# Lake Water Quality Assessment for Edward Arthur Patterson Lake Stark County, North Dakota

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**Prepared by:**
Peter Wax
Environmental Scientist
North Dakota Department of Health
Division of Water Quality
918 East Divide Avenue
Bismarck, ND 58501-1947

**North Dakota Department of Health**
**Division of Water Quality**

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# for Edward Arthur Patterson Lake
# Stark County, North Dakota

John Hoeven, Governor
Terry Dwelle, M.D., State Health Officer

North Dakota Department of Health
Division of Water Quality
1200 Missouri Avenue
P.O. Box 5520
Bismarck, North Dakota 58506-5520

701.328.5210

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**SUMMARY**

Edward Arthur Patterson Lake is a Bureau of Reclamation project completed in 1950 to supply potable water for the city of Dickinson, irrigation for the local area, downstream flood protection and water-based recreation. The rolled earthen structure dams the Heart River approximately 1 mile southwest of the town of Dickinson impounding 649.6 surface acres with a maximum depth of 27 feet and an average depth of 8.8 feet (Figure 1).

The original impoundment survey in 1954 showed E. A. Patterson Lake as having a surface area of 819 acres and a maximum depth of 32 feet. The loss of depth and storage is the result of sediment carried by the Heart River. Erosion within the watershed is at times severe and compounded through inadequate conservation practices on cultivated and grazed agricultural lands.

Topography of E. A. Patterson Lake's watershed is rolling to hilly uplands except in badland areas and near prominent buttes. In general, slopes are gentle with relief ranging form 300 to 500 feet. This region of North Dakota has well-defined drainages in the form of intermittent and perennial streams. Few shallow aquifers exist in the watershed other than along stream channels.

Approximately 20 percent of this region is composed of badlands. Badlands are eroded formations composed of buttes and steeply eroded draws. Soils are thin in badlands areas and are formed from sandy and clayey material. Badlands areas within the watershed are highly susceptible to wind and water erosion.

E. A. Patterson Lake is classified as a warm water fishery, i.e., "waters capable of supporting growth and propagation of nonsalmonoid fishes and associated biota." (NDDH, 1991) The North Dakota Game and Fish Department (NDGF) manages the fishery by annually assessing the fish community through test-netting operations and stocking accordingly.

Initial fishery management by the NDGF began after dam closure in 1950. In 1958, E. A. Patterson Lake was chemically eradicated to remove undesirable fish species. The NDGF estimated the eradication attempt was 98 percent successful. Intensive management efforts followed but resulted in only a marginal improvement in the warm water fishery.

Major factors suppressing the fishery are poor water quality and undesirable fluctuations in the water levels resulting in a lack of food organisms. The reservoir is typically turbid, a result of the fine, clayey materials which are carried as a sediment load in the Heart River.

In recent years, the stocking regimen by the NDGF has included northern pike, walleye, yellow perch, bluegill, smallmouth bass, largemouth bass and channel catfish. Fish community assessments conducted by the NDGF capture a multitude of fish species including black crappie, bluegill, white sucker, black bullhead, common carp, walleye, yellow perch, northern pike and channel catfish.

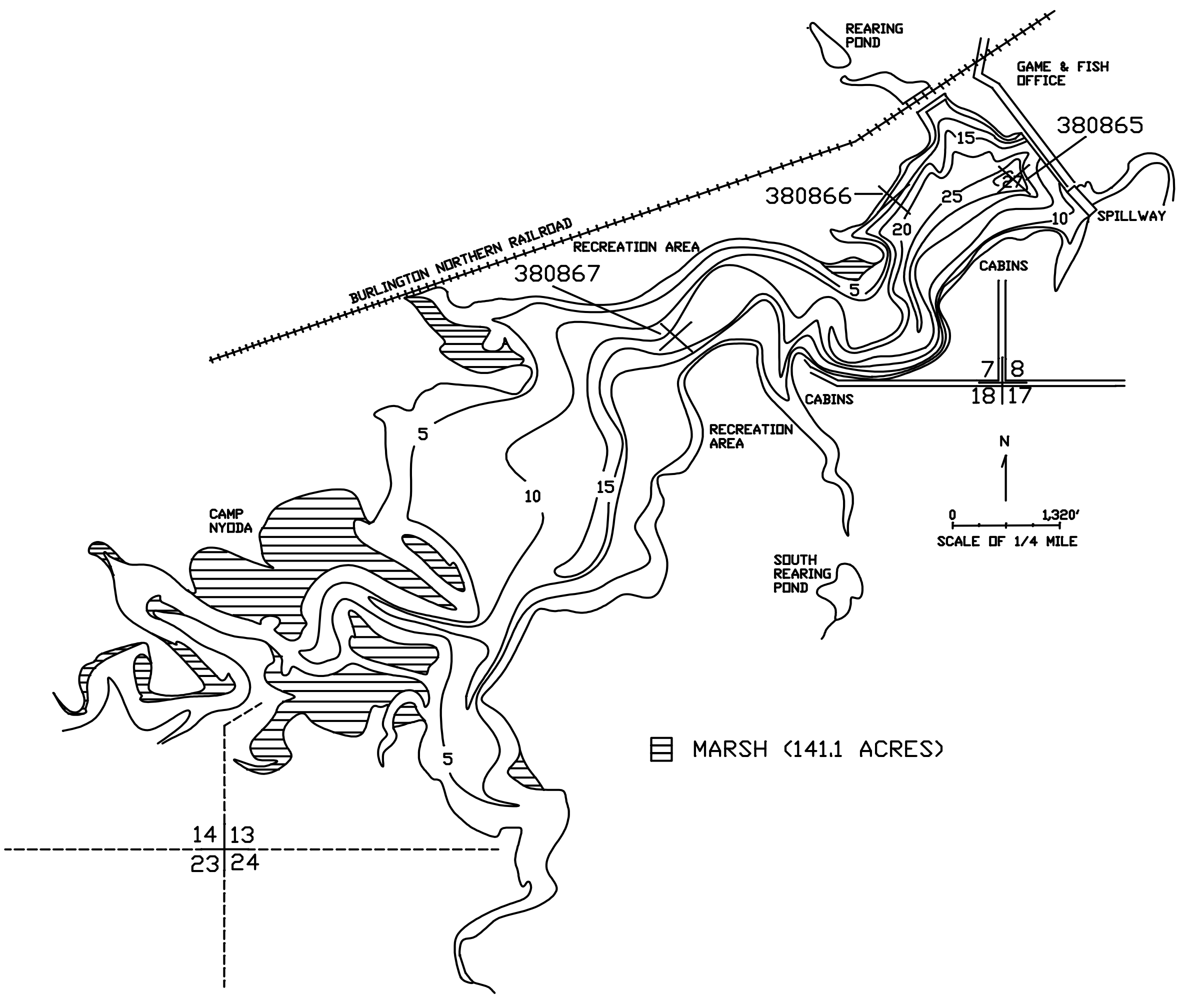


**Figure 1. Map of Edward Arthur Patterson Lake**

Public facilities on E. A. Patterson Lake developed on Bureau of Reclamation lands include a city park with camping playground and swim beach, a public picnic area with drinking water and shelters, a public swim beach, two boat ramps and associated parking and toilets. Approximately 25 percent of E. A. Patterson Lake's shoreline has designated areas for private summer and permanent cabins. There are approximately 30 private cabins and a Girl and Boy Scout camp with archery and trapshooting ranges.

Future fisheries management and recreational potential for E. A. Patterson Lake presently are in jeopardy due to declining water quality. Public concern for the water quality and general health of Patterson Lake is high within the local community.

## WATER QUALITY

Water quality and physical data were collected from E. A. Patterson Lake in 1992-1993, 1995-1996 and 2000-2001. Data were collected in 1992-1993 and 2000-2001 as part of the Lake Water Quality Assessment project (LWQA) and in 1995-1996 for a diagnostic and feasibility project. The LWQA data is used as a general water quality assessment, and the diagnostic and feasibility project was used to identify the causes and sources of degradation to E. A. Patterson Lake and to develop pollution reduction targets. This section discusses the water quality results of the 1992-1993 and 2000-2001 LWQA Projects followed by a summary of the 1995-1996 diagnostic and feasibility project.

Water quality data was collected on two open-water dates in 1992 and four open-water dates in 2000 and once during the ice-covered period in1993 and 2001. Samples were collected at one sample site located at the deepest area of the lake (Site 380865, Figure 1). Water column samples were collected for analysis at three discrete depths. The first depth was 1 meter below the surface, the second at mid-depth and the third at ½ meter off the bottom.

During the open-water period of 2000, the temperature and oxygen profile data indicates that E. A. Patterson Lake was not thermally stratified; however, in1992, both the July and August profiles identified weak thermal stratification occurring between 2 and 3 meters and 3 and 4 meters of depth, respectively. During the ice-covered period in 1993, E. A. Patterson Lake was thermally stratified; however, on January 30, 2001, no thermal stratification was identified (Figures 2 and 4).

Dissolved oxygen concentrations on E. A. Patterson Lake were excellent as long as the reservoir remained well mixed. However, once thermal stratification occurred, the dissolved oxygen concentrations dropped rapidly within the hypolimnion (Figures 3 and 4). Dissolved oxygen concentrations ranged between 5.9 milligrams per liter (mg/L) and 10.25 mg/L in 2000-2001 for the entire sampling period and 4.5 mg/L to 11.5 mg/L for the open-water period of 1992. On February 17, 1993, E. A. Patterson Lake’s dissolved oxygen concentrations were between 6.9 mg/L and 8.1 mg/L above the metalimnion, but ranged between non-detectable to 0.3 mg/L below (3 and 4).

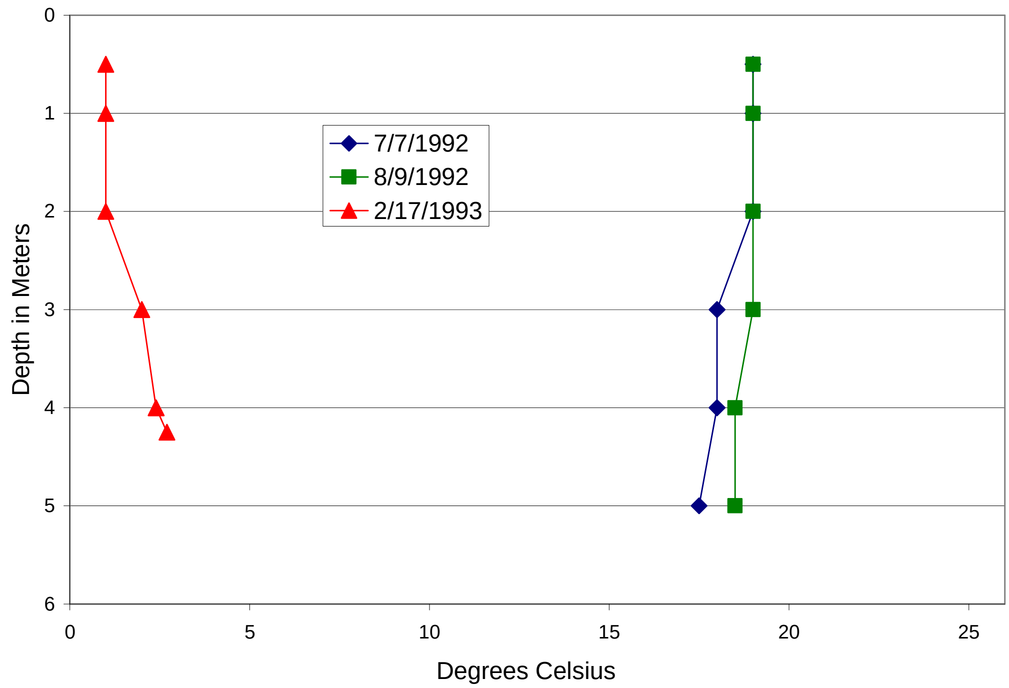


**Figure 2. E. A. Patterson Lake Temperature Profiles 1992-1993**

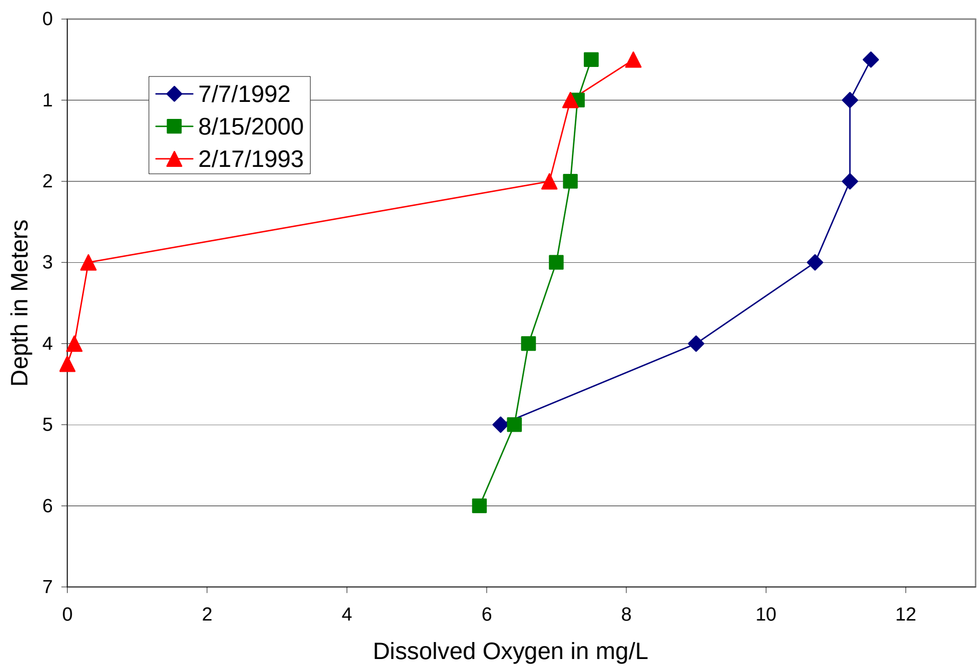


**Figure 3. E. A. Patterson Lake Dissolved Oxygen Profiles 1992-1993**

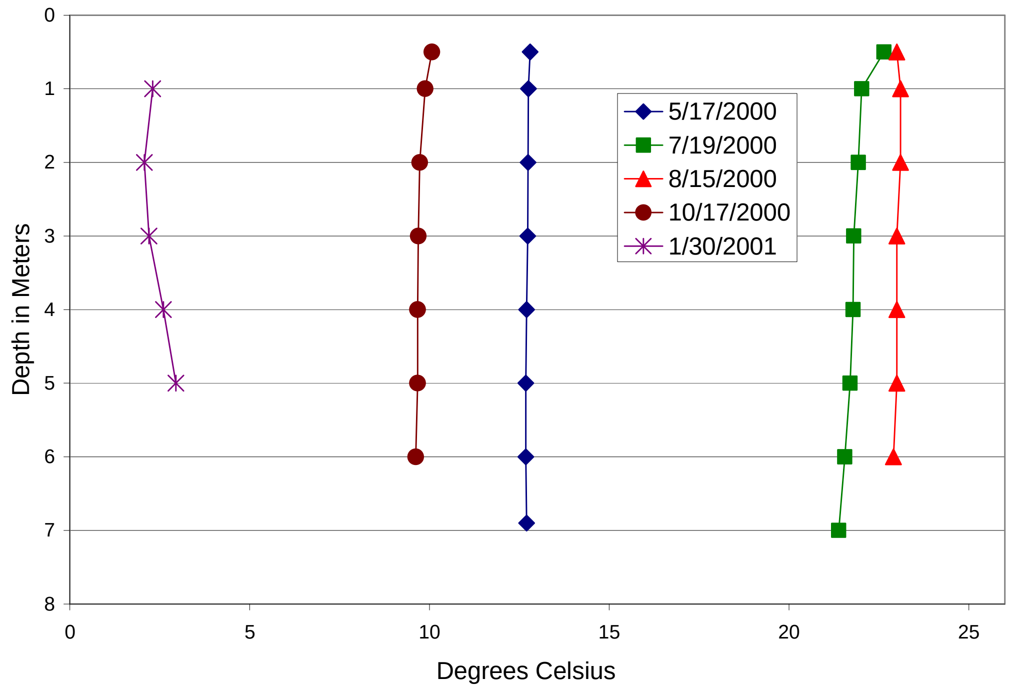


**Figure 4. E.A. Patterson Lake Temperature Profiles 2000-2001**

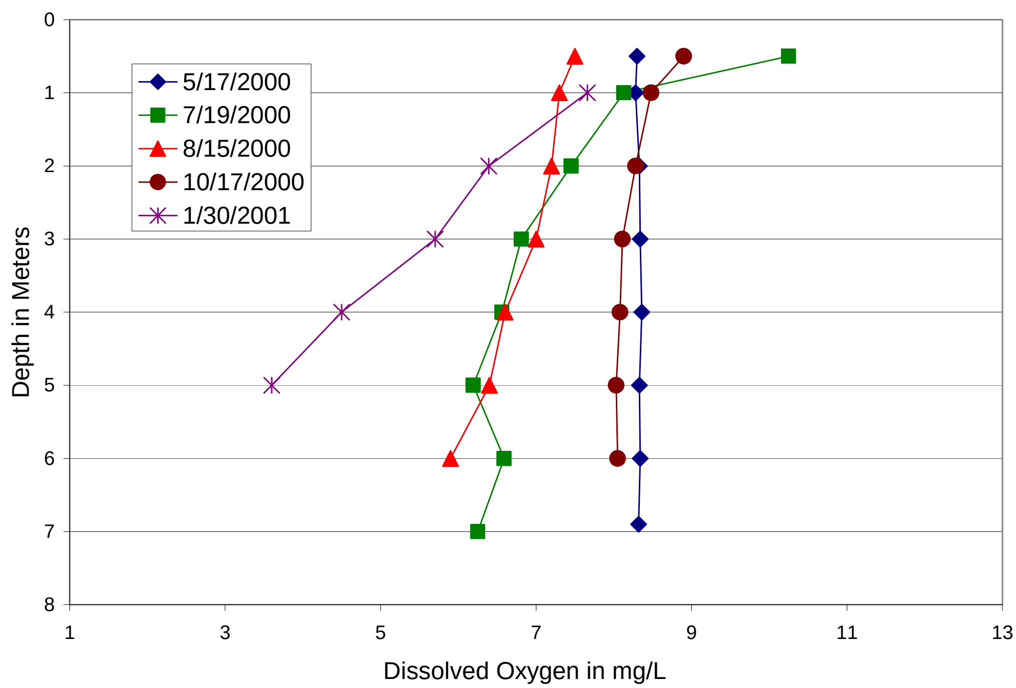


**Figure 5. E. A. Patterson Lake Dissolved Oxygen Profiles 2000-2001**

Water quality data collected during the 2000-2001and 1992-1993 LWQA Projects is very similar. Major cations and anion concentrations identified E. A. Patterson Lake as a well-buffered water body. Concentrations of total alkalinity as $CaCo_3$ ranged between 271 mg/L and 428 mg/L in 2000-2001 and 356 mg/L and 577 mg/L in 1992-1993 with volume-weighted mean concentrations of 426 mg/L and 321 mg/L, respectively (Table 1).

Concentrations of total dissolved solids and conductivity exceeded the state's long-term average. Volume-weighted mean concentrations were 1659 mg/L and 2296 mg/L in 2000-2001 and 1655 mg/L and 2,370 mg/L in 1992-1993. Total hardness as calcium concentrations were slightly below the state's long-term average with a volume-weighted mean concentration of 402 mg/L in 2000-2001 and 302 mg/L in 1992-1993. The dominant anions in the water column were sulfates and bicarbonates, with volume-weighted mean concentrations of 927 mg/L and 822 mg/L and 360 mg/L 470 mg/L, respectively.

During the LWQA Project, Patterson Lake's water column contained relatively high concentrations of the two primary nutrients phosphorus and nitrogen. Total phosphate as phosphate concentrations ranged between 0.082 mg/L and 0.247 mg/L in 2000-2001 and 0.18 mg/L and 0.639 mg/L in 1992-1993 exceeding the state's target concentration of 0.02 mg/L on all occasions sampled.

Nitrate + nitrite as nitrogen concentrations ranged between 0.02 mg/L and 0.410 mg/L in 2000-2001 and non-detectable to 0.26 mg/L in 1992-1993, violating the state's target concentration of 0.25 mg/L three times in 2000-2001 and once in 1992-1993.

**LIMITING NUTRIENT**

Data collected during the 1992-1993 and 2000-2001 LWQA Projects indicates that E. A. Patterson Lake is nitrogen limited. In brief, the nutrients driving the lake’s trophic response are nitrogen and phosphorus. Which nutrient is limiting is identified by comparing the ratio of total nitrogen to total phosphorus (N:P). For purposes of this report, when the N:P ratio is 15, the nutrients are assumed to be in balance. A ratio greater than 15 indicates a phosphorus limitation, and a ratio of less than 15 indicates a nitrogen limitation.  Ratios of N:P in1992-1993 and 2000-2001 ran between 2.6 and 15.6 with an average of 8.9 indicating that E. A. Patterson Lake  is nitrogen limited (Figure 6).

**Table 1. E. A. Patterson Lake - Volume-Weighted Mean Water Chemistry Concentrations for Selected Parameters Reported During the 1992-1993 and 2000-2001 LWQA Projects and the Arithmetic Mean for all North Dakota Lakes Sampled Between 1995 and 2000**

| Parameter | 1994-1995 Volume-Weighted Mean | 2000-2001 Volume-Weighted Mean | 1995-2001 North Dakota Mean |
|---|---|---|---|
| Total Dissolved Solids | 1655 mg/L | 1659 mg/L | 1545 mg/L |
| Hardness as Calcium | 302 mg/L | 402 mg/L | 474 mg/L |
| Sulfates as $SO_4$ | 822 mg/L | 927 mg/L | 785 mg/L |
| Chlorides | 21 mg/L | 14 mg/L | 64 mg/L |
| Total Alkalinity as $CaCO_3$ | 426 mg/L | 322 mg/L | 229 mg/L |
| Bicarbonate | 470 mg/L | 360 mg/L | 274 mg/L |
| Conductivity | 2370 umhos/cm | 2296 umhos/cm | 1984 umhos/cm |
| Total phosphorus as $PO_4$ | 0.350 mg/L | 0.161 mg/L | 0.152 mg/L |
| Nitrate + Nitrite as N | 0.075 mg/L | 0.108 mg/L | 0.117 mg/L |
| Total Ammonia as N | 0.212 mg/L | 0.221 mg/L | 0.272 mg/L |
| Total Kjeldahl Nitrogen | 2.410 mg/L | 1.455 mg/L | 1.775 mg/L |

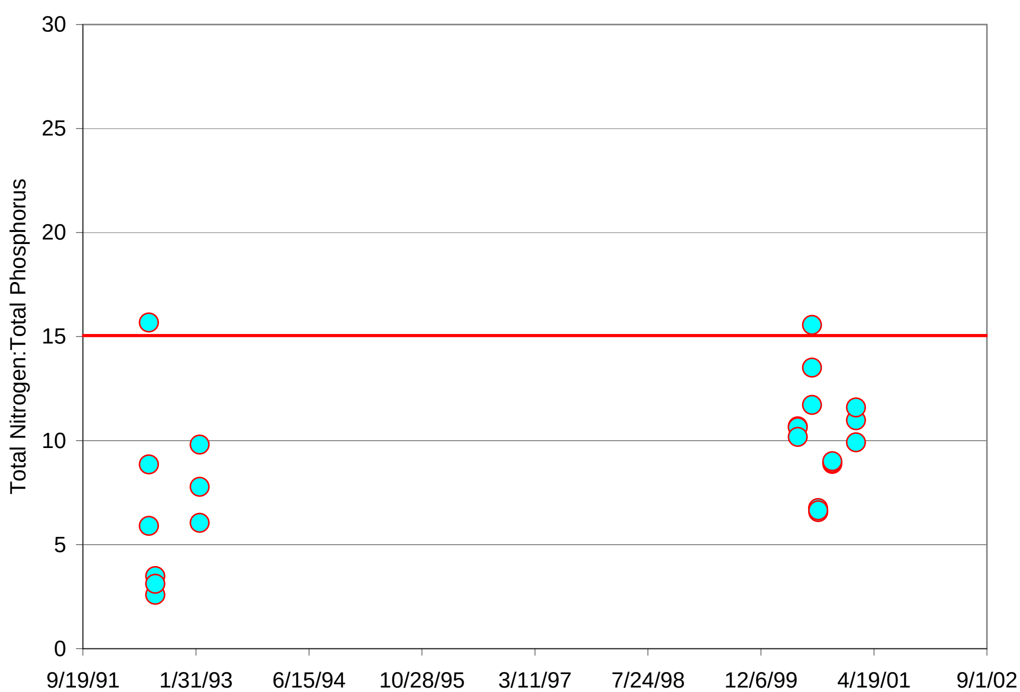


**Figure 6. E. A. Patterson Lake Total Nitrogen to Total Phosphorus Ratio**

## PHYTOPLANKTON

Edward Arthur Patterson Lake's phytoplankton community was sampled twice during the summer of 1992. At the time of the assessment, the phytoplankton community had representation from five divisions and 62 genera. The largest contributors to the phytoplankton community by numerical density were the blue-green algae, Cyanophyta, followed by the divisions Chlorophyta and Bacillariophyta. The largest genera diversity was in the division Chlorophyta, with 42 genera present. Other divisions present in the sample were Cryptophyta and Euglenophyta.

At the time of the assessment, mean phytoplankton concentrations by volume were more evenly distributed, with the division Chlorophyta occupying the largest volume. The other divisions present in descending order of volume occupied were Cyanophyta, Bacillariophyta, Cryptophyta and Euglenophyta.

## TROPHIC STATUS

Water quality data collected during the LWQA project indicate that E. A. Patterson Lake is eutrophic. This project estimated trophic status using Carlson’s Trophic Status Index (TSI). Carlson’s TSI was selected because of its common use among limnologists and because it was developed for lakes in Minnesota, a state geographically close to North Dakota. Carlson’s TSI uses a mathematical relationship based on secchi disk transparency, concentrations of total phosphorus at the surface and chlorophyll-a concentrations. This numerical value then corresponds to a trophic condition ranging from 0 to 100 with increasing values indicating a more eutrophic condition (Figure 7).

Trophic Status Index scores for the lake ranged between 22 and 68 for an average of 57. Carlson's TSI scale places the average in the middle of the eutrophic range. Ancillary data supporting a eutrophic assessment are a rapid dissolved oxygen deduction rate below the hypolimnion and decreasing lake depth and overall hydraulic storage.

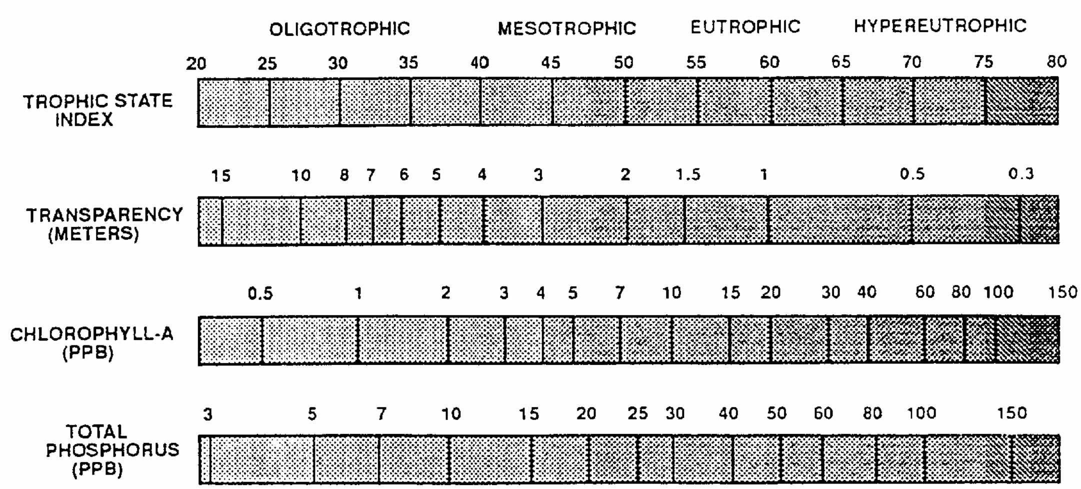


**Figure 7. Graphic Depiction of Carlson's Trophic Status Index**

## SEDIMENT

Sediments were collected from Patterson Lake and analyzed for trace elements, PCBs and selected pesticides (Table 2). Sediments were collected at the deepest area of the lake (Site 380865), the littoral zone (Site 380866) and the inlet (Site 380867) (Figure 1).

**Table 2. List of Analytes Completed for Sediment and Whole Fish Samples Collected from E. A. Patterson Lake in 1992**

| 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 |

Sediment samples collected from E. A. Patterson Lake had detectable levels of all trace elements tested, except for mercury. Reported concentrations of trace elements in the sediments collected were compared to the reported concentrations for all lakes assessed in the LWQA project up to that date.

In general, the trace element concentrations in the sediments collected from E. A. Patterson Lake were relatively high, ranging from approximately the median to above the 75th percentile. The exceptions were mercury which was non-detectable and selenium which was equal to or below the 25th percentile. Of note, the copper concentrations in the deepest and inlet area sediments were the highest reported in any sediments collected to that date.

Concentrations of selected pesticides and PCBs were below detectable limits for all samples collected from Patterson Lake.

**WHOLE FISH**

Fish were collected for contaminant analysis from E. A. Patterson Lake on July 7, 1992. A walleye and white sucker sample was collected representing the piscivore and bottom feeder groups. The walleye sample was composed of two fish with a mean length of 61 centimeters and a mean weight of 2,250 grams. The white sucker sample was a composite of five fish with a mean length of 42 centimeters and a mean weight of 748 grams.

In order to evaluate the fish tissue data, the results for the walleye and white sucker samples were compared to all samples collected from similar groups (i.e., piscivores and bottom feeders) during the LWQA Project. Trace element concentrations in the walleye sample collected from E. A. Patterson Lake were generally near or below the median concentration for all piscivore samples assessed with the exception of barium and mercury which were slightly below and above the 75th percentile, respectively.

The white sucker sample collected from E. A. Patterson Lake had reported trace element concentrations which were similar to the walleye sample. Reported trace element concentrations were generally near or below the median with the exception of barium. None of the trace element concentrations were high enough to warrant triggering of a consumption advisory; however, the reported concentration of 0.61 micrograms per liter (µg/L) for mercury in the walleye sample is high enough to warrant further investigations.

Detectable contaminant residues in the walleye sample collected from E. A. Patterson Lake included DDT, DDE, DDD, dieldrin, trifluralin and PCBs. The white sucker sample collected contained only DDE and DDD. DDE and DDD are both breakdown derivatives of the agricultural insecticide DDT. DDT is an agricultural insecticide which was banned in 1973 due to its adverse effects upon the environment. Dieldrin, like DDT, is an agricultural insecticide which was removed from agricultural use at approximately the same time and for similar reasons. Trifluralin, commonly known as Treflan, is a selective, pre-emergent herbicide commonly used in North Dakota. PCBs are generally considered industrial wastes and are used in industrial manufacturing and dielectric fluids.

The walleye sample contained reported concentrations of DDT, DDE, DDD, dieldrin and PCBs that were equal to or above the 75th percentile for all piscivores sampled during the LWQA Project. Of note is the reported concentration of 0.008 µg/G for DDT, which was the highest concentration reported during this period of sampling.

The reported concentration of trifluralin in the walleye sample collected from Patterson Lake was equal to the median concentration for all piscivores sampled. The white sucker sample contained reported concentrations of DDE and DDD that were slightly below and above the reported 75th percentile for all bottom feeders collected during the project.

**OVERVIEW OF THE 1995-1996 DIAGNOSTIC FEASIBILITY PROJECT**

In 1995, the city of Dickinson implemented a diagnostic/feasibility study in cooperation with the North Dakota Department of Health. As described by the city, the goals of the project were to: (1) determine a nutrient and sediment budget for Patterson Lake; (2) identify the primary sources and causes of nutrient and sediment loading to E. A. Patterson Lake; and (3) examine methods to reduce nutrient and sediment loading to E. A. Patterson Lake with the goal of improving the trophic condition and maintaining or improving the beneficial uses of the lake.

In general, the data collected was designed to (1) characterize the hydraulic and pollution loadings from Ash Creek, South Branch of the Heart River, North Creek, the Heart River and the immediate watershed surrounding Patterson Lake and (2) determine the effect of this loading on E. A. Patterson Lake. Lake sampling was combined with the loading analysis for the development of a working trophic response model for E. A. Patterson Lake. The trophic response model was then manipulated to simulate reductions in the external and internal loads of phosphorus and to identify the amount of phosphorus reduction needed to maintain or improve E. A. Patterson Lake's trophic condition.

Water quality, stream stage and flow data were collected by the U.S. Geological Survey (USGS) from the E. A. Patterson Lake and watershed on June 3, 1995 and continued through July 7, 1996. Data were collected to measure the hydrologic, nutrient and sediment loadings from four discrete drainages and two segments of the Heart River and E. A. Patterson Lake. Physical and chemical data were collected on three contributing tributaries, over the deepest area of the lake and downstream of the lake's outfall.

Data interpretations can be broken down into three major groups. Data group 1 is the physical data needed to estimate a mean daily discharge of water from each sub-watershed combined with the chemical water quality results to calculate a load (e. g., pounds per unit of time), time flow-weighted means and the reservoir's budget (e. g., what goes into the lake, what comes out and what is left behind). Data group 2 is the combination of data group 1 with the in-lake data to identify the relationship between load and reservoir trophic response. Data group 3 is a comparison of water quality data and land use. Water quality and land use was compared to identify any direct relationships between land use and pollution loading.

**DIAGNOSTIC AND FEASIBILITY WATER QUALITY RESULTS**

Concentrations of total phosphorus in the E. A. Patterson Lake watershed ranged from a maximum of 2.83 mg/L to a low of 0.029 mg/L. Median concentrations ranged between 0.373 mg/L on North Creek to 0.494 mg/L on South Branch of the Heart River near South Heart (Table 3).

Nitrogen concentrations were highest on the two tributaries Ash and North Creeks. Maximum concentrations ranged from a high of 3.8 mg/L to 3.18 mg/L on North and Ash Creeks, respectively, to a low of 0.081 mg/L on the South Branch of the Heart River near South Heart. Median concentrations ranged from a high of 1.435 mg/L on North Creek to a low of 1.175 mg/L on the South Branch of the Heart River near South Heart (Table 4).

**Table 3. Total Phosphorus Concentrations in the E. A. Patterson Lake Watershed in mg/L**

| Site | Maximum | Median | Minimum |
|---|---|---|---|
| Heart at South Heart | 2.830 | 0.442 | 0.107 |
| North Creek | 0.520 | 0.373 | 0.125 |
| So. Br. Heart at South Heart | 1.620 | 0.473 | 0.029 |
| Ash Creek | 0.595 | 0.409 | 0.250 |
| So. Br. Heart Below Bull Creek | 1.880 | 0.494 | 0.067 |
| Heart at State Street | 0.250 | 0.090 | 0.039 |

**Table 4. Total Nitrogen Concentrations in the E. A. Patterson Lake Watershed in mg/L**

| Site | Maximum | Median | Minimum |
|---|---|---|---|
| Heart at South Heart | 2.560 | 1.226 | 0.794 |
| North Creek | 3.800 | 1.435 | 1.013 |
| So. Br. Heart at South Heart | 2.970 | 1.175 | 0.081 |
| Ash Creek | 3.180 | 0.999 | 1.189 |
| So. Br. Heart Below Bull Creek | 2.350 | 1.381 | 0.534 |
| Heart at State Street | 1.445 | 0.749 | 0.624 |

In general loadings are highest during early spring run off in response to winter stored nutrients associated with livestock, wind, and water-eroded soils. These pollutants and pollutant-enriched soils are then easily moved into the creeks with the melting snow and spring rains from ditches, creek banks and smaller tributaries. After the initial melt and pollution delivery from these critical areas, there is a marked decrease in stream concentration and hydraulic discharge.

The relationship between hydraulic discharge and nutrient load did not vary significantly between sites. Additionally, no site showed a short-duration loading event which was not related to a runoff event that might indicate a point source pollution discharge. In short, all sites are similar with the nutrient load and hydraulic discharge increasing rapidly with each significant snow melt or precipitation event, then decreasing as the spring progresses into summer and again rising as winter approaches.

## LOADING ANALYSIS

The USGS reported that between June 1995 and May 1996 the E. A. Patterson Lake watershed discharged 109.38 tons (299,210.9 kilograms [Kg]) of nitrogen, 33.45 tons (30,340.1 Kg) of nitrogen and 67,740 tons (61,1442,176.9 Kg) of suspended solids (Table 5).

**Table 5. E. A. Patterson Lake Watershed Gross Nutrient and Suspended Solids Loading Estimates in Tons by Site**

| Site | Total Phosphorus | Total Nitrogen | Suspended Solids |
|---|---|---|---|
| Heart at South Heart | 10.08 | 2.79 | 12,100 |
| North Creek | 17.26 | 6.96 | 15,400 |
| So. Br. Heart at South Heart | 4.10 | 1.02 | 1,130 |
| Ash Creek | 4.44 | 1.51 | 1,490 |
| Heart at State Street | 17.26 | 12.70 | 17,500 |

## TRIBUTARY FLOW-WEIGHTED MEANS

Flow-weighted mean (FWM) or Flux/Flow is a way to compare individual streams and stream segments on a more equal footing than concentrations or load alone. The volume-weighted mean (VWM) concentration for phosphorus ranged from 0.038 mg/L on North Creek to 0.69 mg/L on the South Branch of the Heart River near South Heart (Table 6). Overall, the VWM for total phosphorus were higher for the Heart and South Branch of the Heart River than the smaller tributaries.

Total nitrogen VWM ranged from a high of 1.91 mg/L on North Creek to a low of 1.43 mg/L on the South Branch Heart River near South Heart. The total nitrogen VWM concentrations are inversely related to the phosphorus concentrations, with the streams with the highest nitrogen concentration having the lowest phosphorus concentrations and vise versa (Table 6).

**Table 6. E. A. Patterson Lake Watershed – Volume-Weighted Mean Concentrations in mg/L**

| Site | Total Phosphorus | Total Nitrogen |
|---|---|---|
| Heart at South Heart | 0.48 | 1.690 |
| North Creek | 0.69 | 1.438 |
| So. Br. Heart at South Heart | 0.38 | 1.910 |
| Ash Creek | 0.57 | 1.600 |
| Heart at State Street | 0.54 | 1.630 |

## MODELED TROPHIC CONDITION

Inlake water quality data collected between June 1995 and May 1996 indicated that E. A. Patterson Lake is a hypereutrophic, nitrogen-limited reservoir. Volume-weighted mean concentrations of total nitrogen and total phosphorus were 1.385 mg/L and 0.158 mg/L, respectively. The total nitrogen to total phosphorus ratio in the epilimnion during the growing season was 8.8, indicating a nitrogen limitation. Chlorophyll-a and secchi disk transparency measurements averaged 15 ug/L and 0.3 meters, respectively, supporting a hypereutrophic assessment (Table 7).

**Table 7. E. A. Patterson Lake Watershed - Volume-Weighted Mean Concentrations for Principal Nutrients, Chlorophyll-a and Secchi Disk Depth Transparency**

| Variable | Observed Value | Units |
|---|---|---|
| Total Phosphorus | 0.158 | mg/L |
| Total Nitrogen | 1.386 | mg/L |
| N/P Ratio | 8.8 | N/A |
| Organic Nitrogen | 0.808 | mg/L |
| Chlorophyll-a | 15.000 | µg/L |
| Secchi Disk Depth | 0.300 | Meter |

## LOADING AND BUDGET ANALYSIS

Combining the USGS flow data and water quality results, a hydraulic discharge and nutrient load was calculated using the U.S. Army Corps of Engineers Flux Model. The Flux Model output was then entered into the Corps of Engineers Bathtub Model. The Bathtub model is a steady-state, eutrophic response model developed by the Corps of Engineers for use on medium to large reservoirs.

Combined, these models estimate that between June 1995 and May 1996, the Heart River, the ungauged watershed and direct rainfall delivered 8,903 million gallons (33.1 $HM^3$), 109,799 pounds (49,795 Kg) of nitrogen and 39,526 pounds (17,846.5 Kg) of phosphorus (Tables 8, 9, 10 and 11).

Over this same period, E. A. Patterson Lake released and evaporated approximately an equal amount of water, 98,816 pounds (44,814 Kg) of nitrogen and 11,309 pounds (5,129 Kg) of phosphorus. The net gain in nutrients to E. A. Patterson Lake between June 1995 and May 1996 is estimated at 10,983 pounds (4,981 Kg) of nitrogen and 28,217 pounds (12,797 Kg) of phosphorus.

Additionally, the USGS estimated the sediment load entering E. A. Patterson Lake from all sources as 20,120 tons (18,347,595 Kg) annually with 7,120 tons (6,463,873 Kg) of sediment passing through for an annual net gain of 13,000 tons (11,791,383 Kg).

In short, based on data collected between June 1995 and May 1996, E. A. Patterson Lake is fertilized at an annual rate of 88 pounds of nitrogen and 33 pounds of phosphorus per acre with a residue coverage composed of silts and fine organics of 21,667 pounds per acre. This is in addition to the previous year's estimated residue of available nitrogen and phosphorus of 10.5 and 23.5 pounds per acre, respectively.

**Table 8. E. A. Patterson Lake Water Budget for June 1995 - May 1996**

| Source | Gallons of Water |
|---|---|
| Over Land Flow | 8,604,201,400 |
| Precipitation | 298,810,200 |
| Total Inflow | 8,903,011,600 |
| Evaporation | 524,172,800 |
| Total Outflow | 8,378,838,800 |
| Net Retention | 00 |
| Residence Time | 0.22 Years (80 Days) |

**Table 9. E. A. Patterson Lake Nitrogen Budget for June 1995 - May 1996**

| Source | Pounds of Nitrogen |
|---|---|
| Over Land Flow | 104,000 |
| Precipitation | 5,799 |
| Total Inflow | 109,799 |
| Evaporation | 00 |
| Total Outflow | 98,816 |
| Net Retention | 10,983 |

**Table 10. E. A. Patterson Lake Phosphorus Budget for June 1995 - May 1996**

| Source | Pounds of Nitrogen |
|---|---|
| Over Land Flow | 39,352 |
| Precipitation | 174 |
| Total Inflow | 39,526 |
| Evaporation | 00 |
| Total Outflow | 11,309 |
| Net Retention | 28,217 |

**Table 11. E. A. Patterson Lake Sediment Budget for June 1995 - May 1996**

| Source | Tons of Sediment |
|---|---|
| Total Inflow | 20,210 |
| Total Outflow | 7,120 |
| Net Retention | 13,000 |

## MODELED LAKE RESPONSE TO REDUCED POLLUTANT LOADS

E. A. Patterson Lake's observed and predicted nutrient, biological and physical responses for the study period are depicted in Table 12. The predicted responses are a product of a calibrated BATHTUB model. The model was calibrated using the measured load and lake response in 1995-1996.

Nitrogen and phosphorus are controlling E. A. Patterson Lake's trophic response. Trophic response is a measure of primary production which can be predicted using concentrations of phosphorus, chlorophyll-a and secchi disk depth transparency. These are calculated for E. A. Patterson Lake using Carlson's Trophic Status indexes (TSI) (Table 12). Carlson's TSI uses a scale of 1 through 100, where increases in the TSI score indicate increases in trophic response (Figure 7).

**Table 12. E. A. Patterson Lake Observed and Calibrated Trophic Response Model**

| Variable | Observed Value | Modeled Value | Unit |
|---|---|---|---|
| Total Phosphorus | 0.158 | 0.159 | mg/L |
| Total Nitrogen | 1.386 | 1.386 | mg/L |
| Chlorophyll-a | 15.000 | 15.000 | µg/L |
| Secchi Disk Depth | 0.030 | 0.300 | Meter |
| Organic Nitrogen | 0.808 | 0.808 | mg/L |
| Carlson's TSI-Phosphorus | 77.190 | 77.210 | TSI |
| Carlson's TSI-Chlorophyll-a | 57.170 | 57.230 | TSI |
| Carlson's TSI-Secchi | 77.350 | 77.540 | TSI |

The following diagnostic evaluations were preformed using the Corps of Engineer's BATHTUB model. The model has been calibrated to match E. A. Patterson Lake's trophic response between June 1995 - May 1996. Following calibration, the model was fed a series of reduced phosphorus loads to evaluate the relative range of trophic response likely to occur through implementation of best management practices (BMPs) and in-lake reductions of available phosphorus. Phosphorus was selected as it is known to cause eutrophication and because it is controllable through the implementation of BMPs.

The effectiveness of a given restoration alternative was evaluated by comparing the model's predicted response in relation to the current trophic condition. Note that under ideal circumstances a minimum of two years of monitoring is desired for calibration with a third year for validation. However, the scope of this project does not require extremely accurate trophic response prediction but rather a dependable direction and relative range of response. Keeping this in mind, the interpretations are within the limits of the data and model employed.

While many of the restoration alternatives overlapped (requiring multiple model runs), there were three basic alternatives: (1) improving trophic response through reduced pollution inputs; (2) improving trophic response by reducing internally available pollutants; and (3) reducing external and internal pollution loads.

Following are the BATHTUB model-predicted reductions in trophic response if E. A. Patterson Lake's phosphorus load is reduced 25, 50, 75 and 85 percent. Reductions are simulated by reducing the concentrations in the Heart River and other external delivery sources by the appropriate percentage while leaving the hydraulic budget constant. The hydraulic inflows and outflows remained constant as there was no reliable means of estimating how much hydraulic discharge would be reduced or increased from BMP implementation.

**Alternative 1: Reducing External Phosphorus Loading**

The model results of Alternative 1 indicate that if it were possible to reduce the nutrient concentrations being delivered by 50 percent or more, the trophic response would be reduced a measurable amount. However, it is unlikely that this change would be noticeable to the average lake user. To induce a response that would be noticeable to the average lake user, it is estimated that a 75 percent reduction would have to be achieved (Table 13, 14, 15 and 16).

**Table 13. Actual Trophic Condition and Modeled Response Using a 25-Percent Reduction in Inflow Phosphorus Concentrations**

| Variable | Observed Value | Modeled Value | Unit |
|---|---|---|---|
| Total Phosphorus | 0.158 | 0.134 | mg/L |
| Total Nitrogen | 1.386 | 1.386 | mg/L |
| Chlorophyll-a | 15.000 | 14.180 | µg/L |
| Secchi Disk Depth | 0.030 | 0.300 | Meter |
| Organic Nitrogen | 0.808 | 0.784 | mg/L |
| Carlson's TSI-Phosphorus | 77.190 | 74.790 | TSI |
| Carlson's TSI-Chlorophyll-a | 57.170 | 56.610 | TSI |
| Carlson's TSI-Secchi | 77.350 | 77.400 | TSI |

**Table 14. Actual Trophic Condition and Modeled Response Using a 50-Percent Reduction in Inflow Phosphorus Concentrations**

| Variable | Observed Value | Modeled Value | Unit |
|---|---|---|---|
| Total Phosphorus | 0.158 | 0.104 | mg/L |
| Total Nitrogen | 1.386 | 1.386 | mg/L |
| Chlorophyll-a | 15.000 | 13.950 | µg/L |
| Secchi Disk Depth | 0.030 | 0.300 | Meter |
| Organic Nitrogen | 0.808 | 0.781 | mg/L |
| Carlson's TSI-Phosphorus | 77.190 | 71.240 | TSI |
| Carlson's TSI-Chlorophyll-a | 57.170 | 56.450 | TSI |
| Carlson's TSI-Secchi | 77.350 | 77.400 | TSI |

**Table 15. Actual Trophic Condition and Modeled Response Using a 75-Percent Reduction in Inflow Phosphorus Concentrations**

| Variable | Observed Value | Modeled Value | Unit |
|---|---|---|---|
| Total Phosphorus | 0.158 | 0.067 | mg/L |
| Total Nitrogen | 1.386 | 1.386 | mg/L |
| Chlorophyll-a | 15.000 | 9.630 | µg/L |
| Secchi Disk Depth | 0.030 | 0.310 | Meter |
| Organic Nitrogen | 0.808 | 0.781 | mg/L |
| Carlson's TSI-Phosphorus | 77.190 | 64.730 | TSI |
| Carlson's TSI-Chlorophyll-a | 57.170 | 52.810 | TSI |
| Carlson's TSI-Secchi | 77.350 | 76.940 | TSI |

**Table 16. Actual Trophic Condition and Modeled Response Using an 85-Percent Reduction in Inflow Phosphorus Concentrations**

| Variable | Observed Value | Modeled Value | Unit |
|---|---|---|---|
| Total Phosphorus | 0.158 | 0.047 | mg/L |
| Total Nitrogen | 1.386 | 1.386 | mg/L |
| Chlorophyll-a | 15.000 | 7.260 | µg/L |
| Secchi Disk Depth | 0.030 | 0.310 | Meter |
| Organic Nitrogen | 0.808 | 0.609 | mg/L |
| Carlson's TSI-Phosphorus | 77.190 | 59.630 | TSI |
| Carlson's TSI-Chlorophyll-a | 57.170 | 50.050 | TSI |
| Carlson's TSI-Secchi | 77.350 | 76.680 | TSI |

**Alternative 2: Reducing Internal Phosphorus**

Options for reducing internal phosphorus cycling include sediment/macrophyte removal and aeration. While there are three options for reducing internal nutrient cycling, the response is modeled the same for all. In other words, a 50-percent reduction in internal nutrient cycling would result in a similar trophic response if it is achieved through the removal of sediments through dredging or preventing their release by aeration. This alternative does not affect residence time or atmospheric or watershed loadings.

For purposes of this evaluation, a reduction in internal cycling of phosphorus was modeled by adjusting calibration coefficients for phosphorus in the calibrated model. This assumed that the amount of internal nutrient cycling is approximately equivalent to the amount of calibration required to achieve an accurate model. The internal nutrient cycling reductions are then modeled by reducing the amount of calibration by the percentage of internal nutrient cycling to be control.
For example, if the decay rate of phosphorus needed to be changed from 1 to 0.50 to get a calibrated model, a 50-percent reduction in internal cycling would be represented by increasing the decay rate

to 0.75. While there is obvious unknown error in this process, the exercise should provide a useful estimation of the decreased trophic response to expect from a single reduction of a specific percentage of internal cycling of phosphorus.

Alternative 2 shows that a single reduction in internal cycling of 50 percent, similar to the 50 percent reduction in external, would most likely result in a measurable change in trophic response. However, it is debatable if it would be great enough for the average lake user to recognize (Table 17).

**Table 17. Actual Trophic Condition and Modeled Response Using a 50-Percent Reduction in Internal Cycling of Phosphorus**

| Variable | Observed Value | Modeled Value | Unit |
|---|---|---|---|
| Total Phosphorus | 0.158 | 0.116 | mg/L |
| Total Nitrogen | 1.386 | 1.386 | mg/L |
| Chlorophyll-a | 15.000 | 13.350 | µg/L |
| Secchi Disk Depth | 0.030 | 0.300 | Meter |
| Organic Nitrogen | 0.808 | 0.764 | mg/L |
| Carlson’s TSI-Phosphorus | 77.190 | 72.790 | TSI |
| Carlson’s TSI-Chlorophyll-a | 57.170 | 56.030 | TSI |
| Carlson’s TSI-Secchi | 77.350 | 77.350 | TSI |

**Alternative 3: Reducing Internal Cycling and External Phosphorus Load**

The third alternative involves a modeling a 50-percent reduction in internal phosphorus cycling and graduated decreases in phosphorus concentrations in external load. All methods and assumptions are the same as in previous alternatives.

In brief, the results of this modeling exercise is a predicted measurable and noticeable change in E. A. Patterson Lake’s trophic condition with a 50-percent reduction in internal cycling and a 25-percent reduction in external load (Table 18). The lake condition continues to improve with each sequential model run where phosphorus concentrations in the inflow waters are decreased (Tables 19, 20 and 21).

**Table 18. Actual Trophic Condition and Modeled Response Using a 50-Percent Reduction in Internal Cycling and a 25-Percent Reduction in Inflow Concentrations of Phosphorus**

| Variable | Observed Value | Modeled Value | Unit |
|---|---|---|---|
| Total Phosphorus | 0.158 | 0.100 | mg/L |
| Total Nitrogen | 1.386 | 1.386 | mg/L |
| Chlorophyll-a | 15.000 | 12.370 | µg/L |
| Secchi Disk Depth | 0.030 | 0.300 | Meter |
| Organic Nitrogen | 0.808 | 0.739 | mg/L |
| Carlson’s TSI-Phosphorus | 77.190 | 70.560 | TSI |
| Carlson’s TSI-Chlorophyll-a | 57.170 | 55.270 | TSI |
| Carlson’s TSI-Secchi | 77.350 | 77.240 | TSI |

**Table 19. Actual Trophic Condition and Modeled Response Using a 50-Percent Reduction in Internal Cycling and a 50-Percent Reduction in Inflow Concentrations of Phosphorus**

| Variable | Observed Value | Modeled Value | Unit |
|---|---|---|---|
| Total Phosphorus | 0.158 | 0.080 | mg/L |
| Total Nitrogen | 1.386 | 1.386 | mg/L |
| Chlorophyll-a | 15.000 | 10.850 | µg/L |
| Secchi Disk Depth | 0.030 | 0.300 | Meter |
| Organic Nitrogen | 0.808 | 0.700 | mg/L |
| Carlson’s TSI-Phosphorus | 77.190 | 67.290 | TSI |
| Carlson’s TSI-Chlorophyll-a | 57.170 | 53.980 | TSI |
| Carlson’s TSI-Secchi | 77.350 | 77.080 | TSI |

**Table 20. Actual Trophic Condition, and Modeled Response Using a 50-Percent Reduction in Internal Cycling and a 75-Percent Reduction in Inflow Concentrations of Phosphorus**

| Variable | Observed Value | Modeled Value | Unit |
|---|---|---|---|
| Total Phosphorus | 0.158 | 0.053 | mg/L |
| Total Nitrogen | 1.386 | 1.386 | mg/L |
| Chlorophyll-a | 15.000 | 8.030 | µg/L |
| Secchi Disk Depth | 0.030 | 0.310 | Meter |
| Organic Nitrogen | 0.808 | 0.628 | mg/L |
| Carlson’s TSI-Phosphorus | 77.190 | 61.340 | TSI |
| Carlson’s TSI-Chlorophyll-a | 57.170 | 51.040 | TSI |
| Carlson’s TSI-Secchi | 77.350 | 76.760 | TSI |

**Table 21. Actual Trophic Condition and Modeled Response Using a 50-Percent Reduction in Internal Cycling and an 85-Percent Reduction in Inflow Concentrations of Phosphorus**

| Variable | Observed Value | Modeled Value | Unit |
|---|---|---|---|
| Total Phosphorus | 0.158 | 0.038 | mg/L |
| Total Nitrogen | 1.386 | 1.386 | mg/L |
| Chlorophyll-a | 15.000 | 6.010 | µg/L |
| Secchi Disk Depth | 0.030 | 0.320 | Meter |
| Organic Nitrogen | 0.808 | 0.578 | mg/L |
| Carlson’s TSI-Phosphorus | 77.190 | 56.670 | TSI |
| Carlson’s TSI-Chlorophyll-a | 57.170 | 48.190 | TSI |
| Carlson’s TSI-Secchi | 77.350 | 76.540 | TSI |

## LAND USE

Land use was assessed in the E. A. Patterson Lake watershed by utilizing a systematic random sampling method (SRSM). The SRSM identified 315 quarter, quarter-section plots (40 acres) within the Patterson Lake watershed. The watershed was further divided into six sub-watersheds of which five had discrete water quality and loading data. The breakdown of plots between sub-watersheds is 55 for the Ash Creek drainage, 34 for South Branch of the Heart River drainage below Bull Creek to its confluence with the Heart River, 86 for the South Branch of the Heart River above Bull Creek and Bull Creek drainage, 69 for the Heart River above the confluence of the South Branch of the Heart drainage, 49 for the North Creek drainage and 21 for the Duck Creek drainage. All sub-watersheds, with the exception of Duck Creek, have discrete water quality and quantity data.

Land use was assessed by observed use and condition. If more then one practice or condition was observed, the unit was split and each practice and corresponding condition recorded and an average for the entire 40-acre plot calculated.

Land uses identified were range, pasture, hayland, conservation reserve program (CRP), other (cemetaries, churches, roads, etc) and farmsteads. Tilled conditions were assessed for the previous crop, the present crop, the amount of crop residue in the fall after winter preparations and the amount of crop residue in the spring after tillage. These observations were combined with rainfall and slope length to estimate the amount of soil loss using the Universal Soil Loss Equation (USLE). It is not assumed that the soil loss estimates formulated using this methodology are accurate predictions of real soil loss; however, it is assumed that the error in the soil loss estimates are equal and provide a useful vehicle to compare sub-watersheds.

Non-tilled acreage was assessed for general condition using four qualitative observations. The four observations are:

1. Is grazing management being used?
2. Is erosion evident?
3. Are there invader plant species?
4. What is the general condition of the range (good, fair, poor)?

Land use in the E. A. Patterson Lake watershed is approximately 42 percent cropped with the remainder in some form of permanent or semi-permanent grass (Table 22). By sub-watershed the percentage of tilled percentages ranged from a high of 46.5 percent in the South Branch of the South Heart River between the confluences of Bull Creek and the Heart River to a low of 34.4 percent in the Duck Creek drainage. The estimated soil loss from tilled lands per sub-watershed ranged from a high of 1.9 tons per acre in the South Branch of the Heart River below Bull Creek drainage to a low of 0.9 tons per acre in the Duck Creek drainage (Table 22).

**Table 22. Land Use Percentages in the E. A. Patterson Lake Watershed**

| Sub-Watershed | Crop | Range | Pasture | Hay | CRP | Other | Farm |
|---|---|---|---|---|---|---|---|
| Ash Creek | 39.80 | 17.8 | 13.8 | 14.7 | 3.8 | 6.3 | 4.5 |
| So. Br. Heart Below Bull Creek | 46.5 | 5.0 | 20.2 | 1.2 | 22.0 | 3.8 | 1.8 |
| So. Br. Heart at South Heart | 40.7 | 24.6 | 12.1 | 7.3 | 9.6 | 3.2 | 2.6 |
| Heart at South Heart | 43.0 | 8.3 | 24.9 | 10.5 | 7.3 | 4.0 | 2.0 |
| North Creek | 44.3 | 17.5 | 11.5 | 11.9 | 9.4 | 2.0 | 3.4 |
| Duck Creek | 34.4 | 24.1 | 11.8 | 24.5 | 0.0 | 0.2 | 5.1 |
| Average for Entire Watershed | 41.7 | 16.6 | 15.9 | 10.8 | 8.5 | 3.6 | 3.0 |

**Table 23. Residue/Soil Loss Estimates in the E. A. Patterson Lake Watershed**

| | Percent Crop Residue | | Tons/Acre |
|---|---|---|---|
| Sub-Watershed | Fall | Spring | Soil Loss |
| Ash Creek | 60.8 | 25.7 | 1.3 |
| So. Br. Heart Below Bull Creek | 65.7 | 22.2 | 1.9 |
| So. Br. Heart at South Heart | 63.6 | 22.1 | 1.7 |
| Heart at South Heart | 66.7 | 3.4 | 1.4 |
| North Creek | 59.8 | 19.7 | 1.6 |
| Duck Creek | 60.7 | 33.7 | 0.9 |
| Average for Entire Watershed | 63.3 | 26.0 | 1.5 |

The observed condition of the range and pasture lands in the Patterson Lake watershed ranged from good to poor with an overall average of 35.6 percent in good condition, 44.4 percent in fair condition and 20.0 percent in poor condition. This is exceptional considering only 34.8 percent of the range or pasture lands have a management system, 56.5 percent had noted erosion and 82.2 percent have invader plant species.

There are three conclusions drawn from the diagnostic and feasibility water quality project:
(1) pollutant loadings into E. A. Patterson Lake are exceeding the assimilative ability of E. A. Patterson Lake leading to increased eutrophication and premature aging and shallowing of the reservoir; (2) if the phosphorus loadings (either internal, external or combined) to E. A. Patterson Lake are reduced 75 percent, a noticeable improvement would occur; and (3) nutrients and total suspended solids loadings are heavily influenced by snow melt and precipitation runoff events.

The largest amounts of total phosphorus, total nitrogen and total suspended solids were carried by the individual creeks during the first melts of spring. This coincides with the period when the fields have the least amount of residue, the sub-surface soils are frozen and animal wastes have been concentrated as a result of winter feeding.

Each creek entering into E. A. Patterson Lake affects the trophic condition to varying degrees. The highest amounts of phosphorus per acre were received from the South Branch of the Heart River followed by Ash Creek, Bull Creek and North Creek.

The land use assessment indicates the tillable acreage in the E. A. Patterson Lake watershed are well managed against soil loss from water erosion. Annual soil loss estimates range from a sub-watershed low of 0.9 tons per acre to a sub-watershed high of 1.9 tons per acre. The overall average is 1.5 tons per acre.

The high crop residue percentages are the reason for the relatively low soil loss estimates. After spring tillage, the sub-watershed with the lowest amounts of crop residues averaged 19.7 percent crop residue, the highest was 34 percent and the overall average within the watershed was 26 percent.

In general, soil and nutrient loss per square mile correlated well to the land use assessment. The only exceptions are the nitrogen loads on Ash Creek and the phosphorus loads on the drainage that include the South Branch of the Heart River above Bull Creek and Bull Creek. Ash Creek discharged a larger amount of nitrogen per square mile than would be expected from the estimated amount of soil loss, and the South Branch of the Heart River above Bull Creek and Bull Creek discharged a smaller amount of phosphorus than would be expected from the amount of soil loss (Table 24).

Range and pasture lands, while not assessed for soil loss, can be a significant source of both nutrients and sediments. Improper or overgrazing of pastures, especially riparian pastures, contributes to a stream's pollution load by physically depositing sediment and nutrients and by destroying stream bank and bed. A stream that has been degraded through this process has a decreased ability to clean itself and also a decreased ability to move its sediment load, causing further degradation to the stream.

**Table 24. Sediment and Nutrient Delivery (in Tons) Compared to Soil Loss Estimates Using the Universal Soil Loss Equation and No Delivery Reduction Factor**

| | Actually Monitored Tons Per Square Mile | | | Estimated Tons Per Square Mile |
|---|---|---|---|---|
| **Sub-Watershed** | **Sediment** | **Phosphorus** | **Nitrogen** | **Soil** |
| Ash Creek | 16 | 0.018 | 0.244 | 576 |
| So. Br. Heart Below Bull Creek | 28 | 0.025 | 0.100 | 896 |
| So. Br. Heart at South Heart | 53 | 0.054 | 0.159 | 1024 |
| Heart at South Heart | 107 | 0.025 | 0.089 | 1088 |
| North Creek | 150 | 0.031 | 0.326 | 1216 |

In summary, the data shows that E. A. Patterson Lake receives a large nutrient and sediment load annually and that the reservoir is an efficient trapper of these pollutants. The budget analysis, combined with the modeling experiments, strongly suggests that if left unchanged, E. A. Patterson Lake will continue to experience increased symptoms of eutrophication such as fish kills, increases in the frequency and intensity of algal blooms and loss of depth.

The water quality data, lake modeling and land use assessments were encouraging as well. The water quality data and modeling suggest that a measurable improvement in E. A. Patterson Lake's condition could be achieved with as little as a 50-percent reduction in either its internal or external phosphorus load. Additionally, a measurable and noticeable improvement could be achieved with a 75-percent reduction.

Land use data shows a good linkage between monitored sediment and nutrient delivery to estimated soil loss. This supports the hypothesis that at least some measure of control can be achieved through implementation of BMPs to (1) increase soil retention on the upland and (2) reduce phosphorus loading to E. A. Patterson Lake.