A PHOSPHORUS LOADING STUDY

By The

WHITEFISH AREA PROPERTY OWNERS ASSOCIATION (WAPOA)

For The

WHITEFISH CHAIN of LAKES.

CROW WING COUNTY, MINNESOTA

NOVEMBER, 2001

Report Prepared by J. O. Wallschlaeger

TABLE OF CONTENTS

FIGURES

TABLES

CREDITS

The Whitefish Area Property Owners Association (WAPOA) Crosslake, Minnesota undertook this phosphorus study of the Whitefish Chain of 14 lakes with financial support in the form of a $ 2,500 grant from the Central Minnesota Initiative Fund. A like amount of financial support was provided by WAPOA. We are grateful for the financial assistance and encouragement from the WAPOA Board of Directors

We are eternally grateful for the technical consulting, direction and training that was graciously provided by Mr. John S. Persell, Director of The Minnesota Chippewa Tribe Water Research Laboratory at Cass Lake, Minnesota. Water sampling labor was performed by a small group of WAPOA novice hydrology volunteers. Thanks and recognition goes to Mr. Mike Higgins and Mr. Ray Steffens for their long hours during sample collection and flow measurements, sometimes under very difficult conditions

We also wish to thank Mr. Ray Nelson of the Corps of Engineers at Crosslake for the use of a Marsh McBurney water flow meter and information on soil types around the Whitefish Chain of Lakes.

In addition, we thank the Minnesota Department of Natural Resources for lake area, depths and volume calculations, precipitation data, watershed area calculations and maps. The lake area, depths and volume calculations were provided by Ms. Mandy LaZella, Division of Fish and Wildlife, Section of Ecological Services via Mr. Tim Bastrup, Division of Fisheries. Mr. Bryan Hargrave, Forestry, created the maps to identify sampling locations on the Chain. The Forestry Station at Pequot Lakes provided historical precipitation data for the study area. Mr. Jim Solstad, Division of Waters provided the calculations of watershed areas for the sheds feeding the Chain of Lakes.

We also thank Mr. Nick Pond of the Pine River Area Sanitary District for the treatment plant through put volume and phosphorus concentration data.

STUDY OBJECTIVE

The objective of this study is to provide quantitative data on the amount of phosphorus coming into, and out of, the Whitefish Chain of lakes so that remedial recommendations can be developed if the data indicates manageable phosphorus sources.

Historic water quality measurements by WAPOA have indicated a general reduction in water quality. For example the Trophic State Indices (TSI) for all the lakes covering both Secchi (TSIS) and Total Phosphorus (TSIP) had grown by one point from 1985 versus a six-year running average. TSIS from 40.9 to 41.9 and the TSIP grew from 40.4 to 41.7 for three meter column samples taken annually in March and August. These indices categorize the chain as mesotrophic, which indicates that they are moderately clear with moderate amounts of nutrients and phytoplankton. Hydrolab measurements showed that many of the Chain lakes were becoming anoxic (without oxygen) in the hypolymnion during the late summer. Increased phosphorus in the lakes leads to a condition called eutrophication; a condition which typically degrades aesthetic and recreational values of the affected waters by increased weed growth and algae blooms. These negative indicators prompted this study objective.

INTRODUCTION

The focus of this study is the Whitefish Chain of 14 lakes located in northwestern Crow Wing County, Minnesota. The Chain contains some 14, 800 acres of surface water with 100 miles of shoreline. The Chain is part of the 502,000 acre Pine River Watershed, comprised of 51 minor watersheds in the counties of Aitkin, Cass, Crow Wing and Hubbard. Lake levels in the Chain are controlled by the Corps of Engineers Pine River Dam located in Crosslake, Minnesota, which was originally built in the 1800's and is now undergoing major renovation. The nominal control level is 1229.05 to 1229.55 feet above sea level in the summer and a draw down to 1227.3 in the winter. The level ranged between 1227.4 and 1229.7 during the period of this study which was from May 2000 to May 2001. Surface water input to the Chain is from seven tributaries (Hay Creek, Pine River, Willow Creek, Spring Brook, Thompson Creek, Fox Creek and Daggett Brook) and the total surface water output from the Chain is the Pine River via the Pine River Dam at Crosslake. Big Trout lake is known to be fed by several deep springs. Seventy seven per cent of the input surface water is from the Pine River flowing into Upper Whitefish Lake. In general, the Chain shorelines are over developed with each dwelling having its own septic system. There are over 2,700 dwellings on the 100 miles of shoreline. As a frame of reference, in 1973 there were 1,080 dwellings on the same 100 miles of shoreline. (Environmental Review of the Headwaters of the Mississippi Reservoir Projects, Bemidji State College, 1773) At this time, none of the lakeshore dwellings are served by municipal sewage disposal.

Soils within the watershed are primarily Alfisoils, which are generally underneath deciduous forests underlain by silty soils and are present in woodland and mixed woodland and cropland areas and Entisols commonly found in glacial outwash and alluvium. The bedrock consists of primarily Precambrian crystalline rocks. The watershed lies within calcareous glacial deposits associated with the Des Moines Lobe Association and the siliceous glacial deposits associated with the Rainy Lobe Association. The bedrock hydrogeology and ground water in the watershed consists of primarily Precambrian igneous and metamorphic rocks. The suffacial aquifers are glacial outwash consisting of course-grained sands and fine-grained alluvium of calcareous and siliceous deposits. (Upper Mississippi River Basin Information Document 2000 Minnesota Pollution Control Agency) In some areas of the watershed these glacial deposits are up to 600 feet deep. The sandy shorelines around the lakes chain are known to be highly susceptible to ground water contamination.

PRECIPITATION:

Precipitation in the study area averaged 30.9 inches over the previous ten years as reported by the Department of Natural Resources (DNR) Forestry Station in Pequot Lakes, Minnesota. Precipitation amounts (inches) for the study period are listed in the table below. Study period precipitation was 15 percent above the ten-year average.

Date	*Corps of Engrs.Crosslake, MN	DNR Pequot Lakes, MN
May 2000	4.06	4.74
June 2000	3.89	4.49
July 2000	2.24	3.46
August 2000	2.95	4.11
September 2000	1.75	1.64
October 2000	2.61	2.11
November 2000	3.92	4.86
December 2000	0.95	0.98
January 2001	0.85	0.90
February 2001	2.55	1.84
March 2001	0.34	0.38
April 2001	7.14	5.99
TOTAL	33.25	35.51

Note: frozen precipitation is listed as the liquid equivalent.
*Data from the Corps of Engineers Web Site (mvp-wc.usace.army.mil) for the Pine River Dam at Crosslake, Minnesota.

Total Phosphorus measurements from wet and dry depositions (precipitation), during the study period averaged 50.2 micro grams per liter. Precipitation samples were collected during the one year study period from a site at the Steffen's residence on Lower Hay lake Section 24, Jenkins Township in Crow Wing County, Minnesota.

LAKE AND STREAM CHARACTERISTICS

Demographics of the lakes are presented in table form as Table 1.

Upper Hay lake is located on the southeastern quadrant of the Whitefish Chain and is separated from Lower Hay lake and the Chain by a shallow stream. Upper Hay has a surface area of 580 acres and an average depth of 18 feet. The maximum depth is 42 feet, and the volume is 8,700 acre-feet. Hay Creek enters in the northwestern quadrant and exits in the northeastern quadrant which probably indicates incomplete mixing of the low volume creek flow. The hydraulic flush time (Tw) during the study period was one year. Lakeshore development includes 61 seasonal dwellings, 26 year round dwellings and three commercial sites. The Planning Zoning Offices of Crosslake and Crow Wing County provided the number and type of dwellings from Property Classification Tax Records

Lower Hay lake is fed in the southeastern quadrant by Hay Creek from Upper Hay lake and discharges through a constriction in the southwestern quadrant into Upper Whitefish Lake. This is the first of seven lakes, which provide tributary input to Whitefish lake, to be discussed here. Lower Hay lake has a surface area of 691 acres and an average depth of 49 feet, a maximum depth of 100 feet and a volume of 34,166 acre-feet. The low volume feeder stream, which is about one half mile from the constriction exit, and in the same southeastern quadrant, may indicate incomplete mixing of the input waters. The hydraulic flush time was 4 years. Shoreline development includes 93 seasonal dwellings, 33 year round dwellings and three commercial sites.

Arrowhead lake in the upper northeast quadrant of Upper Whitefish Lake is fed by two small streams in the northeastern quadrant and exports some water to Whitefish through a constriction in the southwestern quadrant. Arrowhead has a surface area of 304 acres, with average depth of 11 feet, a maximum depth of 13 feet and a volume of 3,310 acre-feet. The hydraulic flush time (Tw) of Arrowhead Lake is 0.7 years Shoreline development includes 24 seasonal dwellings and five year round dwellings. This lake is the most shallow and least developed of all the chain lakes.

Bertha and Clamshell lakes provide some input, although there are no feeding tributaries, through a common constriction to the southeastern quadrant of Upper Whitefish lake. Bertha lake has a surface area of 356 acres, an average depth of 30 feet, a maximum depth of 64 feet and a volume of 9,940 acre-feet. Clamshell lake has a surface area of 256 acres, an average depth of eight feet, a maximum depth of 44 feet and a volume of 2,114 acre-feet. Shoreline development for Bertha includes 88 seasonal dwellings, 46 year round dwellings and one commercial site. Clamshell has similar shoreline development with 84 seasonal dwellings, 22 year round dwellings and two commercial sites.

Pig lake located in the south central quadrant of Lower Whitefish, has no tributaries and is one of the smaller lakes with 256 surface acres. The average depth for Pig lake is 23 feet, the maximum depth is 56 feet and the volume is 4,308 acre-feet. Shoreline development includes 147 seasonal dwellings, 11 year round dwellings and one commercial site.

Big Trout lake is located in the northeast quadrant of Whitefish Lake, and although there are no tributaries, there are underground springs which prevent complete freezing of the north shoreline during the winter months. There is a constriction in the south east quadrant which exports a low volume of surface water to Lower Whitefish lake. Big Trout lake has 1,341 surface acres, an average depth of 51 feet, a maximum depth of 128 feet and a volume of 68,726 acre-feet. Shoreline development includes 129 seasonal dwellings and 38 year round dwellings. The hydraulic flush time is 38 years.

Island lake is the last of seven feeder lakes to Whitefish lake and has no tributaries. Island lake has a surface area of 257 acres, an average depth of 21 feet, a maximum depth of 75 feet and a volume of 5,305 acre-feet. Shoreline dwellings include 59 seasonal units and 22 year round dwellings.

Whitefish lake is the largest lake in the Chain of 14 lakes and has inputs from the previously described seven lakes. The Pine River entering at Delta Bay is the main feeder stream and Willow Creek enters in the northwest quadrant. Whitefish is sometimes considered to be three lakes known as Upper, Middle and Lower. The entire export from Whitefish lake is to Rush lake which will discussed along with the three remaining lakes of the Chain. Whitefish has a surface area of 7,471 acres, an average depth of 41 feet, a maximum depth of 138 feet and a volume of 263,991 acre-feet. The hydraulic flush time (Tw) is three years. Whitefish lake has 644 seasonal dwellings, 242 year round dwellings and 29 commercial sites.

The import to Rush Lake is from the southeastern quadrant of Whitefish and the export is to Crosslake from the southeasterly quadrant of Rush lake. Rush lake has 961 surface acres, an average depth of 20 feet, a maximum depth of 128 feet and a volume of 19,384 acre-feet. Rush lake is subjected to a large volume of boat traffic between the eight westerly Whitefish lakes and

Crosslake. Traffic has been counted to be as high as 1,000 boats per hour on the fourth of July. Shoreline dwellings consist of 147 seasonal dwellings, 81 year round dwellings and three commercial sites. The hydraulic flush time is 146 days. Because the moving water is largely on the southerly, shallow portion of the lake, incomplete mixing is therefore suspected. The inlet and outlet of Rush lake never freezes because of relatively fast moving constriction water.

Little Pine lake is in the northeastern quadrant of the lakes chain and receives import from Daggett Brook and Fox Creek in the north quadrant. The export from Little Pine is to Daggett lake before emptying into Crosslake. Little Pine has 384 surface acres, an average depth of 13 feet, a maximum depth of 38 feet and a volume of 5,046 acre-feet. Little Pine lake has 67 seasonal dwellings, 36 year round dwellings and one commercial site.

Daggett lake receives import from Little Pine Lake and has a surface acreage of 225, an average depth of 13 feet, a maximum depth of 23 feet and a volume of 2,950 acre-feet. The export from Daggett lake is to Crosslake. Daggett lake has 152 seasonal dwellings, 70 year round dwellings and 3 commercial sites. The hydraulic flush time is 0.2 years when combined with Little Pine.

Crosslake is the final collecting basin of the chain with inputs from Rush and Daggett lakes. Export from Crosslake is to the Pine River via the Corps of Engineers Pine River Dam in the City of Crosslake. Crosslake has a surface area of 1,773 acres, an average depth of 32 feet, a maximum depth of 84 feet and a volume of 55,818 acre -feet. Crosslake has 292 seasonal dwellings, 151 year round dwellings and ten commercial sites. The hydraulic flush time is 2.6 years.

DATA COLLECTION METHODS

The Minnesota Chippewa Tribe Water Research Laboratory in Cass Lake, Minnesota analyzed all water samples for total phosphorus in accordance with USEPA 365.1 with a detection level of 2.0 micro grams per liter.
Physical water quality data were measured with a HydroLab Surveyor 4.

SAMPLING PROCEDURES

The surface water samples were collected by WAPOA volunteers trained by the Chippewa Research Laboratory Director in the use of sampling equipment and techniques. All samples were collected during daylight hours. Lake water samples were taken at the deepest location of each of the lakes in the chain every three months beginning in July 2001. Grab samples of the streams were taken within two days of the lake samples.

The 1.2 liter Lab-Line, polyethylene Water Sampler and the one half liter acid washed polyethylene sample collection bottles were rinsed three times with the sample water to be collected prior to sample collection. The water samples were taken at ten meter intervals from the lake surface to within one half meter of the lake bottom. Grab samples from flowing tributaries and constrictions were taken with care to preclude sediment from the stream bottom or bank.

Precipitation samples (wet and dry deposition) were collected continuously during the study period in an acid washed Productive Alternatives one-liter gauge. Liquid samples were then transferred to one half liter, acid washed, polyethylene bottles. The collector was triple washed with distilled water after removing each sample. The phosphorus concentration from all forms of precipitation is presented in Table 5. The phosphorus import to the lakes is 21 per cent of the total input (6,216 pounds).

All water samples were kept cool in ice chests or refrigerators until delivery to the Chippewa Laboratory for analysis.

Water velocity measurements of the streams and constrictions were measured with a Marsh McBurney Flowmeter, model 210D, serial number 910116, on loan from the Corps of Engineers.

All computations for lake depth, area and volume were provided courtesy of the Minnesota Department of Natural Resources, Division of Fish and Wildlife, Section of Ecological Services by Ms. M LaZella via Mr.T. Bastrup, Department of Fisheries.

PHOSPHORUS LOADING CALCULATIONS

The lake phosphorus loading was calculated utilizing the flow-weighted average formula recommended by the U.S. Environmental Protection Agency for lake diagnostic studies:

$$T=5.394\ QCI$$

Where: T= the total amount of phosphorus in pounds
Q= The average daily flow for the period in cubic feet per second
C= The total phosphorus concentration of the flow in micro grams per liter
I= The number of days in the period (1)

Phosphorus loading from lakeshore septic systems was calculated using one pound of phosphorus per person per year. The generally accepted range for this loading factor is one half to 2.2 pounds per person per year depending on soil type and efficiency of the system (Wilson, 1991). An average of three persons per dwelling was used for both seasonal and permanent occupants. The number of seasonal, year round dwellings and commercial sites were furnished (from tax records) by Ms.N.E. Joslin for Crosslake and Ms. B Finnerty for the remainder of the chain. A summary of the dwellings and the resultant phosphorus loading is shown in Table 6. Nine point eight percent of the imported phosphorus is due to septic systems (3,869 pounds). The recently completed, total lakeshore inspection program of septic systems and the resulting upgrade of failing systems should keep this source of phosphorus in check for at least ten years.

Ground water inputs and outputs were not quantified in the study because of the complex measurements required. It is expected that ground water and surface water phosphorus concentrations are very similar. If this is true, ground water inputs and outputs to the lakes will not significantly alter the measured phosphorus budgets of the lakes.

LAKE PHOSPHORUS LOADING

Several terms will be used in the following section to quantitatively describe the phosphorus loading to the lakes. These terms are briefly defined below along with their significance.

1. Average total phosphorus (TP) is the average phosphorus in a vertical column from the lake surface to the lake bottom measured in micro grams per liter (ug/l). These data are found in Table 2.
2. The Total Phosphorus annual Input or Import is from three sources; tributaries (Table 3) or constrictions (Table 4), precipitation (wet or dry) (Table 5), and lakeshore septic systems (Table 6). .
3. Total Output is the annual mass of phosphorus leaving a lake via a stream or constriction.
4. Annual Phosphorus Storage (APS) is the difference between Input and Output (Table 7). If the output is less than the total input, it means that difference is the amount of phosphorus being stored in the lake basin.
5. Lake Phosphorus Mass (LPM) (Table 7) is the total mass of phosphorus contained in a lake's water volume and is determined by multiplying the average TP by the lake (basin) volume. This is a measure of the total amount of phosphorus in a lake basin during the period of time that the measurements were taken.
6. Phosphorus Loading Ratio (Table 7) is a comparison of how much phosphorus is being added to a basin versus the total amount (APS) that is in the basin expressed as a percentage. A result of 100 percent indicates that the amount being added annually (APS) is the same as the total amount that was measured to be in the basin (LPM). A percentage greater than 100 indicates that the amount being added annually (APS) is greater than the amount that was measured to be in the basin (LPM).
7. Water Residence Time (Tw) (Table 7), also called Hydraulic Flush Time is a measure of how long it would take to output all the water in a lake basin based upon the measured output flow rate.
8. Phosphorus Export Coefficient is a measure how much phosphorus, from all sources, is derived from the land area of the supplying watesheds, expressed in pounds per acre. Rast and Lee have reported that Northern Lakes and Forest Areas, such as this area, typically have Export Coefficients of 0.1 pounds per acre. The upland watershed area for the 14 Lakes Chain is

250,293 acres (71.2 %), wetlands of 58,626 acres (16.7%) and surface waters of 42,435 acres (12.1%) for a total watershed area of 351,364 acres.

The average Total Phosphorus (TP) concentration for Upper Hay lake was 14.7 micro grams per liter (ug/l) and the lake received a total of 814 pounds of phosphorus from all sources. Import from Hay Creek was 452 pounds or 56 percent of the total input, precipitation (wet or dry deposition) accounted for 29 percent (238 pounds) and lakeshore septic systems contributed 15 percent or 124 pounds. Hay Creek leaving Upper Hay lake exported 300 pounds, 514 pounds less than was imported to the lake. Lake Phosphorus Mass (LPM) was measured to be 347 pounds. The Phosphorus Loading Ratio during the study period was calculated to be 148 per cent.

The average TP concentration for Lower Hay lake was 11.5 ug/l. The lake received a total of 768 pounds of phosphorus and exported 277 pounds for a net storage of 491 pounds. Import from Hay Creek (output from Upper Hay) was 300 pounds (39 % of the total), precipitation accounted for 284 pounds (37%) and lakeshore septic systems contributed 184 pounds (24%). Lake Phosphorus Mass (LPM) was measured to be 1067 pounds and the Phosphorus Loading Ratio was calculated to be 46 percent.

Arrowhead lake had an average TP concentration of 20.8 ug/l. The lake received 827 pounds of phosphorus from Spring and Thompson Creeks which was 84 percent of the total input from all sources (which was 985 pounds). Arrowhead exported 233 pounds through a constriction to Whitefish for a net gain (APS) of 751 pounds. Precipitation accounted for 125 pounds (12.7% of all inputs) and lakeshore septic systems accounted for 33 pounds (3.3%). LPM was measured at 188 pounds and the Phosphorus Loading Ratio was calculated to be 399 percent.

Bertha lake had an average TP concentration of 27.2 ug/l. The lake received a total input of 377 pounds of phosphorus (and APS) and has no feeder tributaries. Precipitation accounted for 125 pounds (47.6% of the total input) and lakeshore septic systems contributed 161 pounds (54.2%). LPM was 250 pounds and the Phosphorus Loading Ratio was calculated to be 123 percent. Because of the elevated phosphorus levels in the hypolimnion the LPM was calculated using volume weighting.

Clamshell lake had an average TP concentration of 20.5 ug/l. This lake with no feeder streams received a total input of 234 pounds, of which 105 pounds (44.9%) was received from precipitation and 129 pounds (55.1%) from lakeshore septic systems. LPM was 118 pounds and the Phosphorus Loading Ratio was calculated to be 199 percent.

The next lake in the series was Pig lake which had an average TP concentration of 47 ug/l. The total annual input and APS was 159 pounds. Precipitation accounted for 76 pounds, or 47.8 percent of the total. Lakeshore septic systems contributed a calculated 83 pounds of phosphorus or 52.2 percent of the total input. LPM was measured at 286 pounds and the Phosphorus Loading Ratio was 57 percent. Pig lake exhibited a high TP concentration in the hypolimnion and as a result a volume weighting calculation was used to calculate the LPM.

Big Trout lake had an average annual TP concentration of 12.0 ug/l. The total phosphorus input was 765 pounds, of which 551 pounds was due to precipitation (72%) and the remaining 214 (285) pounds was due to lakeshore septic systems. The total output for Big Trout Lake was 47 pounds which resulted in an APS of 718 pounds. The LPM was 2243 pounds and the Phosphorus Loading Ratio was calculated to be 29%. This lake has no feeder tributaries but does have a series of underground springs.

Island lake had an average TP concentration of 38.4 ug/l. The total phosphorus input was 216 pounds, of which 106 pounds (49%) was due to precipitation and 110 pounds or 51 percent was due to lakeshore septic systems. Island lake has no feeder streams. The LPM value was 329 pounds and the Phosphorus Loading Ratio was calculated to be 66 percent. Volume weighting was used to calculate LPM because of elevated Phosphorus concentrations in the hypolimnion

The total average TP concentration for Whitefish lake was 16.4 ug/l. The total phosphorus input was 21,310 pounds and the total output was 3,224 pounds for a net APS of 18,086 pound. Input from three constrictions and two streams was 16,993 pounds or 79.7 percent of the total input. Precipitation accounted for 3,068 pounds (14.4%) and lakeshore septic systems accounted 1,249 pounds or 5.9 percent. The LPM value was 11,862 pounds and the Phosphorus Loading Ratio was calculated to be 153 percent.

Rush lake had an average TP concentration of 13.6 ug/l. Rush received a total phosphorus input of 3,978 pounds and had a total output of 3,224 pounds for a net APS value of 753 pounds. The great majority of the input was due to tributaries at 3224 pounds or 81 percent of the total. Precipitation accounted for 395 pounds (10%) and lakeshore septic systems provided an additional nine percent or 358 pounds. LPM for Rush lake was 717 pounds and the Phosphorus Loading Ratio was calculated to be 105 percent.

Little Pine lake had an average TP concentration of 24.2 ug/l. The total input and APS for Little Pine was 2,083 pounds. 1,761 pounds of the input (84.6 % of the total) came from Fox Creek and Daggett Brook. Precipitation accounted for 159 pounds or 7.6 percent. Lakeshore septic systems accounted for another 163 pounds or 7.8 percent of the total input. LPM was measured to be 571 pounds and the Phosphorus Loading Ratio was calculated to be 365 percent. The inputs were combined with Daggett for Total Output, APS, LPM, Loading Ratio and Hydraulic Flush calculations shown in Table 7

Daggett lake had an average TP concentration of 18.2 ug/l. The total phosphorus input to Daggett 2,514 pounds versus a total output of 2,554 pounds when combined with Little Pine for a net APS of just 40 pounds. Combining inputs from Little Pine and Daggett the precipitation accounted for 251 pounds or 10 percent, tributaries accounted for 1,761 pounds or 70 percent and finally lakeshore septic systems accounted for just 502 pounds or 20 percent of the total. LPM was measured to be 719 pounds and the Phosphorus Loading Ratio was calculated to be 6 percent.

The final lake in this series is Crosslake which had an average TP concentration of 15.7 ug/l. the total input of phosphorus to Crosslake was 7,212 pounds and the total output was measured to be 7363 pounds resulting in an APS of –151 pounds. Tributary inputs to Crosslake come from both Rush and Daggett and accounted for 5,778 pounds or 80.1 percent of the total input. Precipitation amounted to 712 pounds or 9.9 percent and lakeshore septic systems accounted for 722 pounds or 10 percent of the total inputs. LPM was 2,383 pounds and the Phosphorus Loading Ratio was calculated to be – 6.3 percent.

The phosphorus export from the watershed for the entire chain was calculated to be 0.121 pounds per acre, which is slightly high, but in the range of expectations. Watershed area data was taken from The National Wetland Inventory with wetland classifications based on circular 39. Export Coefficients (pounds per acre) for some individual lake sheds are as follows: Whitefish lake 0.0971, Hay Lakes 0.095, Arrowhead lake 0.072, Little Pine/Daggett 0.0463. Earlier work by Persell for Big Wolf, Andrusia, Cass and Winnibigoshish lakes reported coefficients ranging from 0.037 to 0.051 pounds per acre.

RESULTS SUMMARY

There are eight tributaries feeding the Whitefish Chain of Lakes and one output stream which is the Pine River at the Corps of Engineers Cross Lake dam. By far the most significant input to the Chain is the Pine River that enters Upper Whitefish at Delta Bay and dominates all tributary inputs. The Pine River at Delta Bay provides 94 percent of all the tributary water that feed Whitefish lake (excluded is Crosslake, Little Pine and Daggett). The Pine River at Delta Bay also provides 75 percent of the input from all eight streams that feed the entire Chain.

The surface inflow of all incoming tributary waters is 406 cubic feet per second, which is 27 percent less than the surface outflow at the single output over the Crosslake dam (297 cubic feet per second). Surface inflow is cumulative stream flow into the lakes and precipitation; surface out flow is cumulative stream flow out of the lake and evaporation. Surface inflow minus surface outflow, therefore, is net cumulative stream flow plus the gain from precipitation minus the loss from evaporation. The net seepage is either ground water discharge into the lakes, or lake water recharge into the ground water system.

The Pine River also dominates the phosphorus inputs from the tributaries. The Pine River supplies 92 percent of the 16,993 pounds of phosphorus that is imported annually to Upper and Lower Whitefish. The Pine River input of 15,664 pounds of phosphorus constitutes 53 percent of all annual tributary input (29,335 pounds) to the entire Chain. This indicates that phosphorus (nutrient) loading is more a function of stream flow rate than concentration.

The total annual phosphorus input to the Whitefish Chain of lakes in this study was 39,261 pounds. Phosphorus contained in wet or dry deposition accounts for 6,057 pounds annually, or 15 percent of the total input. Lakeshore septic systems contribute another 3,869 pounds of phosphorus annually, or 10 percent of the total input from all sources. The 29,335 pounds from all tributaries, mentioned previously, provides the remaining 75 percent of the total annual input.

SOURCE	PHOSPHORUS – Pounds	%
Tributaries	29,335	74.7 **
Precipitation	6,057	15.4
Lakeshore Septic Systems	3,869	9.9
Total Input	39,261	100.0

**The Pine River tributary input at Delta Bay contributes 15,664 pounds of phosphorus, or 40 percent of the total input to the Whitefish Chain (39,261 pounds) and more than all of the precipitation and septic input combined.

CONCLUSIONS

Clearly, the single most dominant phosphorus input is from the Pine River at Delta Bay. The average phosphorus concentration coming from The Pine River is a reasonable 26.0 micrograms per liter. However, the Pine River flow volume of 306.1 cubic feet per second supplies 75.4 percent of all tributary input (405.9 cubic feet per second) to the Whitefish Chain of Lakes. This large flow volume is the reason for the large mass of imported phosphorus. The source (s) of this phosphorus input to the Pine River upstream is unknown at this time. There are many branches on the Pine River upstream that have not been thoroughly investigated. To name a few: Arvig Creek, Behler Creek, Hoblin Creek, Bungo Creek, Dabill Creek, Brittan Creek and Cedar Creek.

The new (1998) Pine River Area Sanitary District Plant meets all Minnesota treatment requirements and is licensed by the Minnesota Pollution Control Agency (MPCA). The plant throughput averages 128,570 gallons per day and the total phosphorus averages 0.43 milligrams per liter which is a daily output of 0.4614 pounds per day or 168.4 pounds per year. Therefore, the plant is an insignificant contributor of phosphorus to the Pine River.

There are five MPCA permitted feedlots along the Pine River branches, which are potential phosphorus sources from livestock. Additionally, there is agricultural activity along the branches of the Pine, which could be sources of phosphorus from fertilizers.

The various branches of the Pine River must be investigated to determine significant sources of phosphorus. Once the major contributors are identified, it is expected that implementation of Best Management Practices could reduce phosphorus concentrations to an acceptable level.

The impact of the excessive import of phosphorus from all sources is that, the lake basins are being filled with phosphorus as shown by these quantitative studies and the qualitative aquatic weed increase assessment. The total phosphorus input during the one year study period was 39,261 pounds, and the total export was just 17,222 pounds, leaving 22,039 pounds in the lake basins that add to 21,340 pounds that was previously stored. Because of the deep basins in many of the study lakes it is unreasonable to expect that the phosphorus nutrient will be flushed out, to become a downstream problem for others. It is expected that, without significant watershed management diagnostic and corrective action, that the eutrophication and recreational quality of the Whitefish Chain of Lakes will continue to decline at an increasing rate.

Phosphorus resulting from lakeshore septic systems could be the one bright spot in the study. The individual septic treatment system (ISTS) inspection program conducted by Crosslake, Crow Wing County, Manhattan Beach and WAPOA should bring this source under control. The inspection program, completed in 2000, inspected all lakeshore properties on the Chain for conformance with ordinance requirements. Some 2,400 systems were inspected with the result that approximately 500 were found to be non-conforming. Most of these systems have now been brought into conformance. We will however, continue to see phosphorus from the failed systems, leaching into the lakes for some time. Composting or Swedish toilets provide one environmentally friendly method for handling human waste in areas not served by municipal sewage treatment systems.

Precipitation delivered 6,057 pounds of phosphorus to the lakes. This is a difficult source to control because the atmosphere born phosphorus comes from fossil fueled power plants, incinerators, pollen events, and agricultural fertilizers. The power plants and incinerators are also the major source for mercury.

RECOMMENDATIONS

1. The Pine River must be investigated to determine the source(s) of phosphorus upstream and a plan of action implemented to minimize the nutrients that are causing the eutrophication of the Chain of Lakes. A reduction of phosphorus concentration in the Pine River of 75 percent is a reasonable goal. Continued monitoring of the Pine River for nutrients will be required to determine the effectiveness of corrective actions. The branches of the Pine traverse both Cass and Crow Wing Counties and as a result Water Planners and Soil and Water Conservation groups from both bodies should be involved in diagnostic and remedial action.
2. Elimination of lakeshore phosphorus fertilizers, restoration of vegetative shoreline buffers to at least 30 feet, erosion control to save the lakeshore and maintain fishery-spawning areas. These activities will help to minimize the culturally induced phosphorus due to extremely dense development of the lakeshores. Education of, and participation by, landowners is critical to implementation of these practices.
3. Many of the lakeshore dwellings, which were built prior to ordinance adoption, are too close to water bodies and are impacting the water quality due to runoff and related cultural impacts. Local units of government as the permitting authority can control land use through ordinances and enforcement. It is incumbent upon those affected to work with government units to strengthen ordinances and discourage ordinance variances to save the economic, aesthetic and ecological values of the lakes.
4. A watershed management plan must be developed and eventually a Watershed District authorized to control land use practices and thereby minimize the impact of our culture on the environment.

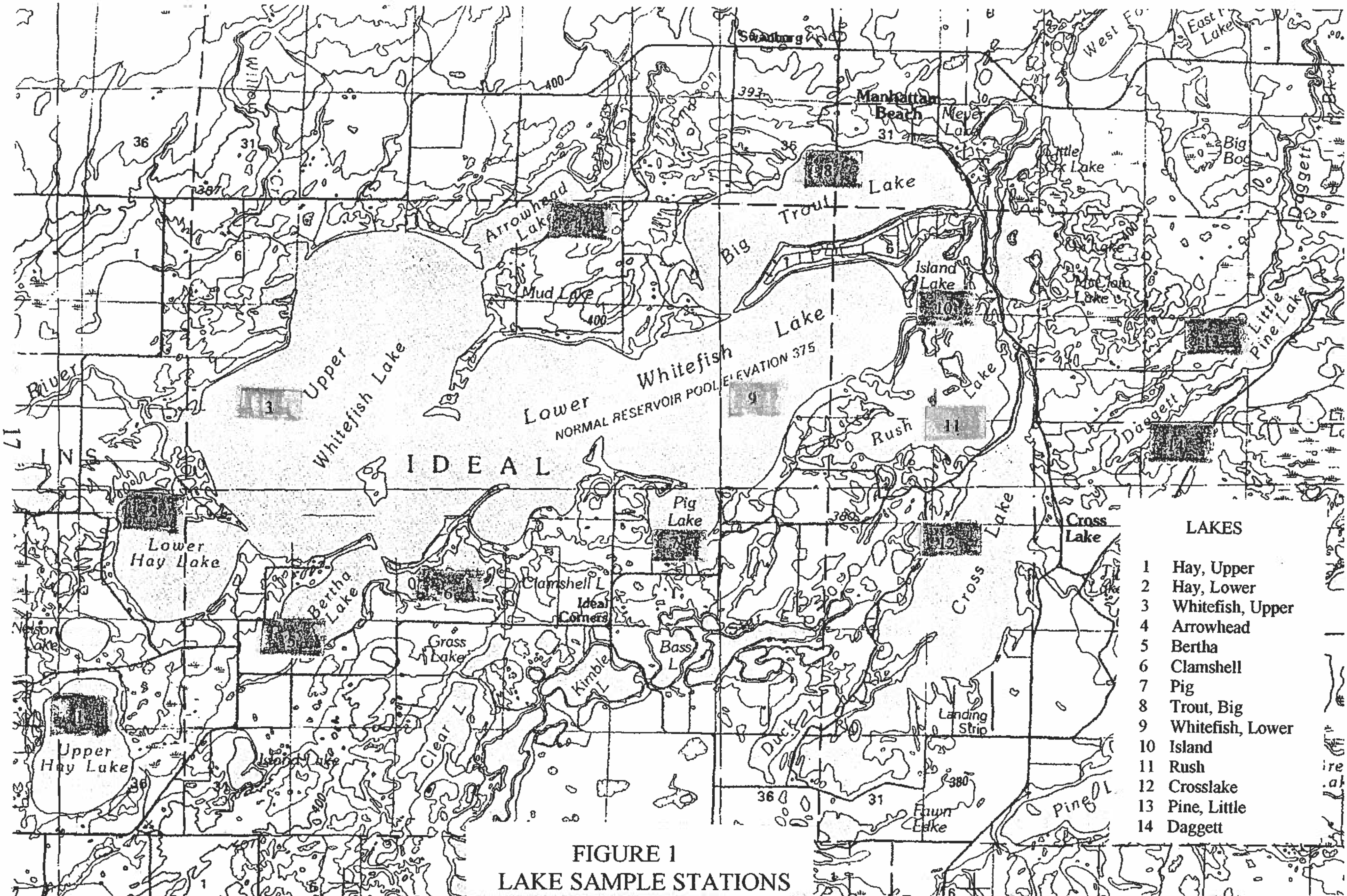

FIGURE 1
LAKE SAMPLE STATIONS

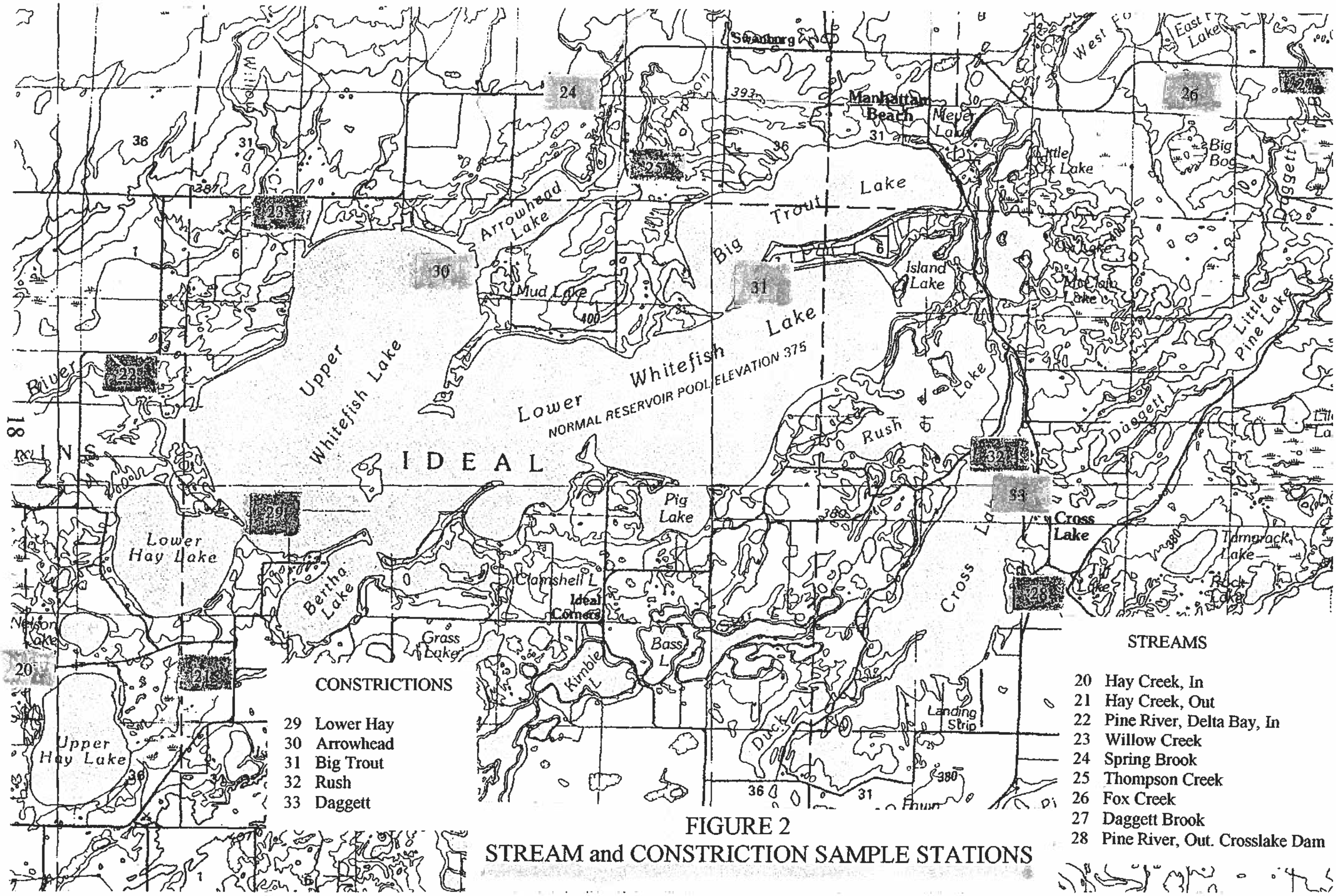

FIGURE 2
STREAM and CONSTRICTION SAMPLE STATIONS

Table 1

Whitefish Chain Demographics.

Location, Area, Volume, Depth

Lake	I.D. #	Location		Surface	Volume	**Volume	Max.Depth	Ave. Depth	lakeshore
		N Latitude	W Longitude	Area-acres	Acre feet	Cubic meters	feet	feet	mi.
Hay, Upper	18-412	46m 38.418	94m 17.967	580	8,700	10.7E+6	42	18	
Hay, Lower	18-378	39.798	16.976	691	34,166	42.1E+6	100	49	4
Whitefish Up.	18-310	41.279	15.983	5,261	142,862	176.2E+6	86	27	
Arrowhead	18-366	42.572	12.746	304	3,310	4.1E+6	13	11	
Bertha	18-355	39.754	15.039	356	9,940	12.3E+6	64	30	3.7
Clamshell	18-356	40.232	13.63	256	2,114	2.6E+6	44	8	4.3
Pig	18-354	40.613	10.857	187	4,308	5.3E+6	56	23	
Trout, Big	18-315	42.748	10.161	1,341	68,726	84.8E+6	128	51	
Whitefish Low	18-310	42.051	10.053	2,210	121,129	149.4E+6	138	55	
Island	18-183	42.583	8.076	257	5,305	6.5E+6	75	21	
Rush	18-311	42.024	7.544	961	19,384	23.9E+6	128	20	11.6
Crosslake	18-312	40.722	7.384	1,773	55,818	68.9E+6	84	32	19.6
Pine, Little	18-266	42.183	4.061	384	5,046	6.2E+6	38	13	6.5
Daggett	18-271	41.319	5.697	225	2950	3.6E+6	23	13	

200, 118

E+6=10 to the 6th power

file: Phos, Loading Study-Lake Demographics

**cubic meters = acre feet x 1233.482

10/15/01

Table 2
Whitefish Chain
10 meter Column Phosphorus Data

LAKE	Total Phosphorus-micro gms./ l. 0-10 m.	10 - 20 m.	20 - 30 m.	Total	Average	LAKE	Total Phsphorus-micro gms/ l. 0 - 10 m	10 - 20 m	20 -30 m	Total	Average
Hay, Upper						Trout, Big					
7/11/00	11.4	(12) 10.3		21.7	10.85	7/11/00	8.9	9.3	(23) 14.9	33.1	11.0
10/10/00	19.9			19.9	19.9	10/10/00	12.2	11.0	14.1	37.3	12.4
1/12/01	11.6			11.6	11.6	1/7/01	11.2	8.8	11.9	31.9	10.6
5/16/01	20.5			20.5	20.5	5/14/01	11.5	15.9	14.8	42.2	14.1
Total	63.4	10.3		73.7		Total	43.8	45.0	55.7	144.5	
Average	15.9	10.3			14.7	Average	11.0	11.3	13.9		12.0
Hay, Lower						Whitefish, Lower					
7/11/00	9.3	10.3	(27) 18.8	38.4	12.8	7/11/00	10.1	14.2	8.6	32.9	11.0
10/10/00	8.4	7.3	10.2	25.9	8.6	10/9/00	20.5	14.4	12.6	47.5	15.8
1/4/01	11.6	10.8	12.6	35.0	11.7	1/7/01	22.9	8.5	10.2	41.6	13.9
5/14/01	11.5	15.7	11.5	38.7	12.9	5/14/01	18.3	14.3	13.8	46.4	15.5
Total	40.8	44.1	53.1	138.0		Total	71.8	51.4	45.2	168.4	
Average	10.2	10.8	13.2		11.5	Average	18.0	12.9	11.3		14.0
Whitefish, Upper						Island					
7/10/00	12.6	26.2	(26) 26.6	65.4	21.8	7/11/00	21.4	27.4		48.8	24.4
10/10/00	13.9	15.0	15.3	44.2	14.7	10/9/00	12.5	144.3		156.8	78.4
1/4/01	9.7	17.2	33.5	60.4	20.1	1/7/01	9.1	16.0		25.1	12.6
5/14/01	21.7	18.1	14.9	54.7	18.2	5/14/01	14.9	12.7		27.6	13.8
Total	57.9	76.5	90.3	224.7		Total	57.9	200.4		258.3	
Average	14.5	19.1	22.6		18.7	Aversge	14.5	50.1			32.3
Arrowhead						Rush					
7/10/00	(3) 16.2			16.2	16.2	7/11/00	11.0	16.5	(26) 10.9	38.4	12.8
10/10/00	20.6			20.6	20.6	10/9/00	7.5	8.6	12.4	28.5	9.5
1/4/01	23.1			23.1	23.1	1/12/01	10.8	10.8	29.2	50.8	16.9
5/14/01	23.3			23.3	23.3	5/14/01	12.2	16.3	17.5	46.0	15.3
Total	83.2			83.2		Total	41.5	52.2	70.0	163.7	
Average	20.8				20.8	Average	10.4	13.1	17.5		13.6
Bertha						Crosslake					
7/10/00	10.6	(15) 22.2		32.8	16.4	7/11/00	9.5	11.7		21.2	10.6
10/10/00	6.8	128.7		135.5	69.7	10/10/00	12.1	11.8	(25) 29.2	53.1	17.7
1/4/01	11.3	(17) 9.8		21.1	10.6	1/12/01	11.2	10.9	29.2	51.3	17.1
5/16/01	14.3	14.2		28.5	14.3	5/14/01	16.3	13.4	(27) 17.4	47.1	15.7
Total	43.0	174.9		217.9		Total	49.1	47.8	75.8	172.7	
Average	10.8	43.7			27.2	Average	12.3	12.0	25.3		15.7
Clamshell						Pine, Little					
7/11/00	27.4			27.4	27.4	7/11/00	40.9			40.9	40.9
10/10/00	11.4			11.4	11.4	10/9/00	19.1			19.1	19.1
1/4/01	13.5			13.5	13.5	1/12/01	16.8			16.8	16.8
5/16/01	29.8			29.8	29.8	5/14/01	19.9			19.9	19.9
Total	82.1			82.1		Total	96.7			96.7	
Average	20.5				20.5	Average	24.2				24.2
Pig						Daggett					
7/10/00	20.6	(16) 77.0		97.6	48.8	7/11/00	(6) 22.7			22.7	22.7
10/10/00	12.3	204.2		216.5	108.3	10/9/00	23.1			23.1	23.1
1/7/01	11.9	22.9		34.8	17.4	1/12/01	13.9			13.9	13.9
5/14/01	13.1	14.2		27.3	13.7	5/14/01	(7) 13.1			13.1	13.1
Total	57.9	318.3		376.2		Total	72.8			72.8	
Average	14.5	79.6			47.0	Average	18.2				18.2

Table 3
Whitefish Stream Flow Volume and Phosphorus Loading

	STREAM	Flow Volume cubic feet/sec	Total Phosphorus micro gms./liter
20	Hay Creek into Upper Hay		
	7/11/00	4.9	50.0
	10/10/00	3.8	20.9
	1/12/00	est. 4.4	49.0
	5/16/01	14.9	35.8
	Total	23.6	155.7
	Average	5.9	38.9
21	Hay Creek into Lower Hay		
	7/11/00	8.4	14.9
	10/10/00	3.4	9.6
	1/15/01	est 5.9	11.6
	5/16/01	31.9	12.9
	Total	49.6	49.0
	Average	12.4	12.3
22	Pine River into Upper Whitefish		
	7/11/00	463.0	38.6
	10/10/00	68.0	7.9
	1/15/01	est. 265.5	19.6
	5/16/01	428.0	37.8
	Total	1224.5	103.9
	Average	306.1	26.0
23	Willow Creek into Upper Whitefish		
	7/11/00	1.6	112.6
	10/10/00	0.8	43.7
	1/15/01	est. 1.2	67.6
	5/16/01	18.3	61.4
	Total	21.9	285.3
	Average	5.5	71.3
24	Spring Brook into Arrowhead		
	7/11/00	2.4	33.4
	10/11/00	0.4	est. 31.8
	1/15/01	est. 1.4	30.2
	5/16/01	7.6	59.8
	Total	11.8	155.2
	Average	3.0	38.8
25	Thompson Creek into Arrowhead		
	7/11/00	dry 0	dry
	10/10/00	dry 0	dry
	1/12/01	est. 2.0	79.4
	5/16/01	11.5	104.3
	Total	13.5	183.7
	Average	3.4	91.9
26	Fox Creek into Little Pine Lake		
	7/11/00	3.7	13.9
	10/11/00	0	no sample
	1/12/01	est. 3.7	9.1
	5/16/01	9.1	12.5
	Total	16.5	35.5
	Average	4.1	11.8
27	Daggett Brook into Little Pine Lake		
	7/11/00	58.9	13.2
	10/10/00	57.1	9.1
	1/15/01	est. 58.0	15.4
	5/16/01	88.2	14.0
	Total	262.2	51.7
	Average	65.6	12.9
28	Pine River below Crosslake Dam		
	7/11/00	145.0	11.2
	10/10/00	102.0	7.0
	1/12/01	482.0	19.1
	5/16/01	458.0	13.1
	Total	1187.0	50.4
	Average	296.8	12.6

P.14
Pine River accounts for
75% of flow into the chain
53% of P from tribs into the chain
40% of P going into chain
94% of flow into Whitefish
92% of P into Whitefish

file: Phosphorus Study Stream Loading.
8/4/01

Flow volume estimates were made for Jan. 01 when ice conditions precluded flow measurements

Table 4

Constriction Volume Fl
ow and Phosphorus Loading

		Flow Volume	Total Phosphorus
	CONSTRICTION POINT	cubic feet/sec.	micro gms./liter
29	Lower Hay to Upper Whitefish		
	7/18/00	-76.0	15.9
	10/11/00	2.6	7.6
	1/12/01	est. 10.0	11.4
	5/16/01	110.3	12.7
	Total	46.9	47.6
	Average	11.8	11.9
30	Arrowhead to Whitefish		
	7/18/00	-9.3	16.2
	10/11/00	19.2	14.9
	1/12/01	est. 20.0	26.4
	5/16/01	4.7	18.9
	Total	24.6	76.4
	Average	6.2	19.1
31	Big Trout to Lower Whitefish		
	7/18/00	17.7	9.2
	10/11/00	1.6	7.5
	1/12/01	est. 10.0	9.2
	5/16/01	-19.3	12.3
	Total	10.0	38.2
	Average	2.5	9.6
32	Rush to Crosslake		
	7/18/00	260.0	15.1
	10/11/00	49.3	9.8
	1/12/01	est. 75.0	8.8
	5/16/01	97.2	14.5
	Total	481.5	48.2
	Average	120.4	12.1
33	Daggett to Crosslake		
	7/18/00	83.2	18.0
	10/11/00	19.8	12.7
	1/12/01	est. 60.0	13.0
	5/16/01	204.8	12.6
	Total	367.8	56.3
	Average	92.0	14.1

Flow volume estimates were made for Jan 01 when ice conditions p

Negative flows ignored in totals and averages.

file: Phosphorus Study Constriction Loading 8/15/01

Table 5

Phosphorus Study
Precipitation,
Total Phosphorus

Samples Collected at the
Steffen's Residence
on Lower Hay, Jenkins

Sample Date	Total Phosphorus micro gms./liter
8/12/00	86.7
8/17/00	60.3
10/15/00	16.5
1/15,1/30/01	31.5
4/7/01	26.0
4/11/01	12.2
4/22/01	21.2
5/1,5/6/01	137.2
Total	555.3
	ave. 50.2

file: Phosphorus Study, Precipitation Phosphorus 7/12/01

Table 6

Lakeshore Dwellings and Phosphorus Deposition from Septic Systems

Dwelling	Arrowhead	Bertha	Clamshell	Crosslake	Daggett	Hay, Lower	Hay, Upper	Island	Rush	Pig	Pine, L	Trout, Big	Whitefish	TOTAL
Year around	5	46	22	151	70	33	26	22	81	11	36	38	242	783
Seasonal	24	88	84	292	152	93	61	59	147	60	67	129	644	1900
Resort/Comm.	0	1	0	10	3	3	0	0	1	1	1	0	8	28
TOTAL	29	135	106	453	225	129	87	81	229	72	104	167	894	2711
Phos. Yield(lbs)														
Year around	15	138	66	453	210	99	78	66	243	33	108	117	726	2352
Seasonal	18	18	63	219	114	70	46	44	110	45	50	97	483	1377
Resort/Comm.	0	5	0	50	15	15	0	0	5	5	5	0	40	140
TOTAL	33	161	129	722	339	184	124	110	358	83	163	214	1249	3869

file: Dwellings 8/20/01

Table 7
TOTAL PHOSPHORUS INPUTS/OUTPUTS FOR LAKES CHAIN

	Wet & Dry Precipitation			Tributary Input			Septics Input			Total Input		Total Output	APS	LPM	APS/LPM	Tw
Lake Name	Lbs.	%	%	Lbs.	%	%	Lbs.	%	%	Lbs.	%	Lbs.	Lbs.	Lbs.	x100=%	Year
		Input	Precip.		of Input	of Trib's.		of Input	of Septics		of Input					
Hay, Upper	238	29.4	3.9	452	55.5	1.5	124	15.1	3.2	814	2.0	300	514	347	148	1.0
Hay, Lower	284	37	4.7	300	39	1.0	184	24	4.8	768	1.9	277	491	1067	46	4.0
Arrowhead	125	12.7	2.1	827	84	2.8	33	3.3	0.9	985	2.4	233	751	188	399	0.8
Bertha	146	47.6	2.4	0	0	0	161	52.4	4.2	307	0.7	0	307	505	61	
Clamshell	105	44.9	1.7	0	0	0	129	55.1	3.3	234	0.6	0	234	118	199	
Pig	76	47.8	1.2	0	0	0	83	52.2	2.1	159	0.4	0	159	286	57	
Trout, Big	551	72	9.1	0	0	0	214	28	5.5	765	1.9	47	718	2243	29	38.0
Island	106	49	1.8	0	0	0	110	51	2.8	216	0.5	0	216	329	66	
Whitefish	3068	14.4	50.7	16993	79.7	57.9	1249	5.9	32.2	21310	51.5	3224	18,086	11,867	152	3.0
Rush	395	10	6.5	3224	81	11.1	358	9	9.3	3978	9.6	3224	753	717	105	0.4
Pine, Little	159	7.6	2.6	1761	84.6	6	163	7.8	4.2	2083	0	0	2083	571	365	
Daggett	92	21.4	1.5	0	0	0	339	78.6	8.8	431	6.1	2554	40	719	6	0.2
Crosslake	712	9.9	11.8	5778	80.1	19.7	722	10	18.7	7212	17.4	7363	-151	2383	-6.3	2.6
TOTAL	6057	15.4	100.0	29335	74.7	100	3869	9.9	100	39262	100	17222	24201	21340		

NOTE: Little Pine and Daggett were treated as one basin with the combined inputs shown in Daggett calculations

APS = annual phos. storage
LPM = lake phos. mass
Tw =water retention time
APS/LPM=Phos loading ratio

file: Inputs/Outputs

12/03/01