Percent Developed Imperviousness from the MLRC. Figure 10 shows the 2001 and 2006 NLCD mapped impervious area (MIA), but it is important to determine the effective impervious area (EIA) to accurately represent hydrologic processes. 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) and the resulting overland flow will not run onto pervious areas and, therefore, will not have the opportunity to infiltrate along its respective overland flow path before reaching a stream or waterbody. The EIA will be calculated using Equation 1 for average basins from Sutherland [1995][4]. The percent EIA will be used to separate the developed urban land use areas into urban impervious and pervious land segment categories.

$$EIA = 0.1\left(MIA\right)^{1.5} \qquad (1)$$

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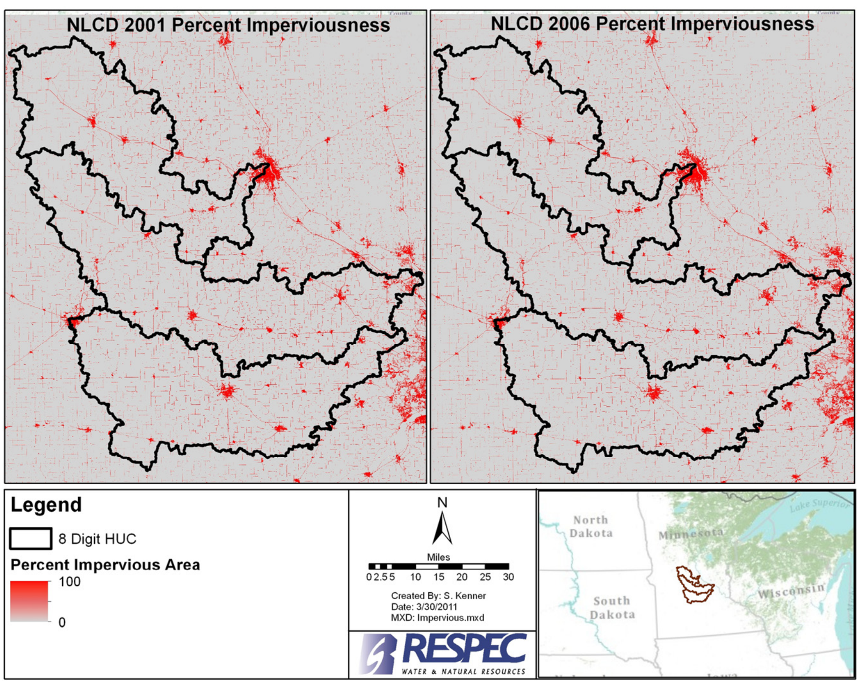

Figure 10. National Land Cover Dataset 2001 and 2006 Percent Imperviousness for the Watersheds of Interest.

LAND SEGMENT CLASSIFICATION

Figure 11 shows a diagram of how unique pervious and impervious classifications were developed using the watershed characteristics and classification methods previously discussed.

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

First, NLCD land use categories were aggregated into model land use categories. Second, urban areas were divided into pervious and impervious urban classifications using the calculated EIA. Next, the cropland was separated into artificially drained and undrained categories. Then the forest, grassland, and undrained cropland categories were separated with the hydrologic soil group classifications to create the unique land characteristic classifications. Finally, the area of AFOs on each of the other land classes was removed from the corresponding class to create the feedlot classification. The 43 meteorological zones will include the 13 land characteristic classifications, creating 516 possible land segment operations for the two model applications combined. The calculated EIA varies within the urban areas so an area weighted average is calculated to determine the final EIA for each unique urban operation.

RSI-1953-11-014

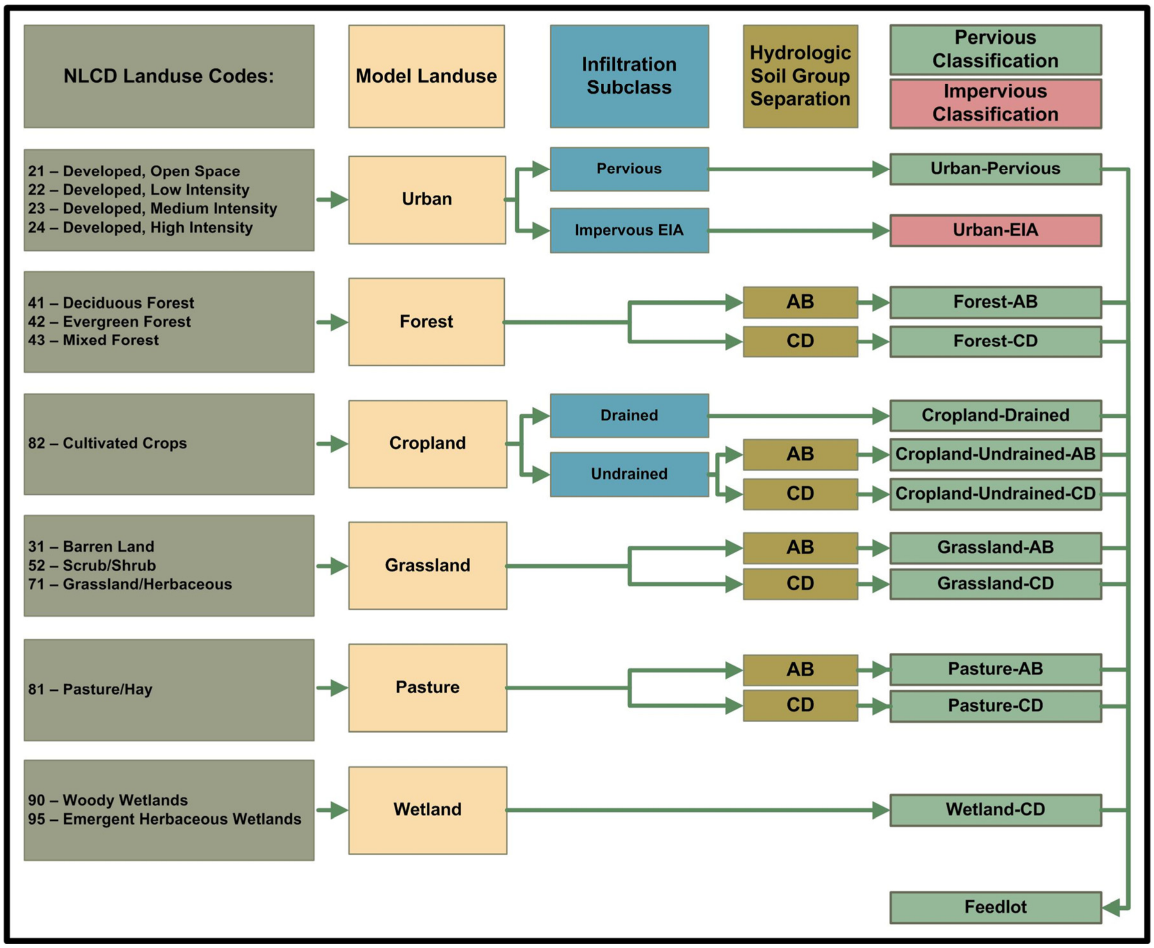


Figure 11. National Land Cover Dataset 2001 and 2006 Percent Imperviousness for the Watersheds of Interest.

The pervious land segment (PERLND) and impervious land segment (IMPLND) operation numbers in HSPF are limited to three digits and can range from 1–999. The large number of meteorological zones are represented with the tens and hundreds places and labeled as odd numbers to allow for 20 possible unique classifications of the remaining watershed land characteristics. Although the major watersheds of interest will be represented as two model applications, the 43 meteorological zones will be labeled as one group to reduce processing time and because some zones will be used for both model applications. There were 12 pervious and 1 impervious unique classifications from the watershed land characterization model, which leaves 8 classifications available for possible future expansion of model categories. The operations of the first 10 classes can be directly identified with the meteorological zone number, which have an odd number in the tens place and numbers 0–9 in the ones place. The eleventh and twelfth class, which are wetland and feedlot in this case, will be identified with an even number with one greater than the meteorological zone number in the tens place and a 0 in the ones place. For example, the fourth class, Cropland-Undrained-AB, in Meteorological Zone 17, is given a PERLND operation number of 174. The eleventh class, Wetland, in the same Meteorological Zone 17, was given a PERLND operation number of 180. Table 6 has the numbering of all the unique PERLND operations. The urban IMPLND will be given the same operation number as the urban PERLND. Initial HSPF parameters were assigned by landuse class drawing from calibrated model applications of the Le Sueur and Minnesota River Waterhseds.

MUNICIPAL SEPARATE STORM SEWER SYSTEMS (MS4)

The work plan requests that the Municipal Separate Storm Sewer System (MS4) areas be represented in the model applications. However, the MS4 areas will be parameterized the same as non-MS4 areas within the same land classification. Therefore, the MS4 areas will be separated from non-MS4 areas during the calculation of the schematic and assigned a different mass link number to the lines in the schematic corresponding to MS4 areas. This will maintain a lower number of unique land segment operations while also being able to facilitate waste load allocation for MS4 areas.

Thank you for your time reviewing the proposed method for developing the PERLND and IMPLND land segment categories for the Sauk, North Crow, and South Crow River Watersheds. Please feel free to provide feedback with any questions or concerns.

Sincerely,

Jason Love

Jason T. Love
Vice President, Water & Natural Resources

JTL:llf

cc: Project Central File 1953 — Category A

Table 6. Unique PERLND Operation Numbering Scheme (Page 1 of 3)

Meteorological Zone	Urban	Forest AB	Forest CD	Cropland Drained	Cropland Undrained AB	Cropland Undrained CD	Grassland AB	Grassland CD	Pasture AB	Pasture CD	Wetland CD	Feedlot
Hundreds, Tens Place	*Ones Place*											
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**0**	**1**
1	10	11	12	13	14	15	16	17	18	19	20	21
3	30	31	32	33	34	35	36	37	38	39	40	41
5	50	51	52	53	54	55	56	57	58	59	60	61
7	70	71	72	73	74	75	76	77	78	79	80	81
9	90	91	92	93	94	95	96	97	98	99	100	101
11	110	111	112	113	114	115	116	117	118	119	120	121
13	130	131	132	133	134	135	136	137	138	139	140	141
15	150	151	152	153	154	155	156	157	158	159	160	161
17	170	171	172	173	174	175	176	177	178	179	180	181
19	190	191	192	193	194	195	196	197	198	199	200	201
21	210	211	212	213	214	215	216	217	218	219	220	221
23	230	231	232	233	234	235	236	237	238	239	240	241
25	250	251	252	253	254	255	256	257	258	259	260	261
27	270	271	272	273	274	275	276	277	278	279	280	281
29	290	291	292	293	294	295	296	297	298	299	300	301
31	310	311	312	313	314	315	316	317	318	319	320	321
33	330	331	332	333	334	335	336	337	338	339	340	341
35	350	351	352	353	354	355	356	357	358	359	360	361
37	370	371	372	373	374	375	376	377	378	379	380	381

Table 6. Unique PERLND Operation Numbering Scheme (Page 2 of 3)

Meteorological Zone	Urban	Forest AB	Forest CD	Cropland Drained	Cropland Undrained AB	Cropland Undrained CD	Grassland AB	Grassland CD	Pasture AB	Pasture CD	Wetland CD	Feedlot
Hundreds, Tens Place	*Ones Place*											
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**0**	**1**
39	390	391	392	393	394	395	396	397	398	399	400	401
41	410	411	412	413	414	415	416	417	418	419	420	421
43	430	431	432	433	434	435	436	437	438	439	440	441
45	450	451	452	453	454	455	456	457	458	459	460	461
47	470	471	472	473	474	475	476	477	478	479	480	481
49	490	491	492	493	494	495	496	497	498	499	500	501
51	510	511	512	513	514	515	516	517	518	519	520	521
53	530	531	532	533	534	535	536	537	538	539	540	541
55	550	551	552	553	554	555	556	557	558	559	560	561
57	570	571	572	573	574	575	576	577	578	579	580	581
59	590	591	592	593	594	595	596	597	598	599	600	601
61	610	611	612	613	614	615	616	617	618	619	620	621
63	630	631	632	633	634	635	636	637	638	639	640	641
65	650	651	652	653	654	655	656	657	658	659	660	661
67	670	671	672	673	674	675	676	677	678	679	680	681
69	690	691	692	693	694	695	696	697	698	699	700	701
71	710	711	712	713	714	715	716	717	718	719	720	721
73	730	731	732	733	734	735	736	737	738	739	740	741

Table 6. Unique PERLND Operation Numbering Scheme (Page 3 of 3)

Meteorological Zone	Urban	Forest AB	Forest CD	Cropland Drained	Cropland Undrained AB	Cropland Undrained CD	Grassland AB	Grassland CD	Pasture AB	Pasture CD	Wetland CD	Feedlot
Hundreds, Tens Place	*Ones Place*											
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**0**	**1**
75	750	751	752	753	754	755	756	757	758	759	760	761
77	770	771	772	773	774	775	776	777	778	779	780	781
79	790	791	792	793	794	795	796	797	798	799	800	801
81	810	811	812	813	814	815	816	817	818	819	820	821
83	830	831	832	833	834	835	836	837	838	839	840	841
85	850	851	852	853	854	855	856	857	858	859	860	861

July 8, 2011

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

Dear Mr. Regan:

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

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

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

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

TURBIDITY APPROACH

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

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

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

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

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

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

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

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

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

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

TEMPERATURE/DO/BOD DYNAMICS/NUTRIENT APPROACH

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

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

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

OVERVIEW OF WATERSHED MODEL DATA NEEDS

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

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

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

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

Atmospheric Deposition Data Available

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

Dry atmospheric deposition data were downloaded from the EPA's Clean Air Status and Trends Network (CASTNet). CASTNet sites, shown in Figure 3, nearest to the Sauk, North Fork Crow, and South Fork Crow Watersheds, include MN32/VOY413 in northern Minnesota, WI35/PRK134 in west-central Wisconsin, IL18/STK138 in northwestern Illinois, and SD99/SAN189 on the border of South Dakota and Nebraska. Theissen polygons were not created for the dry deposition sites because ambient concentration trends were reviewed which show that data trends from the South Dakota/Nebraska border site and the west-central Wisconsin site are far more representative of central Minnesota than the northern Minnesota site and the northwestern Illinois site. Figure 3 shows nitrate and ammonia trends from 2007 through represent the three watersheds because the South Dakota/Nebraska border site was not active until mid-2006. Site WI35 is also referred to as PRK134. Because dry deposition is not dependent on precipitation, nitrate and ammonia dry deposition data (originally in kg/ha) was applied in the model application using a pound-per-acre approach. Phosphorus data were not available from CASTNet or NADP and will not be represented.

Table 2. Minnesota Pollution Control Agency and U.S. Geological Survey Ambient Water-Quality Sites in the Crow and Sauk Watersheds (Page 1 of 6)

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

Table 2. Minnesota Pollution Control Agency and U.S. Geological Survey Ambient Water-Quality Sites in the Crow and Sauk Watersheds (Page 2 of 6)

MPCA Site	USGS Site	Description	Period of Record*	Watershed	Number Of Samples													
					BOD	Chlorophyll-a	DO	NH3	NO2	NO3	Total NO2+NO3	Total Kjeldahl Nitrogen	Dissolved Ortho-Phosphate	Total Phosphorus	Water Temperature	Suspended Solids Concentration	Total Suspended Solids	Turbidity
N/A	5270500	Sauk River near St. Cloud, MN	1995 - 2001	Sauk			11		2	14		2	7	4	14	1		
N/A	5270380	Sauk River at Richmond, MN	1995	Sauk			2								1			
N/A	5270195	Sauk River above Melrose WWTP at Melrose, MN	2009	Sauk					2	2						1		
N/A	5270197	Sauk River below Melrose WWTP at Melrose, MN	2009	Sauk					2	2						1		
N/A	5270183	Sauk River below Sauk Centre WWTP at Sauk Centre, MN	2009	Sauk					2	2						1		
N/A	5270181	Sauk River above Sauk Centre WWTP A at T Sauk Centre, MN	2009	Sauk					2	2						1		
N/A	5270103	Sauk River below Lake Osakis near Osakis, MN	2007	Sauk					4	4						1		
S000-004	N/A	Crow River at bridge ON CSAH-36 AT DAYTON	1995–2009	North Crow	42	44	118	77			91	26	3	82	93		84	96

Table 2. Minnesota Pollution Control Agency and U.S. Geological Survey Ambient Water-Quality Sites in the Crow and Sauk Watersheds (Page 3 of 6)

MPCA Site	USGS Site	Description	Period of Record*	Watershed	Number Of Samples													
					BOD	Chlorophyll-a	DO	NH3	NO2	NO3	Total NO2+NO3	Total Kjeldahl Nitrogen	Dissolved Ortho-Phosphate	Total Phosphorus	Water Temperature	Suspended Solids Concentration	Total Suspended Solids	Turbidity
S000-847	N/A	Grove Creek A At T CSAH-3 7.5 Miles Northeast Of Grove City	2001–2009	North Crow	16	23												
S001-255	N/A	South Fork Crow River, BR at BRIDGE Ave. in Delano	1998 - 2009	North Crow	34	25		74			133	133	42				140	158
S001-257	N/A	Crow River at BR at Bridge Street in Rockford, MN	1998–2007	North Crow	5	6		5			5	5	2				6	7
S001-502	N/A	Jewett Creek near 300th Street BRG, 4 miles north of Litchfield	2000 - 2009	North Crow	15	23		77			66		37					59
S001-517	N/A	North Fork Crow River at CSAH-4 BRG, 1.5 miles west of Albright	2001–2009	North Crow	19	22							39					
S001-972	N/A	Twelvemile Creek at CSAH 7, 2 miles northwest of Waverly, MN	2001–2009	North Crow									36					
S002-018	N/A	Mill Creek on CSAH-12, 3½ miles southwest of Buffalo	2001–2009	North Crow	15	24							40					
S002-020	N/A	CO. DT 31 ON MN-25,NO OF US-12, 4 miles northwest of Delano	2001–2009	North Crow	23	15												

Table 2. Minnesota Pollution Control Agency and U.S. Geological Survey Ambient Water-Quality Sites in the Crow and Sauk Watersheds (Page 4 of 6)

MPCA Site	USGS Site	Description	Period of Record*	Watershed	Number Of Samples													
					BOD	Chlorophyll-a	DO	NH3	NO2	NO3	Total NO2+NO3	Total Kjeldahl Nitrogen	Dissolved Ortho-Phosphate	Total Phosphorus	Water Temperature	Suspended Solids Concentration	Total Suspended Solids	Turbidity
S002-295	N/A	Crow River Middle Fork Inlet to Nest Lake, 3 miles north northwest of Spicer, MN	2000–2009	North Crow				12			7	85					130	13
S002-384	N/A	Sedan Break and Ironside Road, 3.5 miles northeast of Brooten, MN	2000–2009	North Crow				3			3						57	18
S002-387	N/A	Crow River, North Fork, at CSAH 30 BRG, east Side Manannah, MN	2000– 2009	North Crow				3			3							
S002-391	N/A	JD1 near Dam at South Grove Lake Street, 4 miles northeast of Sedan, MN	1997–2009	North Crow				1				23		88			84	15
S002-403	N/A	Crow River, North Fork, Rice Lake Inlet, 3 miles east of PAYNESVILLE	1997–2001	North Crow										33			33	
N/A	5276005	North Fork Crow River above Paynesville, MN	1995–1998	North Crow			72		70	70		35	70	35	36	35		
N/A	5276000	North Fork Crow River near Regal, MN	1995	North Crow			2			2				4	6			

Table 2. Minnesota Pollution Control Agency and U.S. Geological Survey Ambient Water-Quality Sites in the Crow and Sauk Watersheds (Page 5 of 6)

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

Table 2. Minnesota Pollution Control Agency and U.S. Geological Survey Ambient Water-Quality Sites in the Crow and Sauk Watersheds (Page 6 of 6)

MPCA Site	USGS Site	Description	Period of Record*	Watershed	Number Of Samples													
					BOD	Chlorophyll-a	DO	NH3	NO2	NO3	Total NO2+NO3	Total Kjeldahl Nitrogen	Dissolved Ortho-Phosphate	Total Phosphorus	Water Temperature	Suspended Solids Concentration	Total Suspended Solids	Turbidity
S002-017	N/A	Buffalo Creek on CSAH-24, 4 miles northeast of Buffalo Lake	2002–2009	South Crow	44	30												
N/A	5278880	Buffalo Creek Near New Auburn, MN	1997	South Crow			2		2	2		1	2	1	1	1		1
N/A	5278590	South Fork Crow River at Highway 22 near Biscay, MN	1995–2007	South Crow			14		6	6		1	6	4	8	1		3
N/A	5278580	South Fork Crow River below Hutchinson, MN	2007–2009	South Crow					6	6						1		
N/A	5278570	South Fork Crow River above wastewater treatment plant (WWTP) at Hutchinson, MN	2009	South Crow					2	2						1		
N/A	5278560	South Fork Crow River above Otter Lake near Hutchinson	2007	South Crow					4	4								

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

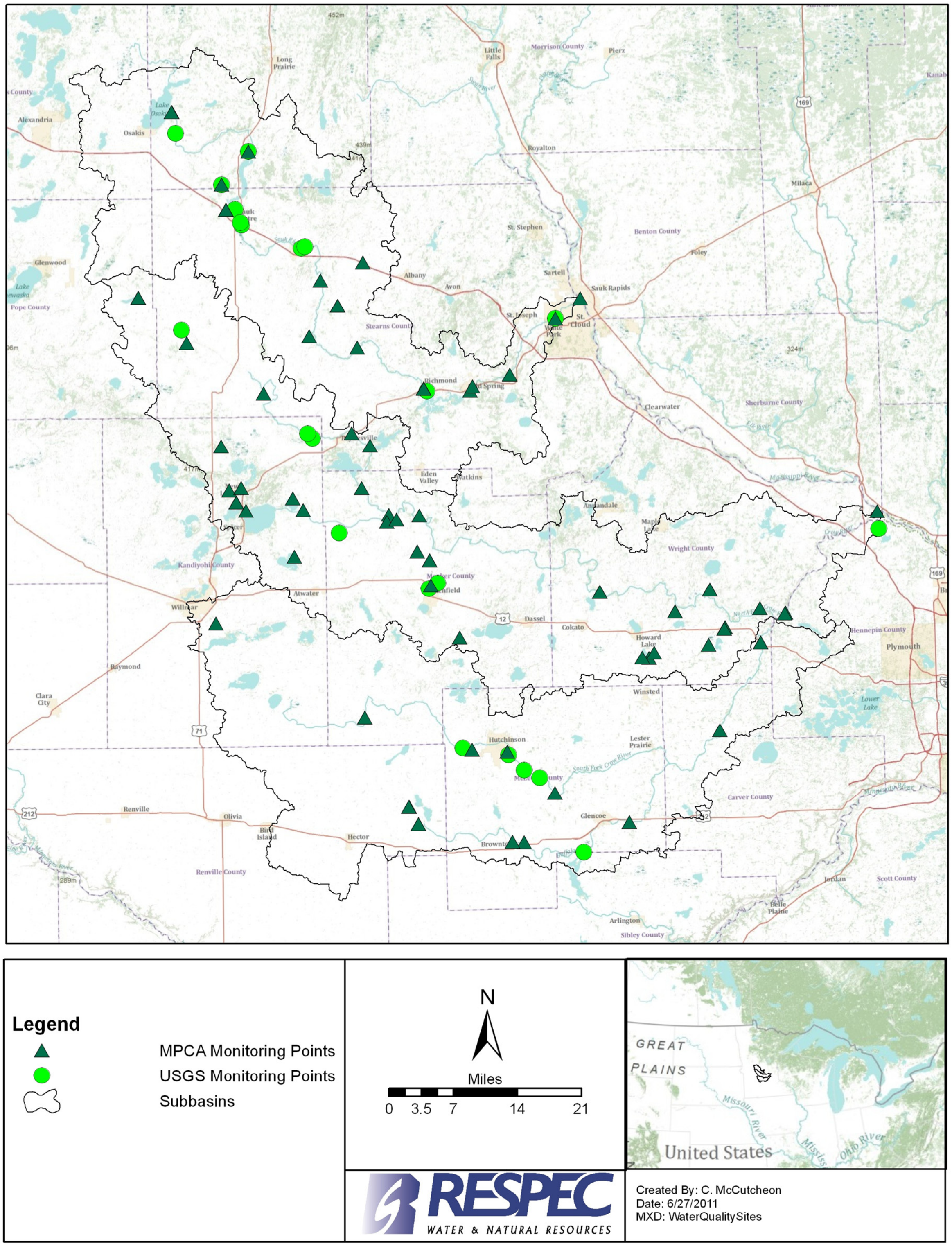


Figure 1. Ambient Water-Quality Monitoring Sites Within the Sauk and Crow Watersheds.

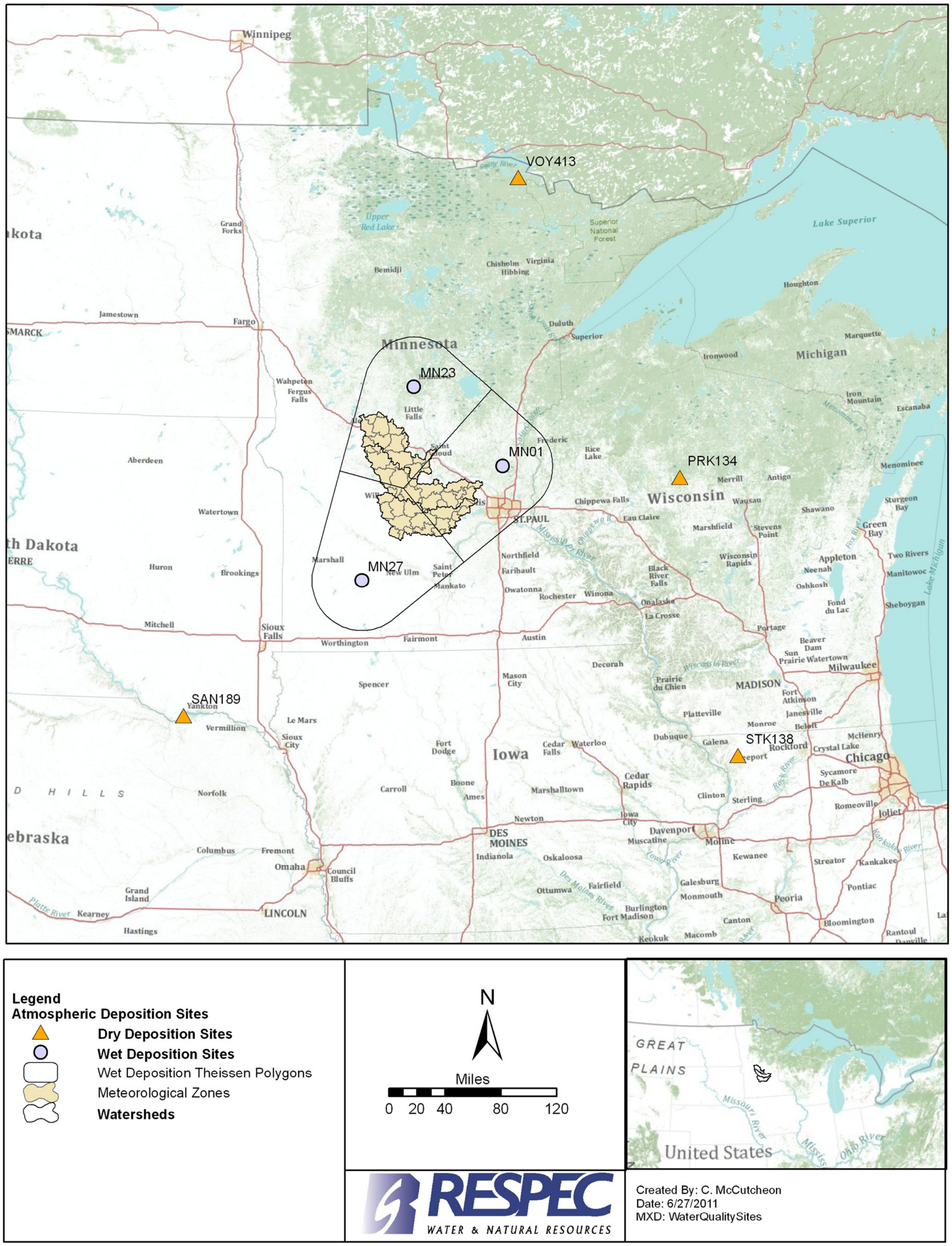
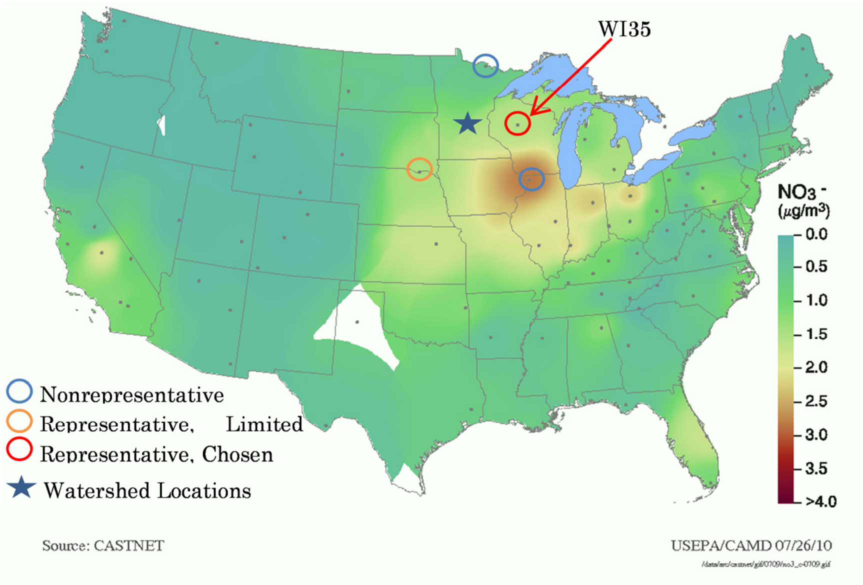


Figure 2. Atmospheric Deposition Sites and Wet Deposition Site Thiessen Polygons.



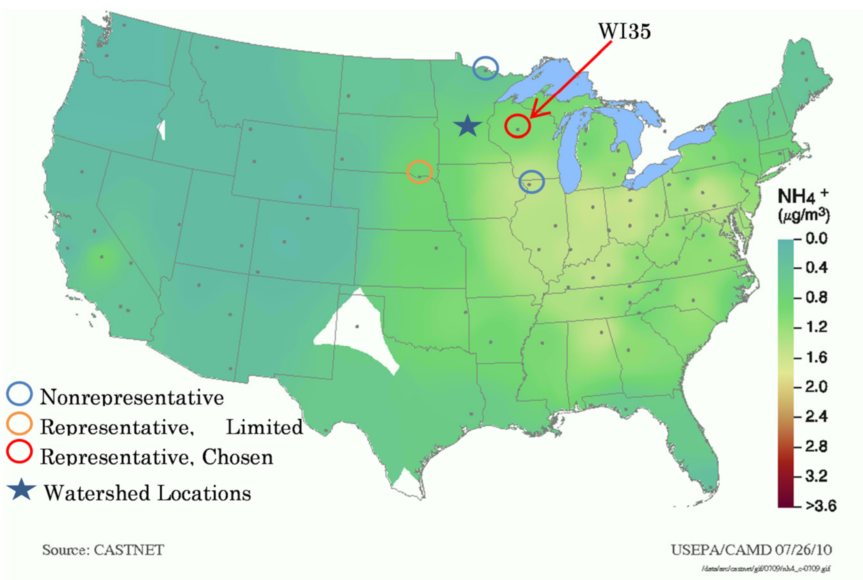


Figure 3. Particulate Nitrate (Top) and Ammonia (Bottom) Concentrations for 2007–2009 [CASTNet, 2011].

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

Point Source Data Available

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

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

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

Effluent water-quality parameters available at all point source sites which will be included in the model application include carbonaceous 5-day biological oxygen demand ($CBOD_5$), total suspended solids (TSS), phosphorus (P), dissolved oxygen (DO), ammonia (NH3), and temperature. Water-quality data at point sources was filled using interpolation between the previous and later dates when less than 7 days occurred between values and using monthly mean values when greater than 7 days occurred between values. Table 4 shows parameter

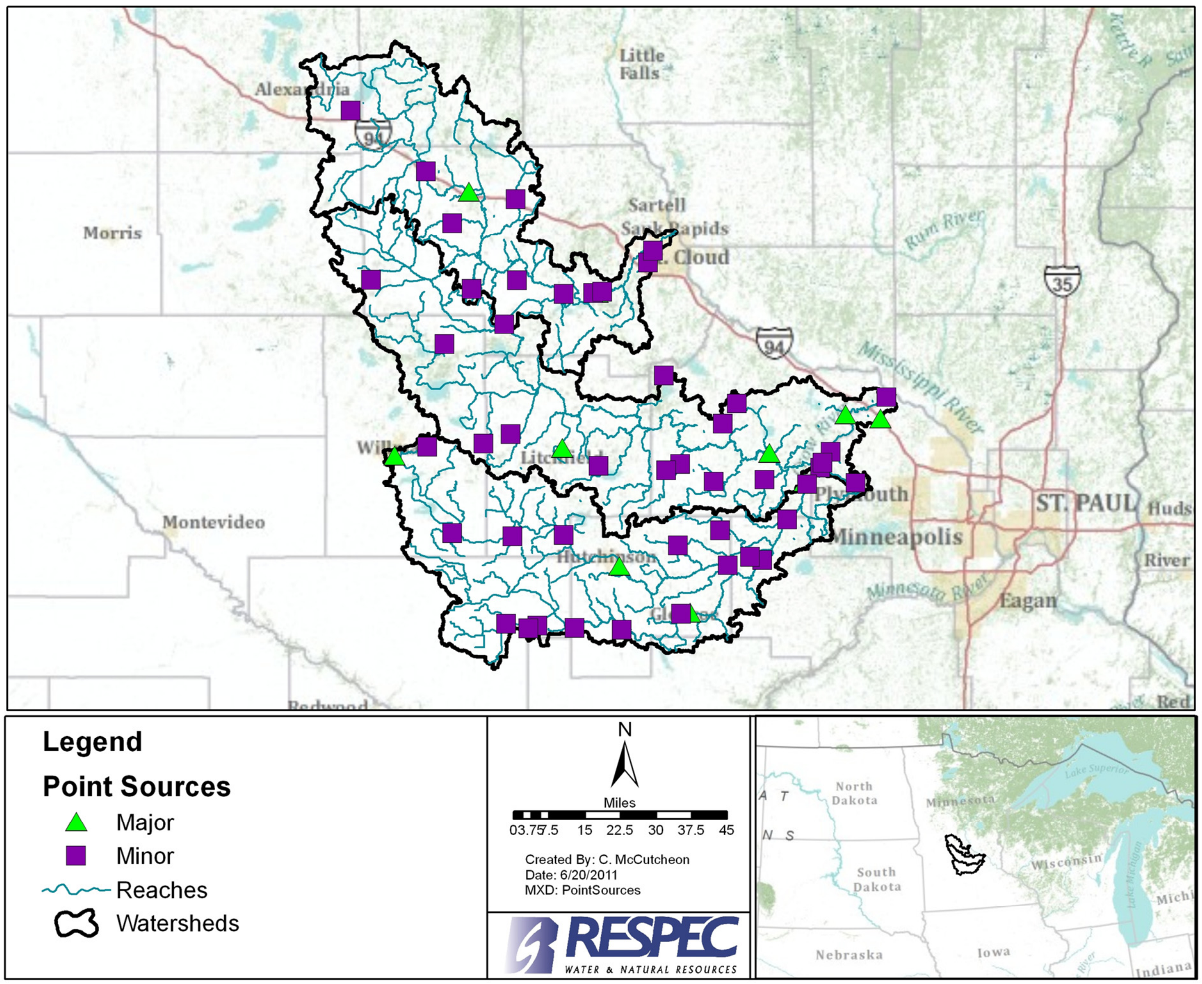


Figure 4. Major and Minor Point Sources in the Sauk, North Fork Crow, and South Fork Crow Watersheds.

availability for each site, with "x" representing the ability to fill daily load time series, "~" representing sites with minimal available samples (generally less than 5) for which a constant time series can be calculated using ratios and/or means, and blanks representing when no data are available.

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

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

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

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

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

where:

$L_0 = CBOD_u$

$y_5 = CBOD_5$

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

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

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

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

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

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

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

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

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

REFERENCES

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

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

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

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

Sincerely,

Jason T. Love
Vice President, Water & Natural Resources

JTL:llf

cc: Project Central File 1953 — Category A

APPENDIX A. MINNESOTA RIVER EXTERNAL SOURCE BLOCK

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

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

July 8, 2011

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

Dear Mr. Regan:

RE: Hydrology Calibration and Validation of Sauk, North Crow, and South Crow HSPF Watershed Models

Please review the following methodology for hydrologic calibration and validation and initial results for select calibration gages of the Sauk, North Crow, and South Crow HSPF Watershed Model Applications.

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

CALIBRATION DATA

The continuous observed stream flow data required for calibration is available at 12 gages within the Sauk River Watershed and 39 gages within the Crow (North and South Fork) River Watershed. The distribution of stream flow gage sites is shown in Figure 1. A PDF of these sites, labeled with reach numbers, is included on the Deliverables DVD. Six mainstem calibration/validation gages are on the Sauk River and 20 gages are on the North and South Fork Rivers. Five tributary calibration/validation gages are in the Sauk River Watershed and 19 gages are in the Crow River Watershed. Table 1 lists the stream flow gages and their period of record to support model calibration and validation of hydrology. Main stem gages are in bold font. Hourly flow data were supplied by the Minnesota Pollution Control Agency (MPCA) from their database. The hourly data were compiled and supplemented with daily flow data from the Minnesota Cooperative Stream Gaging Program website (*www.dnr.state.mn.us/waters/csg/index.html*).

3824 Jet Drive, PO Box 725, Rapid City, South Dakota 57709-0725 Phone: 605.394.6400 Fax: 605.394.6456 www.respec.com

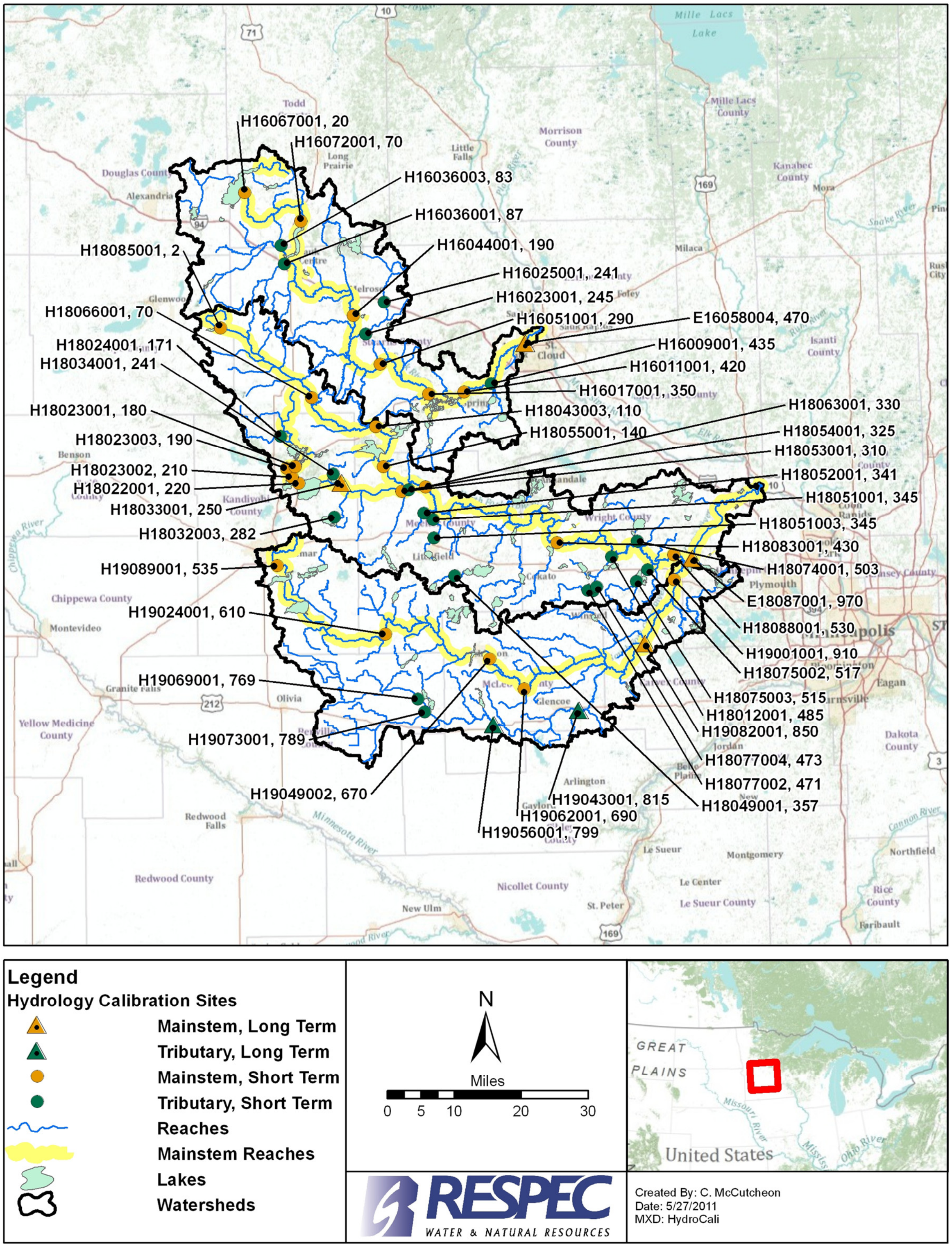


Figure 1. Flow Calibration Gages Within the Sauk and Crow Watersheds.

Table 1. Discharge Calibration Gages Within the Sauk, North Fork, and South Fork Crow River Watersheds (Page 1 of 3)

Watershed	Gage	Gage Description	HSPF Reach I.D.	Data Availability	Sample Count
Sauk River	**H16067001**	**Lake Osakis Outlet near Osakis**	**30**	**2005–2009**	**1,012**
Sauk River	**H16072001**	**Sauk River Inlet near Little Sauk**	**70**	**2004–2009**	**1,410**
Sauk River	H16036003	Ashley Creek near Sauk Centre	83	2004–2009	742
Sauk River	H16036001	Hoboken Creek at Sauk Centre	87	2004–2009	1,302
Sauk River	**H16044001**	**Sauk River near New Munich**	**190**	**2006–2009**	**946**
Sauk River	H16025001	Getchell Creek near Freeport	241	2007	105
Sauk River	H16023001	Getchel Creek near New Munich	245	2004–2008	1,081
Sauk River	**H16051001**	**Sauk River near St. Martin**	**290**	**2005–2009**	**942**
Sauk River	**H16017001**	**Sauk River near Richmond**	**350**	**2005–2009**	**1,122**
Sauk River	**H16011001**	**Sauk River at Cold Spring**	**420**	**2005–2009**	**1,210**
Sauk River	H16009001	Mill Creek at Rockville	435	2007–2009	687
Sauk River	**E16058004**	**Sauk River near St. Cloud**	**470**	**1995–2009**	**5,479**
North Fork Crow	H18085001	Grove Lake Outlet near Sedan	2	2005–2009	627
North Fork Crow	**H18066001**	**North Fork Crow River near Georgeville**	**70**	**2002–2009**	**1,146**
North Fork Crow	**H18043003**	**North Fork Crow River near Paynesville**	**110**	**2009**	**178**
North Fork Crow	**H18055001**	**North Fork Crow R. near Paynesville**	**140**	**2000–2009**	**1,875**
North Fork Crow	H18024001	Middle Fork Crow River near Spicer	171	2007–2009	376
North Fork Crow	**H18023001**	**Crow River Middle Fork at New London**	**180**	**2003–2005**	**550**
North Fork Crow	**H18023003**	**Middle Fork Crow River near New London**	**190**	**2004–2006**	**507**
North Fork Crow	**H18023002**	**Middle Fork Crow River near New London**	**210**	**2005–2009**	**964**
North Fork Crow	**H18022001**	**Crow River Middle Fork at Spicer**	**220**	**1996–2005**	**1,215**
North Fork Crow	H18034001	Kandiyohi CD26 near Hawick	241	2005–2007	484
North Fork Crow	**H18033001**	**Middle Fork Crow River near Spicer**	**250**	**1997–2009**	**3,792**

Table 1. Discharge Calibration Gages Within the Sauk, North Fork, and South Fork Crow River Watersheds (Page 2 of 3)

Watershed	Gage	Gage Description	HSPF Reach I.D.	Data Availability	Sample Count
North Fork Crow	H18032003	Diamond Lake Outlet near Atwater	282	2009	195
North Fork Crow	**H18053001**	**Middle Fork Crow River near Manannah**	**310**	**2007–2009**	**674**
North Fork Crow	H18054001	Grove Creek near Manannah	325	2008–2009	1,681
North Fork Crow	**H18063001**	**North Fork Crow River near Manannah**	**330**	**2007–2009**	**906**
North Fork Crow	H18052001	Battle Creek near Litchfield	341	2009	134
North Fork Crow	H18051003	Jewitts Creek near Litchfield	345	2009	266
North Fork Crow	H18051001	Jewitts Creek near Litchfield	345	2001–2009	971
North Fork Crow	H18049001	Sucker Creek near Casey	357	2005–2006	301
North Fork Crow	**H18083001**	**North Fork Crow River near Cokato**	**430**	**2001–2009**	**1,671**
North Fork Crow	H18077002	Wright CD10 above Lake Ann nr Howard Lake	471	2007–2009	630
North Fork Crow	H18077001	Lake Ann Outlet near Howard Lake	472	2007–2009	569
North Fork Crow	H18077004	12 Mile Creek near Howard Lake	473	2009	365
North Fork Crow	H18012001	12 Mile Creek near Waverly	485	2001–2009	1,229
North Fork Crow	H18074001	Mill Creek near Buffalo	503	2008–2009	380
North Fork Crow	H18075003	Wright CD31 near Montrose	515	2008–2009	433
North Fork Crow	H18075002	Wright CD31 near Montrose	517	2008–2009	363
North Fork Crow	**H18088001**	**North Fork Crow River near Rockford**	**530**	**2001–2009**	**1,666**
South Fork Crow	H19089001	Kandiyohi CD23A near Willmar	535	2009	174
South Fork Crow	**H19024001**	**South Fork Crow River near Cosmos**	**610**	**2000–2008**	**2,109**
South Fork Crow	**H19049002**	**South Fork Crow River at Hutchinson**	**670**	**2008–2009**	**449**
South Fork Crow	**H19062001**	**South Fork Crow River near Biscay**	**690**	**2002–2008**	**892**
South Fork Crow	H19069001	Buffalo Creek near Lakeside	769	2002–2009	1,646
South Fork Crow	H19056001	Buffalo Creek at Brownton	799	1998–2008	1,963

Table 1. Discharge Calibration Gages Within the Sauk, North Fork, and South Fork Crow River Watersheds (Page 3 of 3)

Watershed	Gage	Gage Description	HSPF Reach I.D.	Data Availability	Sample Count
South Fork Crow	H19073001	Judicial Ditch 15 near Buffalo Lake	789	2002–2009	1,613
South Fork Crow	H19043001	Buffalo Creek near Glencoe	815	1997–2009	2,975
South Fork Crow	**H19082001**	**South Fork Crow River near Mayer**	**850**	**1998–2009**	**2,808**
South Fork Crow	**H19001001**	**South Fork Crow River at Delano**	**910**	**1999–2009**	**3,117**
North Fork Crow	**E18087001**	**Crow River at Rockford**	**950**	**1995–2009**	**5,479**

CALIBRATION AND VALIDATION TIME PERIODS

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. As discussed in Love [2011], separate user control inputs (UCIs) were created to represent land use changes: one UCI represents 1995 through 2003 using National Land Cover Data (NLCD) 2001 land use data and the other represents 2004 through 2009 using NLCD 2006 land use data. Because the majority of the available sites have discharge between 2004 and 2009, the primary calibration period will be 2004 to 2009 (based on NLCD 2006 land use data), and the validation period will be from 1996 to 2003 (based on NLCD 2001 land use data). The initial year (1995) will be simulated to let the model adjust to existing conditions. The available flow data indicates that long-term (at least 5 years) calibration can be performed using data from 8 Sauk River gages and 14 North and South Fork Crow River gages. Long-term validation can be performed using data from one Sauk River gage and seven North and South Fork Crow River gages using the 1996 to 2003 simulation period as the validation period. Maintaining a consistent calibration of the model application using multiple gages and representing variability of parameters throughout the watershed is in itself a form of validation.

STANDARD HYDROLOGIC CALIBRATION

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

- **Establish an annual water balance.** This consists of comparing the total annual simulated and observed flow (in inches) and is governed by the input (rainfall and evaporation), the listed parameters (lower zone nominal storage (LZSN), lower zone evapotranspiration parameter (LZETP), deep groundwater recharge losses (DEEPFR), and infiltration index (INFILT)), and the factor applied to pan evaporation to calculate potential evapotranspiration (ET).

- **Make seasonal adjustments.** Differences in the simulated and observed total flow over summer and winter are compared to see if runoff 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, and LZETP. LZETP will vary greatly by land use, especially during summer months, because of evapotranspiration differences. Adjustments to KVARY (variable groundwater recession) and BASETP (baseflow ET index) as well as snow accumulation and melt parameters are also used.
- **Adjust low flow/high flow distribution.** This phase compares high and low flow volumes using flow percentile statistics and flow duration curves. This component is generally affected by adjusting parameters such as INFILT, AGWRC (groundwater recession), and BASETP.
- **Adjust storm flow/hydrograph shape.** The storm flow, which is largely composed of surface runoff and interflow, is compared using daily and hourly hydrographs. Adjustments are made to the UZSN (upper zone storage), INTFW (interflow parameter), and IRC (interflow recession). INFILT can also be adjusted slightly.

Monthly variation in the CEPSC and LZETP parameters will initially be applied to all PERLND categories. Monthly variation in UZSN, NSUR, INTFW, and IRC parameters will initially be applied to cropland categories with the capability of adding additional categories if necessary for improving model performance.

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

Land cover and soil properties typically represent most of the variability in the hydrologic responses of a watershed; thus, they were the basis for estimating initial hydrologic parameters, along with parameter values used in previous Minnesota model applications. 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 (i.e., crops, pasture, or open) and associated characteristics. Soil properties primarily affect infiltration, interflow, and soil storage parameters. **HSPF** model categories were developed based on the aggregation of the existing land use and hydrologic soil group classifications into representative hydrologic areas.

Initial parameter estimates and their relative variances between land segment categories are crucial to maintaining appropriate representation of the hydrologic components. Engineering judgment is used to adjust parameters congruently within land segment categories during calibration because of their diversity and spatial distribution within the watershed. It is difficult to isolate each discrete category during calibration to justify deviations from initial estimated intra-parameter variations within land segments because of the detailed classification of land segments and spatial availability of observed data.

INITIAL SNOW ACCUMULATION AND MELT CALIBRATION

Snow accumulation and melt is a significant element of hydrology in Minnesota because the climate is generally cold, dry, and windy. Thus snow simulation is an integral part of the hydrology calibration, especially during the winter and spring, and it 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 (air temperature, solar radiation, wind, and dew point temperature) along with a suite of adjustable parameters. Initial values for TSNOW (the wet bulb air temperature below which precipitation occurs as snow under saturated conditions), CCFACT (the factor to adjust the rate of heat transfer from the atmosphere to the snowpack because of condensation and convection), MGMELT (the maximum rate of snowmelt by ground heat), SNOEVP (the factor to adjust evaporation/sublimation from the snowpack), and MWATER (the maximum rate of snowmelt by ground heat) will be attained from previous **HSPF** applications in Minnesota and will be adjusted as necessary. The initial snow parameter calibration will be supported using comparisons of observed and simulated snowfall and snow depth data to verify reasonable representation of snow accumulation and melt processes. However, detailed calibration of snow parameters will be based more heavily on comparisons of observed and simulated flow data during the standard hydrologic calibration process. Observed snowfall and depth data were downloaded from the Minnesota Climatology Working Group retrieval system website (*www.climate.umn.edu/ hidradius/radius.asp*) for three locations in the Sauk River Watershed and five locations in the Crow River watershed. Figure 2 shows examples of the calibration figures constructed to compare observed snowfall to simulated snowfall (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 as well as to verify 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 a majority of the lakes to be modeled, and it can be used for comparison to simulated lake levels. The initial lake level calibration, which was completed as an early portion of the hydrology calibration, involved adjusting the reference outlet elevations to 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 3 shows an example of the calibration figures constructed for the comparison of observed lake level data and simulated lake level. Storm hydrographs will also be used to

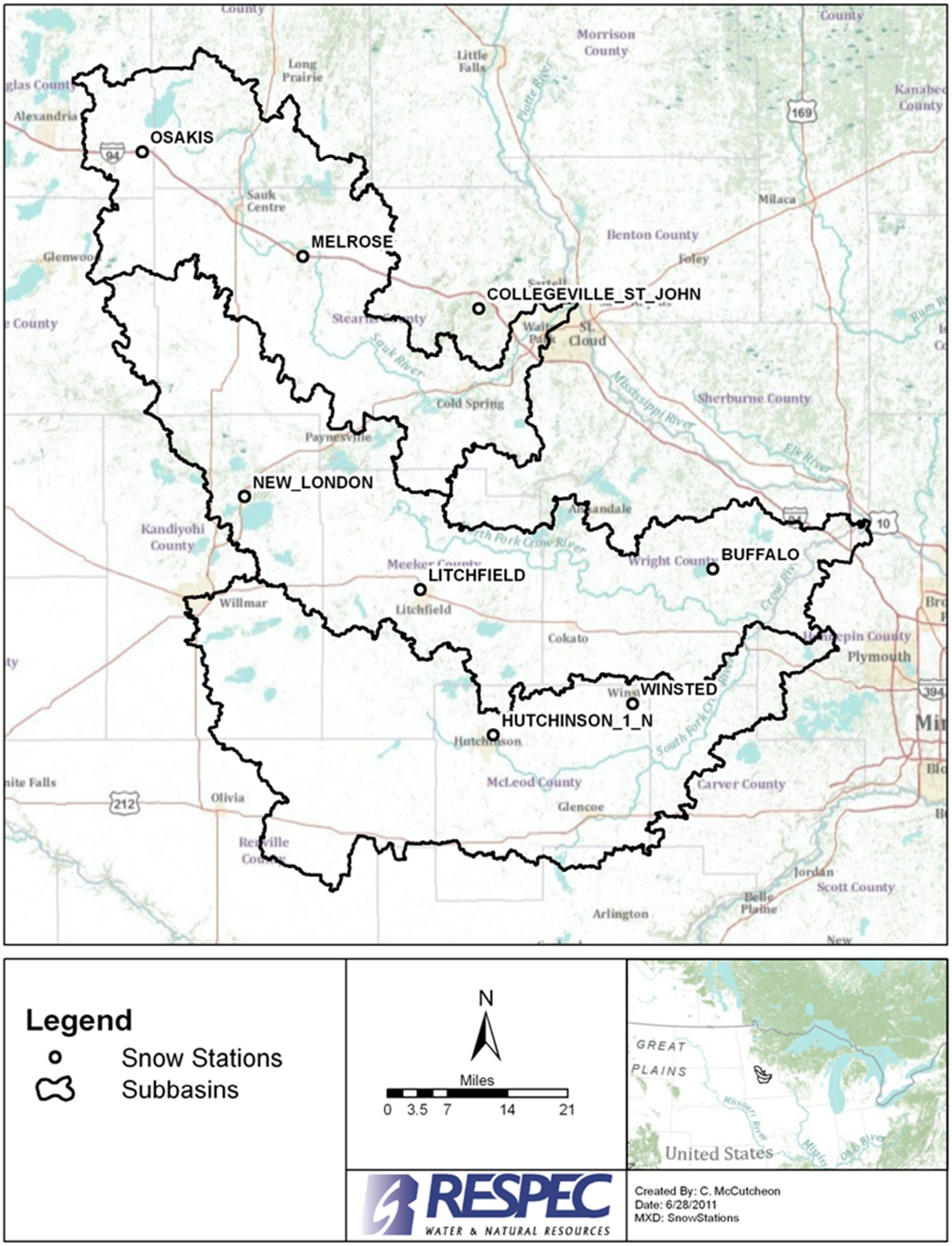


Figure 2. Map of Meteorological Stations With Snow Data Used for Calibration.

calibrate lake F-tables to represent flow attenuation throughout the watershed. In cases where multiple lakes are represented as one F-table, simulated lake levels cannot be 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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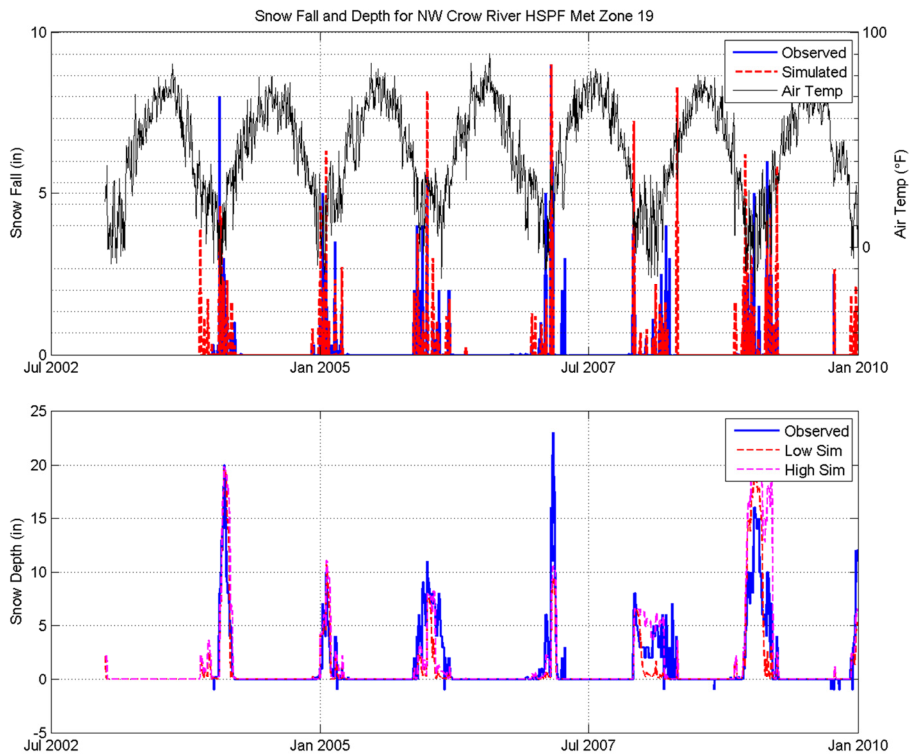

Figure 3. Snow Level (Top) and Snow Depth (Bottom) Calibration Figures.

WEIGHT OF EVIDENCE APPROACH

Model performance will be evaluated 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 will be integrated into the hydrologic calibration to continuously evaluate model results to efficiently improve calibration performance until there is no apparent improvement from further parameter adjustment. This process is performed at each flow gage by adjusting parameters for land segments upstream. Moreover, greater weight will be applied to the performance of the model at gages where there is more contributing area and a longer period of record. It is also desired to maintain comparable parameter values and intra-parameter variations for each land segment category throughout the watershed. The specific model-data comparisons of simulated and observed values for the calibration period are grouped below with their associated phase of the standard hydrologic calibration.

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

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

Annual and monthly plots will be used to visually compare runoff volumes over the contributing area. This method includes transferring the amount of flow measured at a gage to an amount of water in inches over the entire contributing area to normalize the data and create a more realistic picture. Monthly plots help to verify the model's ability to capture the variability in the runoff between the watersheds and also verify that the snowfall/snowmelt processes are simulated accurately. Average yearly plots help to verify that the annual water balances are reasonable and also allow trends to be considered. Flow frequency curves, or flow duration curves, will be used to characterize the flow conditions under which flows are occurring. The flow duration curve presents 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 which parameters to adjust to better fit the data. Daily flow time-series plots will allow observations of individual storm events to be analyzed as well the snow accumulation/melt processes and the baseflow trends. Examples of daily flow time-series plots, monthly plots, annual plots, and flow duration curves which will be used for the calibration/validation process are shown in Figures 4 through 7, respectively.

In addition to the above comparisons, the water balance components of watershed hydrology will be reviewed. The review of the water balance involves 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**
- **Total Actual ET (sum of following components)**
  - – Interception ET
  - – Upper zone ET
  - – Lower zone ET
  - – Baseflow ET
  - – Active groundwater ET
- Deep Groundwater Recharge/Losses.

Although observed values are not available for each of the water balance components listed above, the average annual values must be consistent with expected values for the region, as impacted by the individual land use and soil group categories. If you know of a document for Minnesota that would contain this sort of information, please email the document to RESPEC.

MODEL PERFORMANCE CRITERIA

The calibration parameters will be adjusted to improve the performance of the model until the desired performance criteria are met or there is no apparent improvement from parameter refinement. The graphical plots will be visually evaluated to objectively assess the model performance while the statistics will be compared to objective criteria developed from 20 years of experience with **HSPF** applications. The percent error statistics will be evaluated with the hydrology criteria in Table 2. The correlation coefficient (r) and coefficient of determination (r^2) will be compared with the criteria in Figure 8 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 the decision to accept or reject the model application. The developed performance criteria are explained in detail in Donigian [2002].

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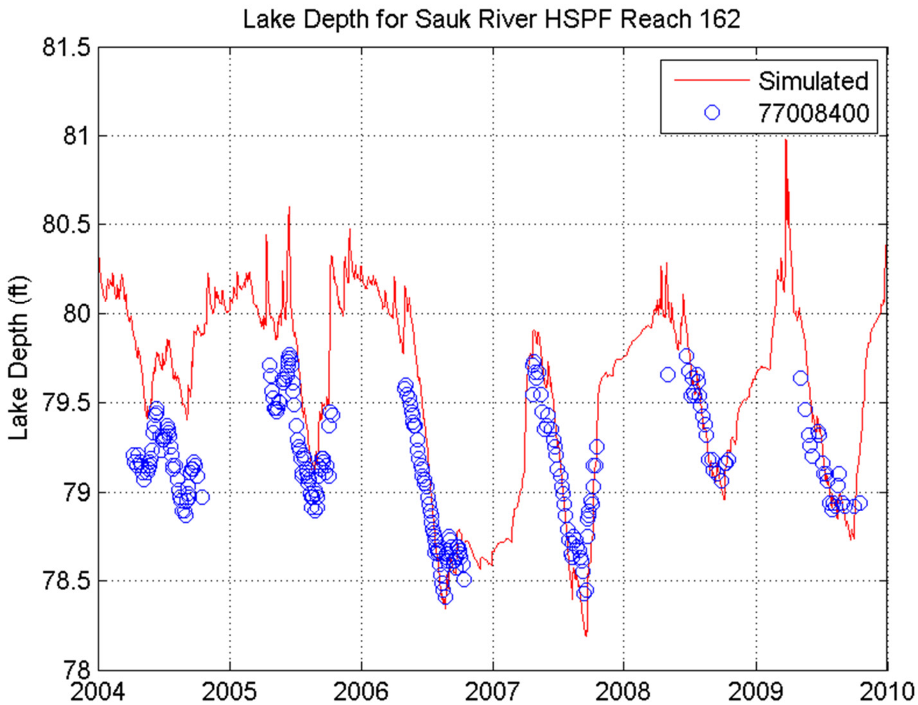

Figure 4. Lake Level Calibration.

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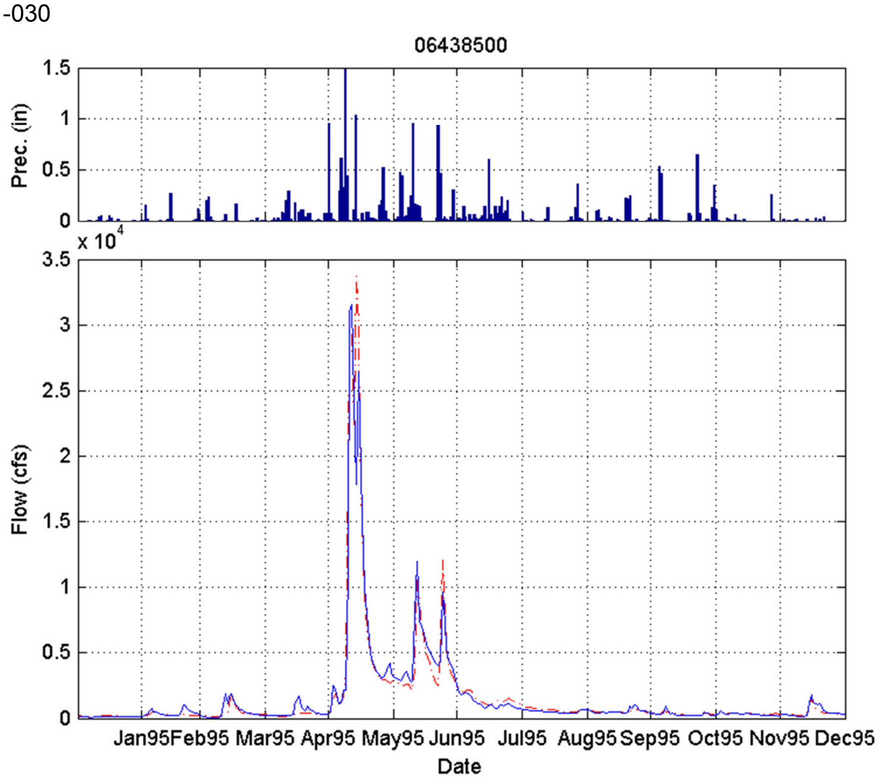

Figure 5. Daily Flow Timeseries Plot Example.

RSI-1953-11-031

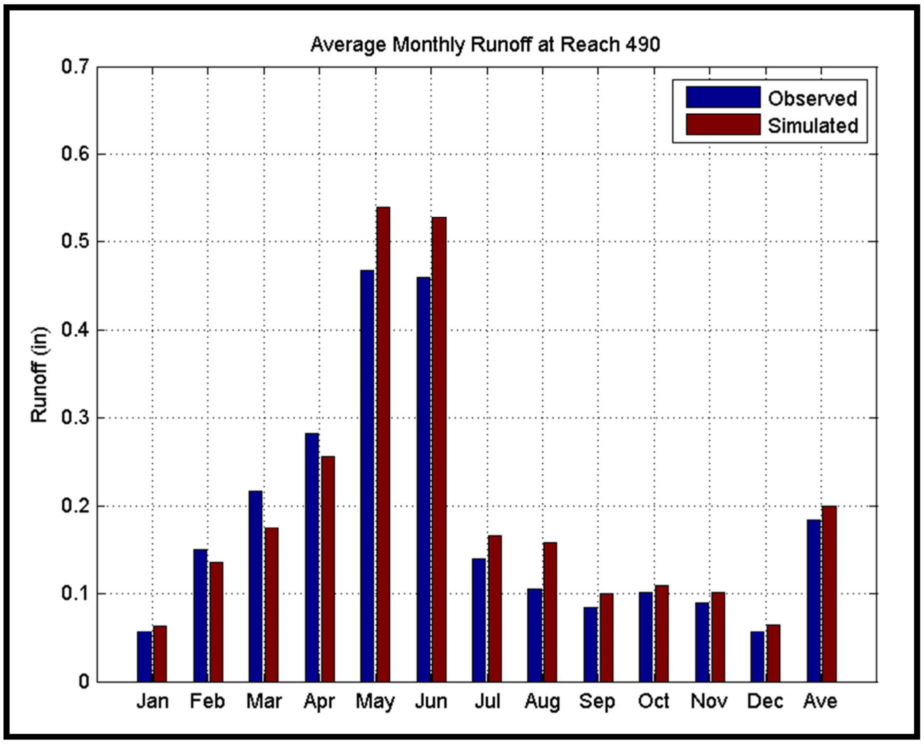

Figure 6. Average Monthly Runoff Plot Example.

RSI-1953-11-032

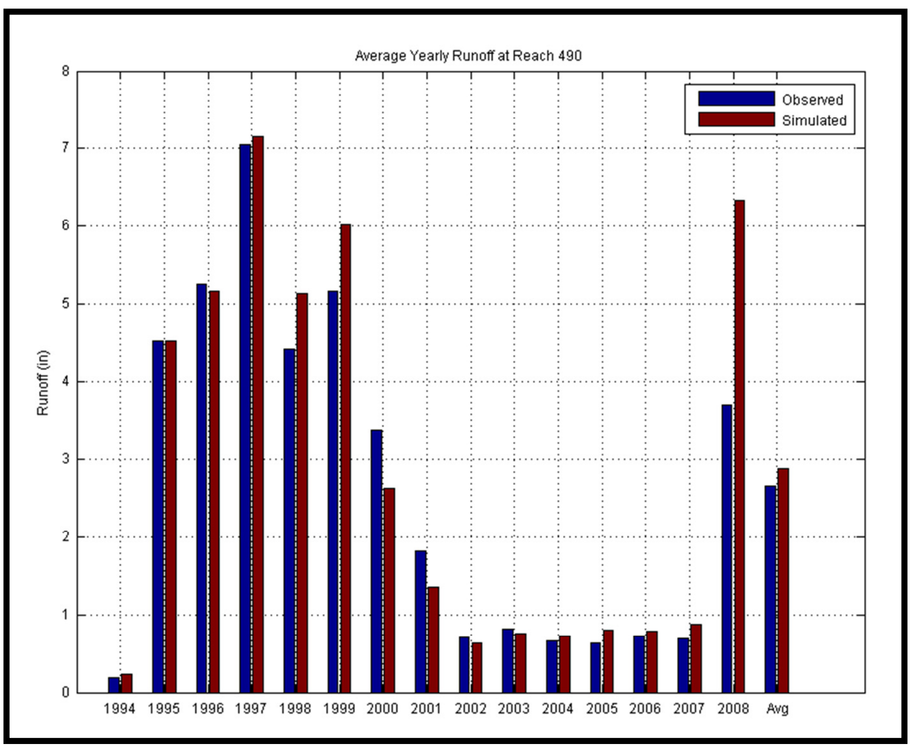

Figure 7. Average Yearly Runoff Plot Example.

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, personnel).

Source: Donigian [2000].

RSI-1737-09-008

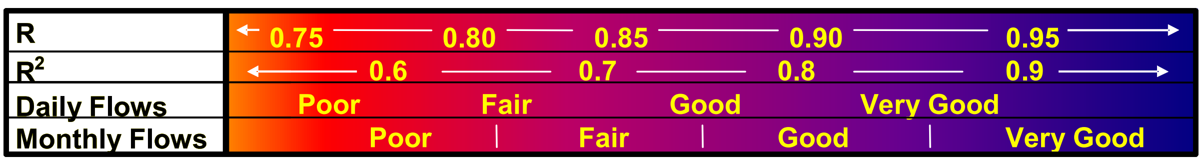

Figure 8. General Calibration/Validation R and R^2 Targets for HSPF Applications.

Once the specifications document is developed, RESPEC will evaluate the reasonableness of criteria and work to the maximum extent practicable to achieve agreed upon criteria.

INITIAL CALIBRATION RESULTS

The initial calibration was performed using the primary downstream gages for the Sauk and Crow Watershed model applications. Secondary gages upstream and on tributaries were used to help calibrate parameters for less influential land segment categories. A map of the primary discharge gages from initial calibration results is shown in Figure 9. Tables 3 and 4 have the overall assessment criteria for the Sauk and Crow model applications respectively. The overall statistics are based on drainage area and time period weighted average of the primary calibration gage statistics. Table 5 summarizes the weighted water balance components at the outlets of the Sauk and Crow Watershed model applications. Appendix A contains initial calibration figures for the primary gages in the Sauk Watershed. Appendix B contains initial calibration figures for the primary gages in the North and South Fork Crow River Watersheds. The DVD provided with this memorandum provides the full suite of calibration figures and tables for all sites investigated as part of the initial calibration.

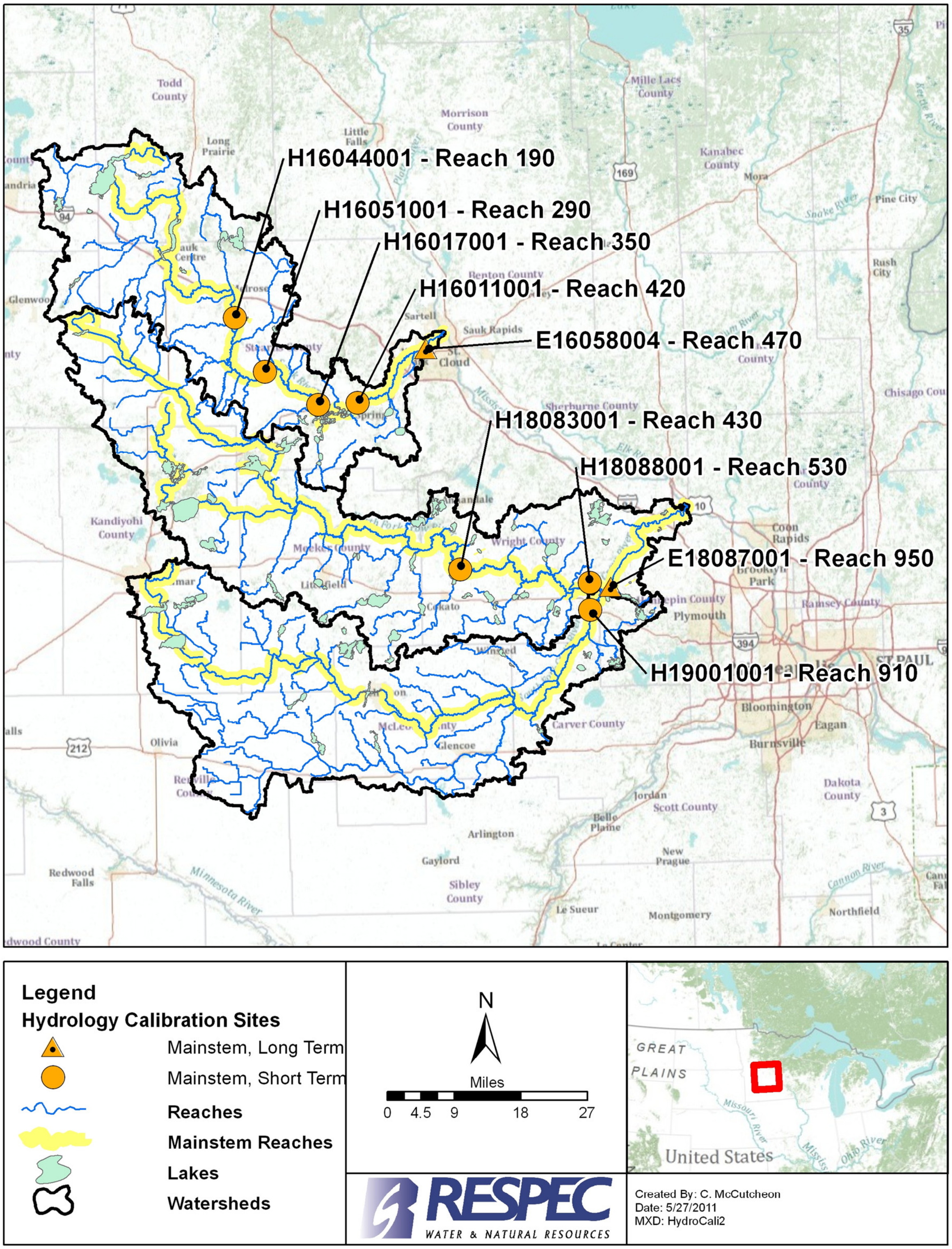

Figure 9. Map of Primary Gages for Initial Calibration.

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

Observed Flow Gage	HSPF Reach I.D.	Total Runoff Volume			Monthly			Daily			Storm % Error	
		Obs (in)	Sim (in)	% •	*R*	R^2	MFE	*R*	R^2	MFE	Volume	Peak
H16044001	190	3.91	4.01	2.4	.93	.86	.82	.90	.82	.70	–2.8	–2.5
H16051001	290	3.30	3.39	2.6	.91	.84	.83	.86	.74	.65	2.3	–0.8
H16017001	350	4.16	4.01	–3.5	.94	.89	.86	.92	.85	.84	–5.6	–18
H16011001	420	4.22	4.12	–2.3	.96	.92	.92	.94	.89	.89	–2.9	–1.8
E16058004	470	4.95	5.05	2.05	.95	.90	.89	.94	.89	.88	2.4	4.6
Weighted Overall		4.18	4.18	0.12	.94	.89	.87	.92	.84	.81	–1.13	–3.29

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

Observed Flow Gage	HSPF Reach I.D.	Total Runoff Volume			Monthly			Daily			Storm % Error	
		Obs (in)	Sim (in)	% •	*R*	R^2	MFE	*R*	R^2	MFE	Volume	Peak
H18083001	430	3.35	4.01	–0.86	.96	.93	.91	.91	.84	.82	–3.7	–0.07
H18088001	530	3.60	3.44	–4.65	.91	.83	.82	.93	.86	.86	–5.7	–10.9
H19001001	910	4.21	4.10	–2.77	.92	.85	.85	.84	.71	.69	–7.74	6.2
E18087001	950	5.00	4.90	–1.8	.96	.92	.92	.93	.86	.86	–4.1	–7.7
Weighted Overall		4.28	4.29	–2.4	.94	.90	.89	.92	.85	.82	–5.1	–4.2

Multiple differences exist between the Crow and Sauk Watersheds which require differences in the parameterization of these watersheds. A larger number of lakes and wetlands exist in the Sauk Watershed than in the Crow Watershed. The higher surface water area increases the volume of upper zone evapotranspiration (UZET), there is more riparian forest area in the Sauk which has the potential to increase the baseflow evapotranspiration (BASET) in the model application, and the area of land drained by tile drainage is larger in the Crow Watershed than it is in the Sauk Watershed. The large amount of artificial drainage decreases the surface outflow (SURO) volume in the Crow Watersheds. Similarly, the lower zone evapotranspiration (LZET) will be higher in the artificially drained watershed because water is being transferred to the lower zone.

REFERENCES

Donigian, Jr., A. S., 2000. ***HSPF*** *Training Workshop Handbook and CD*, Lecture #19: Calibration and Verification Issues, Slide #L19-22, EPA Headquarters, Washington Information Center, presented to and prepared for U.S. EPA, Office of Water, Office of Science and Technology, Washington, D.C., January 10–14.

Table 5. Summary of Water Balance Component Volumes

Water Balance Component	Water Balance Component Description	Sauk Watershed Weighted Volume (in)	Crow Watershed Weighted Volume (in)
SUPY	Water supply to soil surface	26.94	28.50
SURO	Surface outflow	0.24	0.09
IFWO	Interflow outflow	1.77	1.08
AGWO	Active groundwater outflow	3.17	4.35
PERO	Total outflow from pervious land	5.18	5.52
IGWI	Inflow to inactive groundwater	0.10	0.23
AGWI	Active groundwater inflow	3.46	4.60
PET	Potential evapotranspiration	36.78	37.54
CEPE	Evaporation from interception storage	5.20	5.30
UZET	Evapotranspiration from upper zone	7.38	4.94
LZET	Evapotranspiration from lower zone	8.66	11.79
AGWET	Evapotranspiration from active groundwater storage	0.01	0.13
BASET	Evapotranspiration from active groundwater outflow (baseflow)	0.23	0.11
TAET	Total simulated evapotranspiration	21.47	22.27

Donigian, A. S., Jr.; J. C. Imhoff; B. R. Bicknell; and J. L. Kittle, Jr., 1984. *Application Guide for the **Hydrological Simulation Program–FORTRAN***, EPA 600/3-84-066, Environmental Research Laboratory, U.S. Environmental Protection Agency, Athens, GA.

Donigian, Jr., A. S. 2002. "Watershed Model Calibration and Validation: The ***HSPF*** Experience," *WEF National TMDL Science and Policy 2002*, Phoenix, AZ, November 13-16.

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

Lumb, A. M.; R. B. McCammon; and J. L. Kittle, Jr., 1994. *Users Manual for an Expert System (HSPEXP) for Calibration of the **Hydrological Simulation Program-FORTRAN***, U.S. Geological Survey Water Resources Investigations Report 94-4168, U.S. Geological Survey,Reston, VA.

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

Sincerely,

Jason T. Love
Vice President, Water & Natural Resources

JTL:llf

cc: Project Central File 1953 — Category A

APPENDIX A
INITIAL CALIBRATION RESULTS AT PRIMARY GAGES
FOR THE SAUK WATERSHED MODEL

RSI-1975-11-034

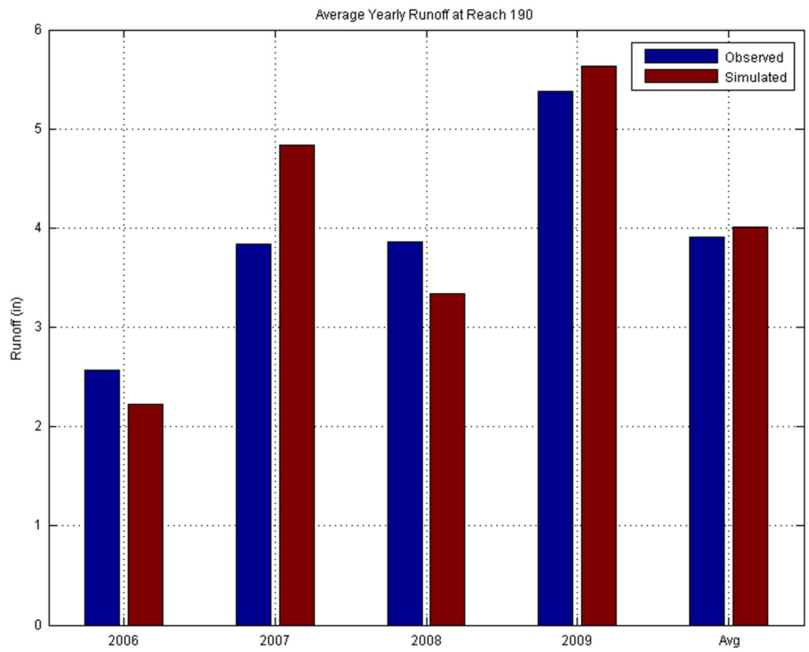

Figure A-1. Average Yearly Runoff at Reach 190.

RSI-1953-11-035

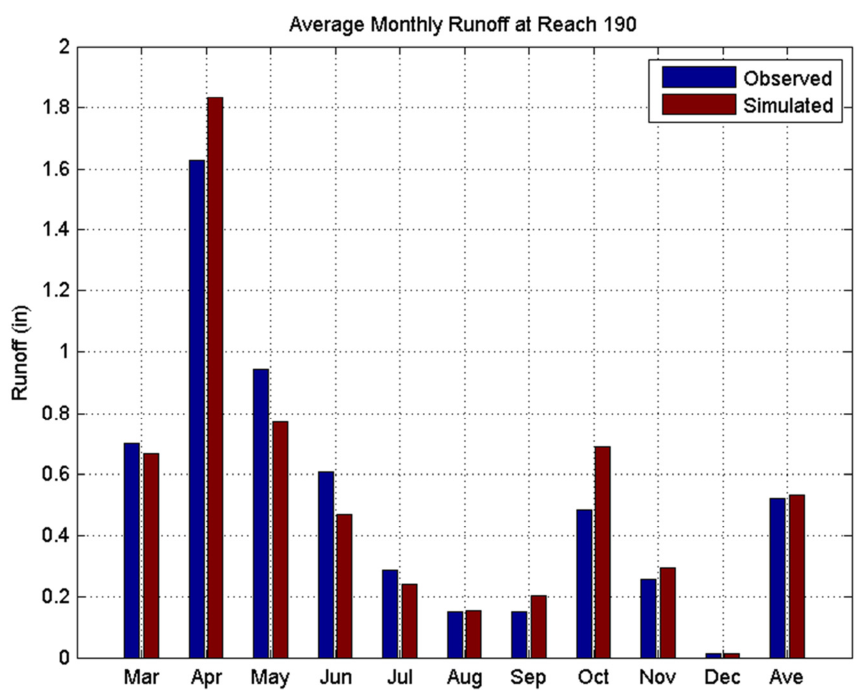

Figure A-2. Average Monthly Runoff at Reach 190.

RSI-1953-11-036

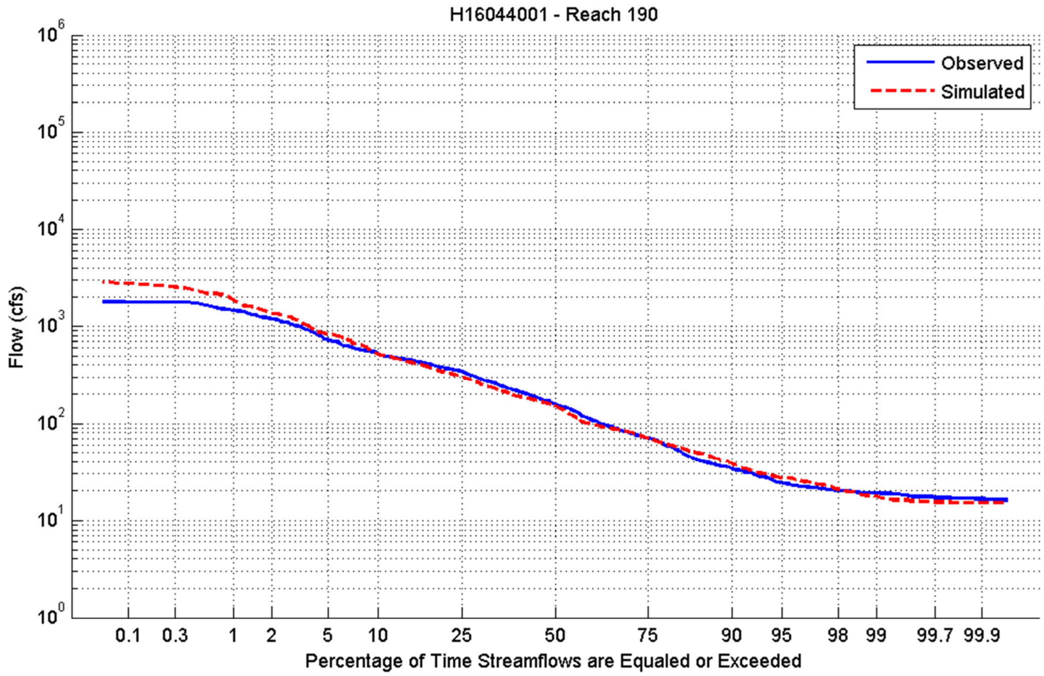

Figure A-3. Flow Duration Plot for Reach 190.

RSI-1953-11-037

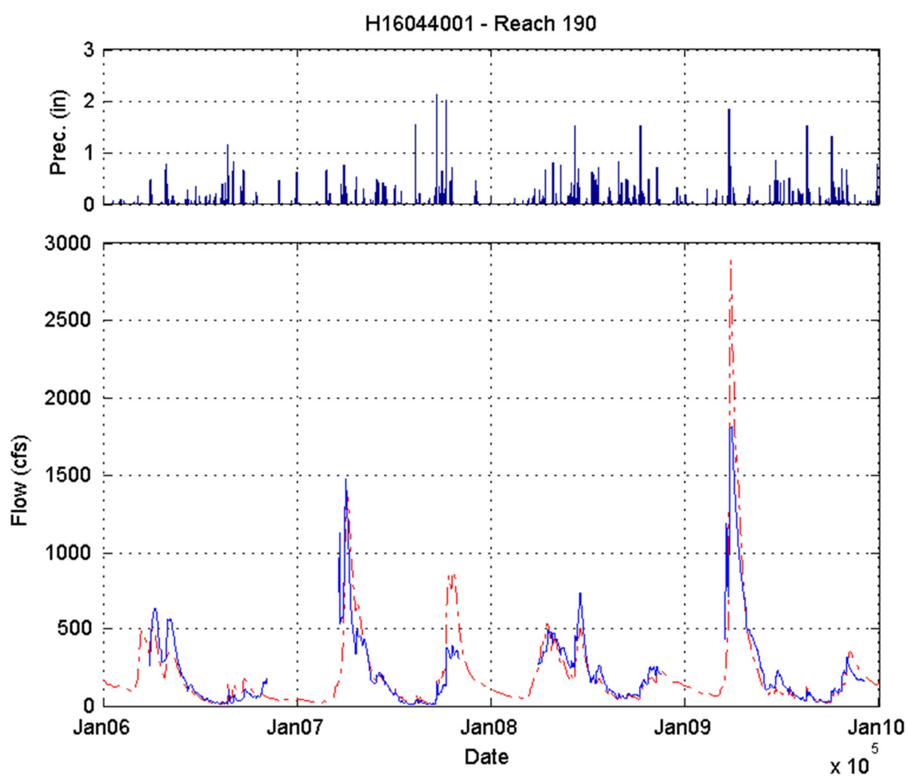

Figure A-4. Daily Hydrographs for Reach 190.

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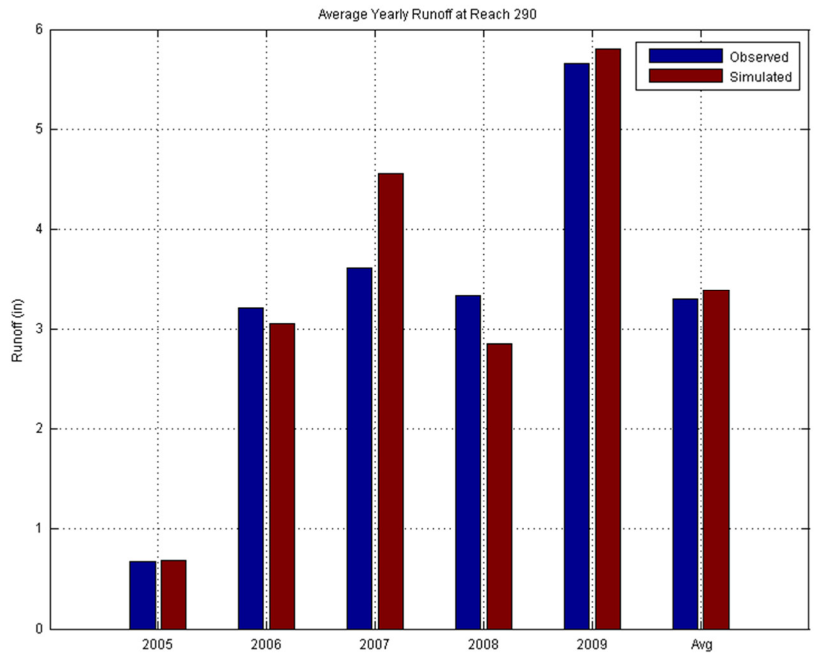

Figure A-5. Average Yearly Runoff at Reach 290.

RSI-1953-11-039

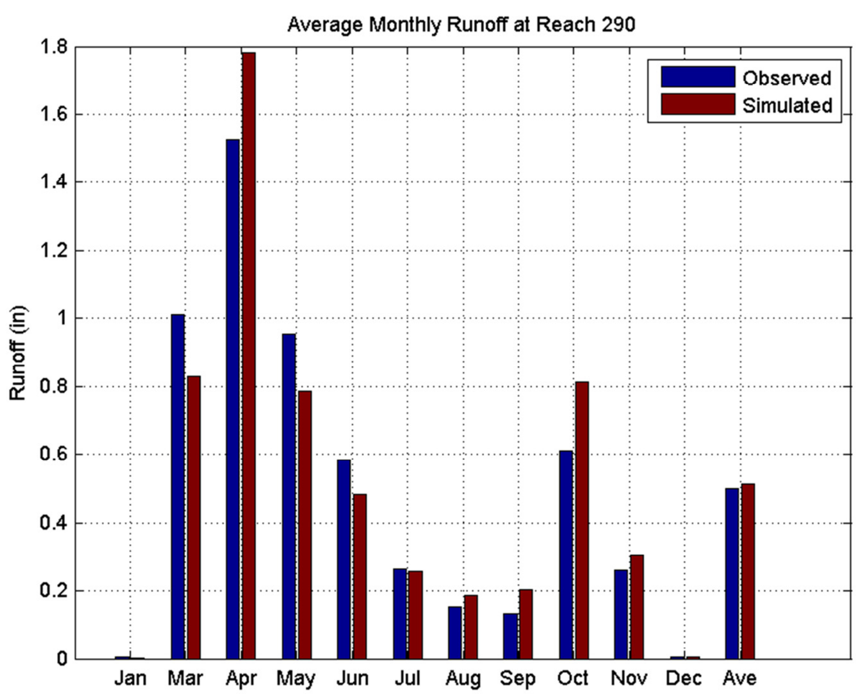

Figure A-6. Average Monthly Runoff at Reach 290.

RSI-1953-11-040

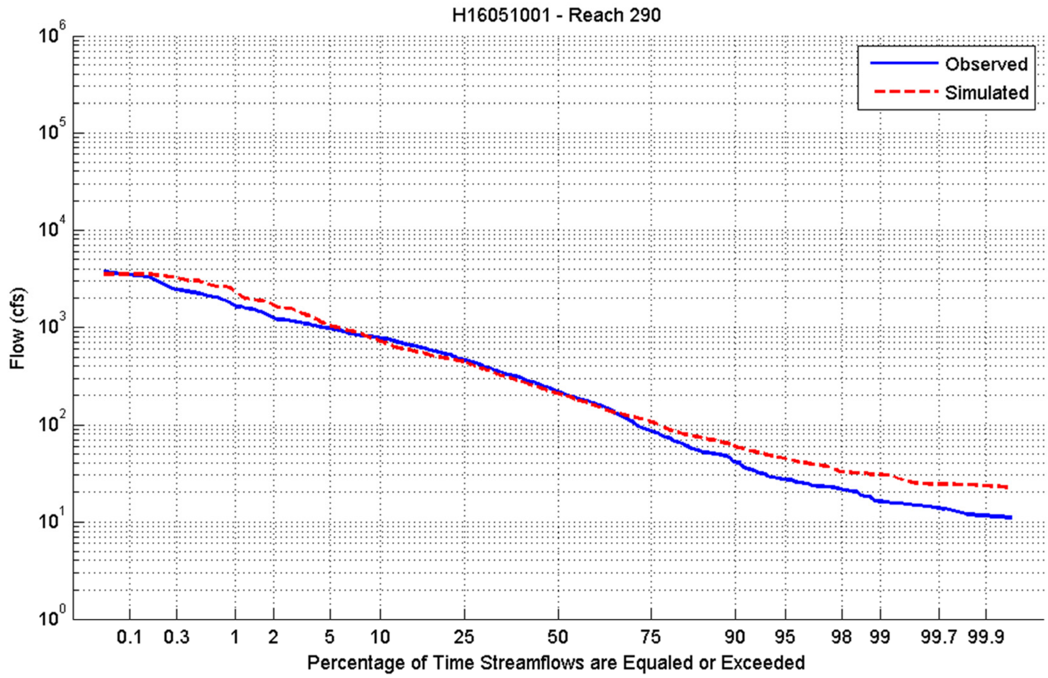

Figure A-7. Flow Duration Plot for Reach 290.

RSI-1953-11-041

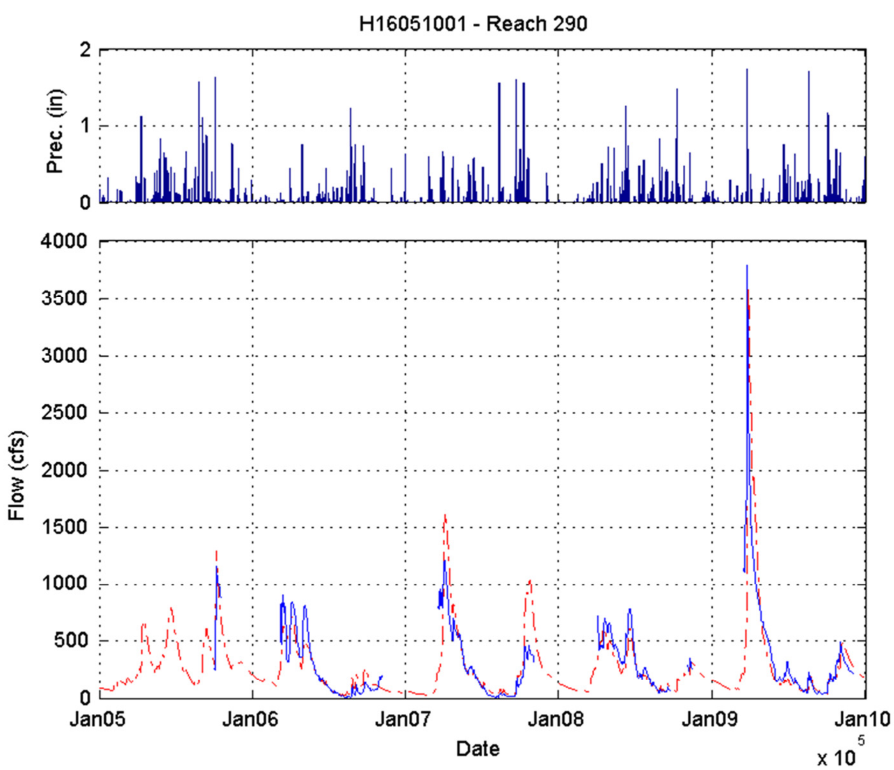

Figure A-8. Daily Hydrographs for Reach 290.

RSI-1953-11-042

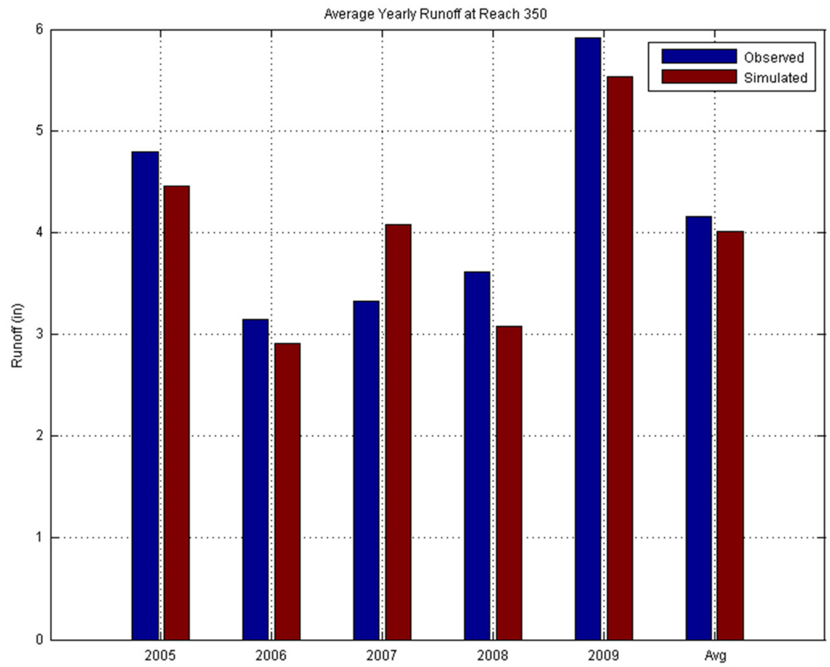

Figure A-9. Average Yearly Runoff at Reach 350.

RSI-1953-11-043

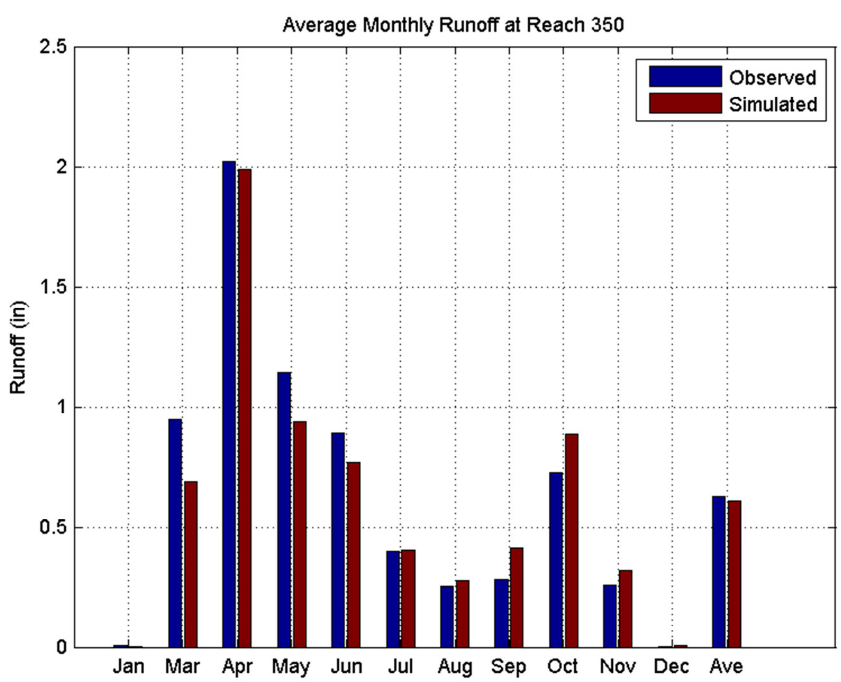

Figure A-10. Average Monthly Runoff at Reach 350.

RSI-1953-11-044

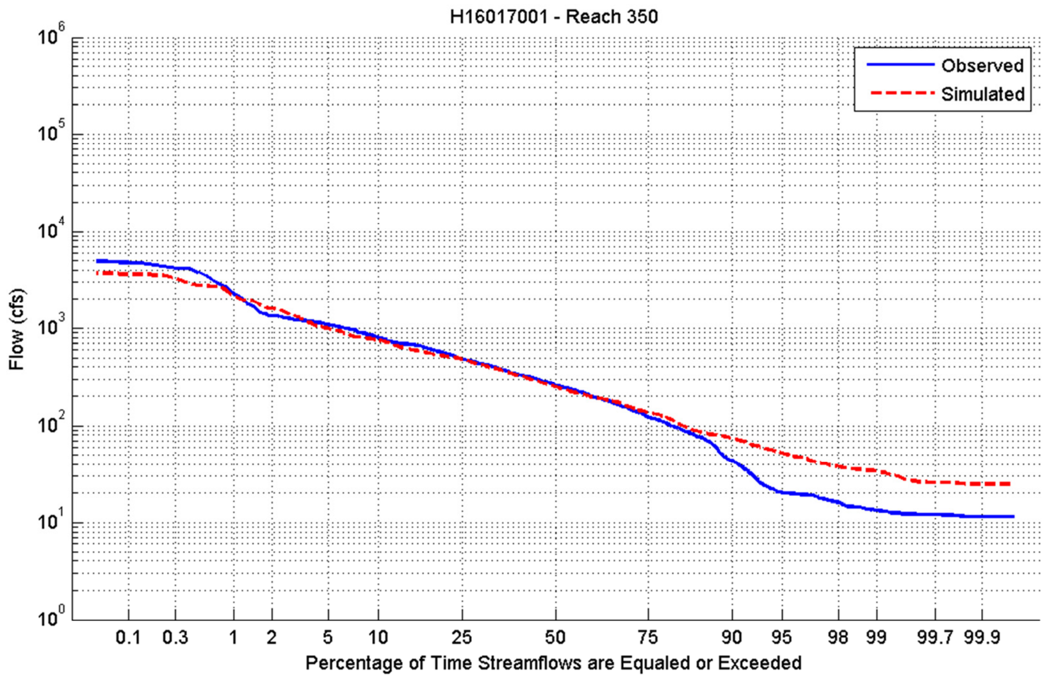

Figure A-11. Flow Duration Plot for Reach 350.

RSI-1953-11-045

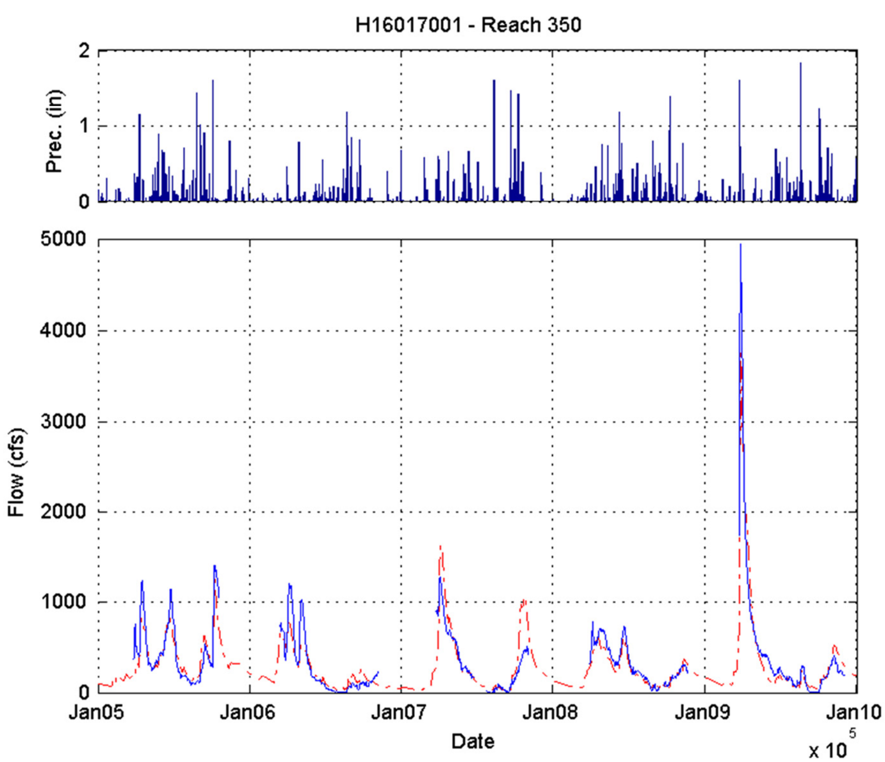

Figure A-12. Daily Hydrographs for Reach 350.

RSI-1953-11-046

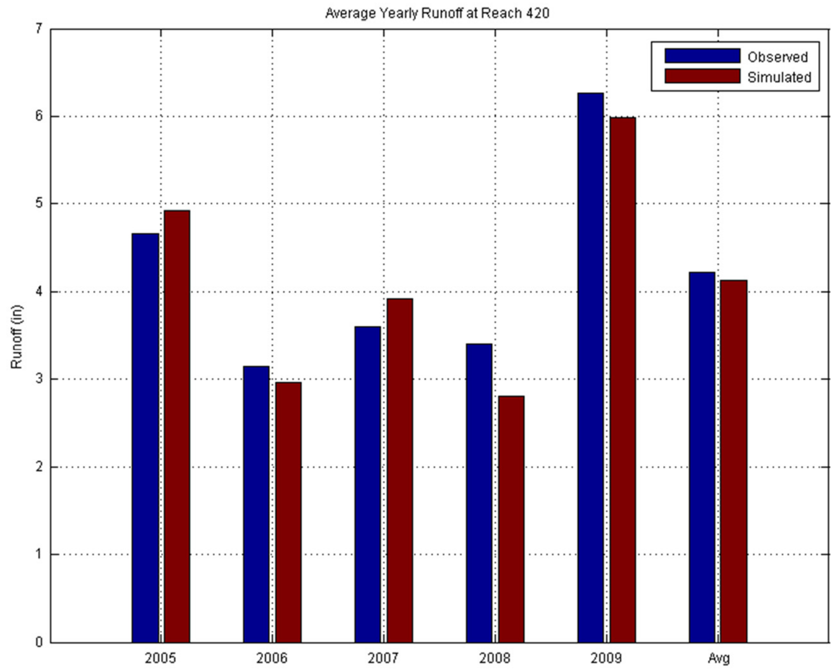

Figure A-13. Average Yearly Runoff at Reach 420.

RSI-1953-11-047

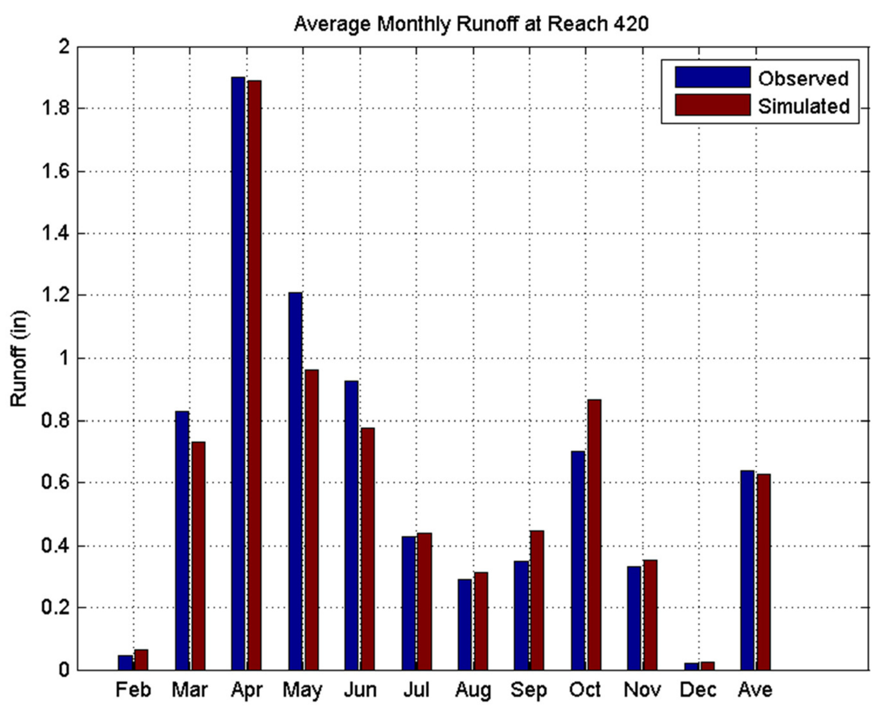

Figure A-14. Average Monthly Runoff at Reach 420.

RSI-1953-11-048

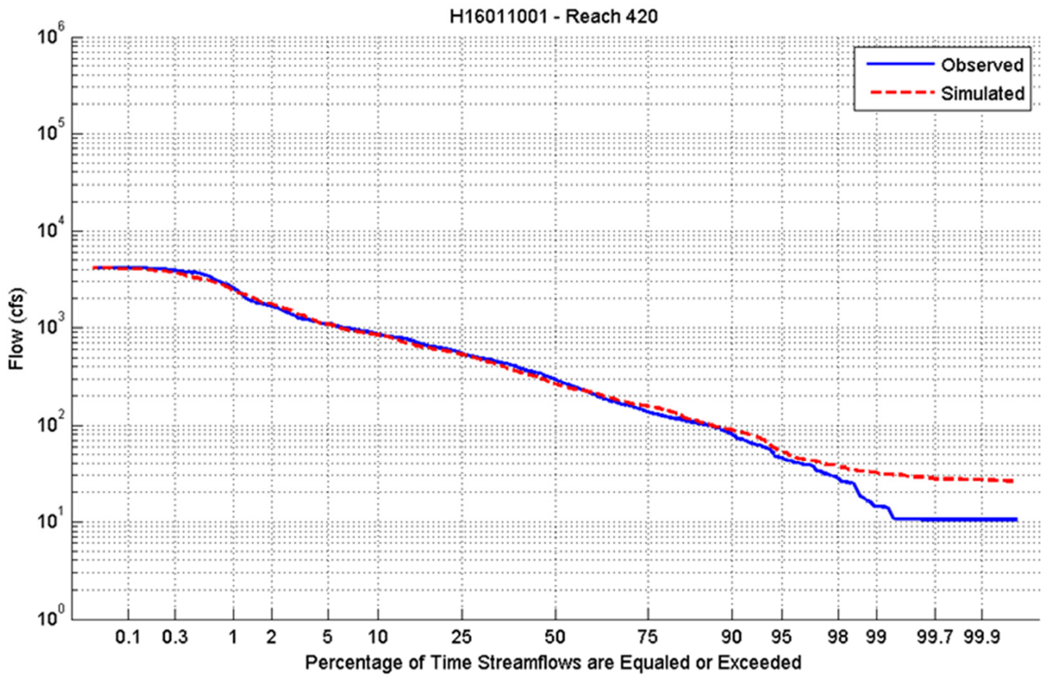

Figure A-15. Flow Duration Plot for Reach 420.

RSI-1953-11-049

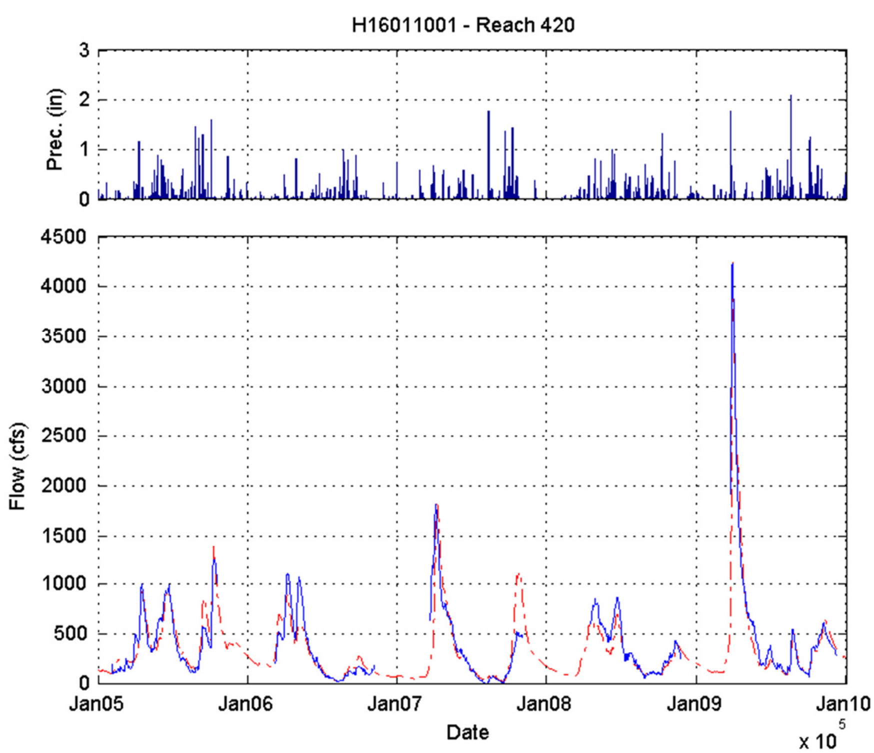

Figure A-16. Daily Hydrographs for Reach 420.

RSI-1953-11-050

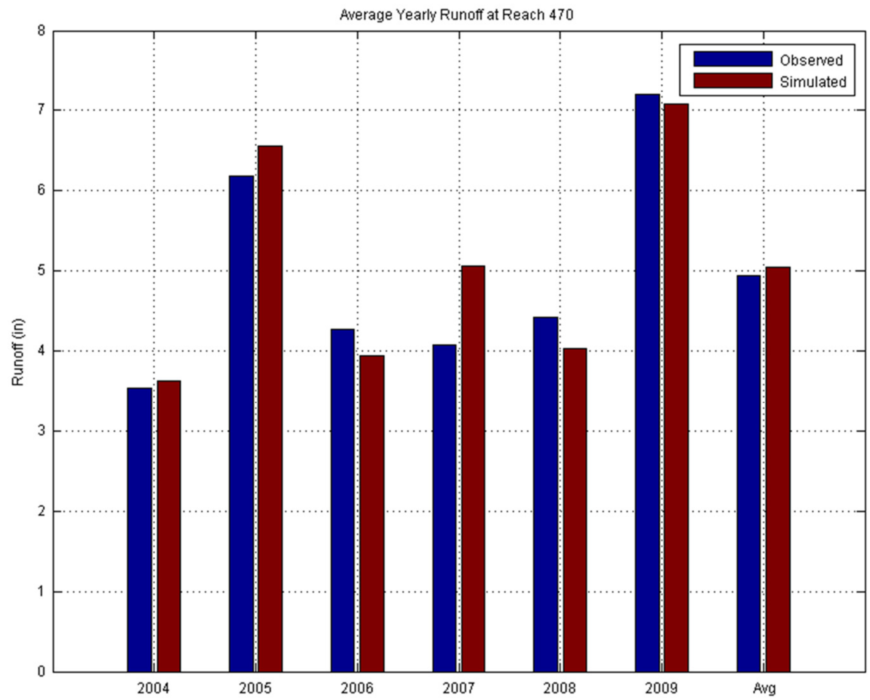

Figure A-17. Average Yearly Runoff at Reach 470.

RSI-1953-11-051

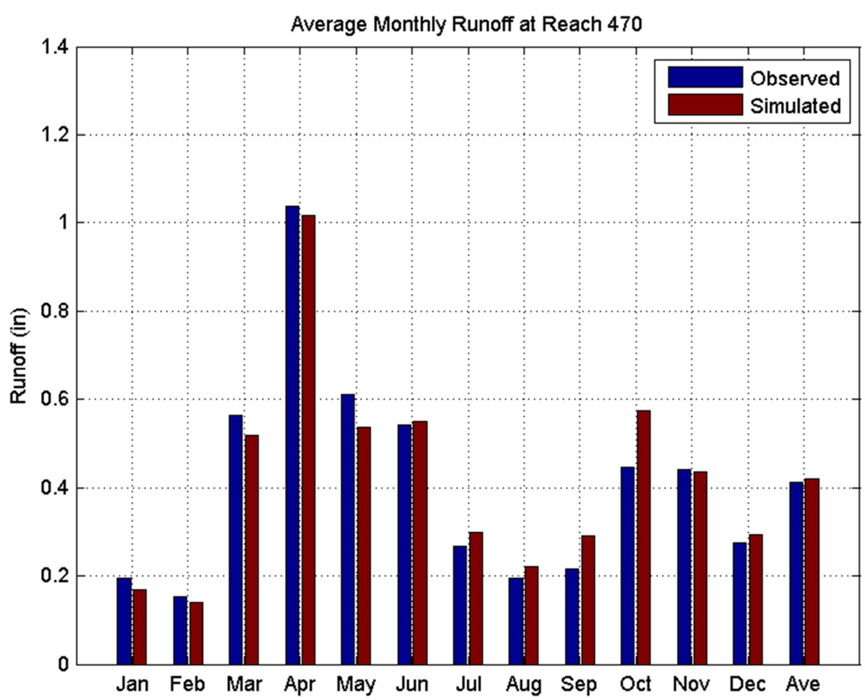

Figure A-18. Average Monthly Runoff at Reach 470.

RSI-1953-11-052

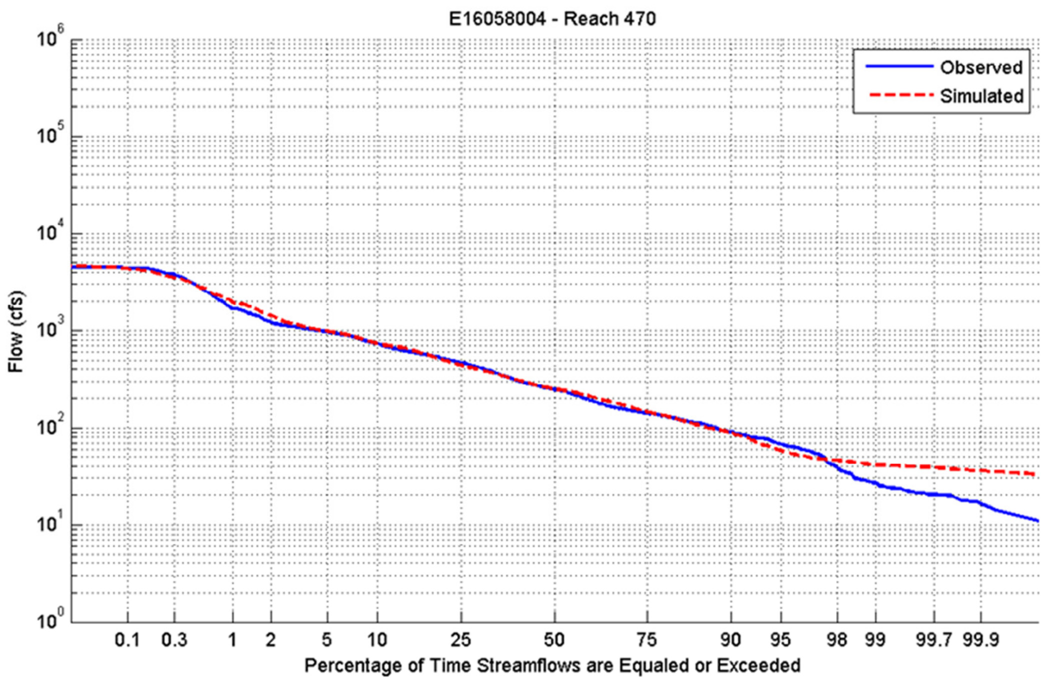

Figure A-19. Flow Duration Plot for Reach 470.

RSI-1953-11-053

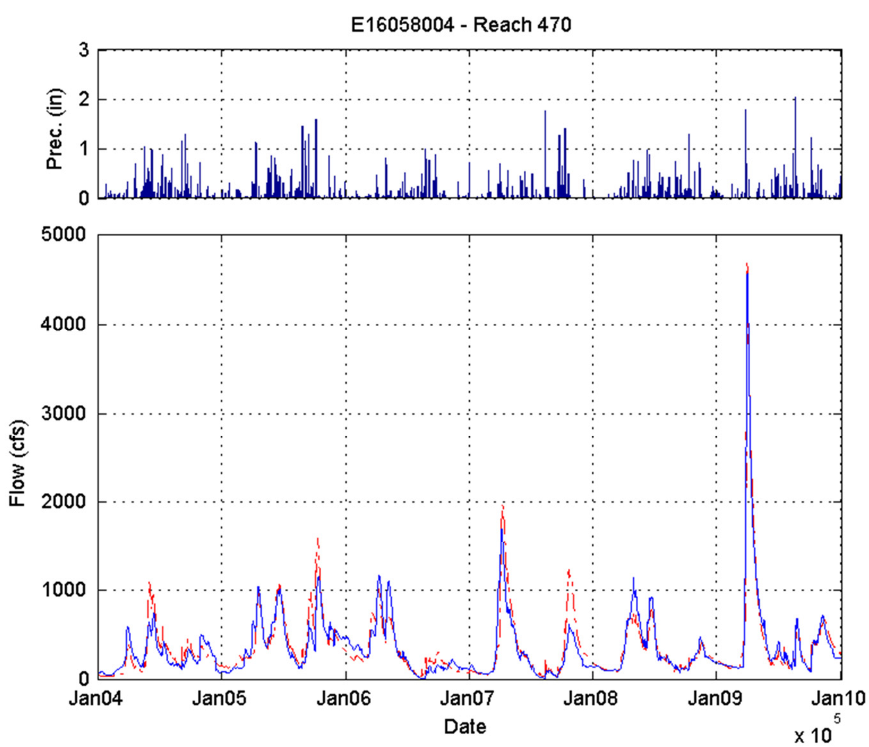

Figure A-20. Daily Hydrographs for Reach 470.

APPENDIX B
INITIAL CALIBRATION RESULTS AT PRIMARY GAGES FOR THE CROW WATERSHED MODEL

RSI-1953-11-054

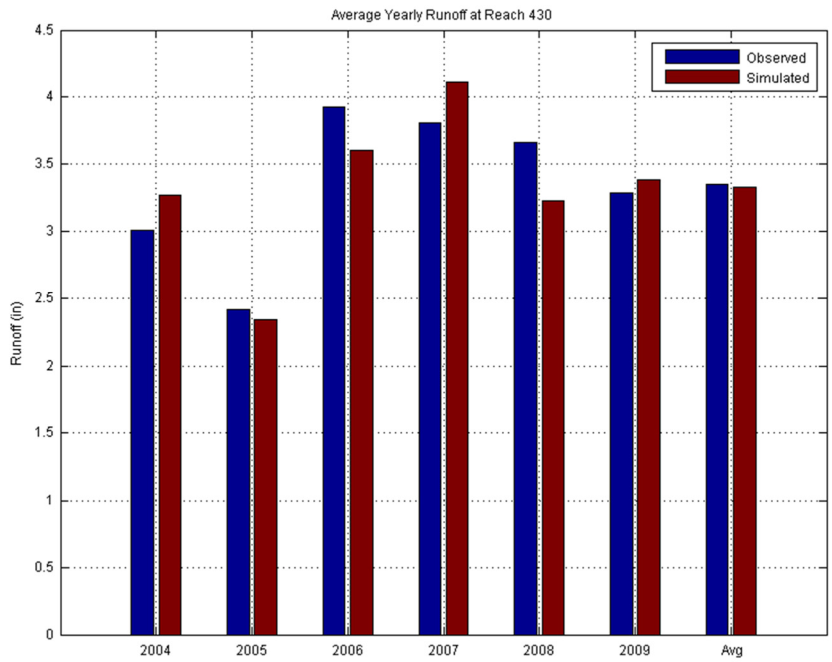

Figure B-1. Average Yearly Runoff at Reach 430.

RSI-1953-11-055

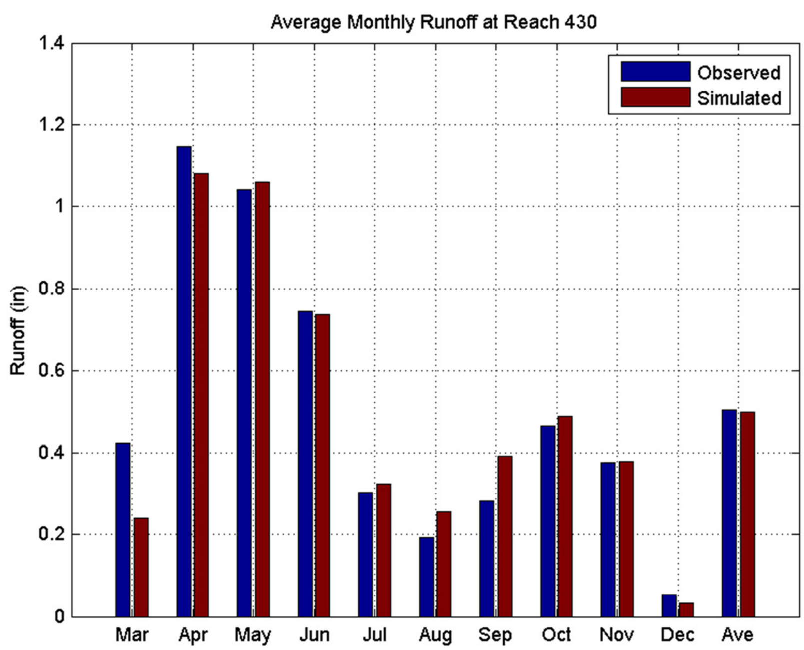

Figure B-2. Average Monthly Runoff at Reach 430.

RSI-1953-11-056

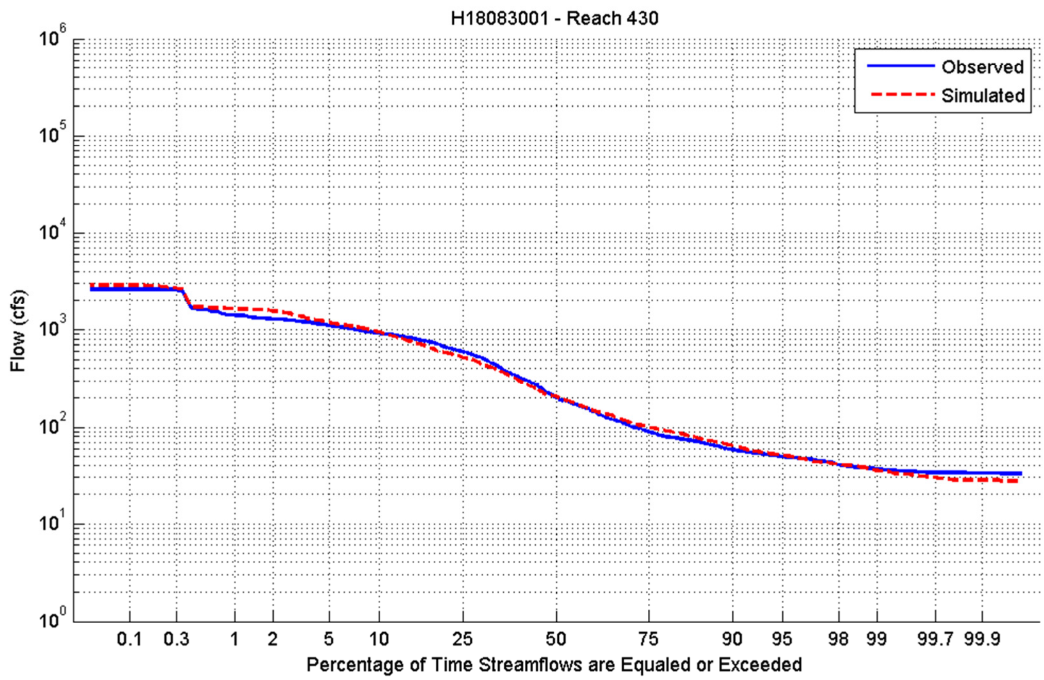

Figure B-3. Flow Duration Plot for Reach 430.

RSI-1953-11-057

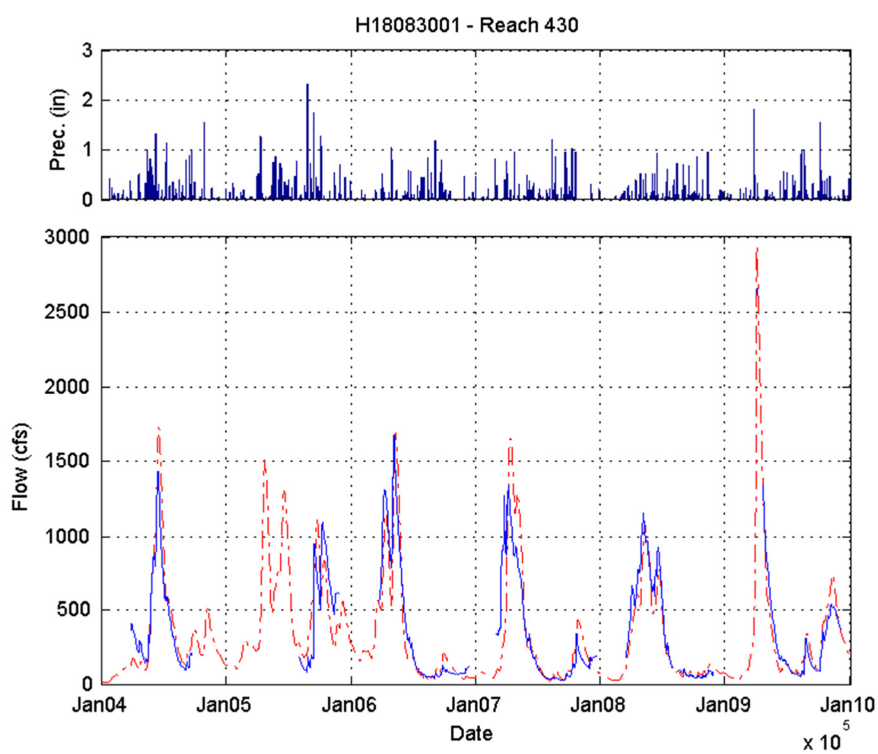

Figure B-4. Daily Hydrographs for Reach 430.

RSI-1953-11-059

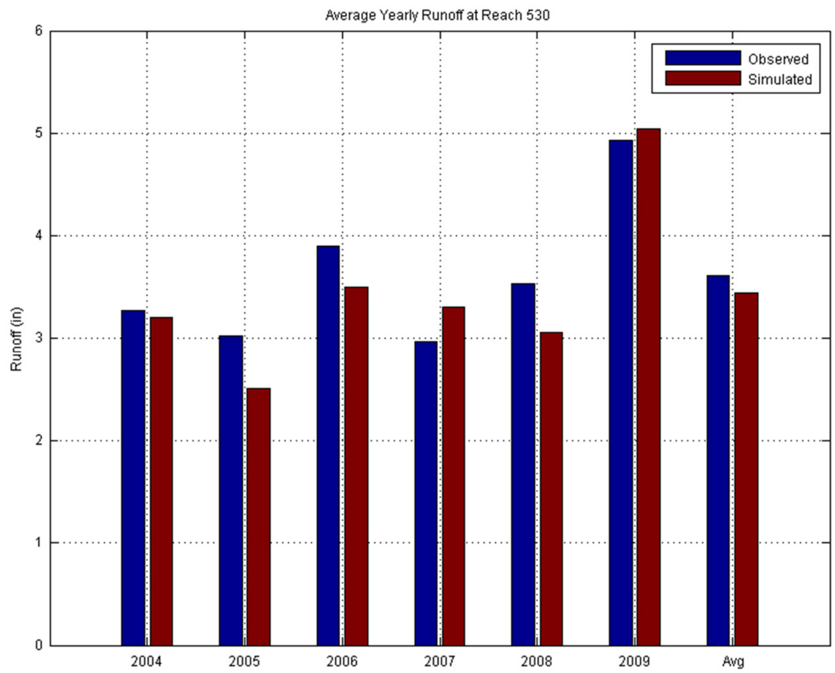

Figure B-5. Average Yearly Runoff at Reach 530.

RSI-1953-11-060

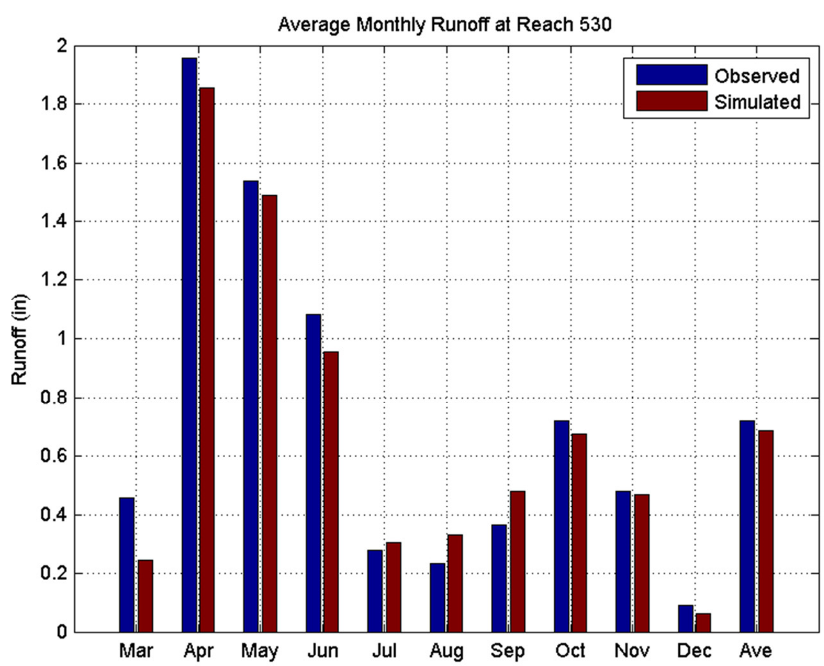

Figure B-6. Average Monthly Runoff at Reach 530.

RSI-1953-11-060

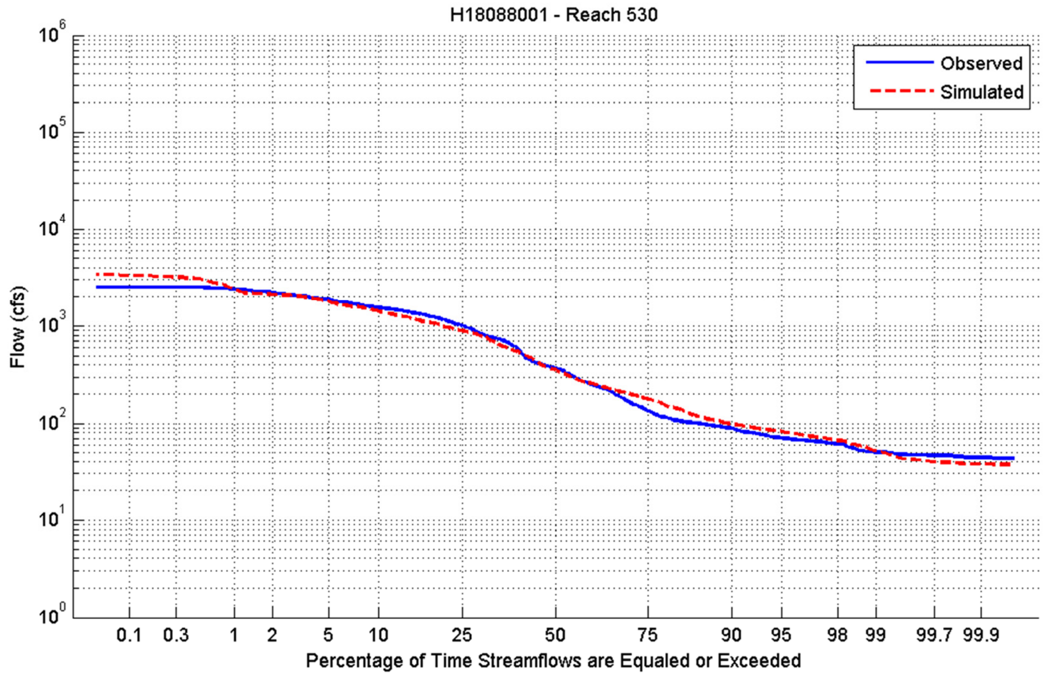

Figure B-7. Flow Duration Plot for Reach 530.

RSI-1953-11-061

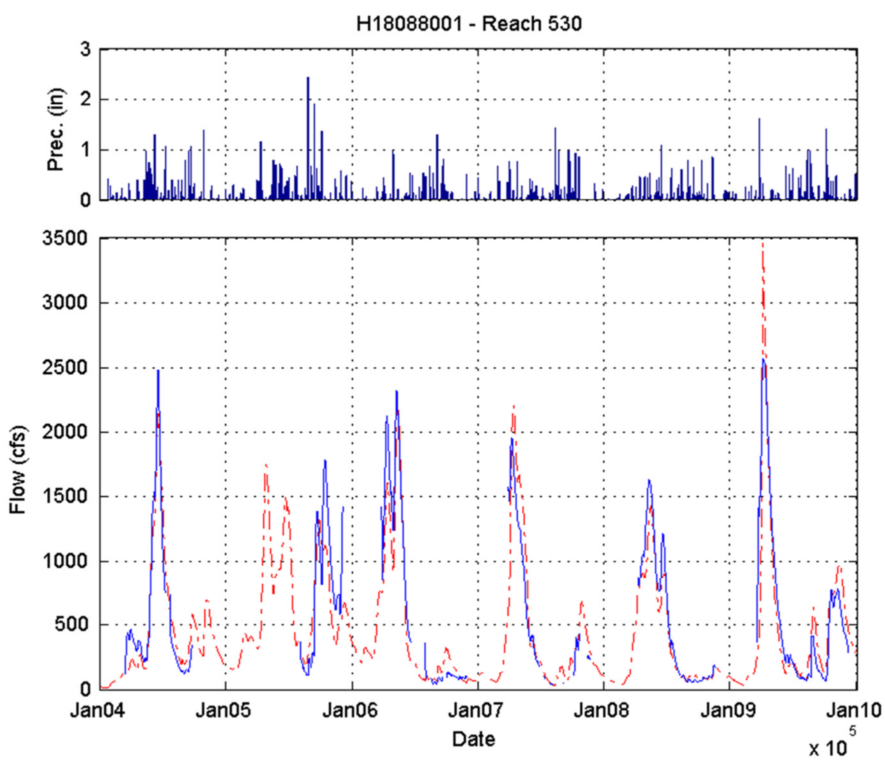

Figure B-8. Daily Hydrographs for Reach 530.

RSI-1953-11-062

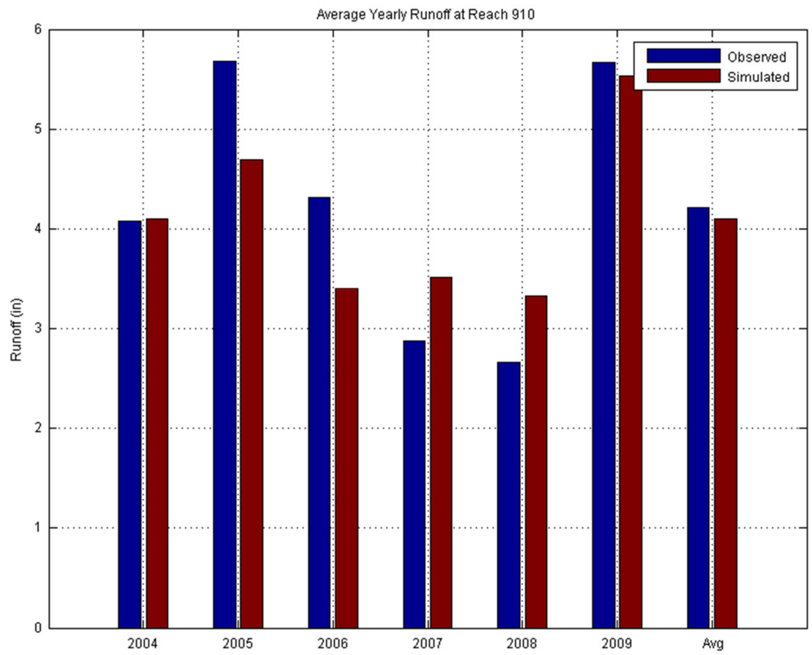

Figure B-9. Average Yearly Runoff at Reach 910.

RSI-1953-11-063

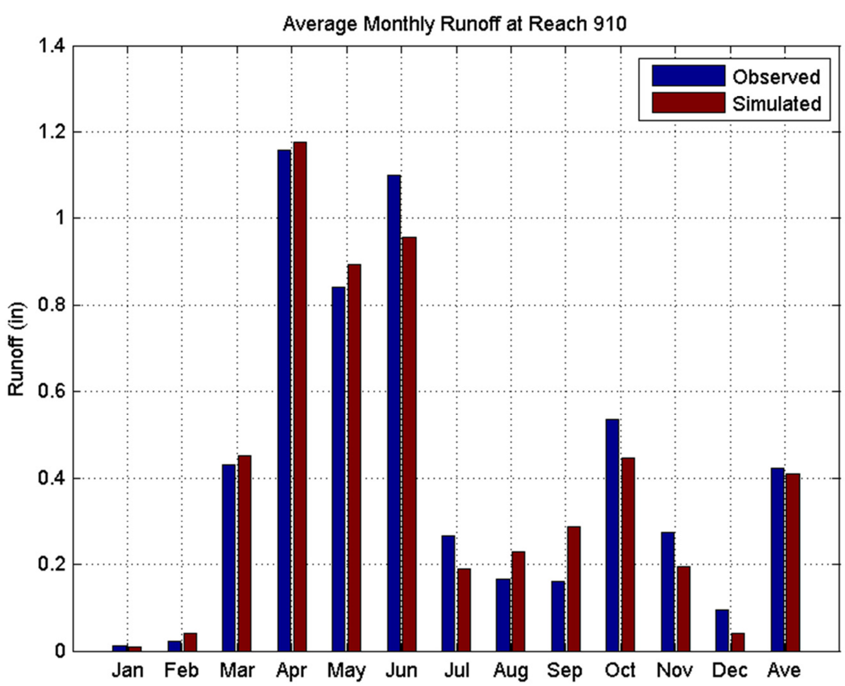

Figure B-10. Average Monthly Runoff at Reach 910.

RSI-1953-11-064

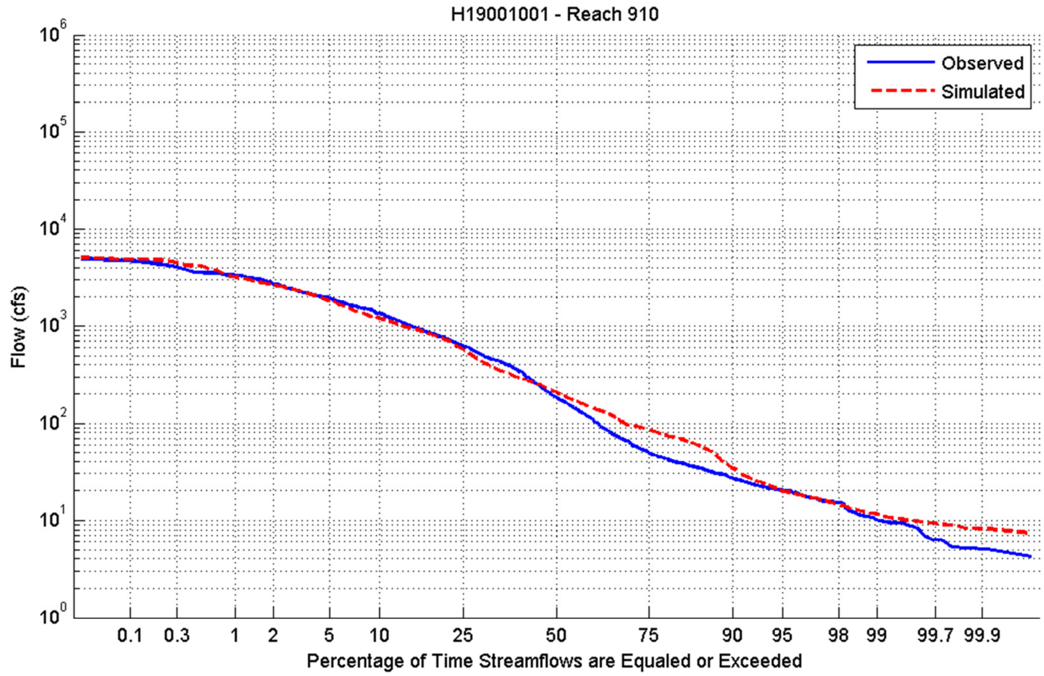

Figure B-11. Flow Duration Plot for Reach 910.

RSI-1953-11-065

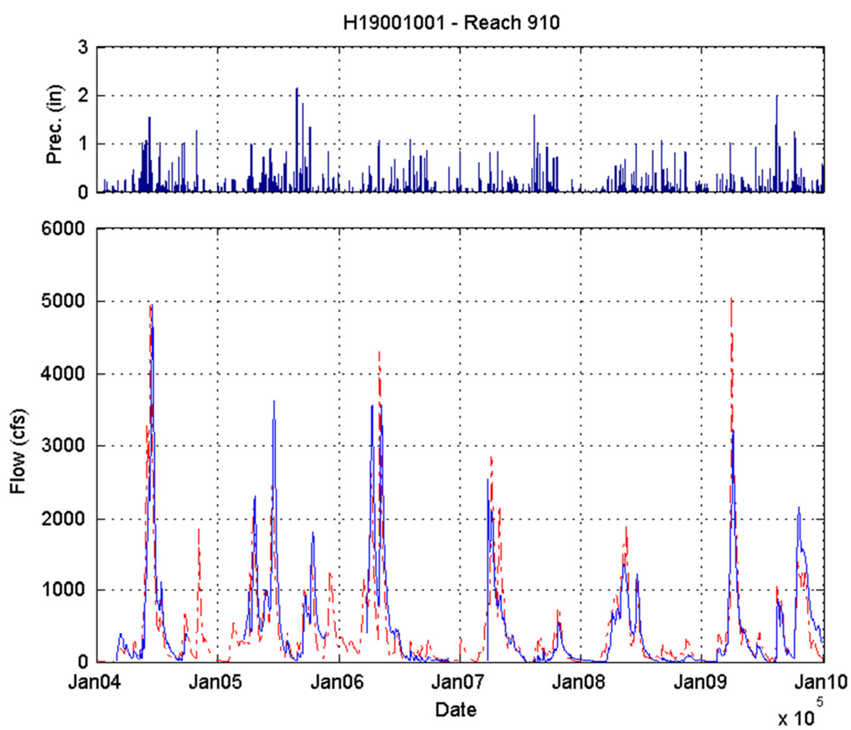

Figure B-12. Daily Hydrographs for Reach 910.

RSI-1953-11-066

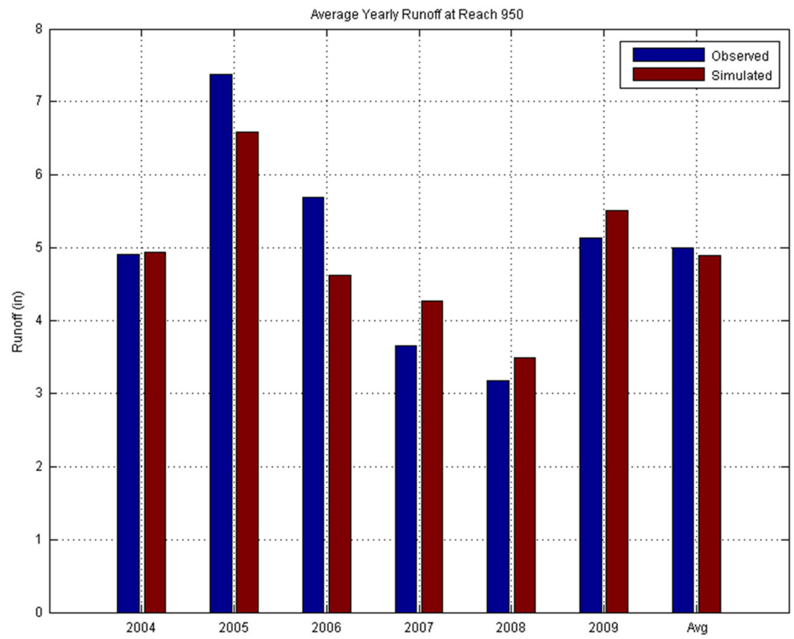

Figure B-13. Average Yearly Runoff at Reach 950.

RSI-1953-11-067

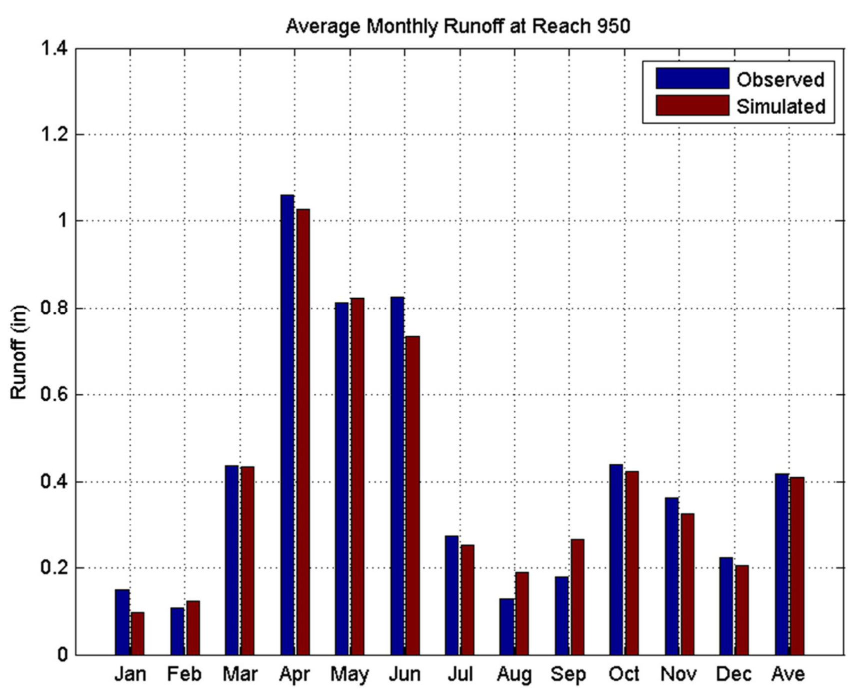

Figure B-14. Average Monthly Runoff at Reach 950.

RSI-1953-11-068

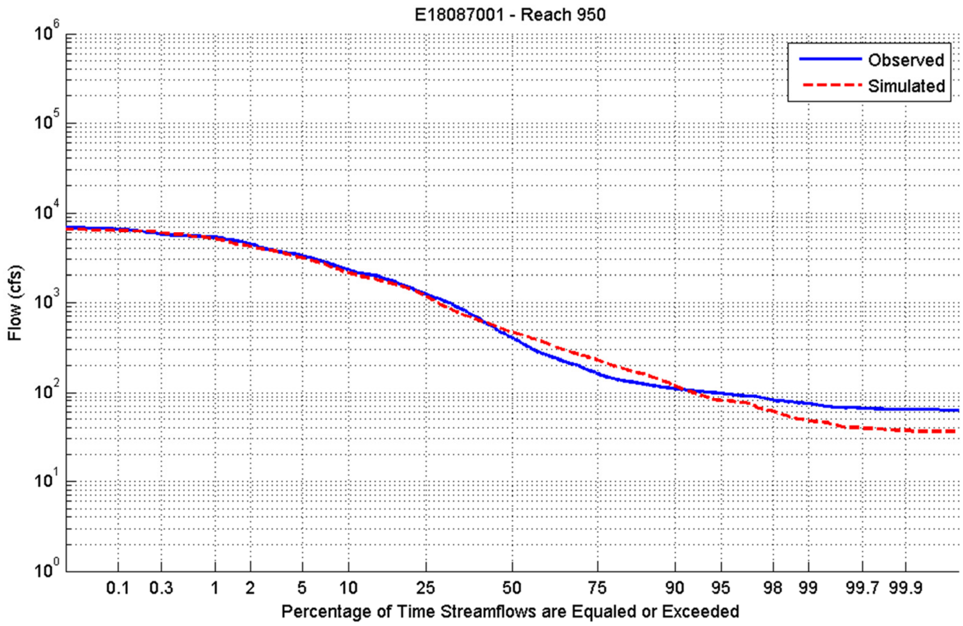

Figure B-15. Flow Duration Plot for Reach 950.

RSI-1953-11-069

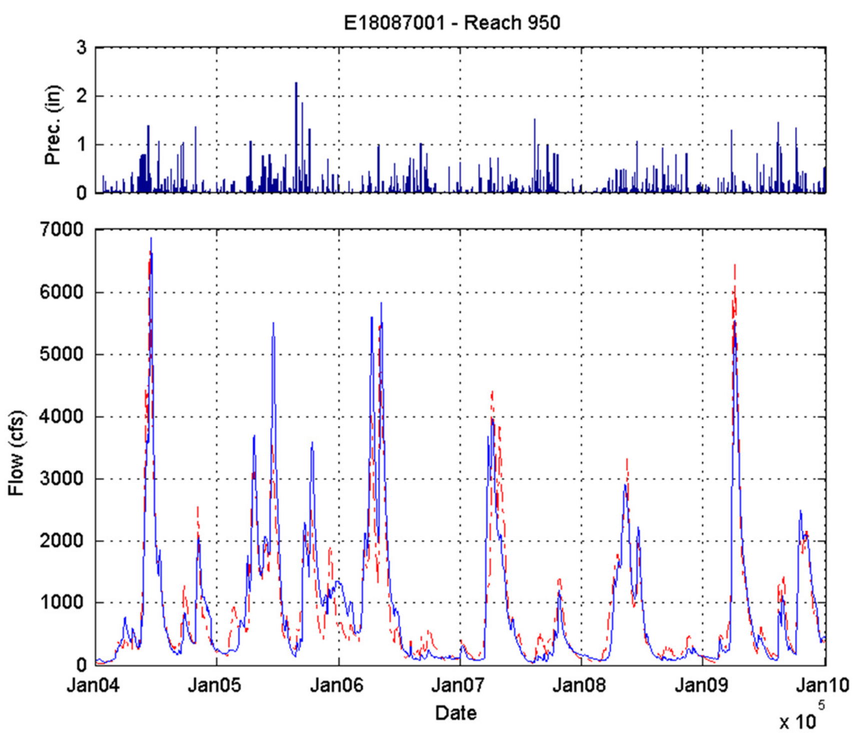

Figure B-16. Daily Hydrographs for Reach 950.

January 13, 2012

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

Dear Mr. Regan:

RE: Update of Cropland Pervious (PERLND) Category Development

Please review the following methodology for the development of new cropland pervious land segment categories for the Sauk, North Crow, and South Crow River Watersheds. These watersheds serve as example watersheds for the purposes of this memorandum, but we intend to use these methodologies as a guideline for all Minnesota model applications having similar land use distributions. Similarly, other consultants modeling Minnesota cropland-heavy watersheds with **HSPF** should consider these methods and/or propose other options for representing cropland PERLNDS, as requested by the Minnesota Pollution Control Agency (MPCA). Having land use consistency for all **HSPF** model applications throughout Minnesota would be ideal; however the northern portion of the state will be an exception as cropland is minimal and forest is a dominant land use and the impacts of timber harvesting need to be considered. This memo serves as an addendum to the original North Crow, South Crow, and Sauk PERLND and IMPLND Development memorandum [Love, 2011][1] for overall land use development.

Previously, watershed characteristics selected for categorization of the land segments included available meteorological data, drainage patterns, land use distribution, hydrologic soil classification, artificial drainage, animal feedlot operations, and percent impervious area. These watershed characteristics will still be represented; however, the three cropland classifications will be changed from *drained cropland, undrained AB cropland, and undrained CD cropland to conventional-till (residue less than or equal to 30 percent) manured cropland, conventional-till nonmanured cropland, and conservation-till (residue greater than 30 percent) cropland*. The feedlot land classification will remain unchanged. Figure 1 shows previous land use classifications, while Figure 2 shows the new land use classifications. These changes are aimed at better classifying land uses, particularly when developing Best Management Practices (BMPs) and management scenarios. A key assumption for the proposed classification is that farmers are working to maintain ideal soil moisture conditions on cropland through irrigation (when available) and through tile drainage, tillage, and manure application. Thus, the hydrologic soil group may not provide a good representation of field conditions. Hydrologic soil groups (AB and CD soils) will still be represented on forest, grassland, and pastureland as soil moisture conditions are not likely to be as highly regulated on the majority of these lands.

[1] **Love, J. T., 2011.** *Pervious (PERLND) and Impervious (IMPLND) Category Development (Revision1)*, RSI(RCO)-1953/4-11/5, personal communication from J. T. Love, RESPEC, Rapid City, SD, to C. Regan, Minnesota Pollution Control Agency, St. Paul MN.

3824 Jet Drive, PO Box 725, Rapid City, South Dakota 57709-0725 Phone: 605.394.6400 Fax: 605.394.6456 www.respec.com

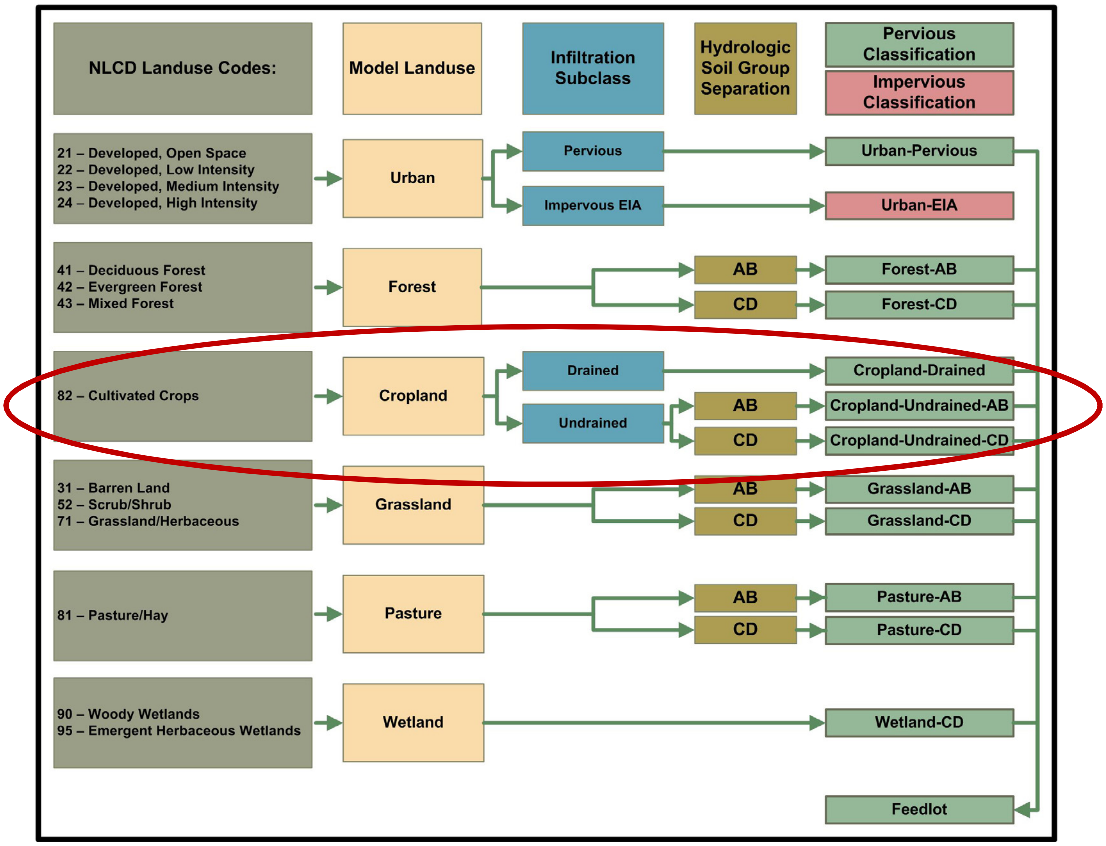

Figure 1. Previous Watershed Classification for the Crow and Sauk Watershed Model Applications.

ESTIMATING CONSERVATION AND CONVENTIONAL TILLAGE AREAS

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 acres farmed, total conservation tillage acres, and total conventional tillage acres in 1995 through 1998, 2000, 2002, 2004, and 2007. 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. Conventional tillage is categorized by 30 percent or less residue remaining on the field and includes reduced-till and intensive-till practices. Residue on the fields can increase the upper zone storage capacity which in turn can decrease runoff, impacting sediment and water-quality processes.

ArcGIS can be used with these data to estimate weighted area fractions of conservation tillage versus conventional tillage for each subwatershed. Because one model application will be used to represent 1995 through 2003 (based upon National Land Cover Database (NLCD) 2001 v2 land use) and one model application will be used to represent 2004 through 2009 (based upon NLCD 2006 land use), an average of 1995 through 1998, 2000, and 2002 will be used for the first modeling period and an average of 2004 and 2007 will be used for the second modeling period.

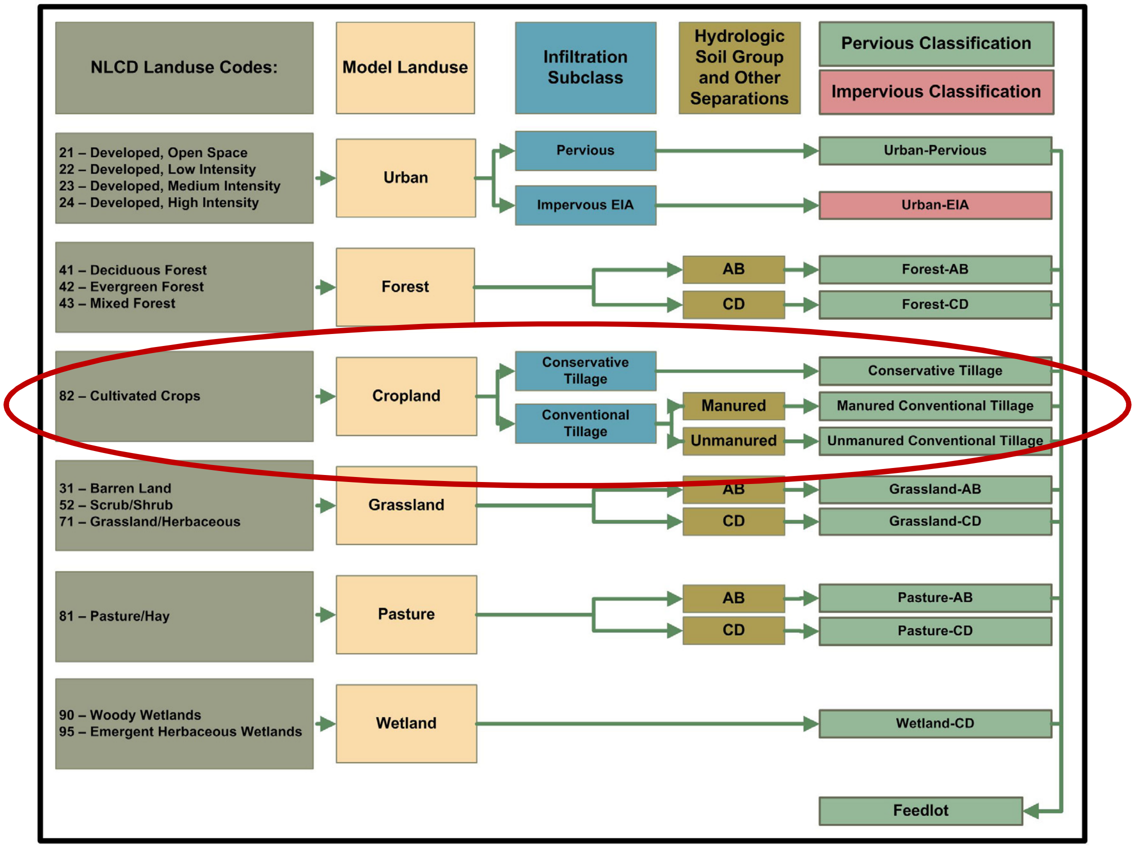

Figure 2. New Classification for the Crow and Sauk Watershed Model Applications.

ESTIMATING MANURE APPLICATION AREAS

There are an estimated 1,664, 1,133, and 824 animal feedlot operations in the Sauk, North Crow, and South Crow River Watersheds, respectively. Feedlot operations are required to adhere to health, safety, and environmental laws. Those with 1,000 or greater animal units are required to have no surface discharge. Figure 3 shows the distribution of animal feeding operations (AFOs) in the major watersheds. Manure generated at these operations is used throughout the watersheds as a fertilizer and to increase water retention in the soil. Manure, as well as inorganic fertilizers, may be contributing to impaired water-quality in waterbodies. From a modeling standpoint, manure contributes oxygen-demanding substances, ammonia, nutrients, and solids into the surrounding water sources through accumulation and wash-off processes on cropland. Additionally, manured agricultural lands may have higher upper zone storage than nonmanured agricultural lands. The representation of the feedlot landuse class, which will be retained, is further discussed in Love [2011][1].

Feedlot data will also be used to calculate the new *conventional-till manured cropland* landuse class. The MPCA-supplied Geographic Information System (GIS) coverage of feedlots includes number of animal units of birds, bovines, deer and elk, goats and sheep, horses, llamas and alpacas, pigs, and other animals in 2010. An updated GIS coverage for the North Fork

Crow Watershed confirmed that approximately 5 percent of the North Fork Crow animal units were gone from the watershed by 2011. According to Schmitz [2012][2], manure generally stays in the localized feedlot area with the maximum distance of transport of approximately 30 miles. Therefore, GIS coverages can be spatially joined with a subwatershed coverage to approximate number of animal units in each subwatershed. Number of animal units can then be used to estimate the agronomic manure application area using a similar methodology to that used in the Minnesota River Model [Butcher, 2008][3]. The Minnesota River Model calculated number of animal units in each county and multiplied it by an estimated manure agronomic application area per animal unit of 1.29623 acres per animal unit. This estimated area was obtained from a "unit county" (Blue Earth County) in Minnesota. For the Minnesota River Model Application, the probable application area was estimated by MPCA to be one-fourth of the agronomic application area [Gervino, 2002][4].

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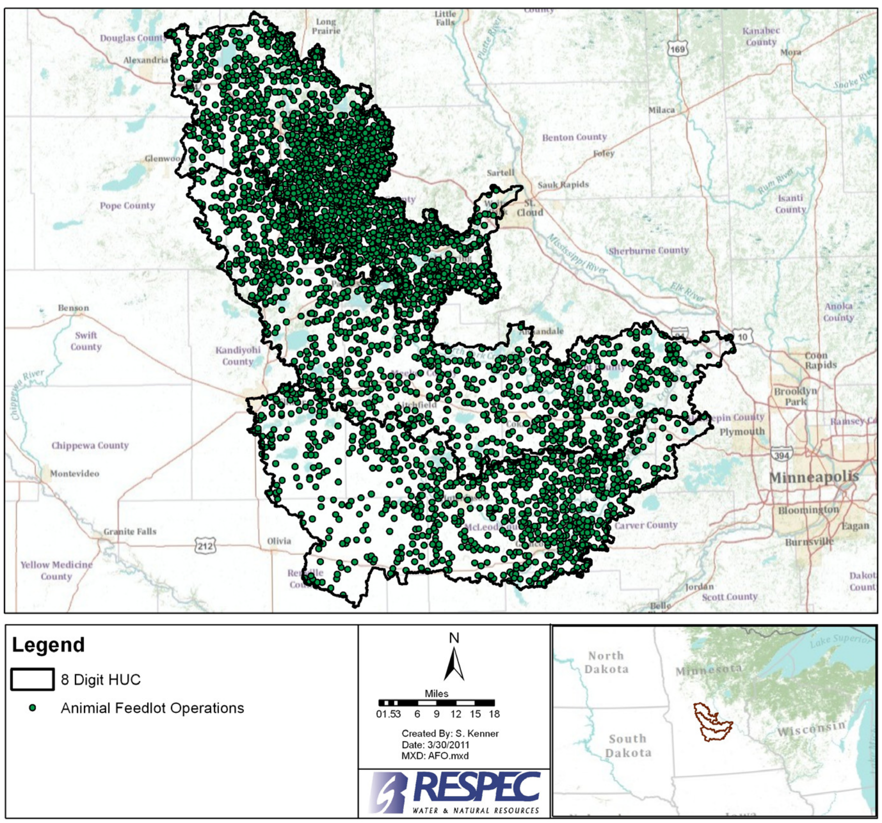

Figure 3. Animal Feedlot Operations in the Crow and Sauk Watersheds.

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2 **Schmitz, C., 2012.** Personal communication between C. Schmitz, National Resource Conservation Service, Glencoe, MN, and C. M. McCutcheon, RESPEC, Rapid City, SD.

3 **Butcher, J., 2008.** *Minnesota River Basin Turbidity TMDL and Lake Prepin Excessive Nutrient TMDL Model Calibration and Validation Report*, prepared by TETRATECH, Research Triangle Park, NC, for Minnesota Pollution Control Agency, St. Paul, MN.

4 **Gervino, N., 2002.** *Manure Application Areas, Minnesota River Basin Model*, internal memorandum from N. Gervino, Minnesota Pollution Control Agency, St. Paul, MN, to H. Munir, Minnesota Pollution Control Agency, St. Paul, MN, June 27.

The actual application of manure can vary greatly. Based on Gervino [2012][5], we propose that the initial probable application area be equal to the agronomic application area. If the calculated agronomic application area exceeds the conventional tilled area, the initial probable manure application area should be set at the full conventional tillage area. The probable application area may be refined by meteorological zone based on interviews with local conservationists. Table 1 contains a summary of the animal data and estimated agronomic areas manure application.

Table 1. Summary of Animal Feedlot Operations Data and Estimated Area Calculations

Major Watershed	AFOs	Animal Counts	Animal Units	Estimated Feedlot Area (acres)	Estimated Application Area (AUs×1.29623) (acres)	Percent of Total Cropland Area[(a)] (acres)
Sauk	1,664	470,2486	249,376	1,717	323,249	97
North Crow	1,133	626,9390	175,788	1,211	227,862	43
South Crow	824	189,2380	140,844	970	182,566	31

(a) Percent application area of total cropland area because tilled not yet calculated.

The timing of manure application may differ from mineral fertilizers. Schmitz [2012][2] stated that approximately 60 percent of manure is applied in the fall and the rest is applied during winter, spring, and summer. Bierman et al. [2011][6] found that the majority of inorganic nitrogen fertilizer used in the watersheds was in the form of anhydrous ammonia, and the majority of farmers reported applying anhydrous ammonia in the fall. However, urea fertilizer was also extensively used and were typically applied in the spring.

Current modeling efforts used a generalized representation of the accumulation and runoff of water-quality constituents (PQUAL block). The model represents when the nutrients, regardless of original fertilizer type, would be environmentally available for wash-off. Consistent with farm operations, the majority of available nutrients accumulate in the spring. Rates of nitrogen or phosphorous leaching into the groundwater are represented in both the interflow and active groundwater.

ARTIFICIAL DRAINAGE

Artificial drainage practices on agricultural lands can significantly influence hydrology and water-quality processes. Water with shorter travel time and higher runoff volumes will interact less with the mineral and organic components of the soil profile and have less opportunity for

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5 **Gervino, N., 2012.** Personal communication between N. Gervino, Minnesota Pollution Control Agency, St. Paul, MN, and C. M. McCutcheon, RESPEC, Rapid City, SD, January 10.

6 **Bierman, P., C. Rosen, R. Venterea, and J. Lamb, 2011.** *Survey of Nitrogen Fertilizer Use on Corn in Minnesota,* prepared for the Minnesota Department of Agriculture, St. Paul, MN.

biological and chemical interactions to process dissolved nutrients carried with the drainage water to the streams [Fausey et al., 2008][7]. As mentioned earlier, artificial drainage practices on agricultural lands will still be represented in the model; however, they will be implicitly modeled through parameterization rather than explicitly represented by a PERLND. The percentage of artificial drainage within individual meteorological zones can be calculated in ArcGIS, and parameterized in the model to shorten travel time and increased runoff volumes. Consistent with the Minnesota River modeling methods [Butcher, 2008][3], hydrologic impacts of artificial drainage will be primarily represented through interflow parameters. However, we suggest using/considering a simpler GENER approach to include sediment and sediment adsorbed pollutant addition to water through tile drainage.

A GIS coverage was made available by MPCA showing likely tile drainage throughout the state. Areas were designated as drained for this MPCA GIS coverage where 2009 U.S. Department of Agriculture (USDA) Crop Data Layer row crops had a 0 to 3 percent slope from the U.S. Geological Survey (USGS) National Elevation Dataset (30-meter digital elevation model (DEM)) and a poorly drained or very poorly drained Soil Survey Geographic Database (SSURGO) soil drain class. In future models, this MPCA GIS tile drainage coverage will be used to represent tile drainage. However, for the Crow and Sauk watersheds, a GIS methodology derived from Sugg [2007][8] was used to calculate the drained cropland in the Sauk and Crow Watersheds. The GIS methodology from the paper was "based on the simple idea that if row crops are cultivated on a poorly drained soil, then an artificial drainage improvement likely exists on that soil." For the Sauk and Crow analysis, SSURGO was used as opposed to the USDA/Natural Resources Conservation Service (NRCS) State Soil Geographic Database (STATSGO) used in Sugg's study because it has higher resolution and more detailed information. The ArcGIS Soil Data Viewer was used to query the soil drainage classifications throughout each county. These classifications included excessively drained, somewhat excessively drained, well drained, moderately well drained, somewhat poorly drained, poorly drained, and very poorly drained soil. The soil drainage classification layer was intersected with the NLCD land use layers. Figure 4 is a map of the areas where cultivated crops were present on poorly drained or very poorly drained soils that were classified as likely drained and very likely drained. Further detail on the GIS methodology used is available in Love [2011]. Total tile drainage areas calculated by MPCA and RESPEC are shown in Table 2.

In summary, HSPF model application cropland PERLNDs should consist of *conventional-till (residue less than or equal to 30 percent) manured cropland, conventional-till nonmanured cropland, and conservation-till (residue greater than 30 percent) cropland*. This memorandum summarizes the general methods used to develop the cropland categories. Figure 5 shows a flowchart of these methods with decision points (A, B, and C) identifying important parameters that will vary amongst the land uses (i.e., conservation tillage versus conventional tillage and manured land versus unmanured land).

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[7] **Fausey, N. R., D. Pitts, and D. B. Jaynes, 2008.** "Agricultural Drainage Water Management in the Upper Mississippi River Basin: Potential Impact and Implementation Strategies," *16th National Nonpoint Monitoring Results Workshop,* Columbus, OH, September 14–18.

[8] **Sugg, Z., 2007.** *Assessing U.S. Farm Drainage: Can GIS Lead to Better Estimates of Subsurface Drainage Extent?,* World Resources Institute, Washington, DC, August.

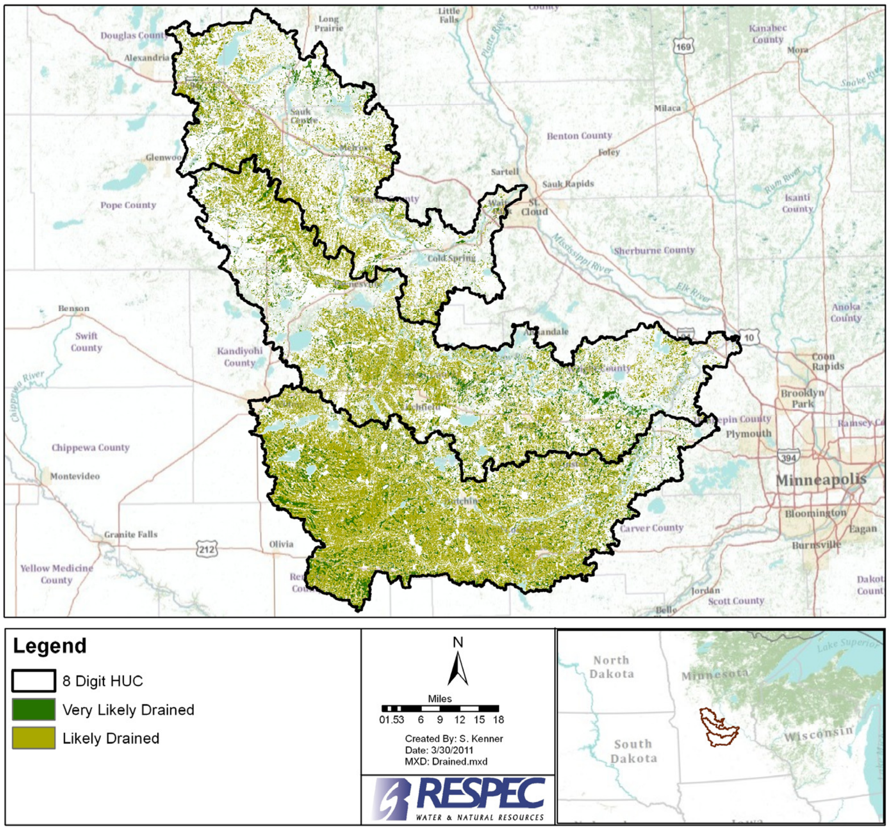

Figure 4. Cultivated Cropland Areas Most Likely to Be Drained With Artificial Drainage.

Table 2. Summary of Differences between Tile Drains

Watershed	Minnesota Tile Drainage Coverage		RESPEC Tile Drainage Coverage		Difference
	Area (acres)	Percent Total	Area (acres)	Percent Total	Acres
Sauk	51,858	8	98,330	15	46,472
North Fork Crow	107,522	11	195,875	21	88,353
South Fork Crow	295,037	36	355,093	43	60,056

In summary, HSPF model application cropland PERLNDs should consist of *conventional-till (residue less than or equal to 30 percent) manured cropland, conventional-till non-manured cropland, and conservation-till (residue greater than 30 percent) cropland*. This memo summarizes the general methods used to develop the cropland categories. Figure 5 shows a flowchart of these methods with decision points (A, B, and C) identifying important parameters that will vary amongst the land uses (i.e., conservation tillage versus conventional tillage and manured land versus unmanured land).

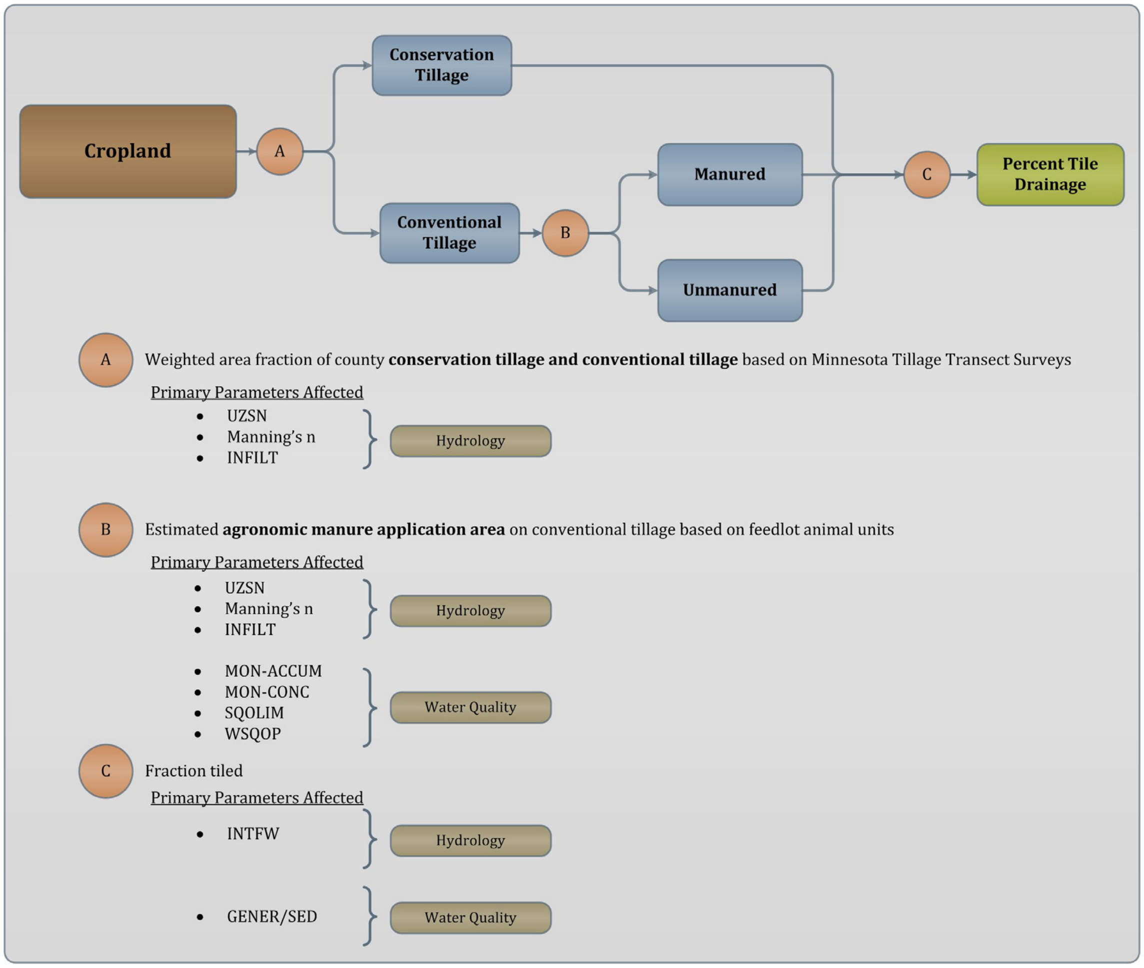

Figure 5. Cropland PERLND Flowchart.

Thank you for your time reviewing the proposed method for updating the cropland PERLND land segment categories for the Sauk, North Crow, and South Crow River Watersheds and for future watershed models. Please feel free to provide feedback with any questions or concerns.

Sincerely,

Jason T. Love
Vice President, Water & Natural Resources

JTL:llf

cc: Project Central File 1953 — Category A

February 3, 2015

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

Dear Dr. Regan:

RE: Model Extension and Recalibration for South Fork Crow River Watershed Model Application

The methodology documentation for updating the User Control Input (UCI) and Watershed Data Management (WDM) files for the Hydrologic Simulation Program Fortran (HSPF) model application is completed for your review. The memorandum covers model extension and hydrologic and water quality recalibration and validation for the South Fork Crow Watershed (HUC 07010205), which is illustrated in Figure 1. The procedures followed for delineating subwatersheds, selecting primary reaches/lakes, creating function tables (F-tables), developing time-series data inputs, and determining pervious (PERLND) and impervious land (IMPLND) land-cover categories are described in previous RESPEC reports and memoranda [Love, 2011a, 2011b, 2011c, 2011d, 2011e, 2011f, 2012].

EXTENSION OF TIME-SERIES DATA

Separate WDM files were created for meteorological time series and point sources discharging within the watershed (i.e., added flow time-series and pollutant loading). Meteorological data used in the HSPF model application were obtained from the U.S. Environmental Protection Agency's (EPA) BASINS system and precipitation data through a combination of sources including BASINS and extensive supplementary HIDEN (HIgh spatial DENsity, daily observations) provided by the Minnesota Pollution Control Agency (MPCA). The disaggregated-filled, daily precipitation (PREC) time series allowed for the use of 18 unique PREC base stations (12 HIDEN and 6 BASINS) to provide comprehensive spatial coverage of the watershed. An overall map of PREC stations is illustrated in Figure 2.

This section describes the procedures used to extend the existing meteorological, point source, and atmospheric deposition time series (1995–2009) through 2012. Because the BASINS database has not been updated since 2009, additional meteorological data were obtained through a variety of sources to extend those time series. The Automated Surface/Weather Observing System (ASOS/AWOS) and the National Weather Service Cooperative Network (COOP) data were provided by the Midwestern Regional Climate Center (MRCC) and HIDEN data was provided by the MPCA. Selecting the new meteorological data used to extend the existing time series was based on the proximity to an existing station, as well as the completeness and quality of data. All of the extension data were processed before appending or filling the existing time series. The extension sites often overlapped with the existing BASINS met locations (Figure 3).

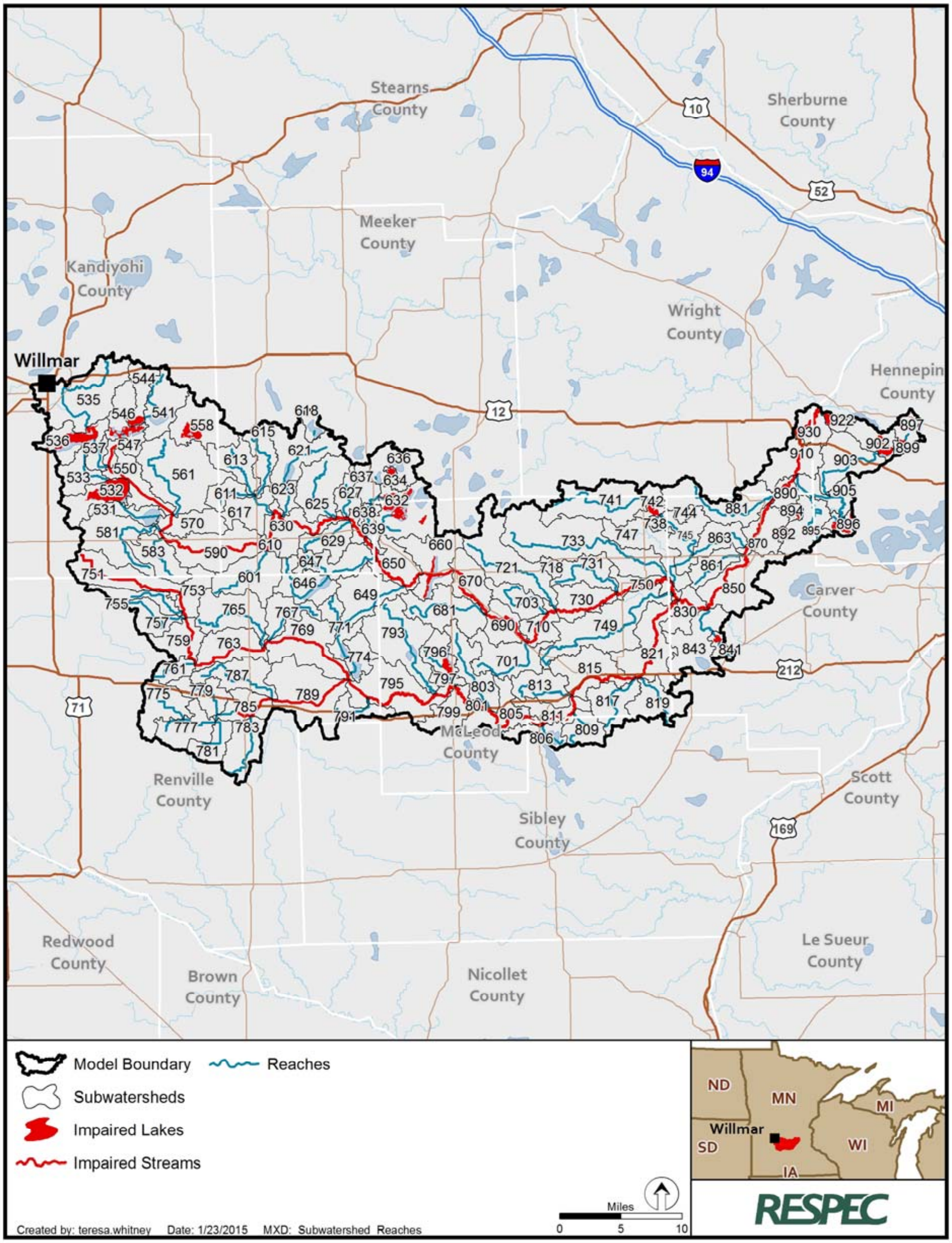

Figure 1. Subwatersheds and Reaches.

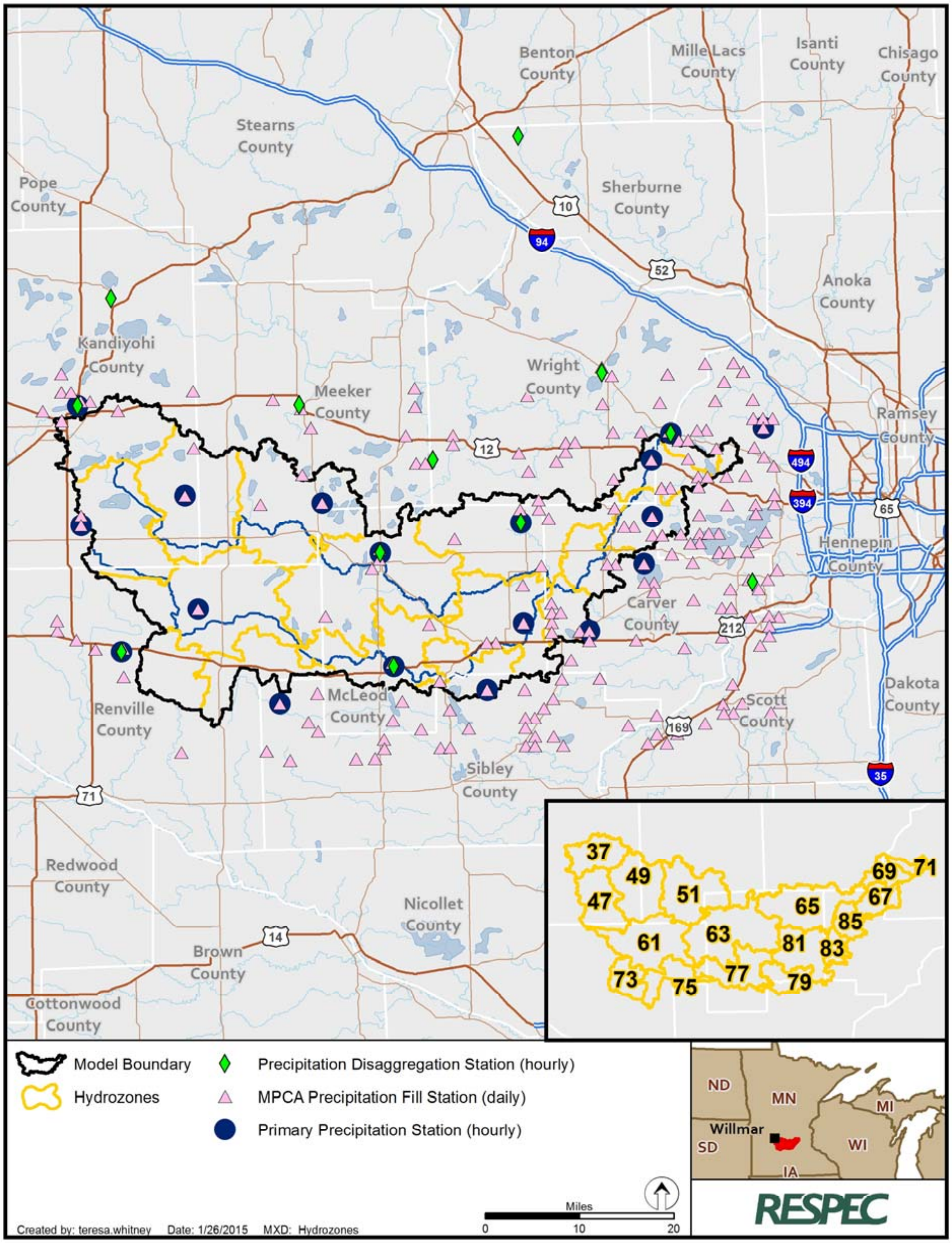

Figure 2. Hydrozones and Meteorological Stations.

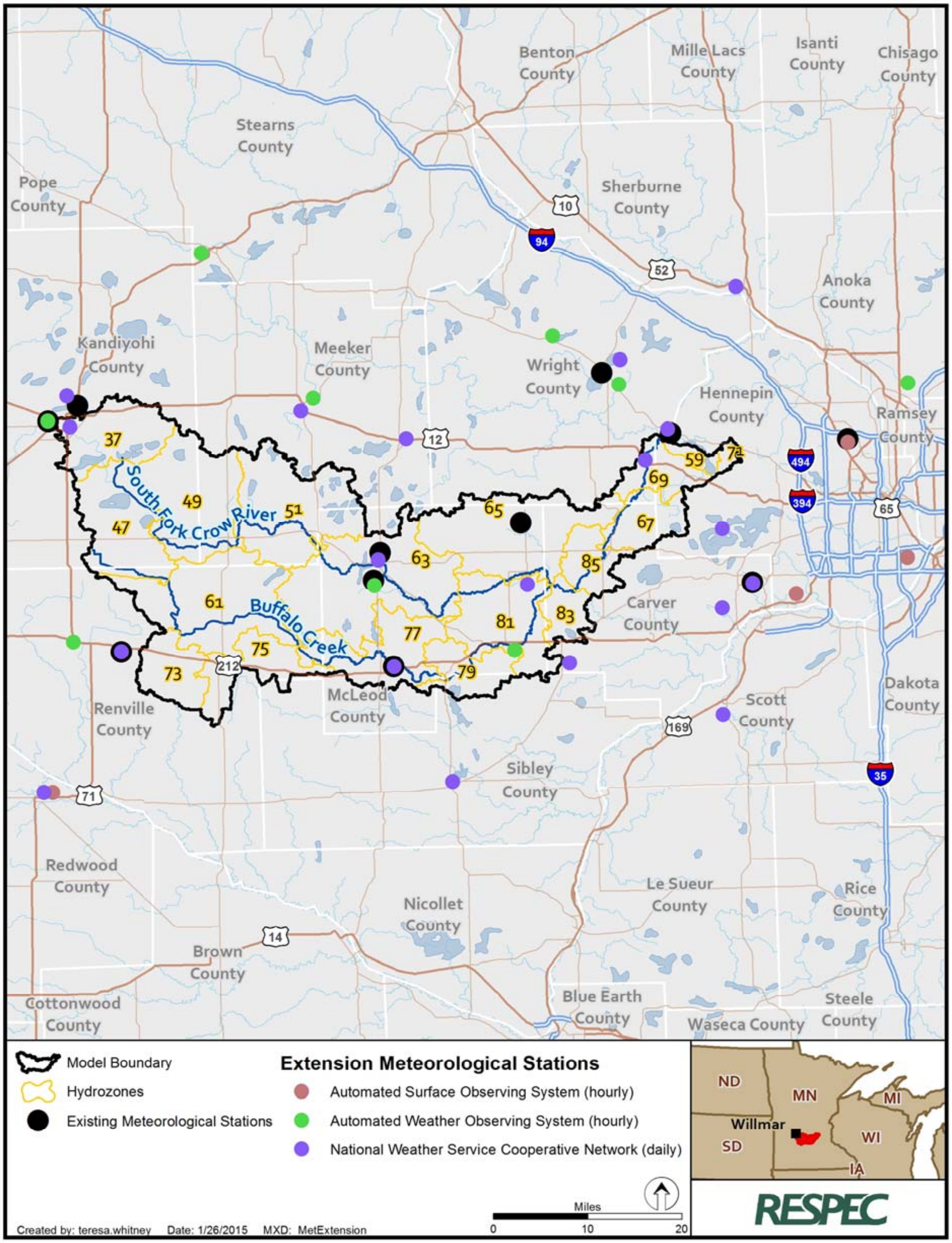

Figure 3. Existing and Extension Meteorological Sites.

Precipitation

The original and existing PREC time series consisted of BASINS and HIDEN stations. Daily COOP and hourly ASOS/AWOS stations were filled with the nearest like station until no missing values remained. Filled daily precipitation stations were disaggregated in WDMUtil to an hourly time series by using the filled hourly ASOS/AWOS sites and a 90 percent data tolerance. The existing BASINS stations were then appended with the nearest filled/disaggregated extension station.

HIDEN stations were reprocessed for the entire modeling period by filling missing data using the nearest HIDEN station or newly extended and aggregated BASINS sites. After the missing values were filled, the HIDEN stations were disaggregated to an hourly time series in WDMUtil.

Air Temperature

Daily COOP and hourly ASOS/AWOS stations were filled by using ratio of means with the nearest like site until no missing values remained. Filled daily minimum and maximum temperature sites were disaggregated in WDMUtil to an hourly time series by using the observation hour. BASINS stations were extended with the nearest extension site.

Cloud Cover, Wind Speed, and Dew Point Temperature

Hourly ASOS/AWOS sites were filled (ratio of means for Wind Speed [WIND] and Dew Point Temperature [DEWP]) with the nearest like station until no missing values remained. DEWP was unavailable so it was calculated by using a simple temperature and relative humidity (RH) relationship [Lawrence, 2005]:

$$\mathrm{DEWP} = \mathrm{ATEM} - \frac{9}{25}\left(100 - \mathrm{RH}\right). \quad (1)$$

Cloud Cover (CLOU) descriptions at the uppermost cloud layer were assigned real numbers based on a 0–10 scale (CLR–0, FEW–1, SCT–4, BKN–7, and OVC–10). BASINS stations were extended with the nearest extension site.

Potential Evapotranspiration and Solar Radiation

Data for Potential Evapotranspiration (PEVT) and Solar Radiation (SOLR) were largely unavailable or incomplete. Daily SOLR was recalculated from average daily cloud cover for the entire modeling period (1995–2012) in WDMUtil by using latitude and disaggregated to an hourly time series. Hourly Penman Pan Evaporation was estimated by loading hourly time-series data into the WDMUtil and aggregating these data to calculate daily PEVT as a function of minimum and maximum daily Air Temperature (ATEM), mean daily DEWP, total daily WIND, and total daily SOLR and then disaggregated to hourly time series. Penman Pan Evaporation is converted to PEVT in the external sources block of the UCI (where model inputs are called and distributed) by using an adjusted pan factor of 0.70, which was from the National Oceanic and Atmospheric Administration (NOAA) Evaporation Atlas. PEVT and SOLR time series were recalculated for the entire modeling period to ensure consistency in data.

Point Sources

A total of 18 point sources (3 major and 15 minor), illustrated in Figure 4, are represented in the South Fork Crow River Watershed (Table 1). All explicitly represented point-source flows and loads were recalculated for the entire modeling period to ensure consistency during processing.

Point-source data were processed into daily time series by distributing the total discharge from each source throughout the month. Mechanical sites were assumed to discharge for the entire month in which it had data. Controlled ponds generally discharge intermittently for variable lengths of time, and data for the sites were provided by the MPCA as a combination of monthly volumes 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. An estimate of the number of discharge days was supplied by the MPCA and was incorporated by using the following logic supplied by Henningsgaard [2012]:

1. If there are only a few discharge days followed by a month, with only a few discharge days or if the first month has only a couple and the next month has up to approximately 10 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 approximately 18 discharge days, they can be placed anywhere consecutively.
3. If there are over approximately 18 discharge days, one-half should be placed in the first half of the month and one-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 biochemical oxygen demand (CBOD5), total suspended solids (TSS), total phosphorus (TP), and dissolved oxygen (DO). Point-source water quality data were filled by using monthly mean values. Where monthly means were unavailable, interpolation was used. The available effluent water quality parameters vary by site, but in general, most parameters were available from wastewater treatment facilities.

Nitrogen species data and orthophosphate-phosphorus were largely unavailable in the minor point-source data. Facility classes for each point source determined loads for nitrogen species and were calculated by using numbers supplied by Weiss [2012]. Methods for estimating other phosphorus species from point sources were derived from methods similar to those used in the earlier version of the South Fork Crow River model application [Love, 2011e]. The nutrient portions of the South Fork Crow River Watershed external sources blocks contain estimates where nutrient data were unavailable. Temperature data were derived from the Hutchinson Waste Water Treatment Plant (WWTP). All available data for model inputs have been uploaded into the project WDM file, and all available data used for comparison to model simulations are in an observed data Microsoft Excel file.

Atmospheric Deposition

Atmospheric deposition of nitrate and ammonia was reprocessed for the entire modeling period to ensure consistency of time-series data.

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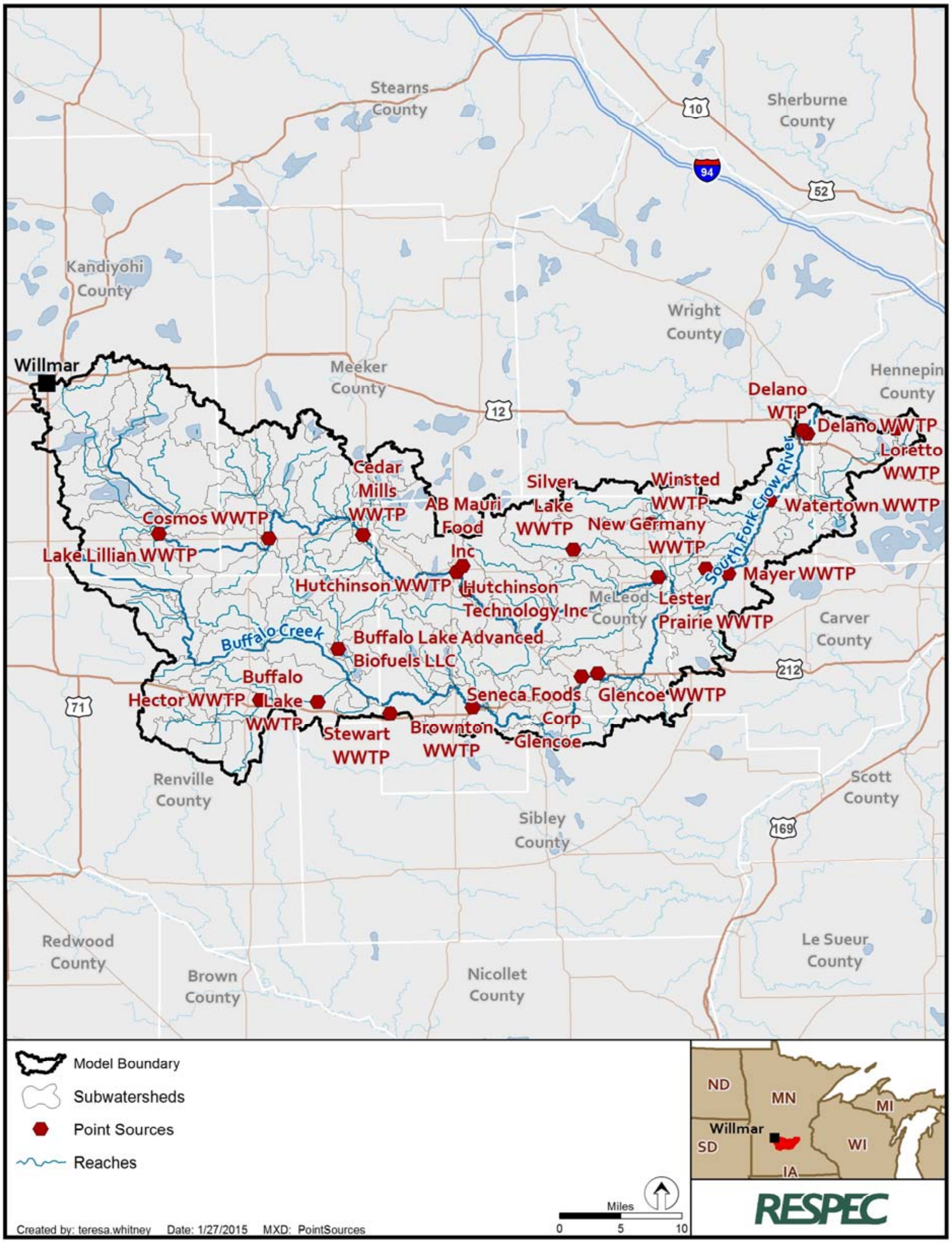

Figure 4. Point Sources.

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

Site I.D.	Facility Name	Reach
MN0055832	**Hutchinson WWTP**	**670**
MN0022233	**Glenco WWTP**	**815**
MN0051250	**Delano WWTP**	**930**
MN0023841	Kandiyohi WWTP	535
MN0021954	Lake Lillian WWTP	590
MN0038792	Cosmos WWTP	610
MN0066605	Cedar Mills WWTP	630
MN0024902	Silver Lake WWTP	733
MN0021571	Winsted WWTP	738
MN0023957	Lester Prairie WWTP	750
MN0025445	Hector WWTP	785
MN0063151	Buffalo Lake Advanced Biofuels LLC	789
MN0050211	Buffalo Lake WWTP	789
MN0053210	Stewart WWTP	795
MN0022951	Brownton WWTP	801
MN0001236	Seneca Foods Corp— Glencoe	815
MN0021202	Mayer WWTP	850
MN0024295	New Germany WWTP	861

Wet atmospheric deposition data were downloaded from the National Atmospheric Deposition Program (NADP). The NADP sites chosen to represent the South Fork Crow River Watershed wet deposition were MN23 and MN01. Wet deposition includes atmospheric nutrients in rainfall. Thus, nitrate and ammonia wet deposition was applied as concentrations (milligrams per liter [mg/L]) to the precipitation input time series.

Dry deposition is independent of precipitation. Dry atmospheric deposition data were downloaded from the EPA's Clean Air Status and Trends Network (CASTNet). The CASTNet site chosen to represent the South Fork Crow River Watershed dry deposition was PRK134. The nitrate and ammonia dry deposition data (originally in kg/ha) were converted to a pound/acre flux. Both the wet and dry atmospheric deposition sites are illustrated in Figure 5.

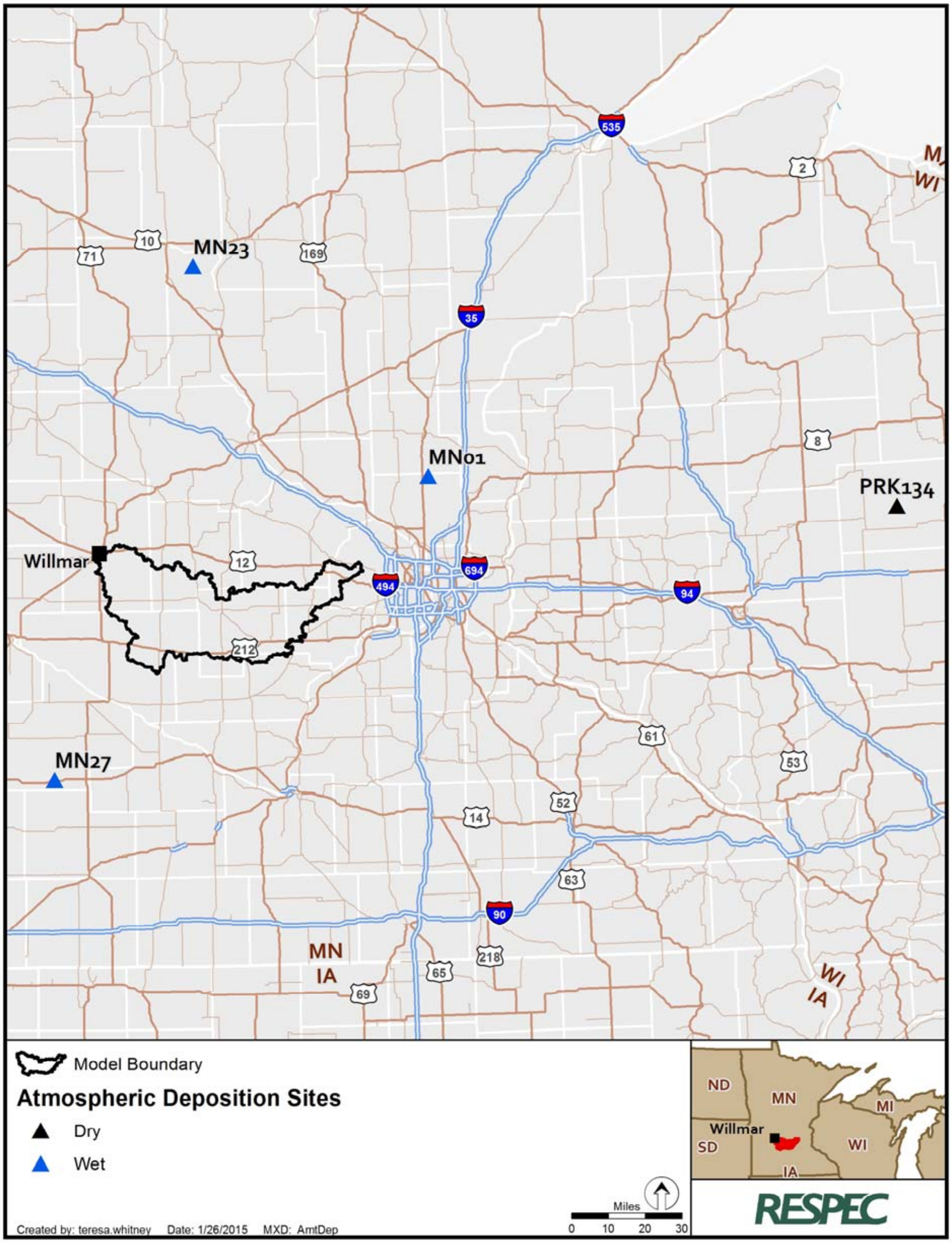

Figure 5. Atmospheric Deposition Sites.

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 the sampling period. After they were 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 dataset) and by using monthly mean values when more than 7 days occurred between values (likely scenario).

Atmospheric deposition of phosphorus is estimated to account for approximately 8.3 percent of the TP load in the Minnesota River Basin [Barr Engineering, 2007] and was included in the model application. Because of the lack of temporal data, atmospheric phosphorus deposition was represented by using monthly values of daily dry fluxes using the MONTH-DATA block in HSPF. A value of 0.417 kilogram/hectare per year (kg/ha/yr) (0.001 pounds per acre per day) was provided by Barr Engineering and was distributed throughout the months with higher values in the summer and lower values in the winter. Because it was represented as a monthly value as opposed to a time series, it did not need to be extended.

Discharge

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

Observed discharge time-series data were obtained to compare simulated discharge during model calibration. Observed discharge data were obtained as daily time series from the USGS, the MPCA, and the Minnesota Department of Natural Resources (MNDNR). The continuous, observed stream-flow data required for calibration are available at ten gages within the South Fork Crow River Watershed (5 calibration/validation gages are located on the mainstem and 5 gages are located on tributary rivers and streams). Table 2 provides the stream-flow gages and their period of record to support hydrology calibration and validation. The locations of all flow gages are illustrated in Figure 6. 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*) and the MNDNR/MPCA Cooperative Stream Gaging network (*http://www.dnr.state.mn.us/waters/csg/index.html*).

Calibration is typically performed over at least a 5-year period with a range of hydrologic conditions from wet to dry. A single UCI was used for calibrating each model application. The calibration period is from 1996 to 2012 and was based on the National Land Cover Database (NLCD) 2006; the initial year (1995) was simulated to let the model adjust to existing conditions. The availability of flow data allowed for a long-term (at least 5 years) calibration to be performed at all primary calibration gages.

Table 2. Discharge Calibration Gages Within the South Fork Crow River Watershed

Gage	Gage Description	HSPF Reach I.D.	Drainage Area (mi^2)	Data Availability	Sample Count
19001001	South Fork Crow River near Cosmos MN7	610	223	2000–2012	3,165
19049002	South Fork Crow River at Hutchinson CSAH 25 (Adams Street)	670	446	2008–2012	2,011
19062001	South Fork Crow River near Biscay Lace Avenue	690	481	2002–2008	893
19069001	Buffalo Creek near Lakeside CSAH24	769	113	2002–2011	2,143
19073001	Judicial Ditch 15 near Buffalo Lake MN	789	100	2002–2012	2,477
19056001	Buffalo Creek at Brownton CR25	799	299	1998–2012	3,486
19043001	Buffalo Creek near Glencoe CR 1	815	374	1997–2012	3,958
19082001	South Fork Crow River near Mayer MN	850	1,151	1998–2012	3,931
19001001	South Fork Crow River at Delano Bridge Ave	910	1,269	1998–2012	4,576

For the validation, a UCI was created for each model application by using land-cover data derived from the NLCD [2001], and the calibration was run for three different time periods: 1996–2003, 2004–2012, and 1996–2012. Additionally, the model application's ability to maintain a high-quality calibration at multiple gages that represent the variability of the watershed while maintaining consistent parameters throughout each watershed is, in itself, a form of validation.

HYDROLOGY 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:

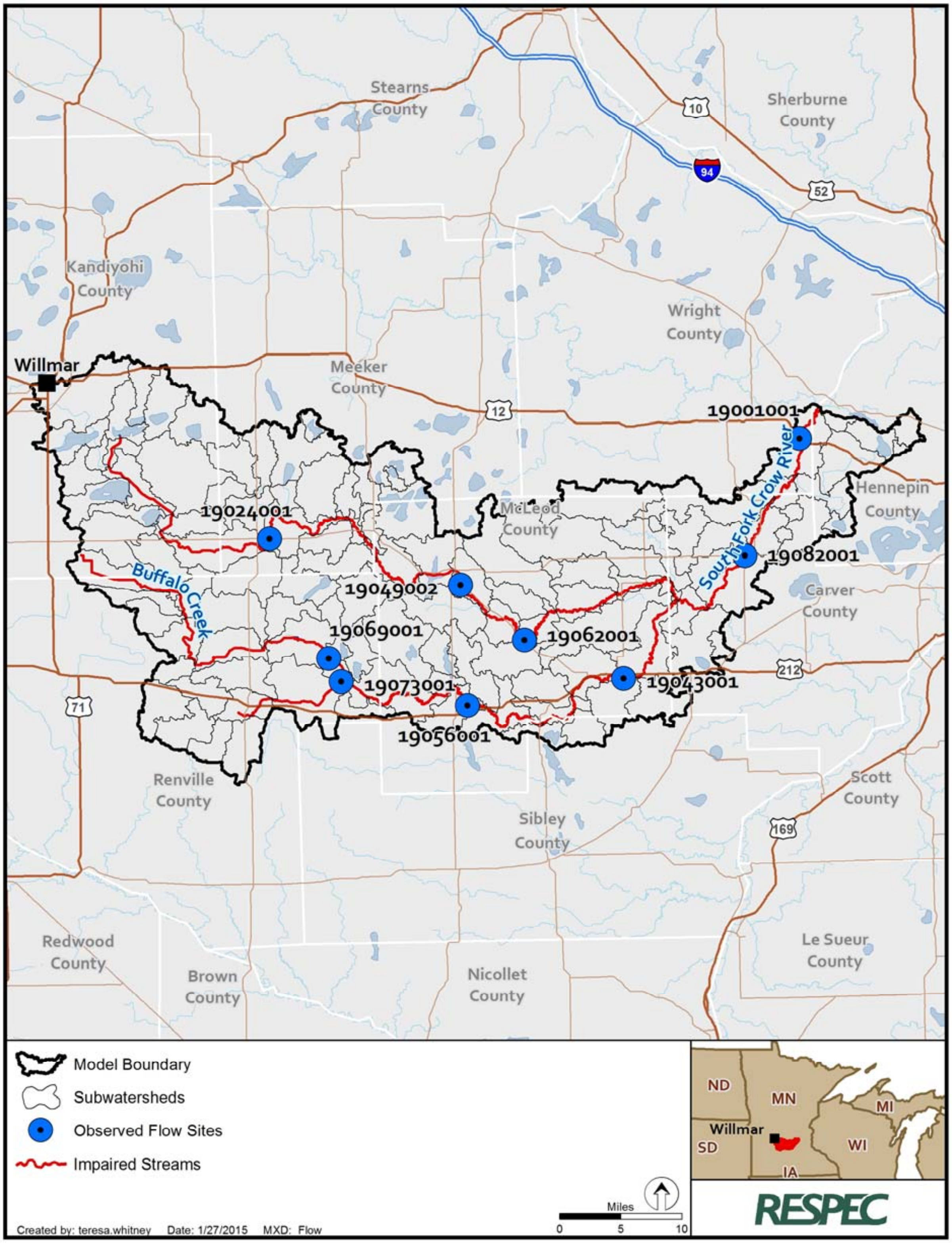

Figure 6. Flow Calibration Gages Within the South Fork Crow River Watershed.

- **Establish an annual water balance.** This consists of comparing the total annual simulated and observed flows (in inches) and is governed by meteorological inputs (rainfall and evaporation); the listed parameters LZSN (lower zone nominal storage), LZETP (lower zone evapotranspiration parameter), DEEPFR (deep groundwater recharge losses), and INFILT (infiltration index); and the factor applied to pan evaporation to calculate potential evapotranspiration.

- **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 evapotranspiration [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 water movement 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.

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 energy-balance method was chosen because it resulted in a better hydrologic calibration. Values for the density of cold, new snow relative to water (RDCSN), the wet bulb air temperature below which precipitation occurs as snow under saturated conditions (TSNOW), the factor to adjust evaporation/sublimation from the snowpack (SNOEVP), the factor to adjust the rate of heat transfer from the atmosphere to the snowpack because of condensation and convection (CCFACT), the maximum water content of the snow pack (MWATER), the maximum rate of snowmelt by ground heat (MGMELT), the factor by which the input precipitation will be multiplied to account for poor catch efficiency under snow conditions (SNOWCF), and the maximum snowpack at which the entire pervious land segment will be covered with snow (COVIND) 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 two locations and five locations north of the watershed, as illustrated in Figure 7. Greater weight was given to gages with a full period of record and located within the watershed. Calibration figures were constructed to compare observed snowfall to simulated snowfall, as illustrated in Figure 8 (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

Lake level is considered an important factor for the hydrology calibration. Lake-level data was compared to simulated lake level for 6 of the modeled lakes within the watershed (i.e., Big Kandiyohi, Otter, Preston, Eagle, Swede, and Oak) as a part of the calibration. The lake-level 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 9 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

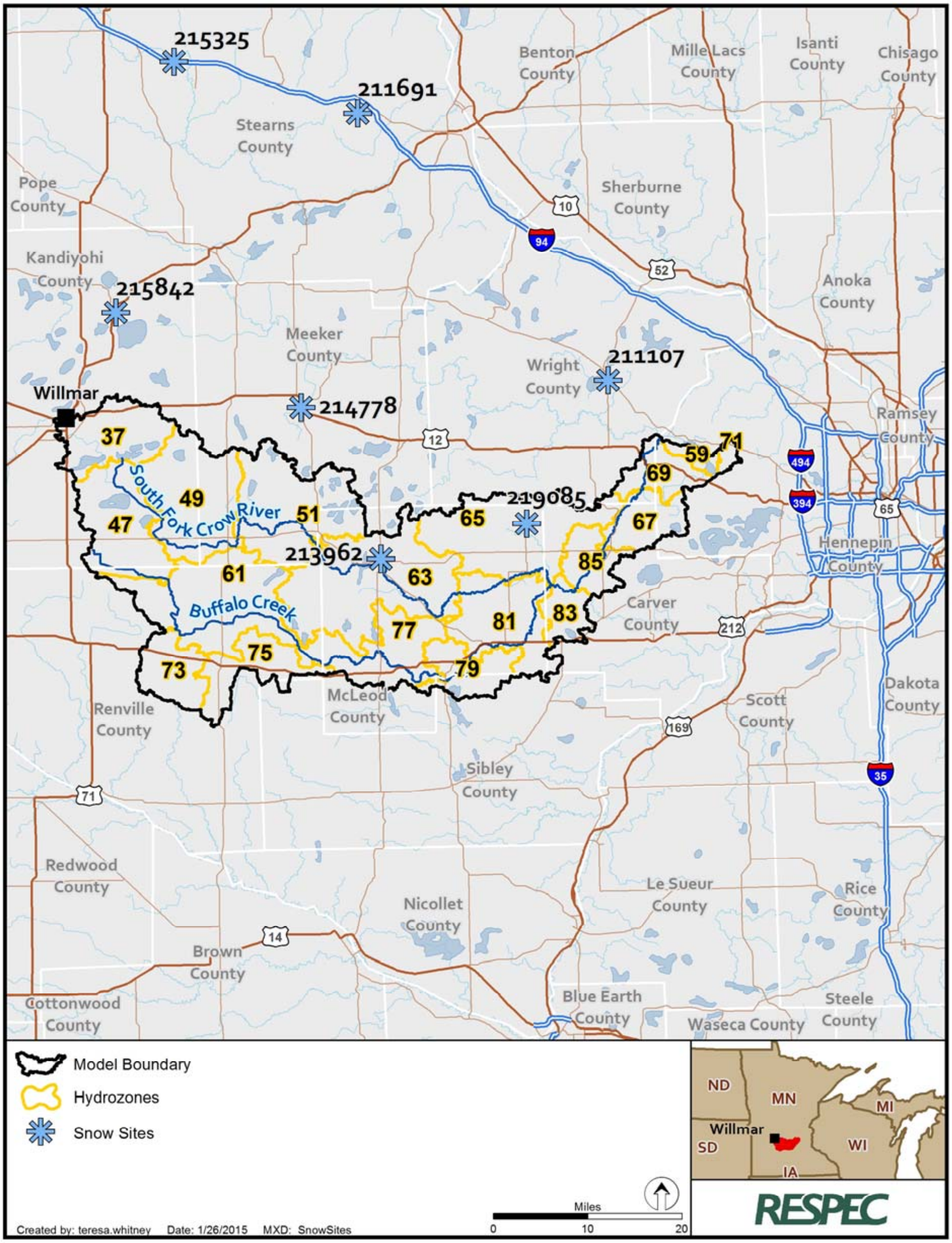

Figure 7. Meteorological Stations With Snow Data Used for Calibration.

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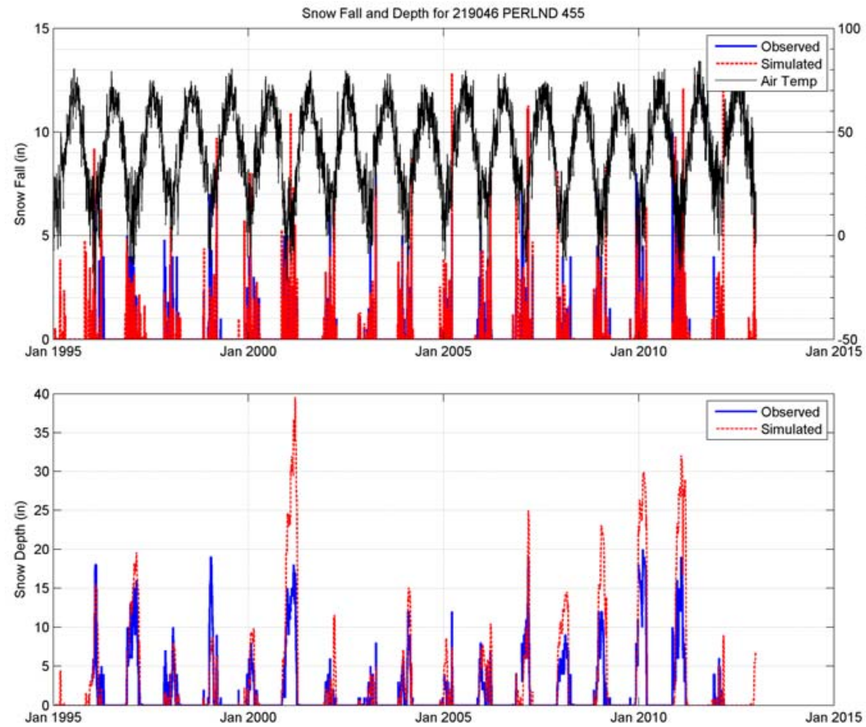

Figure 8. Snowfall (Top) and Snow Depth (Bottom) Calibration Example.

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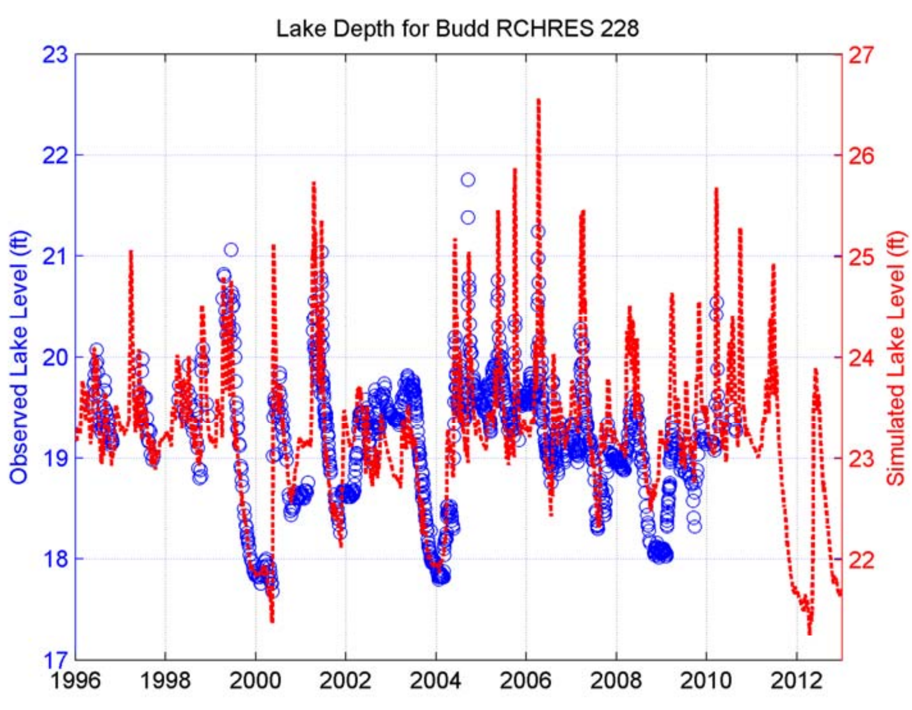

Figure 9. Lake-Level Calibration Example.

because of greater storage volumes associated with the same depths. These combined F-tables were evaluated by comparing patterns in the lake-level data instead of actual lake-level values. When lake level, hydrologic, or water quality data supported it, a groundwater base flow and nutrient load was added to some headwater lakes by using the NETWORK block in HSPF.

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 intraparameter 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.

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

Annual and monthly plots were used to visually compare runoff volumes over the contributing area. This method includes transferring the amount of flow (measured at each calibrated gage) to a volume of water (measured in inches 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 to verify that the annual water balances are reasonable and allow trends to be considered. Flow-frequency distributions, or flow-duration curves, present measured flow and simulated flow versus the corresponding percent of time the flow is exceeded. Thus, the flow-duration curves provide a clear way to evaluate model performance for various flow conditions (e.g., storm events or baseflow) and to determine which parameters to adjust to better fit the data. Daily flow time-series plots allow for analyzing individual storm events, snow accumulation and snowmelt processes, and baseflow trends. Examples of the daily flow time-series plots, monthly plots, annual plots, and flow-duration curves used for the calibration/validation process are illustrated in Figures 10 through 13, 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)**
- T**otal 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.

Model Performance Criteria

The calibration parameters were adjusted to improve the performance of the model until the preferred 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 3. The correlation coefficient (r) and the coefficient of determination (r^2) were compared with the criteria illustrated in Figure 14 to evaluate the performance of the

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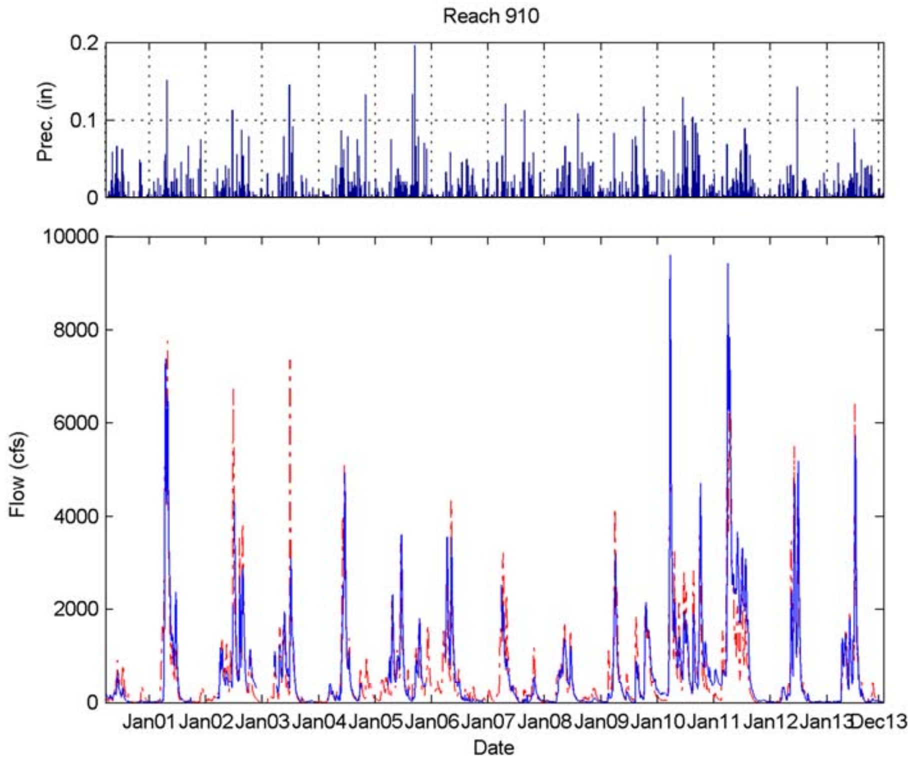

Figure 10. Daily Flow Time-Series Plot Example.

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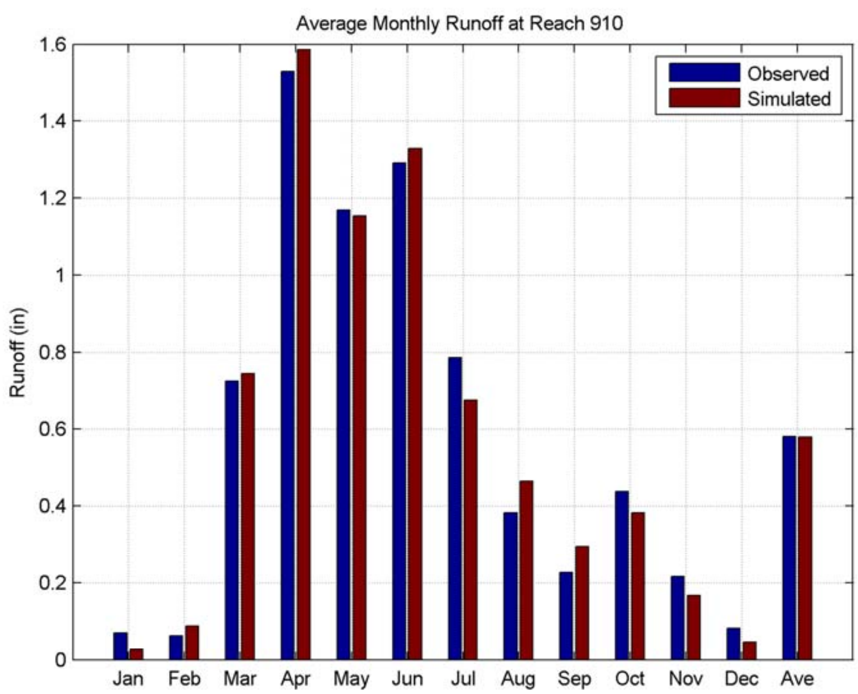

Figure 11. Average Monthly Runoff Plot Example.

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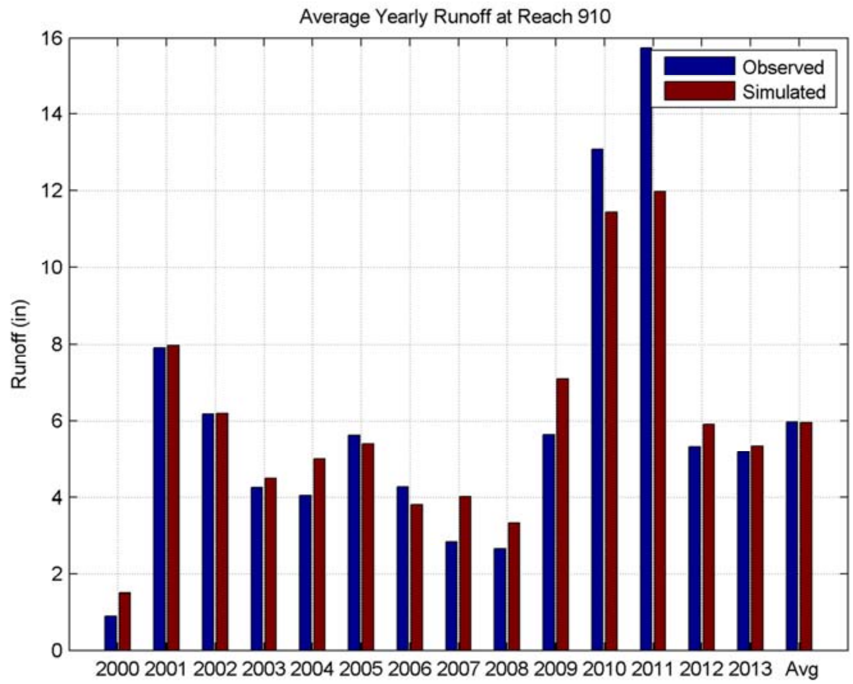

Figure 12. Average Yearly Runoff Plot Example.

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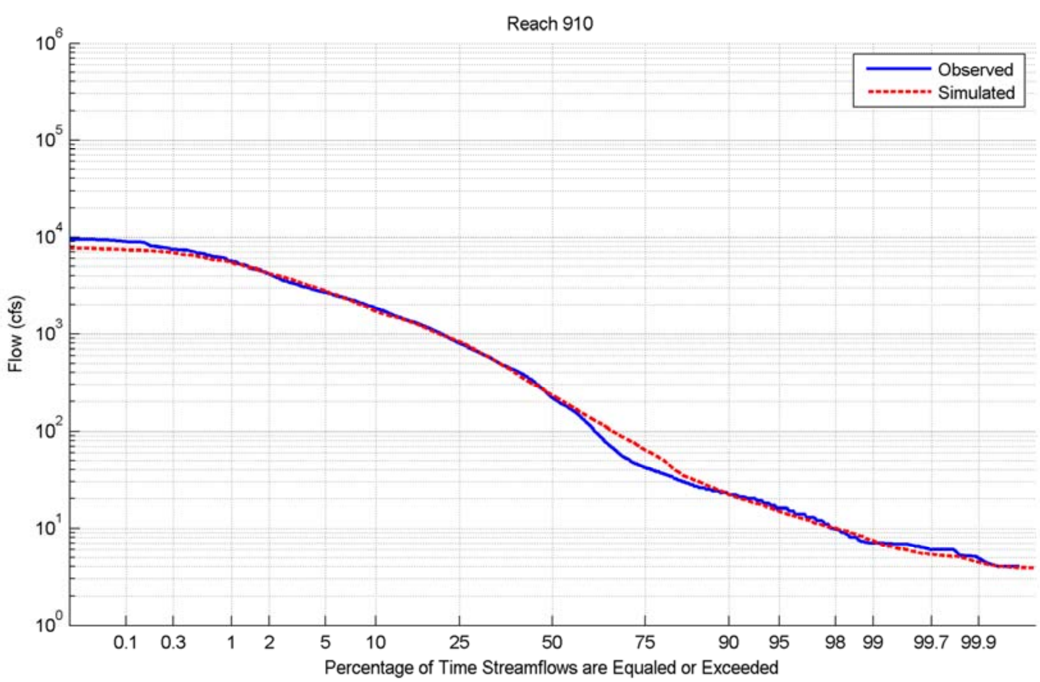

Figure 13. Flow-Duration Curve Example.

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. Donigian [2002] explains the developed performance criteria in detail.

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

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

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

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Figure 14. General Calibration/Validation *R* and R^2 Targets for HSPF Applications.

CALIBRATION RESULTS

The hydrology calibration was performed with emphasis on the downstream gage in the South Fork Crow River Watershed. The gages on the smaller tributaries were used ensure that the land-use drainages were properly represented in the model. The calibration results for the South Fork Crow River Watershed most downstream, mainstem gage are very good with respect to the calibration and validation targets (Figure 14). 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 4 provides results for mainstem gages in the South Fork Crow River Watershed model application. Table 5 summarizes the weighted water balance components at the outlet of the South Fork Crow River Watershed model application, and Attachment A contains hydrologic calibration figures for mainstem gages in the South Fork Crow River Watershed.

WATER QUALITY CALIBRATION

The water quality constituents that were modeled in the South Fork Crow River Watershed include TSS, temperature, DO, biochemical oxygen demand (BOD), and nutrients. The methods

Table 4. Summary Statistics for Calibration Gages in the South Fork Crow River Watershed

Observed Flow Gage	HSPF Reach I.D.	Total Runoff Volume			Monthly			Daily			Storm Error (%)	
		Obs (in)	Sim (in)	% Δ	R	R^2	MFE	*R*	R^2	MFE	Volume	Peak
19001001	610	5.61	4.90	–12.58	0.92	0.85	0.84	0.87	0.76	0.75	–12.15	–19.79
19049002	670	7.36	6.95	–5.63	0.93	0.86	0.85	0.90	0.81	0.81	–3.16	–10.43
19062001	690	1.86	2.06	10.84	0.92	0.84	0.80	0.91	0.83	0.78	8.33	10.91
19082001	850	6.22	5.86	–5.72	0.96	0.91	0.91	0.91	0.83	0.83	–5.76	-6.66
19001001	910	5.98	5.96	–0.26	0.95	0.90	0.90	0.90	0.82	0.81	–0.20	8.78

described in the following section provide RESPEC with the ability to estimate TSS, temperature, DO, and nutrient loads; calculate contributions from point, nonpoint, and atmospheric sources where necessary; and provide a means to evaluate the impacts of alternative management strategies to reduce these loads and improve water quality conditions. The model applications apply empirical buildup/washoff functions. Separate UCIs were created to represent land-use changes for the hydrology calibration. To use the largest possible dataset, the water quality calibration was completed on the entire modeling period (1995 through 2012) and was based on the NLCD 2006 land-use data.

Table 5. Summary of Water-Balance Components

Water-Balance Component	Water-Balance Component Description	Percent
SURO	Surface outflow	0.8
IFWO	Interflow outflow	10.2
AGWO	Active groundwater outflow	10.8
IGWI	Inflow to inactive groundwater	0.3
CEPE	Evaporation from interception storage	16.6
UZET	Evapotranspiration from upper zone	23.0
LZET	Evapotranspiration from lower zone	33.9
AGWET	Evapotranspiration from active groundwater storage	0.3
BASET	Evapotranspiration from active groundwater outflow (baseflow)	3.3

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 and turbidity, which allows the model TSS predictions to support future total maximum daily load (TMDL) studies. The calibration focus was at locations where TSS concentration data are available. TSS concentration data are widely available, while suspended sediment concentrations (SSC) are more limited. The model application is capable of identifying sources of sediment and the processes that drive sediment erosion, delivery, and transport in the watersheds, as well as point-source sediment contribution.

The sediment-parameter estimation and calibration was performed according to guidance from the 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 nearby models when appropriate, and 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 [U.S. EPA, 2006].

Sediment erosion and delivery and in-stream sediment transport were represented in the sediment model application. Parameters that predict 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. The primary calibration parameters involved in landscape erosion simulation are the coefficients and exponents from three equations that represent 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 wash off or transport equation; and KGER and JGER are the coefficient and exponent, respectively, from the matrix soil equation, which simulates gully erosion. KRER was estimated as the soil erodibility coefficient from the RUSLE equation, 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.

After landscape sediment erosion rates were adjusted to provide the expected loading to the stream channel, calibration was continued with adjusting parameters governing the processes of deposition, scour, and transport of sediment within the stream. Calibration was performed on a reach-by-reach basis from upstream to downstream because downstream reaches are influenced by upstream parameter adjustments. Sediment behavior was adjusted to approximate a dynamic steady-state condition where none of the sediment classes (sand, silt and clay) were dramatically accumulating or eroding. Bed behavior and sediment budgets were analyzed at each reach to ensure that the results are consistent with field observations, historical reports, and expected behavior from past experience. The initial composition of the channel beds was estimated by 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. Silt and clay are transported when the bed shear stress is higher than TAUCD, and they settle and deposit when the bed shear stress is lower than TAUCD. Sediment is scoured from the bed when the shear stress is greater than TAUCS. The erodibility parameter (M) for silt and clay determines the intensity of scour when it is occurring. KSAND and EXPSAND are the coefficient and exponent of the sand transport power function, respectively.

A significant amount of tile drainage exists in the South Fork Crow River Watershed. This artificial drainage is being implicitly represented in HSPF by using a shallow subsurface flow component called interflow. Interflow was given a concentration based on the simulated TSS concentration multiplied by a reduction factor to account for the settling of the simulated surface concentration before it enters the artificial drainage network. Agricultural modifications during planting and harvesting can increase the amount of sediment that is readily transported by overland flow. Detached sediment storage (DETS) in HSPF represents the sediment on the surface that is available to wash off. To represent agricultural practices on cropland, DETS was increased at four different days of the year to simulate the increases in sediment available to wash off from plowing, planting, cultivating, and harvesting practices. Cropland classified as high-till was given higher increases in DETS than cropland classified as low-till.

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

The model application simulates in-stream temperature (using HTRCH), organic and inorganic nitrogen, total ammonia, organic and inorganic phosphorus (using NUTRX), DO and BOD (using OXRX), and algae (using PLANK). The adsorption/desorption of total ammonia and orthophosphate to sediment was also simulated. Modeled output can be used to support the MPCA's activities for TMDL development, in-stream nutrient criteria compliance testing, and point-source permitting support. Initial calibration parameters were estimated from nearby 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, and BOD were simulated through accumulation and depletion/removal and a first-order washoff rate from overland flow. Because of the affinity of orthophosphate to bind to sediments, orthophosphate was simulated using a linear relationship with sediment washing off the land. 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 applicable counties by using information provided in the MPCA Individual Sewage Treatment Systems (ISTS) report [MPCA, 2004]. The number of ISTS in each subwatershed were estimated using Geographic Information Systems (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 BOD–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 was configured to simulate the in-stream and lake processes that contribute to algal growth, nutrient consumption, and dissolved oxygen dynamics. All required in-stream parameters were specified for total ammonia, inorganic nitrogen, orthophosphate, and BOD. The 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 ideally would have observed values of temperature, DO, BOD, nitrogen species (nitrate/nitrite, ammonia, and Kjeldahl nitrogen [TKN]), 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 and the USGS. Figure 15 shows the spatial locations of stream and lake ambient water quality data. Table 6 summarizes TSS, water temperature, DO, BOD, chlorophyll *a*, ammonia, TKN, nitrate/nitrite, orthophosphate, TN, and TP ambient water quality monitoring data available at each site.

The number of total nitrogen samples is limited, but it can be calculated by summing concurrent samples of nitrate, nitrite, and TKN. Similarly, organic nitrogen can be calculated as the difference between concurrent samples of TKN and ammonia-nitrogen.

The final results from the most data-intensive downstream reach in the South Fork Crow River Watershed are included in Attachment B. 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 South Fork Crow River deliverables results folder.

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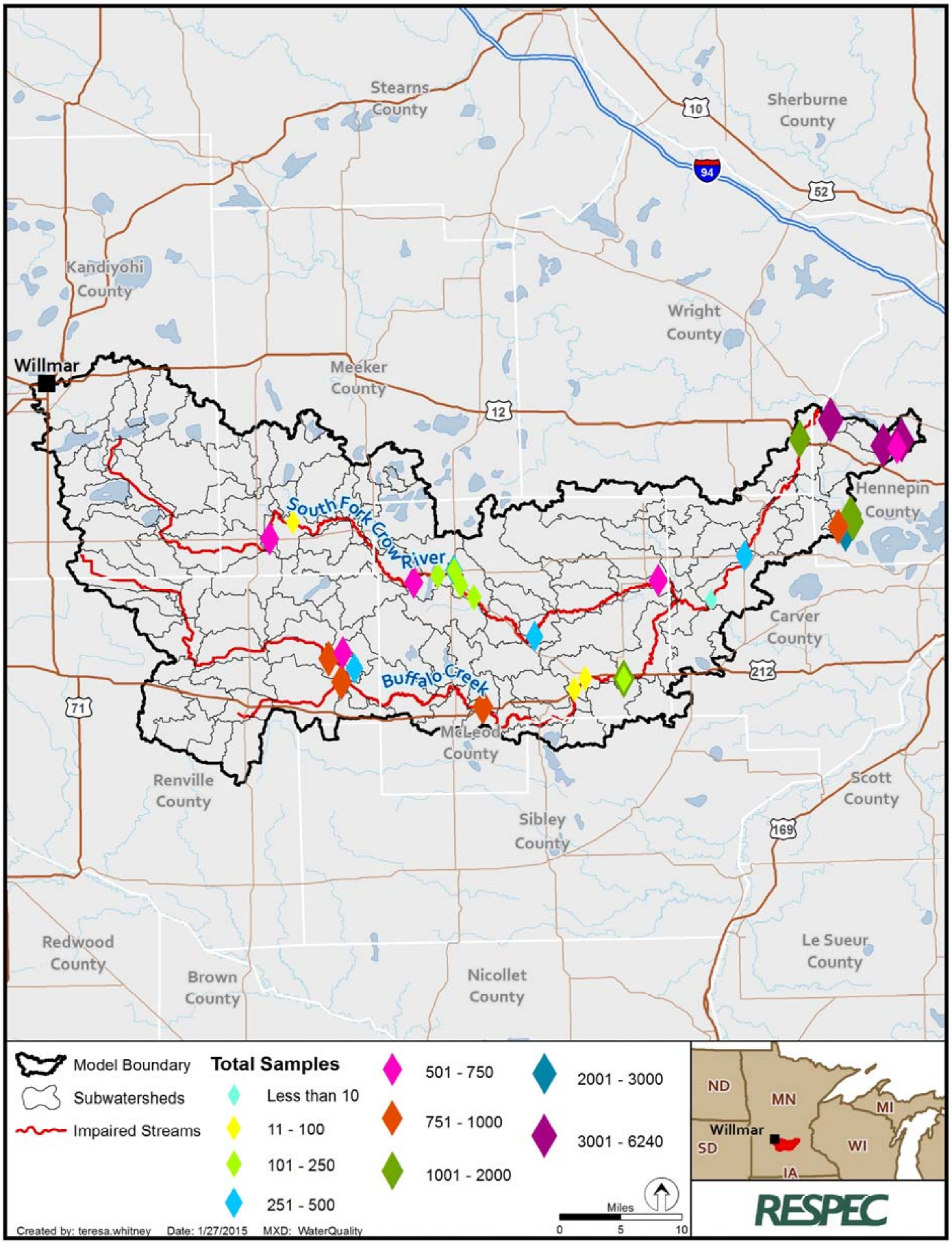

Figure 15. Sites with Water Quality Data.

Table 6. Stream and Lake Sites With Any Applicable Constituent (Page 1 of 4)

Site I.D.	Reach I.D.	Number of Samples											
		BOD[(a)]	Chlorophyll *a*	DO[(b)]	Suspended Solids	Water Temperature	TAM[(c)]	TKN[(d)]	NO2+NO3[(e)]	TN[(f)]	T-ORTHO[(g)]	TP[(h)]	Total
34-0072-00	528		16	29	15	28		15	15			11	129
S004-750	531	5	11	9	7	11	6		5			11	65
34-0086-00	532		25	15	9	31		9	5			23	117
34-0169-03	536		15	14	8	27		8	5			12	89
34-0076-00	542		16	31	15	27		15	15			11	130
34-0105-00	544		21			1						22	44
34-0096-00	546		26		5	1		5	5			22	64
34-0022-02	558		12	34	10	34		10	10			12	122
47-0129-00	618		16	60	15	52		15	15			11	184
S000-575	630				27			29				29	85
S002-015	630	30	14	87	72	89	59	58	46		3	71	529
43-0104-00	631		25	81	19	86	3	20	13	2	1	33	283
43-0115-00	632		25	55	16	57		17	10			22	202
47-0062-00	634		10	48	10	45		10	8			18	149
47-0061-00	636		9									9	18
47-0106-00	638		10									10	20
S006-990	639			21		21							42
65-0013-00	646		14	14	14	13		14	14			10	93
05278560	650			6		6				2		2	16
S002-014	650	30	13	85	70	87	56	54	47		3	71	516
43-0085-01	660		25	39	22	38		21	10			20	175
05278570	670			1		1		1		1		1	5
05278580	670			7		7		1		3		3	21
S000-353	670	3		49	49	51	48	49	49		12	49	359
S001-514	670			43		61							104
S001-844	670			43		81							124

Table 6. Stream and Lake Sites With Any Applicable Constituent (Page 2 of 4)

Site I.D.	Reach I.D.	Number of Samples											
		BOD[(a)]	Chlorophyll *a*	DO[(b)]	Suspended Solids	Water Temperature	TAM[(c)]	TKN[(d)]	NO2+NO3[(e)]	TN[(f)]	T-ORTHO[(g)]	TP[(h)]	Total
S001-845	670			43		86							129
05278590	690			7		7		1		3		3	21
S000-051	690								4		4	4	12
S000-395	710	14	6	55	46	57	39	37	32		12	45	343
43-0034-00	718		21	21	16	20		17	10			17	122
S006-992	733			21		21							42
43-0014-00	738		20	11	5	9	1	10	8		3	19	86
S005-079	741				9			9				9	27
43-0012-00	742		20	17	15	16		10	10			15	103
10-0127-00	744		37	48		50		54				54	243
S006-991	745			20		20							40
S004-231	747				14		14	14				14	56
S001-443	750	17	5	103	70	106	56	72	57		26	73	585
S002-017	769	45	30	144	113	150	35	71	69		27	112	796
S005-366	771				11			5				11	27
S005-807	771				6							6	12
65-0006-00	772		66	80	73	71	2	26	82		60	107	567
S005-365	773				7			6				7	20
65-0002-00	774		44	67	24	55	2	25	23		1	40	281
S002-016	789	48	29	155	125	147	48	89	81		28	130	880
43-0098-00	793		13		10			10	10			10	53
43-0084-00	796		44		21			21	15			42	143
S000-460	801	50	31	153	140	169	54	105	90		30	144	966
S000-458	805					88							88
05278880	811			1		1		1		1		1	5

Table 6. Stream and Lake Sites With Any Applicable Constituent (Page 3 of 4)

Site I.D.	Reach I.D.	Number of Samples											
		BOD[a]	Chlorophyll *a*	DO[b]	Suspended Solids	Water Temperature	TAM[c]	TKN[d]	NO2+NO3[e]	TN[f]	T-ORTHO[g]	TP[h]	Total
S000-531	811				8	20		9				9	46
05278930	815				1	29							30
S000-528	815				8	21		9				9	47
S000-582	815	51	33	157	195	196	58	107	94		30	142	1,063
S001-506	815					248							248
S005-396	815					44							44
S000-579	821	1		22		22							45
S000-580	821					130							130
S003-629	830					11							11
S003-909	841				7	5	7	7				7	33
10-0121-00	842		143	263		257		210				226	1,099
S002-498	843			5	8	28	8	8				8	65
S000-165	850	16	23	33	66	43	48	63	65		2	66	425
S001-731	850			2	2	2	1		2				9
10-0104-00	863			1		1		1				1	4
S001-801	870			2	2	65	1		2				72
S001-827	870			14	4	29	4	4				4	59
10-0095-00	892		144	87		183		169				177	760
10-0093-00	894		106	87		115		115				115	538
10-0094-00	895		11							11	11	11	44
27-0179-01	896		73	623	2	758	3	116	14	1	28	160	1,778
27-0179-02	896		41	549		560				43	7	44	1,244
27-0184-01	896		106	199		190		47	11	65	73	140	831
27-0184-02	896		172	1,029		1,035	1	87	12	127	134	308	2,905
S005-812	897				19						17	19	55
27-0149-00	898		183	1,397	4	1,468		4	15	176	186	285	3,718

Table 6. Stream and Lake Sites With Any Applicable Constituent (Page 4 of 4)

Site I.D.	Reach I.D.	Number of Samples											
		BOD[a]	Chlorophyll *a*	DO[b]	Suspended Solids	Water Temperature	TAM[c]	TKN[d]	NO2+NO3[e]	TN[f]	T-ORTHO[g]	TP[h]	Total
27-0152-00	898		71	184		185			11	60	63	74	648
27-0176-00	902		247	2,418		2,500			11	234	327	503	6,240
S005-811	903			76	19	77					18	19	209
27-0178-00	905		1					1				1	3
86-0032-00	905		11							11	11	11	44
S006-369	905	2	1	43	1	44	1	1	1		1		95
27-0192-00	922	4	173	1,038		1,030			10	165	242	345	3,007
S001-255	930	36	36	186	242	248	87	230	231		224	180	1,700

(a) BOD = Biochemical Oxygen Demand

(b) DO = Dissolved Oxygen

(c) TAM = Total Ammonia

(d) TKN = Total Kjeldahl Nitrogen

(e) NO2 + NO3 = Nitrate-Nitrite

(f) TN = Total Nitrogen

(g) T-ORTHO = Total Orthophosphate

(h) TP = Total Phosphorus

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Thank you for reviewing the methods for the extension and recalibration for the South Fork Crow 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,

Drew Ackerman
Principal Consultant

DA:llf

cc: Project Central File 2418 — Category A

ATTACHMENT A

SOUTH FORK CROW WATERSHED MAINSTEM HYDROLOGY CALIBRATION FIGURES

RSI-2418-15-016

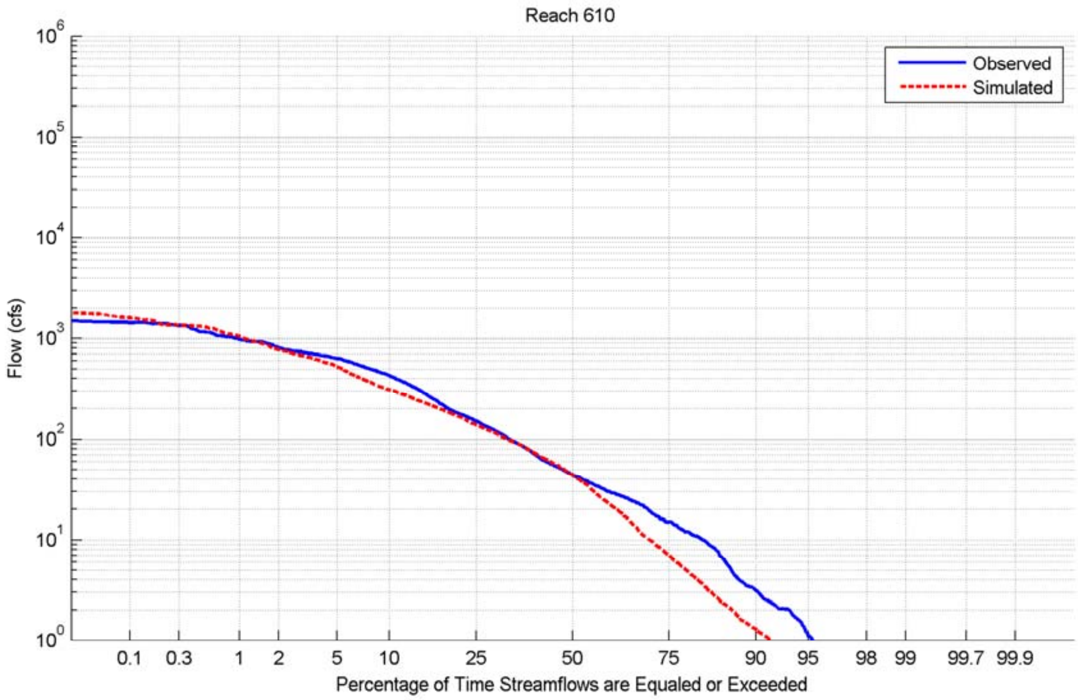

Figure A-1. Flow Duration Curve at Reach 610.

RSI-2418-15-017

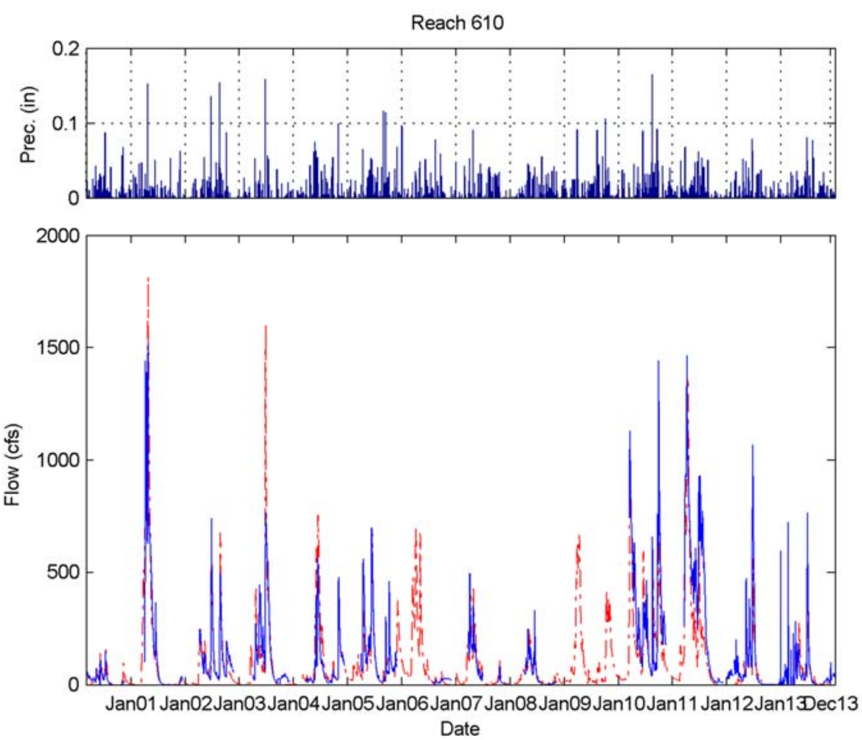

Figure A-2. Discharge Time Series at Reach 610.

RSI-2418-15-018

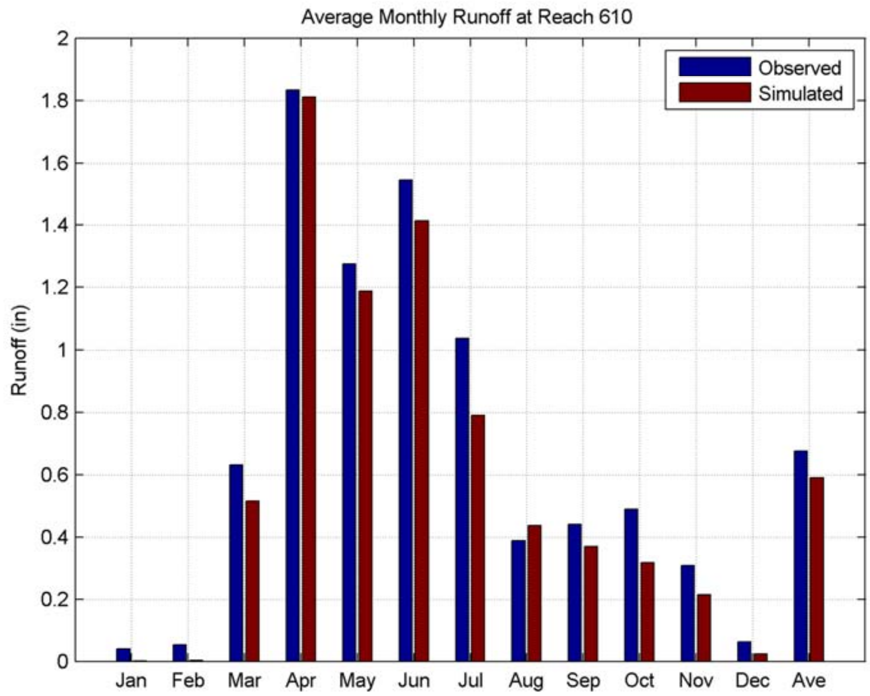

Figure A-3. Average Monthly Runoff at Reach 610.

RSI-2418-15-019

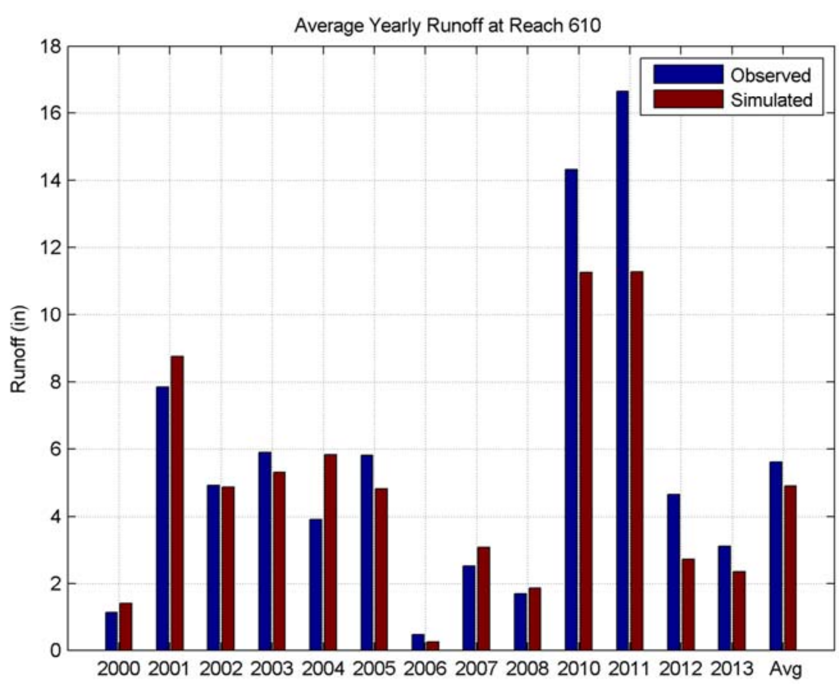

Figure A-4. Average Yearly Runoff at Reach 610.

RSI-2418-15-020

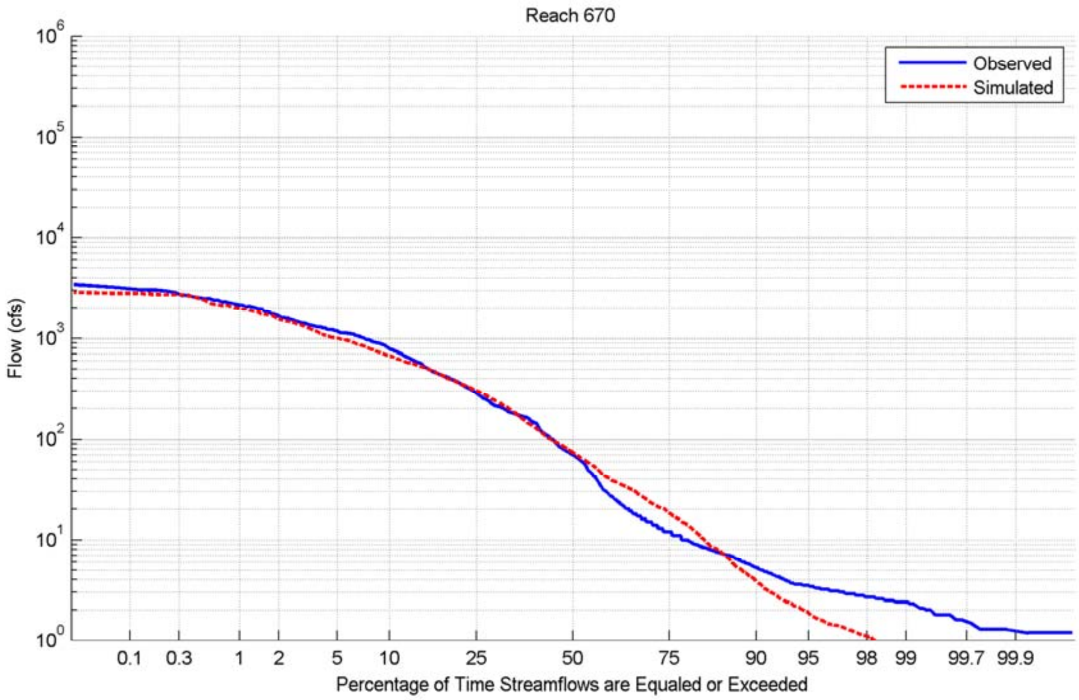

Figure A-5. Flow Duration Curve at Reach 670.

RSI-2418-15-021

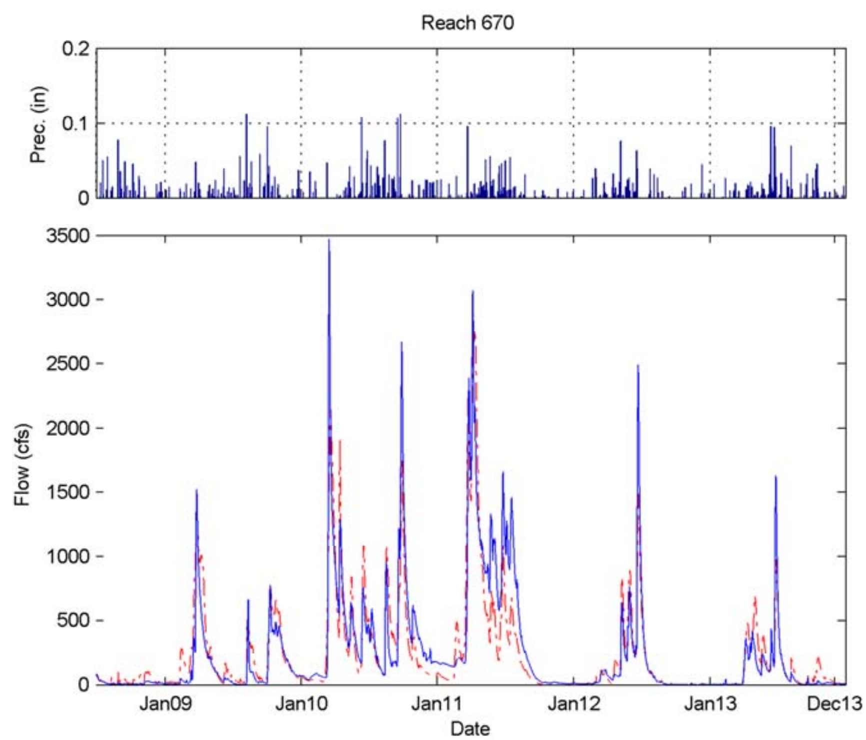

Figure A-6. Discharge Time Series at Reach 670.

RSI-2418-15-022

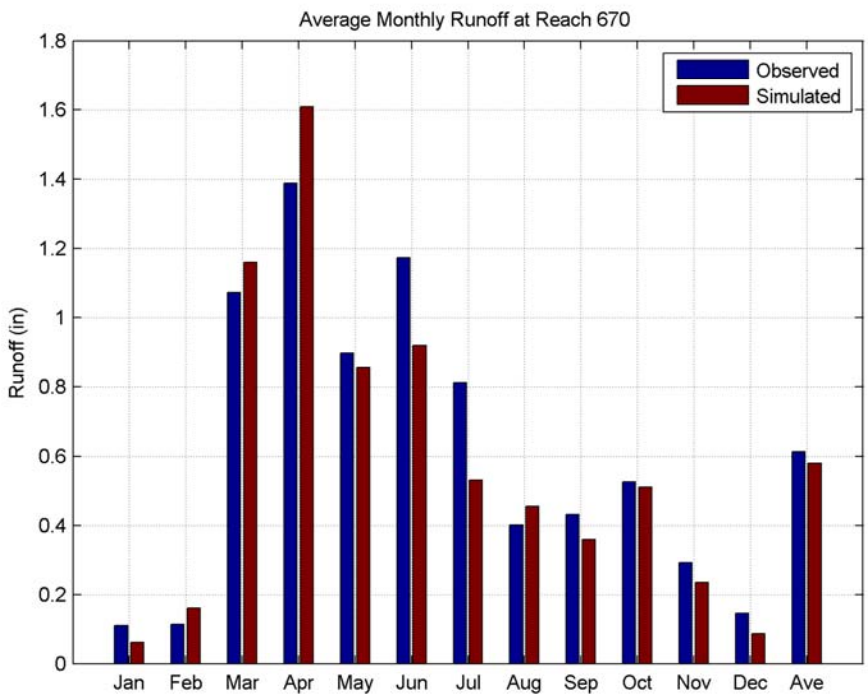

Figure A-7. Average Monthly Runoff at Reach 670.

RSI-2418-15-023

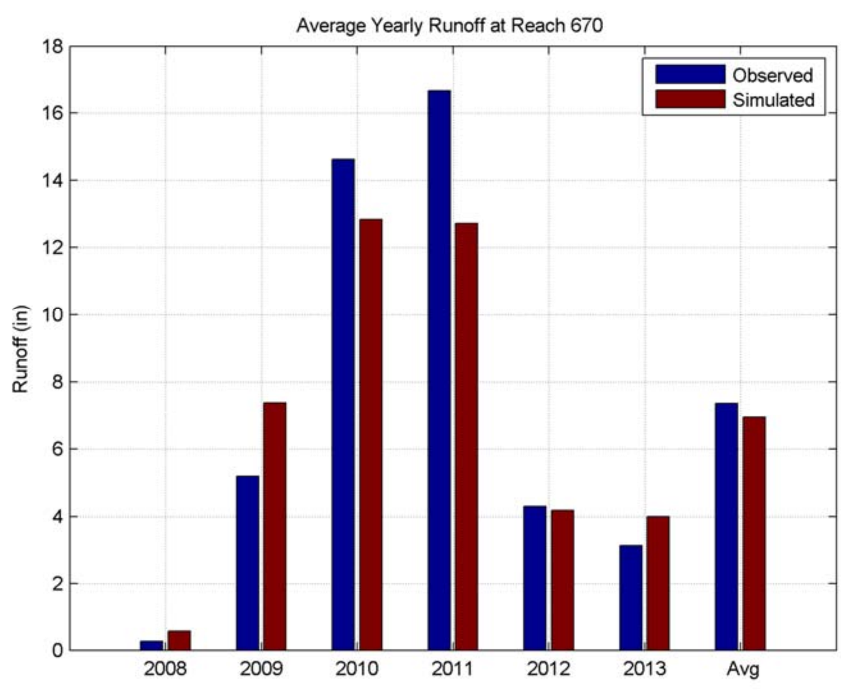

Figure A-8. Average Yearly Runoff at Reach 670.

RSI-2418-15-024

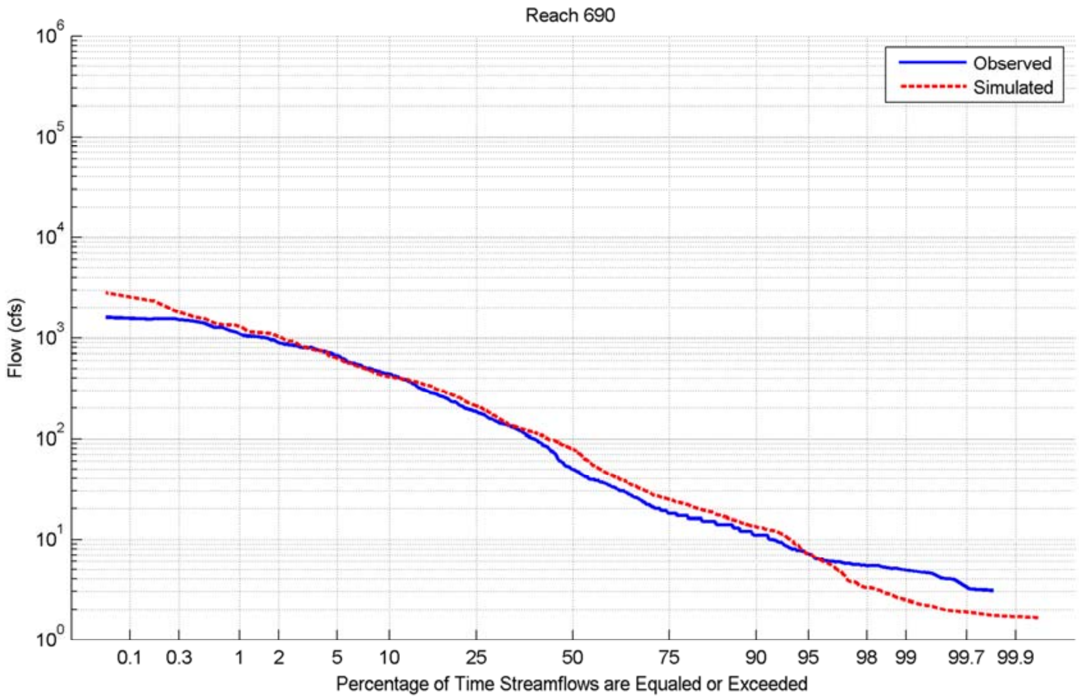

Figure A-9. Flow Duration Curve at Reach 690.

RSI-2418-15-025

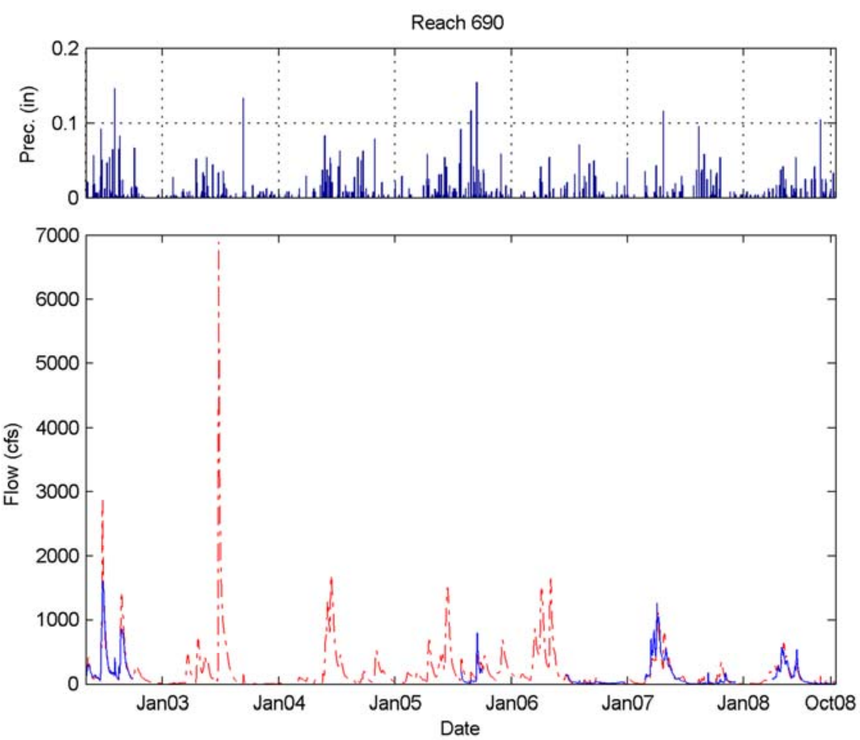

Figure A-10. Discharge Time Series at Reach 690.

RSI-2418-15-026

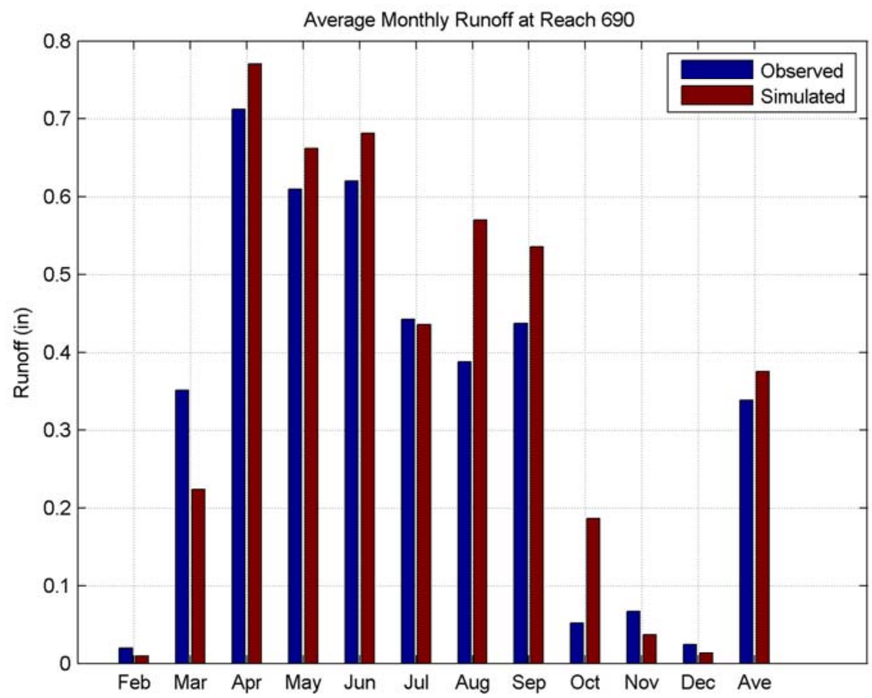

Figure A-11. Average Monthly Runoff at Reach 690.

RSI-2418-15-027

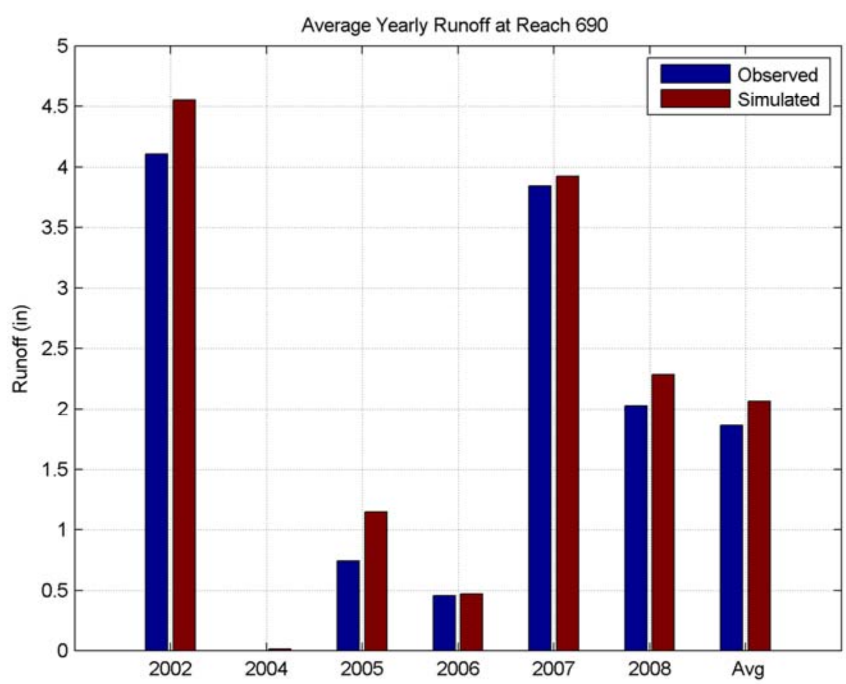

Figure A-12. Average Yearly Runoff at Reach 690.

RSI-2418-15-028

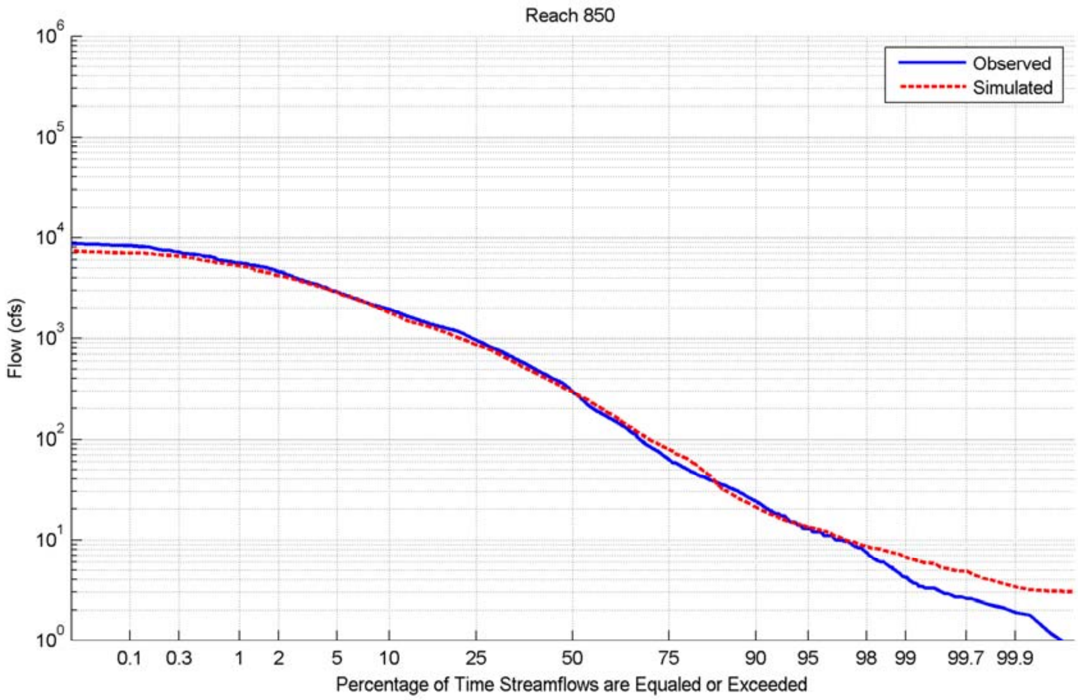

Figure A-13. Flow Duration Curve at Reach 850.

RSI-2418-15-029

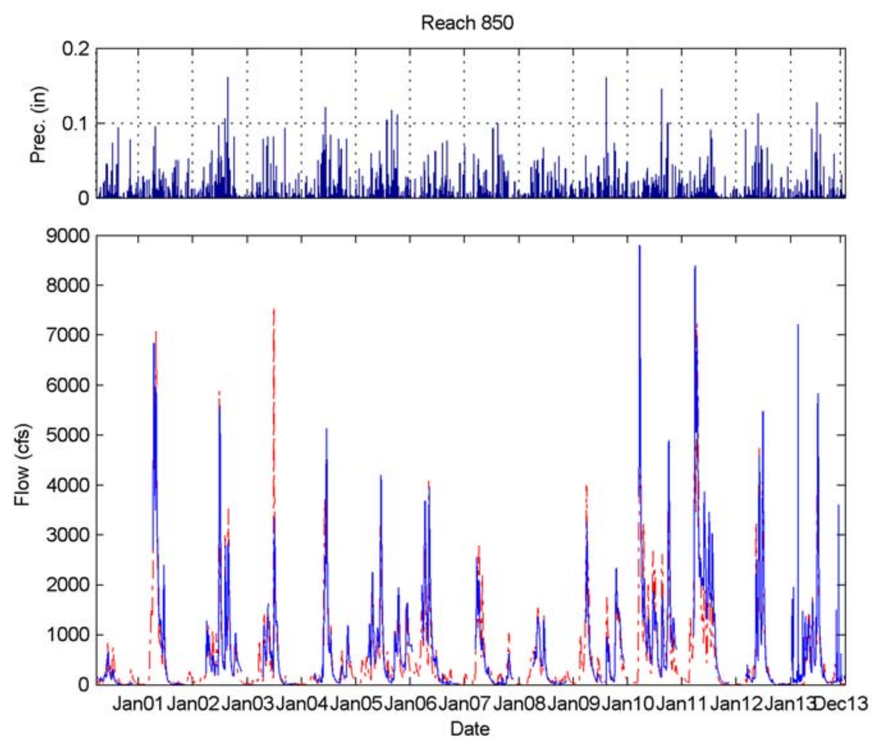

Figure A-14. Discharge Time Series at Reach 850.

RSI-2418-15-030

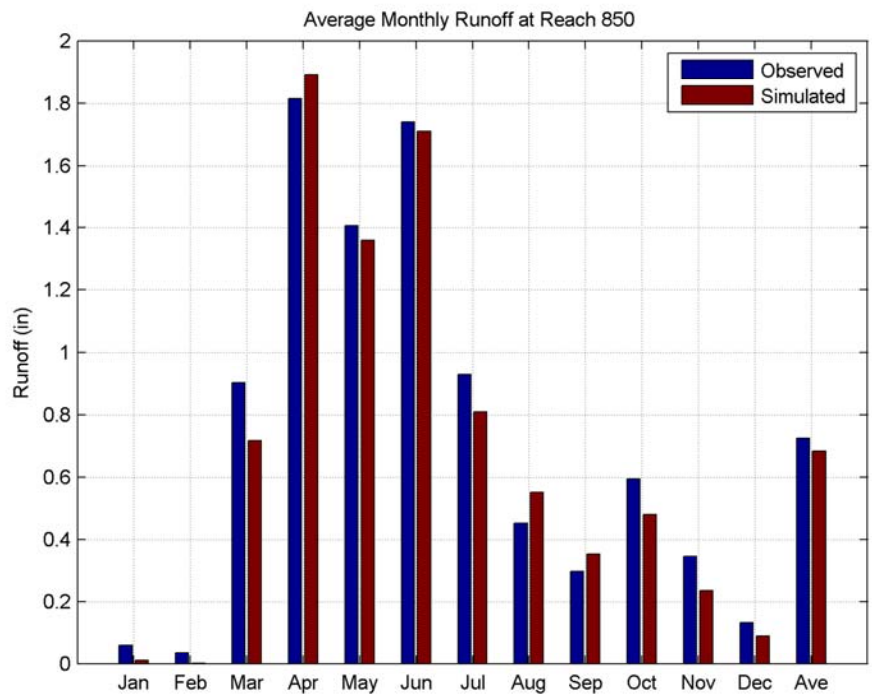

Figure A-15. Average Monthly Runoff at Reach 850.

RSI-2418-15-031

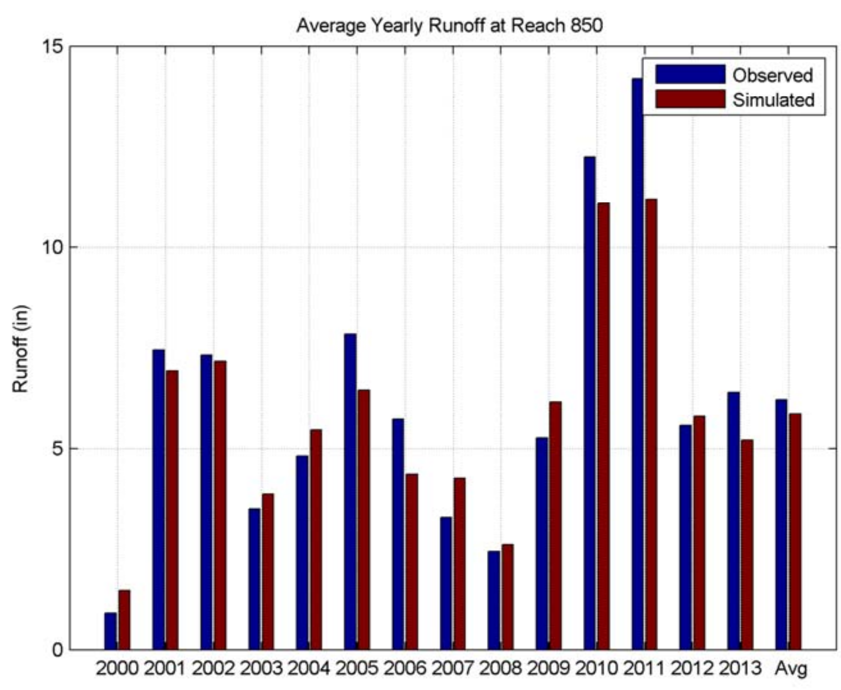

Figure A-16. Average Yearly Runoff at Reach 850.

RSI-2418-15-032

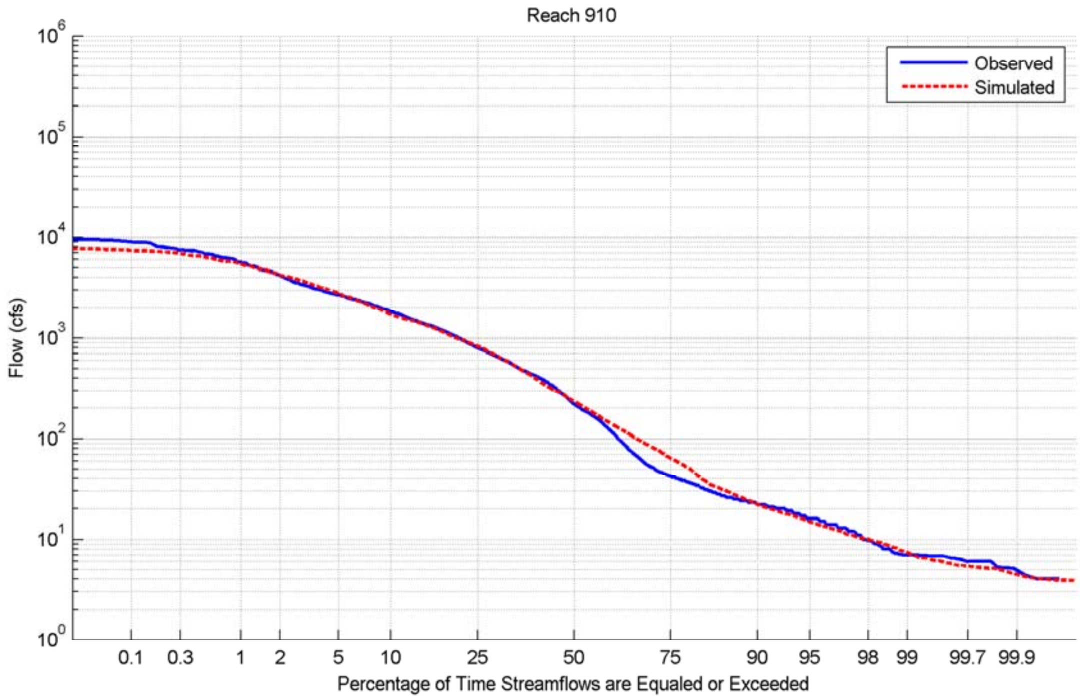

Figure A-17. Flow Duration Curve at Reach 910.

RSI-2418-15-033

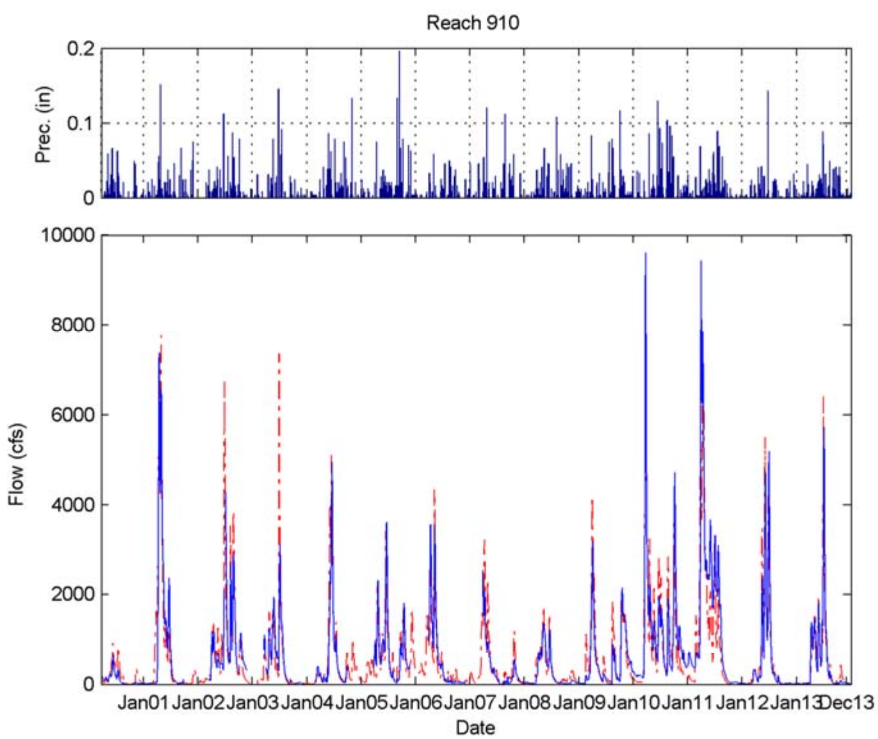

Figure A-18. Discharge Time Series at Reach 910.

RSI-2418-15-034

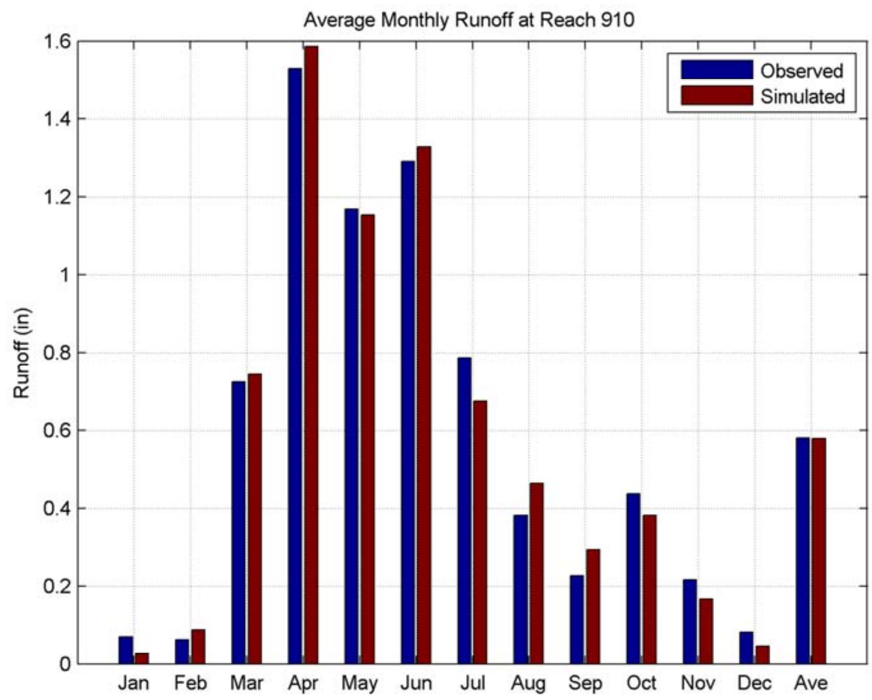

Figure A-19. Average Monthly Runoff at Reach 910.

RSI-2418-15-035

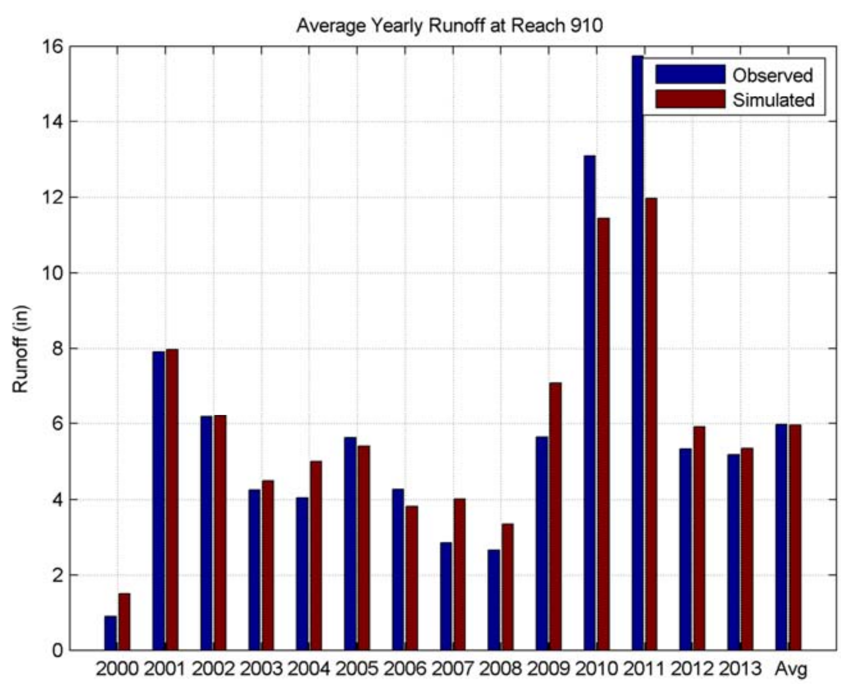

Figure A-20. Average Yearly Runoff at Reach 910.

ATTACHMENT B

SOUTH FORK CROW WATERSHED
WATER-QUALITY CALIBRATION FIGURES

RSI-2418-15-036

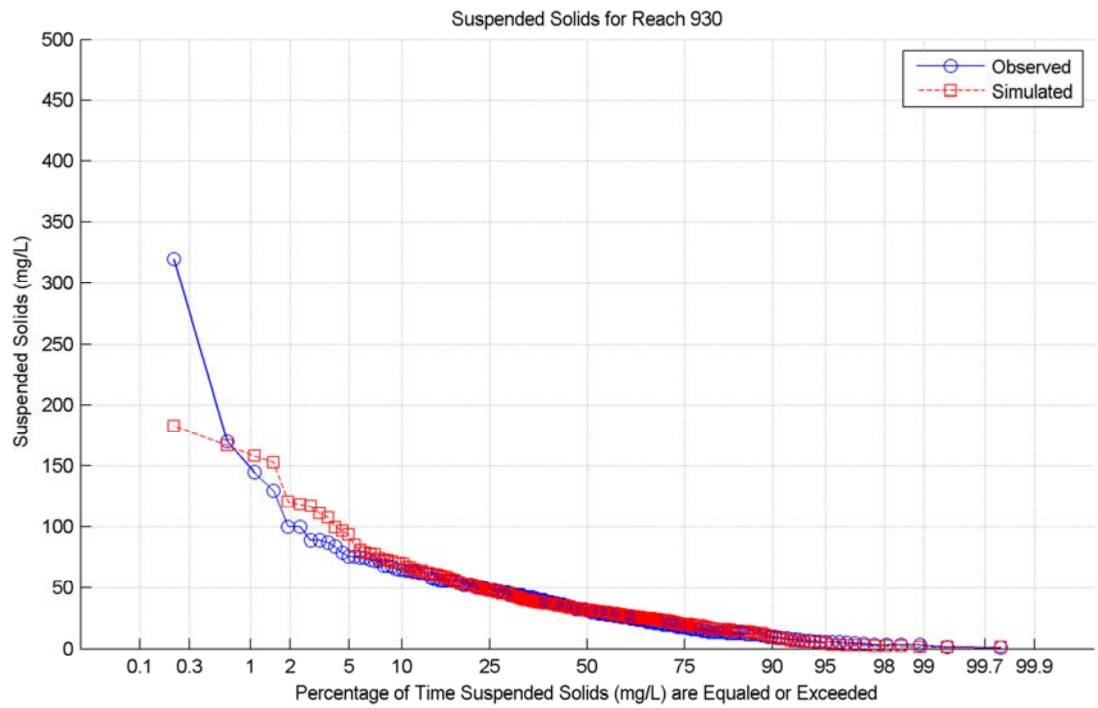

Figure B-1. Suspended Solids Concentration Duration Curve at Reach 930.

RSI-2418-15-037

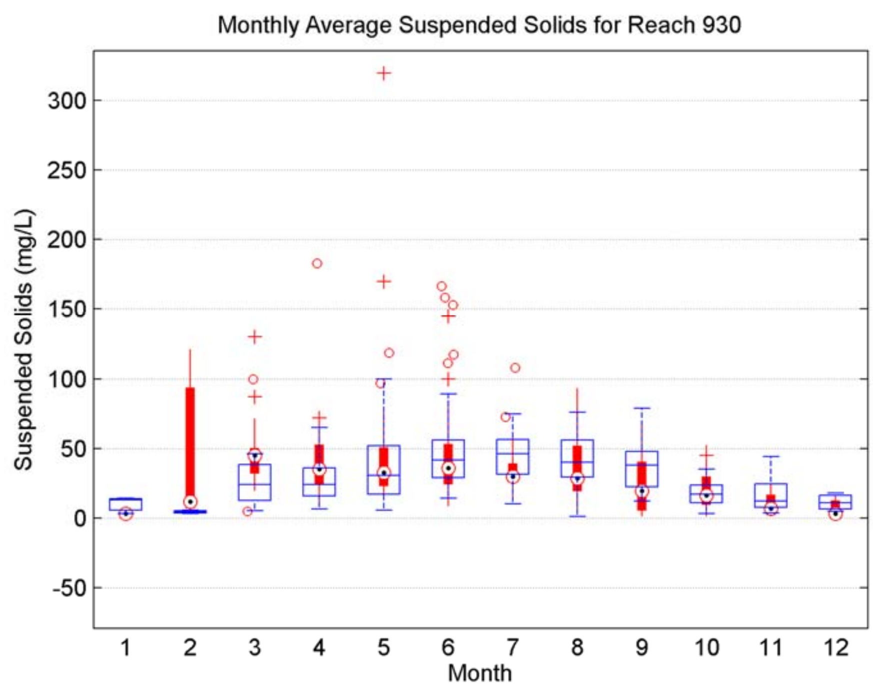

Figure B-2. Suspended Solids Monthly Averages at Reach 930.

RSI-2418-15-038

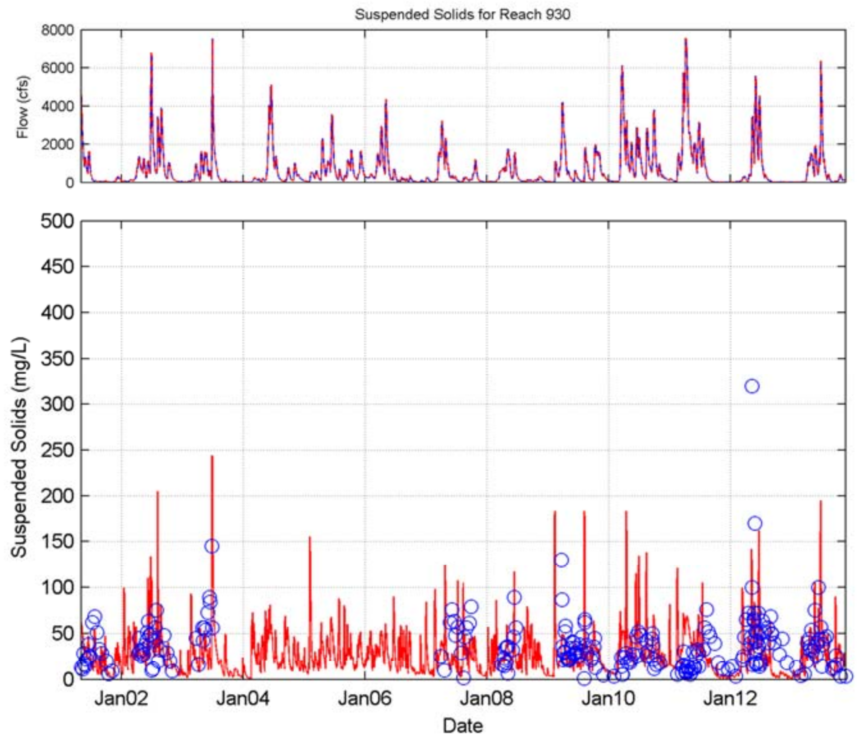

Figure B-3. Suspended Solids Daily Time Series at Reach 930.

RSI-2418-15-039

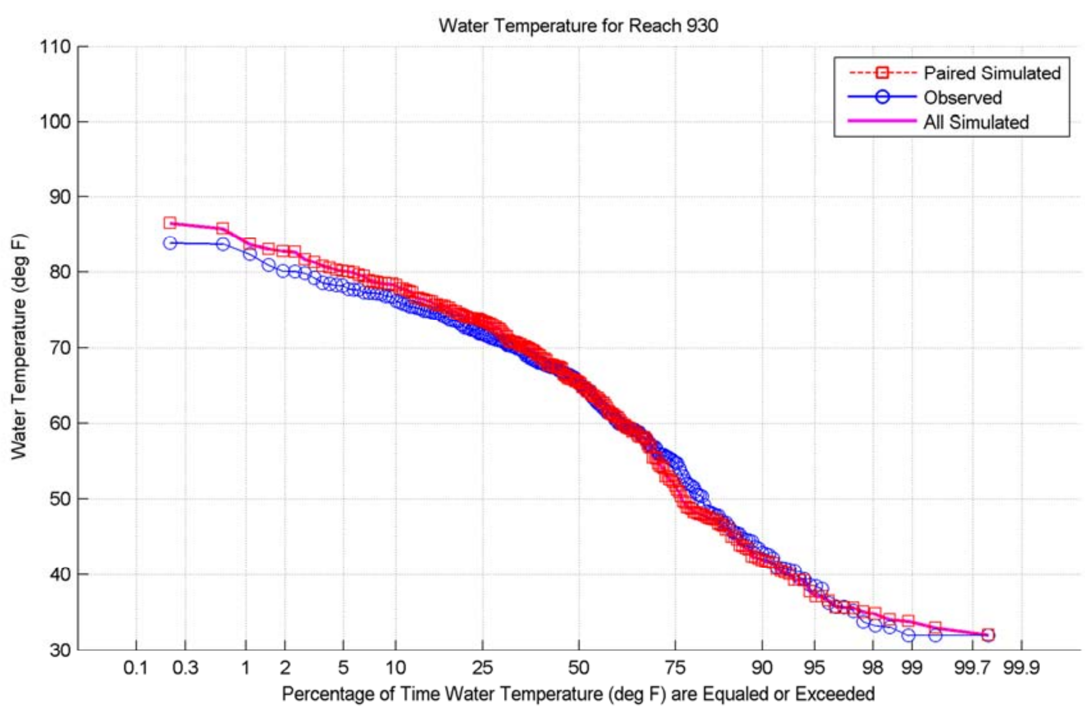

Figure B-4. Water Temperature Concentration Duration Curve at Reach 930.

RSI-2418-15-040

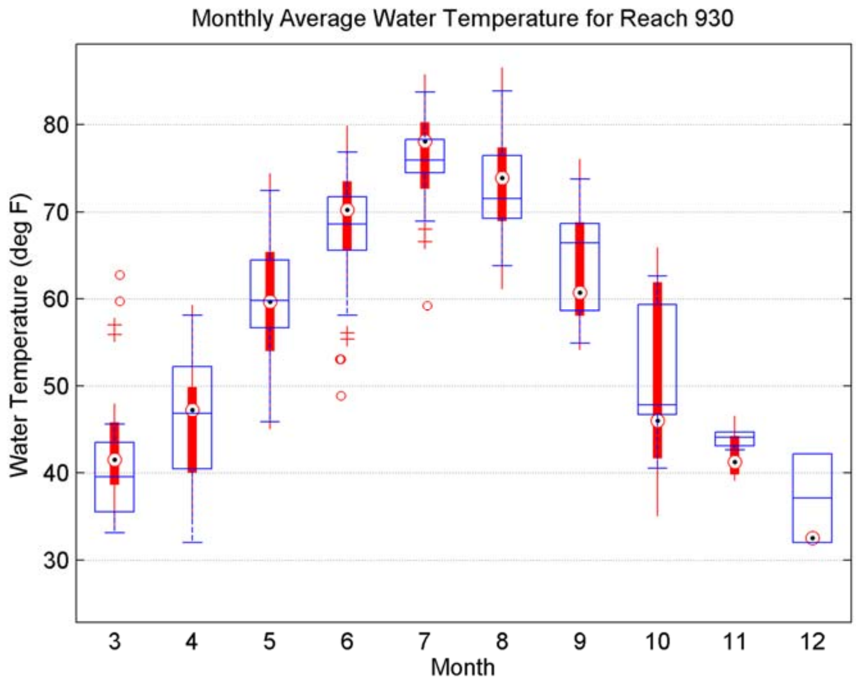

Figure B-5. Water Temperature Monthly Averages at Reach 930.

RSI-2418-15-041

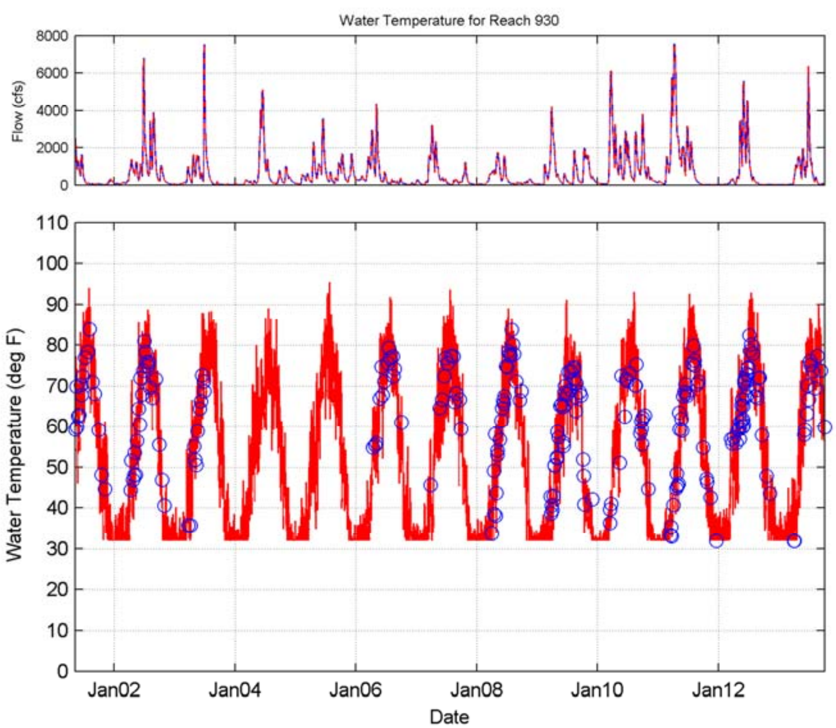

Figure B-6. Water Temperature Hourly Time Series at Reach 930.

RSI-2418-15-042

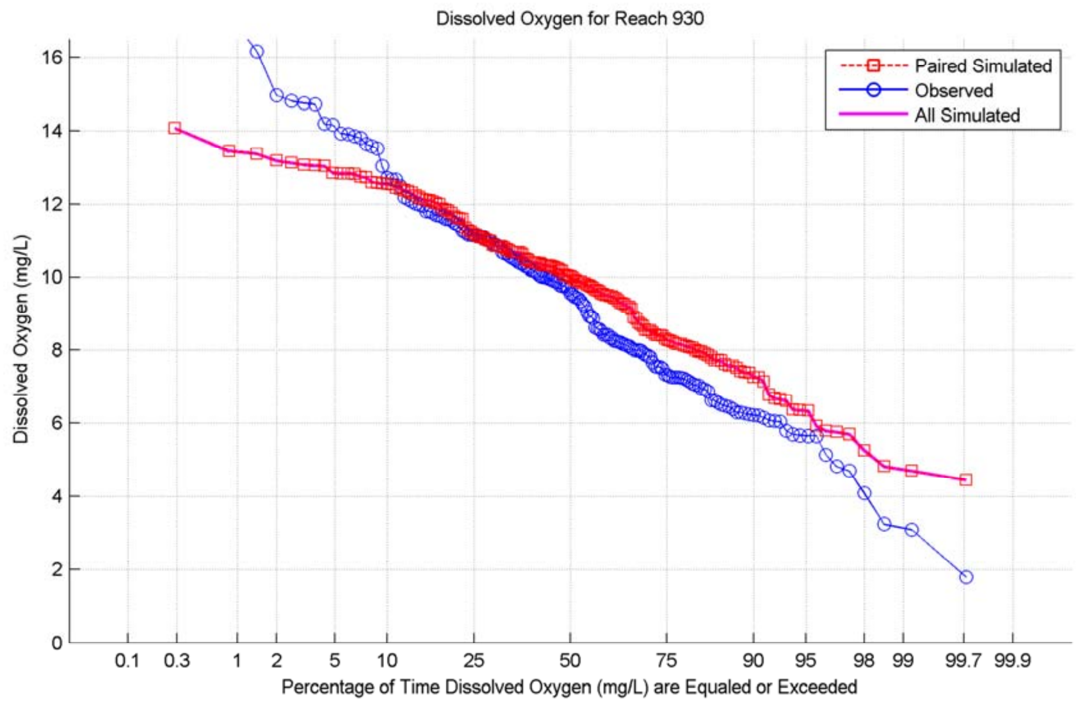

Figure B-7. Dissolved Oxygen Concentration Duration Curve at Reach 930.

RSI-2418-15-043

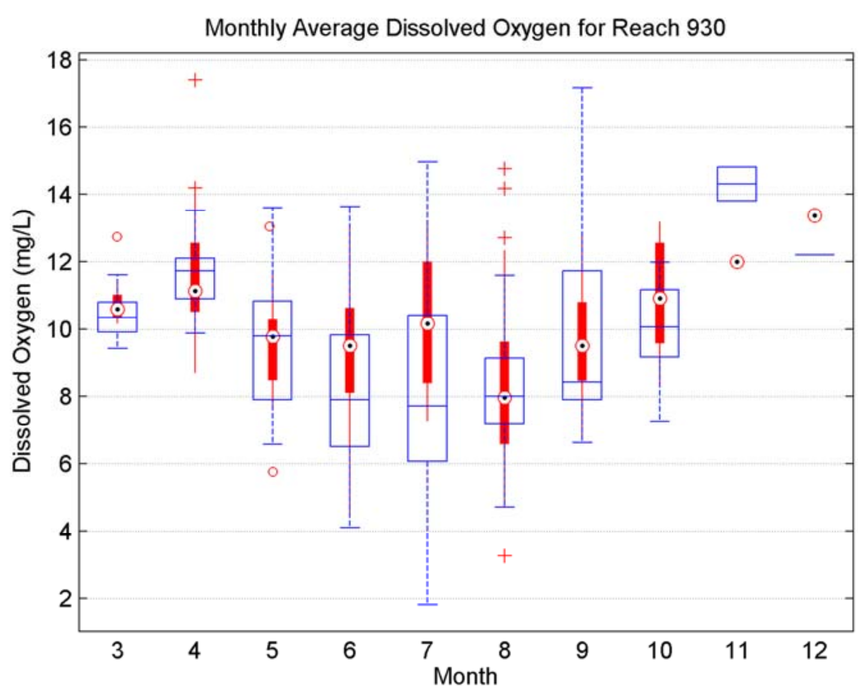

Figure B-8. Dissolved Oxygen Monthly Averages at Reach 930.

RSI-2418-15-044

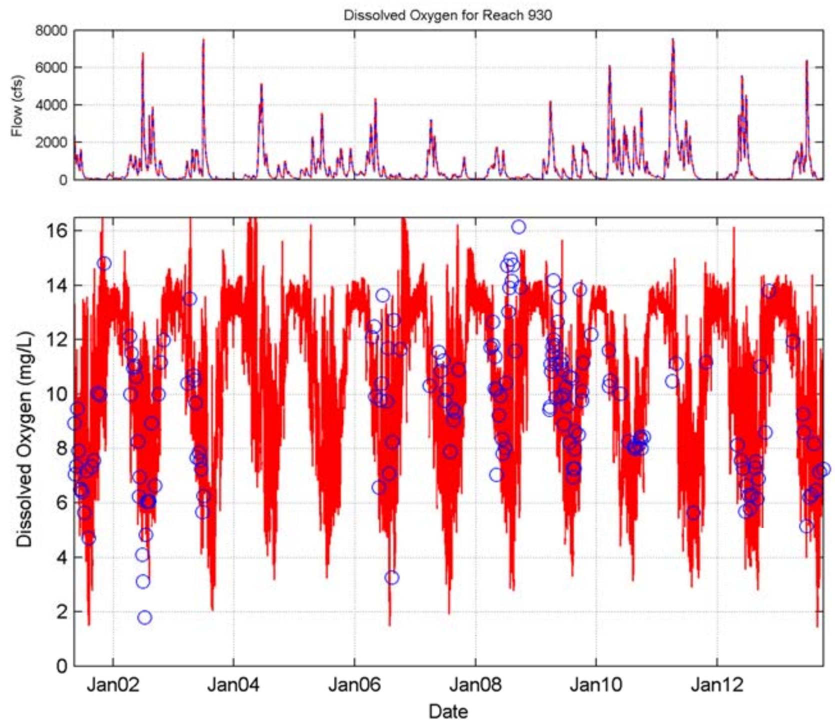

Figure B-9. Dissolved Oxygen Hourly Time Series at Reach 930.

RSI-2418-15-045

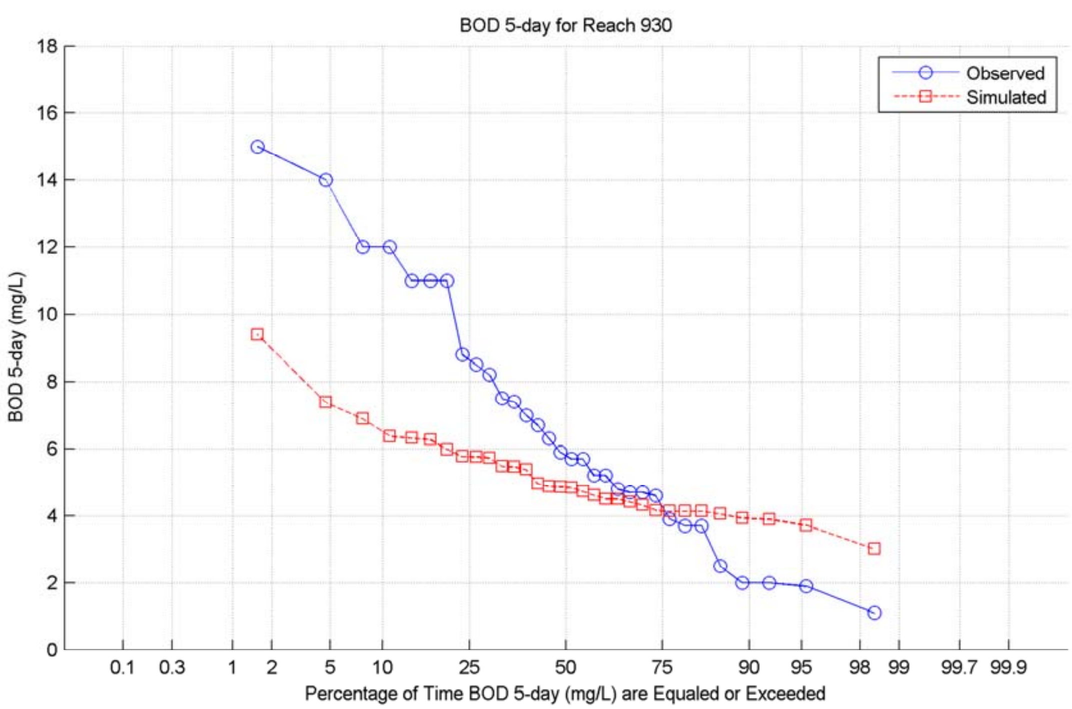

Figure B-10. BOD-5 Concentration Duration Curve at Reach 930.

RSI-2418-15-046

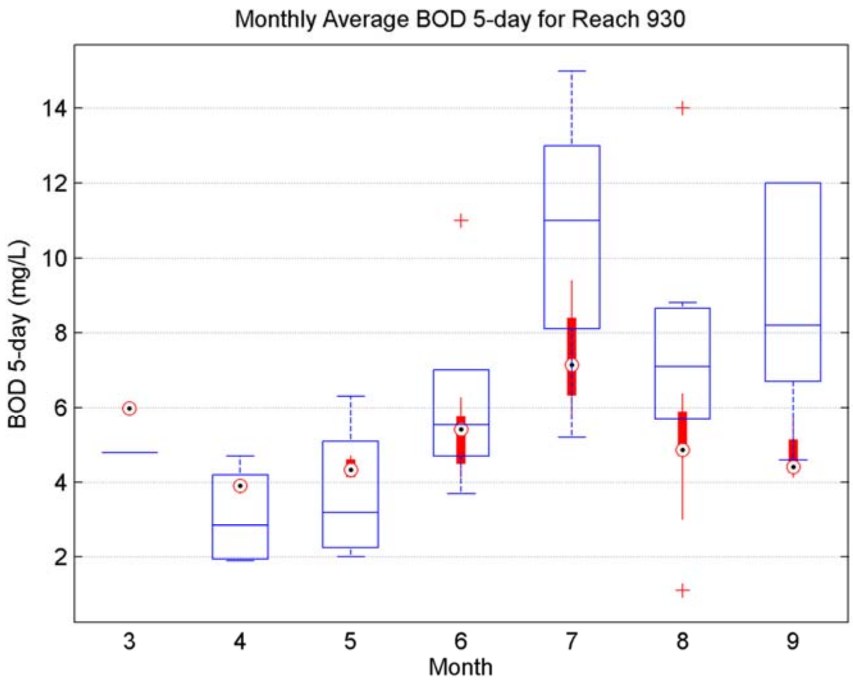

Figure B-11. BOD-5 Monthly Averages at Reach 930.

RSI-2418-15-047

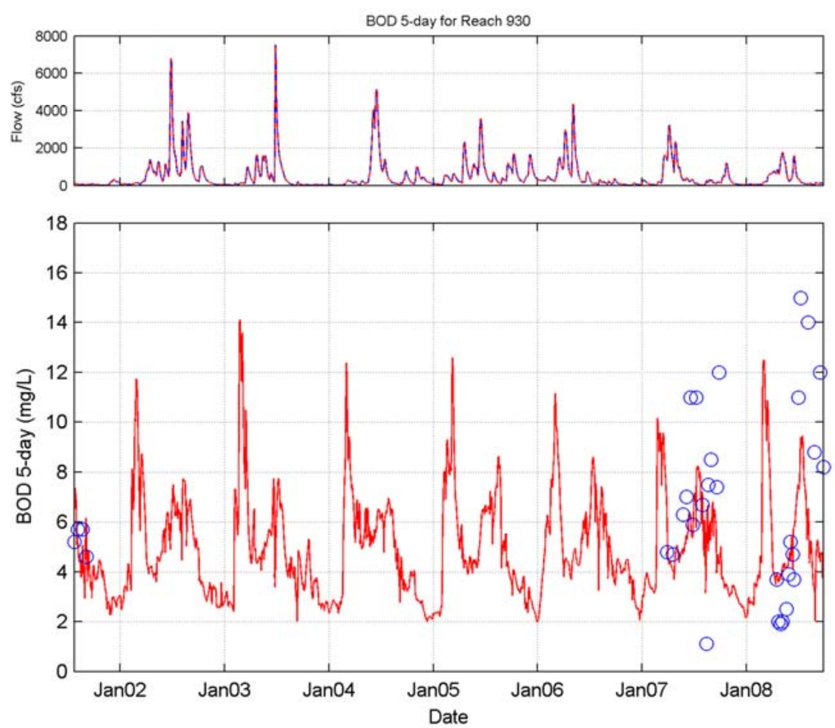

Figure B-12. BOD-5 Hourly Time Series at Reach 930.

RSI-2418-15-048

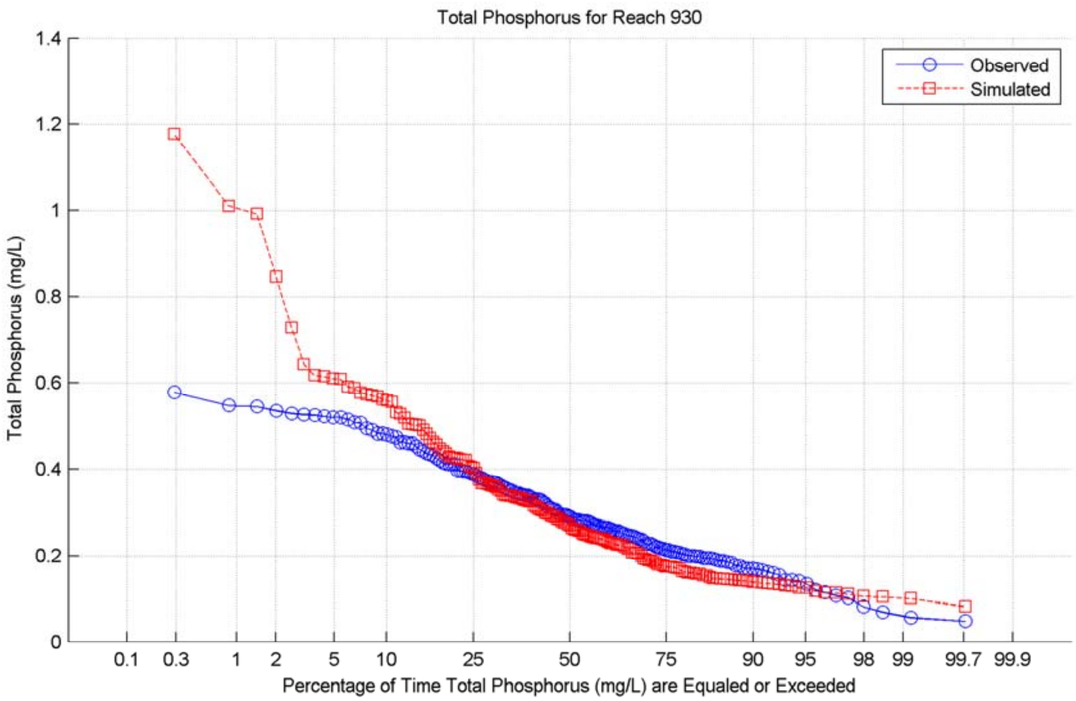

Figure B-13. Total Phosphorus Concentration Duration Curve at Reach 930.

RSI-2418-15-049

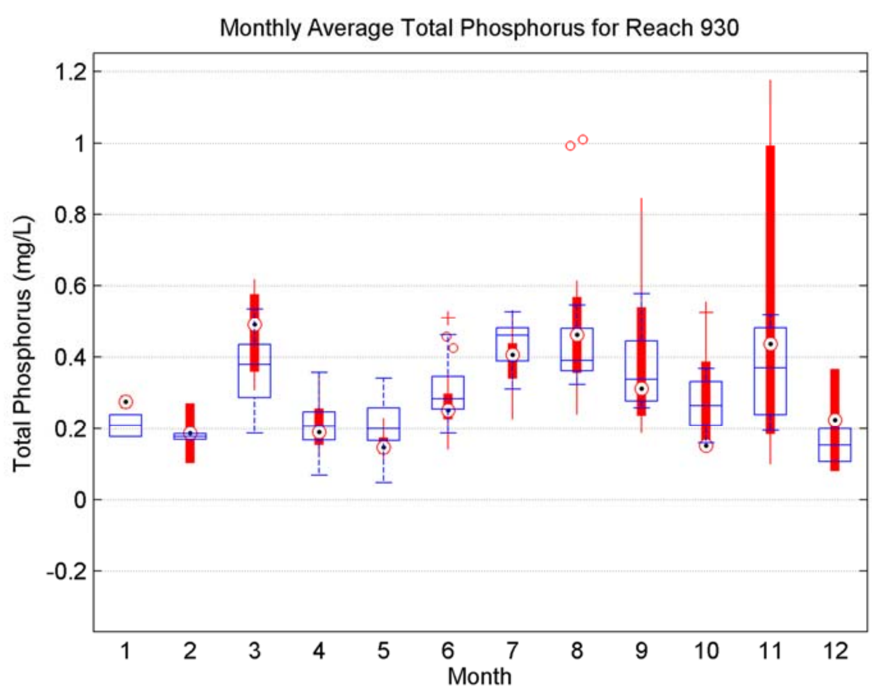

Figure B-14. Total Phosphorus Monthly Averages at Reach 930.

RSI-2418-15-050

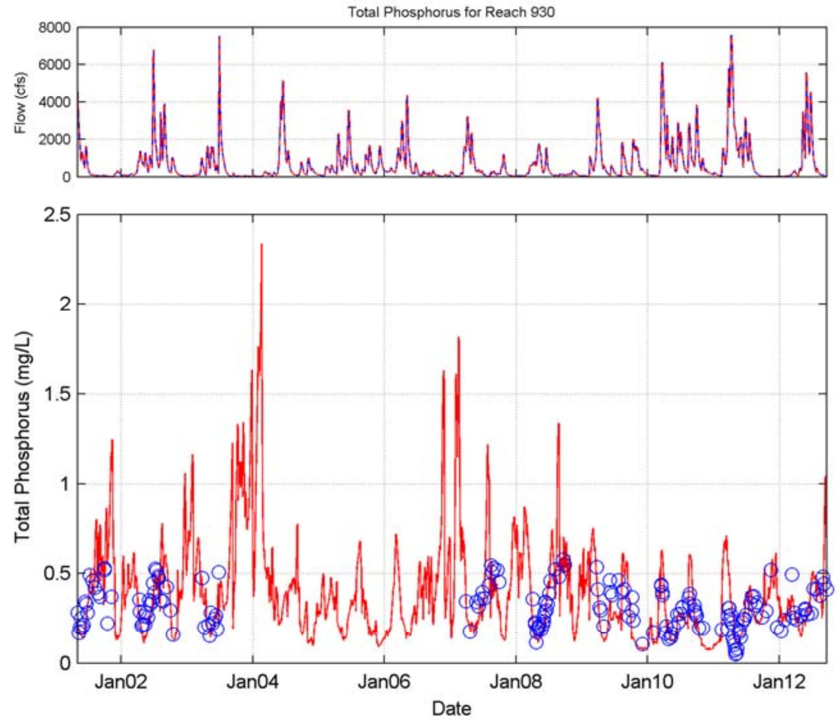

Figure B-15. Total Phosphorus Daily Time Series at Reach 930.

RSI-2418-15-051

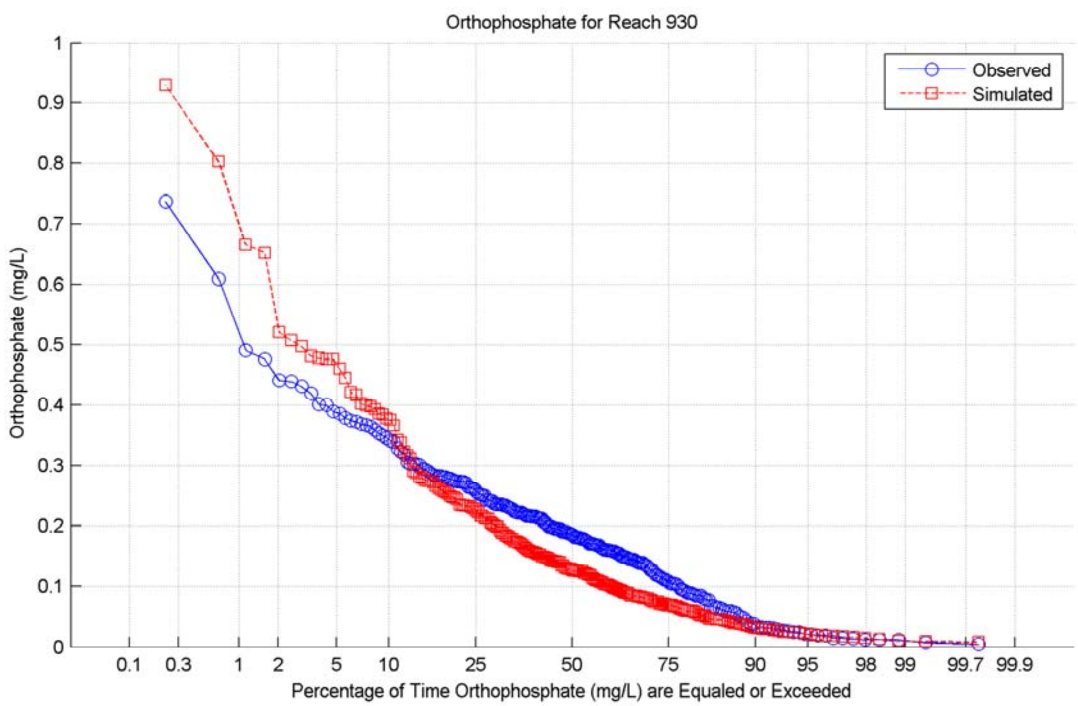

Figure B-16. Orthophosphate Concentration Duration Curve at Reach 930.

RSI-2418-15-052

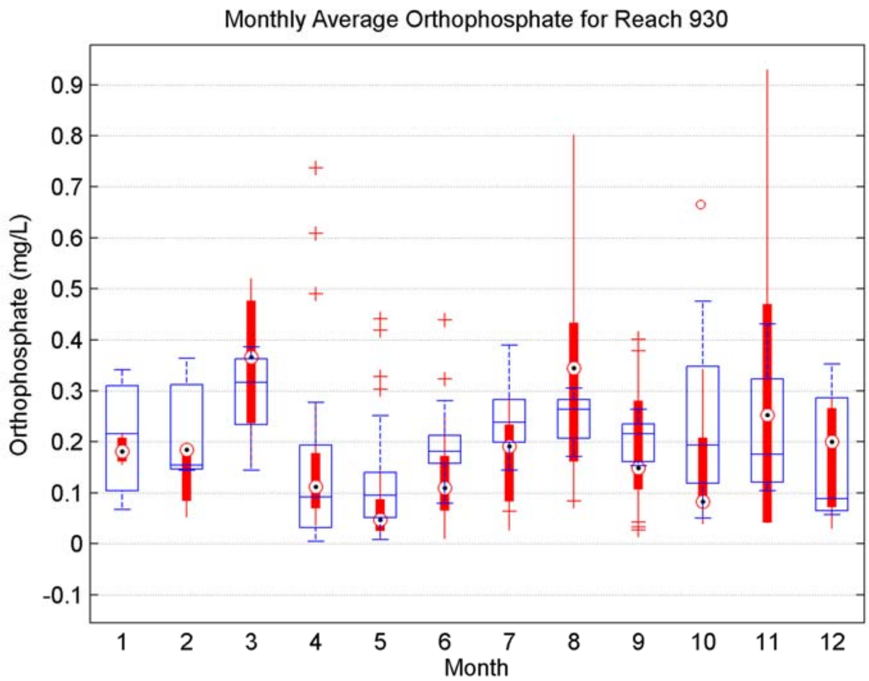

Figure B-17. Orthophosphate Monthly Averages at Reach 930.

RSI-2418-15-053

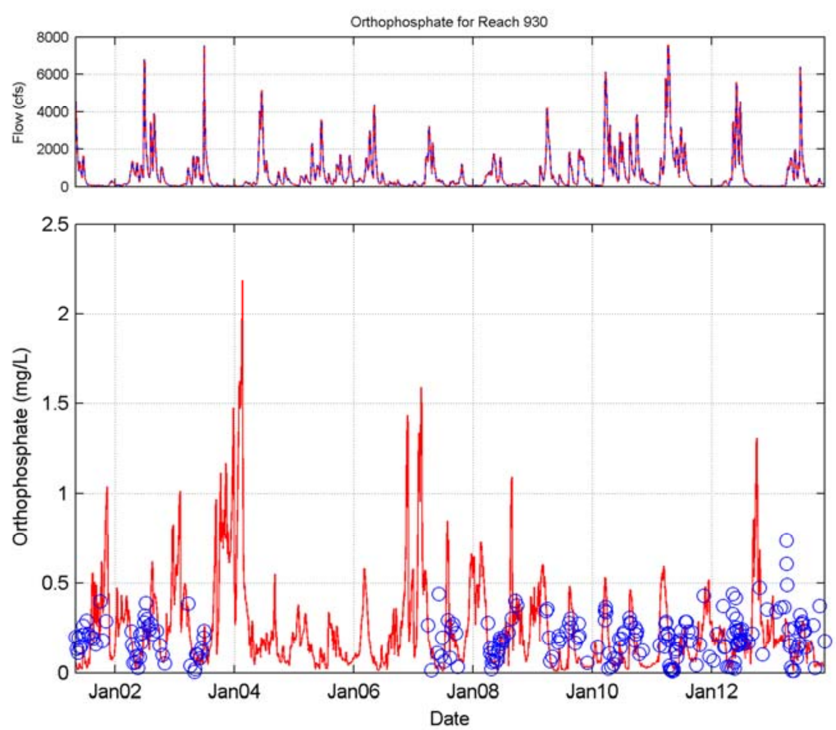

Figure B-18. Orthophosphate Daily Time Series at Reach 930.

RSI-2418-15-054

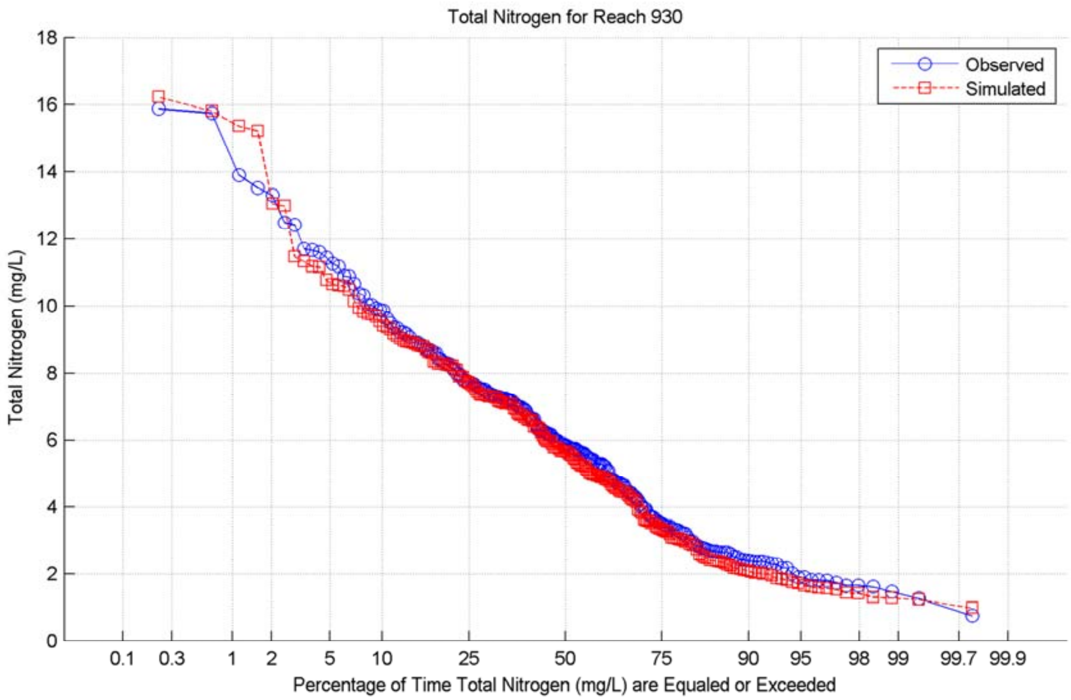

Figure B-19. Total Nitrogen Concentration Duration Curve at Reach 930.

RSI-2418-15-055

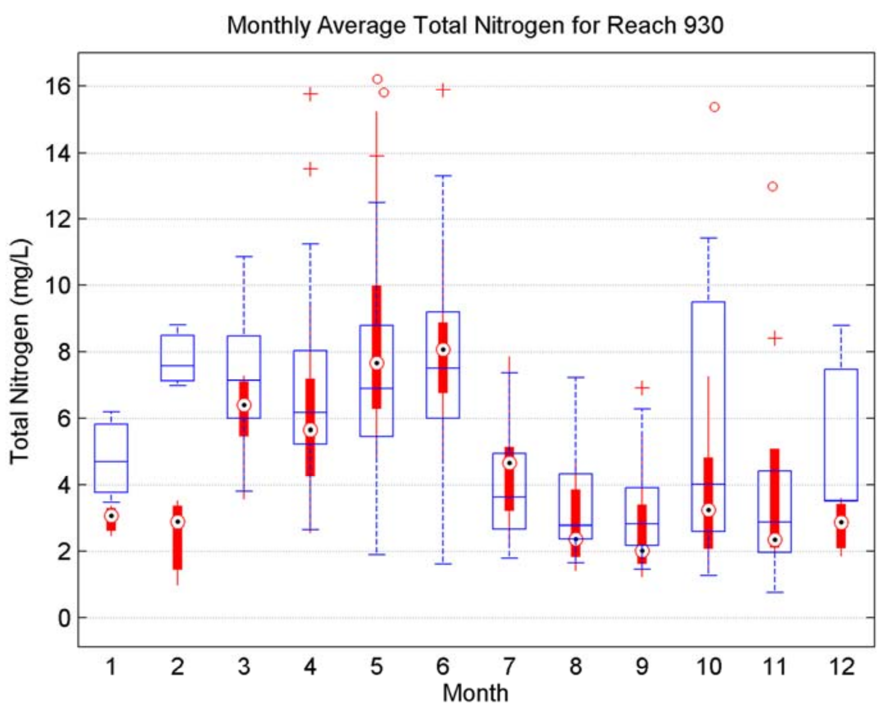

Figure B-20. Total Nitrogen Monthly Averages at Reach 930.

RSI-2418-15-056

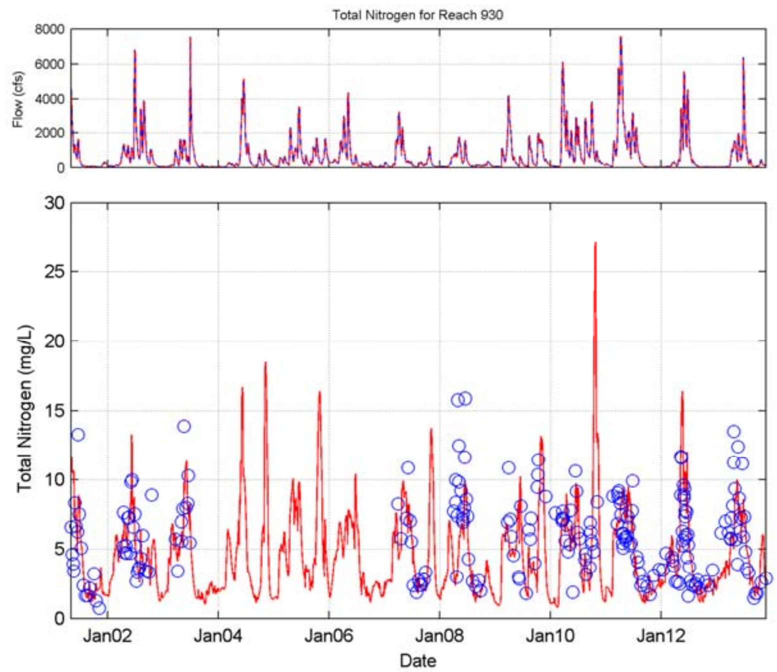

Figure B-21. Total Nitrogen Daily Timeseries at Reach 930.

RSI-2418-15-057

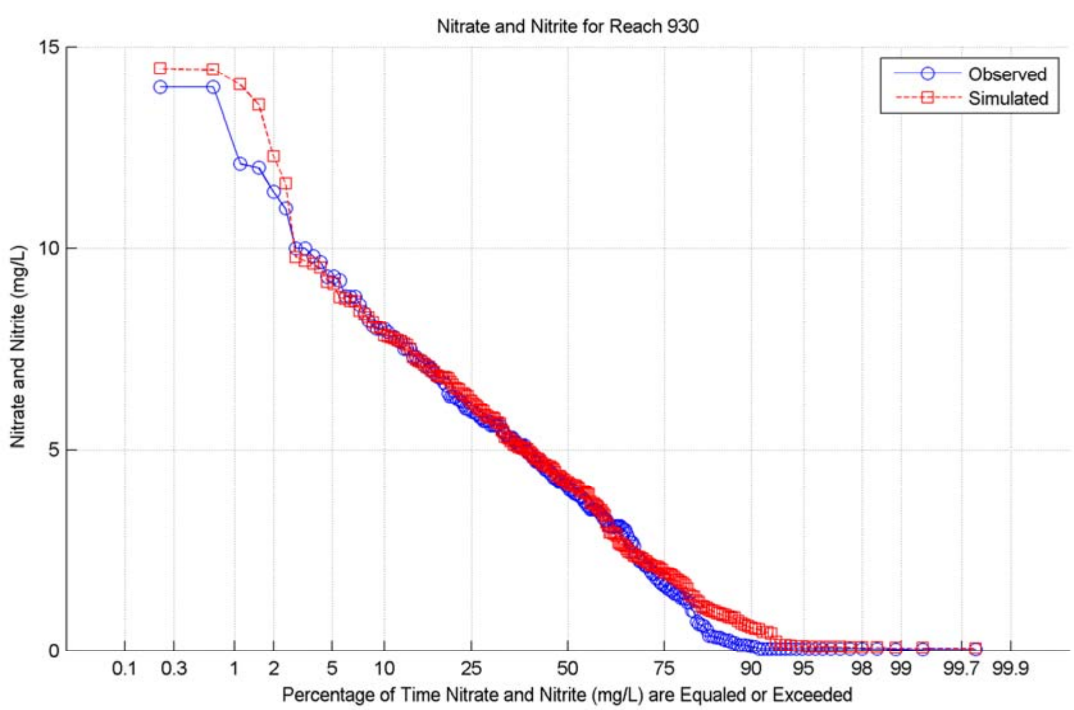

Figure B-22. Nitrate and Nitrite Concentration Duration Curve at Reach 930.

RSI-2418-15-058

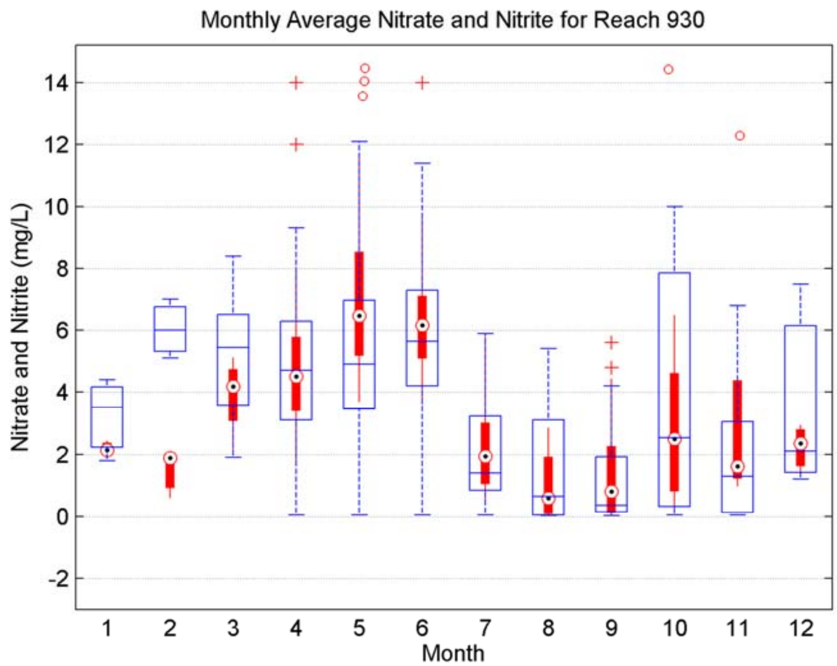

Figure B-23. Nitrate and Nitrite Monthly Averages at Reach 930.

RSI-2418-15-059

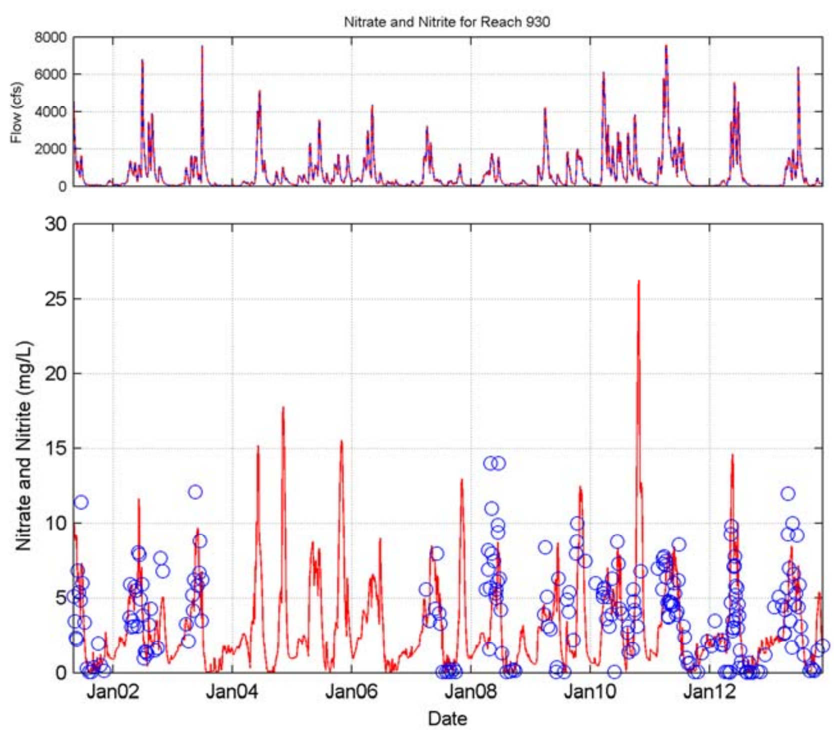

Figure B-24. Nitrate and Nitrite Daily Time Series at Reach 930.

RSI-2418-15-060

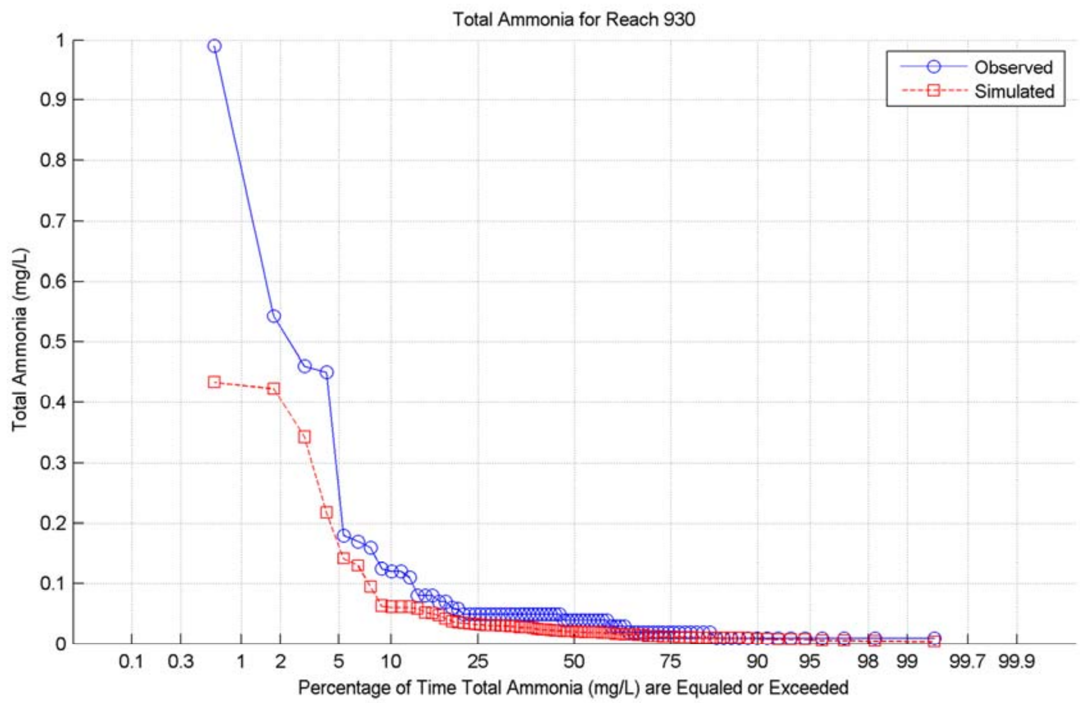

Figure B-25. Total Ammonia Concentration Duration Curve at Reach 930.

RSI-2418-15-061

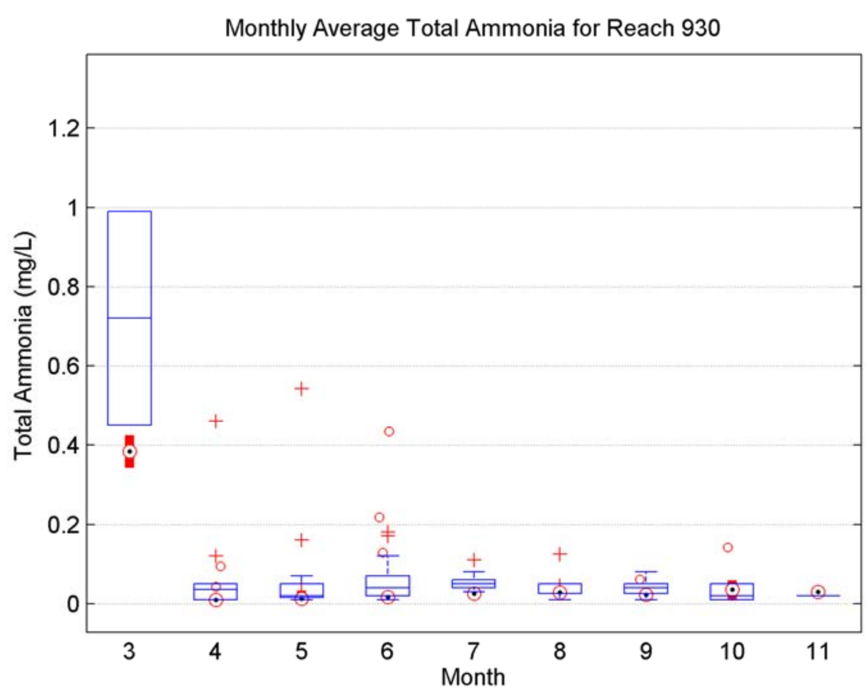

Figure B-26. Total Ammonia Monthly Averages at Reach 930.

RSI-2418-15-062

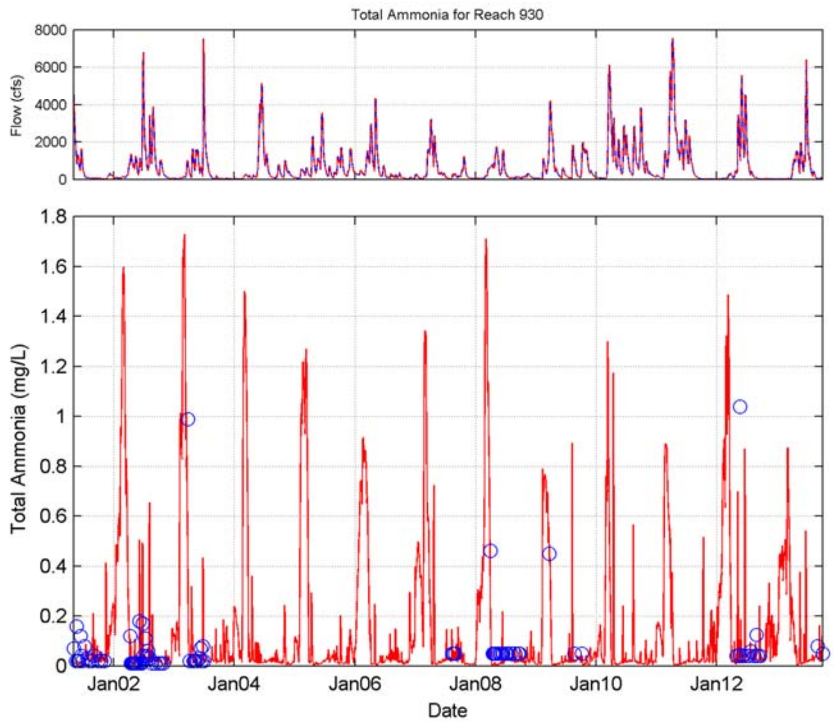

Figure B-27. Total Ammonia Daily Time Series at Reach 930.

RSI-2418-15-063

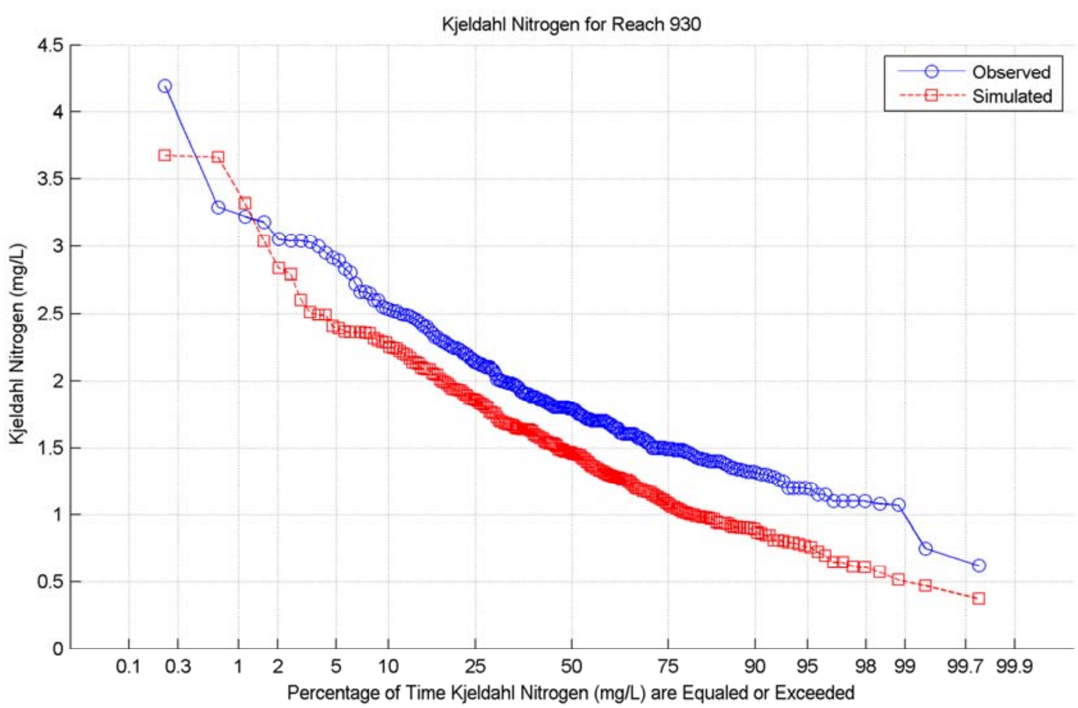

Figure B-28. Kjeldahl Nitrogen Concentration Duration Curve at Reach 930.

RSI-2418-15-064

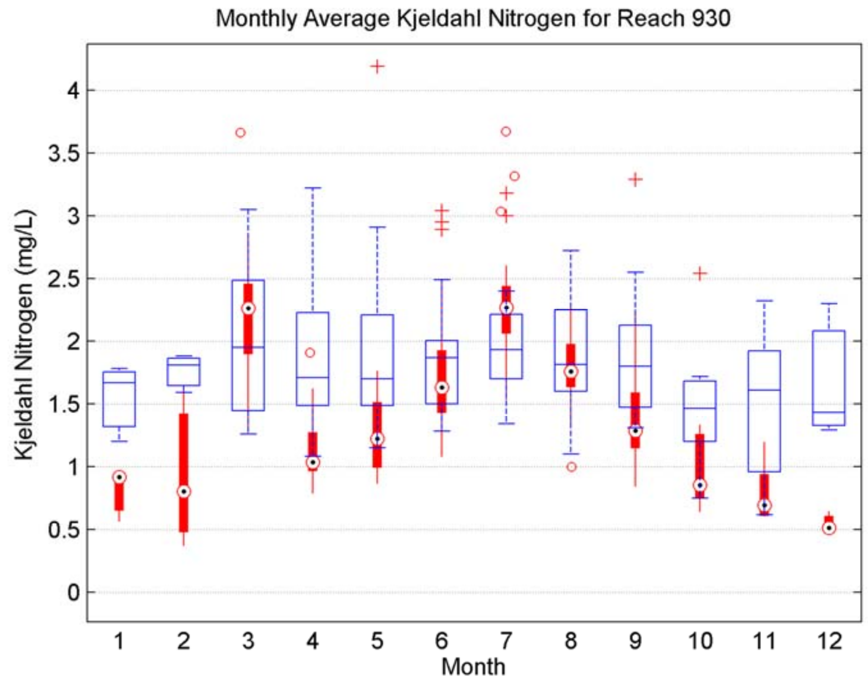

Figure B-29. Kjeldahl Nitrogen Monthly Averages at Reach 930.

RSI-2418-15-065

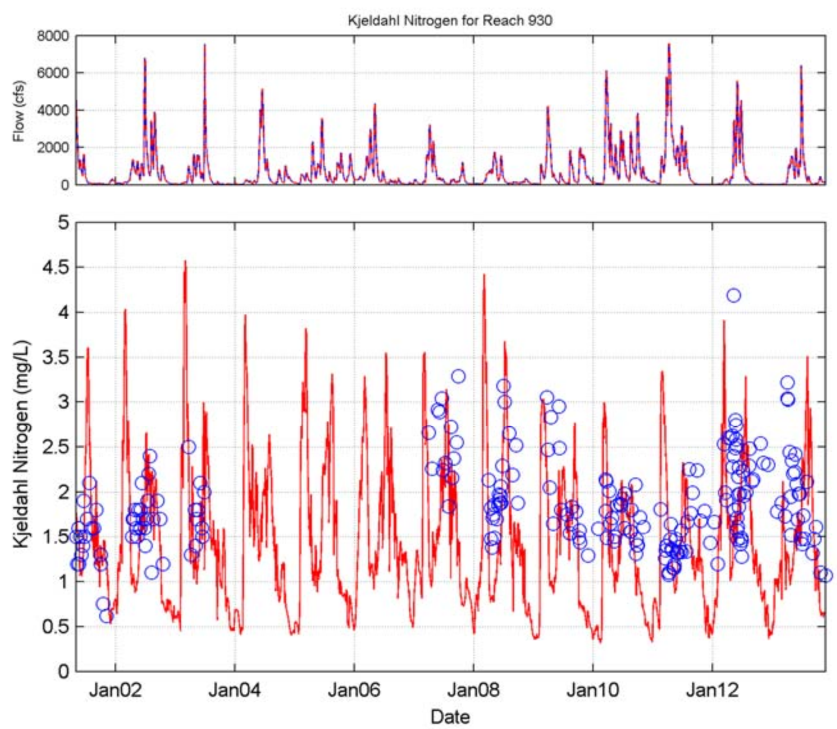

Figure B-30. Kjeldahl Nitrogen Daily Time Series at Reach 930.

RSI-2418-15-066

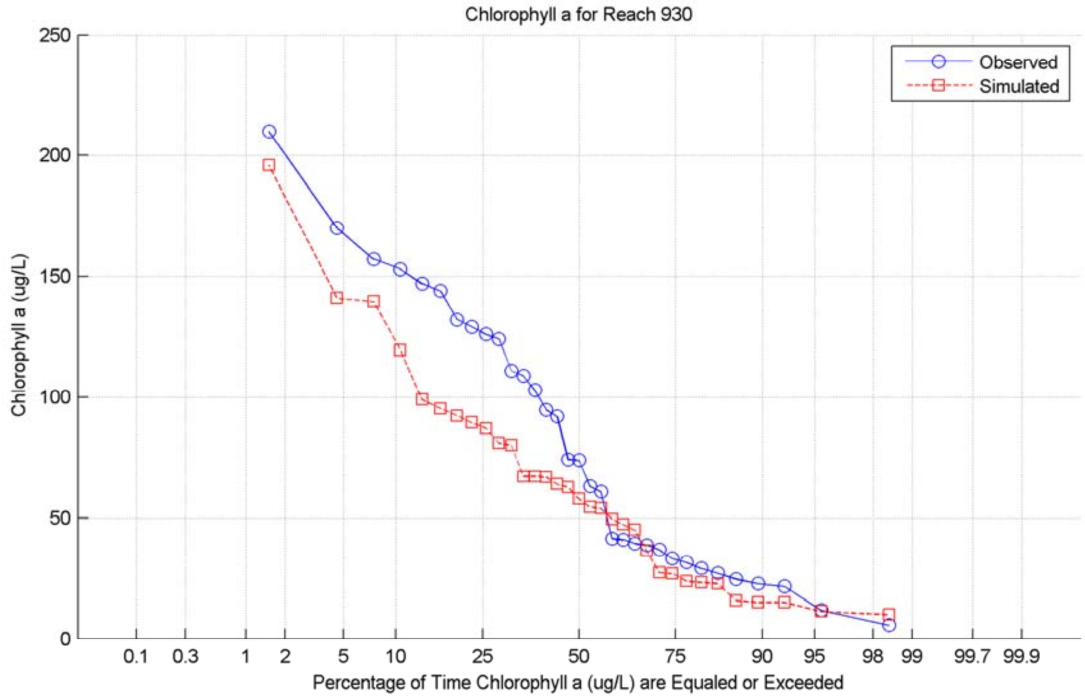

Figure B-31. Chlorophyll *a* Concentration Duration Curve at Reach 930.

RSI-2418-15-067

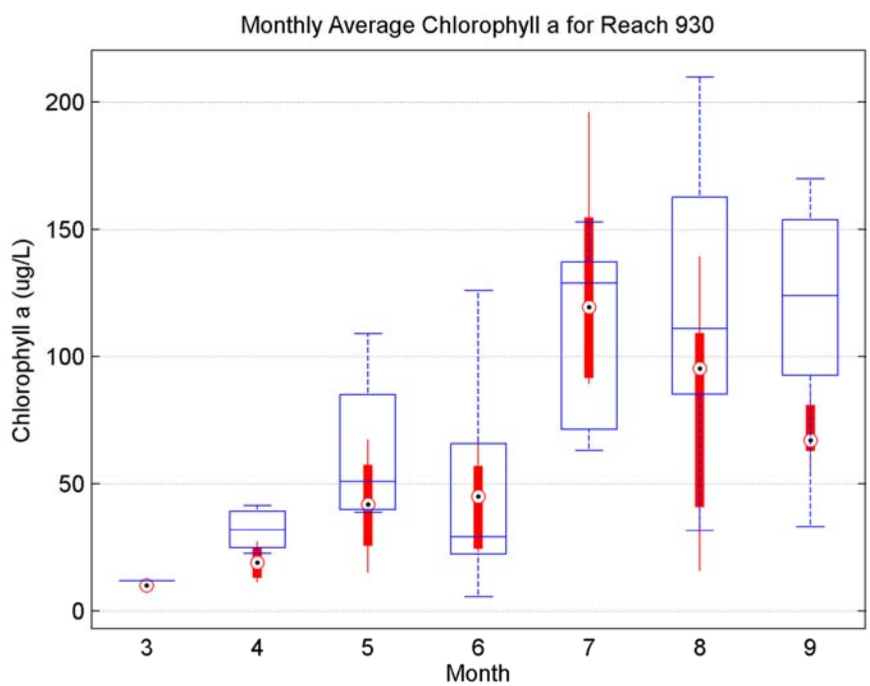

Figure B-32. Chlorophyll *a* Monthly Averages at Reach 930.

RSI-2418-15-068

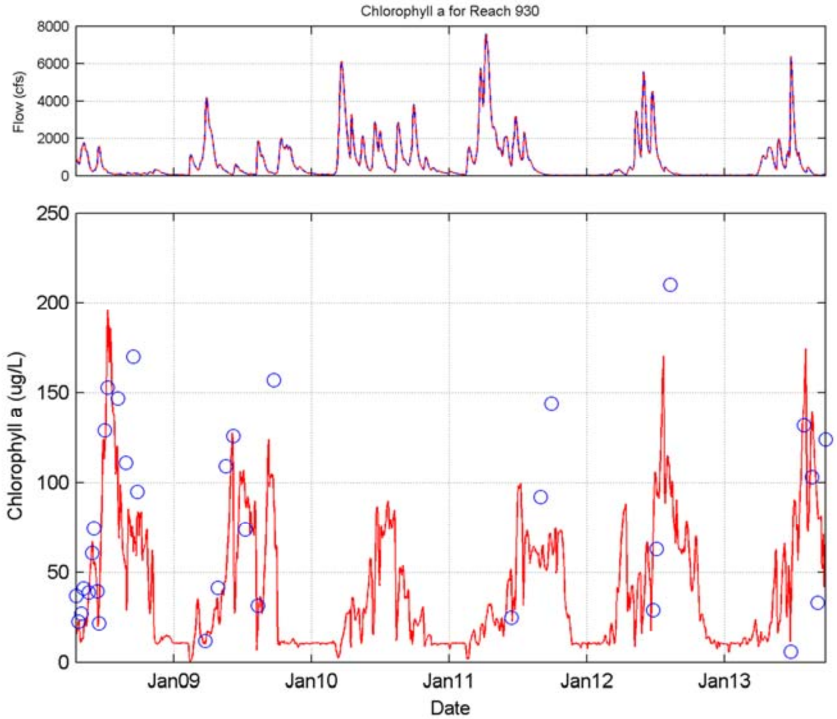

Figure B-33. Chlorophyll *a* Daily Time Series at Reach 930.