# Lake Water Quality Assessment for Lake Darling Renville and Ward Counties, North Dakota

March 2006

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## Acknowledgments

Numerous scientists and technicians have made major contributions to the Lake Water Quality Assessment Project. Funds were provided through a grant from the U.S. Environmental Protection Agency. Appreciation also is extended to the North Dakota Department of Health's, Division of Chemistry for their accurate analyses of all samples; to Eric Hoggarth, Jon Long and Seth Stroup for sample collection and data entry; and lastly to Dean Knauer, manager of the Upper Souris National Wildlife Service, for allowing access to the refuge.

**Summary**

This assessment project has two principal objectives: (1) describe Lake Darling's overall condition for the study period between the spring of 1997 through the winter 1998, and (2) develop a calibrated trophic response model. The trophic response model will be used to assess Lake Darling's range of trophic response based on multiple hydrologic scenarios (e. g., long-term mean flow, high- and low-flow years). In-lake water quality data was collected by the North Dakota Department of Health's (NDDoH) Division of Water Quality. All inflow and outflow water quality and quantity data was collected and reported by the U.S. Geological Survey.

Water quality data collected during the summer of 1997 and winter 1998 describes Lake Darling as a well-buffered hypereutrophic waterbody. Dissolved oxygen conditions remained above 5 milligrams per liter (mg/L) with a single exception in February in the upper third of the reservoir. Lake Darling was not thermally stratified during any of the sampling visits in 1997 or 1998. In addition to general chemistry, Lake Darling was sampled for an array of trace elements. Of these, cadmium, copper, chromium, lead, nickel and zinc have both chronic and acute limits set in the *Standards of Water Quality for the State of North Dakota* (NDDoH, 1991). While none of the trace elements exceeded the state's acute standard, copper concentrations exceeded the state's chronic standard in 20 of the 42 water samples collected.

During the 1997-1998 hydrologic year, Lake Darling received 57,638 million gallons (gauged inflow) and discharged 58,729 million gallons (gauged outflow) for a hydraulic residence period of 102 days. Inflow contributed 95,929 pounds of phosphorus and 758,227 pounds of nitrogen, of which Lake Darling discharged 62,947 pounds of phosphorus and 643,317 pounds of nitrogen, resulting in a net gain of 32,982 pounds of phosphorus and 114,910 pounds of nitrogen within the reservoir. The nutrient load in 1997-1998 caused a hypereutrophic response in the upper two- thirds of the reservoir and a border line eutrophic-hypereutrophic response in the lower third.

Model simulations of varying hydrologic years suggest that initially Lake Darling's trophic response is lower during low-flow years, increases with average inflows and then decreases again with high-flow years. Model-predicted trophic response ranged from mesotrophic to hypereutrophic with 1988 (low-flow year) having the least trophic response and the long-term average (1930-present) the greatest trophic response. The model predicted that Lake Darling's longest residence time of 90,608 days occurred in 1988 and its shortest residence time (62 days) occurred in 1976. Lake Darling's average residence time (1930-present) is 431 days.

**Table 1. Lake Darling Statistics**

| | |
|---|---|
| **Location** | |
| State: | North Dakota |
| County: | Ward, Renville |
| Nearest Municipality: | Carpio |
| Ownership: | U.S. Fish & Wildlife Service |
| Physical Description | |
| Surface Area: | 9,000 – 9,500 acres |
| Major Tributary: | Souris (Mouse) River |
| Major Basin: | Hudson Bay |
| Drainage Area: | 9,446 square miles |
| Average Depth: | 10 feet |
| Maximum Depth: | 26 feet |
| Type of Water Body: | Reservoir |
| Fishery Type: | Walleye, northern pike, yellow perch, bullhead. |
| Trophic Condition: | Hypereutrophic |
| **Facilities** | |
| Public Facilities: | Three lake access points with boat ramps, parking lots, vault toilets, two picnic areas, fishing areas, hunting access, automobile tours, hiking paths, information center and refuge headquarters. Note: All public use and access rights are limited and controlled by the Upper Souris National Wildlife Refuge. For open periods and list of restrictions, contact the Upper Souris National Wildlife Refuge. |
| **Consumption Advisory** | |
| Fish: | Northern pike, walleye, white sucker, yellow perch |
| **Beneficial Uses** | |
| Classified beneficial uses[1]: | Recreation/agricultural/aquatic life/cool water fishery/municipal water supply |

[1]Based on classified uses as defined in the *Standards of Water Quality for the State of North Dakota*, February 1, 1991.

## Introduction

Lake Darling Dam is located near the Renville-Ward county line approximately 30 miles northwest of Minot, North Dakota. It is a U.S. Fish and Wildlife Service (FWS) dam built in 1936 for water supply, wildlife propagation and waterfowl staging and resting. The reservoir lies completely within the boundaries of the Upper Souris National Wildlife Refuge (NWR). An additional benefit of the dam is downstream flood control.

Lake Darling is a long narrow reservoir with a surface area of 9,500 acres and a volume of 110,000 acre-feet at a full pool elevation of 1,957 feet above mean sea level (Figure 1). The reservoir has a maximum depth of 26 feet and a mean depth of 10 feet. At the time of this investigation, the dam was being raised an additional 4 feet and its outlet updated to accommodate additional storage and discharge capacity as part of the basin-wide flood control project.

Lake Darling is classified in the *Standards of Water Quality for the State of North Dakota* as a cool water fishery, i.e., “waters capable of supporting growth and propagation of nonsalmonoid fishes and marginal growth of salmonoid fishes and associated aquatic biota (NDDoH, 1991). The FWS, in cooperation with the North Dakota Game and Fish Department (NDGF), manages Lake Darling’s fishery. The fishery developed naturally after the construction of the dam and has ranged from exceptional to poor over the last 60-plus years. The fishery consists of many species, but is dominated by northern pike, walleye and yellow perch.

Public facilities include three lake access points, two with day-use picnic areas, vault toilets, parking and boat ramps, and one with a boat ramp, parking lot and vault toilets. Boating and refuge access are controlled by the NWR with restrictive operational times and seasons.

## Water Quality

Lake water quality assessment data was collected on Lake Darling during the summer of 1997 and winter of 1997-98 from three locations (Figure 1). Data collected included water quality chemistry (Table 2), phytoplankton species identification and population enumeration, fish flesh analysis and sediment analysis. The data was used to evaluate Lake Darling’s condition over the sampling period of May 5, 1997 through February 24, 1998. In-lake water quality interpretations are facilitated using the U.S. Army Corp of Engineers Profile model.

Additionally, the 1997-1998 in-lake water quality and quantity data was combined with the U.S. Geological Survey (USGS) stream gauging and water quality data on the Souris River at Sherwood and Foxholm to model water and nutrient budgets for Lake Darling utilizing the Corps of Engineers Bathtub Model. The Bathtub Model was then calibrated using 1997-1998 water quality data, and an average water and nutrient budget was calculated.

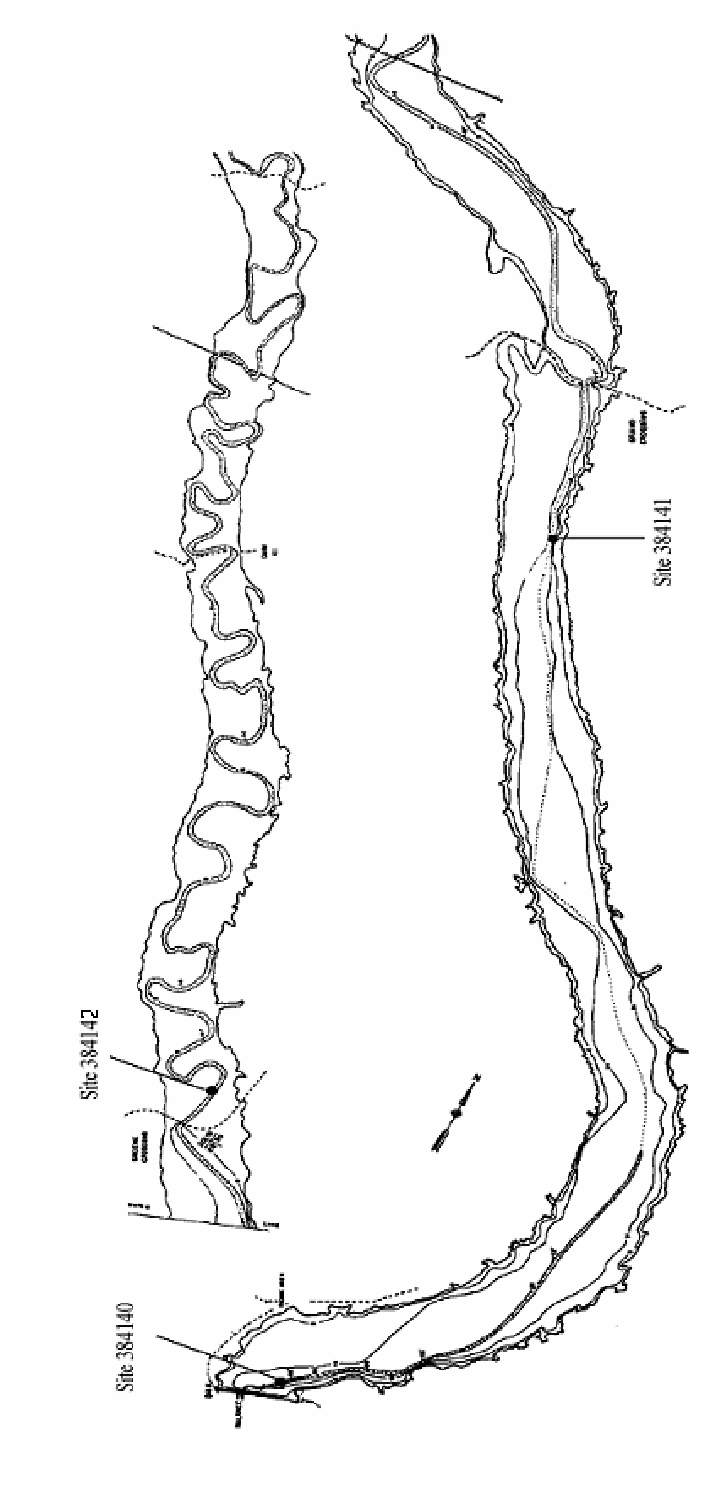


**Figure 1. Map of Lake Darling and Sampling Locations**

**Table 2. Water Quality Parameters**

| Analyte | Units | Analyte | Unit |
|---|---|---|---|
| Temperature | C | Spc. Conductance | Umhos/cm |
| Carbonate | mg/L | Bicarbonates | mg/L |
| Total Kjeldahl Nitrogen | mg/L | Nitrate + Nitrite as N | mg/L |
| Total Phosphorus as P | mg/L | Dissolved Phosphorus as P | mg/L |
| Total Hardness | mg/L | Calcium | mg/L |
| Magnesium | mg/L | Potassium | mg/L |
| Potassium | mg/L | Manganese | mg/L |
| Iron | µg/L | Sulfates | mg/L |
| Chlorides | µg/L | Boron | µg/L |
| Total Dissolved Solids | µg/L | Potassium | µg/L |
| Aluminum | µg/L | Chromium | µg/L |
| Beryllium | µg/L | Copper | µg/L |
| Nickel | µg/L | Arsenic | µg/L |
| Zinc | µg/L | Silver | µg/L |
| Selenium | µg/L | Antimony | µg/L |
| Cadmium | µg/L | Thallium | µg/L |
| Barium | µg/L | pH | µg/L |
| Lead | µg/L | | |

Water quality samples were collected from Lake Darling on four separate occasions and at three locations. Sampling times were May 5, August 11 and September 10, 1997, and February 24, 1998. The three sampling locations divided Lake Darling approximately into thirds. The first site (384040) is located just in front of the dam; the second site (384041) is located approximately two miles south of the Grano Crossing; and the third site (384042) is located ½ mile north of the Green Crossing (Figure 1). Water samples were collected for analysis at ½ meter below the surface and ½ meter above the lake floor on each sampling visit.

For purposes of this evaluation, one full degree change in Celsius per meter defines thermal stratification. Using this definition, at no time during the sampling period did Lake Darling thermally stratify (Figures 2, 4, 6, 8); however, occasionally portions of the reservoir appeared to be approaching thermal stratification. For the length of the project, dissolved oxygen concentrations remained within acceptable limits with a single exception in February, when the uppermost sampling site (384042) dropped below the state's water quality standard of 5.0 mg/L (Figures 3, 5, 7, 9).

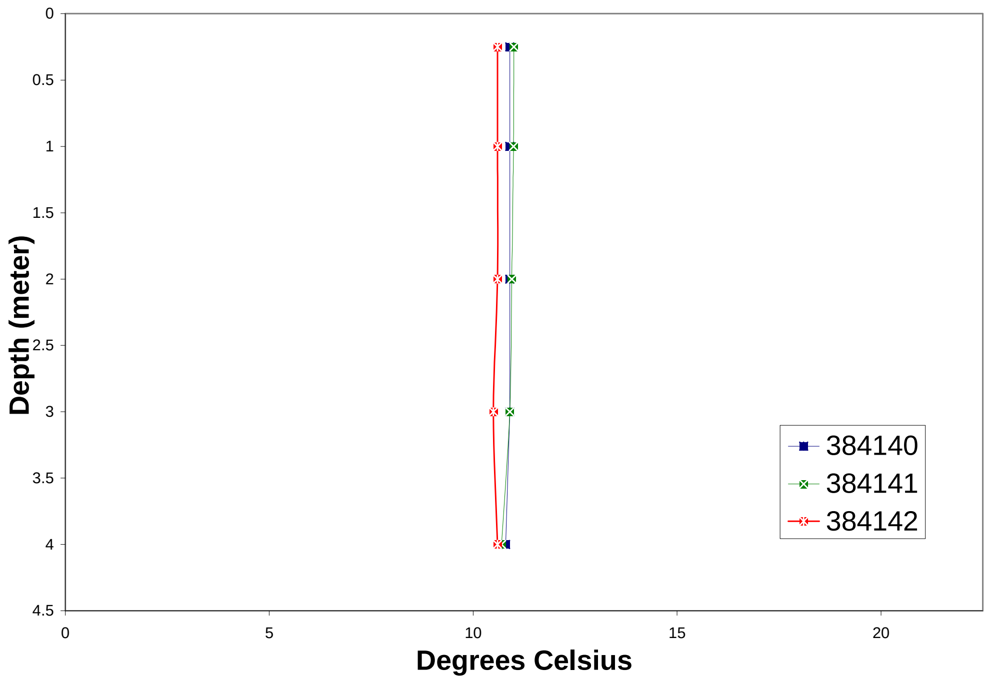


**Figure 2. May 5, 1997 Temperature Profiles**

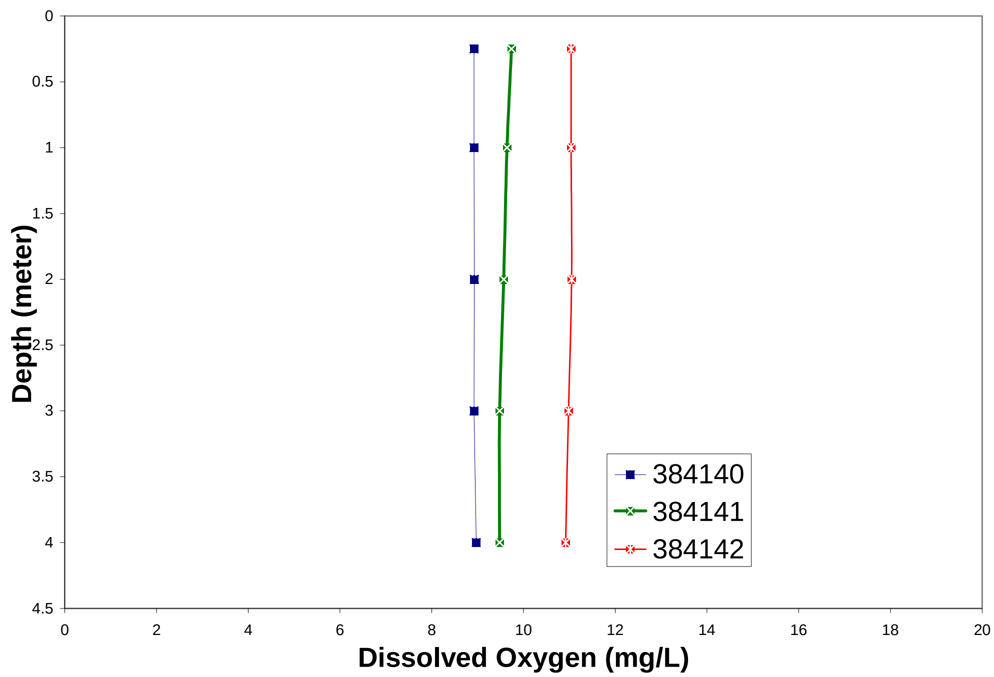


**Figure 3. May 5, 1997 Dissolved Oxygen Profiles**

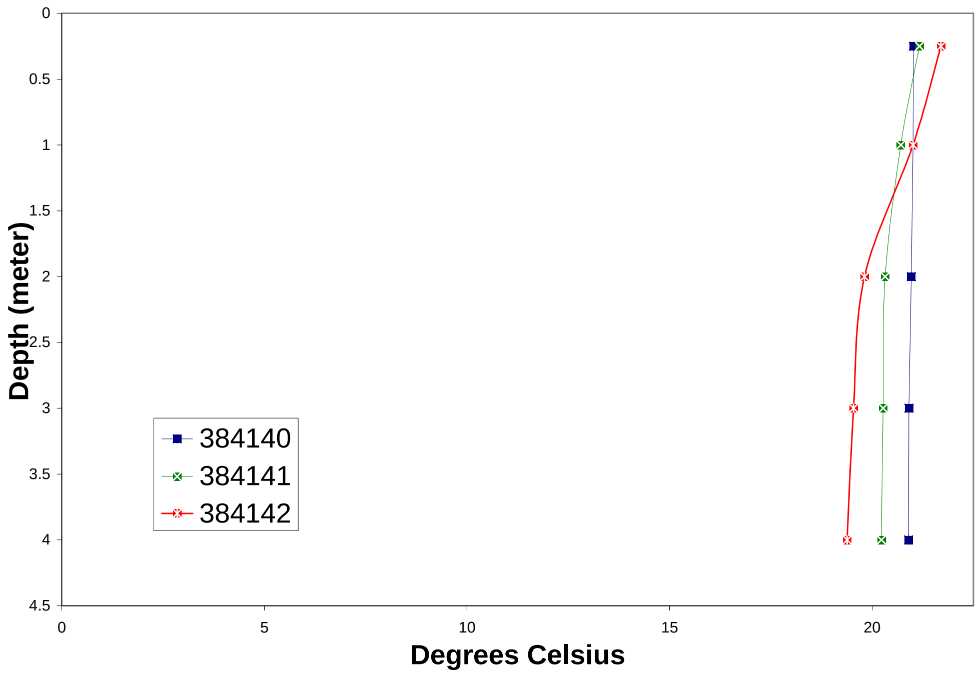


**Figure 4. August 11, 1997 Temperature Profiles**

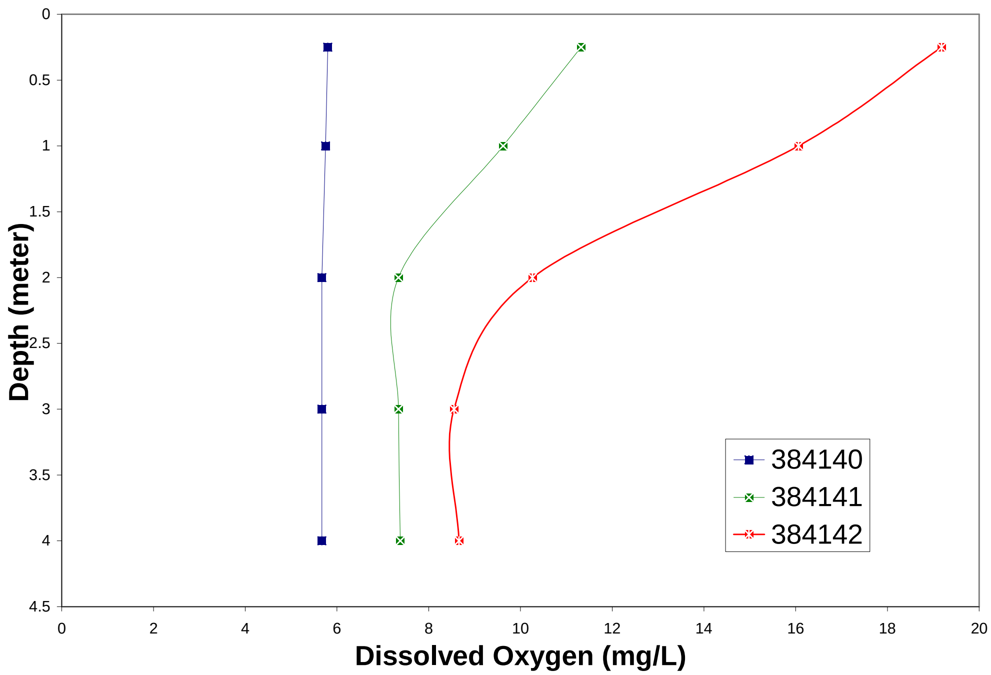


**Figure 5. August 11, 1997 Dissolved Oxygen Profiles**

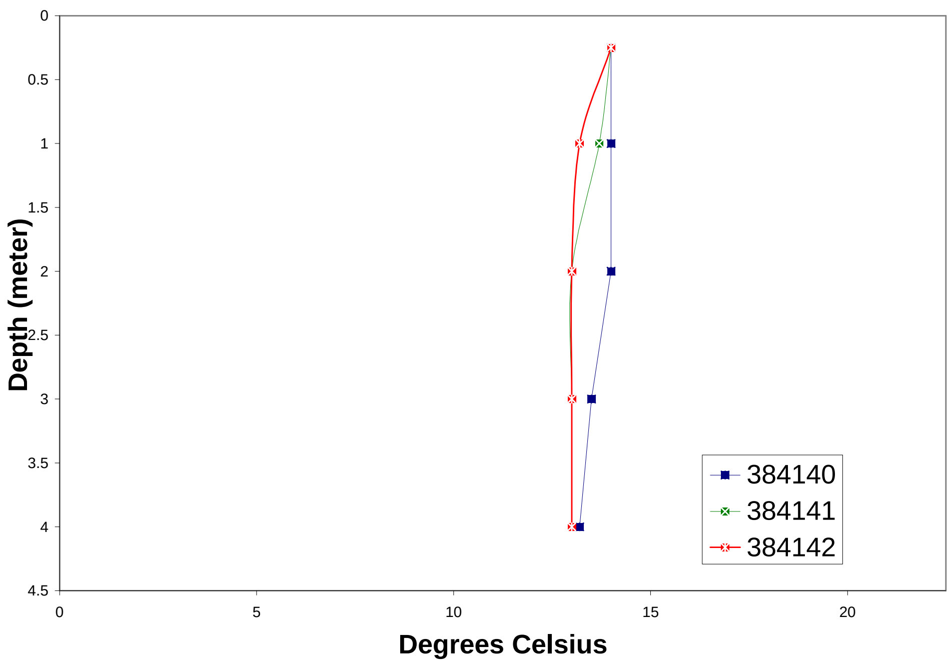


**Figure 6. September 10, 1997 Temperature Profiles**

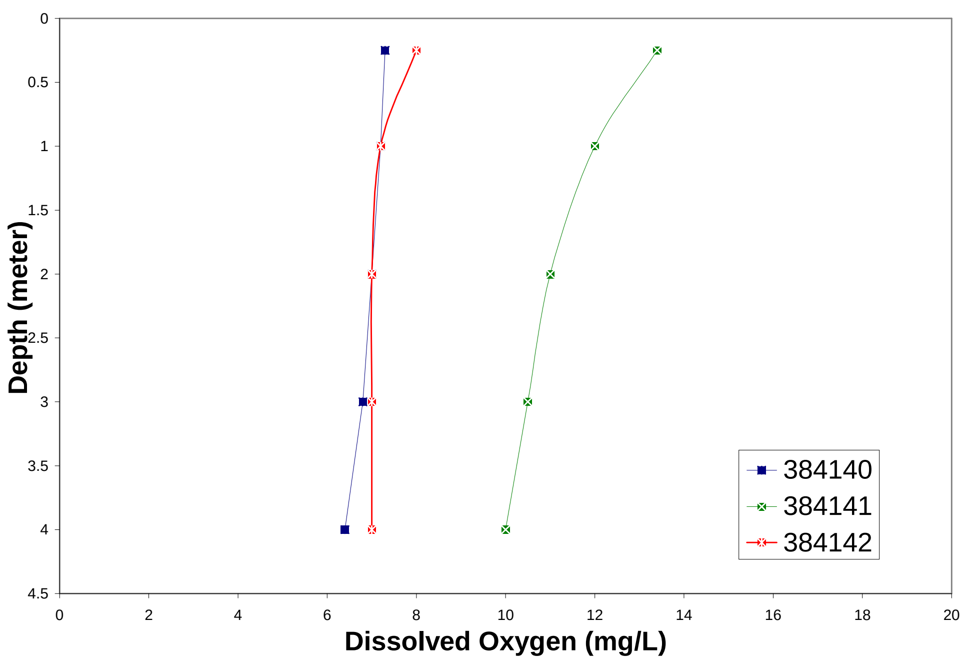


**Figure 7. September 10, 1997 Dissolved Oxygen Profiles**

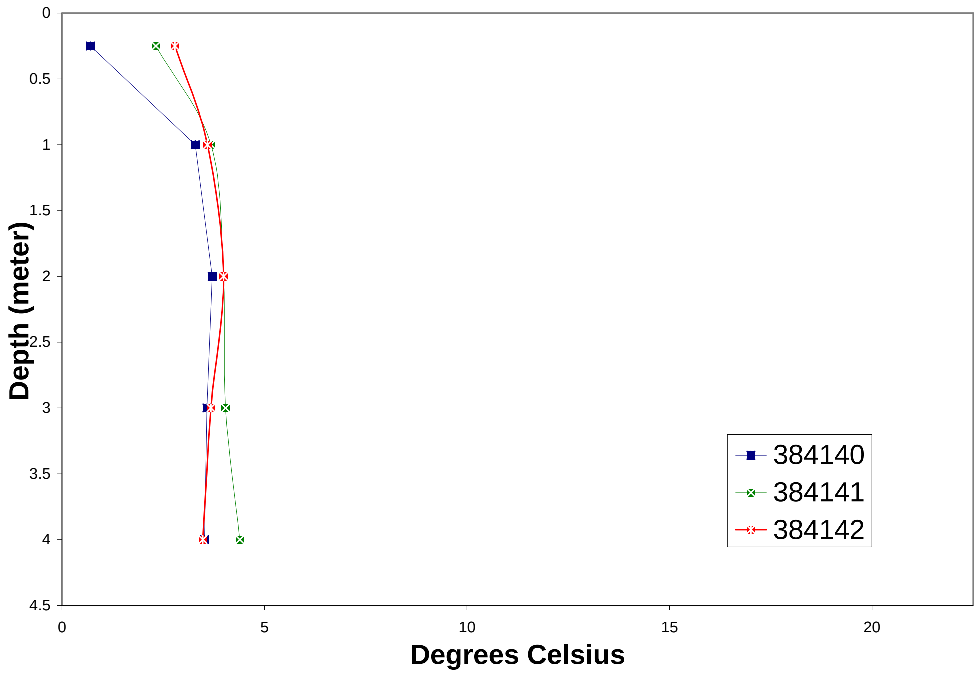


**Figure 8. February 24, 1998 Temperature Profiles**

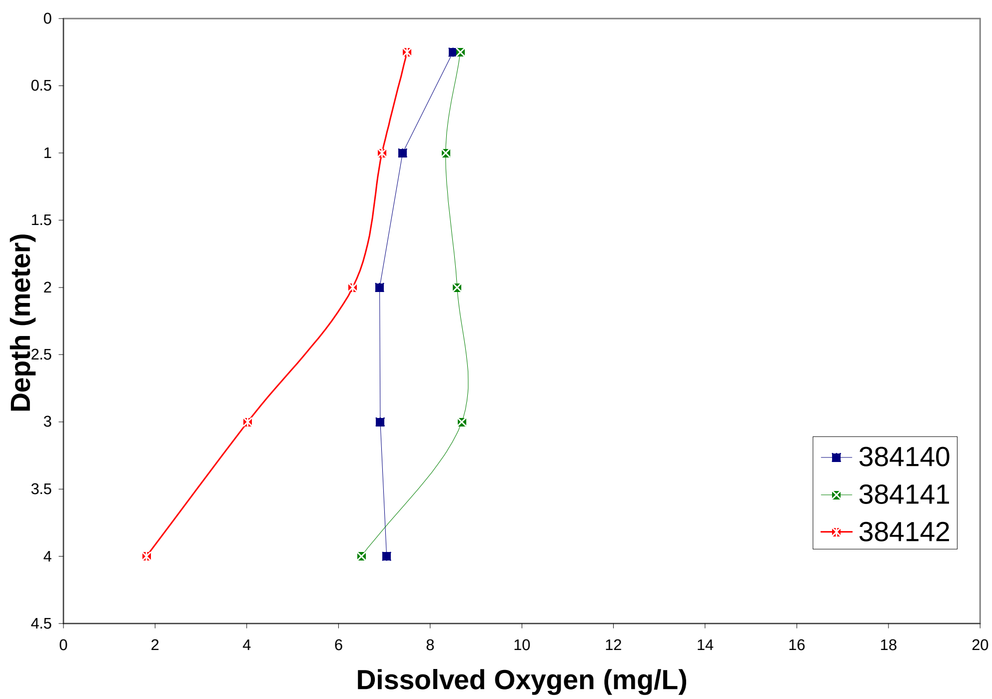


**Figure 9. February 24, 1998 Dissolved Oxygen Profiles**

Table 3 contains ranges for selected water quality variables within Lake Darling (during the assessment project) and the arithmetic mean on all lakes and reservoirs sampled in North Dakota by the NDDoH between 1985 and 1995. General water quality samples collected from Lake Darling describe a well-buffered eutrophic reservoir. Total alkalinity as calcium ranged from 170 to 324 mg/L with a mean of 231 mg/L. The dominant anions within the water column are bicarbonates and sulfates. Bicarbonates ranged from 191 to 396 mg/L with a mean of 259 mg/L, while sulfates ranged between 141 to 229 mg/L with a mean of 179 mg/L.

**Table 3. Concentration Ranges for Select Parameters within Lake Darling and the North Dakota Arithmetic Mean for all North Dakota Lakes Sampled between 1985 and 1995**

| Analyte | Mean | Minimum | Maximum | 1985-1995 Mean | Units |
|---|---|---|---|---|---|
| Total Dissolved Solids | 505 | 384 | 693 | 1271 | mg/L |
| Hardness as Calcium | 232 | 172 | 310 | 428 | mg/L |
| Sulfate as $SO_4$ | 179 | 141 | 229 | 408 | mg/L |
| Chlorides | 20.1 | 6.6 | 38.9 | 234 | mg/L |
| Total Alkalinity as Calcium | 231 | 170 | 324 | 309 | mg/L |
| Bicarbonate | 259 | 191 | 396 | 348 | mg/L |
| Total Phosphorus as P | 0.157 | 0.07 | 0.294 | 0.295 | mg/L |
| Nitrate + Nitrite as N | 0.100 | 0.02 | 0.260 | 0.137 | mg/L |
| Total Ammonia as N | 0.072 | 0.02 | 0.221 | 0.269 | mg/L |
| Total Kjeldahl Nitrogen | 1.253 | 0.895 | 2.010 | 2.204 | mg/L |
| Total Nitrogen as N | 1.353 | 0.915 | 2.270 | 2.341 | mg/L |

Total nitrogen and total phosphorus concentrations ranged from 0.915 to 2.270 mg/L and 0.07 to 0.294 mg/L, respectively, with mean concentrations of 1.353 and 0.157 mg/L. Total nitrogen to total phosphorus ratios ranged from 4.5:1 at site 384041 on August 11, 1997 to 19:1 at the same site on February 24, 1997. The 1997-1998 mean annual nitrogen and phosphorus ratio for all three sites is 8.6:1, indicating that for most of the year and particularly during the productive times of the year, Lake Darling is nitrogen limited. For purposes of this assessment, a waterbody is assumed to be in equilibrium when the ratio of nitrogen to phosphorus is 15:1. A ratio greater than 15:1 indicates a waterbody is phosphorus limited, and a ratio of less than 15:1 indicates a waterbody is nitrogen limited. When nitrogen becomes the limiting nutrient, primary production is not limited but altered. The altered condition favors certain species of primary producers that are tolerant of low-nitrogen conditions.

In addition to general chemistry, Lake Darling was sampled for an array of trace elements. Of these, cadmium, copper, chromium, lead, nickel, silver and zinc have both chronic and acute limits set in the *Standards of Water Quality for the State of North Dakota* (NDDoH, 1991). The standard is hardness dependent and is calculated using the equations in Table 4.

**Table 4. Trace Elements - Acute and Chronic Water Quality Standards for North Dakota**

**Hardness Dependent Equation**

Acute = exp(ma[ln{hardness}]+ba)
Chronic = exp(mc[ln{hardness}]+bc) Where:

| Element | ma | ba | mc | bc |
|---|---|---|---|---|
| Cadmium | 1.1280 | -3.828 | 0.7852 | -3.490 |
| Copper | 0.9422 | -1.464 | 0.8545 | -1.465 |
| Chromium | 0.8190 | 3.6881 | 0.8190 | 1.561 |
| Lead | 1.2780 | -1.460 | 1.2780 | -4.705 |
| Nickel | 0.8460 | 3.361 | 0.8460 | 1.165 |
| Silver | 1.7200 | -6.520 | NA | NA |
| Zinc | 0.8473 | 0.860 | 0.8473 | 0.7614 |

While none of the trace element concentrations exceeded the state's acute standard, copper exceeded the state's chronic standard in 20 of 42 water samples analyzed. The 20 samples exceeded the state's chronic standard by 6 to 9 micrograms per liter (ug/L). Of the 22 samples that did not exceed the state's copper standard, most were significantly below, with total concentrations ranging between 4 and 6 ug/L.

**Phytoplankton**

Phytoplankton (algae) can be used as indicators of nutrient availability and the trophic condition of a waterbody. Lake Darling's phytoplankton community was sampled twice in 1997 (August and October). Lake Darling's phytoplankton community is relatively diverse with representation from six divisions and 39 genera.

The divisions Chrysophyta, Cyanophyta and Chlorophyta dominated the community by density followed by Cryptophyta, Bacillariophyta and Euglenophyta. Division densities ranged from a low of 2,000 cells/mL of Euglenophyta to a high of 4,705,341 cells/mL of Cyanophyta. In general, densities decreased at the near-dam site but were fairly constant in the middle and upper areas of the reservoir (Table 5, Figure 10). The greatest density recorded was for the division Cyanophyta (commonly known as blue-green algae) supporting the assessment that Lake Darling is nitrogen limited.

**Table 5. Mean Algal Densities (Cells/mL) for Lake Darling (Aug. 12 and Oct. 6, 1997)**

| Division | Site 384040 | Site 384041 | Site 384042 |
|---|---|---|---|
| Chlorophyta | 927,341 | 3,183,409 | 1,440,455 |
| Cryptophyta | 1,500,818 | 1,730,114 | 1,832,000 |
| Cyanophyta | 1,495,364 | 4,705,341 | 4,096,909 |
| Euglenophyta | 0 | 0 | 2,000 |
| Chrysophyta | 1,683,977 | 3,529,432 | 4,484,455 |
| Bacillariophyta | 189,091 | 1,161,989 | 614,000 |
| Totals | 5,796,592 | 12,753,285 | 12,469,819 |

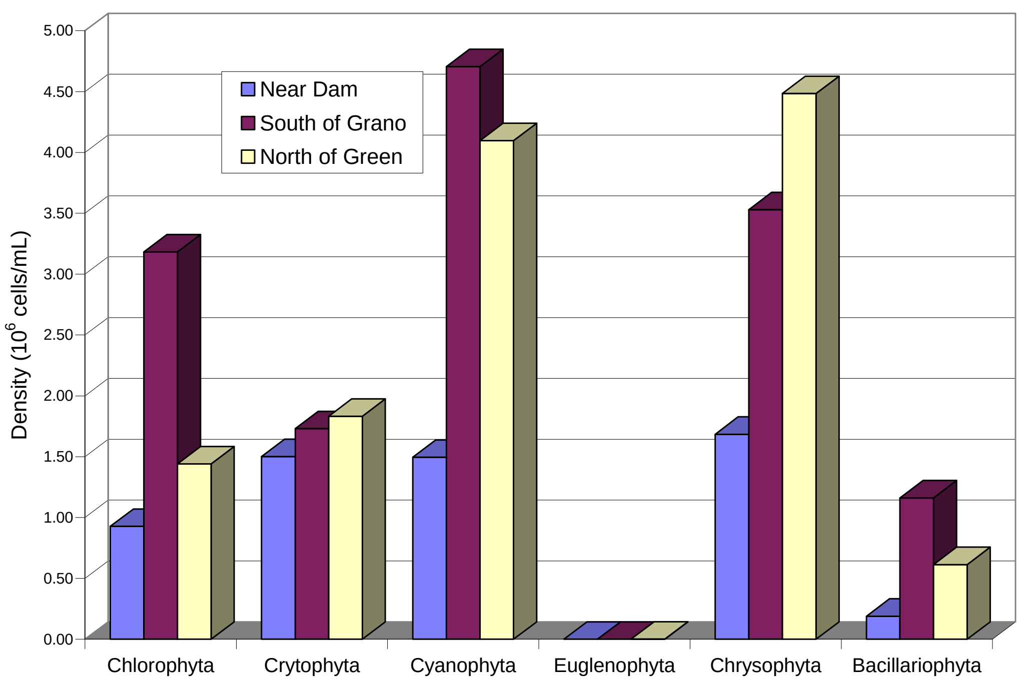


**Figure 10. Phytoplankton Densities Expressed as Cells/mL**

Spatial trends in the algal community by volume, expressed as cubic micrometers of algae per mL, were similar to those algal results expressed as density (cells/mL) in that division Cyanophyta occupied the greatest volume. The further up the reservoir from the dam, the greater the volume of algae (Table 6, Figure 11) is found. The division Bacillariophyta occupies a relatively large portion of the algae community by volume, and Chlorophyta occupies a relatively small portion. This is opposite to the algae density results expressed as cells per mL of lake water and is due to the relatively large size of the organisms in the division Baccilariophyta and small size of the organisms in the division Chlorophyta.

**Table 6. Mean Algal Volumes (Cubic Micrometers/mL) for Lake Darling (Aug. 12 and Oct. 6, 1997)**

| Division | Site 384040 | Site 384041 | Site 384042 |
|---|---|---|---|
| Chlorophyta | 121,159,195 | 73,597,876 | 29,426,308 |
| Cryptophyta | 347,192,337 | 245,879,131 | 1,760,275,181 |
| Cyanophyta | 13,832,910 | 2,349,664,364 | 1,365,865,096 |
| Euglenophyta | 0 | 0 | 4,629,000 |
| Chrysophyta | 153,906,308 | 321,385,908 | 401,851,437 |
| Bacillariophyta | 500,635,784 | 2,222,117,955 | 191.349.204 |
| Totals | 1,136,726,534 | 5,212,645,234 | 3,753,396,226 |

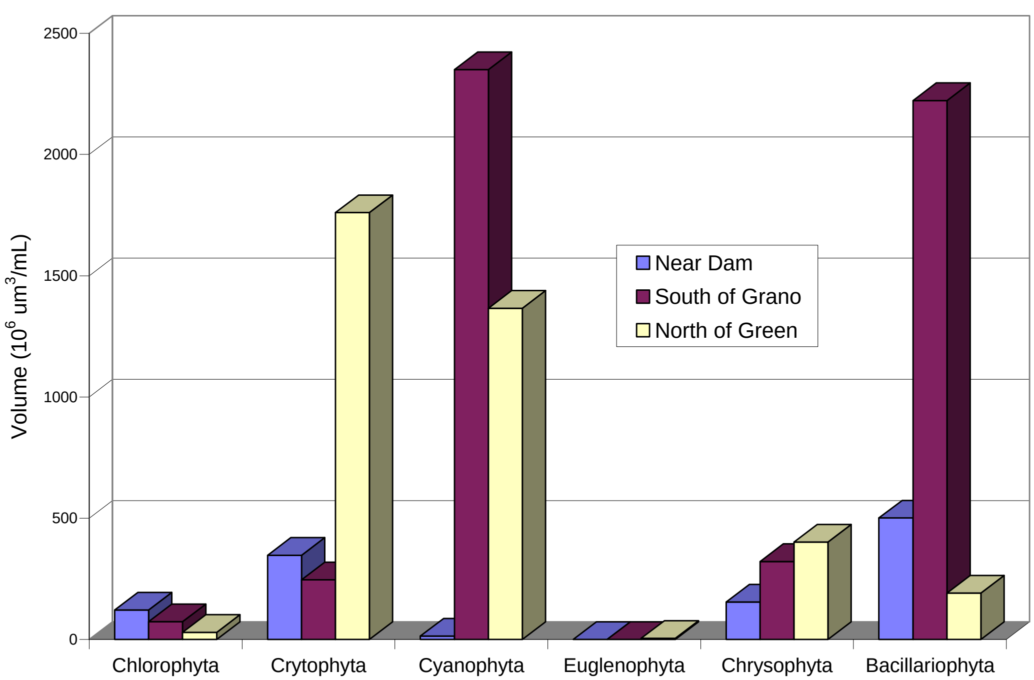


**Figure 11. Phytoplankton Volumes Expressed as Cubic Micrometers/mL**

## Lake Model Results

Lake Darling's hydraulic budget and eutrophic response was estimated using the Corps' Bathtub Model. The Bathtub Model includes several empirical techniques for predicting nutrient and trophic response as well as hydrologic residence time. The Bathtub Model lends itself well to Lake Darling as it is designed to develop steady-state water nutrient balances on spatially-segmented reservoirs with defined tributary and atmospheric inputs. Eutrophication-related water quality responses (chlorophyll-a, transparency, organic nitrogen, etc.) are predicted based on measured and estimated nutrient levels, reservoir morphology and hydrology.

Lake Darling's trophic response is measure by calculating the actual trophic status and estimated changes in this status due to changes in the annual or seasonal nutrient and hydraulic load. Trophic status is a measure of a lake's or reservoir's productivity. In general, as a lake ages, it becomes more productive (eutrophication). As a lake ages, it can reach an advanced stage of eutrophication indicated by loss of depth through sedimentation and frequent algal blooms due to an overabundance of nutrients. This condition is known as hypereutrophic, and a lake in this condition will often also give off a foul order, suffer from fish kills and have a rapid oxygen depletion rate during thermal stratification and under ice-cover conditions. Reservoirs which inundate large areas of deep, fertile soils covered with organic growth are especially susceptible to rapid eutrophication and often start out in an over-productive condition.

For purposes of this project, trophic status will be measured using Carlson's Trophic Status Index (TSI) (Carlson 1977). Carlson's TSI was selected because of its common use among limnologists and because it was developed for lakes, a state close to North Dakota geographically.

Carlson's TSI uses a mathematical relationship based on secchi disk transparency and concentrations of total phosphorus and chlorophyll-a. This numerical value then corresponds to a trophic state index condition ranging from 0 to 100, with increasing values indicating a more eutrophic condition. Carlson's TSI ranges are visually displayed in Figure 12.

Accurate trophic status assessments are essential in making sound management decisions. In order to ensure an accurate assessment has been made, it is desirable to have two consecutive years of monitoring and employ a multiple indicator approach. Because this project was a one-year investigation, the trophic response model should be viewed conservatively.

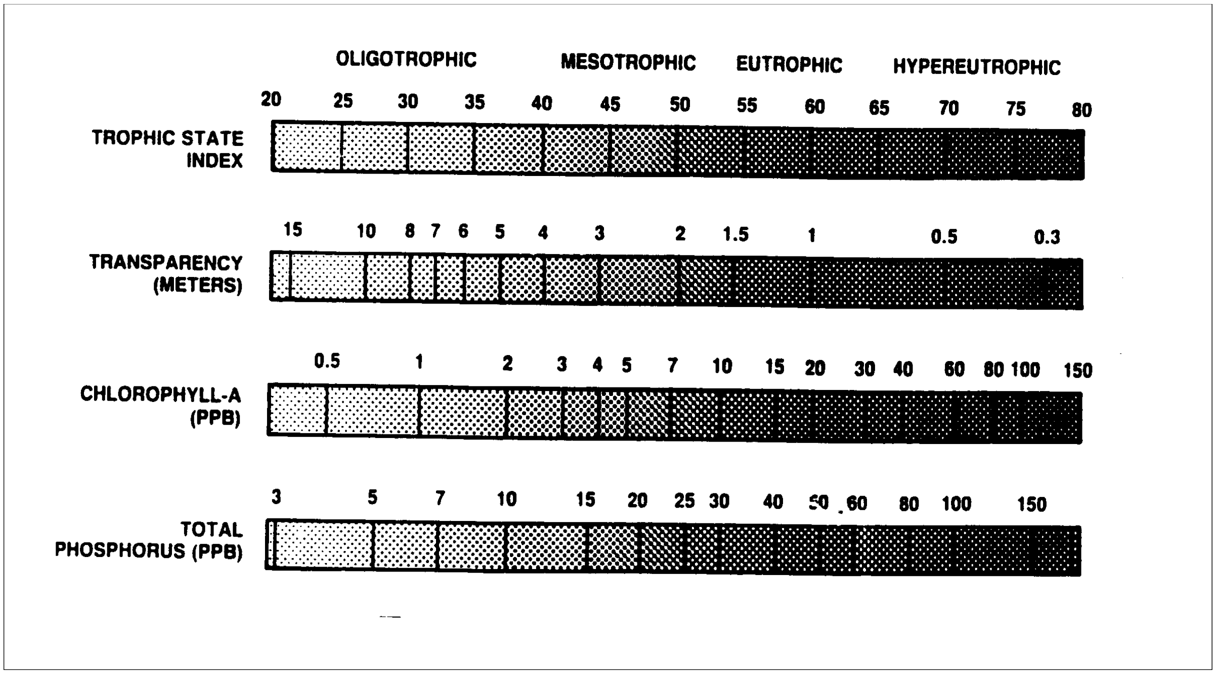


**Figure 12. A Graphic Representation of Carlson's Trophic Status Index**

Stream flow data was provided by the USGS to meet the inlet and outlet requirements of the model. Inlet data included stream flow and water quality data from the USGS site on the Souris River at Sherwood (site 05114000), with an additional 1 percent added to represent the un-gauged inflow from between Sherwood and the reservoir outlet. Outlet data was obtained from the USGS site on the Souris River at Foxholm (site 05116000). Outlet data is not corrected for the drainage area between the dam and the gauge. No factors were entered to represent precipitation, evaporation or loss and gain in reservoir storage.

The Bathtub Model for Lake Darling is spatially segmented into three parts. The first segment covers approximately 11.5 square kilometers ($km^{2)}$, or 30 percent of the lake's surface area beginning at the inlet and extending approximately 5.7 miles down reservoir. Water quality for this segment was represented by data collected at site 384042 (Figure 1). The second segment covers an additional 11.5 $km^2$ and extends an additional 5.5 miles down reservoir. Water quality for this segment was represented by data collected at site 384041. The third segment begins 11.2 miles down reservoir from the inlet and extends to the dam's face covering 15.4 $km^2$ or the remaining 40 percent of the reservoir's surface area. Water quality for this segment was represented by data collected at site 384040.

Model output includes area-weighted mean lake response and individual segment responses. The first model run predicted the eutrophic response and hydrologic balance for the period from May 5, 1997 through February 24, 1998, and was calibrated using water quality data collected during this same time period. Additionally, once the model was calibrated, three model simulations were made by changing the inlet and outlet assumptions. The three simulations represent variations in the annual inflows and outflows. The first simulation was made using the lowest annual inflows and outflows ever recorded (1988); the second simulation uses the highest inflows and outflows ever recorded (1976); and the third simulation uses the mean inflows and outflows from 1930 to 1997. All inlet and outlet flow and water quality data for these runs was obtained from the USGS. Complete Bathtub Model input and output files are contained in Appendix D.

Using the USGS stream flow data, Lake Darling had a hydraulic residence time of 0.614 years or 224 days during 1997-1998 (Table 7). Lake Darling's hydraulic residence time increases with depth. The uppermost segment has a residence time of 58 days; the middle segment 64 days; and the lowermost segment 102 days. Lake Darling received a total stream inflow of 57,638 million gallons (218.16 cubic hectameters ($hm^3$) and discharged 58,729 million gallons (222.29 $hm^3$).

Lake Darling's nutrient load of phosphorus and nitrogen are significant. During the 1997-1998 hydrologic year, Lake Darling received 95,929 pounds (43,505.3 kg) of phosphorus and discharged 62,947 pounds (28,547.6 kg), resulting in the storage of 32,982 pounds (14,957.7 kg). During this same period, Lake Darling received 758,227 pounds (343,867.2 kg) of nitrogen, discharged 643,317 pounds (291,753.7 kg) and retained 114,910 pounds (52,113.5 kg) (Tables 8, 9).

To put this nutrient load in perspective, think of Lake Darling as a field or garden and the pounds of phosphorus and nitrogen as fertilizer applied in a year. Using this simple example, Lake Darling was fertilized at a phosphorus and nitrogen rate of 10 and 80 pounds per acre, resulting in 3.5 and 5.5 pounds of N and P stored in the soil, respectively.

**Table 7. Lake Darling 1997-1998 Water Budget**

| Source | Water Load (hm3) | Water Load (million gallon) |
|---|---|---|
| External inflows | 218.16 | 57,638 |
| Gauged outflows | 222.29 | 58,729 |
| Un-gauged outflows | -4.13 | -1.091 |

| Area | Residence Time (years) | Residence Time (days) |
|---|---|---|
| Inlet to outlet | 0.6145 | 224 |
| Site 384042 | 0.1597 | 58 |
| Site 384041 | 0.1740 | 64 |
| Site 384040 | 0.2823 | 102 |

**Table 8. Lake Darling 1997-1998 Phosphorus Budget**

| Source | Load (kg) | Load (lb) |
|---|---|---|
| Precipitation | 1,152.0 | 2,540 |
| Souris River at Sherwood Inflows | 41,385.6 | 91,255 |
| Un-gauged Contribution Inflows | 967.7 | 2,134 |
| Total External Inflows | 43,505.3 | 95,929 |
| Souris River at Foxholm Outflows | 29,088.0 | 64,139 |
| Un-gauged Outflows | -540.4 | -1,192 |
| Total Outflows | 28.547.6 | 62,947 |
| Net Retention | 14,957.7 | 32,982 |

**Table 9. Lake Darling 1997-1998 Nitrogen Budget**

| Source | Load (kg) | Load (lb) |
|---|---|---|
| Precipitation | 38,400.0 | 84,672 |
| Souris River at Sherwood Inflows | 302,400.0 | 666,792 |
| Un-gauged Contribution Inflows | 3,067.2 | 6,763 |
| Total External Inflows | 343,867.2 | 758,227 |
| Souris River at Foxholm Outflows | 297,276.9 | 655,495 |
| Un-Gauged Outflows | -5,523.2 | -12,179 |
| Total Outflows | 291,753.7 | 643,317 |
| Net Retention | 52,113.5 | 114,910 |

Tables 10, 11, 12 and 13 contained the actual and calibrated bathtub model response for the period between May 5, 1997 and February 24, 1998. Tables 10 through 12 contain the spatially segment response, and Table 13 contains the area-weighted mean response for the entire reservoir.

Spatially, Lake Darling's water quality improves as one travels down reservoir toward the dam. Trophic status scores begin in the hypereutrophic range of 65 to 79 Carlson TSI points in the upper reaches of the reservoir to borderline eutrophic of 55 to 75 at the dam. Ancillary data, such as the large macrophyte biomass, frequent algal blooms and a history of occasional partial winter or summer fish die-offs, support an assessment of hypereutrophic in the upper reaches and becoming eutrophic below the mid-section of the reservoir.

**Table 10. Lake Darling Upstream Segment Observed and Calibrated Bathtub Model's Trophic Response for the 1997-1998 Hydrologic Year** (uppermost third of the reservoir from the inlet to 5.7 miles downstream) (water quality data collected at Site 384042 located ½ mile north of the Green Crossing)

| Variable | Actual | Modeled | Units |
|---|---|---|---|
| Total Phosphorus | 182.50 | 172.46 | Ug/L |
| Total Nitrogen | 1,540.00 | 1,379.70 | Ug/L |
| Chorophyll-a | 69.00 | 48.29 | Ug/L |
| Secchi Disk Depth Transparency | 0.70 | 0.45 | Meter |
| Organic Nitrogen | 1,374.00 | 1,266.64 | Ug/L |
| Ortho Phosphorus | 165.50 | 153.06 | Ug/L |
| Hypolimnion Oxygen Depletion | Not Measured | 390.07 | $Mg/m^3/Day$ |
| Metalimnion Oxygen Depletion | Not Measured | 264.23 | $Mg/m^3/Day$ |
| Carlson's TSI-Phosphorus | 79.23 | 78.42 | None |
| Carlson's TSI Chlorophyll-a | 72.14 | 68.64 | None |
| Carlson's TSI Secchi Disk Depth | 65.14 | 71.41 | None |

**Table 11. Lake Darling Central Segment Observed and Calibrated Bathtub Model Trophic Response for the 1997-1998 Hydrologic Year** (central third of reservoir beginning 5.7 miles from inlet and extending 11.2 miles down reservoir) (water data collected at Site 384041 located 2 miles south of the Grano Crossing)

| Variable | Actual | Modeled | Units |
|---|---|---|---|
| Total Phosphorus | 150.10 | 156.33 | ug/L |
| Total Nitrogen | 1,338.00 | 1,361.04 | ug/L |
| Chlorophyll-a | 82.64 | 84.79 | ug/L |
| Secchi Disk Depth Transparency | 0.70 | 0.48 | Meter |
| Organic Nitrogen | 1,187.00 | 1,168.18 | ug/L |
| Ortho Phosphorus | 134.30 | 141.40 | ug/L |
| Hypolimnion Oxygen Depletion | Not Measured | 390.07 | $Mg/M^3/Day$ |
| Metalimnion Oxygen Depletion | Not Measured | 264.23 | $Mg/M^3/Day$ |
| Carlson's TSI-Phosphorus | 76.41 | 77.00 | None |
| Carlson's TSI Chlorophyll-a | 63.97 | 67.67 | None |
| Carlson's TSI Secchi Disk Depth | 65.14 | 70.65 | None |

**Table 12. Lake Darling Lower Segment Observed and Calibrated Bathtub Model Trophic Response for the 1997-1998 Hydrologic Year** (lower third of reservoir beginning 11.2 miles from inlet and extending to dam face) (water quality data collected at Site 384040 located one-quarter mile north of the dam face)

| Variable | Actual | Modeled | Units |
|---|---|---|---|
| Total Phosphorus | 139.30 | 130.86 | ug/L |
| Total Nitrogen | 1,176.00 | 1,337.34 | ug/L |
| Chlorophyll-a | 15.50 | 36.64 | ug/L |
| Secchi Disk Depth Transparency | 1.40 | 0.52 | Meter |
| Organic Nitrogen | 1,022.00 | 1,014.30 | ug/L |
| Ortho Phosphorus | 123.80 | 122.99 | ug/L |
| Hypolimnion Oxygen Depletion | Not Measured | 520.09 | $Mg/M^3/Day$ |
| Metalimnion Oxygen Depletion | Not Measured | 315.83 | $Mg/M^3/Day$ |
| Carlson's TSI-Phosphorus | 75.34 | 74.43 | None |
| Carlson's TSI Chlorophyll-a | 57.49 | 65.93 | None |
| Carlson's TSI Secchi Disk Depth | 55.15 | 69.37 | None |

**Table 13. Lake Darling Area-Weighted Mean Observed and Calibrated Bathtub Model Trophic Response for the 1997-1998 Hydrologic Year**

| Variable | Actual | Modeled | Units |
|---|---|---|---|
| Total Phosphorus | 155.47 | 150.95 | ug/L |
| Total Nitrogen | 1,333.53 | 1,357.12 | ug/L |
| Chlorophyll-a | 35.86 | 42.27 | ug/L |
| Secchi Disk Depth Transparency | 0.98 | 0.49 | Meter |
| Organic Nitrogen | 1,176.83 | 1,136.15 | ug/L |
| Ortho Phosphorus | 139.43 | 137.51 | ug/L |
| Hypolimnion Oxygen Depletion | Not Measured | 442.21 | $Mg/M^3/Day$ |
| Metalimnion Oxygen Depletion | Not Measured | 284.21 | $Mg/M^3/Day$ |
| Carlson's TSI-Phosphorus | 76.92 | 76.49 | None |
| Carlson's TSI Chlorophyll-a | 65.72 | 67.33 | None |
| Carlson's TSI Secchi Disk Depth | 60.28 | 70.34 | None |

USGS's historical data show that stream flow into Lake Darling is seasonally and annually variable. Historical records exist for the Souris River at Sherwood (0511400) and Foxholm (0511600) flow gauging stations from 1930 to present. The mean annual discharge for the entire period of record from the Souris River at Sherwood is 30,021 million gallons, resulting in an average hydraulic residence for Lake Darling of 1.1798 years or 431 days (Table 14).
The driest hydrologic year ever recorded was 1988, when the mean annual discharge for the Souris River at Sherwood only discharged 142 million gallons, resulting in a hydraulic residence

time for Lake Darling of 248 years and 88 days (Table 15). In contrast, the wettest hydrologic year of 1976 resulted in a mean annual discharge of 209,089 million gallons for a lake hydraulic residence time of 0.1694 years or 62 days (Table 16).

**Table 14. Lake Darling 67-Year Annual Mean Water Budget (1930-Present)**

| Source | Water Load (hm3) | Water Load (million gallons) |
|---|---|---|
| External Outflows | 113.63 | 30,021 |
| Gauged Outflows | 115.13 | 30.417 |
| Un-gauged Outflows | 1.50 | 396 |
| **Residence Time** | **Residence Time (years)** | **Residence Time (days)** |
| Inlet to Outlet | 1.1798 | 431 |
| Site 384042 | 0.3067 | 112 |
| Site 384041 | 0.3334 | 122 |
| Site 384040 | 0.5421 | 198 |

**Table 15. Lake Darling Low-flow Mean Annual Water Budget (1988)**

| Source | Water Load (hm3) | Water Load (million gallons) |
|---|---|---|
| External Outflows | 0.54 | 142 |
| Gauged Outflows | 1.01 | 267 |
| Un-gauged Outflows | 0.47 | 125 |
| **Residence Time** | **Residence Time (years)** | **Residence Time (days)** |
| Inlet to Outlet | 248.241 | 90,608 |
| Site 384042 | 64.486 | 23,538 |
| Site 384041 | 70.277 | 25,651 |
| Site 384040 | 114.486 | 41,787 |

**Table 16. Lake Darling High-flow Mean Annual Water Budget (1976)**

| Source | Water Load ($hm^3$) | Water Load (million gallons) |
|---|---|---|
| External Outflows | 791.40 | 209,089 |
| Gauged Outflows | 846.10 | 223,540 |
| Un-gauged Outflows | 54.70 | 14,452 |
| **Residence Time** | **Residence Time (years)** | **Residence Time (days)** |
| Inlet to Outlet | 0.1694 | 62 |
| Site384042 | 0.0440 | 16 |
| Site 384041 | 0.0480 | 18 |
| Site 384040 | 0.0778 | 28 |

The phosphorus and nitrogen budget for Lake Darling fluctuated with the changing inflow volumes as did its trophic response. Tables 17 and 18 contain the phosphorus and nitrogen budget for Lake Darling's long-term mean (1930-1997), lowest annual mean flow year (1988) and highest annual mean flow year (1976). The long-term nutrient budget uses the USGS-calculated mean for the Souris River sites at Sherwood and Foxholm and the average reported nutrient concentrations reported by the USGS between the water years 1976 and 1988 at the same location.

**Table 17. Lake Darling Phosphorus Balances for 1976 and 1988 and Long-term Average Between 1930-1997**

| Source | 1930-1976 Load (kg) | 1930-1976 Load (lb) |
|---|---|---|
| Total Inflows | 34,174.1 | 75,354 |
| Total Outflows | 15,989.9 | 35,258 |
| Net Retention | 18,184.2 | 40,096 |
| **Source** | **1976 Load (kg)** | **1976 Load (lb)** |
| Total Inflows | 120,653.4 | 266,041 |
| Total Outflows | 106,596.8 | 235,046 |
| Net Retention | 14,056.6 | 30,995 |
| **Source** | **1988 Load (kg)** | **1988 Load (lb)** |
| Total Inflows | 1,380.4 | 3,044 |
| Total Outflows | 5.4 | 12 |
| Net Retention | 1,375.0 | 3,032 |

**Table 18. Lake Darling Nitrogen Budget for 1976 and 1988 and Long -term Average Between 1930-1997**

| Source | 1930-1976 Load (kg) | 1930-1976 Load (lb) |
|---|---|---|
| Total Inflows | 243,070.1 | 535,969 |
| Total Outflows | 179,770.4 | 396,394 |
| Net Retention | 63,299.7 | 139,576 |
| **Source** | **1976 Load (kg)** | **1976 Load (lb)** |
| Total Inflows | 1,502,646.0 | 3,313,334 |
| Total Outflows | 1,432,635.0 | 3,158,960 |
| Net Retention | 70,011.0 | 154,374 |
| **Source** | **1988 Load (kg)** | **1988 Load (lb)** |
| Total Inflows | 39,345.0 | 119,766 |
| Total Outflows | 1,010.3 | 2,228 |
| Net Retention | 39,804.8 | 85,565 |

The total inflow load of phosphorus and nitrogen was substantially different between the water years 1976, 1988 and the 67-year average, yet net retentions were surprisingly similar especially between the high-flow year (1976) and the 67-year average. This is due to the inverse relationship between residence time and nutrient retention.

The Bathtub Model was also used to predict Lake Darling's trophic response throughout the range of hydrologic conditions represented by 1988 (low flow), 1976 (high flow) and the long-term average (1930-present). Without at least one additional year of data for validation, the trophic response estimates should be viewed not as estimates of the actual trophic response but rather as indicators of the direction and range of trophic response in relation to an increase or decrease in mean annual inflows and outflows.

In general, the model predicts an improvement in Lake Darling's trophic response with a decrease in annual nutrient and hydraulic loading, with the exception of extremely high flows like those experienced in 1976 (Tables 19, 20, 21). The deviation from an increased trophic response to an increased mean annual nutrient load is due to a reduction in residence time.

The model predicted a near-negative hydrologic budget and a very small nutrient budget in 1988. This low load resulted in a model prediction of a reduced trophic response. The bathtub model predicts that in 1988 there was a substantial reduction in nutrient availability, a switch to phosphorus limitation and Carlson's TSI scores in the mesotrophic range (Table 20).

It is unrealistic to expect a trophic response reduction as dramatic as predicted, since there is a significant amount of sediment-stored nutrients that would not get tied up in a single year. However, it would be realistic to expect this type of reduction if the stored nutrients could be controlled.

**Table 19. Lake Darling Average (1930-1997) Predicted Trophic Response**

| Predicted Variable | Site 384040 Near Dam | Site 384041 Below Grano | Site 384040 Above Green | Area-Weighted Mean | Units |
|---|---|---|---|---|---|
| Total Phosphorus | 140.73 | 193.41 | 238.75 | 185.80 | ug/L |
| Total Nitrogen | 1,582.14 | 1,660.35 | 1,725.28 | 1,648.43 | ug/L |
| Chlororphyll-a | 39.40 | 54.16 | 66.85 | 52.04 | ug/L |
| Secchi Disk Depth | 0.91 | 0.68 | 0.56 | 0.74 | ug/L |
| Organic Nitrogen | 1,010.77 | 1,330.32 | 1,605.27 | 1,284.51 | ug/L |
| Ortho Phosphorus | 99.67 | 137.75 | 170.51 | 132.29 | ug/L |
| Carlson's TSI-P | 75.48 | 80.07 | 83.11 | 79.49 | TSI |
| Carlson's TSI-N | 66.64 | 69.76 | 71.83 | 69.37 | TSI |
| Carlson's TSI-C | 61.36 | 65.53 | 68.35 | 64.40 | TSI |

**Table 20. Lake Darling Low-Flow (Water Year 1988) Predicted Trophic Response**

| Predicted Variable | Site 384040 Near Dam | Site 384041 Below Grano | Site 384040 Above Green | Area-Weighted Mean | Units |
|---|---|---|---|---|---|
| Total Phosphorus | 10.08 | 12.58 | 21.30 | 14.19 | ug/L |
| Total Nitrogen | 1,000.34 | 1,003.69 | 1.031.07 | 1,010.54 | ug/L |
| Chlorophyll-a | 2.82 | 3.52 | 5.96 | 3.97 | ug/L |
| Secchi disk depth | 5.54 | 5.05 | 3.86 | 4.89 | ug/L |
| Organic Nitrogen | 218.17 | 233.29 | 286.21 | 243.08 | ug/L |
| Ortho Phosphorus | 5.12 | 6.92 | 13.23 | 8.09 | ug/L |
| Carlson's TSI-P | 37.47 | 40.66 | 48.26 | 42.40 | TSI |
| Carlson's TSI-N | 40.78 | 42.95 | 48.12 | 44.13 | TSI |
| Carlson's TSI-C | 35.34 | 36.67 | 40.54 | 37.13 | TSI |

**Table 21. Lake Darling High-Flow (Water Year 1976) Predicted Trophic Response**

| Predicted Variable | Site 384040 Near Dam | Site 384041 Below Grano | Site 384040 Above Green | Area-Weighted Mean | Units |
|---|---|---|---|---|---|
| Total Phosphorus | 134.69 | 141.96 | 146.59 | 140.43 | ug/L |
| Total Nitrogen | 1,810.25 | 1,826.00 | 1,837.69 | 1,823.19 | ug/L |
| Chlorophyll-a | 37.71 | 39.75 | 41.05 | 39.32 | ug/L |
| Secchi disk depth | 0.95 | 0.91 | 0.88 | 0.92 | ug/L |
| Organic nitrogen | 973.91 | 1,018.00 | 1,046.08 | 1,008.73 | ug/L |
| Ortho Phosphorus | 95.18 | 100.43 | 103.78 | 99.32 | ug/L |
| Carlson's TSI-P | 74.85 | 75.61 | 76.07 | 75.45 | TSI |
| Carlson's TSI-N | 66.21 | 66.73 | 67.04 | 66.62 | TSI |
| Carlson's TSI-C | 60.74 | 61.42 | 61.84 | 61.27 | TSI |

**Mercury in Fish**

Table 22 provides a summary of the results of fish tissue collected from Lake Darling in 1997. Fish were captured, scaled, filleted (skin on) and analyzed for mercury. Fish species collected for analyses were northern pike, walleye and yellow perch. Fish collected were divided into groups based on species and length, then composited and ground for analysis.

**Table 22. Results of Skin-on Fillet Mercury Analysis for Fish Collected from Lake Darling in 1997**

| Fish Species | Composite Size | Average Length (cm) | Concentration ug/L |
|---|---|---|---|
| Northern Pike | 1 | 63.5 | 0.01 |
| Northern Pike | 1 | 63.578.5 | 0.34 |
| Walleye | 5 | 24.8 | 0.06 |
| Walleye | 3 | 37.6 | 0.09 |
| Walleye | 3 | 38.1 | 0.10 |
| Walleye | 3 | 47.9 | 0.24 |
| Walleye | 3 | 48.3 | 0.17 |
| Walleye | 1 | 54.0 | 0.63 |
| Yellow Perch | 8 | 15.5 | 0.05 |
| Yellow Perch | 3 | 22.7 | 0.04 |

All species and sizes of fish collected from Lake Darling in 1997 contained mercury. In general, the larger fish of each species contained the greater concentrations of mercury. While none of the species or sizes exceeded the state's advisory maximum of 0.72 ug/L wet weight, enough samples were collected that a consumption advisory could be developed for Lake Darling. Figure 13 contains a graphic illustration of the relationship between mercury concentration and fish length. These relationships provide the basis for developing a consumption advisory.

It is not the intent of the fish consumption advisory to prevent people from consuming fish as eating fish regularly may decrease a person's chance of heart disease. Fish are low in fat, high in protein and provide substantial benefits when eaten in place of high-fat foods. The fish consumption advisory is designed to provide people the information to make healthy decisions on the number and types of fish they consume.

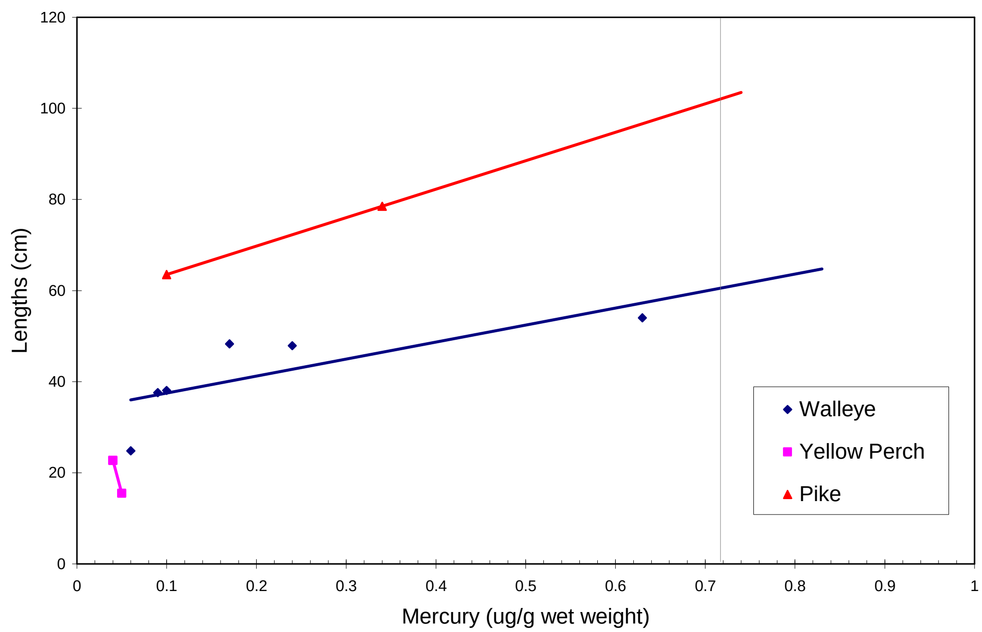


**Figure 13. Graphic Illustration of Mercury Increases per Fish Length**

The general guideline for safe fish consumption is to keep smaller fish for eating, and release larger fish, especially whopper-type fish. Because humans excrete mercury over time, visitors or residents can safely consume several meals (even of larger fish) over a period of a week or two. Mercury is contained in the fillet of the fish, so removing the skin and fatty tissue will not reduce the amount of mercury in a meal.

Fish consumption advice is targeted to two groups: Group A - women who plan to become pregnant, are pregnant or are breast feeding, and children under the age of 7; and Group B - all other persons.

People in Group A are advised to consume up to, but not exceed, two meals a month composed of northern pike less than 28 inches in length, walleye less than 21 inches in length and yellow perch less than 13 inches in length. This same group cannot safely consume any fish over these lengths.

People in Group B can consume up to five meals per week of northern pike less than 28 inches in length, walleye less than 21 inches in length, white sucker less than 21 inches in length and yellow perch less than 13 inches in length. There is not enough data to develop an advisory for group B with fish larger than the above numbers.

**Sediment Analysis**

Sediment samples were collected from Lake Darling at all three water quality monitoring sites (Figure 1). Sediments were collected using a 1-inch core sampler and sampling a minimum of the top 6 inches of sediments. Sediment samples were analyzed for 12 elements and 14 pesticides (Table 23).

**Table 23. List of Analytes Completed for Sediment Samples Collected from Lake Darling in 1997**

| Analyte | Analyte | Analyte |
|---|---|---|
| Aluminum (Al) | Manganese (Mn) | Iron (Fe) |
| Copper (Cu) | Zinc (Zn) | Barium (Ba) |
| Chromium (Cr) | Lead (Pb) | Mercury (Hg) |
| Hoelon | 2-4-D | Dicamba |
| Dinoseb | MCPA | Tordon |
| 2-4-5-T | Silvex | Pentachlorobenzoic Acid |
| Bromoxynil | Dichloprop | Bentazon |

Reported concentrations of trace elements in Lake Darling's deep water sediments are contained in Table 24. Sediment samples collected from Lake Darling contained detectable levels of all elements analyzed. In order to evaluate the sediment data for Lake Darling, the results are compared to the deep water sediment samples collected from 87 North Dakota lakes and reservoirs between 1991 and 1995.

In summary, the reported concentrations are relatively high in comparison to the 50th and 100th percentiles of the 87 deep water sediments collected from select North Dakota lakes and reservoirs. The reported concentrations of copper, zinc, barium, chromium, arsenic, selenium, lead, cadmium and mercury all exceeded the 50th percentile, while zinc, barium and chromium exceeded the 100th percentile in two of the three samples collected.

The only pesticide detected was 3, 5 dichlorobenzoic acid at a concentration of 0.05 ug/g wet weight. This is a very small amount and is equal to the minimum detection concentration for this pesticide

**Table 24. Reported Concentrations of Trace Elements in Lake Darling Sediment and the 100th and 50th Percentiles from 87 Sediment Samples Collected From Select North Dakota Lakes and Reservoirs (1991-1995)**

| | 1991 - 1995 Statistics | | Lake Darling Results | | |
|---|---|---|---|---|---|
| **Elements** | **50th** | **100th** | **Near Dam** | **South of Grano** | **North of Green** |
| Aluminum | Not Sampled | Not Sampled | 10,100 | 9,600 | 19,500 |
| Manganese | Not Sampled | Not Sampled | 307 | 872 | 564 |
| Iron | Not Sampled | Not Sampled | 15,000 | 19,500 | 26,000 |
| Copper | 5.48[1] | 25.80 | 9.98 | 14.7 | 17.7 |
| Zinc | 22.20 | 41.00 | 41.0 | 56.8 | 74.0 |
| Barium | 56.60 | 165 | 99.60 | 166 | 182 |
| Chromium | 4.82 | 14.1 | 16.80 | 18 | 38.7 |
| Arsenic | 1.61 | 5.71 | 4.86 | 4.1 | 3.87 |
| Selenium | 0.158 | 1.88 | 0.75 | 0.818 | 1.02 |
| Lead | 4.49 | 33.8 | 7.92 | 11.60 | 13.2 |
| Cadmium | 0.21 | 0.97 | 0.253 | 0.425 | .475 |
| Mercury | <0.01 | 0.044 | 0.030 | 0.030 | 0.04 |

[1]**Concentrations are in ug/g wet weight.**