Big Sandy Lake and Lake Minnewawa Total Maximum Daily Load Report

Prepared for
Minnesota Pollution Control Agency

April 2011

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BARR

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Big Sandy Lake and Lake Minnewawa
Total Maximum Daily Load Report
April 2011

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LA (kg/day)</td><td rowspan="5">56, 57</td></tr>
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Executive Summary

Big Sandy Lake and Lake Minnewawa are currently listed on the Minnesota Pollution Control Agency's (MPCA) 2008 303(d) Impaired Waters List due to excessive nutrients (phosphorus). Both lakes are located in Aitkin County, Minnesota and are within the Northern Lakes and Forests (NLF) ecoregion.

The MPCA projected schedule for Total Maximum Daily Load (TMDL) report completion, as indicated on Minnesota's 303(d) impaired waters list, implicitly reflects Minnesota's priority ranking of these TMDLs. The Big Sandy Lake and Lake Minnewawa TMDLs were scheduled to begin in 2006 and be complete in 2011. Ranking criteria for scheduling TMDL projects include, but are not limited to: impairment impacts on public health and aquatic life; public value of the impaired water resource; likelihood of completing the TMDL in an expedient manner; including a strong base of existing data and restorability of the waterbody; technical capability and willingness locally to assist with each TMDL; and appropriate sequencing of TMDLs within a watershed or basin. The historical growing season water quality for each lake is compared to the MPCA lake eutrophication standards for the NLF ecoregion below (Table EX-1).

Table EX-1 MPCA Lake Eutrophication Standards for Northern Lakes and Forest Ecoregion

Water Quality Parameter	MPCA Lake Eutrophication Standards (NLF Ecoregion)	Big Sandy 2008 Summer Average Water Quality (Area-Weighted)	Lake Minnewawa 2008 Summer Average Water Quality
Total Phosphorus (µg/L)	30 µg/L	38	31
Chlorophyll *a* (µg/L)	9 µg/L	9.8	9.6
Secchi disc (m)	2.0 m	1.0	1.5

Big Sandy Lake

Big Sandy Lake is a reservoir operated by the U.S. Army Corps of Engineers (USACE). Big Sandy Lake was a natural lake system prior to construction of a dam at the lake outlet (1895) which was upgraded to its current design in 1911. The dam has raised the average water level approximately 9 feet above natural lake levels. Big Sandy Lake has a surface area of 6,526 acres and a maximum depth of approximately 84 feet.

The Big Sandy Lake watershed (including the area tributary to Lake Minnewawa) is located within the Northern Lakes and Forests (NLF) Ecoregion and is generally dominated by forests, wetlands, and open water. A large portion of the wetlands are peat wetlands located mainly in the southern and eastern portions or the watershed. Lake Minnewawa is within the Big Sandy watershed. The lake has a surface area of 2,355 acres and a maximum depth of approximately 21 feet.

The TMDL equation is defined as follows:

TMDL = Wasteload Allocation (WLA) + Load Allocation (LA) + Margin of Safety (MOS) + Reserve Capacity.

For Big Sandy Lake, the Load Capacity is 14,913 kilograms (kg) of total phosphorus (TP) per water year.

The TMDL equation used to derive this Load Capacity for Big Sandy Lake is:

<u>Expressed as water year (October 1 through September 30) totals:</u>

TMDL = 259 kg TP (WLA) + 13,831 kg TP (LA) + 746 kg TP (MOS) + 77 kg (Reserve Capacity) = 14,913 kg per water year

<u>Expressed in daily terms (water year)</u>

TMDL = 0.71 kg/d (WLA) + 37.9 kg/d (LA) + 2.0 kg/d (MOS) + 0.21 kg/d (Reserve Capacity) = 41 kg/d, on average

The Wasteload Allocation represents a 5% reduction in load to Big Sandy Lake. The Load Allocation represents a 32% total phosphorus reduction. This will be achieved through a 100% reduction of internal phosphorus load in Big Sandy Lake through management of sediment phosphorus loading. Loading from the tributary watershed will be reduced by 12% through best management practices (BMPs). To meet the overall load capacity of the lake, a 28% decrease in phosphorus load (based on 2008 existing conditions), will be required.

For Lake Minnewawa, the Load Capacity is 809 kg of total phosphorus (TP) per growing season.

The TMDL equation used to derive this Load Capacity for Lake Minnewawa is:

<u>Expressed as water year (October 1 through September 30) totals:</u>

TMDL = 0 kg TP (WLA) + 769 kg TP (LA) + 40 kg TP (MOS) + 0.7 kg (Reserve Capacity) = 810 kg per water year

<u>Expressed in daily terms (water year)</u>

TMDL = 0 kg/d (WLA) + 2.1 kg/d (LA) + 0.11 kg/d (MOS) + 0.002 kg/d (Reserve Capacity) = 2.2 kg/d, on average

Because there is no Wasteload Allocation, there is a 0% reduction in this load to Lake Minnewawa. The Load Allocation represents an 18% total phosphorus reduction. This will be achieved through a

23% reduction of loading from the tributary watershed through best management practices (BMPs). To meet the overall load capacity of the lake, a 14% decrease in phosphorus load (based on 2008 existing conditions), will be required.

The Margin of Safety for each lake is set at five percent (5%) of the overall loading capacity since extensive long-term monitoring for these lake watersheds greatly diminishes the level of uncertainty in setting the TMDL allocations. Reserve capacities have been included for Big Sandy to allow for a future wastewater treatment plant (WWTP) for the city of Wright, conversion of existing subsurface sewage treatment systems (SSTS) to a WWTP system, and for construction stormwater. A reserve capacity has been included for Lake Minnewawa to account for discharges from regulated construction stormwater.

Phosphorus load reductions to Big Sandy Lake and Lake Minnewawa will be achieved by targeting multiple nonpoint sources. The following summarizes phosphorus reductions that will be targeted in the watershed:

- 1% reduction from forested lands;
- 25% reduction from agriculture/pasture/hay field land use areas;
- 43% reduction from streambank erosion;
- 50% reduction from developed land use areas;
- Full conformance for all SSTS adjacent to both lakes;
- Significant reduction of internal loading from lake sediment in Big Sandy Lake (representing most of the internal loading above the implicit load already included in the empirical lake water quality modeling).

1.0 Introduction

Big Sandy Lake (DNR ID 01-0062) and Lake Minnewawa (DNR ID 70-0033) are located in the Upper Mississippi River Basin and are within the Northern Lakes and Forest (NLF) Ecoregion (Figure 1-1). Both lakes are located within Aitkin County, while the watershed of Big Sandy Lake extends east into St. Louis County and Carlton County (Figure 1-2). Lake Minnewawa is within the watershed of Big Sandy Lake. Big Sandy Lake is a reservoir system, created by the construction of a dam in 1886. The U.S. Army Corps of Engineers (USACE) is responsible for dam operations and controls the water level of Big Sandy Lake, which discharges to the nearby Mississippi River.

Big Sandy Lake and Lake Minnewawa are currently listed on the Minnesota Pollution Control Agency's (MPCA) 2008 303(d) Impaired Waters List due to excessive nutrients (phosphorus) and require a Total Maximum Daily Load (TMDL) report. The lakes were first placed on the MPCA's 303(d) list in 2002. The target start date for the TMDL reports for both lakes is 2006, and the target completion date is 2011.

Table 1-1 Impaired Waters in the Big Sandy watershed.

Lake	DNR Lake ID #	Listing Year	Affected Use	Pollutant or Stressor	Target TMDL Completion
Big Sandy	01-0062	2002	Aquatic Recreation	Excess nutrients	2011
Minnewawa	01-0033	2002	Aquatic Recreation	Excess nutrients	2011

The allocations calculated within this TMDL pertain to Minnesota waters only. A portion of the Mille Lacs Band and Minnesota Chippewa Indians tribal lands are located within the Big Sandy watershed boundaries (shown in Figure 1-2). There are approximately 359 acres of tribal lands within the 260,000 acre watershed of Big Sandy Lake. The majority of these tribal lands are forest land and wetland. This TMDL is not applicable to waterbodies or land located within the boundary of the tribal lands.

The MPCA's projected schedule for TMDL completions, as indicated on Minnesota's 303(d) impaired waters list, implicitly reflects Minnesota's priority ranking of this TMDL. Ranking criteria for scheduling TMDL projects include, but are not limited to: impairment impacts on public health and aquatic life; public value of the impaired water resource; likelihood of completing the TMDL in an expedient manner, including a strong base of existing data and restorability of the waterbody, technical capability, and willingness locally to assist with the TMDL; and appropriate sequencing of TMDLs within a watershed or basin.

Current monitoring and study of these lakes is being conducted by the Minnesota Pollution Control Agency (MPCA), as well as Aitkin County Soil and Water Conservation District (SWCD) and citizen volunteers as part of the MPCA's Citizen Lake Monitoring Program (CLMP).

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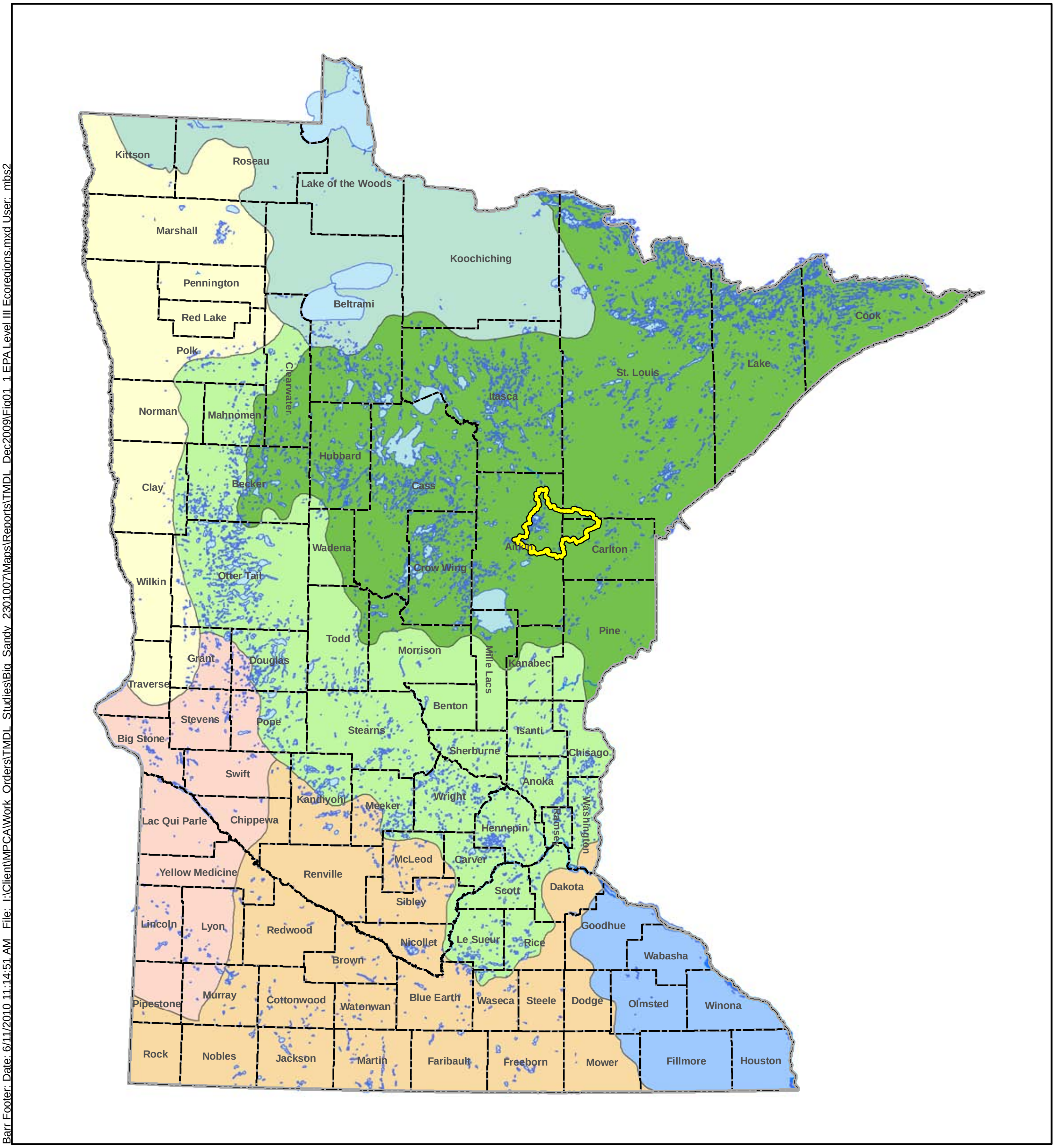


Big Sandy Lake Watershed Boundary

Level III Ecoregion

- Driftless Area
- Lake Agassiz Plain
- North Central Hardwood Forests
- Northern Glaciated Plains
- Northern Lakes and Forests
- Northern Minnesota Wetlands
- Western Corn Belt Plains

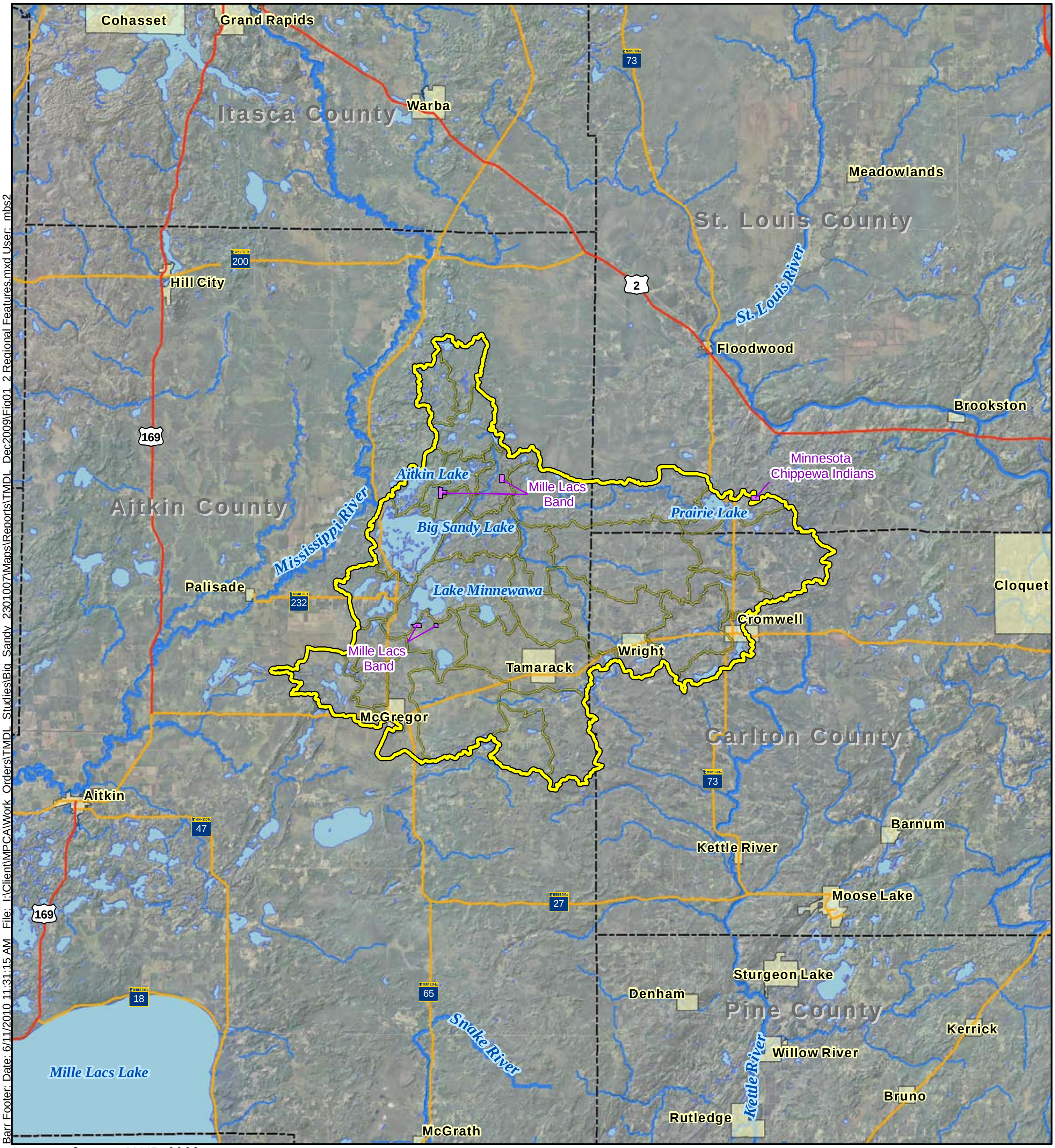
N

Miles
50 0 50

Kilometers
80 0 80

Figure 1-1

EPA LEVEL III ECOREGIONS
IN MINNESOTA
Big Sandy Area Lakes TMDL Study
Minnesota Pollution Control Agency
Aitkin County, Minnesota



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Imagery Source: NAIP, 2008

Big Sandy Lake Watershed Boundary

Minor Watershed Boundary

Tribal Land

Lake/Pond

Stream/River

N

Miles

8 0 8

Kilometers

12 0 12

Figure 1-2

REGIONAL FEATURES
Big Sandy Area Lakes TMDL Study
Minnesota Pollution Control Agency
Aitkin County, Minnesota

2.0 Background Information

The following sections describe the water quality standards that are applicable to Big Sandy Lake and Lake Minnewawa, as well as the general characteristics of the lakes and their respective watersheds.

2.1 Applicable Water Quality Standards

Impaired waters are listed and reported to the citizens of Minnesota and to the EPA in the 305(b) report and the 303(d) list, named after relevant sections of the Clean Water Act. Assessment of waters for the 305(b) report identifies candidates for listing on the 303(d) list of impaired waters. The purpose of the 303(d) list is to identify impaired water bodies for which a plan (the TMDL – this document) will be developed to remedy the pollution problem(s).

Big Sandy Lake and Lake Minnewawa have the following designated uses (Minnesota Administrative Rule 7050):

- Class 2B – Cool or warm water sport or commercial fish and associated aquatic life; and aquatic recreation, including bathing.
- Class 3C – Industrial cooling and materials transport.
- Class 4A – Irrigation;
- Class 4B – Use by livestock and wildlife.
- Class 5 – Aesthetic enjoyment and navigation.

Class 2B water quality standards include eutrophication standards. Eutrophication is a process whereby water bodies such as lakes receive excess nutrients that stimulate excessive plant growth (i.e., algae). The excessive plant growth may directly impact recreational uses. The decomposition of dead plants and algae in the lake consume oxygen. Therefore, excessive plant and algae growth and the subsequent decomposition of plant matter can result in depleted oxygen levels, harming aquatic life dependent on dissolved oxygen in the lake. The basis for assessing Minnesota lakes for impairment due to eutrophication includes the narrative water quality standard and assessment factors in Minnesota Rules 7050.0150. The MPCA has completed extensive planning and research efforts to develop quantitative lake eutrophication standards for lakes in different ecoregions of Minnesota that would result in achievement of the goals described by the narrative water quality standards. To be listed as impaired by the MPCA, the monitoring data must show that the standards for both total phosphorus (the causal factor) and either chlorophyll *a* or Secchi disc depth (the response factors) are not met (MPCA, 2007a). Both lakes are listed based on the eutrophication criteria for the Northern

Lakes and Forest (NLF) ecoregion (Table 2-1).Big Sandy Lake and Lake Minnewawa are considered deep lakes, though the majority of Lake Minnewawa is littoral (less than 15 feet).

Table 2-1 MPCA Lake Eutrophication Standards for Total Phosphorus, Chlorophyll *a*, and Secchi Disc in NLF Ecoregion.

Water Quality Parameter	MPCA Lake Eutrophication Standard (NLF Ecoregion)
Total Phosphorus (µg/L)	30
Chlorophyll-a (µg/L)	9
Secchi disc (m)	2.0

Source: Minnesota Rule 7050.0222 Subp. 4. Class 2B Waters

2.2 General Lake Characteristics

Big Sandy Lake is a reservoir system, with a large watershed (260,000 acres, or 406 square miles) and variable water flow that fluctuates from year to year. The major tributaries to Big Sandy Lake include the Sandy River, Prairie River, and Tamarack River (Figure 2-1). Water levels in Big Sandy Lake are controlled by the U.S. Army Corps of Engineers through operation of the dam at the lake's outlet. Big Sandy Lake is approximately 6,526 acres in size, with a maximum depth of 84 feet. The littoral area (area with a depth of 15 feet or less) is approximately 3,085 acres. Additional characteristics of Big Sandy Lake are listed in Table 2-2. Big Sandy Lake can generally be divided into three sections: Webster's Bay, Bellhorn Bay, and Main Bay (Figure 2-2). Webster's Bay is the shallowest of the three sections, and receives flow from the Sandy River. Bellhorn Bay is the deepest section of the lake, and receives flow from the Prairie River. Main Bay has the greatest surface area of the three sections, but does not receive direct flow from any of the major rivers in the watershed. The outlet of Big Sandy Lake is via the Sandy River, in the northwest corner of Main Bay. The Sandy River discharges to the Mississippi River less than one mile downstream of Big Sandy Lake.

Lake Minnewawa is 2,355 acres in size, with a maximum depth of 21 feet (Figure 2-3). The majority of the lake (2,286 acres) is 15 feet deep or less. Significant portions of the shorelines of Lake Minnewawa and Big Sandy Lake are developed with seasonal and year-round homes. Both lakes are popular recreational resources.

Table 2-2 Characteristics of Big Sandy and Minnewawa Lakes.

Parameter	Big Sandy Lake	Lake Minnewawa
Surface Area (ac)	6,526	2,355
Average Depth (ft)	16	8.2
Maximum Depth (ft)	84	21
Volume (ac-ft)	104,000	19,100
Residence Time (years)	0.47	2.8
Littoral Area (ac)	3,085 (47%)	2,286 (97%)
Watershed (ac)	260,000	13,243

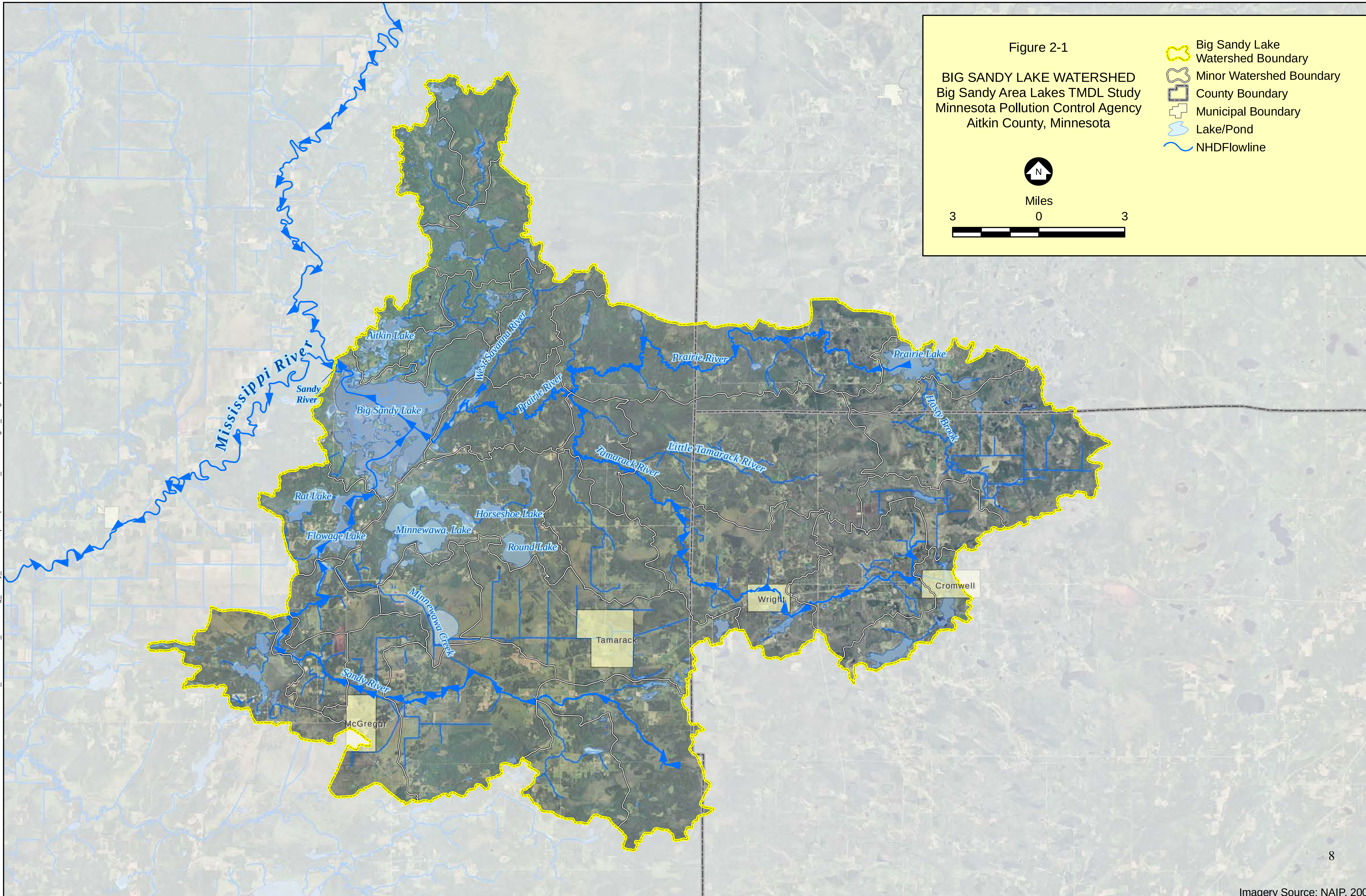


Figure 2-1
BIG SANDY LAKE WATERSHED
Big Sandy Area Lakes TMDL Study
Minnesota Pollution Control Agency
Aitkin County, Minnesota
Big Sandy Lake Watershed Boundary
Minor Watershed Boundary
County Boundary
Municipal Boundary
Lake/Pond
NHDFlowline
N
Miles
3
0
3
Mississippi River
Sandy River
Aitkin Lake
West Savanna River
Prairie River
Prairie Lake
Big Sandy Lake
Hasty Brook
Little Tamarack River
Tamarack River
Rat Lake
Horseshoe Lake
Minnewawa Lake
Flowage Lake
Round Lake
Minnewawa Creek
Cromwell
Wright
Tamarack
Sandy River
McGregor
Imagery Source: NAIP, 2008

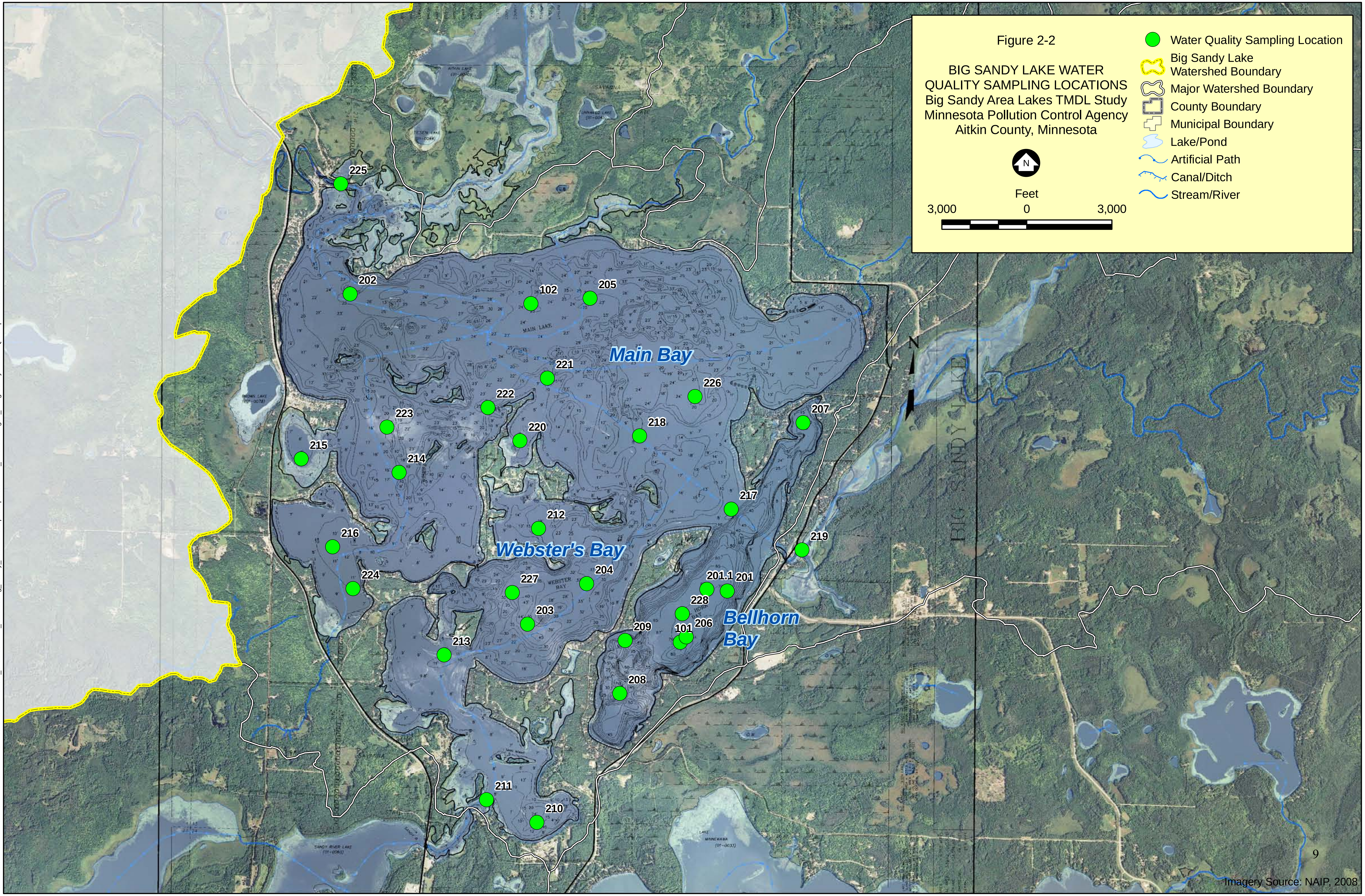
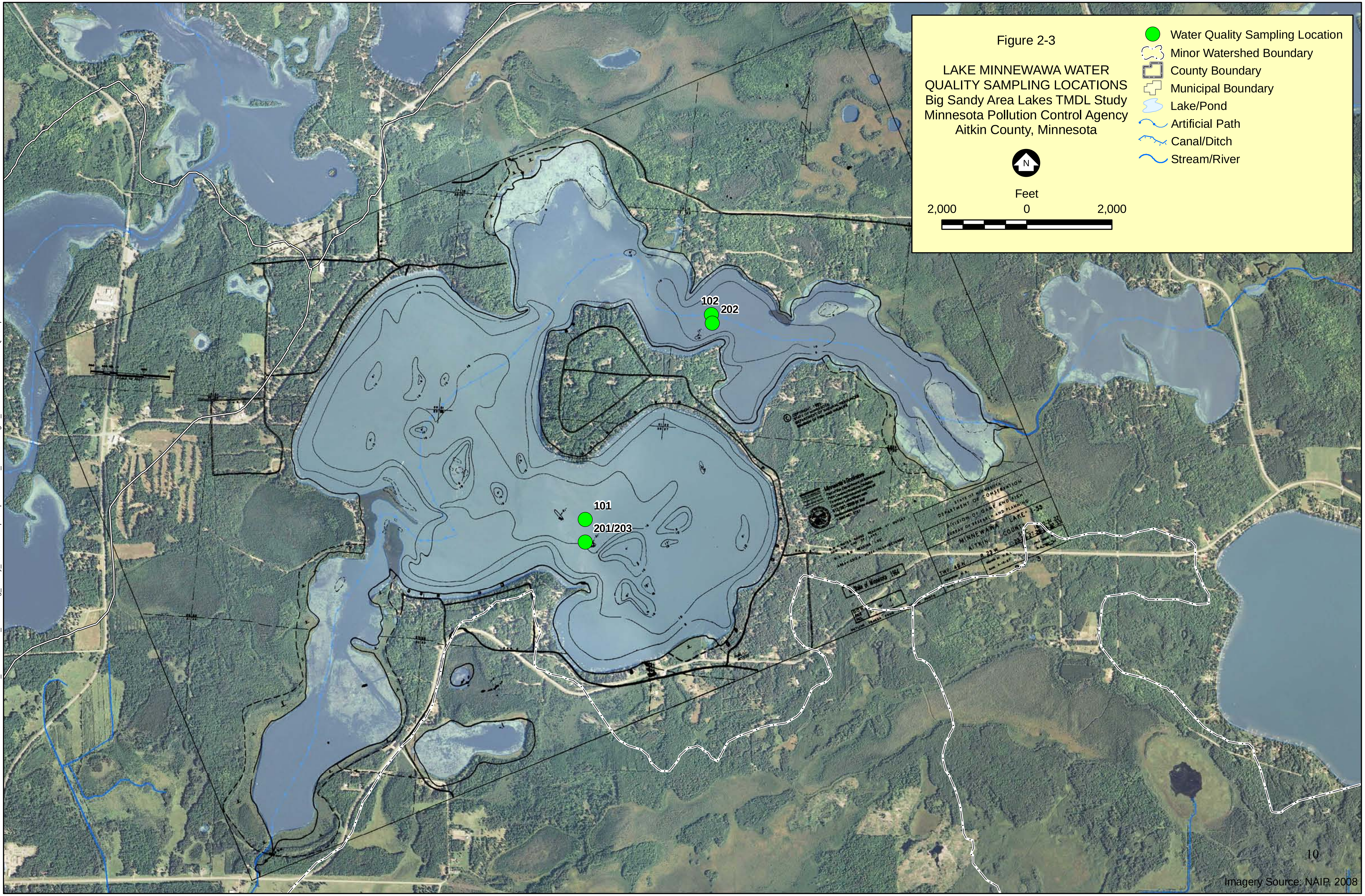


Figure 2-2
BIG SANDY LAKE WATER QUALITY SAMPLING LOCATIONS
Big Sandy Area Lakes TMDL Study
Minnesota Pollution Control Agency
Aitkin County, Minnesota
N
Feet
3,000 0 3,000
Water Quality Sampling Location
Big Sandy Lake Watershed Boundary
Major Watershed Boundary
County Boundary
Municipal Boundary
Lake/Pond
Artificial Path
Canal/Ditch
Stream/River
Main Bay
Webster's Bay
Bellhorn Bay
BIG SANDY LAKE
225
202
102
205
221
226
222
223
220
218
207
215
214
217
212
216
219
204
224
227
201.1
201
228
203
206
209
101
213
208
211
210
Imagery Source: NAIP, 2008



Barr Footer: Date: 6/11/2010 1:05:45 PM File: I:\Client\MPCA\Work_Orders\TMDL_Studies\Big_Sandy_23\01007\Maps\Reports\TMDL_Dec2009\Fig02_3 Lake Minnewawa WQ Sample Locations.mxd User: mbs2

2.3 General Watershed Characteristics

The 2001 National Land Cover Database (NLCD) was used to characterize current land use in the watershed. Land use in the watersheds of Big Sandy Lake and Lake Minnewawa is predominantly forest and wetlands (Figure 2-4). The land uses in the watersheds of each lake are summarized in the following sections.

2.3.1 Big Sandy Watershed

The Big Sandy watershed is approximately 260,000 acres (406 square miles) in size. Land use percentages of the Big Sandy Lake watershed, based on the 2001 National Land Cover Database (NLCD), are summarized as follows:

- 54% forest
- 29% wetland
- 5.7% pasture/hay/cultivated crops
- 4.3% grassland
- 4.1% open water
- 2.4% developed (low, medium, and high density)

In addition to land use changes from natural conditions, the Big Sandy watershed has been altered in other ways. Extensive ditching of wetlands in portions of the watershed has occurred as early as the early 1900s when an effort was made to establish increased farmlands (MN DNR Fisheries 2002). More recently, wetlands have been ditched and drained to allow for peat and wild rice farming. The ditches have likely affected the hydrology and nutrient transport dynamics of the watershed. Peat soils and wetlands that typically remained flooded before ditching may now drain to a greater depth or more frequently during dry periods, thereby allowing them to become more oxygenated. The increase in oxygen is expected to increase decomposition of the nutrient rich organic material in the peat soil, thereby releasing phosphorus. Decomposition of wetland and peat materials is evidenced by the highly colored water of the rivers in the watershed, which is a result of high concentrations of organic compounds that result from decomposition of peat. Ditching may also lead to increased erosion and transport of soil and sediment within stream and river channels, as ditching and channeling of natural stream channels and wetlands will increase the peak flow from storm events. A more detailed discussion of potential water quality impacts is provided in MNDNR Fisheries (2002).

Four rivers constitute the majority of the Big Sandy watershed: Sandy River, Tamarack River, Prairie River, and West Savanna River. The Sandy River drains the southern portion of the Big Sandy watershed and drains into Webster's Bay, at the south end of the lake. The Sandy River flows through two smaller lakes (Flowage Lake and Sandy River Lake) immediately prior to entering Webster's Bay. The Sandy River also receives outflow from Minnewawa Lake, via Minnewawa Creek. Tamarack River and Prairie River originate in the eastern most regions of the Big Sandy watershed. West Savanna River originates in the northern most region of the Big Sandy watershed. The Tamarack and West Savanna Rivers combine with Prairie River, before Prairie River drains into Bellhorn Bay at the east end of Big Sandy Lake. Big Sandy Lake also receives flow from two smaller watersheds to the north of the lake: the Twin/Remote Lakes watershed; and Aitkin Lake. The narrow stream channel connecting Aitkin Lake to Big Sandy Lake is in the northwest corner of Big Sandy Lake, and is immediately adjacent to the outflow of Big Sandy Lake. For the purposes of this study, it was assumed that flow from Aitkin Lake is immediately directed to the Big Sandy Lake outlet and does not contribute phosphorus loading to the main bay of Big Sandy Lake.

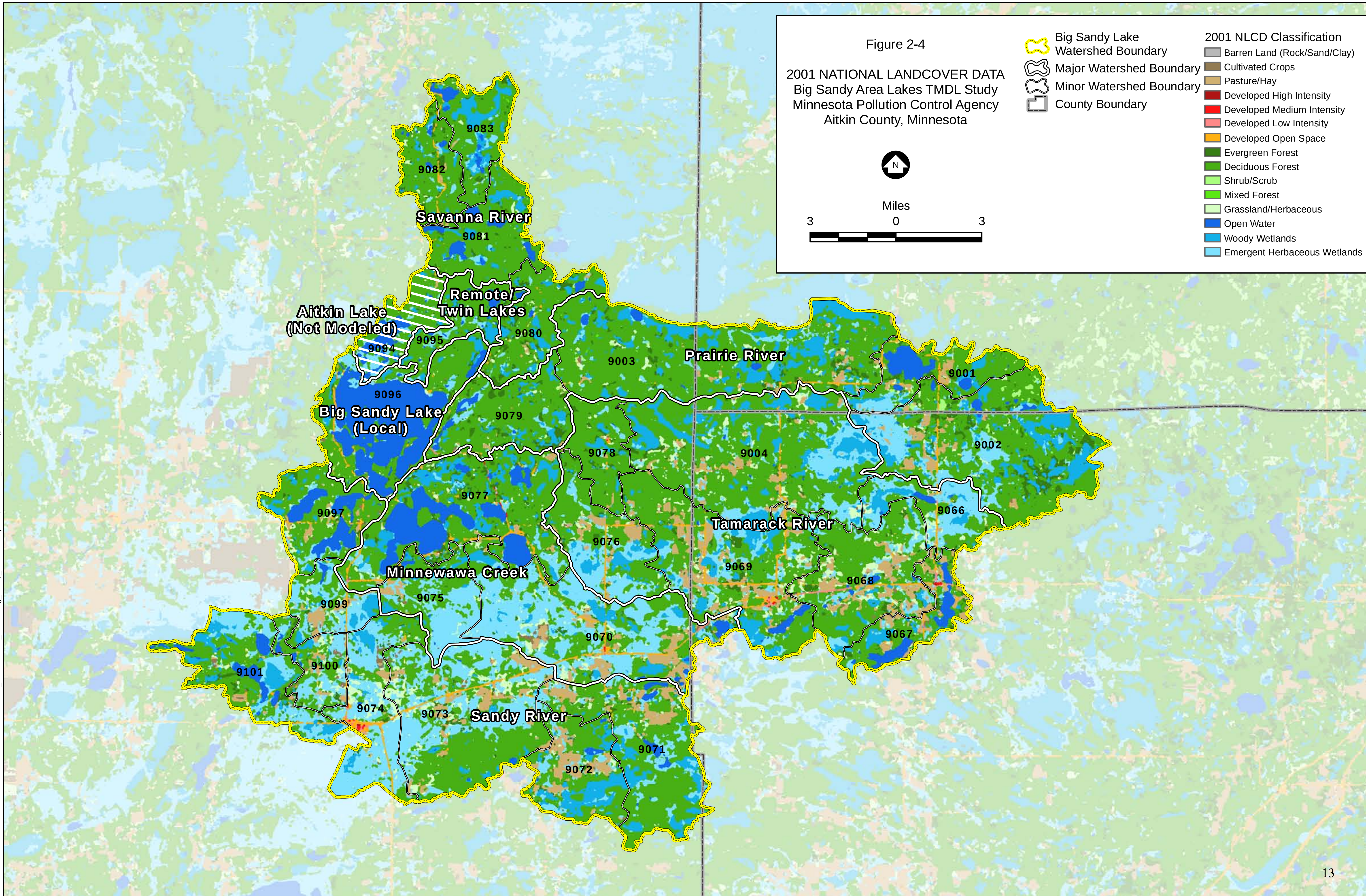


Figure 2-4
2001 NATIONAL LANDCOVER DATA
Big Sandy Area Lakes TMDL Study
Minnesota Pollution Control Agency
Aitkin County, Minnesota
N
Miles
3
0
3
Big Sandy Lake Watershed Boundary
Major Watershed Boundary
Minor Watershed Boundary
County Boundary
2001 NLCD Classification
Barren Land (Rock/Sand/Clay)
Cultivated Crops
Pasture/Hay
Developed High Intensity
Developed Medium Intensity
Developed Low Intensity
Developed Open Space
Evergreen Forest
Deciduous Forest
Shrub/Scrub
Mixed Forest
Grassland/Herbaceous
Open Water
Woody Wetlands
Emergent Herbaceous Wetlands
9083
9082
Savanna River
9081
Remote/Twin Lakes
Aitkin Lake (Not Modeled)
9095
9080
9094
9003
Prairie River
9001
9096
Big Sandy Lake (Local)
9079
9002
9078
9004
9077
9097
9066
Tamarack River
9076
9069
Minnewawa Creek
9068
9075
9099
9070
9067
9101
9100
9074
9073
Sandy River
9071
9072

2.3.2 Lake Minnewawa Watershed

Lake Minnewawa has a much smaller watershed when compared to Big Sandy Lake. Lake Minnewawa receives flow from Horseshoe Lake to the east, as well as from the local watershed immediately surrounding the lake (Figure 2-5). The watershed for Lake Minnewawa is smaller than the extent of subwatershed "9077" shown in Figure 2-4, as the southwest corner of subwatershed "9077" does not contribute to Minnewawa Lake.

The Lake Minnewawa watershed is approximately 13,243 acres (20.7 square miles) in size. Land use percentages of the Lake Minnewawa watershed, based on the 2001 National Land Cover Database (NLCD), are summarized as follows:

- 51.4% forest
- 20.3% wetland
- 4.3% pasture/hay/cultivated crops
- 2.0% grassland
- 21.5% open water
- 0.5% developed (low, medium, and high density)

2.4 Previous Studies and Reports

Several studies and reports have been conducted over the past three decades regarding water quality of Big Sandy Lake and Lake Minnewawa, and their respective watersheds. The historic reports and water quality data from the last three decades were instrumental in helping guide the development of this TMDL document. The most current, comprehensive and detailed of the reports used for reference in this study include the following:

- The 1995 Big Sandy Area Lakes Watershed Project Diagnostic Study (Aitkin County Board of Commissioners, 1995); and
- The 2002 Big Sandy Summary and Recommendations "White Paper" (MN DNR Fisheries, 2002).

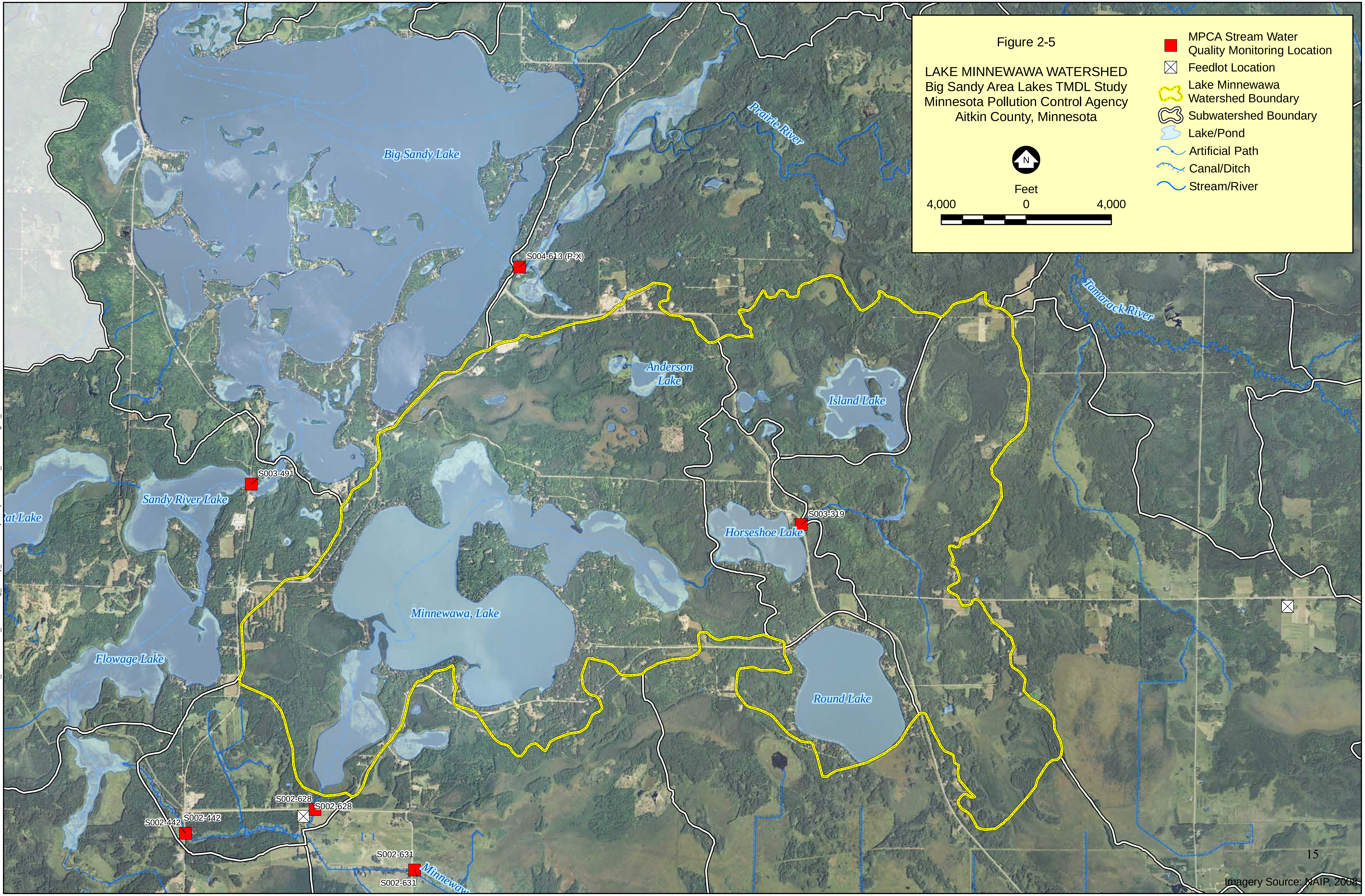


Figure 2-5
LAKE MINNEWAWA WATERSHED
Big Sandy Area Lakes TMDL Study
Minnesota Pollution Control Agency
Aitkin County, Minnesota
N
Feet
4,000
0
4,000
MPCA Stream Water Quality Monitoring Location
Feedlot Location
Lake Minnewawa Watershed Boundary
Subwatershed Boundary
Lake/Pond
Artificial Path
Canal/Ditch
Stream/River
Big Sandy Lake
Prairie River
Tamarack River
Anderson Lake
Island Lake
Sandy River Lake
at Lake
Horseshoe Lake
Minnewawa, Lake
Flowage Lake
Round Lake
Minnewaw
S004-613 (P-X)
S003-491
S003-319
S002-628
S002-628
S002-442
S002-442
S002-631
S002-631
Imagery Source: NAIP, 2008

3.0 Excess Nutrient Impairments

The following sections summarize the available water quality data for Big Sandy Lake and Lake Minnewawa; efforts to model water quality of the lakes; and development of the phosphorus load and wasteload TMDL allocations. The following sources of phosphorus were considered for modeling water quality:

- **Forest –** phosphorus in water yielded from forested and shrub land uses is typically transported to the watershed lakes or streams through natural or silvicultural runoff.

- **Internal Loading –** phosphorus is released or resuspended into the lake from sediments at the lake bottom during periods of bottom-water anoxia and/or wind mixing events. Benthivorous fish and macrophyte die-off may also contribute to internal loading within the watershed lakes.

- **Agriculture –** drain tiles, ditches, and surface runoff from fields and feedlots transport phosphorus from agricultural lands into the watershed tributaries. A combination of transport and source factors directly influence phosphorus movement from cropland and pasture to surface waters. Transport factors include the mechanisms by which phosphorus is delivered to surface waters, such as soil erosion and runoff, along with the characteristics of the downstream pathways. Source factors represent the amount of phosphorus available for transport, including soil test phosphorus content and phosphorus applied (rate and method) in fertilizer and organic forms (such as manure). In addition, riparian livestock can add animal waste to the stream and further contribute to downstream water quality degradation associated with channel erosion by eliminating streamside vegetation directly, or indirectly as a result of trampling the banks.

- **Stream Channel Erosion –** The stability of stream channels is highly influenced by the dynamics of natural and anthropogenic disturbances. Unstable streams typically undergo erosion, both in the form of particle scour and mass failure following erosion of the bank toe. Phosphorus attached to eroded streambank material is typically entrained in the flow where it may ultimately become available for biological uptake, re-deposited or transported downstream. Stream channel stability in the watershed is likely affected most by ditching, ditch cleaning and culvert crossings that have significantly altered channel slope and peak discharge, while reducing substrate resistance and energy dissipation associated with disconnection from floodplains.

- **Open water and wetlands –** lakes, ponds, and wetlands in the watershed drain to tributaries of Big Sandy and Minnewawa Lakes and can contribute additional phosphorus from atmospheric deposition associated with rainfall and dryfall directly on the water surfaces. In addition, wetland and open water areas impacted by ditching may contribute higher phosphorus loadings associated with an increased frequency of wet-dry cycles that trigger more peat decomposition and associated nutrient release.

- **Developed Land Uses –** Increased runoff rates and volumes from impervious surfaces and lakeshore development, combined with higher densities of stormwater conveyances in the watershed, have direct impacts on the lakes and their tributaries. Along with higher runoff volumes, developed land uses contribute additional phosphorus loading associated with lawn clippings, fertilizer, soil erosion, leaf litter, car wash water and animal waste, etc. In addition, septic system discharge and construction-site runoff associated with lakeshore development contributes additional phosphorus loading. Conventional subsurface sewage treatment systems (SSTS) consist primarily of a septic tank and a soil absorption field. Phosphorus is present in significant concentrations in most wastewaters treated by SSTS. Phosphorus export to surface waters from SSTS is dependent on several factors, including: phosphorus content of the wasteload; population served; compliance with SSTS performance standards; and characteristics of soil absorption field, groundwater conditions and proximity to surface waters. Failing SSTS, specifically defined as systems that are failing to protect groundwater from contamination, have relatively direct connections to surface waters through inadequate separation, tile lines or road ditches, resulting in a very high delivery potential. Conventional SSTS have a finite design life and require regular inspection and on-going maintenance.

- **Wasteloads –** Several small municipalities and peat farming discharge phosphorus to tributaries of Big Sandy Lake as surface-water discharges from permitted wastewater or process water treatment facilities.

3.1 Big Sandy Lake Water Quality

Current and historic water quality monitoring locations on Big Sandy Lake are presented in Figure 2-2. Summer (June-September) mean Secchi disc transparencies for Big Sandy Lake are below the NLF ecoregion standard of 2.0 meters for all three bays during the period of 1983-2008, with the exception of Bellhorn Bay in 1988 (Figure 3-1). Summer mean total phosphorus concentrations are presented in Figure 3-2. Summer average chlorophyll *a* concentrations are presented in Figure 3-3.

Average Secchi disc transparencies were some of the lowest on record for Big Sandy Lake in 2008, even though average concentrations of chlorophyll *a* and total phosphorus in 2008 were in the range of concentrations of other recent years. Plotting individual measurements of Secchi disc transparency against concurrent measurements of chlorophyll *a* (Figure 3-4) demonstrates water transparency was generally lower in 2008 when compared to readings taken when chlorophyll *a* concentrations were similar. Likewise, Secchi disc transparency was generally lower in 2008 compared to previous years for similar concentrations of total phosphorus (Figure 3-5). For many Minnesota lakes, a strong relationship exists between Secchi disc transparency, chlorophyll *a*, and phosphorus concentrations. An examination of available data for Big Sandy Lake, including plotting chlorophyll *a* versus total phosphorus (Figure 3-6), reveals there is a relatively weak relationship between Secchi disc transparency, chlorophyll *a*, and phosphorus in Big Sandy Lake.

One possible explanation of the weak relationship between Secchi disc transparency, chlorophyll *a*, and total phosphorus is high humic color in Big Sandy Lake. Big Sandy Lake is generally highly colored, with historic reading ranging from 100 to 300 Platinum-Cobalt Units (PCU) (Figure 3-7). These color readings represent high concentrations of light-absorbing dissolved organic compounds that can severely reduce water transparency. Typical color readings for lakes in the NLF ecoregion are in the range of 10-35 PCU (MN DNR Fisheries 2002). Big Sandy has a large watershed with a high percentage of wetlands, including large areas of peatlands. The decaying organic matter in these wetlands and peatlands are a significant source of dissolved organic compounds, as evidenced by high color readings in the Sandy River and Prairie River.

Historic Secchi disc transparency and chlorophyll *a* readings that were taken in conjunction with color measurements during the period of 1985-1994 were compared (Figure 3-8). Several of the lowest Secchi disc transparency readings during this period correspond to sample dates with high color values, but low to moderate chlorophyll *a*, demonstrating that Secchi disc transparency measurements in Big Sandy Lake can be greatly affected by humic color. Color readings are not available for 2008, but a comparison of 2008 Secchi disc transparency and chlorophyll *a* values suggests Big Sandy Lake was highly colored (>200 PCU) in 2008.

Minnesota lake eutrophication standards are designed such that total phosphorus is the target pollutant or causal factor, as phosphorus is almost always the limiting nutrient for algal growth in

Minnesota lakes. Secchi disc transparency and chlorophyll *a* are response factors of eutrophication that are considered if total phosphorus concentrations are above the water quality standard. This TMDL has been developed to attain the water quality standard for total phosphorus and either one of the response factors in Big Sandy Lake and Lake Minnewawa. While there is a weak relationship between total phosphorus and chlorophyll *a* in Big Sandy Lake, the paired data shown in Figure 3-6 indicate that the chlorophyll *a* concentrations will generally meet the 9 μg/L standard when the total phosphorus concentration is less than the 30 μg/L standard. Although MPCA (2005) indicated that productivity for a given nutrient concentration will be less for highly colored lakes than that observed for clear lakes, there is still a relationship between total phosphorus and chlorophyll *a*. As a result, it is expected that improvements in Secchi disc transparency and chlorophyll *a* will also be achieved through the reduction of total phosphorus, as reductions in phosphorus concentrations will result in decreases in algal growth and increases in water clarity within the lakes. It is also expected that a reduction in some of the decomposing sources of phosphorus (further described in Section 2.3.1) will result in less color in the surface runoff and further improvements in Secchi disc transparency (as indicated in Figure 3-8).

Figure 3-1 Big Sandy Summer Mean Secchi Disc Transparency

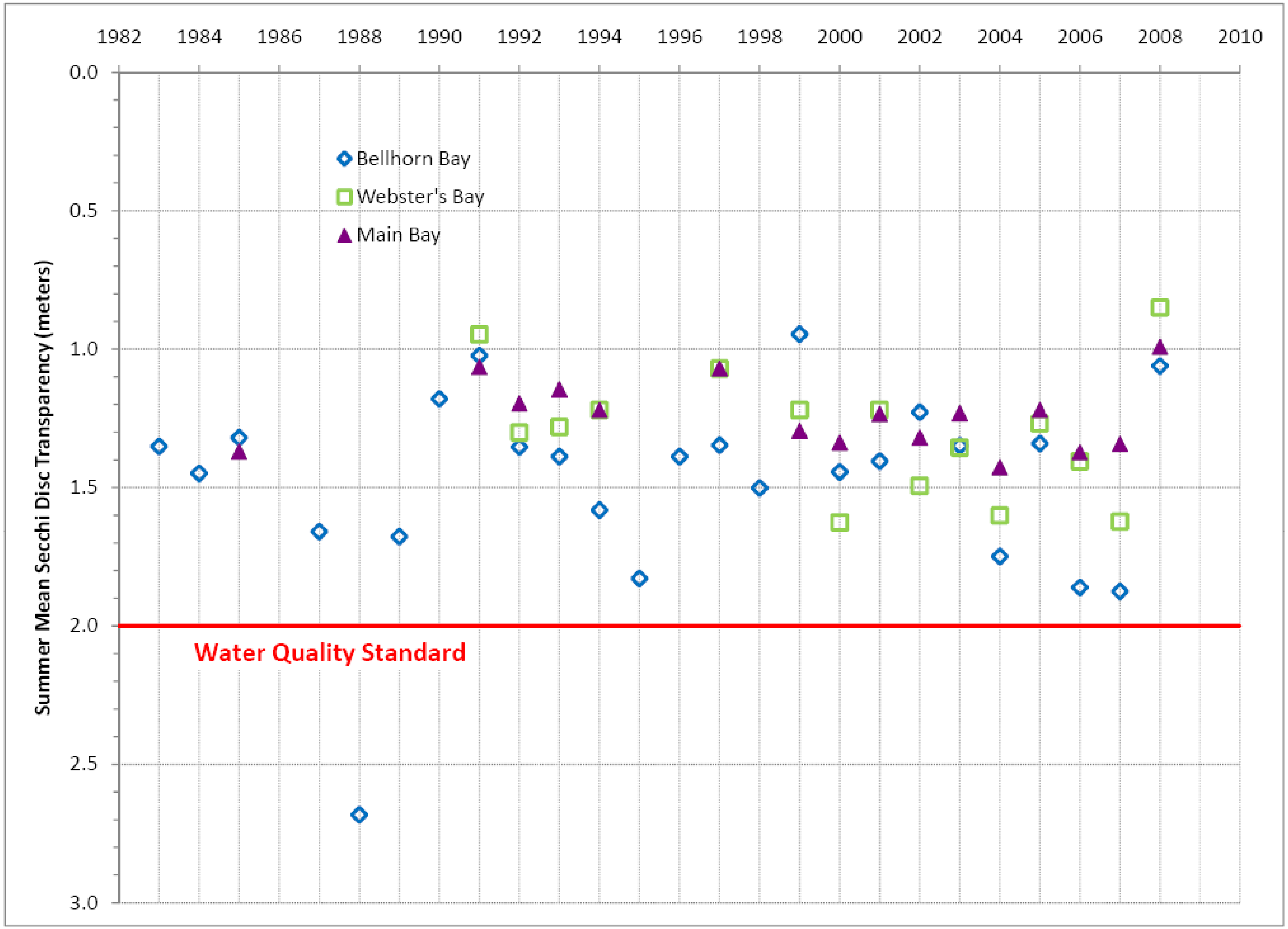


Figure 3-2 Big Sandy Lake Summer Mean Total Phosphorus

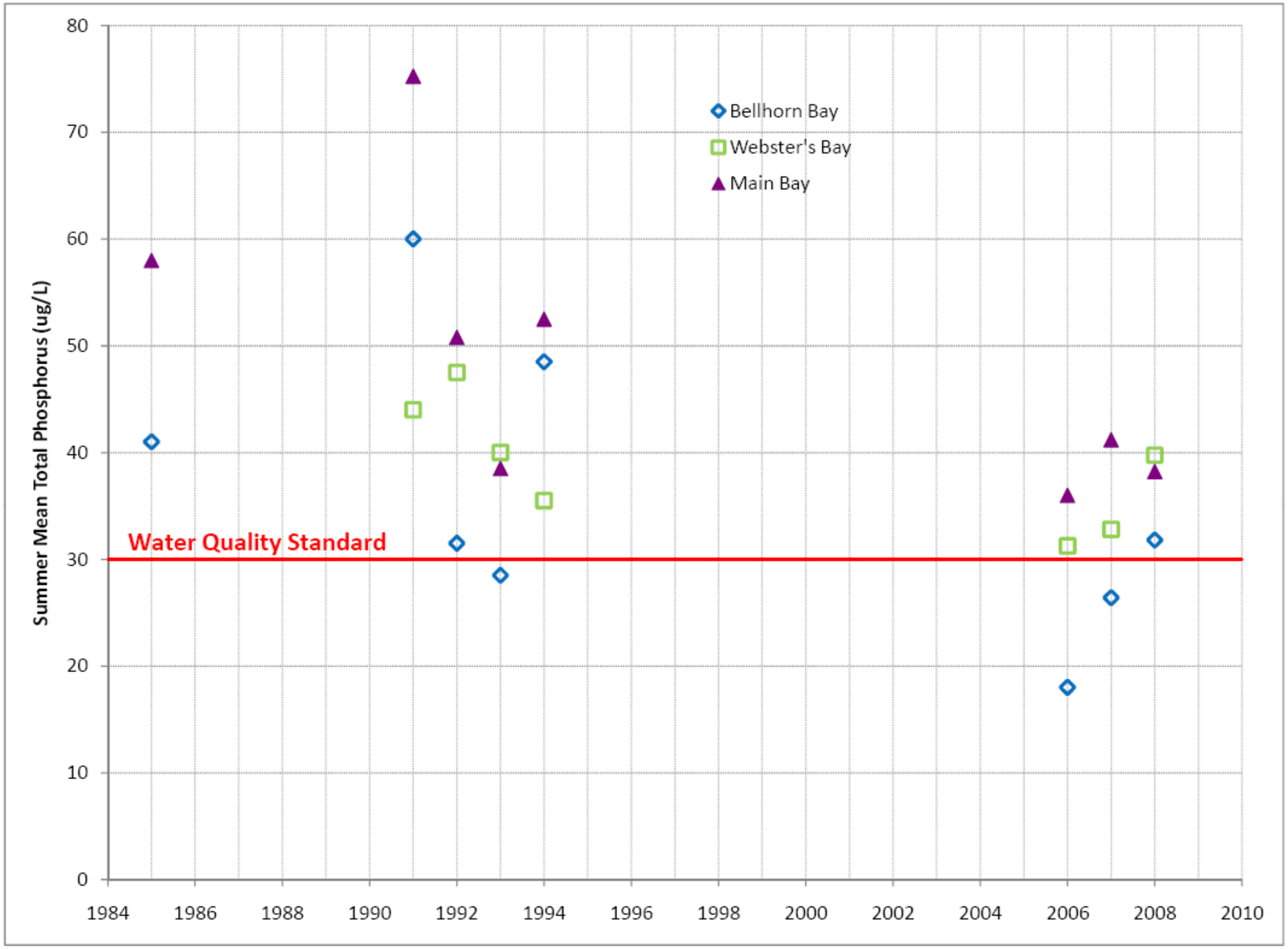


Figure 3-3 Big Sandy Lake Summer Mean Chlorophyll *a*

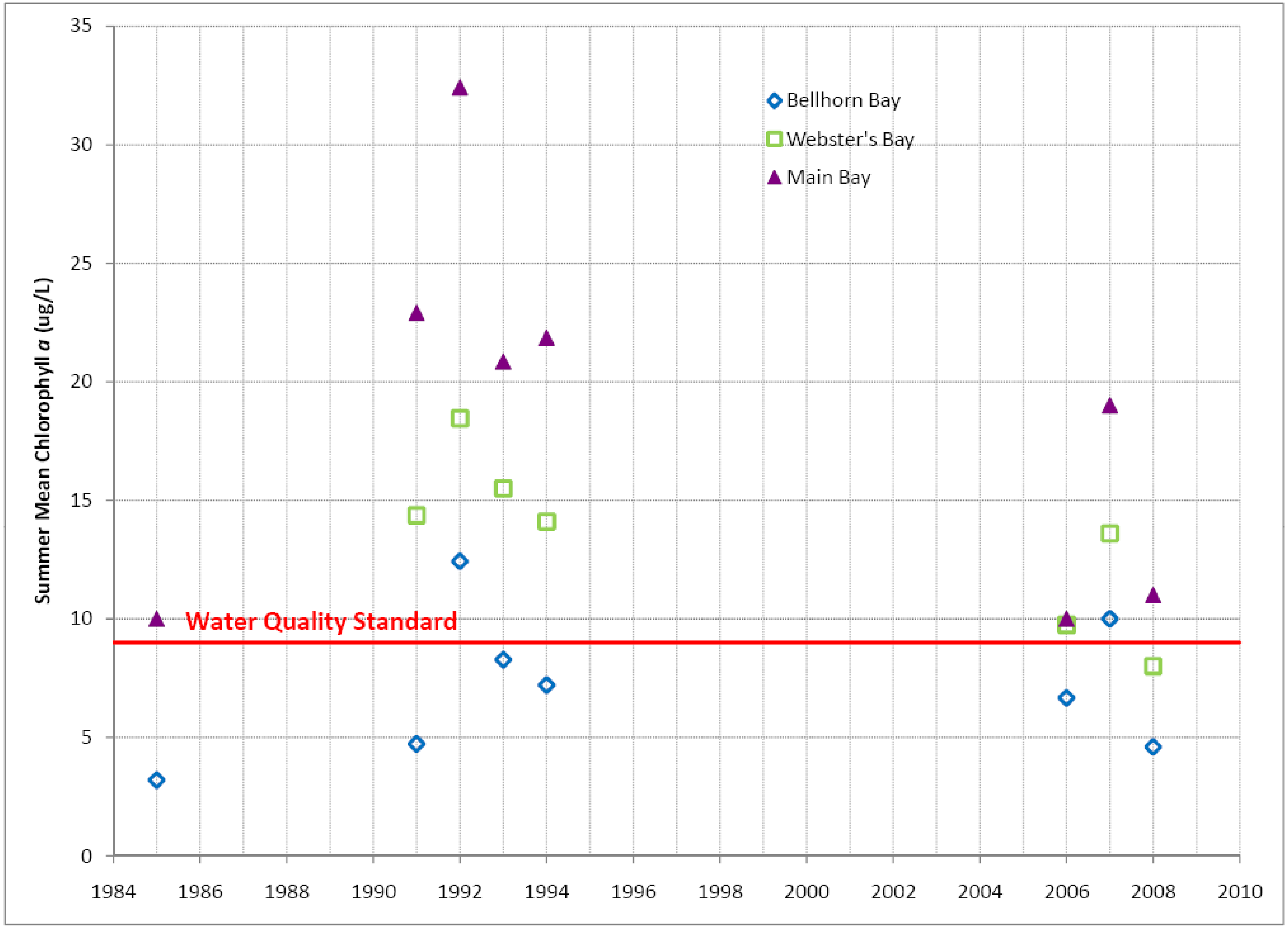


Figure 3-4 Big Sandy Lake Secchi Disc Transparency vs. Chlorophyll *a*

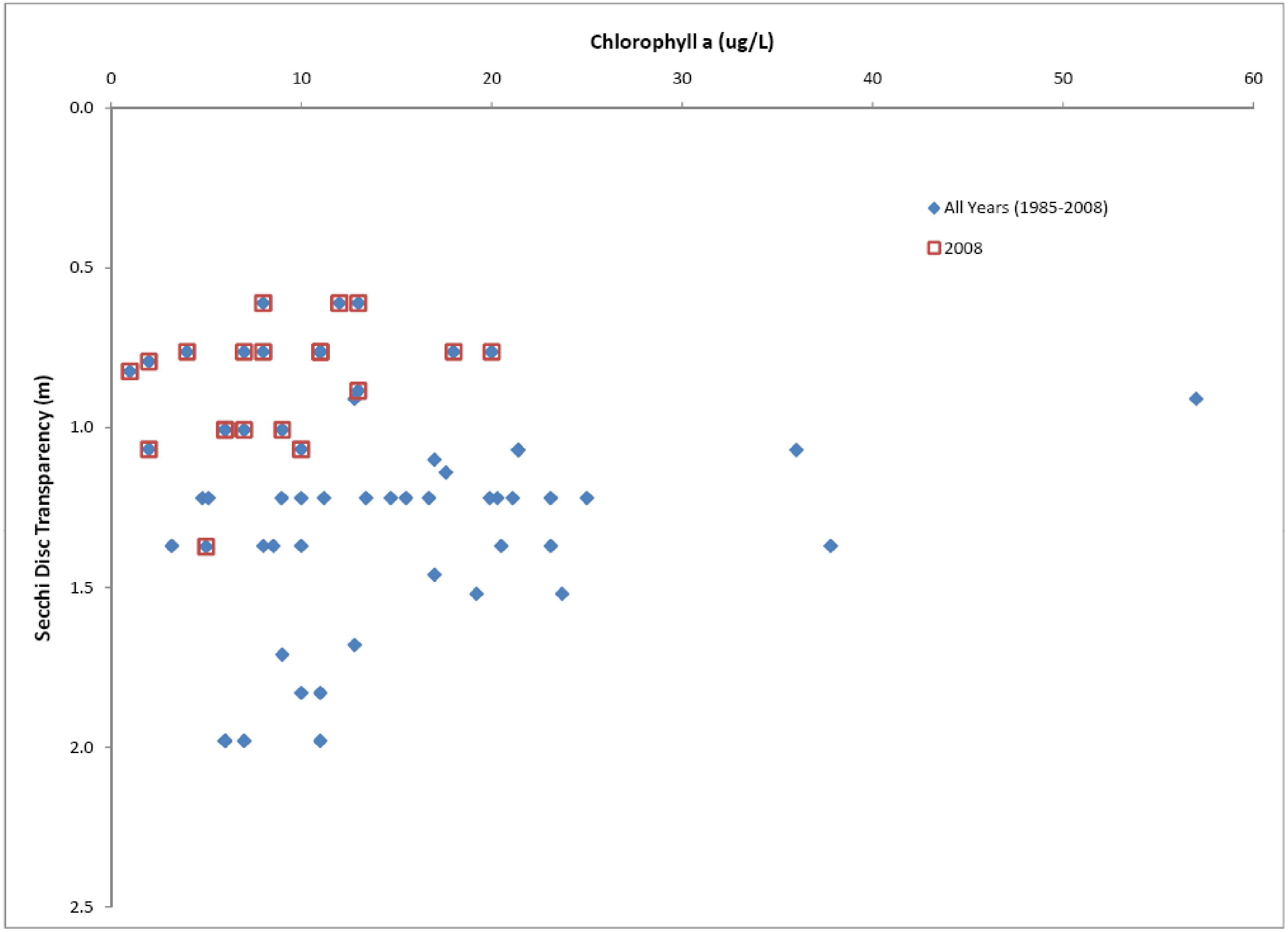


Figure 3-5 Big Sandy lake Secchi Disc Transparency vs. Total Phosphorus

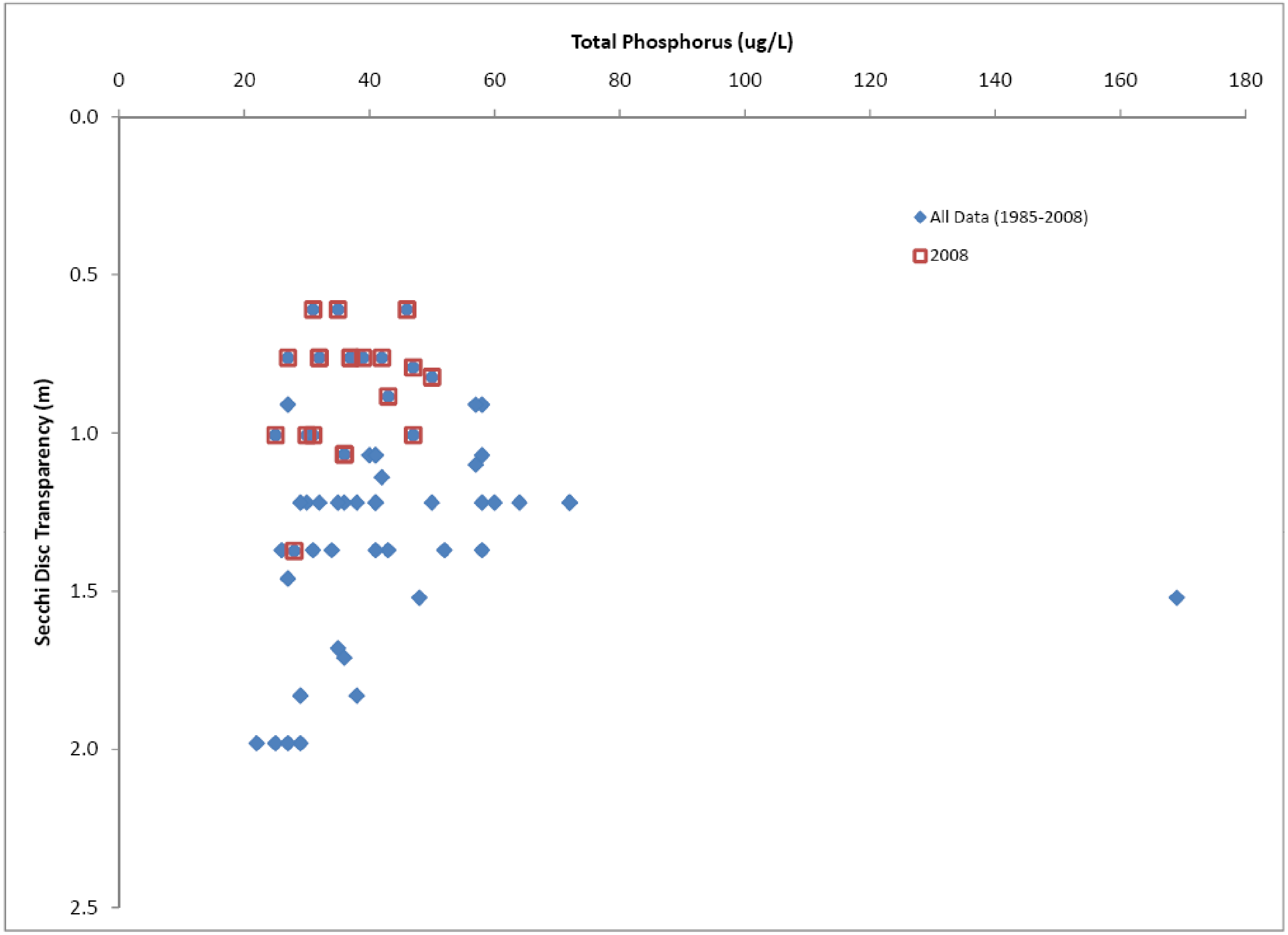


Figure 3-6 Big Sandy Lake Chlorophyll *a* vs. Total Phosphorus

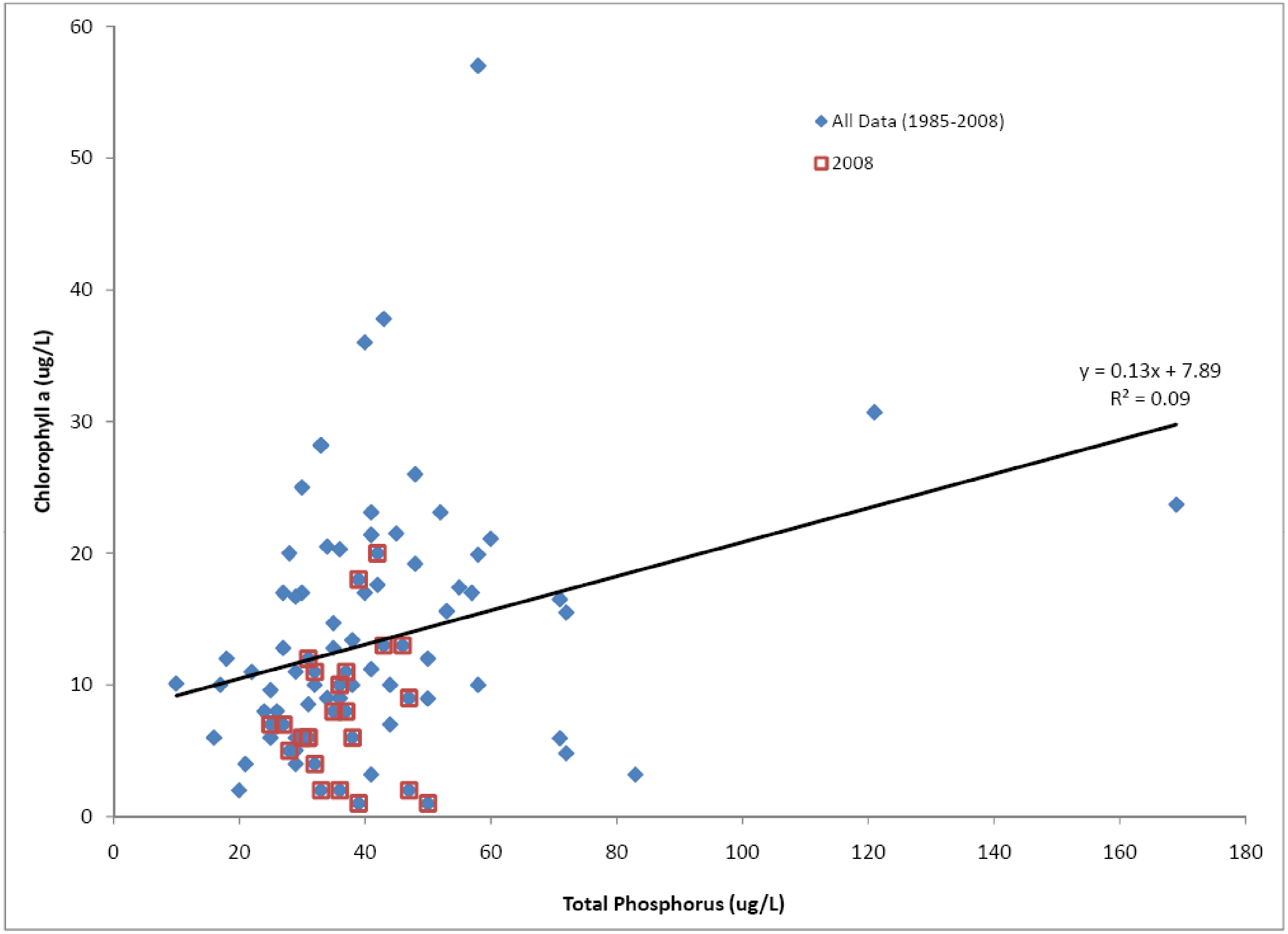


Figure 3-7 Big Sandy Lake Historical Color Observations

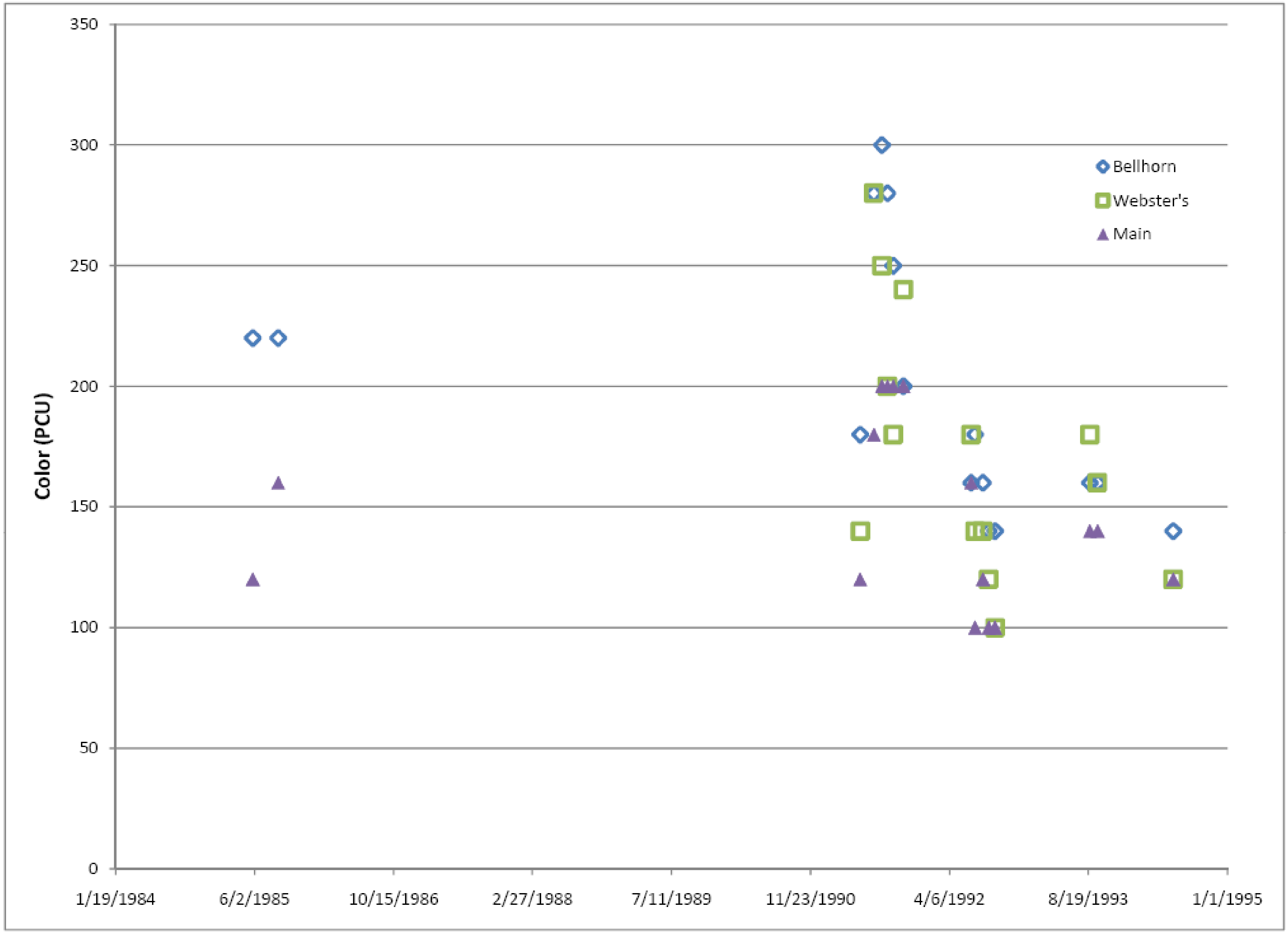
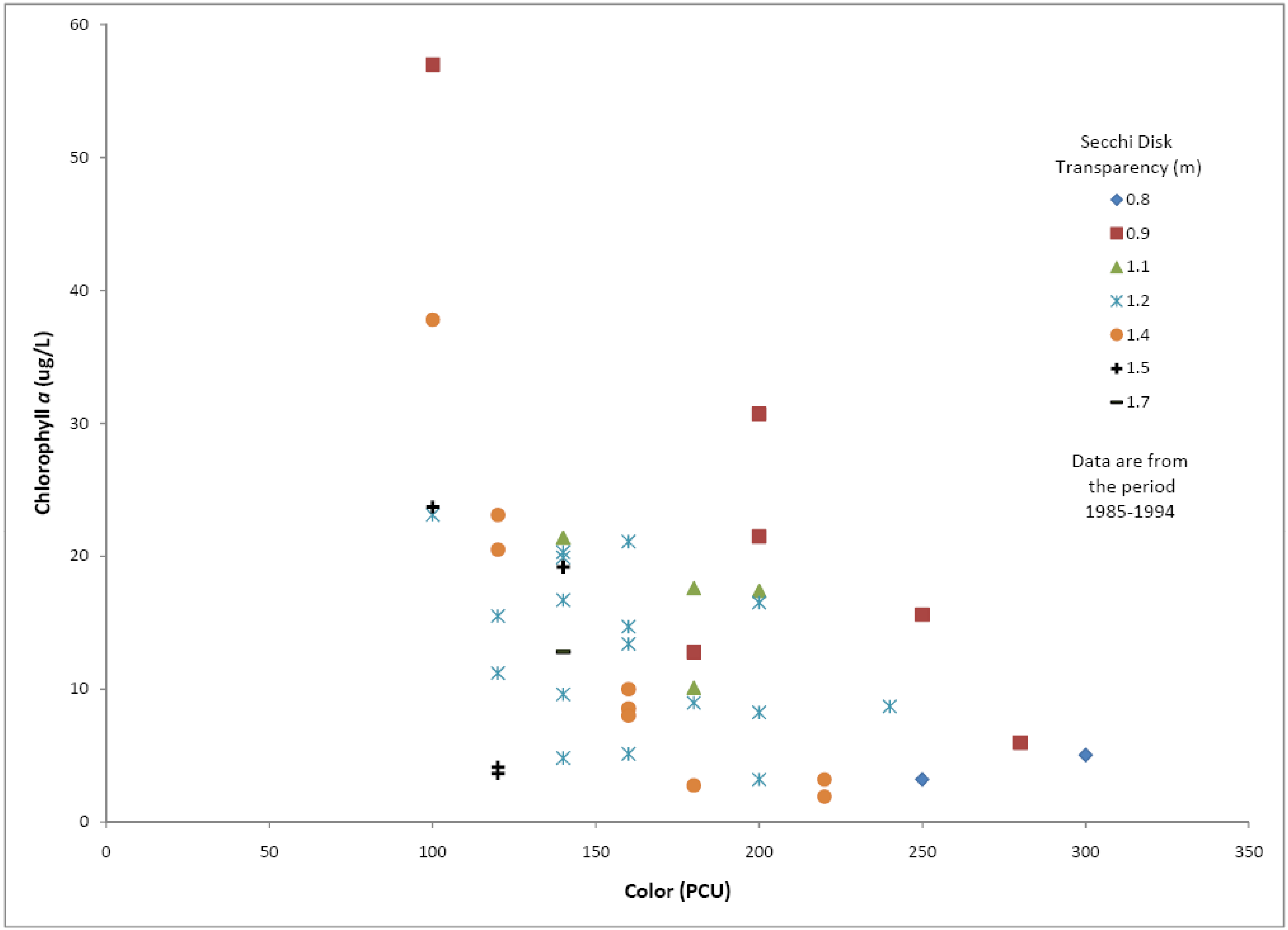


Figure 3-8 Big Sandy Lake Transparency Relationship to Color and Chlorophyll *a*



3.2 Lake Minnewawa Water Quality

Current and historic water quality monitoring locations on Lake Minnewawa are presented in Figure 2-3. After several years of summer mean Secchi disc transparency below the water quality standard (1996-2003), summer mean Secchi disc transparencies have been variable in recent years (Figure3-9). Total phosphorus data for Lake Minnewawa are limited, but summer mean concentrations are generally lower in recent years compared to the period 1979-1996 (Figure 3-10). Available chlorophyll *a* data are also limited (Figure 3-11), but mean summer concentration are generally lower in recent years compared to available data from the period 1989-1993. The results of the recent monitoring data indicate that there is improved water quality in Lake Minnewawa.

Figure 3-9 Lake Minnewawa Summer Mean Secchi Disc Transparency

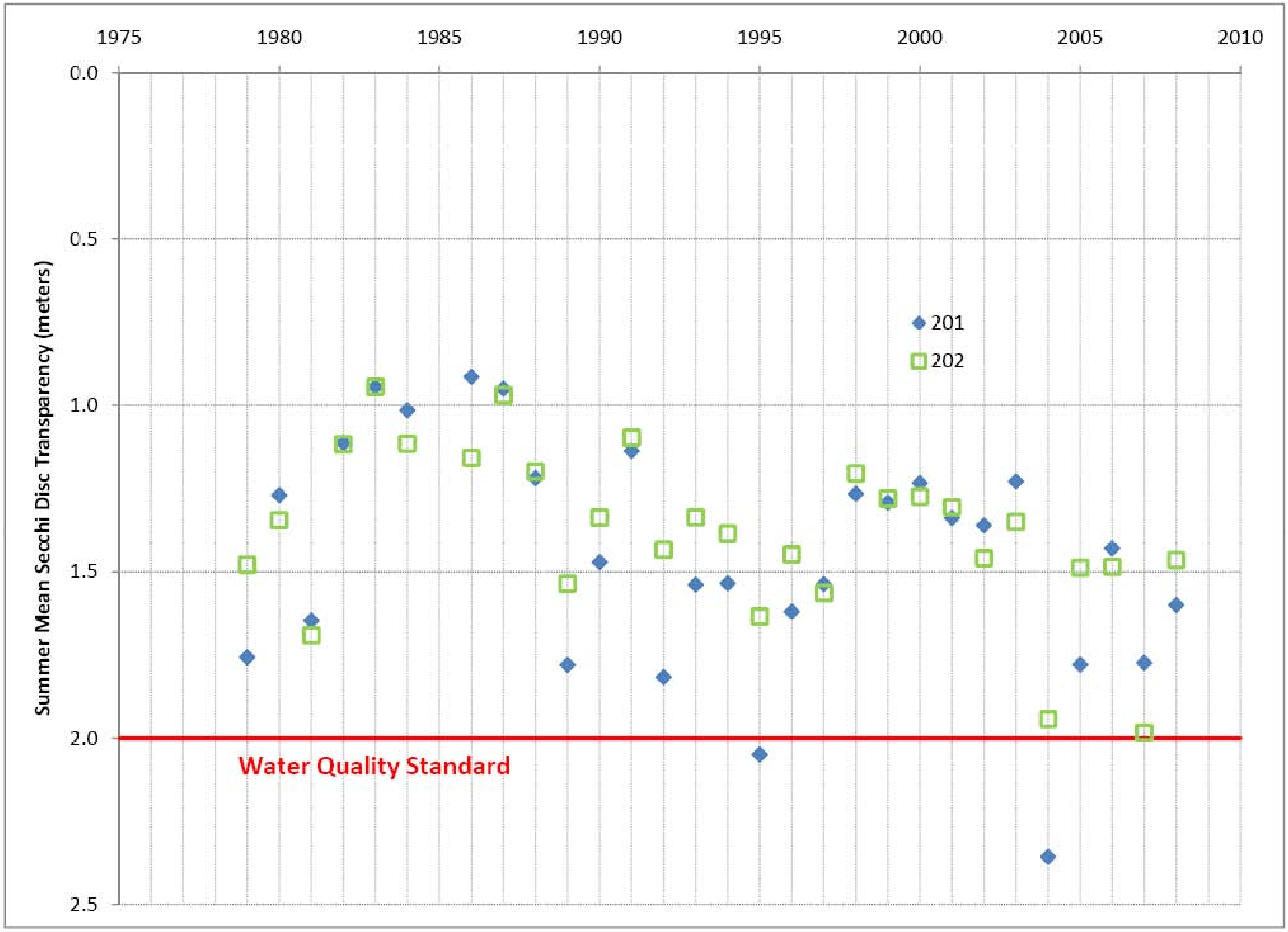


Figure 3-10 Lake Minnewawa Summer Mean Total Phosphorus

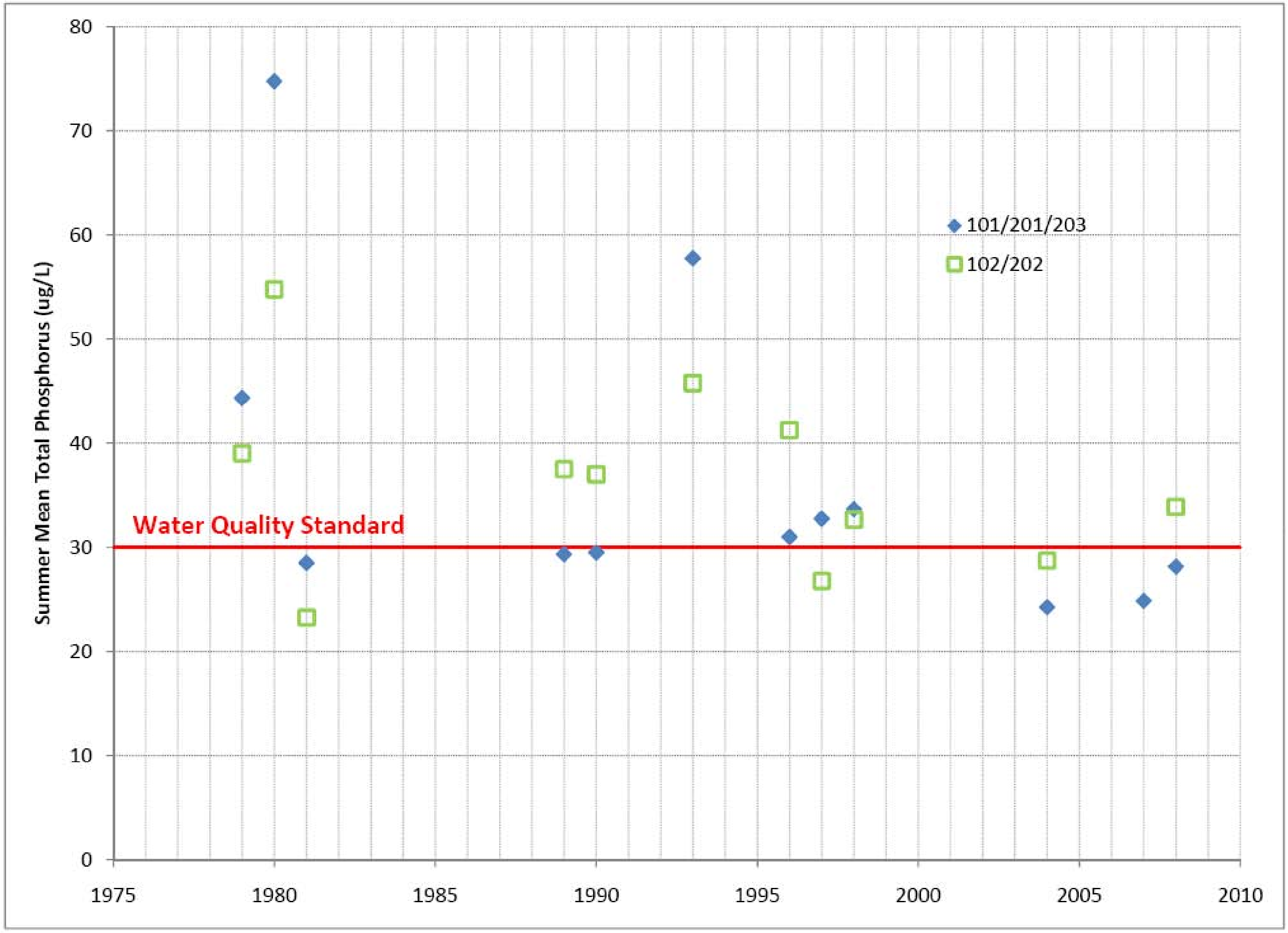
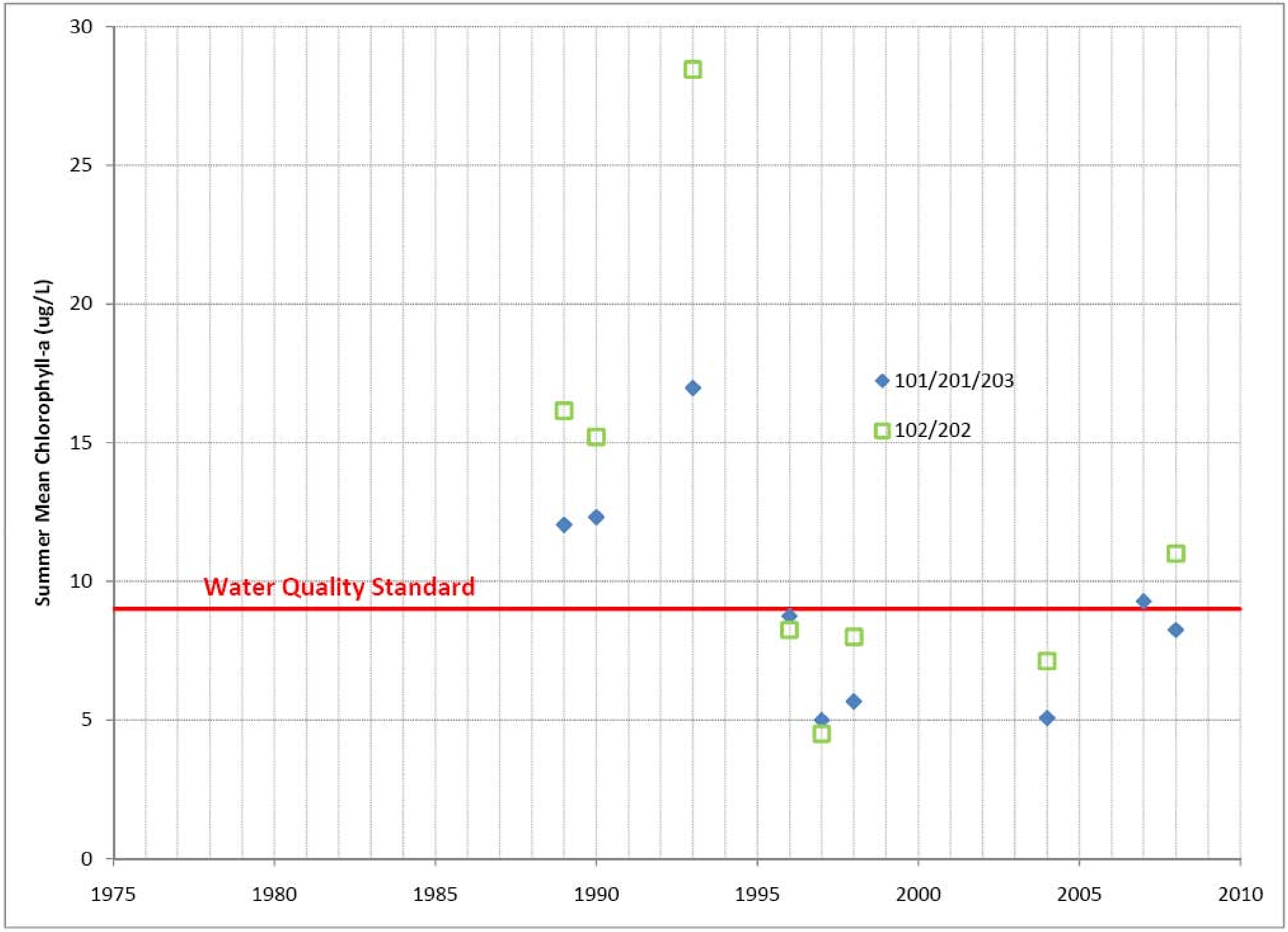


Figure 3-11 Lake Minnewawa Summer Mean Chlorophyll *a*



3.3 Historical Water Quality and Baseline Conditions

A number of tools have been developed to evaluate the attainable or pre-European settlement conditions in lakes. Vighi and Chiaudani (1985) developed a linear regression model to predict growing season total phosphorus in minimally impacted lakes. Wilson and Walker (1988) developed a simple model to predict baseline, non-impact water quality conditions (total phosphorus, chlorophyll *a*, and Secchi disc depth) for lakes in Minnesota based on ecoregion classification. Both of these models, and analysis results, are detailed below.

3.3.1 Vighi and Chiaudani

Vighi and Chiaudani (1985) developed a relationship to predict average, growing season total phosphorus concentrations in lake surface waters, not impacted by anthropogenic inputs, based either on current surface water conductivity or alkalinity. The relationship is based on 53 minimally impacted lakes located mainly in Europe and Canada. Seven lakes from the dataset were located in the US.

The relationship uses conductivity or alkalinity in a morphoedaphic index calculated as the ratio between mean depth and alkalinity or conductivity. The two equations defining these relationships (for US lakes) are shown below:

$$\text{Log } P = 1.44 + 0.33\ (\pm\ 0.10)\ \text{Log } MEI_{alk}$$

$$\text{Log } P = 0.71 + 0.26\ (\pm\ 0.11)\ \text{Log } MEI_{cond}$$

The equation based on alkalinity was chosen to predict historical total phosphorus concentrations in each lake because conductivity levels can be affected by anthropogenic inputs to lakes. The predicted growing season total phosphorus concentrations for each lake are shown in Table 3-1.

Table 3-1 Alkalinity based predictions for historical total phosphorus concentrations in Big Sandy Lake and Lake Minnewawa.

Lake	Bay	Alkalinity TP (µg/L)	Alkalinity TP Confidence Limits (µg/L)	
Big Sandy	Bellhorn	12.9	10.2	16.2
	Main	17.6	15.3	20.1
	Websters	No Data*		
	Whole Lake**	16.7	14.4	19.4
Minnewawa	Whole Lake	19.8	17.9	21.9

*No alkalinity data are available for Websters Bay
**Whole lake values are based on area-weighted averages.

3.3.2 MINLEAP

The Minnesota Lake Eutrophication Analysis Procedure (MINLEAP) is a simple model designed to predict minimally impacted surface water quality in Minnesota lakes based upon lake surface area, mean depth, watershed area and ecoregion in which the lake is located (Wilson and Walker, 1988).

The program is intended primarily as a screening tool for estimating lake conditions with minimal input data. The results output from the model can be considered a baseline for evaluation of eutrophication and applicability of State water standards. Tables 3-2 and 3-3 compare 2008 observations and the model results for each of the study lakes.

Table 3-2 MINLEAP results for Big Sandy Lake compared with 2008 water quality data.

Lake	Parameter	Observed 2008	Predicted	Std. Error
Big Sandy	TP (µg/L)	37	29	8
	Chl a (µg/L)	7.9	10	5.1
	SD (m)	0.9	2	.7

Table 3-3 MINLEAP results for Minnewawa Lake compared with 2008 water quality data.

Lake	Parameter	Observed 2008	Predicted	Std. Error
Minnewawa	TP (µg/L)	31	24	7
	Chl a (µg/L)	9.6	6.7	3.8
	SD (m)	1.5	2.5	1

Comparing 2008 data to the MINLEAP output for both lakes, observed total phosphorus and chlorophyll *a* concentrations were higher while observed Secchi disc depth values were lower for both lakes. However, 2008 observed values for Big Sandy and Minnewawa were within the standard error of the model with the exception of Secchi disc depth in Big Sandy Lake. The significant differences in the observed and modeled Secchi disc depths for Big Sandy Lake may be due to the effects of humic color in the lake water.

Reconstruction of historical water quality in Big Sandy Lake was conducted by the MPCA in conjunction with the Science Museum of Minnesota (Edlund et al., 2009). Sediment was analyzed from a long core taken from the deep hole in Webster's Bay. According to the results (Figure 3-12), total phosphorus in Webster's Bay has ranged from 53 µg/L under current conditions, was as high as 78 µg/L in the 1930s, and was approximately 40 µg/L before European settlement (pre-dam construction).

The results from the historical reconstruction of total phosphorus were compared to MINLEAP output for Webster's Bay. A number of changes were made to the model inputs so that the model would represent pre-dam conditions. The water level in Webster's Bay was decreased by nine feet to compensate for the change in lake water level caused by damming. This caused a decrease in lake water area, volume, and mean depth. The watershed area increased slightly due to the decrease in lake surface area. In addition, it was assumed that Webster's Bay was essentially secluded from the Main Bay of Big Sandy Lake due to the lower water level.

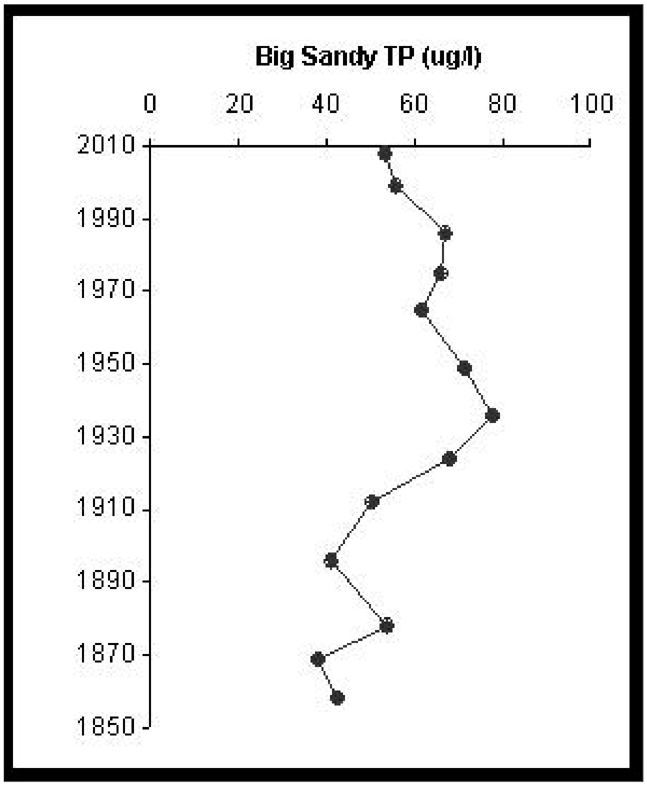


Figure 3-12 Sediment reconstruction of historical total phosphorus in Webster's Bay

The results from MINLEAP match the historical (pre-European) reconstruction of total phosphorus from the sediment core at 40 µg/L (Table 3-4). The results from the historical reconstruction and MINLEAP analysis indicate that a growing season average of 40 µg/L total phosphorus is the baseline, pre-impact level of phosphorus for this portion of the lake and provide some validation for the MINLEAP estimates of the larger Big Sandy Lake area.

Table 3-4 Comparison of reconstructed historical total phosphorus with MNLEAP output for Webster's Bay.

Lake	Parameter	Historical	MINLEAP Predicted	Std. Error
Webster's Bay	TP (µg/L)	40	40	8
	Chl a (µg/L)	NA	14.4	6.7
	SD (m)	NA	1.6	0.5

3.3.3 Mississippi River Backflow

To determine the potential impact of backflows from the Mississippi on water quality in Big Sandy Lake, ACOE level data from the Big Sandy dam was analyzed. Events were located by comparing the upstream (lake) and downstream elevations at the dam. When the downstream elevations were above the lake elevation (and above the dam elevation), it was assumed the river was flowing into the lake contributing flow and phosphorus.

One such event occurred from March 31 through April 6, 1997. Backflow during this time was likely due to a combination of spring runoff and precipitation (0.34 inches). The downstream elevation was as high as 0.33 feet over the lake elevation during the seven day period. To estimate the flow contribution during the backflow event, the change in lake elevation was assumed to be due to flow from the river. Using a storage rating curve for lake area, the increased volume due to the change in lake elevation was estimated (Table 3-5). Because no phosphorus data were available for the event, average total phosphorus during the same period was estimated using USGS data during different years from nearby, upstream stations.

Table 3-5 Backflow Event Impacts on Big Sandy Lake.

Date	Lake Elevation Change	Backflow Volume	Total Phosphorus in Mississippi	Change in Lake Model TP Concentration
	(feet)	(acre-ft)	(mg/L)	(µg/L)
3/31-4/6/1997	2.1	15,234	0.080	1

Using the total change in lake volume of 15,234 acre-ft and an estimated concentration of 0.080 mg/L of total phosphorus for the Mississippi River, the estimated in-lake phosphorus concentration increase from the calibrated Big Sandy Lake Bathtub model is 1 µg/L. This load contribution and increased in-lake TP concentration is small as a percentage of the annual total phosphorus load (7%) and baseline growing season mean lake concentration, but represents a significant portion of the required load reduction resulting from the TMDL analysis and allocations (discussed in Section 3.4).

Two other events were noted where downstream elevations were higher than upstream elevations, both during 1999. However, increases in lake volume were much lower (1,110 and 5,040 acre-ft). If it is assumed that backflow events also occurred when downstream elevation was within 0.5 feet of the upstream elevation, several more events were detected. However, the maximum volume change was 30,000 acre-ft with similar total phosphorus concentrations, giving an estimated increase of 2 μg/L in the Bathtub model output.

Since the Mississippi River water quality is expected to have phosphorus concentrations that are at least an order of magnitude higher than Big Sandy Lake, it is expected that the temporal effects from Mississippi River backflow could be much more significant on a short-term (days-months) basis (than the annual loading impacts previously discussed). On a year-over-year basis, the effects of river backflow would be less significant as the outlet river and lake stage data indicated that one of these events may be occurring between once a year and every other year, on average, and are likely not occurring with the magnitude of the events that were previously illustrated. Mississippi River backflow did not occur during the 2008 water year.

3.4 TMDL Modeling Methodology

Watershed loadings and in-lake concentrations of phosphorus were used to calibrate in-lake models to determine source load impacts on water quality and potential reductions in loading needed to meet the water quality standard in each lake. The modeling methodology is detailed below.

3.4.1 Watershed Monitoring

Pollutant loadings were monitored in 2008 for large portions of the tributary watershed to Big Sandy Lake (Figure 3-13). Inflow monitoring was conducted at six locations within the Big Sandy Lake watershed. The sites for 2008 watershed monitoring that were used in this analysis included:

1. Savanna (V1)-Flow and Water Quality grab samples
2. Prairie (P2)-Flow and Water Quality grab samples
3. Minnewawa (M1)-Flow and Water Quality grab samples
4. Sandy (S3)-Water Quality grab samples
5. Pier 65- Water Quality grab samples
6. Prairie River Inlet (P-X)- Water Quality grab samples
7. Horseshoe Lake Inlet (Creek)- Water Quality grab samples

Precipitation measurements used for modeling of Big Sandy Lake and Lake Minnewawa, were measured by the Corps at the reservoir monitoring station located at Big Sandy Lake.

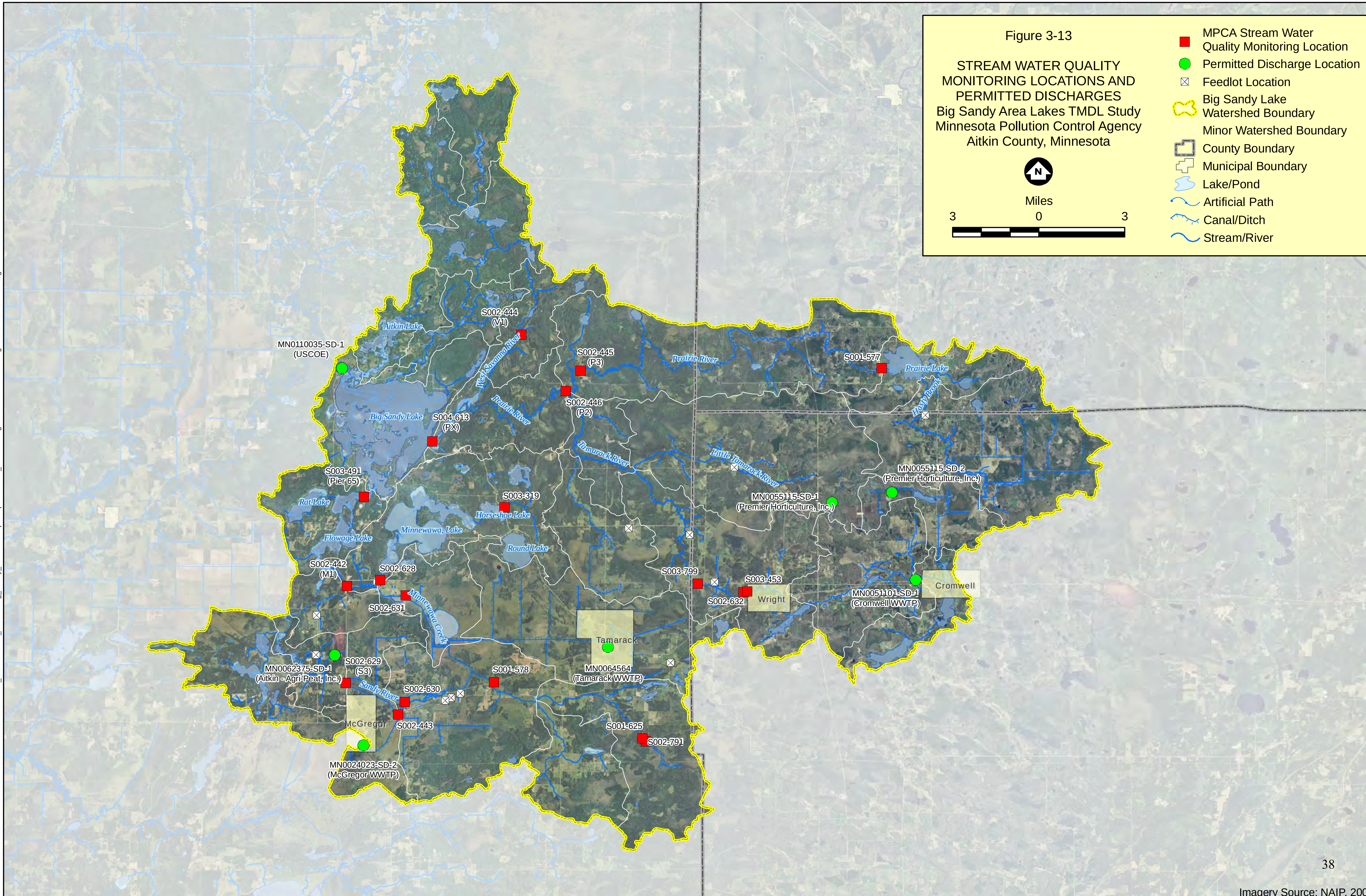


Figure 3-13
STREAM WATER QUALITY MONITORING LOCATIONS AND PERMITTED DISCHARGES
Big Sandy Area Lakes TMDL Study
Minnesota Pollution Control Agency
Aitkin County, Minnesota
N
Miles
3 0 3
MPCA Stream Water Quality Monitoring Location
Permitted Discharge Location
Feedlot Location
Big Sandy Lake Watershed Boundary
Minor Watershed Boundary
County Boundary
Municipal Boundary
Lake/Pond
Artificial Path
Canal/Ditch
Stream/River
Aitkin Lake
Big Sandy Lake
Rat Lake
Flowage Lake
Minnewawa Lake
Horseshoe Lake
Round Lake
Prairie Lake
West Savanna River
Prairie River
Tamarack River
Little Tamarack River
Minnewawa Creek
Sandy River
Hasty Brook
MN0110035-SD-1 (USCOE)
S002-444 (V1)
S002-445 (P3)
S002-446 (P2)
S004-613 (PX)
S003-491 (Pier 65)
S003-319
S001-577
MN0055115-SD-2 (Premier Horticulture, Inc.)
MN0055115-SD-1 (Premier Horticulture, Inc.)
S002-442 (M1)
S002-628
S002-631
S003-799
S003-453
S002-632
Wright
Cromwell
MN0051101-SD-1 (Cromwell WWTP)
Tamarack
MN0064564 (Tamarack WWTP)
MN0062375-SD-1 (Aitkin - Agri-Peat, Inc.)
S002-629 (S3)
S002-630
S001-578
S002-443
McGregor
MN0024023-SD-2 (McGregor WWTP)
S001-625
S002-791
Imagery Source: NAIP, 2008

Lakes were monitored for the following parameters either in the field or through laboratory analysis:

- Total Phosphorus, Total Dissolved Phosphorus, Chlorophyll *a*
- Dissolved Oxygen, Specific Conductance, Temperature, pH, and Secchi Disk

3.4.2 Water Quality Modeling

Water quality modeling provided the means to estimate total phosphorus sources to Big Sandy Lake and Lake Minnewawa, and the resultant water quality in each lake. Water quality modeling involved the following:

- Use of a FLUX loading model for monitored catchments
- Use of land use based runoff coefficients (Barr, 2004) for unmonitored catchments to estimate the water and TP loads from the tributary watersheds for each lake
- Use of a BATHTUB (Walker, 2004) model to reconcile the phosphorus loadings from the watershed with the phosphorus concentrations observed in the lake

The FLUX modeling, export coefficients, and the in-lake BATHTUB model are described in more detail below.

3.4.2.1 Watershed Modeling

FLUX is an interactive computer program designed for use in estimating the loadings of water quality components from tributary sampling. These loading estimates can be used for developing loading balances for lakes and reservoirs.

FLUX uses six calculation techniques, based upon the flow/concentration relationship that is developed from the sample and flow record to calculate mass of pollutants and associated statistics. Uncertainty in the loading estimates is characterized by error variances. The program uses water quality information to estimate the mean (or total) loading that corresponds to flow record for the period of interest.

Uncertainty in the loading estimate is reflected by the reported coefficient of variation (CV) estimate. The CV equals the standard error of the mean loading divided by the mean loading. The CV reflects sampling error in the flow-weighted mean concentration. In practice, CV values <0.1 are usually adequate for use in mass-balance modeling, especially considering that uncertainty in flow measurements is usually in this range (Walker, 2004).

Flow and event water quality data were collected at the four watershed sampling locations used in this study during the 2008 water year. When monitoring records had missing data, values were interpolated between monitoring points to attain annual values for flow and total phosphorus. Where extrapolation was required outside of the monitoring period, watershed yield was estimated using the proportion of watershed yield, based on the USGS outflow data, during the non-monitored period.

Average daily flows varied with rainfall amounts and intensity, and tributary watershed size. The flow volumes and phosphorus loads from the Prairie River (P2) and Savanna River (V1) locations were summed and are called PX. Because continuous data were not available, flow in the Sandy River (S3) was based on event flow measurements and the relationship developed between flow at P2 and the monitored data at S3 (Figure 3-14). Daily total phosphorus concentrations were determined by interpolating between monitoring events. Water and phosphorus loads for Big Sandy and Minnewawa are shown in Tables 3-6 and 3-7, respectively.

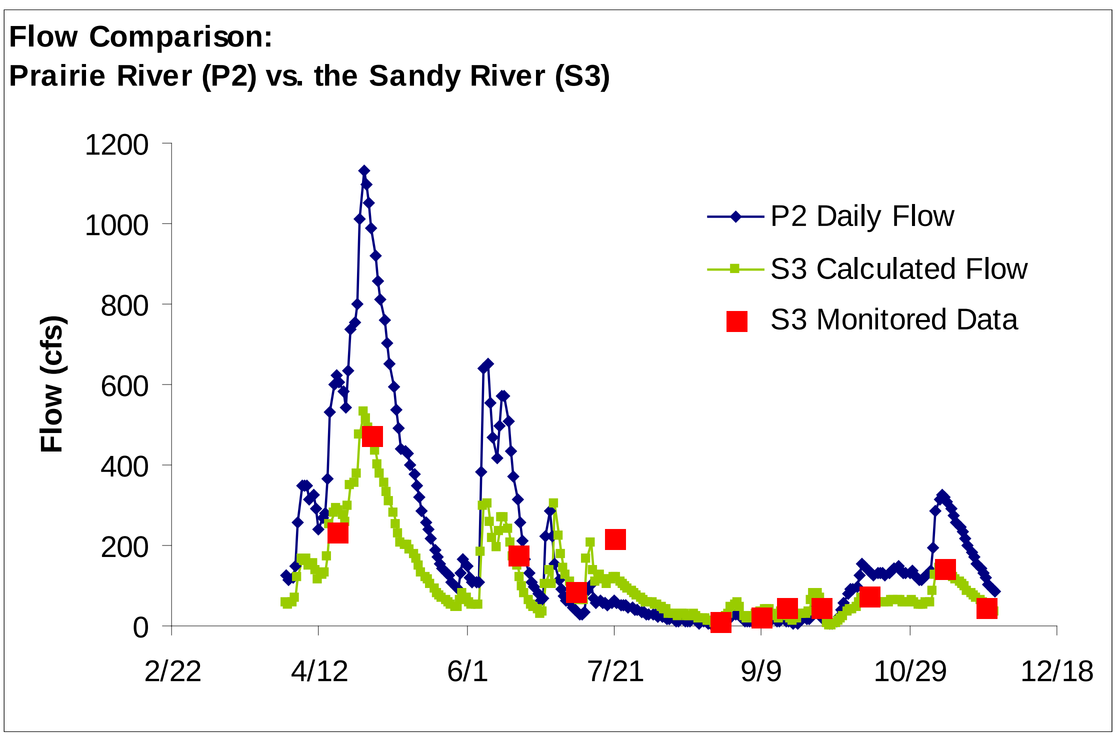


Figure 3-14 Relationship between flow at the Sandy and Prairie Rivers

Table 3-6 Loading data and FLUX statistics for watershed inputs to Big Sandy Lake

Inflow	Site	Flow (acre-ft)	TP (kg)	Concentration (mg/L)	Method	C.V.
Prairie	PX	111,039	7,132	0.052	FWC	.0806
	Unmonitored	8,609	553	0.052		
	Total	**119,648**	**7,685**	**0.052**		
Sandy	M1	12,928	1,026	0.064	C/Q Reg3	.0408
	S3	59,867	4,448	0.060		
	Unmonitored	13,519	1,073	0.064		
	Total	**86,314**	**6,547**	**0.062**		
	Pier 65*	86,314	5,595	0.053		
Big Sandy	**Direct**	**3,864**	**629**	**0.132**		
	Twin/Remote	**2,750**	**180**	**0.053**		

*Arithmetic mean of 2008 phosphorus monitoring data was used with total water load developed for the monitored and unmonitored areas.

Table 3-7 Loading data for the watershed inputs to Lake Minnewawa

Site	Flow (acre-ft)	TP (kg)	Concentration (mg/L)
Direct	3,641	313	0.070
Horseshoe*	3,319	260	0.064

* Arithmetic mean of 2008 phosphorus monitoring data was used with the watershed yield calculated using USGS data (see below).

Flow measurements were collected at sites V1, P2, M1 and were modeled using FLUX. Sites V1 and P2 were combined to form site P-X for modeling purposes. Watershed yield was then calculated as the amount of volume at each site divided by the contributing watershed area. These values were compared to the overall watershed yield calculated using the outflow data collected by the USACE from Big Sandy (Table 3-8, Figure 3-15).

Table 3-8 Watershed yield based on the monitored watershed areas and flow data at the Big Sandy Dam

Location	2008 Watershed Yield (inches)
Big Sandy Dam (USGS)	8.5
PX	10.3
M1	7.5
S3	11.6
Total Watershed	10.1
Ecoregion Yield (average climactic year)	6.9

3.4.2.2 Export Coefficients

To determine phosphorus loads from different land use areas, phosphorus export coefficients based on land-use (Barr, 2004) were used in conjunction with land-use classifications based on 2001 National Landcover Data (Figure 2-4). Export coefficients and phosphorus runoff relationships used to develop phosphorus loads from the unmonitored watershed are listed below in Table 3-9.

The export coefficients were derived for near average year precipitation in the Upper Mississippi River Basin. Local precipitation during water year 2008 (26.7 inches) was slightly lower than average for the area (28.1 inches). The total phosphorus loading for Low Intensity Urban land use was calculated from the expected watershed yield based on the relationship between precipitation and flow measurements and calculations by the USGS at the Big Sandy Lake dam structure (Figure 3-15), the Urban/Developed areas, and the runoff concentration determined from the phosphorus assessment load from these areas (Barr, 2004).

Table 3-9 Phosphorus Export Coefficients for Watershed Land Use Types for Big Sandy Lake and Lake Minnewawa

Land Use	Export Coefficient (kg/ha/yr)
Agricultural	0.370
Deciduous Forest	0.147
Evergreen Forest	0.117
Grasslands	0.139
Pasture/Open/Barren	0.237

3.4.2.3 Estimates of Land Use Contributions to Phosphorus Loading

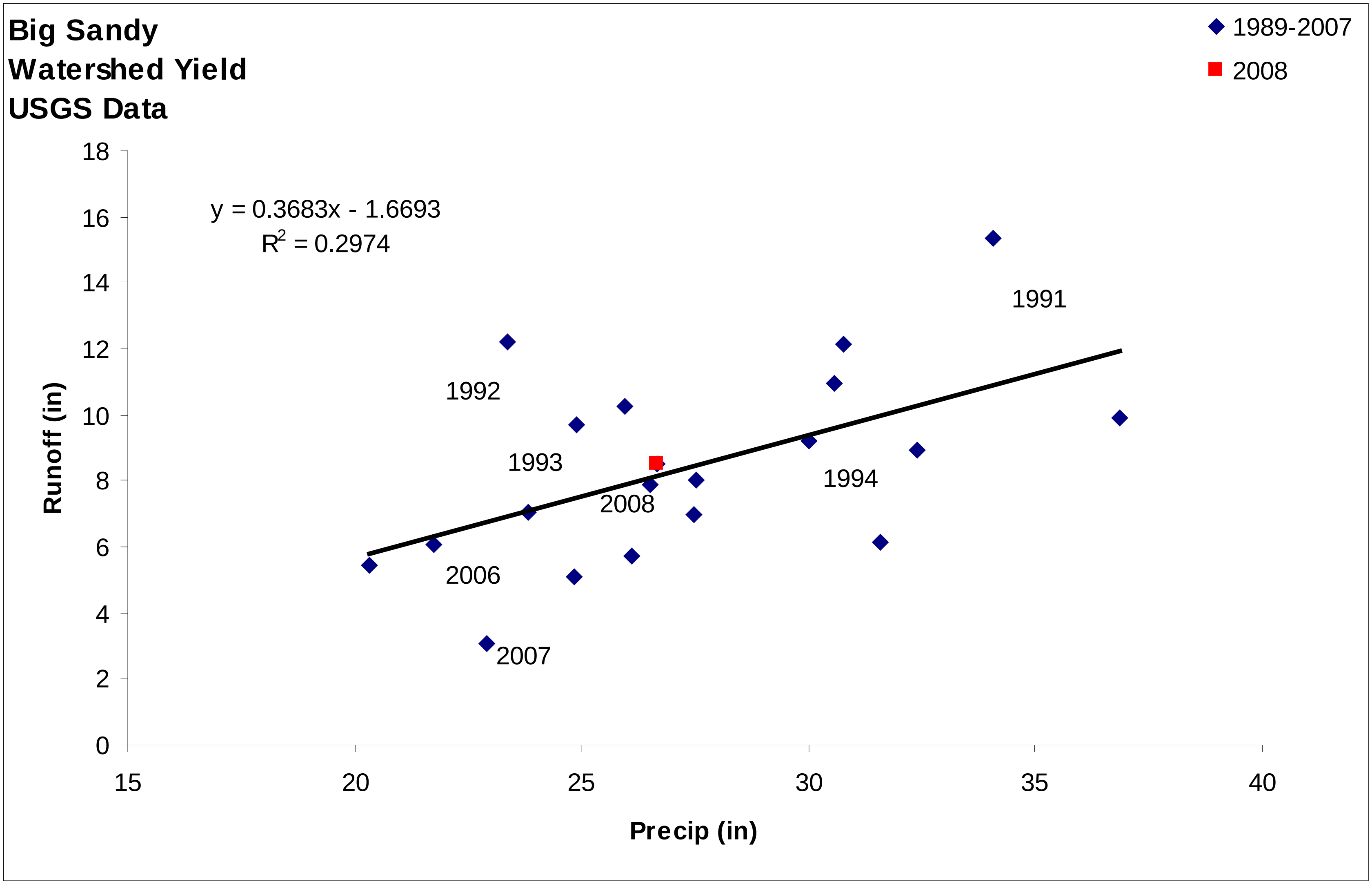
In order to determine what percentage of phosphorus is originating from particular land use classifications, a whole watershed analysis was performed. The 2001 NLCD was used in conjunction with the phosphorus export coefficients (Barr, 2004). A comparison of the 2001 NLCD with 2008 aerial photography identified three shortcomings in the 2001 NLCD.

1. Significant areas of Big Sandy Lake and Lake Minnewawa shorelines were largely identified as forest or wetland where low density residential would be a more suitable classification.

2. Areas that appeared to be non-tilled agriculture (hay or pasture) were identified as grassland.

3. The wild rice farm area near McGregor was largely misclassified as forest, wetland, and grassland.

Figure 3-15 Relationship between precipitation and watershed yield calculated by the USGS using Big Sandy dam flows



The following steps were taken to address the above issues for the purposes of this analysis.

1. Developed shoreline areas were reclassified as low density development.

2. Areas identified as grassland were reclassified as hay/pasture, as natural grassland/prairie is uncommon in this ecoregion.

3. The phosphorus load from the wild rice farms was estimated to be 36 kg/yr, of which 28 kg/yr is assumed to be delivered to the lake with the application of the 76.5% phosphorus delivery factor. These values were calculated by multiplying the area of active wild rice farming, estimated to be 240 acres, by the agricultural phosphorus export coefficient of 0.37 kg/ha-yr, from Table 3-9. This export coefficient is being used in place of other literature citations for the average annual phosphorus loading rates from cultivated wild rice that suggest a range of 0.22 kg/ha-yr (Bloom, 2010) to 1.23 kg/ha-yr (Lundberg and Trihey, 1975; Grava, 1982). It is estimated that the actual phosphorus export rate for this operation could vary significantly from the assumed loading rate depending on rotations of wild rice with other crops; the total cultivated acreage; and fertilization rate and timing. It should be noted that the source of irrigation water lies outside of the subwatershed, and that the existing operation is a surfaced-drained system. Since phosphorus loading associated with wild rice cultivation is not inherent in the agricultural export coefficient provided in Table 3-9 (taken from Barr, 2004), and there has been public interest in the actual phosphorus export from this wild rice operation, additional research should be conducted in the future to better quantify the net phosphorus export for wild rice farming within this watershed area (see Section 4.1).

Stream bank erosion in the Sandy River and Prairie River watershed was estimated to be 0.021 kg/ha-yr total phosphorus (Barr, 2004), or 1,989 kg/yr total phosphorus for the 2008 water year. Phosphorus loads from open water and wetland areas were estimated to be equal to the atmospheric deposition rate (0.172 kg/ha-yr).

The results of this watershed loading analysis overestimates the total non-point phosphorus load to Big Sandy Lake, as would be expected due to the following reasons: the analysis did not factor in lower delivery rates for areas of the watershed a greater distance from Big Sandy Lake; and the analysis did not consider removal of phosphorus in lake and wetland systems upstream of Big Sandy Lake (e.g. Flowage Lake, etc.).

The watershed phosphorus load from the analysis described above was compared to the observed phosphorus load (as estimated by FLUX). The observed phosphorus load was 76.5% of the phosphorus load predicted from the phosphorus land use export coefficient model. Therefore, a phosphorus delivery factor of 76.5% was applied to the land use export coefficient model. The 23.5% difference represents phosphorus that is removed before reaching Big Sandy Lake (e.g. phosphorus removed by intermediate lakes and wetlands).

3.4.2.4 Subsurface Sewage Treatment Systems (SSTS) Loading

Estimates for SSTS loading were based on residence counts on each lake along with ecoregion averages for seasonal versus permanent structures, population per household type, percent conforming and failing systems and an untreated phosphorus load capacity of 0.8845 kg/cap/year from The Detailed Assessment of Phosphorus Sources to Minnesota Watersheds (Barr, 2004). Estimates for the number of seasonal and permanent households around Big Sandy Lake were found in the Big Sandy Summary and Recommendations “White Paper” (MNDNR, 2002). Estimates of phosphorus loading from SSTS were added to the estimates of phosphorus export from developed land use in the direct watershed of Big Sandy Lake and Lake Minnewawa.

3.4.2.5 BATHTUB In-Lake Modeling

In-lake modeling of total phosphorus was performed using the BATHTUB modeling program. BATHTUB applies a series of empirical eutrophication models to morphologically complex lakes and reservoirs. The program performs steady-state water and nutrient balance calculations in a spatially segmented hydraulic network which accounts for advective and diffusive transport, and nutrient sedimentation. Eutrophication-related water quality conditions (i.e. total phosphorus) are predicted using empirical relationships derived from assessments of reservoir data.

Phosphorus enters the lakes from watershed runoff, atmospheric deposition, and sediment release. The latter is referred to as “internal loading” and it is often a significant source of phosphorus in lakes that have a history of high phosphorus loads from their watershed. Phosphorus released from the sediment is typically in a dissolved form, which can be readily utilized by algae, leading to intense algae blooms. Internal loading is influenced by lake mixing and stratification patterns. Bellhorn Bay in Big Sandy appears to be strongly stratified and “dimictic” (becomes completely mixed twice per year) while the other basins in Big Sandy (Main and Webster’s Bays) and Lake Minnewawa do not appear to be as strongly stratified during the summer. Phosphorus released from the sediment during the summer months builds up in the bottom water and can be entrained in the epilimnion whenever the thermocline drops and/or the lake mixes. This process can occur in both shallow and deep lakes.

Simple empirical eutrophication models, such as those available for use in BATHTUB (Walker, 2004), can be used to reconcile phosphorus loadings from a watershed with the phosphorus concentrations observed in the lake. Most of the empirical phosphorus models assume that the lake to be modeled is well-mixed, spatially, meaning that the phosphorus concentrations in the lake are uniform across the surface of the lake regardless of the locations of the major river and stream inlet locations. For BATHTUB modeling purposes, Big Sandy Lake was divided into four segments: Bellhorn Bay South, Bellhorn Bay North, Webster's Bay, and the Main Basin. The unique characteristics of each segment necessitated that they be assigned their own individual group numbers within BATHTUB. The Fischer et al. (1979) dispersion equation was utilized as the dispersion model for this analysis to estimate diffusive transport between adjacent segments. The segment lengths were checked to ensure that the numeric dispersion rate would be less than the calculated dispersion rate. Lake Minnewawa was modeled as single-segment system.

Before determining the internal load, the closest fit to the average observed phosphorus concentration of each lake during 2008 was used to choose the empirical lake water quality model that should be used within BATHTUB. The 2007-2008 water year was chosen for this because it represented a current growing season with more precise epilimnetic total phosphorus data from the lakes, and was intended to be the climate year used to evaluate the proposed lake improvement options for the lakes. As described in the previous sections, watershed phosphorus loads for 2008 were estimated for each lake using the FLUX model and export coefficients, and were then used with the observed in-lake data in BATHTUB to determine which phosphorus sedimentation model provided the best fit to the average observed phosphorus concentration during 2008. The estimated external annual water and phosphorus yields that were input into BATHTUB are summarized in Appendix A. The models chosen for each lake are shown in Table 3-10. A detailed summary of the BATHTUB models for Big Sandy Lake and Lake Minnewawa are included in Appendix B.

The magnitude of the internal load in each lake was verified by calculating the potential release rate of phosphorus from the lake sediment (using sediment data) and comparing that to the BATHTUB modeled internal load from the sediment. In 2008, sediment cores from Big Sandy and Minnewawa Lakes were collected and analyzed for mobile phosphorus and labile organic phosphorus (mobile phosphorus content). Knowing the mobile phosphorus content and depth distribution, a regression equation relating mobile phosphorus and the maximum possible sediment release rate was used to estimate sediment release rate of phosphorus during anoxic conditions at the sediment surface (Pilgrim et al., 2007). This maximum possible release rate was compared to the rate calculated by deduction in each model to confirm that the estimated load was reasonable.

Table 3-10 Model equations chosen to simulate phosphorus settling in Big Sandy Lake and Lake Minnewawa.

Lake	BATHTUB Model	Additional Notes
Big Sandy	Canfield and Bachmann Reservoir	Dispersion used
Minnewawa	Canfield and Bachmann Lakes	

3.5 Modeling Results

The estimated atmospheric, internal and watershed runoff phosphorus and water loads were applied to the BATHTUB water quality model to predict the associated phosphorus concentration in each of the lakes during 2008, an average (climate) year.

Water and total phosphorus loads during the 2008 water year for each of the lakes are shown in Table 3-11. Existing water, external and internal total phosphorus budgets over the water year in the lakes were calculated using monitoring data, runoff coefficients, and in-lake modeling.

Table 3-11 Water, Total Phosphorus and Net Internal Load Budgets in Big Sandy and Lake Minnewawa during the 2008 Water Year

Calibration Year (2008)	External Water Load (AF)	External Total Phosphorus Load (kg)	Internal Total Phosphorus Load (kg)
Big Sandy	224,571	15,957	4,709
Minnewawa	11,822	942	0

3.5.1 Big Sandy Lake In-Lake Model Results

The Big Sandy BATHTUB model was calibrated using 2008 climactic and water quantity and quality data. Internal loading of phosphorus was adjusted in Webster's Bay, Main Bay, and Bellhorn Bay North such that the predicted total phosphorus concentrations matched the observed total phosphorus concentrations. Additionally, the dispersion coefficient for Bellhorn Bay South was increased such that modeled results for Bellhorn Bay matched observed total phosphorus concentrations during 2008.

The internal loading rates resulting from calibration of the BATHTUB model are summarized in Table 3-12. It should be noted that the internal phosphorus loading rates that are listed are input parameters for the BATHTUB model that represent additional internal phosphorus loading above the rate implicit in the Canfield-Bachman model algorithms, and are not representative of total net sediment phosphorus flux values. The Canfield-Bachman model algorithm selected to model Big Sandy Lake is an empirical model, and the algorithm implicitly accounts for some level of internal phosphorus loading. However, the amount of implicit internal loading is not representative of the internal loading conditions of Big Sandy Lake in 2008, and the internal loading was increased in the BATHTUB model to calibrate the model to existing conditions. The internal loading rates listed in Table 3-12 are in addition to the implicit internal loading rate in the BATHTUB Canfield-Bachman reservoir model. Setting the internal loading rates to zero in the BATHTUB model does not imply there is no internal loading in the lake, but rather implies the internal loading rate is equivalent to the implicit internal loading rate in the model algorithm selected (i.e. Canfield-Bachman).

Table 3-12 Big Sandy Lake Internal Loading Rates of Phosphorus (mg/m^2-day) Determined by Calibration of BATHTUB Model

Webster's Bay	Main Bay	Bellhorn North	Bellhorn South
1.1	0.4	0.5	0.1

The various contributions of phosphorus to the Big Sandy Lake system are summarized in Figure 3-16. The phosphorus load from direct precipitation was calculated by multiplying the lake surface area by an atmospheric loading rate of 0.0696 kg P/ac/yr. The phosphorus load from septic systems was estimated using county information on shoreline residences for Big Sandy, aerial photos to determine shoreline residences for Minnewawa, and basin wide averages for percentages of seasonal and non-seasonal type residences, number of people per type of household, and performing and non-performing systems (Barr 2004). A value of 0.8845 kg per capita per year was used for phosphorus load (before treatment) originating from each residence.

The 2008 observed average summer total phosphorus concentration was 38 µg/L, on an area-weighted basis, compared to the 30 µg/L total phosphorus standard for the Northern Lakes and Forests Ecoregion. After calibrating the internal loading rates, the model was utilized to estimate the reduction in phosphorus loading necessary to achieve an average total phosphorus concentration of 30 µg/L. It was determined that a 28% reduction in overall phosphorus loading to Big Sandy Lake would be required to achieve an average phosphorus concentration of 30 µg/L.

3.5.2 Minnewawa Lake In-Lake Model

The Minnewawa Lake BATHTUB model was calibrated using 2008 climactic and water quantity and quality data. No additional internal loading was required in order to match the modeled total phosphorus concentration with the observed total phosphorus concentration. The different contributions of total phosphorus to the Lake Minnewawa system are summarized in Figure 3-17.

The 2008 observed average total phosphorus concentration of 31 µg/L is 1 µg/L above the 30 µg/L total phosphorus standard. Therefore, a relatively small reduction of approximately 9% in the total phosphorus loading would be required to achieve the 30 µg/L standard for 2008 modeled year in Lake Minnewawa and match the overall watershed loading goal for the Big Sandy Lake TMDL.

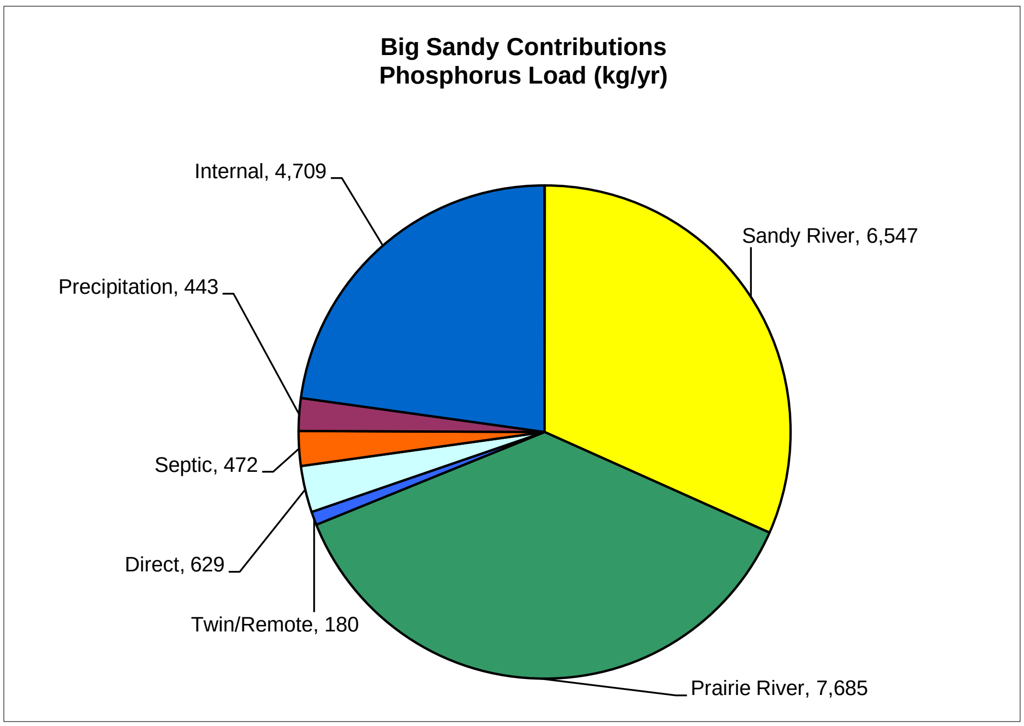


Figure 3-16 Phosphorus Sources to Big Sandy Lake During 2008

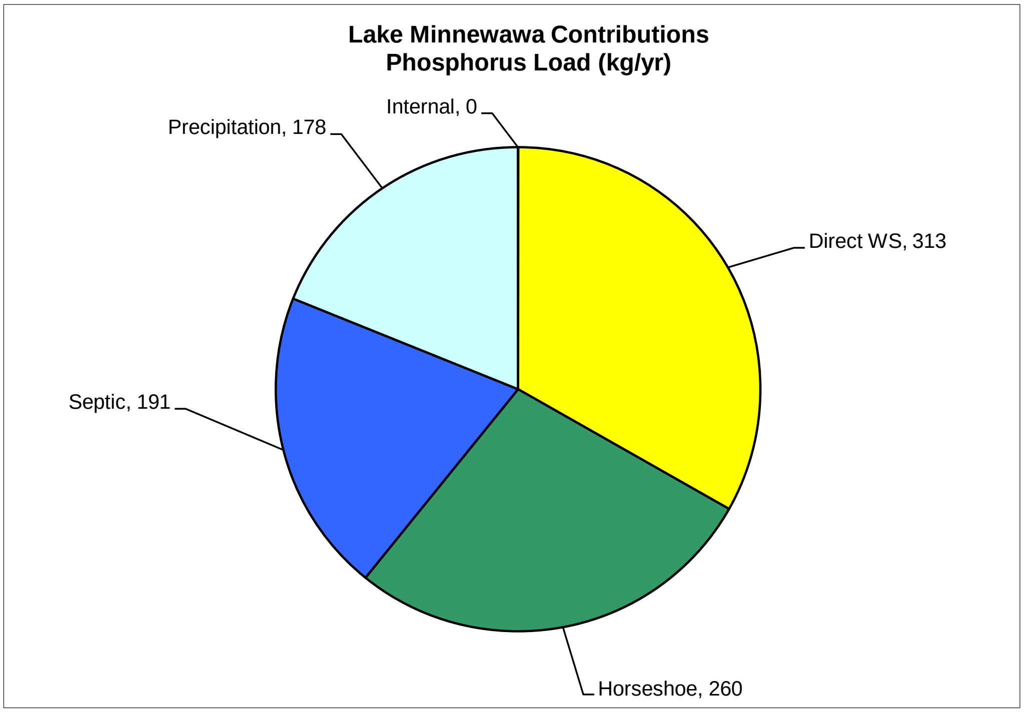


Figure 3-17 Phosphorus Sources to Lake Minnewawa During 2008

3.6 Methodology for Load Allocations, Wasteload Allocations, and Margin of Safety

A TMDL is defined as follows (EPA, 1999):

TMDL = WLA + LA + MOS + Reserve Capacity

Where:

WLA	=	Wasteload Allocation to Point Sources
LA	=	Load Allocation to NonPoint Sources
MOS	=	Margin of Safety
Reserve Capacity	=	Load set aside for future allocations from growth or changes

This section will define each of the terms in this equation for Big Sandy Lake and Lake Minnewawa, and will discuss seasonal variation and reasonable assurances for each TMDL.

The water quality standard requires compliance with the phosphorus criteria during the growing season, which represents the critical condition and the time of the year when the water quality criteria are not being met. As a result, this TMDL Study presents annual waste-load and load allocations that are based on the requirement of keeping the growing-season-average total-phosphorus concentration in each lake at or below 30 µg/L under average climactic conditions. The growing season of 2008 was used as the baseline condition for water quality in each lake, as 2008 represented an "average" precipitation scenario and it represents the water year with the most recent and complete watershed and in-lake monitoring data. Also, because it is a year of average precipitation, it serves as a fair baseline to set allocations. It is reasonable to expect that, on average, phosphorus sources in the respective watersheds will have existing watershed TP loads on the order of those modeled during the growing season of 2008.

3.6.1 Wasteload Allocations

Wasteload allocations were developed based on State discharge limits for each discharger. If no limits were set for phosphorus, a value of 1 mg/L total phosphorus was used in combination with the average flow capacity of the facility (as indicated in the permit) to calculate the annual permitted limit in kg/yr. The actual monitoring results for the 2008 water year are shown in Table 3-13.

Table 3-13 Phosphorus Loads From Monitored Permitted Dischargers, 10/1/07 – 9/30/08

Permitted Discharger (NPDES Permit #)	Phos-phorus (kg/yr)	Flow (ac-ft)	Permitted				Tributary Water-shed
			Flow (mgd)	TP Limit (mg/L)	TP Load (kg/y)	TP Load (kg/day)	
McGregor WWTP (MN0024023)	232	76	0.072 9	1*	101*	0.28	Sandy River
Tamarack WWTP (MN0064564)	33	4	0.007	3.5	34	0.09	Sandy River
AgriPeat (MN0062375)	10	66	--	1	22	0.06	Sandy River
Cromwell WWTP (MN0051101)	42	27	0.052	1	71.8*	0.20	Prairie River
Premier Horticulture (MN0055115)	40**	181**	.017	1*	110***	0.30	Prairie River
Total	357	353	NA	NA	339	0.93	

* Permit limits estimated using 1 mg/L discharge limit
**Values are estimated due to erroneous DMR reports for 2008
*** Value estimate of average yearly load for period of 2005-2009
Phosphorus loads are for end of pipe.

The discharge limits provided by the state (or calculated as stated above) were used to develop the wasteload allocation for Big Sandy Lake. The 76.5% phosphorus delivery factor (discussed in Section 3.4.2.3) was then applied to the total permitted TP load in Table 3-13 to estimate the total wasteload allocation for Big Sandy Lake. Since no reserve capacity is included in this TMDL for the existing and future sources of permitted dischargers, the wasteload allocations represent a mass cap for each facility, such that increased flow capacity can only be accommodated with commensurate reductions in the effluent concentrations.

No permitted dischargers were within the tributary watershed for Lake Minnewawa, and none are currently anticipated in the future

3.6.2 Load Allocations to Nonpoint Sources

The load allocations for Big Sandy Lake and Lake Minnewawa are attributable to the internal, atmospheric, and non-point source (watershed) loads of phosphorus to each lake.

Potential reductions in phosphorus loads were estimated from an evaluation of how existing loading rates compared to the background loading rate estimated from the MINLEAP modeling (discussed in Section 3.3.2). The following summarizes general reductions in phosphorus loads from nonpoint sources that were estimated for the watershed and internal sources:

- 1% reduction from forested lands (through improved silviculture practices);
- 27% reduction from agriculture/pasture/hay field land use areas;
- 39% reduction from streambank erosion;
- 50% reduction from developed land use;
- Assumed full conformance for all SSTS adjacent to both lakes;
- The amount of allowable internal phosphorus loading (sediment phosphorus release) for Big Sandy Lake was estimated using the calibrated BATHTUB in-lake model and the loading capacity for the 2008 water year. The Bathtub modeling for Lake Minnewawa indicated that no internal loading reductions were necessary to meet the loading capacity goal.

3.6.3 Margin of Safety

Under Section 303(d) of the Clean Water Act, a margin of safety is required as part of a TMDL. The MOS accounts for the uncertainty that the allocations set in the TMDL will result in the water body meeting the water quality standard. Thus, an explicit MOS of 5 percent of the total loading capacity for each lake was used to account for uncertainty in the TMDL allocation process. There is a low level of uncertainty expected in setting the TMDL allocations for these lake watersheds due to the fact that a large amount of monitoring data has been collected over a long period of time. In addition, baseline loadings to Big Sandy Lake have been verified using MNLEAP and historic reconstruction of the TP concentration before settlement occurred.

3.6.4 Reserve Capacity

Reserve capacities have been included for Big Sandy to allow for a future wastewater treatment plant (WWTP) for the city of Wright, conversion of existing subsurface sewage treatment systems (SSTS) to a WWTP system, and for construction stormwater. The 76.5% watershed delivery factor was considered when determining the reserve capacities. The reserve capacity for the city of Wright WWTP is 44 kg/yr (0.12 kg/day). A reserve capacity has been included for Lake Minnewawa to account for discharges from regulated construction stormwater. Regulated construction projects in the watershed have been infrequent and sporadic in the past decade.

Significant future development is not expected in the watershed areas in this study. Occasional discharges from construction stormwater are expected to be insignificant and difficult to quantify. Construction stormwater activities are considered in compliance with provisions of the TMDL if they obtain a Construction General Permit under the NPDES program and properly select, install, and maintain all BMPs required under the permit, including any applicable additional BMPs required in Appendix A of the Construction General Permit for discharges to impaired waters, or meet local construction stormwater requirements if they are more restrictive than requirements of the State's Construction General Permit.

3.7 Phosphorus TMDL Allocations for Big Sandy Lake and Lake Minnewawa

Load allocations were set so that each lake met the total phosphorus criterion of 30 µg/L for the NLF Ecoregion. The results for the 2008 water year were used to determine the daily load and wasteload allocations of phosphorus for each lake (shown in Tables 3-14 and 3-15).

3.8 Seasonal Variation

Total phosphorus concentrations in the lakes can vary significantly during the growing season, generally increasing during mid- to late-summer. The TMDL guideline for total phosphorus is defined as the growing season (mid-May or June through September) mean concentration (MPCA, 2007b). Accordingly, water quality scenarios (under different management options) were evaluated in terms of the growing season mean total phosphorus concentration.

Table 3-14 Big Sandy Lake Total Phosphorus Wasteload and Load Allocations

Watershed TP Sources	Existing TP Load (kg)	TMDL Wasteload Allocation (WLA) (kg)	Daily TMDL Wasteload Allocation (WLA) (kg/day)	Percent Reduction of Existing TP Load (Percent)
Permitted Discharges	273	259	0.71	5
Total Wasteload Sources	**273**	**259**	**0.71**	**5**
Internal and Nonpoint Sources	**Existing TP Load (kg)**	**TMDL Load Allocation (LA) (kg)**	**TMDL Load Allocation (LA) (kg/day)**	**Percent Reduction of Existing TP Load (Percent)**
Internal Sources	4,709	0	0	100
Non-point watershed sources				
Agriculture	2,284	1,709	4.7	25
Forest	5,886	5,827	16	1
Developed	1,153	655	1.8	43
Open Water/Wetlands	4,322	4,322	12	0
Stream channel erosion	1,522	875	2.4	43
Atmospheric Sources	443	443	1.2	0
Total Load Sources	**20,319**	**13,831**	**38**	**32**
City of Wright WWTP Reserve Capacity (RC)	0	44	**0.12**	0
Other Reserve Capacity (RC)	0	33	**0.09**	0
Margin of Safety (MOS)	**0**	**746**	**2.0**	**0**
Overall Source Total	**20,592**	**14,913**	**41**	**28**

Table 3-15 Lake Minnewawa Total Phosphorus Wasteload and Load Allocations

Watershed TP Sources	Existing TP Load (kg)	TMDL Wasteload Allocation (WLA) (kg)	Daily TMDL Wasteload Allocation (WLA) (kg/day)	Percent Reduction of Existing TP Load (Percent)
Permitted Dischargers	0	0	0	0
Total Wasteload Sources	**0**	**0**	**0**	**0**
Internal and Nonpoint Sources	**Existing TP Load (kg)**	**TMDL Load Allocation (LA) (kg)**	**TMDL Load Allocation (LA) (kg/day)**	**Percent Reduction of Existing TP Load (Percent)**
Internal Sources	0	0	0	0
Non-point watershed sources				
Agriculture	57	43	0.12	25
Forest	214	212	0.58	1
Developed	344	187	0.51	46
Open Water/Wetlands	149	149	0.41	0
Atmospheric Sources	178	178	0.49	0
Total Load Sources	**942**	**769**	**2.1**	**18**
Reserve Capacity (RC)	**0**	**0.7**	**0.002**	**0**
Margin of Safety (MOS)	**0**	**40**	**0.11**	**0**
Overall Source Total	**942**	**810**	**2.2**	**14**

4.0 Monitoring Plan to Track TMDL Effectiveness

The water quality of Big Sandy and Minnewawa Lakes has been monitored in some capacity for the past three decades and will continue to be monitored for the foreseeable future. A watershed program is also in place with different types of ongoing monitoring in different areas of the watershed being conducted. It will also be important to monitor the long-term effectiveness of any water quality improvement projects being constructed in the Big Sandy or Minnewawa Lake watersheds. Measurements should be collected at a frequency of once every two weeks during the period of May through September. At a minimum, all of the following parameters, except Secchi disc, color, DOC, and chlorophyll *a*, should be measured at multiple depths in the water column (every 1 to 2 meters) of each lake:

- Secchi disc
- Dissolved Oxygen
- Temperature
- Total Phosphorus
- Dissolved Phosphorus
- Chlorophyll *a*
- Color
- Dissolved Organic Carbon (DOC)
- pH
- Turbidity

Watershed monitoring should continue at a frequency of once every two weeks for the period of April through November. The following parameters should be collected from the watershed monitoring locations:

- Total Phosphorus
- Dissolved Phosphorus
- Color
- Dissolved Organic Carbon (DOC)
- pH
- Total Suspended Solids
- Turbidity
- Flow

4.1 Additions to Current Monitoring Program

An additional monitoring site should be added to the current program that focuses on determining the impact of peat wetland systems on nutrient export and delivery to downstream surface waters. A location that contains a high percentage of peat wetlands but is minimally impacted by other factors (e.g. development, agriculture, etc.) should be selected and monitored for the same parameters listed above for the other watershed monitoring sites. Additional monitoring should also be conducted to better quantify the net annual phosphorus export for wild rice farming within the watershed area. This monitoring will need to be done in a way that will account for the background phosphorus load of the source water along with the phosphorus discharged as a result of the overall annual operations at the site.

Color and DOC were added to the monitoring plan to help determine the impact nutrient mobilization from peat wetlands may have on water quality and non-algal turbidity in both lakes. Climactic conditions and changes in hydrology can substantially affect nutrient and organic matter export from peat wetlands, causing varying color and DOC in surface waters. Measuring color and DOC, along with the traditional nutrient related parameters listed and the additional monitoring site described above, will help determine the impact peat wetlands have on water quality in Big Sandy Lake, and to a lesser extent Lake Minnewawa.

Comprehensive phytoplankton, zooplankton, macrophyte and fisheries surveys should be conducted in both lake basins during at least one of the years when surface water quality monitoring occurs. Information on phytoplankton and zooplankton populations is useful in understanding the dynamics of phosphorus cycling within the lake. Macrophytes compete with algae for available resources (phosphorus and light), and can therefore improve water quality. However, the invasive aquatic plant species curlyleaf pondweed is known to have a negative impact on water quality of Minnesota lakes. Fisheries data are useful for understanding the overall food chain (i.e. phytoplankton » zooplankton » small fish » large fish) and how phosphorus is cycled through the food chain. Bottom feeding fish (e.g. common carp) can have a significant impact on water quality by disturbing sediment on the lake bottom and increasing the internal loading of phosphorus.

Additionally, a sediment fingerprinting study is recommended to determine the major sources of sediment loading to the lakes. Stream bank erosion and sediment and nutrient loading due to ditching or other changes in hydrology can be quantified using this process. The study should be conducted under both base flow and storm event flow events to help determine the conditions and frequency of loading events.

The comparison between future monitoring data and the modeling results in this study can be conducted as follows:

1. Using monitoring results (flow and water quality sampling data), calculate the annual load (or the load over some other time period) of water and phosphorus entering each lake.
2. Run the in-lake models for same time period and calculate the load that the model predicts for pre-project conditions.
3. Compare the two loads, and calculate the percent reduction that was achieved over the time period of interest.

5.0 TMDL Implementation Strategies

The following sections summarize implementation strategies that should be implemented in order to achieve reductions in phosphorus loading necessary to achieve water quality targets in Big Sandy Lake and Lake Minnewawa. Overall, the implementation strategy should be adaptive. Implementation strategies should be reevaluated and updated as new data becomes available. Consideration should be given on how implementation of upstream phosphorus reduction strategies may affect downstream phosphorus sources (e.g. reductions in external loading may lead to a reduction in internal phosphorus in the long term).

5.1 Annual Load Reductions

The TMDL implementation plan focuses on reducing external sources of phosphorus to the watershed with additional work to better estimate internal sources of phosphorus loading. Annual overall reductions of 5,679 kg (28 %) and 133 kg (14%) in phosphorus loading in Big Sandy Lake and Lake Minnewawa, respectively, is required to meet the total phosphorus growing-season average of 30 µg/L in Big Sandy and Minnewawa Lakes. Load-reduction projects should be implemented following a priority ranking system for the available nutrient reduction strategies. It is anticipated that it will take more than 20 years to implement all of the projects required to achieve the annual load reduction. Additional monitoring is also recommended to help ascertain the removal efficiency of planned watershed measures to reduce phosphorus loading to the lake.

5.2 Sector-Specific Strategies

The following sections provide detailed implementation strategies associated with each of the significant phosphorus loading sources within the Big Sandy and Minnewawa Lake watersheds.

5.2.1 Public Education for Water Quality Protection

An extensive and innovative public education program should be developed to inform watershed residents of the issues facing each lake and their roles in addressing these issues and to engage them in taking action. Recognizing there are public education activities related to water quality issues currently underway in the watershed, there is a need to coordinate and build on this work. A public education program should promote a community-to-community awareness and clearly identify the contribution that all communities, such as urban dwellers, waterfront property owners, agricultural producers, and industry must make to reduce nutrient loading. An educational program should be developed that integrates public relations advertising, marketing, civic engagement, public involvement, technical assistance, and training to optimize nutrient reductions from all phosphorus loading sectors within the overall watershed. Conservation districts and other environmental agencies and organizations should be actively involved in promoting school projects related to protecting the health of Big Sandy and Minnewawa Lakes and their watersheds.

5.2.2 Environmental Planning for Urban, Rural and/or Seasonal Development

State and local governments should establish an integrated land and water resource planning process that is environmentally conscientious while ensuring planned and orderly growth with respect to land drainage and sewer and water services. "Low-impact development" concepts need to be considered for future land use planning. All new development, redevelopment, industrial, and construction projects should be designed to maintain or improve existing developed hydrology and pollutant loadings and fully comply with the local watershed and government authorities, NPDES, and anti-degradation requirements.

All rural residential, commercial, industrial, and urban developments should be comprehensively reviewed with respect to water and wastewater treatment requirements to protect the environment. Developers should be required to include the full cost-recovery expense of installing the required water and wastewater treatment services for new developments and ensure that these are built into the costs of the development.

Developers should be responsible for land drainage issues for new residential developments that consider the nutrient impacts of the development and should build low-impact, environmentally conscientious concepts into the design of the project, with the aim of reducing environmental service costs to minimize pollution loads. The state and/or local government should establish regulations, such as minimum set-back distances from shorelines for new developments, to prevent significant disturbances which would result in increased erosion along lakes and waterways.

5.2.3 Treatment of Existing Stormwater Sources

Unmanaged stormwater can have devastating consequences on water quality. In addition, unmanaged stormwater frequently overwhelms streams and scours streambanks. It is expected that the MPCA will continue to administer the requirements of the federal Clean Water Act which call for better management of stormwater through programs for the Municipal Separate Storm Sewer System (MS4) Permit, the Construction Stormwater Permit and the Industrial Stormwater Permit.

For existing sources of stormwater that are not subject these permit programs, it is recommended that low-impact design principles be incorporated into all plans for redevelopment or expansion and infrastructure or street replacement projects. Where it is not feasible or cost-effective to improve the existing developed hydrology and pollutant loadings, government entities should pursue other options for providing regional management of stormwater runoff.

5.2.4 Ditch Cleaning

Judicial, private and roadside ditch cleaning has the potential to contribute significant nutrient loadings and exacerbate stream channel erosion due to leaching from dredge spoils and increasing discharge rates and erosion of channel material. An assessment of the current and planned ditch cleaning activities by each jurisdiction in the watershed, along with a review of their best management practices, should be completed and evaluated for structural and non-structural improvements and/or potential solutions for conflicts with jurisdictional requirements.

5.2.5 Livestock Access to Riparian Areas and Waterways

Drainage from confined livestock areas should be directed to retention basins, grassed buffer strips, constructed wetlands, or another generally recommended nutrient-reduction feature. Otherwise, manure accumulated in confined holding areas should be regularly removed and applied to crop or pasture lands at agronomic rates. Livestock producers should be encouraged through enhanced incentives, education, and (when required) regulations to implement measures to protect riparian areas and waterways, such as managing livestock access in riparian areas and providing off-site watering structures.

Agriculture extension programs, as well as those delivered in partnership with other programs, should be used to help producers assess the environmental risk of their operations, and to provide advice on how to prevent the contamination of groundwater and surface water.

5.2.6 Soil Fertility and Manure Testing

Additional strategies that promote and support annual soil testing should be developed to provide producers with the tools necessary to make sound agronomic, economic, and environmental decisions. Incentives for producers conducting soil testing and manure testing should be considered. Enhanced education on the economic and environmental benefits of soil and manure testing is recommended.

5.2.7 Agricultural Drainage

A review of agricultural land drainage networks on a watershed basis should be undertaken. Some of the land historically used for agriculture has been abandoned and left to revert to a natural state, but some actively managed areas remain. This review should explore the feasibility of reducing the velocity of flow in agricultural drains and ditches to allow particulate nutrients an opportunity to settle out. The use of nutrient traps or settling basins along drains should be explored to determine their effectiveness in reducing nutrient loading. This work would include a review of the feasibility of acquiring marginal land and constructing new wetlands, or restoring existing wetland areas that could serve as natural filters for drain water.

5.2.8 Turf Farms and Golf Courses

Additional strategies that promote and support annual soil testing should be developed to provide land owners/operators with the tools necessary to make sound agronomic, economic, and/or environmental decisions. Incentives for conducting soil testing should be considered. In addition to soil fertility testing, other BMPs should be implemented to minimize water usage and treat surface water discharge from each site.

5.2.9 Septic Field Maintenance and Alternatives to Septic Fields

A focused educational campaign should be undertaken to provide guidance to homeowners on how to properly maintain septic fields and how to recognize when they are failing. The local government should require mandatory inspection of private sewage treatment systems at the time of sale. The sale of the property would be conditional on a properly functioning system. Both states and/or local governments should explore the funding options to recover the costs of conducting an ongoing comprehensive septic field inspection program and maintaining a septic field database.

5.2.10 Stream Channel Erosion

All new development, redevelopment, industrial and construction activity projects should be designed to maintain or improve the existing hydrology (i.e. reduce peak flows). In addition, opportunities for correcting existing channel and shoreline erosion sources should be investigated. A protocol should be developed and followed to ensure that all assessments of erosion in the watershed are comparable and can be prioritized. An assessment of all-terrain vehicle (ATV) traffic as a source of erosion should be conducted to determine the potential water quality and biotic habitat impacts in the watershed.

5.2.11 Lakeshore Erosion

Big Sandy Lake is operated as a reservoir. As such, the water level of Big Sandy Lake is subject to fluctuations, which can enhance shoreline erosion. An assessment of shoreline erosion and potential reductions should be conducted.

5.2.12 Water Usage, Sewage Treatment, and Related Financing

The State of Minnesota should ensure that all citizens are served by wastewater treatment practices that safeguard human health and water quality. Citizens should pay the true cost of the operation and maintenance of the systems required to provide the water they consume and the true costs of the services required to adequately treat wastewater. Utility reserves that cover the true costs of infrastructure upgrades or replacement should be established within each community so that monies are available when utility upgrades are required. Monies collected for these reserves need to be protected from competing financial needs within the community. Over the long-term, utilities need to implement cost-recovery funding models that cover complete life-cycle costs.

The sources of extraneous groundwater inflow into wastewater collection systems need to be investigated and minimized where feasible. Building codes should be revised to require water conservation measures wherever possible. Governments should demonstrate leadership by instituting programs to conserve water. When government agencies are leasing space, a condition of tenancy should be the conversion of existing fixtures to low-flow alternatives. All levels of government should consider incentives or rebates for homeowners to retrofit fixtures to low-flow alternatives. An environmental levee for the purchase of higher volume fixtures could be considered. A public education program should be implemented to encourage the safe collection and use of rainwater for lawn and garden use. Water consumers on non-metered community water systems should be metered and billed on a water-use basis at the full cost of the water supply. Consideration should be given to applying higher billing rates for water as usage increases. Discontinuing the practice of bulk discounts and reduced water rates for large commercial and industrial consumers should also be considered.

5.2.13 Wastewater Treatment Services

State and local governments should promote and facilitate regionalization of wastewater treatment systems. Options for regionalization need to be fully explored by the proponent prior to receiving funding. Comprehensive sewage management plans should be developed for areas of the overall watershed where existing sewage treatment practices such as septic fields and holding tanks are releasing excessive nutrients.

Nutrient reduction strategies for larger facilities, such as biological nutrient removal, chemical treatment, effluent irrigation, constructed wetlands, and other proven technologies, need to be evaluated for their effectiveness and practicality. Source-control pollution prevention plans should also be implemented as measures to reduce nutrient input.

A strategy should be developed for handling septage and greywater in an economic and environmentally sensitive manner while considering the potential health issues. This should include options for handling these wastes within existing wastewater treatment facilities, as well as the option of controlled and managed land application of this waste. Efforts to prevent illegal disposal of septage should be strengthened.

5.2.14 Silviculture

Silviculture operations should implement BMPs that are appropriate for each site and process, based on the recommendations in *Water Quality in Forest Management: Best Management Practices in Minnesota* or another state-approved forestry BMP guidebook.

5.2.15 Internal Load Reduction

Internal load reduction should be investigated as a means to reduce phosphorus levels in Big Sandy Lake. Internal loading (above the 'background' amount empirically included in the Bathtub modeling) is a substantial portion of the total phosphorus load to Big Sandy Lake. In addition, phosphorus released from the sediment is in the dissolved form readily available for uptake by algae, whereas external phosphorus loads generally contain both dissolved and particulate phosphorus. It should be noted that the internal phosphorus loading rates that are described in this report are input parameters for the BATHTUB model that represent additional internal phosphorus loading above the rate implicit in the Canfield-Bachman model algorithms, and are not representative of total net sediment phosphorus flux values. The Canfield-Bachman model algorithm selected to model Big Sandy Lake is an empirical model, and the algorithm implicitly accounts for some level of internal phosphorus loading.

Reductions of external loading of phosphorus can lead to a long term reduction of internal loading in Big Sandy Lake. Therefore, internal loading should be reevaluated periodically as part of the overall adaptive management strategy. Additionally, the longevity of internal load reduction technologies is increased substantially if external loads are reduced.

5.2.16 Mississippi River Backflow Control

As with sediment phosphorus release, periodic backflow from the Mississippi River has significant potential to affect the water quality in Big Sandy Lake, especially on a short-term basis.
A review of the outlet management protocol(s) should be conducted to evaluate whether the system could be managed in a way that would reduce the frequency and minimize the potential magnitude of the water quality impacts associated with Mississippi River backflow events. Furthermore, this

review should include recommendations for improving collection of flow and water quality monitoring data at the outlet and in the main bay of the lake during these events.

5.3 Evaluation of BMP Effectiveness and Priority Ranking for Nutrient Reduction Strategies

Local Government Units and appropriate stakeholders will coordinate efforts to determine what best management practices would be practical, economically feasible, and environmentally effective in reducing nutrient loading in the Big Sandy and Minnewawa Lake watersheds. As a first step, the TMDL Implementation Plan should include a review of the cost-effectiveness of best management practices that should be undertaken, based on existing applicable knowledge. BMP cost-effectiveness, combined with information about local water quality impairments and nutrient delivery to each lake and leveraged funding from outside sources, should be used to finalize a priority ranking system for implementing individual nutrient reduction strategies throughout the watershed.

5.4 Implementation Cost

The Clean Water Legacy Act requires that a TMDL include an overall approximation ("…a range of estimates") of the cost to implement a TMDL [Minn. Statutes 2007, section 114D.25]. The initial estimate for implementing this TMDL is expected to exceed $10 million over the next 20 years. This estimate will be refined when the detailed implementation plan is developed, following approval of the TMDL study.

6.0 Reasonable Assurances

The following should be considered as reasonable assurance that implementation will occur and result in nutrient load reductions in Big Sandy Lake and Lake Minnewawa toward meeting their designated uses.

- The BMPs and other strategies outlined in Section 5.0 have all been demonstrated to be effective in reducing transport of pollutants to surface waters.
- The stakeholder group convened to provide feedback, and input into the project had broad representation from government, citizens, and technical experts.
- Monitoring will be conducted to track progress and guide adjustments in the implementation approach.
- NPDES permits provide a reasonable assurance that construction stormwater activities will comply with requirements of this TMDL. All significant development, redevelopment, industrial, and construction projects should be designed to maintain or improve existing developed hydrology and pollutant loadings to fully comply with the local watershed and government authorities, NPDES, and anti-degradation requirements.
- An implementation plan will be finalized one year following EPA approval of the TMDL, which will identify specific BMP opportunities sufficient to achieve the sector-specific load reduction and associated adoption schedule. Individual SWPPPs will be modified accordingly following the recommendations of the implementation plan.

7.0 Public Participation

Two public TMDL meetings have been conducted between Watershed staff, representatives from the various entities that are responsible for loads within each watershed and the public.

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Appendix A

Inputs to BATHTUB Models

Big Sandy Lake and Lake Minnewawa inputs for BATHTUB modeling for calibration of water year 2008.

Total Watershed Yield (in) 10.6

Big Sandy Loads

Description	Watershed	Area	H2O Load	H2O Load	TP Load	TP Load	Flow Weighted TP
		(acres)	(acre-ft)	hm3	(kg)	(lbs)	(mg/L)
Sandy River	Station M1	20,813	12,928	16	1,026		0.064
	Station S3	57,440	59,867	74	4,448		0.060
Unmonitored Areas	Unmonitored Areas South	21,764	13,519	17	1,073		0.064
Total		100,017	86,314	107	6,547		0.062
Prairie River	Station PX	130,057	111,039	137	7,132		0.052
Unmonitored Areas	Unmonitored Areas North	10,084	8,609	10.6	553		0.052
Total		140,141	119,648	148	7,685		0.052
Direct Watersheds	Lake Area	6,107					
	9094 Aitken (not included)	*3,906*					
	9095 Twin/Remote Lakes	4,048	2,750	3.4	180		0.053
	9096 BS Direct	5,688	3,864	4.8	629		0.132
Sanitary Inputs	ISTS				472		
Direct Depositon to Lake			11,994	14.8	443		
Totals		**253,800**	**224,571**	**277**	**15,957**	**35178**	**0.058**

Minnewawa Loads

Description	Watershed	Area	H2O Load	H2O Load	TP Load	TP Load	Flow Weighted TP
		(acres)	(acre-ft)	hm3	(kg)	(lbs)	(mg/L)
Direct Watersheds	Minnewawa Direct	5,359	3,641	4.49	313		0.070
	Horseshoe	5,580	3,319	4.10	260		0.064
	Lake Area	2,304					
Sanitary Inputs	ISTS				191		
Direct Depositon to Lake			4,862	6.0	178		
Totals		**13,243**	**11,822**	**14.6**	**942**	**2,077**	**0.065**

Appendix B

Details of BATHTUB Modeling

File: **Big Sandy Lake calibration for water year 2008**

Overall Water & Nutrient Balances

Overall Water Balance — **Averaging Period = 1.00 years**

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance (hm3/yr)^2	CV -	Runoff m/yr
1	1	1	Sandy River	234.7	107.0	0.00E+00	0.00	0.46
2	1	3	Prairie	82.0	148.0	0.00E+00	0.00	1.80
3	1	4	Twin/Remote	77.6	3.4	0.00E+00	0.00	0.04
4	1	4	BS Direct	451.6	4.0	0.00E+00	0.00	0.01
5	1	4	Septic		0.2	0.00E+00	0.00	
6	4	4	Outlet	1072.4	215.0	0.00E+00	0.00	0.20
7	1	2	Bellhorn South Direct		0.8	0.00E+00	0.00	
PRECIPITATION				24.7	14.8	8.80E+00	0.20	0.60
TRIBUTARY INFLOW				845.9	263.4	0.00E+00	0.00	0.31
***TOTAL INFLOW				870.6	278.2	8.80E+00	0.01	0.32
GAUGED OUTFLOW				1072.4	215.0	0.00E+00	0.00	0.20
ADVECTIVE OUTFLOW					48.4	2.86E+01	0.11	
***TOTAL OUTFLOW				870.6	263.4	2.86E+01	0.02	0.30
***EVAPORATION					14.8	1.98E+01	0.30	

Overall Mass Balance Based Upon Predicted Outflow & Reservoir Concentrations
Component: TOTAL P

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Sandy River	6634.0	31.9%	0.00E+00		0.00	62.0	28.3
2	1	3	Prairie	7696.0	37.0%	0.00E+00		0.00	52.0	93.9
3	1	4	Twin/Remote	180.2	0.9%	0.00E+00		0.00	53.0	2.3
4	1	4	BS Direct	528.0	2.5%	0.00E+00		0.00	132.0	1.2
5	1	4	Septic	480.0	2.3%	0.00E+00		0.00	2400.0	
6	4	4	Outlet	8254.5		3.43E+06		0.22	38.4	7.7
7	1	2	Bellhorn South Direct	105.6	0.5%	0.00E+00		0.00	132.0	
PRECIPITATION				442.5	2.1%	4.89E+04	99.6%	0.50	29.8	17.9

	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
INTERNAL LOAD	4709.2	22.7%	2.18E+02	0.4%	0.00		
TRIBUTARY INFLOW	15623.8	75.2%	0.00E+00		0.00	59.3	18.5
***TOTAL INFLOW	20775.5	100.0%	4.92E+04	100.0%	0.01	74.7	23.9
GAUGED OUTFLOW	8254.5	39.7%	3.43E+06		0.22	38.4	7.7
ADVECTIVE OUTFLOW	1858.2	8.9%	2.09E+05		0.25	38.4	
***TOTAL OUTFLOW	10112.7	48.7%	5.15E+06		0.22	38.4	11.6
***RETENTION	10662.7	51.3%	5.17E+06		0.21		

Overflow Rate (m/yr)	10.7	Nutrient Resid. Time (yrs)	0.2261
Hydraulic Resid. Time (yrs)	0.4690	Turnover Ratio	4.4
Reservoir Conc (mg/m3)	38	Retention Coef.	0.513

Overall Mass Balance Based Upon **Predicted** **Outflow & Reservoir Concentrations**

Component: **TOTAL N**

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Sandy River	149372.0	41.1%	0.00E+00		0.00	1396.0	636.4
2	1	3	Prairie	181300.0	49.9%	0.00E+00		0.00	1225.0	2211.0
3	1	4	Twin/Remote	2907.0	0.8%	0.00E+00		0.00	855.0	37.5
4	1	4	BS Direct	4128.0	1.1%	0.00E+00		0.00	1032.0	9.1
5	1	4	Septic	200.0	0.1%	0.00E+00		0.00	1000.0	
6	4	4	Outlet	199537.0		5.92E+07		0.04	928.1	186.1
7	1	2	Bellhorn South Direct	800.0	0.2%	0.00E+00		0.00	1000.0	
PRECIPITATION				24720.0	6.8%	1.53E+08	100.0%	0.50	1666.7	1000.0
TRIBUTARY INFLOW				338707.0	93.2%	0.00E+00		0.00	1285.9	400.4
***TOTAL INFLOW				363427.0	100.0%	1.53E+08	100.0%	0.03	1306.2	417.4
GAUGED OUTFLOW				199537.0	54.9%	5.92E+07		0.04	928.1	186.1
ADVECTIVE OUTFLOW				44919.0	12.4%	1.99E+07		0.10	928.1	
***TOTAL OUTFLOW				244456.1	67.3%	7.13E+07		0.03	928.1	280.8
***RETENTION				118970.9	32.7%	1.66E+07		0.03		

Overflow Rate (m/yr)	10.7	Nutrient Resid. Time (yrs)	0.3148
Hydraulic Resid. Time (yrs)	0.4690	Turnover Ratio	3.2
Reservoir Conc (mg/m3)	926	Retention Coef.	0.327

File: Big Sandy Lake calibration for water year 2008

Hydraulic & Dispersion Parameters

Seg	Name	Outflow Seg	Net Inflow hm^3/yr	Resid Time years	Overflow Rate m/yr	Velocity km/yr	Dispersion--------> Estimated km^2/yr	Numeric km^2/yr	Exchange hm^3/yr
1	Webster Bay	4	107.0	0.1986	21.1	17.1	1135.7	29.1	2034.4
2	Bellhorn South	3	0.8	32.0675	0.4	1.0	46.1	0.1	204.8
3	Bellhorn North	4	148.8	0.0251	215.7	55.8	328.3	39.1	550.8
4	Main Bay	0	263.4	0.2767	15.5	17.7	6223.1	43.4	0.0

Morphometry

Seg	Name	Area km^2	Zmean m	Zmix m	Length km	Volume hm^3	Width km	L/W -
1	Webster Bay	5.1	4.2	4.2	3.4	21.3	1.5	2.3
2	Bellhorn South	2.0	12.7	7.4	2.4	25.7	0.8	2.9
3	Bellhorn North	0.7	5.4	4.8	1.4	3.7	0.5	2.8
4	Main Bay	17.0	4.3	4.3	4.9	72.9	3.5	1.4
Totals		24.7	5.0			123.5		

File: **Big Sandy Lake calibration for water year 2008**

Segment & Tributary Network

--------Segment:	1	Webster Bay		
Outflow Segment:	4	Main Bay		
Tributary:	1	Sandy River	Type:	Monitored Inflow
--------Segment:	2	Bellhorn South		
Outflow Segment:	3	Bellhorn North		
Tributary:	7	Bellhorn South Direct	Type:	Monitored Inflow
--------Segment:	3	Bellhorn North		
Outflow Segment:	4	Main Bay		
Tributary:	2	Prairie	Type:	Monitored Inflow
--------Segment:	4	Main Bay		
Outflow Segment:	0	Out of Reservoir		
Tributary:	3	Twin/Remote	Type:	Monitored Inflow
Tributary:	4	BS Direct	Type:	Monitored Inflow
Tributary:	5	Septic	Type:	Monitored Inflow
Tributary:	6	Outlet	Type:	Reservoir Outflow

File: **Big Sandy Lake calibration for water year 2008**
Description:

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.6	0.2
Evaporation (m)	0.6	0.3
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km^2-yr)	Mean	CV
Conserv. Substance	0	0.00
Total P	17.9	0.50
Total N	1000	0.50
Ortho P	9	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	4	CANF &BACH, RESERV
Nitrogen Balance	5	BACHMAN FLUSHING
Chlorophyll-a	2	P, LIGHT, T
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	0	NONE
Error Analysis	1	MODEL & DATA
Availability Factors	1	USE FOR MODEL 1 ONLY
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Webster Bay	4	1	5.06	4.2	3.4	4.2	0.12	0	0	0.08	0.2	0	0	1.1	0	0	0
2	Bellhorn South	3	1	2.02	12.7	2.4	7.4	0.12	0	0	0.08	0.2	0	0	0.1	0.2	0	0
3	Bellhorn North	4	1	0.69	5.41	1.4	4.8	0.12	0	0	0.08	0.2	0	0	0.5	0	0	0
4	Main Bay	0	1	16.95	4.3	4.9	4.3	0.12	0	0	0.08	0.2	0	0	0.4	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	39.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	31.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	38.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0
2	5.5	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0
3	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0
4	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0

Tributary Data

				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		Total N (ppb)		Ortho P (ppb)		Inorganic N (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Sandy River	1	1	234.7	107	0	0	0	62	0	1396	0	12	0	135	0
2	Prairie	3	1	82	148	0	0	0	52	0	1225	0	9	0	294	0
3	Twin/Remote	4	1	77.6	3.4	0	0	0	53	0	855	0	10	0	87	0
4	BS Direct	4	1	451.59	4	0	0	0	132	0	1032	0	25	0	133	0
5	Septic	4	1	0	0.2	0	0	0	2400	0	1000	0	2400	0	100	0
6	Outlet	4	4	1072.4	215	0	0	0	38.2	0	1300	0	8	0	10	0
7	Bellhorn South Direct	2	1	0	0.8	0	0	0	132	0	1000	0	25	0	100	0

Model Coefficients	Mean	CV
Dispersion Rate	1.000	0.70
Total Phosphorus	1.000	0.45
Total Nitrogen	1.000	0.55
Chl-a Model	1.000	0.26
Secchi Model	1.000	0.10
Organic N Model	1.000	0.12
TP-OP Model	1.000	0.15
HODv Model	1.000	0.15
MODv Model	1.000	0.22
Secchi/Chla Slope (m^2/mg)	0.025	0.00
Minimum Qs (m/yr)	0.100	0.00
Chl-a Flushing Term	1.000	0.00
Chl-a Temporal CV	0.620	0
Avail. Factor - Total P	0.330	0
Avail. Factor - Ortho P	1.930	0
Avail. Factor - Total N	0.590	0
Avail. Factor - Inorganic N	0.790	0

File: **Big Sandy Lake calibration for water year 2008**

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: **5** **Area-Wtd Mean**

	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	38.0	0.22	39.9%	38.0		39.8%
TOTAL N MG/M3	926.1	0.04	45.1%			
C.NUTRIENT MG/M3	32.8	0.17	45.7%			
CHL-A MG/M3	16.8	0.32	77.5%			
SECCHI M	2.0	0.28	79.5%			
ORGANIC N MG/M3	546.5	0.26	61.0%			
TP-ORTHO-P MG/M3	27.7	0.38	46.7%			
ANTILOG PC-1	254.3	0.46	51.1%			
ANTILOG PC-2	15.1	0.09	94.8%			
(N - 150) / P	20.5	0.23	60.7%			
INORGANIC N / P	37.0	0.89	58.8%			
TURBIDITY 1/M	0.1	0.14	1.1%	0.1	0.14	1.1%
ZMIX * TURBIDITY	0.4	0.16	0.3%	0.4	0.16	0.3%
ZMIX / SECCHI	2.2	0.29	9.7%			
CHL-A * SECCHI	33.5	0.11	95.4%			
CHL-A / TOTAL P	0.4	0.27	89.9%			
FREQ(CHL-a>10) %	69.5	0.25	77.5%			
FREQ(CHL-a>20) %	27.9	0.62	77.5%			
FREQ(CHL-a>30) %	10.9	0.89	77.5%			
FREQ(CHL-a>40) %	4.5	1.09	77.5%			
FREQ(CHL-a>50) %	2.0	1.26	77.5%			
FREQ(CHL-a>60) %	1.0	1.41	77.5%			
CARLSON TSI-P	56.6	0.06	39.9%	56.6		39.8%
CARLSON TSI-CHLA	58.2	0.05	77.5%			
CARLSON TSI-SEC	50.0	0.08	20.5%			

Segment: **1** **Webster Bay**

	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	39.6	0.21	41.7%	39.8		41.8%
TOTAL N MG/M3	944.0	0.04	46.3%			
C.NUTRIENT MG/M3	34.0	0.16	47.6%			
CHL-A MG/M3	17.9	0.32	79.8%			
SECCHI M	1.9	0.29	77.1%			
ORGANIC N MG/M3	570.6	0.26	64.2%			
TP-ORTHO-P MG/M3	29.6	0.37	49.5%			
ANTILOG PC-1	278.2	0.45	53.9%			
ANTILOG PC-2	15.3	0.10	95.0%			

(N - 150) / P	20.0	0.22	59.5%			
INORGANIC N / P	37.2	0.94	59.0%			
TURBIDITY 1/M	0.1	0.20	1.1%	0.1	0.20	1.1%
ZMIX * TURBIDITY	0.3	0.23	0.2%	0.3	0.23	0.2%
ZMIX / SECCHI	2.2	0.29	9.4%			
CHL-A * SECCHI	33.9	0.12	95.5%			
CHL-A / TOTAL P	0.5	0.27	90.5%			
FREQ(CHL-a>10) %	73.5	0.23	79.8%			
FREQ(CHL-a>20) %	31.2	0.58	79.8%			
FREQ(CHL-a>30) %	12.6	0.85	79.8%			
FREQ(CHL-a>40) %	5.4	1.06	79.8%			
FREQ(CHL-a>50) %	2.4	1.23	79.8%			
FREQ(CHL-a>60) %	1.2	1.37	79.8%			
CARLSON TSI-P	57.2	0.05	41.7%	57.3		41.8%
CARLSON TSI-CHLA	58.9	0.05	79.8%			
CARLSON TSI-SEC	50.8	0.08	22.9%			

Segment: 2 Bellhorn South

	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	30.6	0.31	31.0%	31.8		32.4%
TOTAL N MG/M3	854.5	0.06	40.2%			
C.NUTRIENT MG/M3	27.1	0.25	36.6%			
CHL-A MG/M3	10.9	0.36	57.9%			
SECCHI M	2.8	0.29	89.7%			
ORGANIC N MG/M3	412.5	0.25	39.3%			
TP-ORTHO-P MG/M3	17.3	0.43	28.1%			
ANTILOG PC-1	136.9	0.51	32.8%			
ANTILOG PC-2	14.2	0.11	93.3%			
(N - 150) / P	23.0	0.30	67.2%			
INORGANIC N / P	33.1	0.59	54.4%			
TURBIDITY 1/M	0.1	0.20	1.1%	0.1	0.20	1.1%
ZMIX * TURBIDITY	0.6	0.23	1.6%	0.6	0.23	1.6%
ZMIX / SECCHI	2.6	0.30	15.1%			
CHL-A * SECCHI	31.0	0.14	94.2%			
CHL-A / TOTAL P	0.4	0.28	82.8%			
FREQ(CHL-a>10) %	43.5	0.52	57.9%			
FREQ(CHL-a>20) %	10.0	1.01	57.9%			
FREQ(CHL-a>30) %	2.6	1.35	57.9%			
FREQ(CHL-a>40) %	0.8	1.59	57.9%			
FREQ(CHL-a>50) %	0.3	1.79	57.9%			
FREQ(CHL-a>60) %	0.1	1.96	57.9%			
CARLSON TSI-P	53.5	0.08	31.0%	54.0		32.4%
CARLSON TSI-CHLA	54.1	0.06	57.9%			
CARLSON TSI-SEC	45.0	0.09	10.3%			

Segment: 3 Bellhorn North

	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	38.6	0.19	40.6%			
TOTAL N MG/M3	956.6	0.04	47.1%			
C.NUTRIENT MG/M3	33.5	0.14	46.8%			
CHL-A MG/M3	16.4	0.31	76.6%			
SECCHI M	2.0	0.27	79.8%			
ORGANIC N MG/M3	537.6	0.25	59.7%			
TP-ORTHO-P MG/M3	27.0	0.36	45.6%			
ANTILOG PC-1	249.0	0.42	50.5%			
ANTILOG PC-2	15.0	0.10	94.6%			
(N - 150) / P	20.9	0.19	61.9%			
INORGANIC N / P	36.1	0.74	57.8%			
TURBIDITY 1/M	0.1	0.20	1.1%	0.1	0.20	1.1%
ZMIX * TURBIDITY	0.4	0.23	0.3%	0.4	0.23	0.3%
ZMIX / SECCHI	2.4	0.28	11.3%			
CHL-A * SECCHI	33.5	0.12	95.3%			
CHL-A / TOTAL P	0.4	0.27	88.8%			
FREQ(CHL-a>10) %	68.8	0.25	76.6%			
FREQ(CHL-a>20) %	26.5	0.61	76.6%			
FREQ(CHL-a>30) %	10.0	0.88	76.6%			
FREQ(CHL-a>40) %	4.0	1.08	76.6%			
FREQ(CHL-a>50) %	1.8	1.25	76.6%			
FREQ(CHL-a>60) %	0.8	1.39	76.6%			
CARLSON TSI-P	56.8	0.05	40.6%			
CARLSON TSI-CHLA	58.1	0.05	76.6%			
CARLSON TSI-SEC	49.7	0.08	20.2%			

Segment: **4** **Main Bay**

	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	38.4	0.22	40.3%	38.2		40.1%
TOTAL N MG/M3	928.1	0.04	45.2%			
C.NUTRIENT MG/M3	33.0	0.17	46.1%			
CHL-A MG/M3	17.2	0.33	78.5%			
SECCHI M	2.0	0.29	78.3%			
ORGANIC N MG/M3	555.7	0.26	62.2%			
TP-ORTHO-P MG/M3	28.4	0.38	47.8%			
ANTILOG PC-1	261.4	0.46	52.0%			
ANTILOG PC-2	15.2	0.10	94.9%			
(N - 150) / P	20.3	0.23	60.2%			
INORGANIC N / P	37.5	0.92	59.2%			
TURBIDITY 1/M	0.1	0.20	1.1%	0.1	0.20	1.1%
ZMIX * TURBIDITY	0.3	0.23	0.2%	0.3	0.23	0.2%
ZMIX / SECCHI	2.2	0.30	9.1%			
CHL-A * SECCHI	33.7	0.12	95.4%			
CHL-A / TOTAL P	0.4	0.27	90.3%			

FREQ(CHL-a>10) %	71.5	0.25	78.5%		
FREQ(CHL-a>20) %	29.1	0.62	78.5%		
FREQ(CHL-a>30) %	11.4	0.89	78.5%		
FREQ(CHL-a>40) %	4.8	1.11	78.5%		
FREQ(CHL-a>50) %	2.1	1.28	78.5%		
FREQ(CHL-a>60) %	1.0	1.42	78.5%		
CARLSON TSI-P	56.8	0.06	40.3%	56.7	40.1%
CARLSON TSI-CHLA	58.5	0.05	78.5%		
CARLSON TSI-SEC	50.3	0.08	21.7%		

File: **Minnewawa Calibration for Water Year 2008**

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: **1** **Minnewawa**

Variable	Predicted Values---> Mean	CV	Rank	Observed Values---> Mean	CV	Rank
TOTAL P MG/M3	31.4	0.33	32.0%	31.0	0.20	31.4%
TOTAL N MG/M3	1157.0	0.30	58.9%			
C.NUTRIENT MG/M3	29.4	0.30	40.4%			
CHL-A MG/M3	17.4	0.44	78.8%			
SECCHI M	1.9	0.38	78.0%			
ORGANIC N MG/M3	559.6	0.33	62.8%			
TP-ORTHO-P MG/M3	28.8	0.49	48.2%			
ANTILOG PC-1	247.3	0.67	50.3%			
ANTILOG PC-2	15.6	0.10	95.4%			
(N - 150) / P	32.1	0.44	82.4%			
INORGANIC N / P	225.6	5.08	97.9%			
TURBIDITY 1/M	0.1	0.20	1.1%	0.1	0.20	1.1%
ZMIX * TURBIDITY	0.2	0.23	0.0%	0.2	0.23	0.0%
ZMIX / SECCHI	1.3	0.39	1.2%			
CHL-A * SECCHI	33.8	0.13	95.5%			
CHL-A / TOTAL P	0.6	0.26	94.9%			
FREQ(CHL-a>10) %	72.0	0.33	78.8%			
FREQ(CHL-a>20) %	29.6	0.82	78.8%			
FREQ(CHL-a>30) %	11.7	1.18	78.8%			
FREQ(CHL-a>40) %	4.9	1.46	78.8%			
FREQ(CHL-a>50) %	2.2	1.68	78.8%			
FREQ(CHL-a>60) %	1.1	1.86	78.8%			
CARLSON TSI-P	53.9	0.09	32.0%	53.7	0.05	31.4%
CARLSON TSI-CHLA	58.6	0.07	78.8%			
CARLSON TSI-SEC	50.4	0.11	22.0%			

File:

Minnewawa Calibration for Water Year 2008

Overall Water & Nutrient Balances

Overall Water Balance — **Averaging Period = 1.00 years**

Trb	Type	Seg	Name	Area km^2	Flow hm^3/yr	Variance (hm3/yr)^2	CV -	Runoff m/yr
1	1	1	Direct	26.2	4.5	0.00E+00	0.00	0.17
2	1	1	Horseshoe	22.6	4.1	0.00E+00	0.00	0.18
3	4	1	Outlet	55.0	7.3	1.33E-01	0.05	0.13
4	1	1	Septic		0.2	0.00E+00	0.00	
PRECIPITATION				9.9	6.0	1.42E+00	0.20	0.60
TRIBUTARY INFLOW				48.8	8.8	0.00E+00	0.00	0.18
***TOTAL INFLOW				58.7	14.7	1.42E+00	0.08	0.25
GAUGED OUTFLOW				55.0	7.3	1.33E-01	0.05	0.13
ADVECTIVE OUTFLOW				3.7	1.5	4.74E+00	1.46	0.40
***TOTAL OUTFLOW				58.7	8.8	4.61E+00	0.24	0.15
***EVAPORATION					6.0	3.19E+00	0.30	

Overall Mass Balance Based Upon — **Predicted** — **Outflow & Reservoir Concentrations**

Component: — **TOTAL P**

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance (kg/yr)^2	%Total	CV	Conc mg/m^3	Export kg/km^2/yr
1	1	1	Direct	314.3	33.3%	0.00E+00		0.00	70.0	12.0
2	1	1	Horseshoe	262.4	27.8%	0.00E+00		0.00	64.0	11.6
3	4	1	Outlet	229.3		5.72E+03		0.33	31.4	4.2
4	1	1	Septic	190.0	20.1%	0.00E+00		0.00	950.0	
PRECIPITATION				177.6	18.8%	7.88E+03	100.0%	0.50	29.8	17.9
TRIBUTARY INFLOW				766.7	81.2%	0.00E+00		0.00	87.2	15.7
***TOTAL INFLOW				944.3	100.0%	7.88E+03	100.0%	0.09	64.1	16.1
GAUGED OUTFLOW				229.3	24.3%	5.72E+03		0.33	31.4	4.2
ADVECTIVE OUTFLOW				46.8	5.0%	4.48E+03		1.43	31.4	12.6

***TOTAL OUTFLOW	276.1	29.2%	1.00E+04		0.36	31.4	4.7
***RETENTION	668.2	70.8%	1.48E+04		0.18		

Overflow Rate (m/yr)	0.9	Nutrient Resid. Time (yrs)	0.8248
Hydraulic Resid. Time (yrs)	2.8214	Turnover Ratio	1.2
Reservoir Conc (mg/m3)	31	Retention Coef.	0.708

Overall Mass Balance Based Upon **Predicted** **Outflow & Reservoir Concentrations**

Component: **TOTAL N**

Trb	Type	Seg	Name	Load kg/yr	%Total	Load Variance $(kg/yr)^2$	%Total	CV	Conc mg/m^3	Export $kg/km^2/yr$
1	1	1	Direct	6268.0	29.3%	0.00E+00		0.00	1396.0	239.2
2	1	1	Horseshoe	5022.5	23.5%	0.00E+00		0.00	1225.0	222.2
3	4	1	Outlet	8446.3		6.52E+06		0.30	1157.0	153.6
4	1	1	Septic	200.0	0.9%	0.00E+00		0.00	1000.0	
PRECIPITATION				9920.0	46.3%	2.46E+07	100.0%	0.50	1666.7	1000.0
TRIBUTARY INFLOW				11490.5	53.7%	0.00E+00		0.00	1307.2	235.5
***TOTAL INFLOW				21410.5	100.0%	2.46E+07	100.0%	0.23	1452.3	364.6
GAUGED OUTFLOW				8446.3	39.4%	6.52E+06		0.30	1157.0	153.6
ADVECTIVE OUTFLOW				1724.0	8.1%	5.07E+06		1.31	1157.0	463.4
***TOTAL OUTFLOW				10170.3	47.5%	5.90E+06		0.24	1157.0	173.2
***RETENTION				11240.2	52.5%	7.13E+06		0.24		

Overflow Rate (m/yr)	0.9	Nutrient Resid. Time (yrs)	1.3402
Hydraulic Resid. Time (yrs)	2.8214	Turnover Ratio	0.7
Reservoir Conc (mg/m3)	1157	Retention Coef.	0.525

File:

Minnewawa Calibration for Water Year 2008

Hydraulic & Dispersion Parameters

			Net	Resid	Overflow		Dispersion-------->		
		Outflow	Inflow	Time	Rate	Velocity	Estimated	Numeric	Exchange
Seg	Name	Seg	hm^3/yr	years	m/yr	km/yr	km^2/yr	km^2/yr	hm^3/yr
1	Minnewawa	0	8.8	2.8214	0.9	1.8	323.1	4.4	0.0

Morphometry

		Area	Zmean	Zmix	Length	Volume	Width	L/W
Seg	Name	km^2	m	m	km	hm^3	km	-
1	Minnewawa	9.9	2.5	2.5	5.0	24.8	2.0	2.5
Totals		9.9	2.5			24.8		

File: **Minnewawa Calibration for Water Year 2008**

Segment & Tributary Network

--------Segment:	1	Minnewawa	
Outflow Segment:	0	Out of Reservoir	
Tributary:	1	Direct	Type: Monitored Inflow
Tributary:	2	Horseshoe	Type: Monitored Inflow
Tributary:	3	Outlet	Type: Reservoir Outflow
Tributary:	4	Septic	Type: Monitored Inflow

File: Minnewawa Calibration for Water Year 2008
Description:

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.6	0.2
Evaporation (m)	0.6	0.3
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km^2-yr)	Mean	CV
Conserv. Substance	0	0.00
Total P	17.9	0.50
Total N	1000	0.50
Ortho P	9	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	8	CANF & BACH, LAKES
Nitrogen Balance	5	BACHMAN FLUSHING
Chlorophyll-a	2	P, LIGHT, T
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	0	NONE
Error Analysis	1	MODEL & DATA
Availability Factors	1	USE FOR MODEL 1 ONLY
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Minnewawa	0	1	9.92	2.5	5	2.5	0.12	0	0	0.08	0.2	0	0	0	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	31	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0

Tributary Data

				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		Total N (ppb)		Ortho P (ppb)		Inorganic N (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	Direct	1	1	26.2	4.49	0	0	0	70	0	1396	0	15	0	135	0
2	Horseshoe	1	1	22.6	4.1	0	0	0	64	0	1225	0	9	0	294	0
3	Outlet	1	4	55	7.3	0.05	0	0	31	0.1	1300	0.1	8	0.1	10	0.1
4	Septic	1	1	0	0.2	0	0	0	950	0	1000	0	950	0	200	0

Model Coefficients	Mean	CV
Dispersion Rate	1.000	0.70
Total Phosphorus	1.000	0.45
Total Nitrogen	1.000	0.55
Chl-a Model	1.000	0.26
Secchi Model	1.000	0.10
Organic N Model	1.000	0.12
TP-OP Model	1.000	0.15
HODv Model	1.000	0.15
MODv Model	1.000	0.22
Secchi/Chla Slope (m^2/mg)	0.025	0.00
Minimum Qs (m/yr)	0.100	0.00

Chl-a Flushing Term	1.000	0.00
Chl-a Temporal CV	0.620	0
Avail. Factor - Total P	0.330	0
Avail. Factor - Ortho P	1.930	0
Avail. Factor - Total N	0.590	0
Avail. Factor - Inorganic N	0.790	0