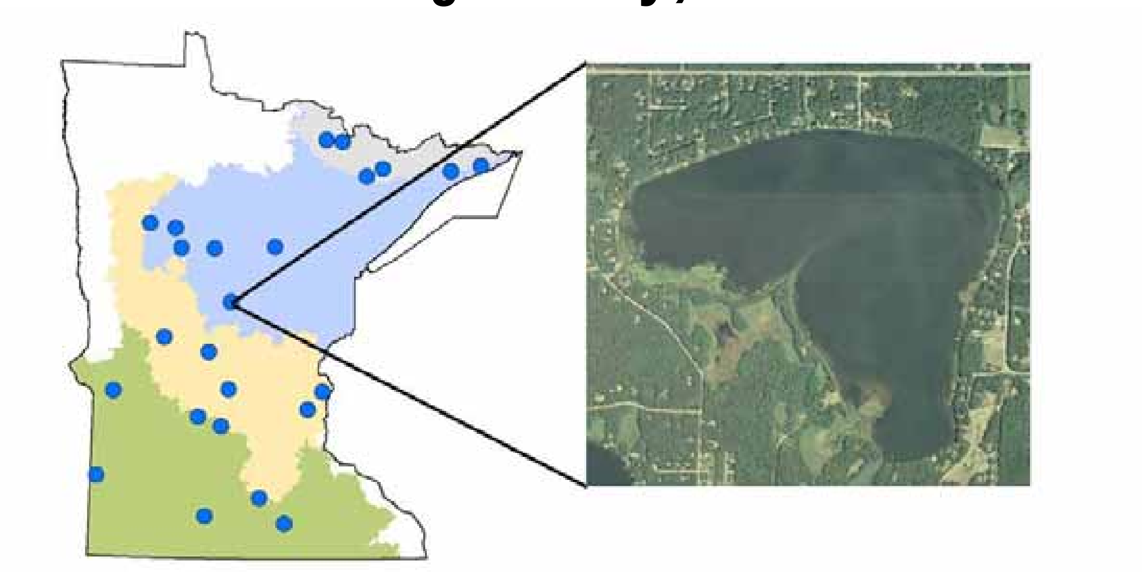
Sentinel Lake Assessment Report
Red Sand Lake (18-0386)
Crow Wing County, Minnesota



Minnesota Pollution Control Agency
Water Monitoring Section
Lakes and Streams Monitoring Unit
&
Minnesota Department of Natural Resources
Section of Fisheries
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Executive Summary

The Minnesota Pollution Control Agency (MPCA) is working in partnership with the Minnesota Department of Natural Resources (MDNR) on the Sustaining Lakes in a Changing Environment (SLICE) Sentinel Lakes Program. The focus of this interdisciplinary effort is to improve understanding of how major drivers of change such as development, agriculture, climate change, and invasive species can affect lake habitats and fish populations, and to develop a long-term strategy to collect the necessary information to detect undesirable changes in Minnesota Lakes (Valley 2009). To increase our ability to predict the consequences of land cover and climate change on lake habitats, SLICE utilizes intensive lake monitoring strategies on a wide range of representative Minnesota lakes. This includes analyzing relevant land cover and land use, identifying climate stressors, and monitoring the effects on the lake's habitat and biological communities.

The Sentinel Lakes Program has selected 24 lakes for long-term intensive lake monitoring (Figure 1). The "Deep" lakes typically stratify during the summer months. "Shallow" lakes are defined as mixing continuously throughout the summer. "Cold Water" lakes are defined as lakes that either harbor cisco, lake whitefish, or lake trout and are the focus of research funded by the Environmental Trust Fund (ETF). "Super sentinel" lakes also harbor cold-water fish populations and research on these lakes is also funded by the ETF.

Red Sand Lake was selected to represent a shallow lake in the Northern Lake and Forest ecoregion. Red Sand Lake is a 211 hectare (522 acre lake), located in Baxter, Minnesota in Crow Wing County, within the Crow Wing River watershed. The lake has a maximum depth of 7.0 meters (23 feet) and a mean depth of 1.1 meters (3.7 feet). The lake is 96% littoral with one public access on the north shore of the lake. The total contributing watershed for Red Sand Lake is 1,132 hectares (2,796 acres). Red Sand Lake is located within the Northern Lake and Forest ecoregion.

Red Sand Lake is a shallow lake that remains mixed throughout the season. Based on recent water quality data (2008), Red Sand Lake is considered to be mesotrophic with total phosphorus (TP), chlorophyll-*a*, and Secchi values of: 23 micrograms per liter (µg/L), 3.7 µg/L, and 3.3 meters (10.8 feet) respectively. TP is generally within the typical ranges (based on reference lakes) for Northern Lakes and Forest Ecoregion. Nuisance algal blooms were not observed and transparency was typically high during much of the summer. Trophic status data collected since 2000 suggest stable nutrient levels and algal growth over the past decade. Based on these data, Red Sand Lake is considered to be fully supporting aquatic recreation use.

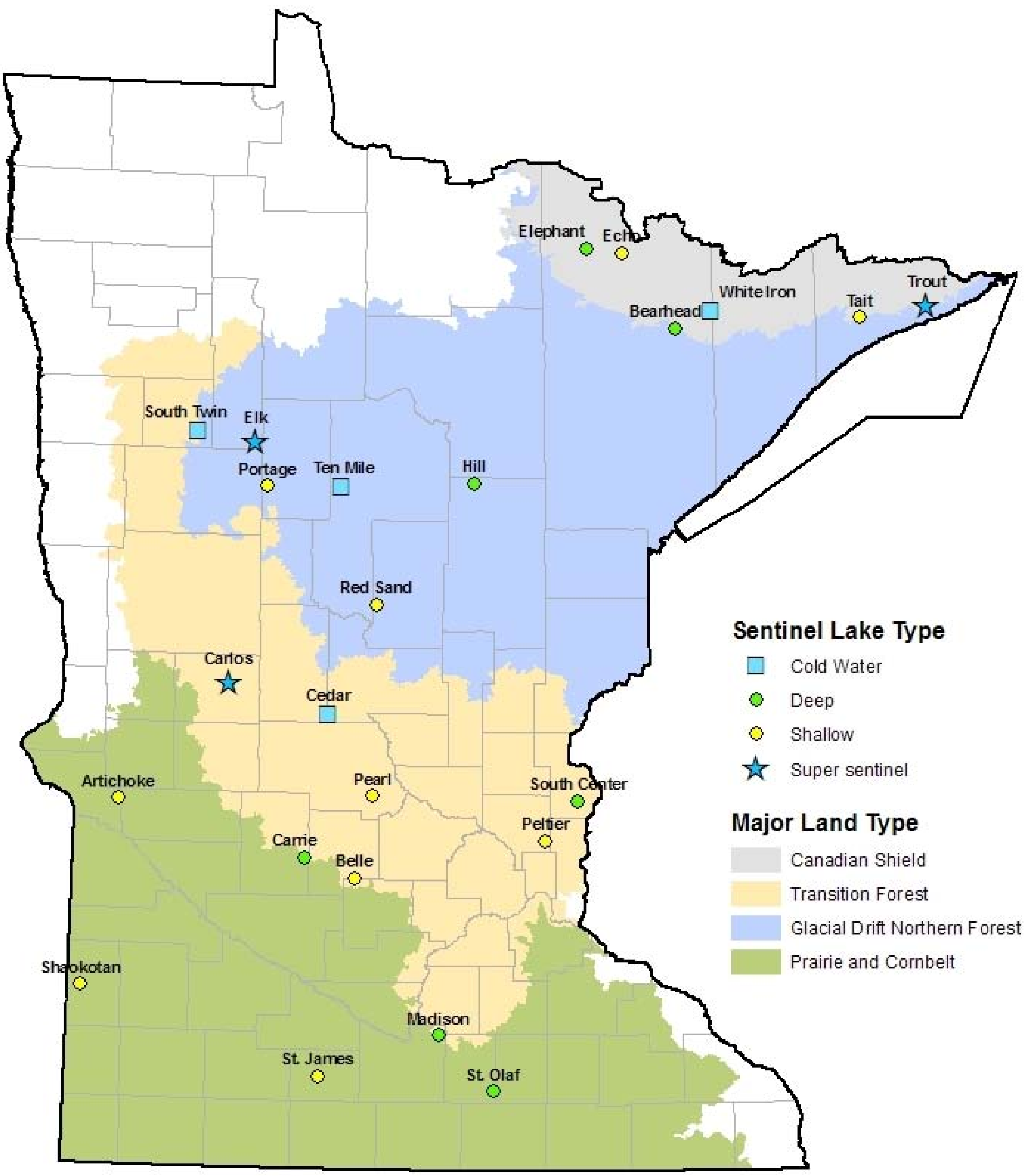
Despite its tendency to periodically winterkill, Red Sand Lake's fish community is of average diversity (e.g., index of biotic integrity) when it compared with other non-winterkill lakes of similar productivity. Least darters, which are a state-listed species of special concern, were sampled in the lake in 2008. A partial winterkill in 2008 substantially reduced largemouth bass populations, while showing lesser impacts on other species. Walleye are typically stocked shortly following winterkill events to sustain a recreational fishery.

Aquatic plants are abundant and modestly diverse in Red Sand Lake and cover almost 100% of the lake bottom. The invasive plant curly-leaf pondweed was first recorded in 2008; however, the exact date of introduction into Red Sand Lake is unknown. Curly-leaf pondweed thrives in nutrient-rich conditions and can exacerbate poor water quality conditions when plants senesce in mid-summer. However, curly-leaf pondweed typically does not grow to nuisance conditions in lakes of moderate productivity like Red Sand Lake. It will be important to keep external nutrient loads at minimal levels to maintain aquatic plant diversity and to keep curly-leaf pondweed at low levels of abundance.

An ecoregion-based eutrophication model was used to predict in-lake TP based on Red Sand Lake's size, depth, and watershed area using inputs from both ecoregions. Using inputs for Northern Lake and Forest ecoregion the model predicted in-lake TP from 30 µg/L, which is higher than the observed 23 µg/L. A separate subroutine within the model estimated "background" TP for the lake at 28 µg/L. The model predictions, along with the overall assessment of Red Sand Lake's water quality data, clearly indicate the lake's water quality is slightly better than anticipated for a lake of this size in this portion of the state.

Red Sand Lake was sampled in 2007 and 2008 as part of the Statewide Endocrine Disrupting Compound (EDC) Monitoring Study (Ferrey, et. al, 2009), which may be found at: http://www.pca.state.mn.us/publications/tdr-g1-08.pdf. The study purpose was to determine the presence of endocrine disrupting compounds, pharmaceuticals, pesticides and other contaminants associated with wastewater. Discussion of the results from this study is beyond the scope of this Sentinel report, since the results must be reviewed within the context of the overall EDC study. Inclusion of EDC monitoring of water, sediments and fish could potentially be a future focus for the Sentinel lakes.

Figure 1. Sentinel lakes and major land types



Introduction

This report provides a relatively comprehensive analysis of physical, water quality and ecological characteristics of Red Sand Lake in Crow Wing, Minnesota (MN). This assessment was compiled based on Minnesota Department of Natural Resources (MDNR) surveys of the lake's fish and aquatic plant communities, Minnesota Pollution Control Agency (MPCA) and volunteer water quality monitoring, and analysis of various other sources of data for the lake. The water quality assessment focuses on data collected during the 2008 season; however, historical data are used to provide perspective on variability and trends in water quality. Water quality data analyzed will include all available data in STORET, the national repository for water quality data. Further detail on water quality and limnological concepts and terms in this report can be found in the Guide to Lake Protection and Management: (http://www.pca.state.mn.us/water/lakeprotection.html).

History

1920's - 1940's	Red Sand Lake was managed for northern pike, perch, and centrarchids through statewide regulations and periodic removal of rough fish (bullheads). Surveys were conducted by fisheries research to evaluate the extent of fish winterkill and the first vegetation and substrate surveys were conducted. On several occasions during the winter, all regulations were removed, allowing anglers to harvest fish before they perished from anoxic conditions. Bass (2,100 fingerlings), sunfish (1,910 fingerlings), and northern pike (480,000 fry) were stocked following winterkill conditions. Considerable winterkill was noted during the winter of 1948. Six cottages were recorded as being on the lake at this time.
1950's – 1960's	As part of a Pittman-Robertson project, the lake was surveyed for waterfowl and muskrat habitat resulting in a classification as a Permanent Waterfowl Lake. The first game fish surveys were conducted by area staff and the lake was continued to be managed for northern pike, perch, largemouth bass, sunfish, and crappies, but the main emphasis was managing the lake as a migratory duck stopover lake. A controlled northern pike spawning area was created to aid in recolonization efforts following winterkill years. To create this area, a water control structure installed in 1959 to moderate water levels between Red Sand and White Sand Lakes. During this time period crappies (13,320 yearling) and bass (6,000 fingerlings) were stocked once and sunfish were stocked 5 times (total=28,100). Considerable winterkill was noted during the winter of 1960 and 1965.
1970's - 1980's	Fisheries management surveyed the fish community in 1971, 1973, and conducted a full survey in 1986. The lake was managed as a regular winterkill fishery with a Lake Class of 39 (Bullhead) with the fishery supported with regular walleye fry stockings. During this time period the lake was suggested for rotenone treatment, development of an aeration system, a special regulation, use as walleye rearing pond, and to be included in a study evaluating vegetation complexity. In 1976, a drought caused the water level to drop 2 feet and the shoreline was classified as 80% developed (32 homes and 1 resort). Northern pike (200 fingerlings) were stocked once and walleye were stocked six times (total=2.3 million fry) with good success coming from 1982 and 1986 year classes. Very good northern pike and walleye fishing was reported before the winterkill of 1986. Winterkill was noted during the winter of 1986 and in 1989

	and it was observed that this lake winterkills more regularly and with more severity than most area lakes.
1990's – 2000's	The fish community was sampled on Red Sand Lake 1992, 2000, 2001, 2008, and 2009. Aquatic vegetation was surveyed in 2001, 2008, and 2009. The outlet between Red Sand and White Sand was modified to better control lake level and reduce the potential for erosion between the two lakes in 1996. The lake management plan was revised with the long range goal of maintaining a walleye population by stocking walleye fry annually especially after winterkills. The operational plan calls for annual winter fish house counts, walleye fry stocking of 400,000 after winterkill (800 fry/surface acre), annual winter dissolved oxygen checks, and re-surveys in five-year intervals. Sixty homes around the shoreline were noted with new lots slated for development near the outlet in 2008. Walleye were stocked eight times during this time period (total= 3.4 million fry). Considerable winterkill was noted during the winter of 1992, 1997, and 2007. Red Sand Lake was sampled in 2007 and 2008 as part of the Statewide Endocrine Disrupting Compound Monitoring Study (Ferrey, et. al, 2009). http://www.pca.state.mn.us/publications/tdr-g1-08.pdf The study purpose was to determine the presence of endocrine disrupting compounds, pharmaceuticals, pesticides and other contaminants associated with wastewater.

Background

Lake Morphometric and Watershed Characteristics

Red Sand Lake is located in Crow Wing County within the Crow Wing River watershed. Red Sand Lake is located in Baxter, MN. A public access is located on the north shore. Red Sand Lake is shallow and polymictic (continually mixing).

Red Sand Lake's morphometric characteristics are summarized in Table 1. Percent littoral area refers to that portion of the lake that is 4.6 meters (15 feet) or less in depth, which often represents the depth to which rooted plants may grow in the lake (Figure 2). Lakes with a high percentage of littoral area often have extensive rooted plant (macrophyte) beds. These plant beds are a natural part of the ecology of these lakes and are important to maintain and protect.

Table 1. Red Sand Lake and watershed morphometric characteristics

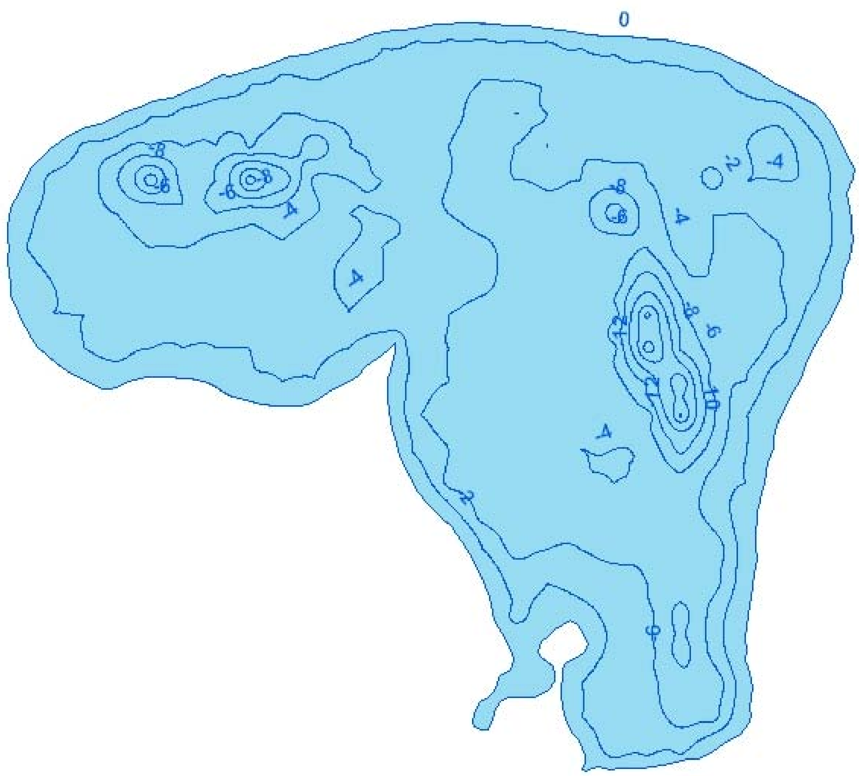
Lake Name	Lake ID	[1]Lake Basin	[2]Lake Basin	Littoral Area	Total Watershed Area	Watershed: Lake	Max. Depth	Mean Depth	Lake Volume
		Hectares (Acres)	Hectares (Acres)	%	Hectares (Acres)	Ratio	Meters (Feet)	Meters (Feet)	Acre-Ft.
Red Sand	18-0386	219 (540)	211 (522)	96	1,132 (2,796)	5.5 : 1	7.0 (23)	1.1 (3.7)	1,857

The Red Sand Lake contributing watershed lies within the Crow Wing River watershed. The lake's watershed has two drainage points located on the west and south shores of the lake. The contributing

[1] Based on the Public Waters Inventory and reflects the area below the ordinary high water elevation, DNR
[2] Based on the 1:100,000 Lakes and Rivers Coverage and reflects the open water area in 2008, DNR

watershed has a total area of 1,132 hectares (2,796 acres) resulting in a watershed-to-lake area ratio of approximately 5.5:1. Watershed delineations are available at http://deli.dnr.state.mn.us/data_search.html "DNRwatersheds - DNR Level 08 – All Catchments"

Figure 2. Red Sand Lake bathymetric map based on depths measured with a survey rod at point locations during aquatic plant surveys in July 2008.



Soils found in the Red Sand area are from the Menahga series. These soils tend to be course- to medium-textured forest soils that were formed from glacial outwash (Arneman 1963).

Red Sand Lake is likely the result of an ice block partially buried in the outwash plain. This most likely occurred during the retreat of the Minneapolis Lobe during the Wisconsin glacial stage (Zumberge, 1952).

Lake Mixing and Stratification

Lake depth and mixing has a significant influence on lake processes and water quality. *Thermal stratification* (formation of distinct temperature layers), in which deep lakes (maximum depths of 9 meters or more) often stratify (form layers) during the summer months and are referred to as *dimictic* (Figure 3). These lakes fully mix or turn over twice per year; typically in spring and fall. Shallow lakes (maximum depths of 6 meters or less), in contrast, typically do not stratify and are often referred to as *polymictic*. Lakes, with moderate depths, may stratify intermittently during calm periods, but mix during heavy winds and during spring and fall. Measurement of temperature throughout the water column (surface to bottom) at selected intervals (e.g. every meter) can be used to determine

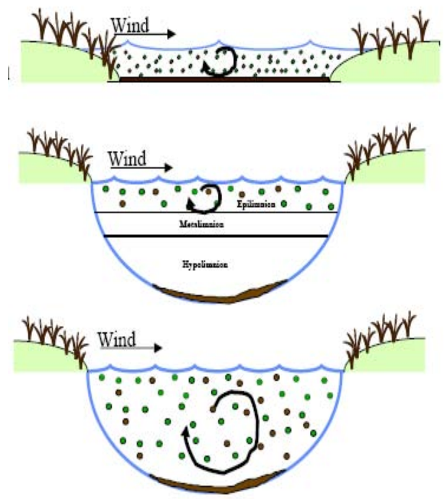
whether the lake is well-mixed or stratified. The depth of the thermocline (zone of maximum change in temperature over the depth interval) can also be determined. In general, dimictic lakes have an upper, well-mixed layer (epilimnion) that is warm and has high oxygen concentrations. In contrast, the lower layer (hypolimnion) is much cooler and often has little or no oxygen. This low oxygen environments in the hypolimnion are conducive to total phosphorus (TP) being released from the lake sediments. During stratification, dense colder hypolimnion waters are separated from the nutrient hungry algae in the epilimnion. Intermittently (weakly) stratified polymictic lakes are mixed in high winds and during spring and fall. Mixing events allow for the nutrient rich sediments to be re-suspended and are available to algae.

Figure 3. Lake stratification

Polymictic Lake
Shallow, no layers,
Mixes continuously
Spring, Summer & Fall

Dimictic Lake
Deep, form layers,
Mixes Spring/Fall

Intermittently Stratified
Moderately deep
Mixes during high winds
Spring, Summer, & Fall



Ecoregion and Land Use Characteristics

Minnesota is divided into seven regions, referred to as ecoregions, as defined by soils, land surface form, natural vegetation and current land use. Data gathered from representative, minimally impacted (reference) lakes within each ecoregion serve as a basis for comparing the water quality and characteristics of other lakes. Red Sand Lake lies within the Northern Lake and Forest (NLF) ecoregion (Figure 4). NLF values will be used for land use (Table 2), summer-mean water quality comparisons (Table 6), and in the model application.

Since land use affects water quality, it has proven helpful to divide the state into regions where land use and water resources are similar. Land use within the watershed is dominated by forested and water/wetland uses. Pasture, open, and developed land uses combined make up only 12% of the total land use while cultivated area makes up only 1% of the watershed (Figure 5).

Figure 4. Minnesota ecoregions as mapped by United States Environmental Protection Agency

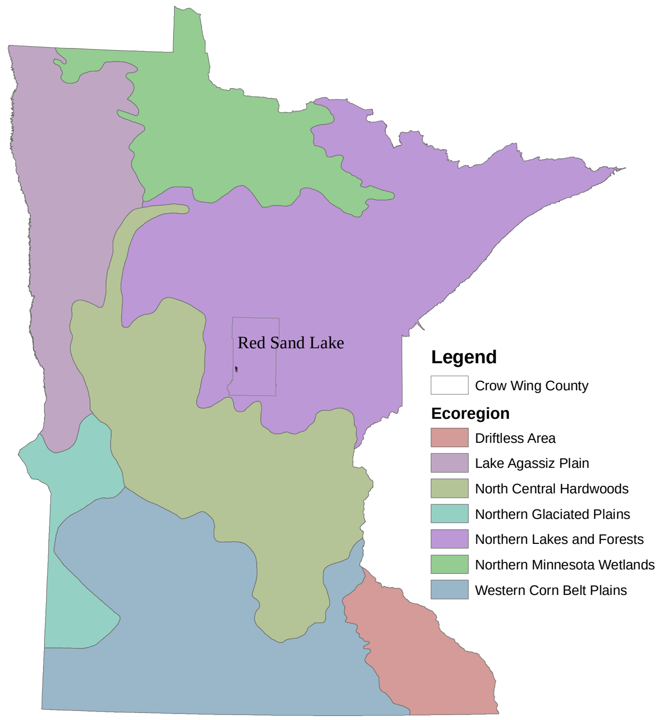
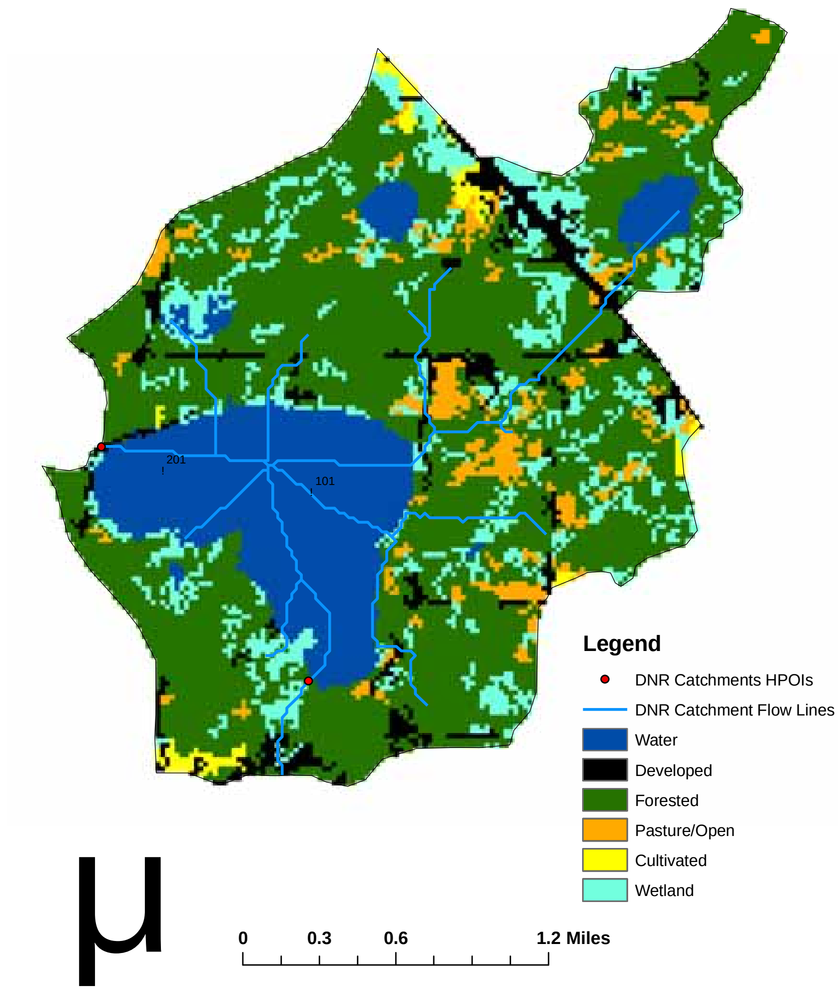


Table 2. Red Sand Lake ecoregion land use comparison
Typical (interquartile) range based on 30 NLF ecoregion reference lakes noted for comparison (Heiskary and Wilson 2005).

Land Use (%)	NLF ecoregion	Applicable (1969)[2]	Applicable (1991)[3]	Applicable (2001)[1]
Developed	0 - 7	5.7	0	5.9
Cultivated (Ag)	< 1	2.4	6.7	1.4
Pasture & Open	0 - 6	9.2	13.9	5.5
Forest	54 - 81	58.4	49.8	56.4
Water & Wetland	14 - 31	24.3	29.6	30.8

[1]National Land Cover Database www.mrlc.gov/index.php
[2]Minnesota Land Management Information Center www.lmic.state.mn.us/chouse/metadata/luse69.html
[3]Minnesota Land Cover 1991-1992:MAP www.lmic.state.mn.us/chouse/land_use_DNRmap.html

Figure 5. Red Sand Lake watershed and land use composition



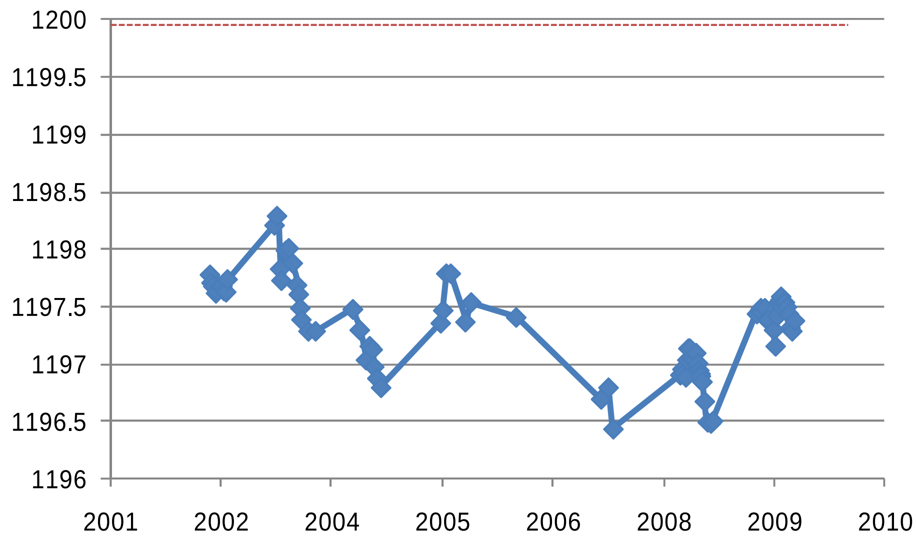
The National Land Cover Database 2001
Multi-Resolution Land Characteristics (MRLC) Consortium

Lake Level and Ice On/Off

The MDNR Division of Waters has been measuring water levels intermittently on Red Sand Lake since 1972. During the period of record (1972 – 2009), the lake has varied by 1.58 feet, based on 70 readings. The highest and lowest recorded elevations are 1198.49 feet on 11/15/1972 and 1196.26 feet on 08/05/1992, respectively. The record is spotty until 2001, when a consistent record is available. The ordinary high water mark (OHW) for Red Sand Lake is 1199.9 feet (Figure 6). Based on the recent record, peak water levels were noted in 2003 with a decline since that time. The lake remained well below the OHW during this period as well (Figure 6). An outlet structure exists on Red Sand Lake. The complete water level record may be obtained from the MDNR web site at: http://www.dnr.state.mn.us/lakefind/showlevel.html?id=18038600.

Ice-on records for Red Sand Lake, dating back to 2001, indicate that ice has typically formed by mid- to late-November. November 19, 2008, is the earliest recorded ice-on date and 12/02/2006 is the latest ice-on date. The ice is historically off of Red Sand Lake by mid-April. April 25, 2008, is the latest ice-off date while 04/05/2007 is the earliest ice-off date on record (Appendix A). Studies with longer datasets have documented a long-term trend of earlier ice-out dates (Johnson and Stefan 2006).

Figure 6. Red Sand Lake water level (OHW in red)



Precipitation and Climate Summary

Rain gage records from Baxter, MN show five one-inch plus rain events during summer 2008 (Figure 7). Large rain events will increase runoff into the lake and may influence in-lake water quality and lake levels. This will be considered in the discussion of lake water quality for 2008. Precipitation records for the 2008 water year (October 2007 through September 2008) showed normal amounts of rainfall were received (Figure 8). The long-term summer (April to October) rain fall amounts exhibit an increase from 1950 to present (Figure 9). Lake level responds to these changes in precipitation (Figure 6); though there may be a lag in this response. For example, lake levels peaked in 2003 following the high rainfall in 2002 and later declined in 2006-2007 in response to declining rainfall. Changes in precipitation over time have a distinct effect on groundwater levels, which are very important in lake level regulation in lakes with small watershed: lake ratios like Red Sand Lake.

Figure 7. Summer (April to October) 2008 rainfall based on records for Baxter, MN

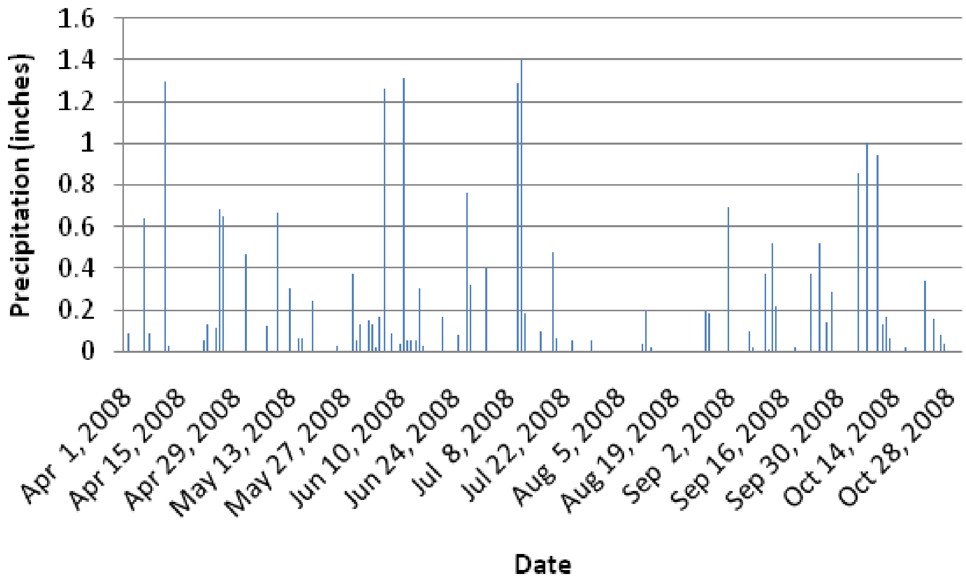
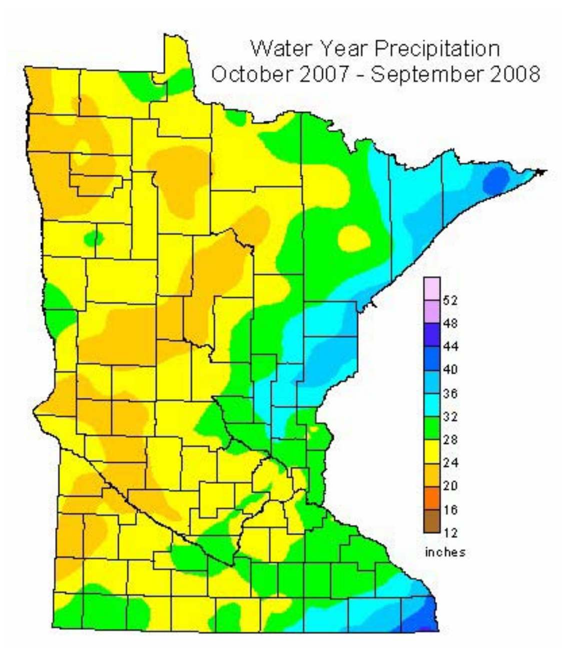


Figure 8. 2008 Minnesota water year precipitation and departure from normal

Prepared by State Climatology Office, MDNR
Values are in inches



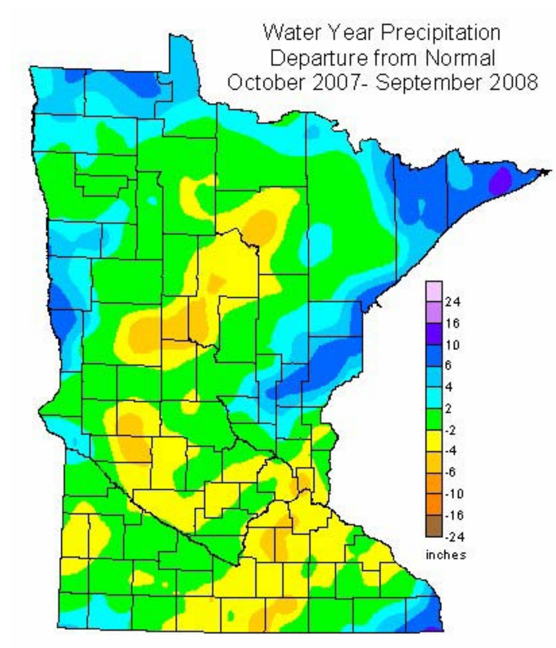
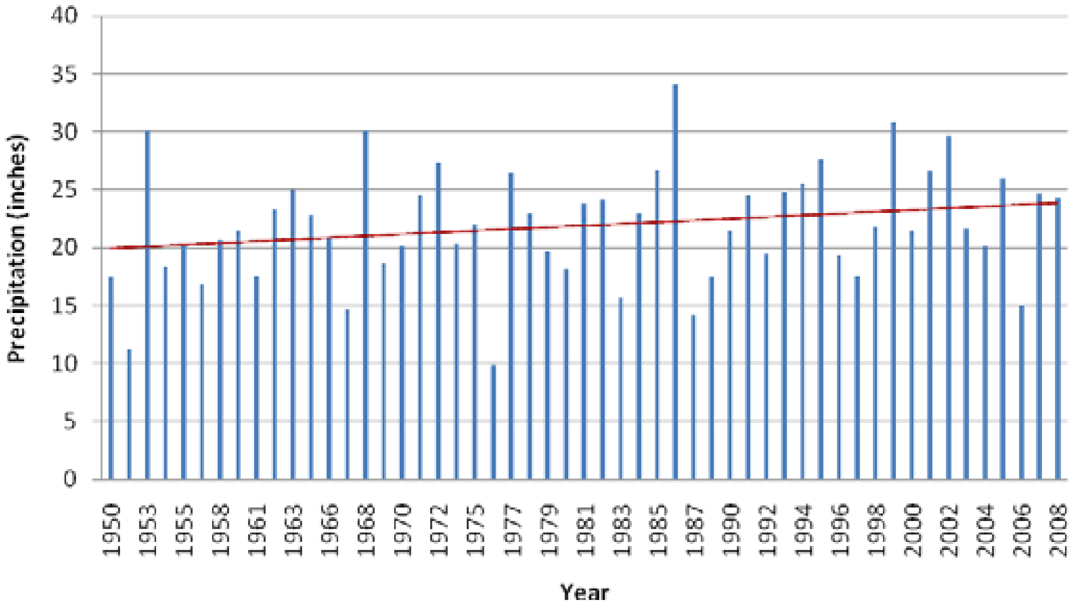


Figure 9. Historical summer (April to October) precipitation trends based on records for Baxter, MN. Mean for period of record indicated by solid blue line and simple linear regression by red dashed line.



Methods

Fisheries and Aquatic Plants

Frequency of occurrence of aquatic plant species were assessed using the point-intercept method (Madsen 1999). This method entailed visiting sampling points on a grid within the vegetated zone of the lake, throwing a two-sided rake over one side of the boat at each point, raking the bottom approximately 1 meter, then retrieving the rake and identifying all species present, and recording the depth. Survey points were spaced approximately 80-meter (0.7 points per littoral acre).

Most recent fisheries surveys follow guidelines outlined by MDNR Special Publication 147 (1993; Manual of Instructions for Lake Survey). Fish community integrity surveys were also completed on each Sentinel lake following methods described by Drake and Pereira (2002).

Water Quality

Water quality data for Red Sand Lake were collected monthly by MPCA staff. Bi-weekly dissolved oxygen (DO) and temperature profiles and Secchi disk measurements were collected by a volunteer. Separate from this monitoring project, local monitoring also occurred monthly; these data are included in the analysis. Lake surface samples were collected by MPCA staff with an integrated sampler, a poly vinyl chloride (PVC) tube 2 meters (6.6 feet) in length, with an inside diameter of 3.2 centimeters (1.24 inches). Zooplankton samples were collected with an 80 µm mesh Wisconsin zooplankton net. Phytoplankton (algae) samples were taken with an integrated sampler. Depth TP samples were collected with a Kemmerer sampler. Temperature and DO profiles and Secchi disk transparency measurements were also taken. Samples were collected at site 201 or 101 (Figure 5). Sampling procedures were employed as described in the MPCA Standard Operating Procedure for Lake Water Quality document, which can be found at http://www.pca.state.mn.us/publications/wq-s1-16.pdf .

Laboratory analysis was performed by the laboratory of the Minnesota Department of Health using United States Environmental Protection Agency-approved methods. Samples were analyzed for nutrients, color, solids, pH, alkalinity, conductivity, chloride, metals, and chlorophyll-a (chl-*a*). Phytoplankton samples were analyzed at the MPCA using a rapid assessment technique.

Zooplankton

Zooplankton samples were collected monthly from May through October 2008 and three times during the 2009 sampling season. Two replicate vertical tows were taken at each sampling event. The net was lowered to within 0.5 meter of the bottom and withdrawn at a rate of approximately 0.5 meters per second. Contents were rinsed into sample bottles and preserved with 100% reagent alcohol. Analysis was conducted by MDNR personnel.

Each zooplankton sample was adjusted to a known volume by filtering through 80 microgram per liter (µg/L) mesh netting and rinsing specimens into a graduated beaker. Water was added to the beaker to a volume that provided at least 150 organisms per 5-milliliter aliquot. A 5-milliliter aliquot was withdrawn from each sample using a bulb pipette and transferred to a counting wheel. Specimens from each aliquot were counted, identified to the lowest taxonomic level possible (most to species level), and measured to the nearest 0.01 millimeter using a dissecting microscope and an image analysis system. Densities (#/liter), biomass (µg/L), percent composition by number and weight, mean length (millimeter), mean weight (µg) and total counts for each taxonomic group identified were calculated with the zooplankton counting program ZCOUNT (Charpentier and Jamnick 1994 in Hirsch 2009).

Results and Discussion

Fisheries Assessment

MDNR fisheries managers utilize netting survey information to assess the status of fish communities and measure the efficacy of management programs. Presence, absence, abundance, physical condition of captured fishes, and community relationships among fish species within survey catch information also provide good indicators of current habitat conditions and trophic state of a lake (Schupp and Wilson, 1993). These data are stored in a long-term fisheries survey database, which has proven valuable in qualifying and quantifying changes in environmental and fisheries characteristics over time.

Despite its tendency to periodically winterkill, Red Sand Lake’s fish community is of average diversity when compared with other lakes of similar productivity and probably better than average compared with other lakes that frequently winterkill (Table 3). In 2008 and 2009, survey crews assessed the “biotic integrity” of the fish community in Red Sand Lake (Drake and Pereira 2002). Indices of biotic integrity (IBI) have been used for decades across North America to assess status of aquatic communities and to classify biotic impairments (Angermeier and Karr 1994). Although formal criteria have yet to be developed for classifying biotic impairments in Minnesota lakes, IBI surveys from over 325 lakes across the state provide a good assessment of the range of conditions we might expect in lakes of differing productivity. IBI surveys conducted in Red Sand Lake in 2008 and 2009 were close to the state median when compared with other lakes of similar productivity (score = 70 and 66 respectively). The least darter (*Etheostoma microperca*) is a state-listed species of greatest conservation need, and one individual was sampled in 2008.

Table 3. Fish species, guilds, and tolerances sampled over the history of fisheries surveys on Red Sand Lake. Thermal tolerances are from Lyons (2009) and environmental tolerances from Drake and Pereira (2002).

Common name	Species name	Trophic guild	Thermal guild	Environmental tolerance	First documented
Northern pike	*Esox lucius*	Predator	Cool	Neutral	1949
Black crappie	*Pomoxis nigromaculatus*	Predator	Warm	Neutral	2008
Walleye	*Sander vitreus*	Predator	Cool-warm	Neutral	1986
Bowfin	*Amia calva*	Predator	Warm	Neutral	2008
Largemouth bass	*Micropterus salmoides*	Predator	Warm	Neutral	1949
Brown bullhead	*Ameiurus nebulosus*	Omnivore	Warm	Neutral	1949
Black bullhead	*Ameiurus melas*	Omnivore	Warm	Tolerant	1986
Yellow bullhead	*Ameiurus natalis*	Omnivore	Warm	Neutral	1986
Iowa darter	*Etheostoma exile*	Insectivore	Warm	Intolerant	2008
Banded killifish	*Fundulus diaphanous*	Insectivore	Cool-warm	Intolerant	1949
Central mudminnow	*Umbra limi*	Insectivore	Cool-warm	Neutral	2008
Yellow perch	*Perca flavescens*	Insectivore	Cool-warm	Neutral	1949
Bluegill sunfish	*Lepomis macrochirus*	Insectivore	Warm	Neutral	1949
Golden shiner	*Notemigonus crysoleucas*	Insectivore	Warm	Neutral	2008
Hybrid sunfish	*Lepomis sp.*	Insectivore	Warm	Neutral	1949
Least darter	*Etheostoma microperca*	Insectivore	Warm	Intolerant	2008
Pumpkinseed sunfish	*Lepomis gibbosus*	Insectivore	Warm	Neutral	1949

Past management activities have included removal of a variety of species in the late 1940's and 1950's. Northern pike (*Esox lucius*) and "sunfish" were stocked until 1971. Since 1973, walleye (*Sander vitreus*) stocking has been conducted, primarily after winterkill events.

See Figure 10 for summaries of net catches of major fish species over the surveyed history of Red Sand Lake. Net catches and electrofishing in 2008 indicated that all species that were present prior to the winter of 2007-08 survived in low to moderate numbers. In ice-out trap nets, walleyes were not sampled until spring of 2009. Since the abundance of adult walleyes was severely reduced by the winterkill event in 2007-08, this result was not surprising. The lake management plan prescribes walleye stocking after winterkill events. Test netting has not been done on a regular enough basis to document the success of this program. Anecdotal information, however, suggests that if there is a long enough interval between winterkill events there is a significant amount of angling pressure on the lake.

Ice-out trap netting, targeting adult northern pike, confirmed good survival of this species. Numbers sampled and average size increased in 2009 compared to 2008. Proportionately, bowfin (*Amia calva)*, brown bullhead (*Ameiurus nebulosus*) and black crappie (*Pomoxis nigromaculatus*) were sampled in greater abundance from ice-out nets in 2009 than was northern pike.

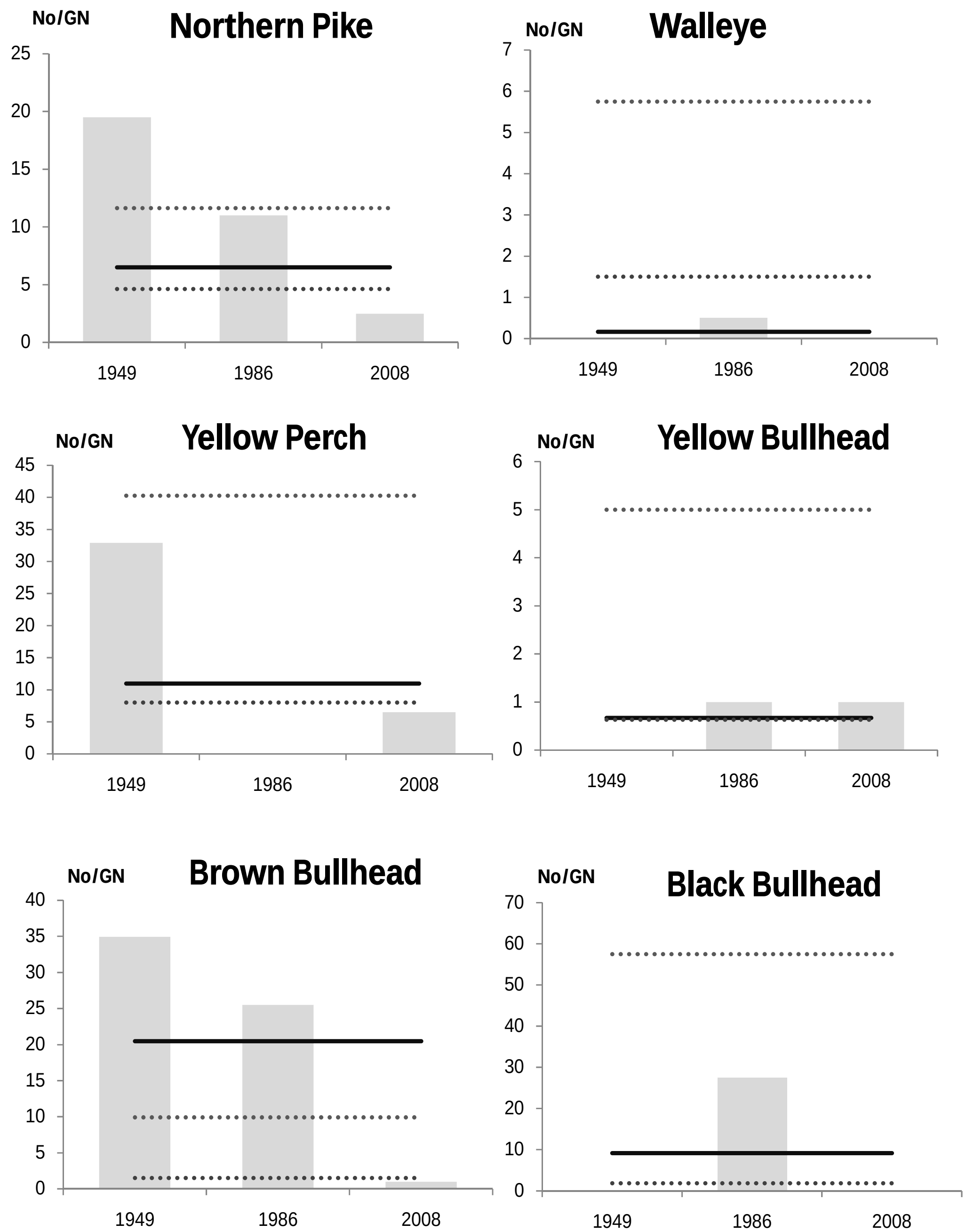
Spring electrofishing targeted largemouth bass (*Micropterus salmoides*). The 2009 catch was three fish, all of yearling size, compared to a 2008 catch of two fish, both nine inches in length. The two largemouth bass sampled in summer, 2009 trap nets were also of yearling size.

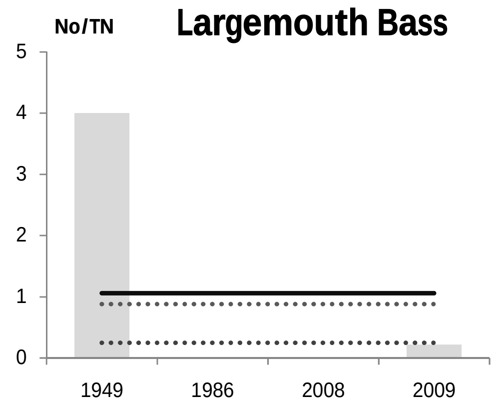
Summer trap netting (TN) samples were fairly similar between 2008 and 2009, both in catch per net of individual species and in number of species present. In 2009, pumpkinseed (5.11/TN) was most abundant, followed by bowfin (3.22/TN) and bluegill (2.33/TN). Other species were sampled at a rate of 1.0/TN or less. The 2008 sample consisted primarily of bowfin (23.61/TN), northern pike (4.71/TN) and brown bullhead (2.31/TN). The largest changes between 2008 and 2009 samples were decreases in the catch rates for bowfin and northern pike, and modest increases in pumpkinseed (*Lepomis gibbosus*) and bluegill (*Lepomis macrochirus*) catches. Yellow perch (*Perca flavescens*) and largemouth bass were sampled in summer trap nets in 2009 but not in 2008. Brown bullhead was sampled in 2008, but not in 2009.

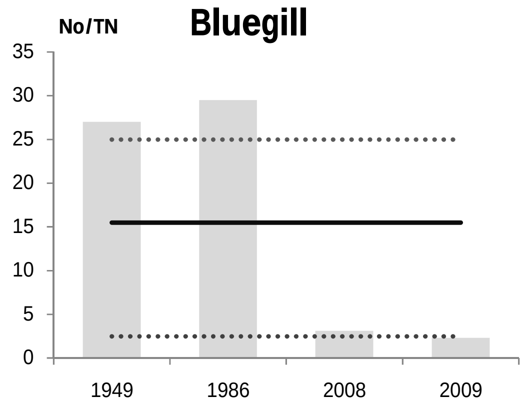
Compared to lake class quartile values, the 2009 summer trap net catches of black and yellow (*Ameiurus natalis*) bullhead were in the "low" category, the bowfin catch was in the "high" category, and other species fell into the "average" category. Catch rates for most species, generally, were in a range to be expected following a winterkill event. Walleyes and centrarchid species were most severely affected. The major exception was that pumpkinseed numbers appeared higher than would normally be expected. Northern pike numbers in spring trap nets remained strong. Another rather unexpected occurrence was the relatively low catch rate of bullhead species. Both brown and yellow bullheads dominated in Red Sand Lake prior to the winterkill event of 2007-08. Both of these species were severely reduced in this event, but maintained their relative superiority, compared to the number of black bullheads.

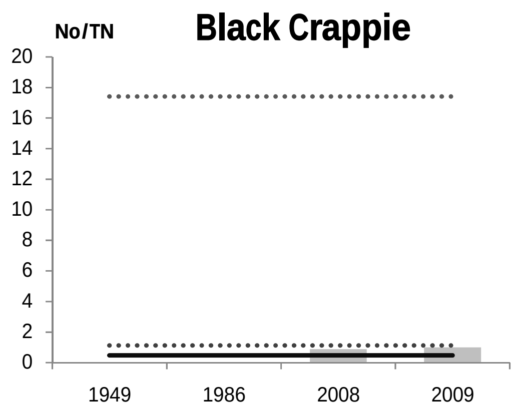
The current lake management plan has a long-range goal of maintaining bluegills at about 15 fish/TN, northern pike at about 5 fish/gill net and largemouth bass at 25 fish per hour of electrofishing. Achievement of those goals is frequently confounded by winterkill events of varying severity. Operational plans include periodic winter oxygen testing and stocking of 400,000 walleye fry after observed winterkill events, most recently in the spring of 2008.

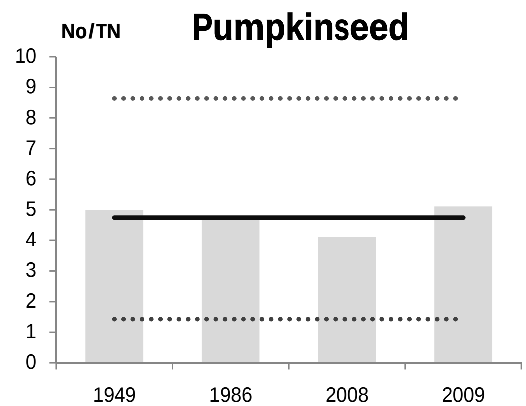
Figure 10. Historical net catches by species for Red Sand Lake and historical interquartile ranges for lake class 39. Dashed lines are median catches for lakes in Red Sand Lake's lake class (39). Solid lines are the historical average for the lake.

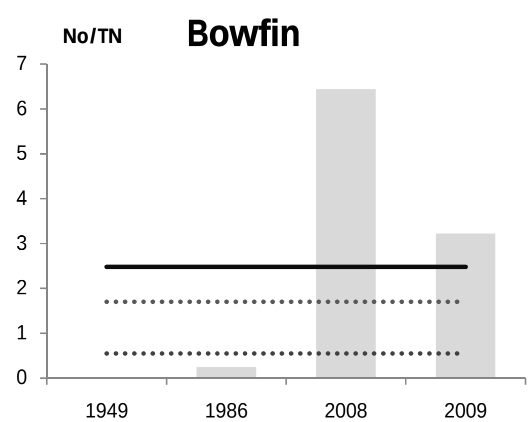



No/TN
Largemouth Bass
5
4
3
2
1
0
1949
1986
2008
2009


No/TN
Bluegill
35
30
25
20
15
10
5
0
1949
1986
2008
2009


No/TN
Black Crappie
20
18
16
14
12
10
8
6
4
2
0
1949
1986
2008
2009


No/TN
Pumpkinseed
10
9
8
7
6
5
4
3
2
1
0
1949
1986
2008
2009


No/TN
Bowfin
7
6
5
4
3
2
1
0
1949
1986
2008
2009

Aquatic Plant Assessment

Aquatic plants were qualitatively assessed during fisheries surveys in 1948 and 1986 (Table 4). In 2008 and 2009, detailed quantitative surveys of vegetation cover were conducted as part of the SLICE suite of lake surveys. Natural inter-annual variability in plant attributes across the years 2008 - 2011will be evaluated for most Sentinel lakes.

It's difficult to conclude with any certainty whether aquatic plant communities have changed appreciably since 1948, but the lack of commonalities between qualitative surveys in 1949 and 1986 (save for yellow water lily) suggests this possibility (Table 4). Comparing qualitative surveys in 1986 with more recent quantitative surveys suggest less change in the aquatic plant community in recent decades.

Emergent plants

The north shore has the lowest density of emergent plants, but sparse plants occur along the entire shoreline. Patches of hardstem bulrush (*Scirpus acutus*), wild rice (*Zizania palustris)*, narrow-leaf cattail (*Typha angustifolia)*, and arrowhead (*Sagittaria latifolia*) are common. Spikerush and three-square bulrush (*Scirpus americanus*) also occur, along with an occasional wetland plant (purple loosestrife, jewelweed, vervain). Most emergent plants occur within 15 meters (50 feet) from shore.

The east shore is dominated by narrow-leaf cattail near-shore in depths of 0-0.6 meters (0-2 feet) and hardstem bulrush in depths of 0.6-1.2 meters (2-4 feet). Other species occurring in this area are; spikerush and arrowhead species scattered in 0.3-0.9 meters (1-3) feet, small patches of needlerush (*Eleocharis)* and sedge (*Carex*) species in 0.3-0.6 meters (1-2 feet) of water, few individuals of wetland species (mint, vervain, reed canary grass). Substrate in this area is sandy. Dense emergent plants typically extend 15-30 meters (50 – 100 feet) from shore with some areas extending into the lake 91 meters (300 feet) or more.

The south shore includes two distinct areas. The bay in the far southwest corner of the lake is shallow with a mucky substrate. Narrow-leaf cattail rings the bay in 0-0.6 meters (0-2 foot) of water and wild rice is sparsely scattered. Some purple loosestrife (*Lythrum salicaria*) also occurs in this bay. The point that extends to the north east from the southern shore has a sandy substrate that is dominated by narrow-leaf cattail in 0-0.6 meters (0-2) feet of water. A large stand of hardstem bulrush extends to the north and east in 0.6-1.2 meters (2-4 feet) of water. Wild rice, arrowhead species, and spikerush are found scattered in this area. The only *Phragmites* found in the lake also occurs on this sandy point.

The southwest shore is generally sandy and is dominated by hardstem bulrush and a second large stand extends to the northeast along this shoreline. Spikerush and arrowhead species were also commonly found in this area. Patches of needlerush, three-square bulrush, and sedge species also occurred along this shoreline as well as some three-way sedge. Emergent plants commonly occur from shore out 15-46 meters (50 – 150) feet from shore.

The northwest portion of the lake has a mucky bottom that is dominated by wild rice in water 0.6-1.5 meters (2-5 feet) deep, often growing out from shore 152 meters (500 feet) or more. Narrow-leaf cattail and arrowhead species are also common near the shoreline. Sedges and wetland species also occur in this area. This portion of the lake has the least amount of hardstem bulrush.

Submersed plants

The aquatic plant community in Red Sand Lake is modestly diverse with 7 – 8 species occurring at frequencies greater than 10% over the entire basin (Table 5, Fig 11). Shallow areas of the western bay were most diverse based on 2008 data with an average of five species co-occurring in this 2.4 hectare (6 acre) area (Figure 11). A small, 4.3 meter (14 foot) hole near the east shore is the only bottom area not covered by aquatic plants. Coontail (*Ceratophyllum demersum*), Robbins' pondweed (*Potamogeton robbinsii*), flat-stem pondweed (*Potamogeton zosteriformis*), Canada waterweed (*Elodea canadensis*),

and bushy pondweed (*Najas flexilis*) are common throughout the littoral zone. A comparison between 2008 and 2009 surveys demonstrates qualitatively similar patterns in species frequency. Additional surveys in Red Sand Lake in 2010 and 2011 compared across repeated surveys in all sentinel lakes will help researchers determine how much aquatic plants naturally vary from year to year and to separate natural 'noise' from a disturbance signal.

Curly-leaf pondweed
In 2008, the invasive curly-leaf pondweed (*Potamogeton crispus*) was first noted at low abundance (Table 5). Curly-leaf pondweed is a non-native invasive submerged aquatic plant that is widespread throughout the southern part of the state. The exact date of introduction into Minnesota is unknown, but it is believed to have been present in Minnesota lakes since the early 1900's when carp were brought into the state. Curly-leaf pondweed grows most abundantly during early spring and senesces by mid-summer. When curly-leaf pondweed is abundant, mid-summer diebacks often promote algae blooms which limit light penetration for native aquatic plants.

Curly-leaf pondweed thrives in nutrient-rich conditions and at some threshold of nutrient levels (exact quantity unknown), can become a self-sustaining internal driver of poor water quality conditions. These self-perpetuating conditions of curly-leaf booms followed by large summer die-offs and algae blooms are most common in eutrophic to hypereutrophic lakes in the southern half of the state. In northern mesotrophic lakes with abundant native aquatic plants, curly-leaf pondweed is less abundant and typically is integrated with other aquatic plants. Because the plant needs to photosynthesize during winter, curly-leaf pondweed is sensitive to long periods of snow and ice cover on lakes. Reduced snow and ice cover due to climate change may favor increases in this plants abundance in infested lakes and latitudinal range of viability. With shorter-winters, curly-leaf pondweed may become more abundant over time in Red Sand Lake; however, the plant may not grow to nuisance levels as long as nutrient levels in Red Sand Lake are kept at or below current levels and native aquatic plants are protected.

Local human impacts on aquatic plant communities
Approximately 50 dock structures were enumerated from aerial photos acquired from the Farm Service Administration in summer 2008 (1 dock for every 147 meters of shoreline). By rule, lakeshore owners are allowed to remove a 232 square meter (2500 square foot) area of submersed aquatic plants without a permit. If we assumed that all who owned a dock also removed 232 square meter (2500 square foot) of aquatic plants, then the lakeshore owners have the option to remove up to 1.2 hectare (2.9 acres) aquatic plants (0.5% of the area of vegetation growth) without a permit. The actual amount of plant removal is probably less. Permits are needed for chemical treatments, removal of floating-leaf or emergent vegetation, automated unattended plant removal devices (e.g., "weed rollers"), or removal greater than the allotted without a permit. Permitted destruction of aquatic plants has varied over time in Red Sand Lake but has overall, been relatively low (Figure 11) Although plant removal in Red Sand Lake is probably not biologically significant from a fish habitat standpoint currently, the cumulative effects of vegetation removal has been detrimental to fish habitat in more developed areas of Minnesota. Further, impacts in sensitive areas of lakes such as shallow bays may have disproportionately harmful effects than other areas where shorelines and bottoms are more stable. The diversely vegetated shallow western bay of Red Sand Lake is an area where efforts will be need to be made to minimize aquatic plant removal.

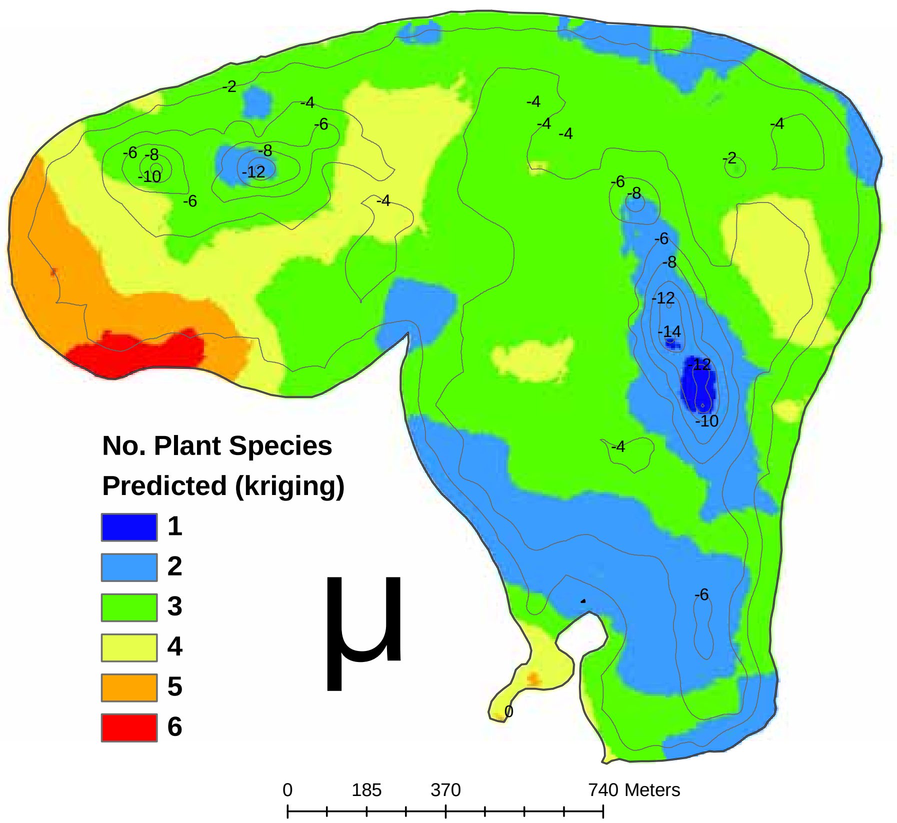
Table 4. Common species sampled during past lake vegetation surveys
Species were deemed common if they were either noted as “common” or “abundant” in past Fisheries surveys.

Date	Common Name	Species Name	Growth Form
6/23/1949	Northern watermilfoil	*Myriophyllum sibiricum*	Submersed
	Yellow waterlily	*Nuphar variegatum*	Floating leaf
	White waterlily	*Nymphaea odorata*	Floating leaf
	Small pondweed	*Potamogeton pusillus*	Submersed
	Muskgrass	*Chara sp.*	Submersed
	Flatstem pondweed	*Potamogeton zosteriformis*	Submersed
	Sago pondweed	*Stuckenia pectinatus*	Submersed
6/18/1986	Softstem bulrush	*Scirpus validus*	Emergent
	Narrow-leaved cattail	*Typha angustifolia*	Emergent
	Yellow waterlily	*Nuphar variegatum*	Floating leaf
	Canada waterweed	*Elodea canadensis*	Submersed
	Large-leaf pondweed	*Potamogeton amplifolius*	Submersed
	Coontail	*Ceratophyllum demersum*	Submersed

Table 5. Percent frequency of aquatic plants in Red Sand Lake sampled on August 2008 and 2009

Common Name	Scientific Name	Growth Form	Frequency (%) 2008	2009
All rooted plants			99.0	98.3
Coontail	*Ceratophyllum demersum*	Submerged	58.8	40.2
Robbins' Pondweed	*Potamogeton robbinsii*	Submerged	58.5	49.4
Flat-stem Pondweed	*Potamogeton zosteriformis*	Submerged	45.2	18.2
Canada Waterweed	*Elodea canadensis*	Submerged	39.8	31.8
Bushy Pondweed	*Najas flexilis*	Submerged	34.4	32.1
White-stem Pondweed	*Potamogeton praelongus*	Submerged	15.1	21.5
Hardstem Bulrush	*Scirpus acutus*	Emergent	12.8	12.0
Large-leaf Pondweed	*Potamogeton amplifolius*	Submerged	11.9	3.1
Straight-leaf Pondweed	*Potamogeton strictifolius*	Submerged	9.4	6.7
Wild Rice	*Zizania palustris*	Emergent	8.2	8.4
White Water lily	*Nymphaea odorata*	Floating-leaf	7.4	8.9
Narrow-leaf Cattail	*Typha angustifolia*	Emergent	6.8	6.4
Northern Water milfoil	*Myriophyllum sibiricum*	Submerged	6.3	5.9
Muskgrass	*Chara sp.*	Submerged	5.1	4.2
Common Bladderwort	*Utricularia vulgaris*	Submerged	4.5	2.5
Watershield	*Brasenia schreberi*	Floating-leaf	3.7	4.7
Needle rush group	*Eleocharis sp.*	Submersed	3.1	1.1
Filamentous Algae			3.1	3.1
Broad-leaved Arrowhead	*Sagittaria latifolia*	Emergent	3.1	0.6
Spike rush group	*Eleocharis sp.*	Emergent	2.8	2.8
Water Marigold	*Bidens beckii*	Submerged	2.6	2.2
Illinois Pondweed	*Potamogeton illinoensis*	Submerged	2.6	2.2
Yellow Water lily	*Nuphar variegata*	Floating-leaf	2.0	2.2
Floating-leaf Pondweed	*Potamogeton natans*	Submerged	2.0	1.1
Stonewort	*Nitella sp.*	Submerged	1.7	0.3
Clasping-leaf Pondweed	*Potamogeton richardsonii*	Submerged	1.7	0.3
Three-square Bulrush	*Scirpus pungens*	Emergent	1.4	0.3
Sago Pondweed	*Potamogeton pectinatus*	Submerged	1.1	0
Narrow-leaf Burreed	*Sparganium angustifolia*	Emergent	1.1	0
Wild Celery	*Vallisneria americana*	Submerged	0.9	2.5
Lesser Duckweed	*Lemna minor*	Free-floating	0.6	0.3
Purple Loosestrife	*Lythrum salicaria*	Emergent	0.6	0.3
Variable-leaf Pondweed	*Potamogeton gramineus*	Submerged	0.6	1.4
Fries' Pondweed	*Potamogeton friesii*	Submerged	0.6	4.5
Blue Vervain	*Verbena sp.*	Wetland	0.6	0.6
Sedge group	*Carex sp.*	Emergent	0.3	1.4
Three-way Sedge	*Dulichium arundinaceum*	Emergent	0.3	0.3
Jewelweed	*Impatiens capensis*	Wetland	0.3	0.3
Curly-leaf Pondweed	*Potamogeton crispus*	Submerged	0.3	0.8
Cane	*Phragmites australis*	Emergent	0.3	0.3
Arrowhead group	*Sagittaria sp.*	Emergent	0.3	2.0
Water Bulrush	*Scirpus subterminalis*	Submerged	0.3	0.3
Broad-leaved Cattail	*Typha latifolia*	Emergent	0.3	0
Water smartweed	*Polygonum amphibium*	Floating-leaf	0	1.4

Figure 11. Aquatic plant cover and diversity in 2008 predicted using indicator kriging interpolation of point-intercept survey data (Isaaks and Srivastava, 1989)



Water Quality

Standard summer-mean water quality data for 2008 are presented in Table 6, and raw data results are provided in Appendix B. In addition, major cations, anions, and total organic carbon were analyzed on three sample dates, and those values and typical ranges as derived from the National Lakes Assessment (NLA) database for Minnesota are summarized in Table 7. The NLA was a statistically-based survey of the nations lakes administered by the United States Environmental Protection Agency in 2007. The typical range provided in Table 7 is based on 64 Minnesota lakes that were included in that NLA study and is intended to provide a regional perspective.

Table 6. Red Sand Lake 2008 summer mean (June to September) water quality
Typical range based on 30 NLF ecoregion reference lakes (Heiskary and Wilson 2005) noted for comparison.

Parameter	Red Sand Lake	NLF
Total phosphorus (µg/L)	23	14 - 27
Chlorophyll mean (µg/L)	3.7	4 - 10
Chlorophyll max (µg/L)	8	<15
Secchi disk (feet) (meters)	10.8 3.3	8 – 15 2.4 – 4.6
Total Kjeldahl Nitrogen (mg/L)	0.84	<0.4 – 0.75
Alkalinity (mg/L)	55	40 - 140
Color (Pt-Co Units)	5	10 - 35
pH (SU)	8.9	7.2 – 8.3
Chloride (mg/L)	12.7	0.6 – 1.2
Total suspended solids (mg/L)	1.2	<1 - 2
Total suspended inorganic solids (mg/L)	1.2	<1 - 2
Conductivity (µmhos/cm)	163	50 - 250
Total nitrogen : Total phosphorus ratio	36:1	25:1 - 35:1

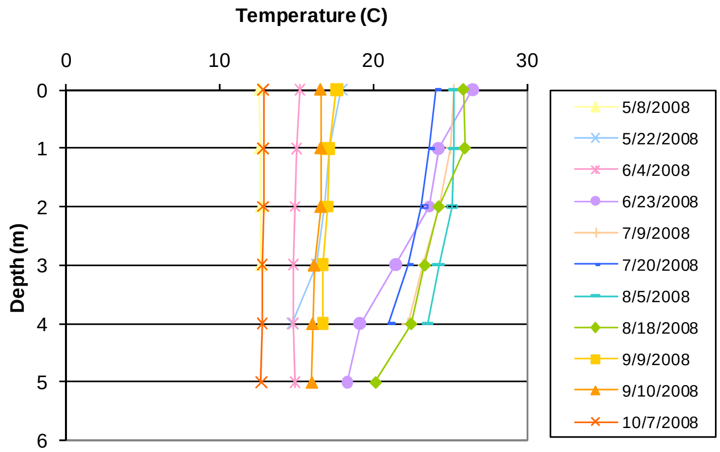
Table 7. Red Sand Lake cation, anion, and total organic carbon measurements
NLA typical range provided as a basis for comparison. Microequivalents (µeq/L) based on average value.

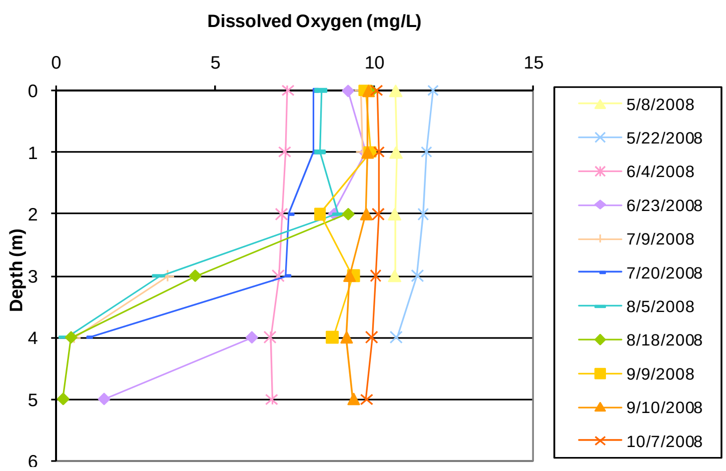
Date	Ca[1] mg/L	Mg mg/L	Na mg/L	K mg/L	Alk mg/L	SO_4 mg/L	Cl mg/L	TOC mg/L
5/8/2008	22.4	5.6	8.8	1.4	79	< 1.0	12.3	6.1
7/16/2008	13.2	5.6	9.4	< 0.3	55	< 1.0	12.7	8.2
10/7/2008	20.4	6.5	10.0	1.4	80	< 1.0	14.0	8.9
Average	18.8	5.9	9.4	1.4	71	< 1.0	12.1	7.7
µeq/L	938	485	409	36	1420	28	252	--
NLA IQ range (mg/L)	19.1 – 33.7	6.7 – 26.9	2.2 – 9.0	0.9 – 4.8		2.2 – 14.0	1.5 – 18.4	7.3 – 14.2

1. Ion concentrations expressed as element (e.g. Ca as Ca)

Dissolved oxygen and temperature profiles were taken twice per month at either site 201 or 101 (Figure 12). The lake is well mixed and weakly stratifies during calm periods. Surface temperatures peaked at 26 C° in late June. Below a depth of approximately 3 meters during the mid-summer months, dissolved oxygen dropped below 5 milligrams per liter (mg/L) and temperature declined slightly with depth. The majority of the lake is less than 2 meters deep and had sufficient oxygen to sustain game fish.

Figure 12. Red Sand Lake 2008 dissolved oxygen and temperature





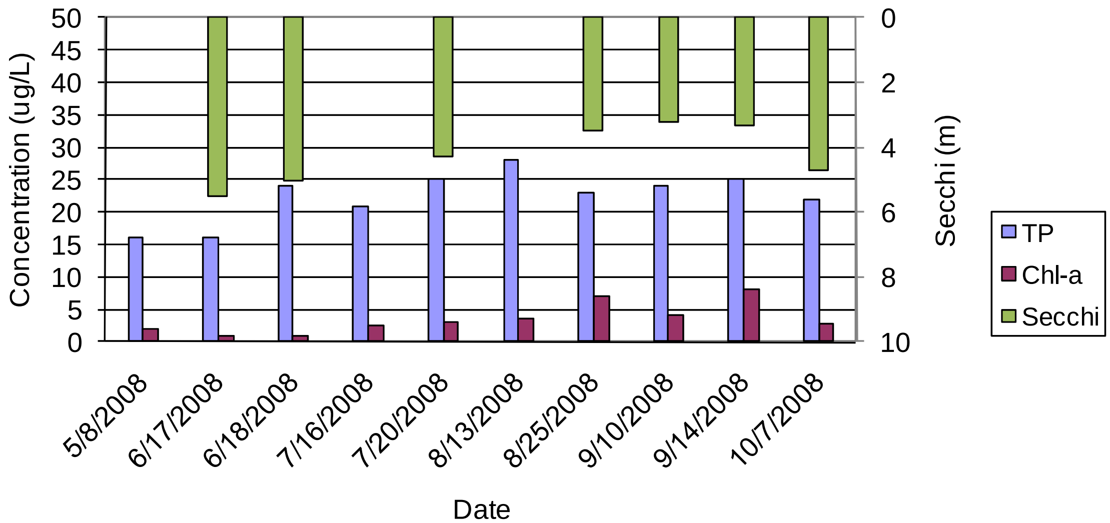
Total phosphorus concentrations in Red Sand Lake averaged 23 micrograms per liter (µg/L) (Figure 13). This is on the high end of the typical range for reference lakes in the NLF ecoregion. TP concentrations increased across the summer reaching a maximum value in mid-August (28 µg/L). Nitrogen, measured as total Kjeldahl nitrogen, a primary nutrient required for algal and plant growth, was slightly above the typical range for NLF lakes (Table 6).

Both external (watershed) and internal (sediments, plants, fish) sources can contribute to elevated TP in lakes. The pattern of increasing TP from June through August in Red Sand Lake is consistent with other shallow lakes in Minnesota; however, the magnitude of the increase is much less than what is observed in more eutrophic lakes. While there was some significant precipitation in June and July, late July and August were very dry (Figure 7). Runoff from precipitation is often a significant source of nutrient input to a lake; however, the highest TP concentrations were observed in the driest month. This increase is often due to internal recycling of nutrients from the bottom sediments. This coincides with increasing water temperatures (typically 20 C° and above) and/or aquatic plant senescence.

Chlorophyll-*a* concentrations provide an estimate of the amount of algal production in a lake. During summer 2008, chl-*a* concentrations averaged 3.7 µg/L, reaching a peak of 8 µg/L in late September (Figure 13). This is below the typical range for NLF reference lakes (Table 6). The lake is dominated by a dense submergent plant community; it is likely that available phosphorus is tied up in the rooted plant

community. It is noted that the highest chl-*a* concentrations occurred after the peak of TP in mid-August. In August and September, rooted aquatic vegetation began to senesce; which, upon decomposition, provides nutrients for increased algal production.

Figure 13. Red Sand Lake 2008 total phosphorus, chlorophyll-*a* concentrations, & Secchi depth



Secchi disk transparency averaged 3.7 meters (12 feet) in 2008. This is within the typical range of NLF reference lakes. Transparency corresponded well to TP and chl-*a* concentrations; declining across the summer and recovering in September (Figure 13). An earlier recovery would be expected based on declining TP in August; however, the chl-*a* increased at that time as algae increased likely due to rooted plant senescence. Measurements that exceeded the depth of the lake were not included in the graph (i.e. the disk was visible when resting on the lake sediment).

Dissolved minerals and organic carbon were measured in 2008 as part of the long-term monitoring of Red Sand Lake and other Sentinel lakes. This includes some of the standard lake assessment measures of total suspended solids (TSS), alkalinity, conductivity and color (Table 6), as well as major cations, anions, and organic carbon (Table 7). While several of these parameters have “typical” ecoregion-based concentrations (e.g. Table 6); some do not. For parameters without ecoregion–based comparisons data from the 2007, National Lakes Assessment (NLA) study were used to provide perspective on reported concentrations (Table 7). Since the NLA lakes were selected randomly they provide a reasonable basis for describing typical ranges and distributions at the state-wide level.

TSS is quite low and consistent with the typical range for NLF reference lakes (Table 6) and most of the TSS can be attributed to inorganic SS. The low color value (Table 6) indicates the water is clear and has minimal amount of total organic carbon (TOC) (Table 7). Lakes that receive a majority of their water inputs from forest and wetland runoff often have correspondingly higher color and TOC values as a result of incompletely dissolved organic matter (plants, leaves, and other organic material).

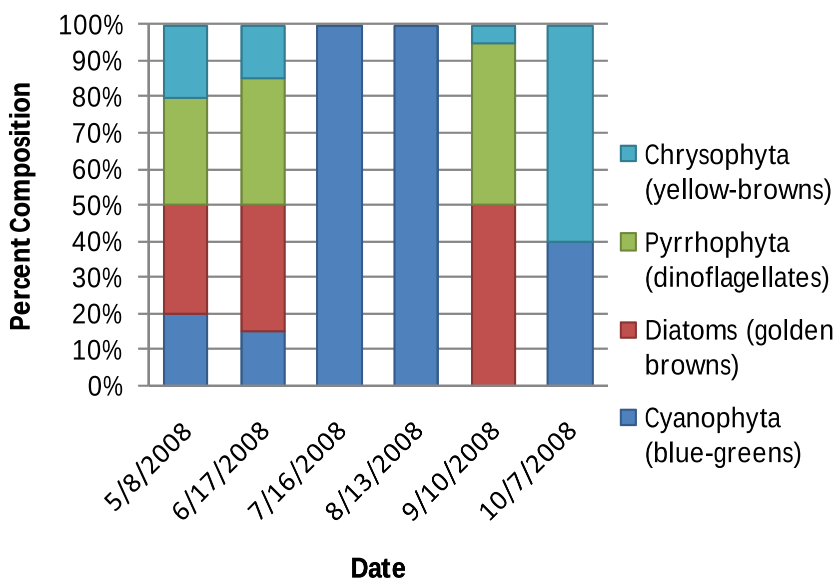
Alkalinity and conductivity are in the typical range for NLF lakes and are indicative of moderately hard water (Table 6). Calcium (Ca) and magnesium (Mg) are the dominant cations (based on ueq/L) and both are within the typical range of the statewide data (Table 7). The other two major cations – sodium (Na) and potassium (K) - are within the typical range as well, though Na is at the upper end of the range. Bicarbonate (alkalinity expressed as calcium carbonate - $CaCO_3$) is the dominant cation, followed by chloride (Cl) and sulfate (SO_4). Chloride is well above the typical range for NLF reference lakes (Table 6); but is within the typical range of the state-wide NLA data (Table 7).

Elevated Cl is most often attributed to application of road salt on roads in the watershed, though leaching from septic systems is a potential source as well. Whatever the source, it is likely responsible for the elevated Na as well. Sulfate is low relative to the NLA data (Table 7). The average cation and anion balance (cation-anions expressed as a % of cations) for 2008 was within 9%, which is well within values exhibited by the NLA lakes.

Most cation and anion concentrations, with the exception of Ca, were quite stable across sample events in 2008 (Table 7), which is consistent with the literature. Mg, Na, K and Cl are noted to be relatively conservative and undergo only minor spatial and temporal change (Wetzel 2001). Mg is required by algae to produce chlorophyll-a. Rooted plant uptake of Ca is a likely reason for the mid-summer decline in Ca (Table 7).

Phytoplankton (algae) composition was mixed throughout the summer. Typically, a transition from diatoms dominating the composition in the spring to blue-greens in the summer occurs. Diatoms and dinoflagellates were the most common forms in May and June (Figure 14). Blue-greens comprised the entire sample in July and August (Figure 14). It should be noted that the algae population was quite low; the water was clear and chl-*a* values were low. No algal blooms were noted. Diatoms, dinoflagellates and yellow-browns were common in September and October. Again, rooted aquatic vegetation dominates the lake and likely contributed to the low chl-*a* values.

Figure 14. Algal composition for Red Sand Lake in 2008



Zooplankton

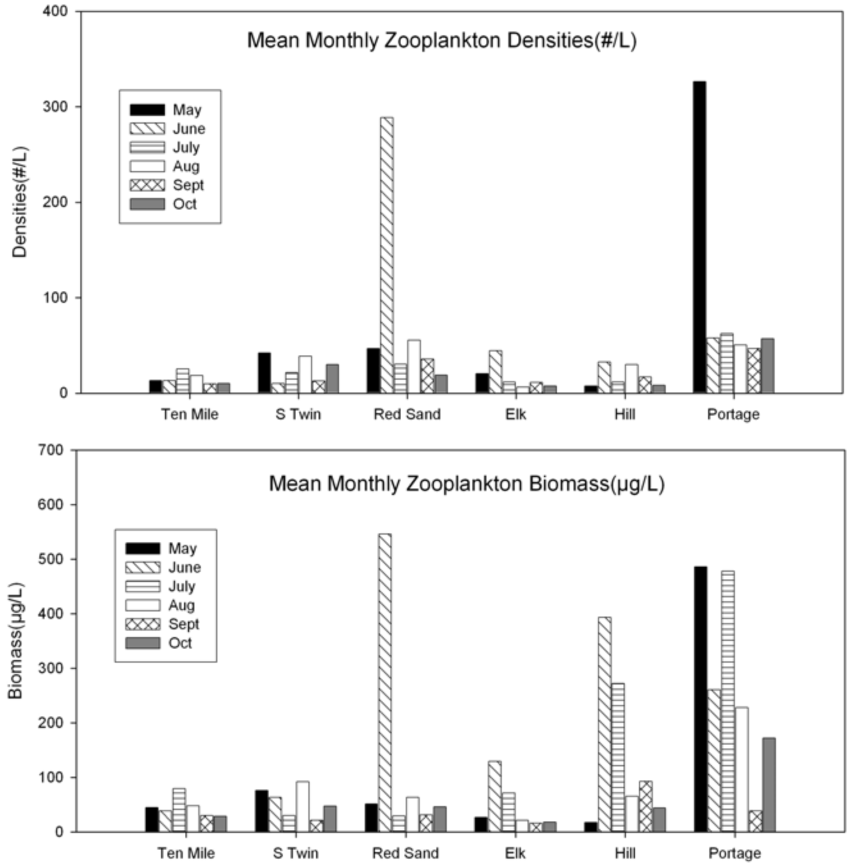
Zooplankton samples were analyzed by Jodie Hirsch at the MDNR. A summary report was prepared that included information for all the Sentinel lakes and that report (Hirsch 2009) is the basis for the following comments on Red Sand Lake.

Red Sand Lake had the highest number of taxa (18) observed in the 2008 season (Table 8). The June sample had both the highest density and biomass across the sampling period; a five-fold difference from all other sampling dates. Hirsch (2009) found that, in general, as lake productivity increased (e.g. TP or chl-*a*) the relative abundance (biomass) of zooplankton increased as well. This appears to be the case for Red Sand Lake and the other NLF lakes (Figure 15). Like most of the NLF lakes, Red Sand Lake zooplankton biomass drops off for most of the lakes following the spring pulse in early summer.

Table 8. Mean annual zooplankton densities, biomass, and total number of taxa for each Sentinel lake

Sentinel lakes zooplankton 2008	Mean annual densities (#/L)	Mean annual biomass (µg/L)	Total # taxa
Western Corn Belt Plains			
Artichoke	139.64	724.05	12
Shaokotan	107.55	1070.97	11
St. James	62.73	108.56	10
St. Olaf	60.23	336.20	15
Carrie	56.41	254.21	13
Madison	52.78	310.93	14
North Central Hardwood Forest			
Peltier	78.75	1098.39	12
Pearl	59.68	221.13	14
Belle	57.67	340.06	12
South Center	24.72	123.71	18
Carlos	19.66	73.49	16
Cedar	11.31	41.85	11
Northern Lakes and Forests			
Portage Lake	100.10	277.38	10
Red Sand	79.31	127.96	18
South Twin	25.83	54.93	12
Hill	17.73	147.29	11
Elk	16.95	47.10	12
Ten Mile	14.94	44.89	14
Border Lakes (NLF)			
Echo	37.03	89.68	12
Elephant	13.26	75.50	12
White Iron	10.00	38.64	14
Trout	6.28	29.52	13
Bearhead	5.15	38.37	14
Northern Light	1.03	4.16	13

Figure 15. Mean monthly zooplankton densities and biomass for Northern Lake and Forest Ecoregion Sentinel lakes in 2008



Trophic State Index

One way to evaluate the trophic status of a lake and to interpret the relationship between TP, chl-*a*, and Secchi disk transparency is Carlson's Trophic State Index (TSI) (Carlson 1977). TSI values are calculated as follows:

Total Phosphorus TSI (TSIP) = 14.42 ln (TP) + 4.15

Chlorophyll-*a* TSI (TSIC) = 9.81 ln (chl-*a*) + 30.6

Secchi disk TSI (TSIS) = 60 – 14.41 ln (SD)

TP and chl-*a* are in µg/L and Secchi disk is in meters. TSI values range from 0 (ultra-oligotrophic) to 100 (hypereutrophic). In this index, each increase of ten units represents a doubling of algal biomass. Comparisons of the individual TSI measures provides a bases for assessing the relationship among TP, chl-*a,* and Secchi (Figure 16). In general, the TSI values are in fairly close correspondence with each other. The TSI values also correspond with observations for 2008. Based on an average TSI score of 45, Red Sand Lake would be characterized as mesotrophic.

Trophic Status Trends

One aspect of lake monitoring is to assess trends in the condition of the lakes, where possible, based on data gathered through the MPCA's Citizen Lake Monitoring Program or other available data in STORET. A review of data in STORET indicates there is a good amount of data for Red Sand Lake to describe annual variability and to statistically assess trends. In general, for trend assessment we seek a minimum of eight years of consistent data. During the most recent trend analysis completed using Citizen Lake Monitoring Program Secchi data, it was determined that Red Sand Lake appeared to be experiencing improving transparency, estimated at 0.6 meter (2 feet) per decade. Based on yearly TSI averages calculated for 2001 through 2009, Red Sand Lake has historically been classified as mesotrophic (Figure 17).

Individual summer-mean TP, chl-*a*, and Secchi data can provide further insight into trends and variability (Figure 18 and 19). The long-term average TP for Red Sand Lake is 24 ± 3 µg/L. The standard error, expressed as a percent of the long-term mean, represents the coefficient of variation (CV) of the mean. For Red Sand Lake the CV equals 12 percent, which is fairly typical for Minnesota lakes (Heiskary et al. 1994). The long-term average chl-*a* for Red Sand Lake is 3.9 ± 1.2 µg/L, with a CV of 31 percent. This suggests that chl-*a* has experienced considerable year to year variation; however, because chl-*a* is so low, minor changes result in a large percent change. Of note, 2007 had extremely low values of chl-*a* measured; all other years are quite similar to each other. The long-term average Secchi is 3.4 ± 0.3 m (Figure 19). The CV for Red Sand Lake Secchi is 9 percent. It should be noted that in 2009, two of the Secchi readings were limited by depth of the lake at the sampling point; this would result in a lower average Secchi value to be calculated.

Based on precipitation records from 1956 to 2008, mean annual precipitation measured within Baxter is nearly 56 centimeters (22 inches) with a slight increase in precipitation over the period (Figure 9). In 2003 and 2006, the area experienced below average rainfall amounts. In 2003, the TP was quite high, exceeding the standard and typical range for lakes in the NLF ecoregion, chl-*a* was slightly elevated and the corresponding Secchi average was the lowest on record. All other years had average or above average rainfall amounts and relatively lower TP, chl-*a*, and Secchi. TP has been relatively uniform from 2005-2008; however chl-*a* has varied and Secchi varied in response to changes in chl-*a*. While this is not a conclusive analysis, it suggests precipitation and climate related factors (precipitation, evaporation, etc.) may play a role in the trophic status and trends for Red Sand Lake.

Figure 16. Carlson's Trophic State Index for Red Sand Lake

TSI < 30 Classical Oligotrophy: Clear water, oxygen throughout the year in the Hypolimnion, salmonid fisheries in deep lakes.

TSI 30 – 40 Deeper lakes still exhibit classical oligotrophy, but some shallower lakes will become anoxic in the hypolimnion during the summer.

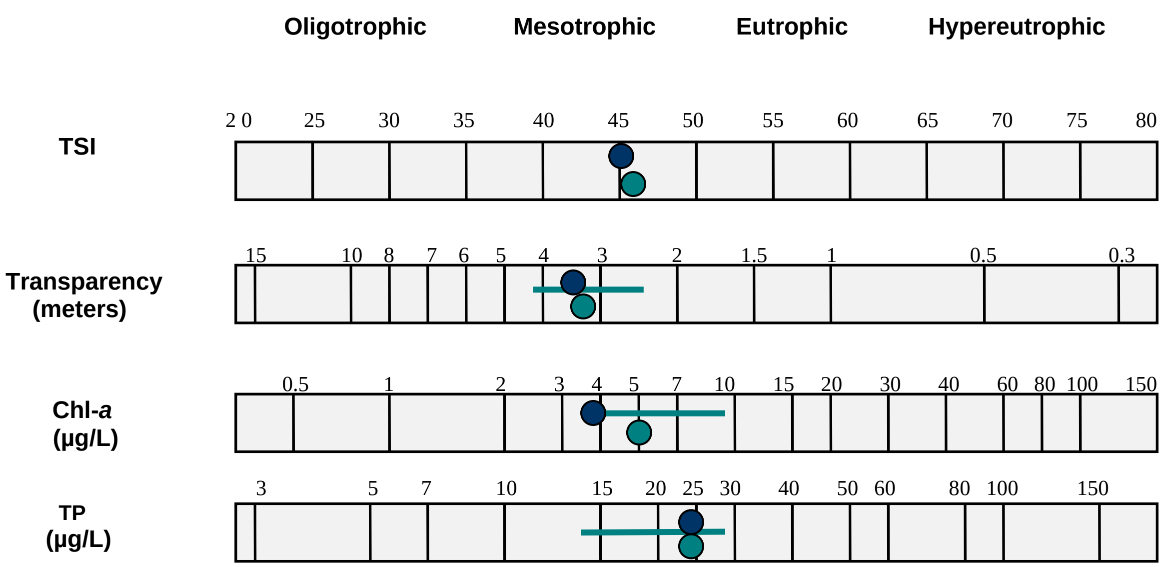
TSI 40 – 50 Water moderately clear, but increasing probability of anoxia in hypolimnion during summer.

TSI 50 – 60 Lower boundary of classical eutrophy: Decreased transparency, anoxic hypolimnia during the summer, macrophyte problems evident, warm-water fisheries only.

TSI 60 – 70 Dominance of blue-green algae, algal scums probable, extensive Macrophyte problems.

TSI 70 – 80 Heavy algal blooms possible throughout the summer, dense macrophyte beds, but extent limited by light penetration. Often would be classified as hypereutrophic.

TSI > 80 Algal scums, summer fish kills, few macrophytes, dominance of rough fish.



After Moore, l. and K. Thornton, [Ed.]1988. Lake and Reservoir Restoration Guidance Manual. USEPA>EPA 440/5-88-002.

Ecoregion Range: 2002 2008

Figure 17. Red Sand Lake trophic status trend

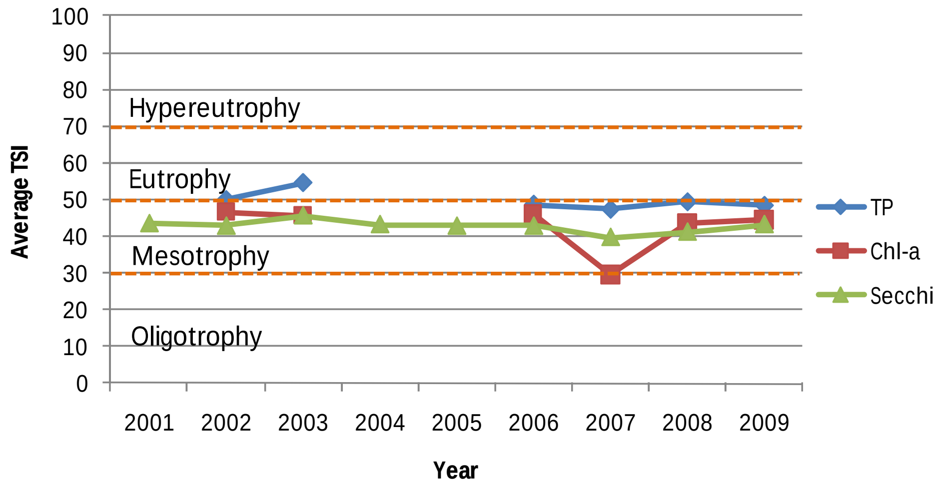


Figure 18. Red Sand Lake long-term summer-mean total phosphorus and chlorophyll-a
Long-term average indicated by dotted line; standard error of the mean noted for each year.

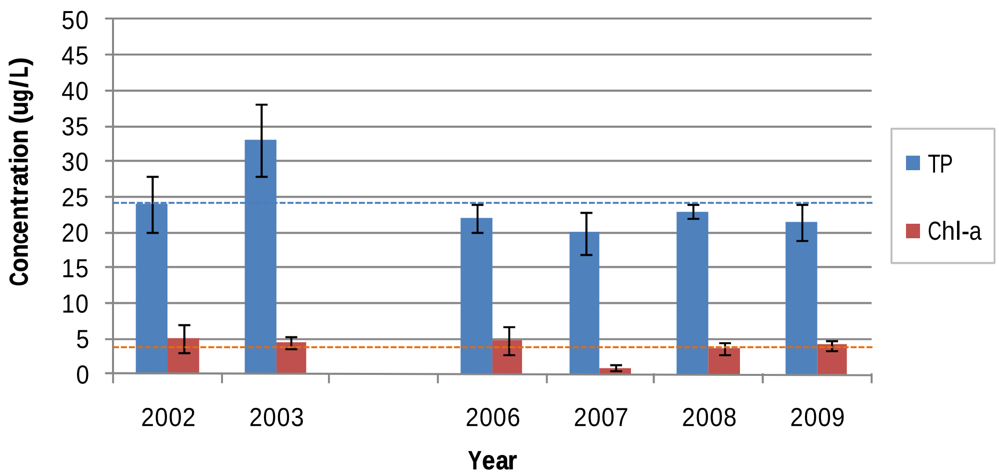
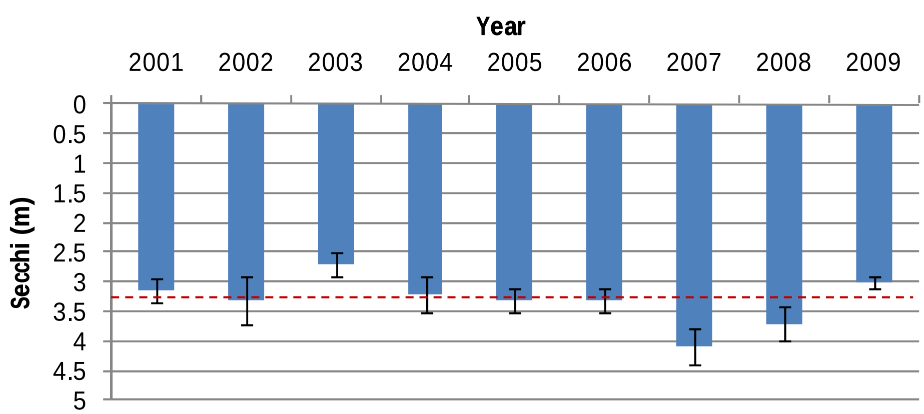


Figure 19. Red Sand Lake long-term summer-mean Secchi disk depth
Long-term mean noted by dashed red line

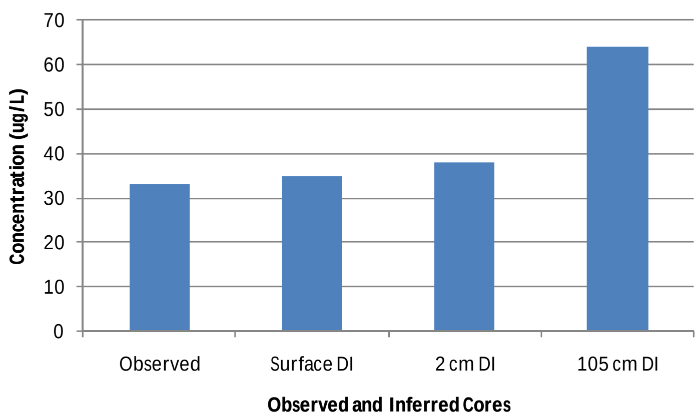


Sediment Core-based Trend Assessment

A sediment core was collected from Red Sand Lake in 2003 as a part of a MPCA and Science Museum of Minnesota study to determine pre-European TP and temporal changes in TP for nutrient criteria development (Edlund 2005). The study focused on 29 shallow lakes in west-central Minnesota. What follows is a summary of the information found in the report regarding Red Sand Lake; complete details can be found in the final report (Edlund 2005).

From the sections of core analyzed in the study, it became apparent that Red Sand Lake has undergone significant changes over time. The pre-European settlement diatom community was dominated by planktonic species. The modern community is dominated by small benthic taxa. The modern inferred TP closely matched the observed values (Figure 20). Pre-European settlement inferred TP suggested higher TP concentrations in Red Sand Lake. It should be noted that in the modern dataset, the planktonic community is not well represented (Edlund, 2005), as evidenced by the low chl-*a* concentrations (Figure 18).

Figure 20. Comparison of Red Sand Lake observed (2003) and diatom inferred total phosphorus values



Modeling

Numerous complex mathematical models are available for estimating nutrient and water budgets for lakes. These models can be used to relate the flow of water and nutrients from a lake's watershed to observed conditions in the lake. Alternatively, they may be used for estimating changes in the quality of the lake as a result of altering nutrient inputs to the lake (e.g., changing land uses in the watershed) or altering the flow or amount of water that enters the lake. To analyze the 2008 water quality of Red Sand Lake, the Minnesota Lake Eutrophication Analysis Procedures (MINLEAP) model (Wilson and Walker, 1989) was used. A comparison of MINLEAP predicted versus observed values is presented in Table 9.

MINLEAP was developed by MPCA staff based on an analysis of data collected from the ecoregion reference lakes. It is intended to be used as a screening tool for estimating lake conditions with minimal input data and is described in greater detail in Wilson and Walker (1989). The model predicts in-lake TP from these inputs and subsequently predicts chl-*a* based on a regression equation of TP and Secchi based on a regression equation based on chl-*a*. For analysis of Red Sand Lake, MINLEAP was applied as a basis for comparing the observed (2008) TP, chl-*a*, and Secchi values with those predicted by the model based on the lake size and depth and the area of the watershed.

Red Sand Lake is located in the NLF ecoregion and the model was run using NLF ecoregion-based inputs. The observed TP and chl-*a* values for Red Sand Lake are better than expected but within the standard error of the model predictions; observed Secchi is significantly better than predicted. This is likely due to the immense submergent plant community on the lake which likely binds the available phosphorus making it unavailable to algal growth. The estimate of "background" TP (Vighi & Chiaudani) is quite close to the modern-day TP for Red Sand Lake. The estimate of residence time is likely low given the limited outflow from Red Sand Lake.

Table 9. MINLEAP model results for Red Sand Lake

Parameter	2008 Red Sand Lake observed	MINLEAP predicted
TP (µg/L)	23	30
Chl-*a* (µg /L)	3.7	9.6
Secchi (m)	3.3	2.0
P loading rate (kg/yr)	-	166
P retention (%)	-	48
P inflow conc. (µg/L)	-	58
Water Load (m/yr)	-	1.41
Outflow volume (hm^3/yr)	-	2.87
Residence time (yrs)	-	0.8
Vighi & Chiaudani	-	27.5

303(d) Assessment and Goal Setting

The federal Clean Water Act requires states to adopt water quality standards to protect waters from pollution. These standards define how much of a pollutant can be in the water and still allow it to meet designated uses, such as drinking water, fishing and swimming. The standards are set on a wide range of pollutants, including bacteria, nutrients, turbidity and mercury. A water body is "impaired" if it fails to meet one or more water quality standards.

Under Section 303(d) of the Clean Water Act, the state is required to asses all waters of the state to determine if they meet water quality standards. Waters that do not meet standards (i.e., impaired waters) are added to the 303(d) list and updated every even-numbered year. In order for a lake to be considered impaired for aquatic recreation use, the average TP concentration must exceed the water quality standard for its ecoregion. In addition, either the chl-*a* concentration or the Secchi depth for the lake must exceed the standard. A minimum of eight samples collected over two or more years are needed to conduct the assessment. There are numerous other water quality standards for which we assess Minnesota's water resources. An example is mercury found in fish tissue. If a water body is listed, an investigative Total Maximum Daily Load (TMDL) study must be conducted to determine the sources and extent of pollution, and to establish pollutant reduction goals needed to restore the resource to meet the determined water quality standards for its ecoregion. The MPCA is responsible for performing assessment activities, listing impaired waters, and conducting TMDL studies in Minnesota.

Red Sand Lake is considered to be fully supporting aquatic recreation use standards (Table 10). The lake should be protected against increases in TP. This implies the importance of minimizing nonpoint source (e.g. stormwater) runoff into the lake. Also, shifts in the plant community may increase the presence of algal blooms. MDNR has confirmed the presence of curly-leaf pondweed and should curly-leaf become

dominant in the lake it could have very negative consequences for Red Sand Lake's water quality and overall ecology.

Table 10. Eutrophication standards by ecoregion and lake type (Heiskary and Wilson, 2005)

Red Sand Lake 2008 and long-term means provided for comparison.

Ecoregion	TP µg/L	Chl-*a* µg/L	Secchi meters
NLF – Lake trout (Class 2A)	< 12	< 3	> 4.8
NLF – Stream trout (Class 2A)	< 20	< 6	> 2.5
NLF – Aquatic Rec. Use (Class 2B)	< 30	< 9	> 2.0
NCHF – Stream trout (Class 2a)	< 20	< 6	> 2.5
NCHF – Aquatic Rec. Use (Class 2b)	< 40	< 14	> 1.4
NCHF – Aquatic Rec. Use (Class 2b) Shallow lakes	< 60	< 20	> 1.0
WCBP & NGP – Aquatic Rec. Use (Class 2B)	< 65	< 22	> 0.9
WCBP & NGP – Aquatic Rec. Use (Class 2b) Shallow lakes	< 90	< 30	> 0.7
Red Sand Lake 2008	**23**	**3.7**	**3.3**
Red Sand Lake long-term mean	**24**	**3.8**	**3.3**

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Appendix A

Ice-on and Ice-off Records for Red Sand Lake

Lake Name	Lake ID	Ice Off Date	Ice On Date
Red Sand Lake	18-0386		11/28/01
Red Sand Lake	18-0386	4/14/02	
Red Sand Lake	18-0386	4/13/03	11/24/03
Red Sand Lake	18-0386	4/14/04	11/24/04
Red Sand Lake	18-0386	4/8/05	
Red Sand Lake	18-0386		12/2/06
Red Sand Lake	18-0386	4/5/07	11/22/07
Red Sand Lake	18-0386	4/25/08	11/19/08
Red Sand Lake	18-0386	4/18/09	

Appendix B

Lake Surface Water Quality Data for Red Sand Lake for 2008.

All water quality data can be accessed at: http://www.pca.state.mn.us/data/eda/STresults.cfm?stID=18-0386&stOR=MNPCA1

Lake Name	Lake ID	Sample Date	Site ID	Secchi Meters	TP µg/L	Chl-*a* µg/L	Alkalinity mg/L	Chloride mg/L	TKN mg/L	Color, Apparent PCU	TSS mg/L
Red Sand	18-0386	5/8/2008	101	> 3.0	16	1.92	79	12.3	0.7	10	1.2
Red Sand	18-0386	6/17/2008	101	5.49	16	0.92			0.72		
Red Sand	18-0386	6/18/2008	201	5.03	24	1					
Red Sand	18-0386	7/16/2008	101	>1.3	21	2.4	55	12.7	0.8	5	1.2
Red Sand	18-0386	7/20/2008	201	4.27	25	3					
Red Sand	18-0386	8/13/2008	101	> 2.4	28	3.56			0.94		
Red Sand	18-0386	8/25/2008	201	3.5	23	7					
Red Sand	18-0386	9/10/2008	201	3.2	24	4.1			0.89		
Red Sand	18-0386	9/14/2008	201	3.35	25	8					
Red Sand	18-0386	10/7/2008	201	4.7	22	2.87	80	14	0.87	20	0.5