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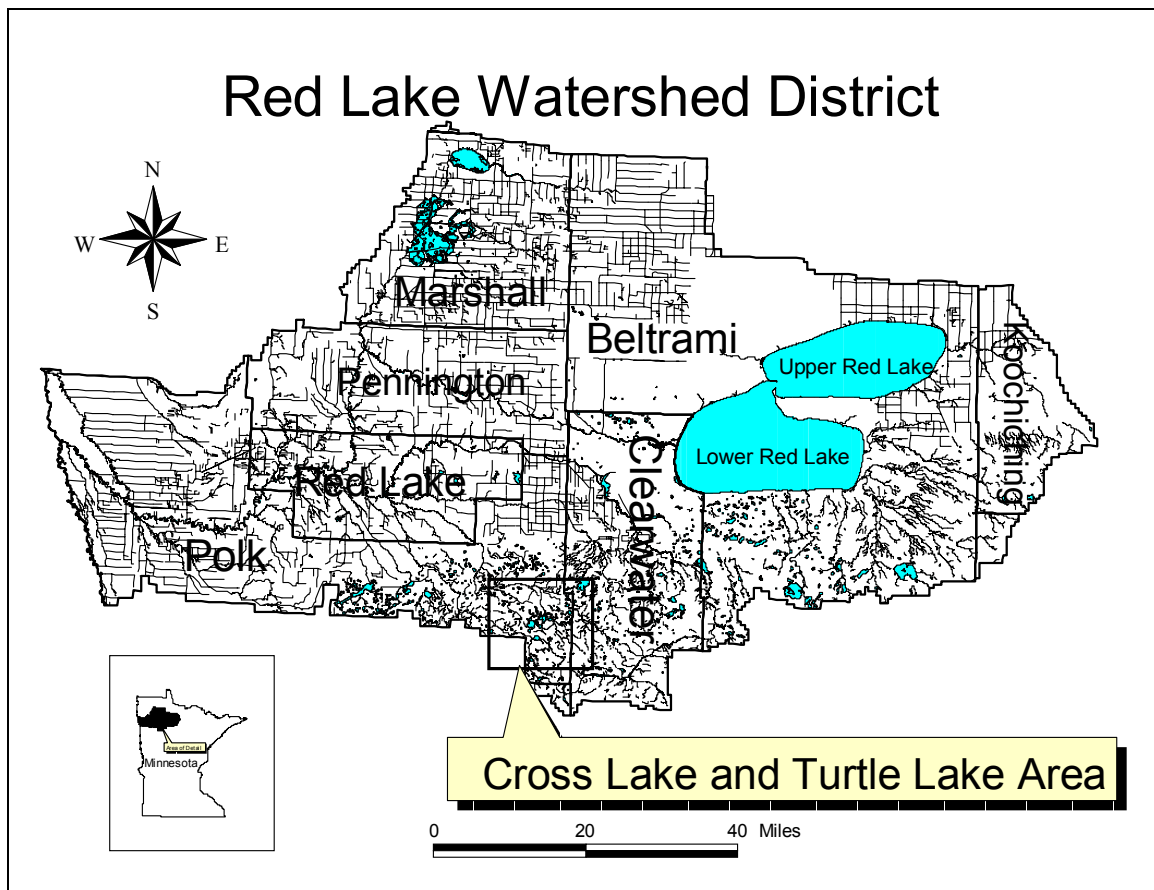
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Background

A long history of public concern exists over the water quality and hydrologic characteristics of the Cross Lake and Turtle Lake system. During the early 1930's, in an effort to control lake levels, the Works Progress Administration (WPA) constructed dams on South Connection Lake, Turtle Lake, and Cross Lake. Local residents often raise concern about the effects of these dams on the hydrology of the lake system. Residents believe some lakes within the system were held artificially high, thereby affecting the flow of water and the water quality of the system. Excessive algae and nutrients are the greatest concerns for Cross Lake and Turtle Lake water quality. There is also an on-going discussion about whether to manage Turtle Lake as a fishery or waterfowl lake. (Preliminary Study Design 1996)

The Cross Lake and Turtle Lake system is located in eastern Polk County, approximately 3 miles north-east of Fosston, Minnesota in the northwest part of the state. The system is near the origin of the Hill River, which is one of the main tributaries to the Clearwater River (Figure 1).

FIGURE 1. AREA OF STUDY



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In 1997 the Red Lake Watershed District (RLWD) initiated a study of the hydrologic and water quality characteristics of the lakes. The purpose is to obtain basic information about the hydrologic characteristics of the lakes and to provide baseline water quality data. This first phase of the study will determine if future water quality monitoring is needed. The second phase (if needed) would provide a detailed nutrient balance for each lake.

History

Cross Lake and Turtle Lake have extended histories of water quality problems along with determining and maintaining water levels. Orrin Torgerson, a long time resident near Turtle Lake, and Paul Stolen, who currently resides in the area, apprised historical accounts and information (Appendix B).

Land Use

Agricultural production is a large part of the land use around the Cross Lake and Turtle Lake system. Agricultural practices in the contributing watershed include dairy farms, beef production, livestock pasture land, and some crop production such as corn, small grains, soybeans, hay and forage crops, sunflowers and other oilseed crops. There is also land in the Conservation Reserve Program along with lowland and forested areas, some of which are National Wildlife Management Areas. Area residents also reported a mink farm, which is no longer in operation, was located on the southeast side of Cross Lake or in the south central part of Section 21, Queen Township. According to residents much of the animal waste generated from the mink farm left in the area may have been buried in adjacent Cross Lake.

Project Overview

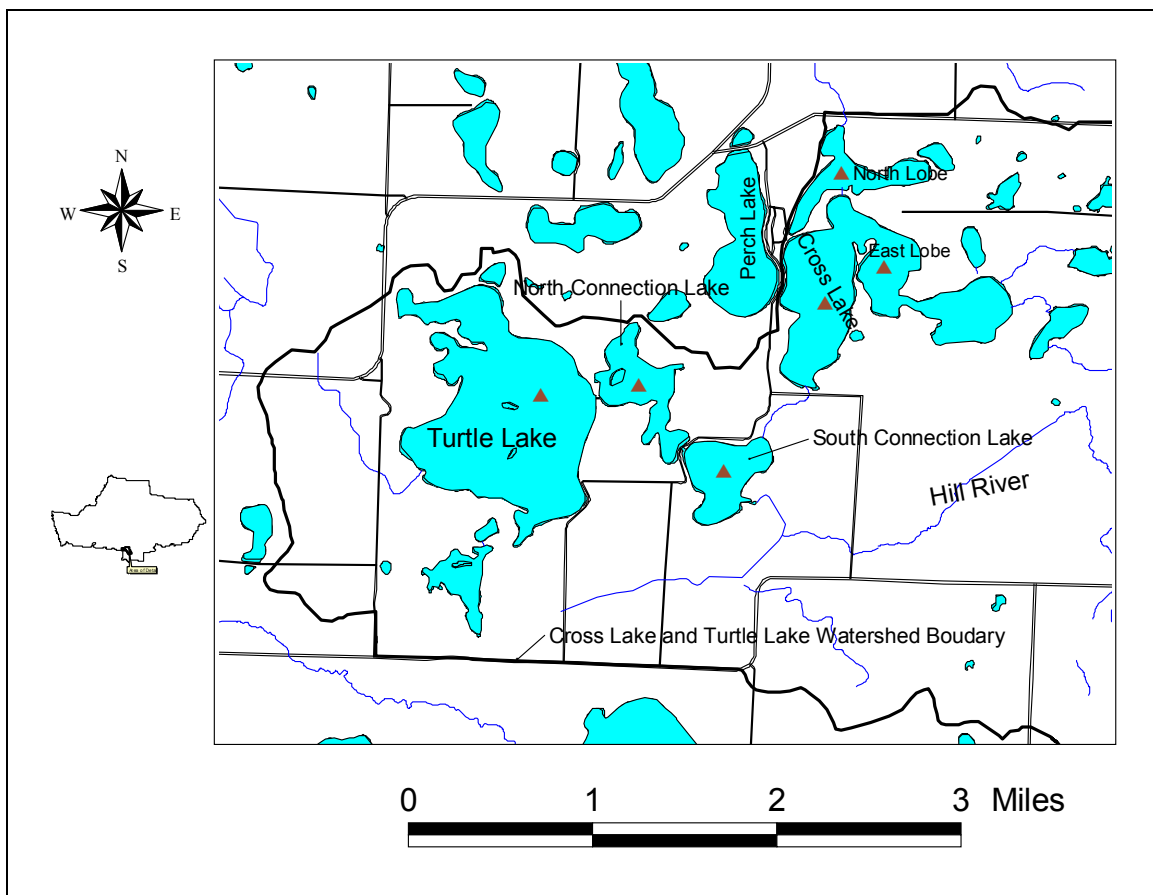
RLWD staff responsibilities included the installation of flow monitoring equipment, stream gaging, surveying, collection and analysis of water quality samples, some reduction of hydrologic data and summarization of the water quality information. Consulting services from Houston Engineering, Inc. used the information collected by RLWD staff to develop rating curves. The firm developed the hydrologic budgets for the study. Houston Engineering, Inc. provided the methods used to develop the hydrologic data, present hydrology data including the hydrologic budgets, some perspective relative to the accuracy of the hydrologic budgets and recommendations relative to the need for additional hydrologic monitoring.

Methods

Water Quality Methods

Water quality samples were collected from six in-lake monitoring locations (Figure 2). The samples were taken from the deepest part of South Connection Lake, North Connection Lake, Turtle Lake and three basin areas on Cross Lake. Water quality parameters included chlorophyll-a and total phosphorus. Secchi disk readings were also taken. More measurements of total phosphorus and chlorophyll-a were taken than secchi disk readings. Dissolved oxygen and water temperature profiles were also taken at the monitoring sites. Each of these parameters is important in determining trophic status. Originally, the preliminary study design specified one year of water quality and flow monitoring. Due to problems in flow monitoring, the study continued and water quality information was collected for two years, 1997 and 1998.

FIGURE 2. TURTLE LAKE AND CROSS LAKE IN-LAKE MONITORING LOCATIONS



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The methods used for collection and analysis of the water quality samples are mainly described in the “Standard Operating Procedures for Field Samplers” manual from the RLWD. The study period did occur before this manual was created, so there are variations in the collection and analysis from this manual. Also, there were variations in methods between 1997 and 1998. The differences include:

- 1) Lab analysis, in 1997 the analysis of total phosphorus and chlorophyll-a took place at the water lab at the University of Minnesota Crookston (UMC). RLWD staff performed the analysis. In 1998 the samples were sent to a private lab, RMB Environmental Laboratories, Inc. in Detroit Lakes. The staff at RMB performed the analysis. Both labs were certified by the Minnesota Department of Health.
- 2) In 1997, all water quality samples were collected using a kemmerer bottle. In 1998, all water quality samples were collected using 2 meter long water column sampler with a diameter of 2 inches. The column sampler was used on all sampling points in 1998. The north lobe of Cross Lake, South Connection Lake and North Connection Lake have a maximum depth around 2 meters or less, a kemmerer bottle should have been used at these sites. Although, all of the sites were deep enough, in 1997 and 1998, for using a kemmerer bottle instead of taking a grab sample by hand.
- 3) In 1997, the chlorophyll-a samples were collected and filtered in the field, the filters were then wrapped in aluminum foil and kept on ice. The filters were transferred to the UMC lab for analysis. In 1998, the samples were collected in two liter opaque bottles with teflon caps. The samples were then put in a cooler with ice and shipped to RMB Environmental Labs, Inc. When the samples arrived, the staff at RMB filtered the samples in the lab. Both of these techniques are acceptable, when comparing data from the same site, although this may be a cause for error.

Both of the labs utilized in this study had laboratory quality assurance/quality control (QA/QC) procedures outlined in their separate QA/QC manuals.

Another problem with collection of water quality data occurred with establishment of permanent markers or buoys at the maximum depth point at each monitoring point. Permanent markers of the maximum depths were never established leading to varying depths on the dissolved oxygen and water temperature profiles.

The water quality data collected at each site is provided (Appendix A). These tables show measurements were taken at each site in 1997 at two-week periods in July and August and once in October; in 1998, from the last part of May through October twice a month or two-week periods.

Hydrological Methods

A determination of the hydrologic budgets for Cross Lake and Turtle Lake includes surface water inflow and system discharge, evaporation, precipitation, groundwater inflow/outflow and the change in lake storage (Deutschman and Erickson 1999). In order to gage the surface water inflow and discharge, the RLWD purchased several Steven's

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model depth transmitters and data recorders. The instruments were installed at seven sites (Figure 3):

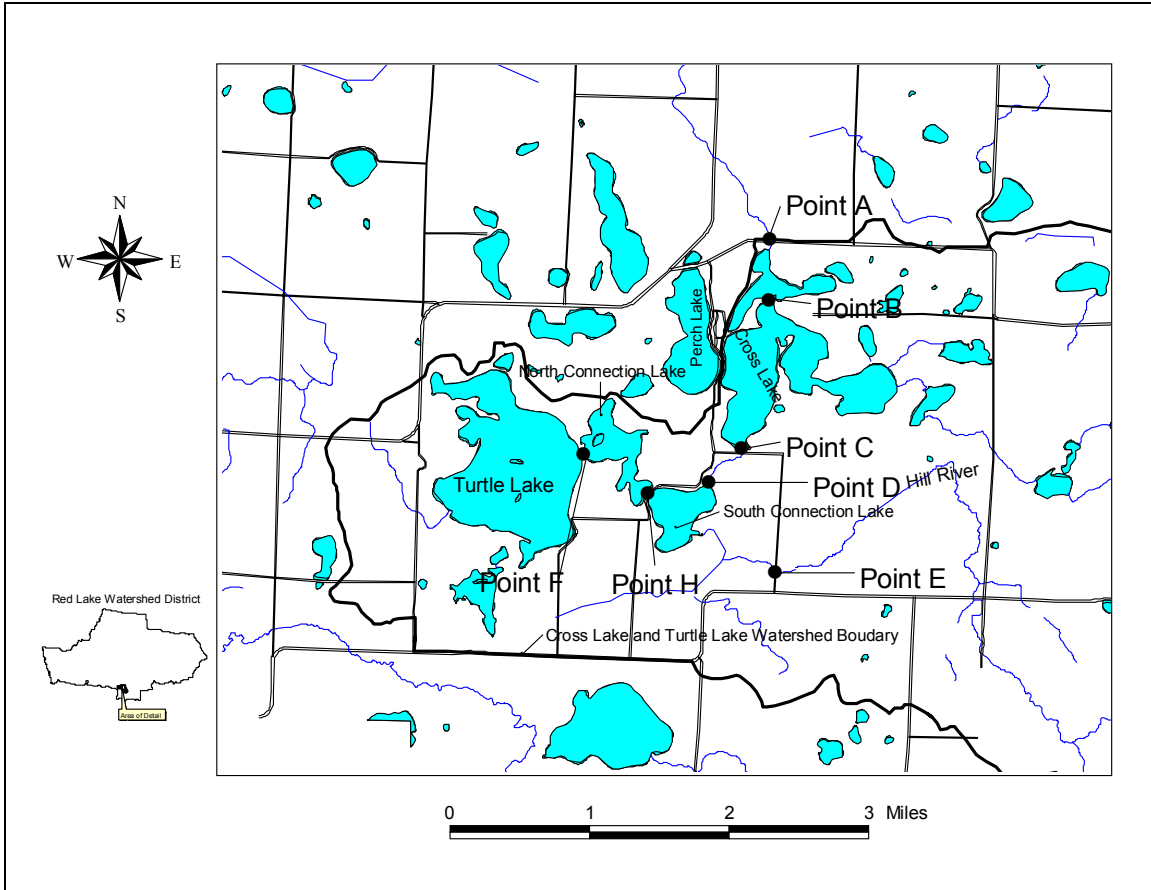
- 1) upstream of the box culvert on the Hill River on Polk County Road # 29 (designated point A)
- 2) near the dam or weir on the north side of Cross Lake (designated point B)
- 3) upstream of the culvert on the gravel road on the South side of Cross Lake (designated point C)
- 4) near the dam or weir on the northeast side of South Connection Lake (designated point D)
- 5) near the box culvert on the Hill River on the gravel road in the south central part of Section 28, Queen Township (designated point E)
- 6) near the dam or weir in the channel between North Connection Lake and Turtle Lake in the northwest corner of Section 29, Queen Township (designated point F)
- 7) near the culvert on the gravel road between South Connection Lake and North Connection Lake in the center of Section 29, Queen Township (designated point H)

The primary surface inflows and system discharges of Cross Lake and Turtle Lake were estimated using rating curves. Weirs serve as the primary flow control structure in Turtle Lake and Cross Lake systems. A specific weir equation was determined by varying a weir coefficient, values from 1.0 to 3.3. HEC-RAS models were utilized for the development of rating curves using the geometry and average slope of channeled stream sections. The rating curves were calibrated with measured stages and streamflows. For the ungaged sections of each watershed, as well as periods without recorded water levels stages within the primary inflow channels, runoff coefficients used in conjunction with assumed rainfall data were utilized to determine surface runoff.

Evaporation was estimated using the mean annual lake evaporation rate provided by the Soil Conservation Service Hydrology Manual. Neither of the watersheds (Cross Lake and Turtle Lake) had rain gages within; therefore, rainfall data provided by the Minnesota State Office of Climatology Volunteer Network was utilized. Because no independent measurements of lake stage were obtained, the net change in lake storage was assumed to be negligible. Groundwater inflow/outflow was assumed to be the difference between the assumed inflows and outflows of each lake. Because groundwater inflow/outflow was not actually measured, the calculated groundwater inflow/outflow also incorporates an error term. (Deutschman and Erickson 1999)

The determination of flow direction provides an understanding of how and when water moves through the Turtle Lake and Cross Lake systems. Flow direction is important for understanding mechanisms in water quality over the course of a year. Of special interest in this report is the flow direction from the Hill River into and out of the Turtle Lake system. A percentage of flow from the Hill River over time into and out of Turtle Lake needs to be determined. The stage at certain locations in the Turtle Lake system, sites E, F and H, could not be used to determine discharge (Figure 3). Problems with measurements will be discussed later in this report. The difference in height between continuous stage recordings was used to determine flow direction.

FIGURE 3. CROSS LAKE AND TURTLE LAKE FLOW MONITORING SITES



Using available survey information, a common datum was established for each of the continuous stage recorders locations. The stage recordings were adjusted to the common datum and the water surface elevations were found at each location. Flow direction, during certain periods of the year, into and out of the Turtle Lake system was found by comparing the water surface elevation at point H, F and D. The procedures for the flow direction determination are outlined in the “Documentation of Flow Direction” (Appendix D).

Trophic Status

The Carlson Trophic State Index (TSI) was used to compare measurements of chlorophyll-a, Secchi transparency and total phosphorus concentration for the determination of lake trophic status (Heiskary 1998 and Olem and Flock 1990).

Ecoregion Concept

To define the natural amount of algal biomass or trophic status, the Environmental Protection Agency (EPA) mapped ecoregions for the United States from information on soils, landform, potential natural vegetation, and land use. The EPA defined seven ecoregions within Minnesota. Cross Lake and Turtle Lake lie within the boundaries of the North Central Hardwood Forests Ecoregion. The Minnesota Pollution Control Agency (MPCA) chose several reference lakes, lakes deemed to be representative of the ecoregion and minimally impacted by human influences, to sample from and gain an understanding of the natural trophic status and water quality (Heiskary, 1998). Since the Cross Lake and Turtle Lake systems have a history of human influences, they are compared to the reference lakes to understand changes in trophic status and water quality.

Results

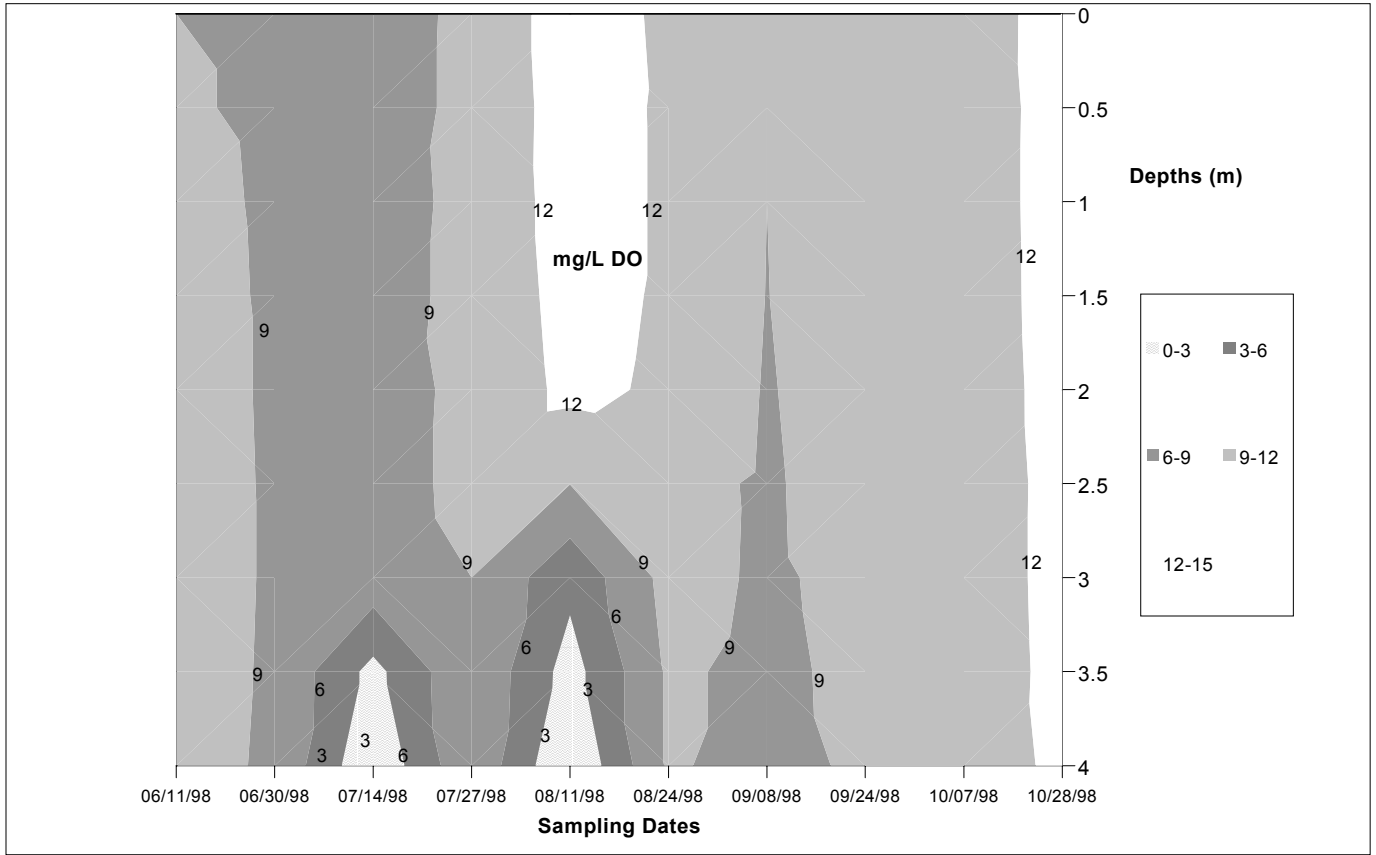
Water Quality Results

Dissolved Oxygen/Water Temperature Profiles

The dissolved oxygen and temperature profiles of Cross Lake are appropriate for lakes with depths greater than 2 meters. South Connection Lake, North Connection Lake and the north lobe of Cross Lake had depths during the sampling period of 2 meters or less. Dissolved oxygen and temperature in shallow lakes are usually evenly distributed throughout the water column. For these sites, a dissolved oxygen and water temperature at mid-level are reported on a table (Appendix A).

At the Cross Lake site, dissolved oxygen levels below 2.5 meters were less than 3 mg/L twice during the sampling period (Figure 4). Cross Lake is shallow with a maximum depth of 19 feet. Possible reasons for the periodic drop in dissolved oxygen levels include periods of mixing and non-mixing through wind and flowing water or temperature changes. The dissolved oxygen/water temperature profiles for Turtle Lake and the east lobe of Cross Lake only cover a depth of 2 meters and 2.5 meters respectively. This depth is not sufficient for identification of stratification or changes in the dissolved oxygen profile at these sites.

FIGURE 4. TEMPERATURE AND DISSOLVED OXYGEN PROFILE

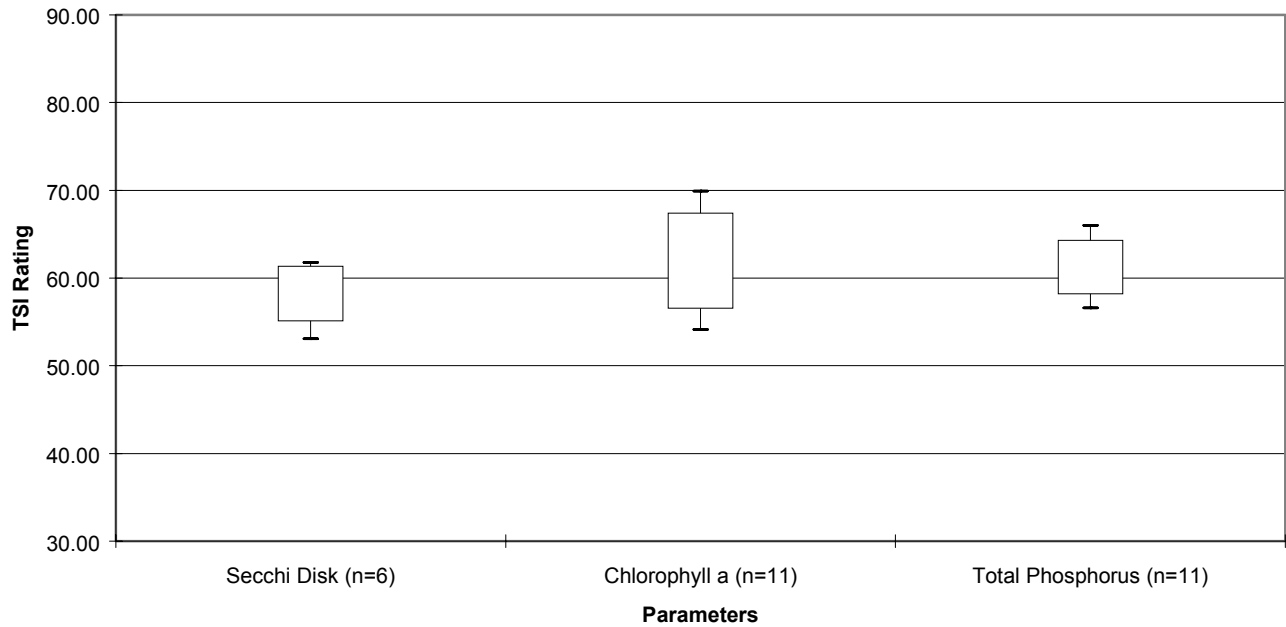


Trophic Status

For total phosphorus, chlorophyll-a and secchi disk measurements, a mean TSI value was found along with the standard deviation among the sets of measurements (Figures 5, 6 and 7). Whisker box plots were created for each site using the 1998 data.

As noted earlier in this report, the 1997 and 1998 measurements were collected utilizing different labs and the sampling methods were different.

FIGURE 5. CROSS LAKE TROPHIC STATUS INDEX



The 1997 water quality data was not considered for this report due to the following reasons.

- 1) For the east lobe of Cross Lake, the largest difference was in the total phosphorus measurements. 1997 phosphorus TSI values had a high of 74.88 and a low of 45.00, whereas the 1998 data had a high of 63.43 and low of 48.72.
- 2) For Cross Lake the TSI values for both chlorophyll-a and total phosphorus .
- 3) The range of the Turtle Lake measurements was less with 1998 data.
- 4) There were very few measurements (4) actually taken in 1997.

FIGURE 6. EAST LOBE OF CROSS LAKE TROPHIC STATUS INDEX

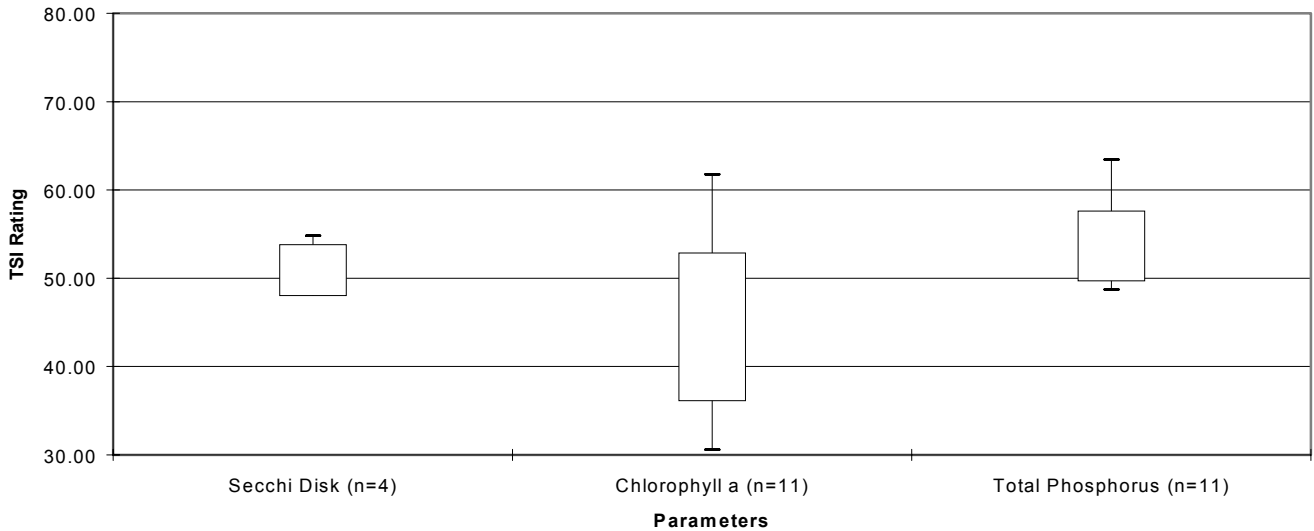
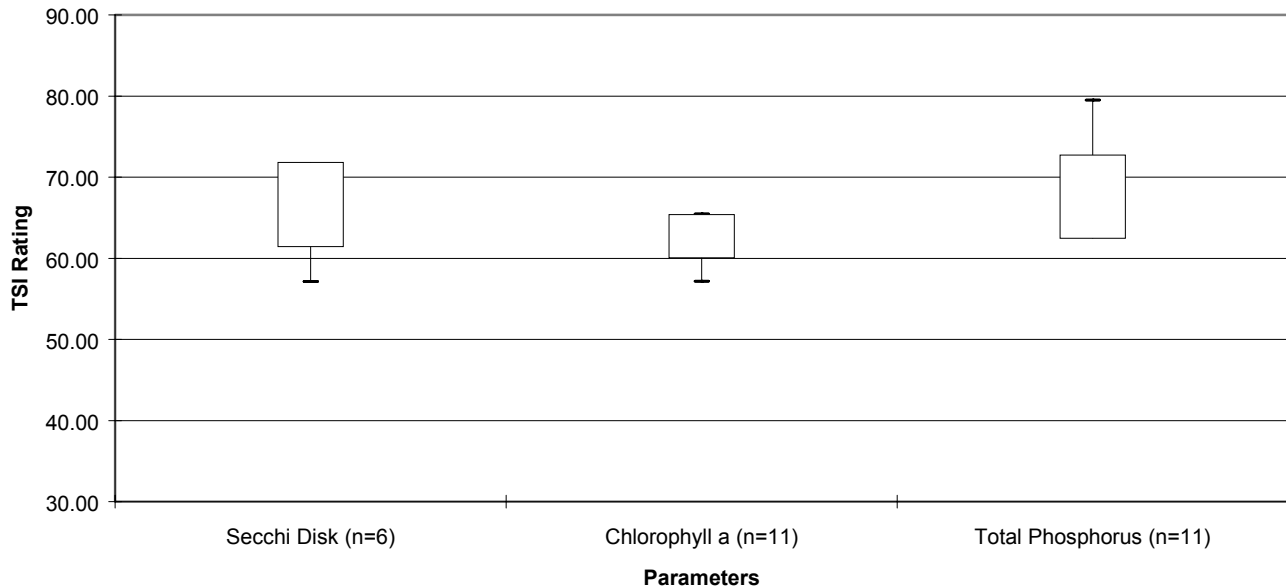


FIGURE 7. TURTLE LAKE TROPHIC STATUS INDEX



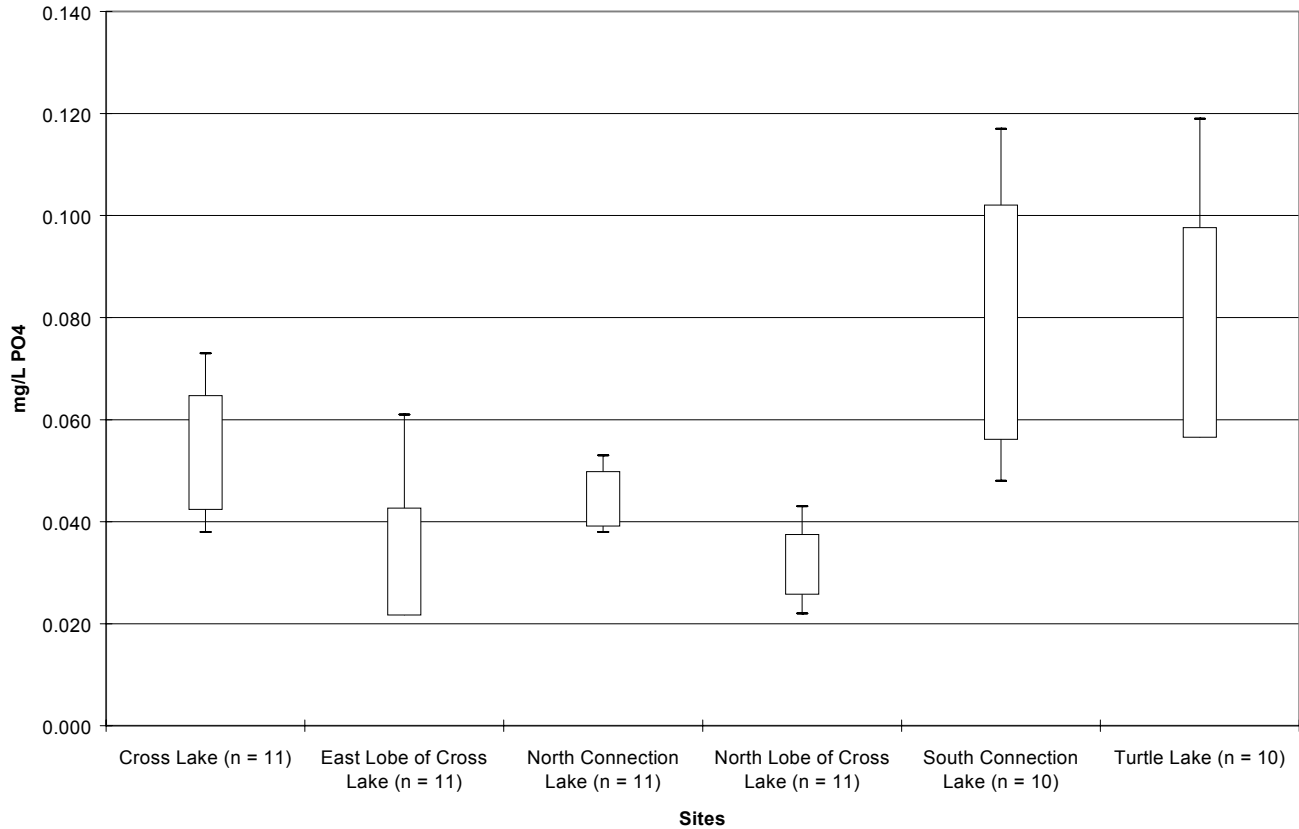
The east lobe of Cross Lake had an average chlorophyll-a TSI of 44.5. The average secchi disk TSI was 51 and the average total phosphorus TSI was 53.66. Much of the east lobe of Cross lake had dense emergent and submergent vegetation. Macrophyte growth competes with algae for nutrients and may give inaccurate chlorophyll-a and secchi disk measurements. In this case the total phosphorus is considered the more accurate TSI value. The average TSI values of Cross Lake and Turtle Lake were close (within 5 TSI). Although, there were fewer secchi disk readings (6) taken so the mean TSI for Cross Lake and Turtle Lake were found by averaging the mean chlorophyll-a TSI and the mean total phosphorus TSI.

Reference data from the North Central Hardwood Forests Ecoregion were used for comparison of TSI values found on the Cross Lake and Turtle Lake systems (Appendix E). The TSI values for Cross Lake exceeded this range by about 1 to 1.5 for both chlorophyll-a and total phosphorus. Turtle Lake exceeded this range by 2 for chlorophyll-a and 7 for total phosphorus. The TSI values for the east lobe of Cross Lake fell within this range.

South Connection Lake, the north lobe of Cross Lake and North Connection lake are all shallow in nature (2 meters max depth or less). Total phosphorus, chlorophyll-a and secchi disk measurements were taken in the same manner as the other three sites. All three sites had heavy submerged plant growth. Secchi disk and chlorophyll-a measurements are affected by this plant growth. This is evident by the “clear to the bottom” secchi disk readings at each of these sites. In this report only total phosphorus measurements are displayed (Figure 7). If points in the data set appeared to be outliers

they were not considered for this report. The mean total phosphorus value for South Connection Lake and Turtle Lake

FIGURE 8. TOTAL PHOSPHORUS IN THE CROSS LAKE AND TURTLE LAKE SYSTEMS



are considerably higher than the mean levels of total phosphorus for any of the Cross Lake sites. It is not known how much phosphorus and other nutrients contained in water from the Turtle Lake system is actually adding to the Cross Lake system. Future monitoring at these sites may address this situation.

Hydrological Results

The estimated magnitude of each hydrologic budget parameter is discussed in the following with regard to each lake system. Graphical representations of the hydrologic budgets in absolute terms as well as percentages of the total volume of water passing through each hydrologic system are shown (Appendix C). Also included are plots of the surface inflow and system discharge hydrographs, as well as the daily rainfall hyetographs representing each lake system (Deutschman and Erickson 1999). An illustration of the flow direction over the year is provided (Appendix D).

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Turtle Lake (Deutschman and Erickson 1999)

The 1998 hydrologic budget determined for Turtle Lake revealed a total inflow volume of 3,230 acre-feet. The principle sources of water to the lakes are precipitation and surface runoff. Total groundwater contribution was considered negligible. Precipitation accounted for a direct input of 1,634 acre-feet (approximately 51%) of the total inflow volume over the 729 acre combined surface area of Turtle Lake and North and South Connection Lakes. Surface runoff to the three lakes accounted for 1,591 acre-feet (approximately 49%) of the total inflow volume from the contributing drainage area (17.2 square miles).

Assuming there was no change in the storage of the system throughout 1998, the total outflow volume was considered equal to the total inflow volume (3,225 acre-feet). The predominant losses of water from Turtle Lake and North and South Connection Lakes resulted from surface outflow and evaporation. The system discharge from the primary outlet of the three lakes accounted for a volume loss of 1,666 acre-feet (approximately 52%) of the total outflow volume. Evaporation accounted for a direct volume loss of 1,564 acre-feet (approximately 48%) of the total outflow volume.

Cross Lake (Deutschman and Erickson 1999)

The 1998 hydrologic budget evaluated for Cross Lake revealed a total inflow volume of 5,808 acre-feet. Sources of water to Cross Lake include precipitation, groundwater inflows and inflow from Turtle Lake, as well as surface runoff from the watershed directly adjacent to Cross Lake. Precipitation accounted for a direct input volume of 735 acre-feet (approximately 13%) of the total inflow volume over the 328 acre surface area of Cross Lake. Surface inflow to Cross Lake accounted for an input volume of 2,144 acre-feet (approximately 37%) of the total inflow volume from the contributing drainage area of 25.9 square miles. Inflow from Turtle Lake accounted for 87% of the total surface inflow volume or 32% of the total inflow volume. Groundwater inflows accounted for 2,929 acre-feet or approximately 50% of the total inflow volume.

Assuming there was no change in the storage of Cross Lake throughout 1998, the total outflow volume of the system was therefore equal to the total inflow volume (5,808 acre-feet). The predominant losses of water from Cross Lake resulted from surface outflow and evaporation. System discharge from the primary outlet of Cross Lake accounted for a volume loss of 5,104 acre-feet (approximately 88%) of the total outflow volume. Evaporation accounted for a direct volume loss of 704 acre-feet (approximately 12%) of the total outflow volume.

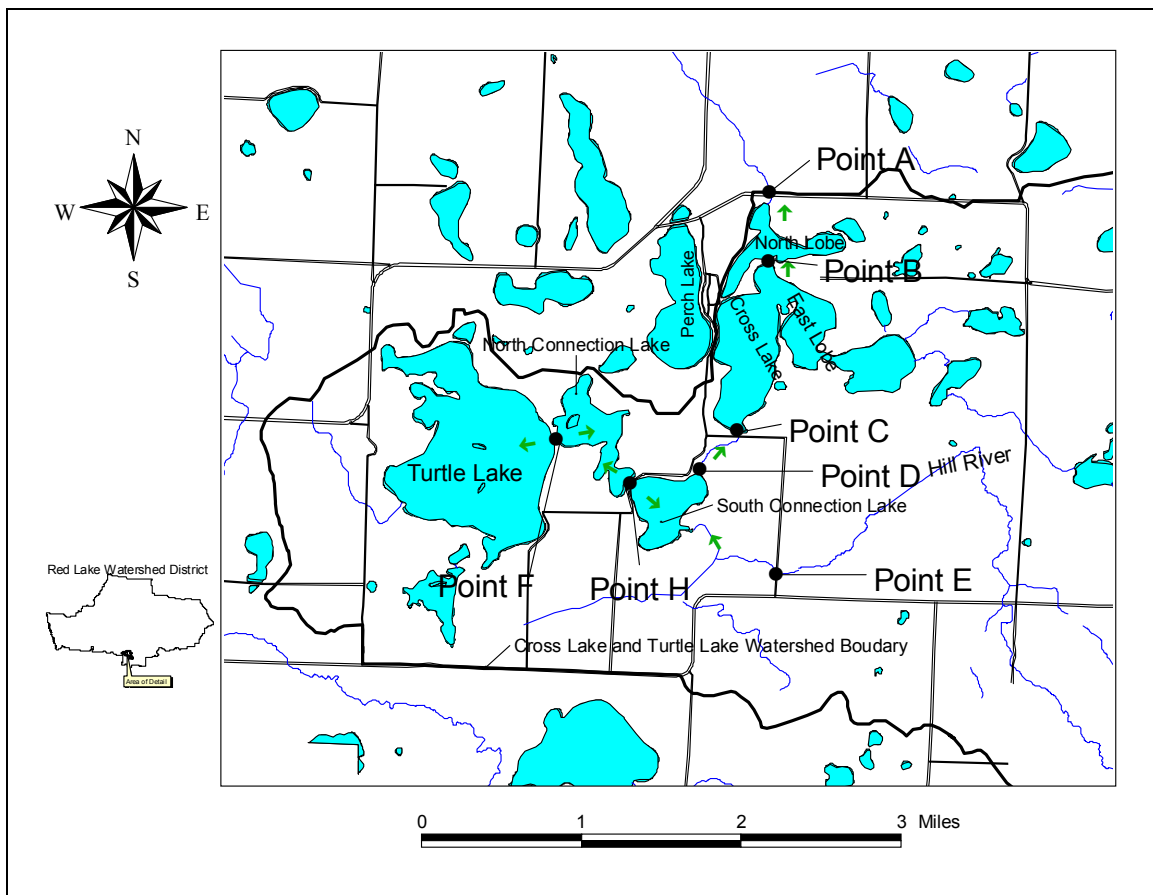
Flow Direction

The flow direction throughout 1998 remained constant, moving from point D, South Connection Lake outlet, to point C, Cross Lake inlet, to point B, Cross Lake outlet, to

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point A, Cross Lake system outlet (Figure 9). The flow direction, from point E (Hill River) into and out of the Turtle Lake system point D, H and F, varied throughout the year. During the first part of 1998, water was either flowing toward Turtle Lake or there was no detectable flow between South Connection Lake and Turtle Lake. The second half of the actual recorded measurements, from 8/07/98 to 8/24/98, the height difference is much greater between Turtle Lake and South Connection Lake. Water was flowing out of Turtle Lake into South Connection Lake. Each step in flow direction determination is documented (RLWD 2000).

FIGURE 9. CROSS LAKE AND TURTLE LAKE SYSTEMS FLOW DIRECTION



Quality/Limitations of Data

The quality and limitations of the data used will be discussed with respect to each lake system. Independent lake stage data, as well as groundwater inflow/outflow data was not collected and, therefore, will not be discussed.

The precipitation data used for the Turtle Lake and Cross Lake systems was obtained from Fosston, Minnesota (Polk County, Township 147, Range 40, Section 4). Fosston is located approximately 3 miles southwest of the Turtle Lake and Cross Lake, watersheds.

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Because of the distance between the rain gage and corresponding watersheds, as well as the probable spatial variation in rainfall, it is possible that the recorded rainfall is not representative of that within the watersheds (Deutschman and Erickson 1999). However, since the data is collected on an annual basis, the total precipitation at Fosston was assumed to be similar to the totals around each lake system.

The estimated evaporation rate for the individual lake systems was 25.75 inches per year. Because meteorological conditions were considered average for 1998, it is likely that the assumed annual evaporation rate is representative of the actual annual evaporation rate (Deutschman and Erickson, 1999).

In general, three factors affected the estimation of surface inflow and system discharge for each lake system. The first factor was the period of recorded stage data. In the absence of this data, other less accurate methods such as the use of runoff coefficients and watershed precipitation data was utilized. For the Cross Lake system, surface inflow and outflow stage data was recorded from May 28, 1998 to November 6, 1998. Because spring runoff occurs from late March through mid April in northern Minnesota, it is possible that a significant portion of the annual water budget was left unaccounted for. Surface outflow stage data was recorded for the Turtle Lake system. However, no useful surface inflow data was recorded. Unfortunately, all recorded stage data had segments of missing data resulting from equipment malfunction, vandalism, etc (Deutschman and Erickson 1999).

The second factor affecting the determination of surface inflows and system discharge was the ungaged sections of each system's watershed. The Cross Lake system had gaged primary inflows; however, significant portions of the total contributing drainage area were ungaged. The Turtle Lake system had no gaged surface inflows over the entire 17.2 square mile watershed. Cross Lake had an 8.7 square mile section of its total contributing watershed that was ungaged. This ungaged section represented approximately 34% of the total contributing watershed for Cross Lake. The ungaged section of the watershed contributes a significant uncertainty to the determination of the hydrologic budget. Therefore, surface runoff was determined for the ungaged section of the watershed using runoff coefficients and the assumed watershed precipitation data (Deutschman and Erickson 1999).

The third factor affecting the determination of surface inflows and system discharge was the placement of the transducers used to determine stage, as well as the collection of data necessary for the determination and adjustment of rating curves. The transducers at the outlet on South Connection Lake, point D, and at the outlet of Cross Lake, point B, were placed on the downstream sides of the weir structures during the first part of 1998. At the outlet of the Cross Lake system (point A) transducer elevations were changed without accurate detail of the elevation changes. Because of the previously mentioned issues, as well as a limited collection of observed streamflows, accurate rating curves could not be established. Therefore, the inflows and discharges determined for the three lake systems are of unknown accuracy (Deutschman and Erickson 1999). Similar problems were encountered in making the flow direction determinations (RLWD 2000).

Another problem with these measurements is the actual difference in water surface elevations between each location in the Turtle Lake system. Each of these locations has a minimal difference in water surface elevation, often less than .1 ft. Human and environmental factors may change the actual height of the transducers over time, and they may not be reflected in the survey data. Due to the flat nature of the Turtle Lake system these problems may be unavoidable.

The third problem is the lack of data from each location. Many stations were missing most of the recorded period (RLWD 2000). Due to these factors the flow direction is also of unknown accuracy.

Recommendations

Hydrologic

The Preliminary Study Design for the Turtle Lake and Cross Lake System study identified specific technical goals. Those goals are:

- 1) Determine the hydrology of the Cross Lake and Turtle Lake system;
- 2) Develop a hydrologic budget of the Cross Lake and Turtle Lake system;
- 3) Prepare a computerized hydrologic model of the Cross Lake and Turtle Lake system and use the model to evaluate water management options;
- 4) Develop a chronological history of lakeshore development within the watershed of the Cross Lake – Turtle Lake system;
- 5) Determine the present trophic status and identify the fisheries resources within the Cross Lake – Turtle Lake system;
- 6) Obtain qualitative information about the composition of the lake bottom through sediment coring and photography;
- 7) Inventory and map current land use within specific lake drainage areas and identify potential non-point pollution sources; and
- 8) Make future lake management and/or water quality monitoring recommendations based on results obtained from the preliminary (Phase I) water quality and hydrologic study.

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A rudimentary understanding of the hydrology of the Cross Lake and Turtle Lake system is possible using the data collected to date. The information collected during 1998 allows for an estimate of how much water enters and leaves the lake. Vandalism of the continuous stage recorders, damage by animals and equipment failure prevented the collection of the daily discharge data needed to obtain a thorough understanding of flow direction and the development of a hydrologic model (Deutschman and Erickson 1999).

The following recommendations are presented, based on meeting the original technical hydrologic goals for the project (Deutschman and Erickson 1999):

- 1) Continuous recording rain gages should be installed within the contributing drainage area. The gages should be strategically placed to allow for the development of drainage area specific rainfall-runoff relationships. The number of gages needed is approximately one gage per 5 square miles of watershed (i.e., ~ 5 gages).
- 2) A velocity transducer capable of determining direction and magnitude of discharge should be installed within the channel between Turtle Lake and North Connection Lake and potentially within the culvert between North and South Connection Lakes.
- 3) Stream gaging should be performed at each location 5-6 times during the ice-free period. These data can be used to adjust the rating curves developed using engineering equations.
- 4) Improved record keeping (in the field) would enhance the ability to reduce and interpret the hydrologic data.
- 5) Daily flow data with sufficient continuous record are needed to successfully obtain the technical goals. Should vandalism, animal damage and other human related factors continue to prevent the development of sufficient high quality data, the study should be terminated.

Water Quality

The study has accomplished the goal of determining the present trophic status. Recommendations for future monitoring include the following:

- 1) Inventory and map of current land use within specific lake drainage areas and identify potential non-point pollution sources. This information would aid in making current land use improvements.
- 2) Future water quality monitoring should include monitoring of nutrients and other parameters at inlet and outlet water sources to the Cross Lake and Turtle Lake systems. The monitoring should correspond with the flow monitoring sites listed above. This would determine the nutrient loading into the lake systems.

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- 3) Permanent buoys or GPS coordinates need to be established at the maximum depths of Cross Lake, Turtle Lake and the east lobe of Cross Lake for more accurate monitoring of depth profiles and other water chemistry.
- 4) The monitoring should follow the “Standard Operating Procedures for Field Samplers” manual from the RLWD.
- 5) Identify fisheries resources (using DNR collected information or as an actual fisheries study).

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Heiskary, S. (1998), *Minnesota Lake Water Quality Assessment Data: 1998*. Update to data presented in the Minnesota Lake Water Quality Assessment Report: 1990, Appendix 1. Minnesota Pollution Control Agency, Environmental Outcomes Division, Environmental Monitoring and Analysis Section, St. Paul, Minnesota.

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