LPL-229

Maurice Prendergast: *Salem Cove*, 1916

Water Quality Study and Lake Management Plan for Half Moon Lake, Lincoln County, Wisconsin

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Submitted to:
Half Moon Lake Protection and Rehabilitation District
Lincoln County, Wisconsin

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HALF MOON LAKE
SUMMARY

Half Moon Lake is an 86 acre lake located in Lincoln County, Wisconsin.

Goals The goals of this project were:

- to check lake acidity, productivity, and to evaluate existing conditions
- to develop a lake management plan that protects, maintains, and enhances the lake's water quality.

Watershed Characteristics

- Half Moon Lake is a seepage lake that has a watershed of about 220 acres.
- The watershed is dominated by wetlands and forest acreage.
- There is little surface inflow. A canal connects Half Moon Lake with Clear Lake but little water runs in from Clear Lake.

Water Quality and Quantity Monitoring Methods

- Sampling was conducted in June, July, and August of 1994.
- Field measurements included secchi disc, temperature and dissolved oxygen profiles and conductivity.
- Chemical analysis was conducted by the Wisconsin Laboratory of Hygiene. The following parameters were analyzed:

Chlorophyll a	pH
Nitrate plus Nitrite	Total Kjeldahl Nitrogen
Total Phosphorus	Iron
Ammonia	Alkalinity
Calcium	

Dissolved Oxygen and Temperature

- Half Moon Lake is shallow with a maximum depth of about 14 feet. During the summer it does not stratify by temperature.
- Dissolved oxygen in June, July, and August was generally over 5 mg/l. In August 1994, oxygen was low at the sediment/water interface.

Nutrients

- Phosphorus levels for June, July, and August averaged 14 ppb. Water transparency was 10 feet, and chlorophyll a was about 1.4 ppb. These values indicate the lake is not very productive and has clear water.

Alkalinity and pH

- Alkalinity is low, at about 2 mg/l as $CaCO_3$. Average summer pH was 5.3. This indicates the lake is an acid sensitive lake. The pH doesn't appear to have changed since the 1984 sample.

Macrophyte Status

- Half Moon Lake survey consisted of several perpendicular and parallel transects in relation to the shoreline. Rooted plants were found in water depths to 8 feet. Plant coverage is about 80% of the bottom of the lake.

Lake Water Quality Trends

- Water chemistry results are comparable to Ecoregion values
- No nuisance open water algae was found in 1994, but filamentous algae was abundant, but mostly submerged.
- The data base does not go back far enough to examine trends, however Half Moon Lake at this time has relatively low phosphorus concentrations (summer average = 14 ppb). In 1989, a single reading in July was 39 ppb.
- We do not know how long Half Moon Lake has been acidic.

Lake Modeling

- The Wisconsin Lake Model Spreadsheet was used to evaluate lake nutrient inputs.
- For Half Moon Lake, the model predicted phosphorus concentrations that ranges from 7 to 74 ppb of phosphorus. The actual lake phosphorus level was 14 ppb.

What Is the Trophic Status?

The Trophic State Index (TSI) rates a lake from 1 to 100, with low numbers being the best. Half Moon Lake is currently rated as a mesotrophic to eutrophic lake. The average TSI value is 44.

Conclusions

Several compounding factors make lake management recommendations difficult. The current fishery does not appear to be very good. It seems this is a result of winterkill rather than of acidic conditions. The last official fish survey was conducted in 1972.

To improve the fishery winter aeration could be installed, but because the lake has low productivity (chlorophyll a is less than 2 ppb), the lake probably will not support high numbers of fish.

Raising the pH may help improve the fertility, but this could cause nuisance algae blooms and is not a desirable outcome.

I would recommend monitoring dissolved oxygen over winter, and if low, consider installing a winter aeration system.

Also, I would recommend continued monitoring of pH. If it drops below 5.0 and averages less than 5.0 over a summer, I would add lime in the form of limestone in low doses over a 2 to 3 year period to bring the pH up.

Dredging the soft sediments of Half Moon Lake would not improve the overall quality of the lake. I do not believe it would be a cost-effective measure. Some spot dredging using a backhoe may increase depths in some nearshore areas, and this would be a project for individual homeowners.

Recommended Lake Management Projects

1. Continue a lake monitoring program, to monitor winter oxygen levels as well as pH, phosphorus, and algae. Consider a fish survey as part of a Lake Management Planning grant program.
2. If winter oxygen levels are low, a winter aeration system should be considered.
3. Landscaping for wildlife on lake resident lots.
4. On-site system maintenance program.
5. If a pH adjustment is needed, liming with limestone would be recommended over groundwater augmentation.

--Contents--

1. Introduction and Project Setting

Half Moon Lake (Figures 1 and 2) is a glacial seepage lake located in Lincoln County, Wisconsin. Half Moon Lake is a mesotrophic to eutrophic lake with moderate phosphorus levels (4-20 μg/l) and a good secchi disc transparency of about 10 feet in summer.

The goals of this project were to examine existing lake conditions and to develop lake management plans to protect, maintain, and enhance lake water quality for the short term and long term.

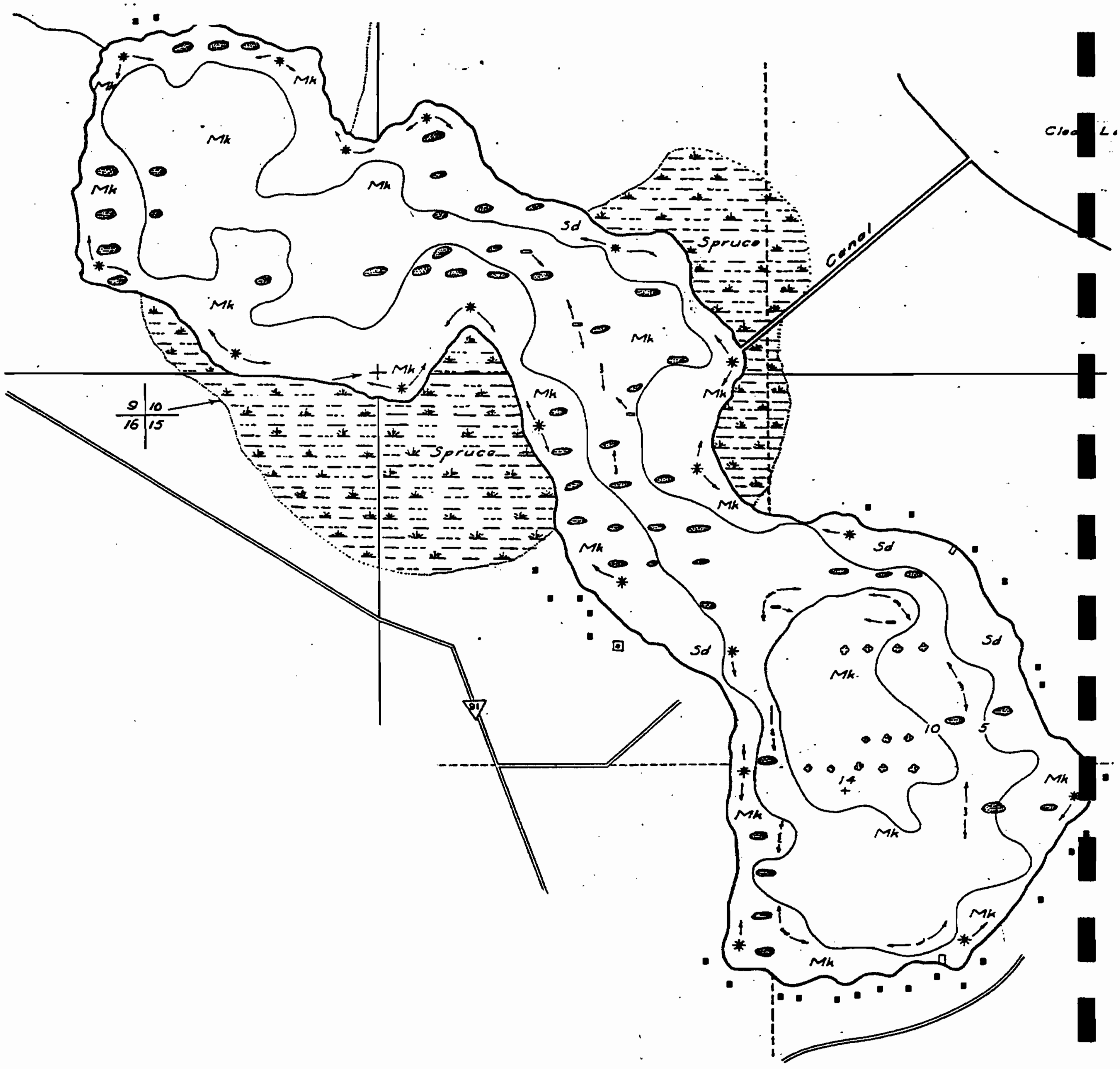

Figure 1. Contour map of Half Moon Lake, Lincoln County, Wisconsin.

2. List of Projects that Have Been Done on Half Moon Lake

Several projects have been conducted on Half Moon Lake, including fish surveys conducted by the Wisconsin Department of Natural Resources and lake status by Northern Lake Service.

The 1972 WDNR fish survey and the 1985 lake baseline report and the 1992 lake sediment report are located in Appendix A.

3. Geologic Setting

Half Moon Lake is located in the older drift outwash and was not effected by the last glaciation (Figure 3, Map 6). Half Moon Lake is located in the northern highland of Wisconsin (Figure 3, Map 8). Half Moon Lake drains to the Wisconsin River which eventually feeds into the Mississippi River (Figure 3, Map 9). Most of the land area is wetlands or forest (Figure 3, Map 11).

4. Watershed Characteristics

Land Use

General land use in the watershed is shown in Figure 4. The Half Moon Lake watershed encompass approximately 222 acres. Of that 222 acres, forested/open dominate with 100 acres followed by 63 acres of residential land and then 59 acres of wetlands (Table 1).

Table 1. Land use in the Half Moon Lake watersheds. Areas presented are in acres. Numbers shown in parentheses are the percent of land use.

Land use of each Lake

	Forest	**Wetlands**	**Urban**	**Total**
Half Moon Lake	100 (45)	59 (26)	63 (28)	222

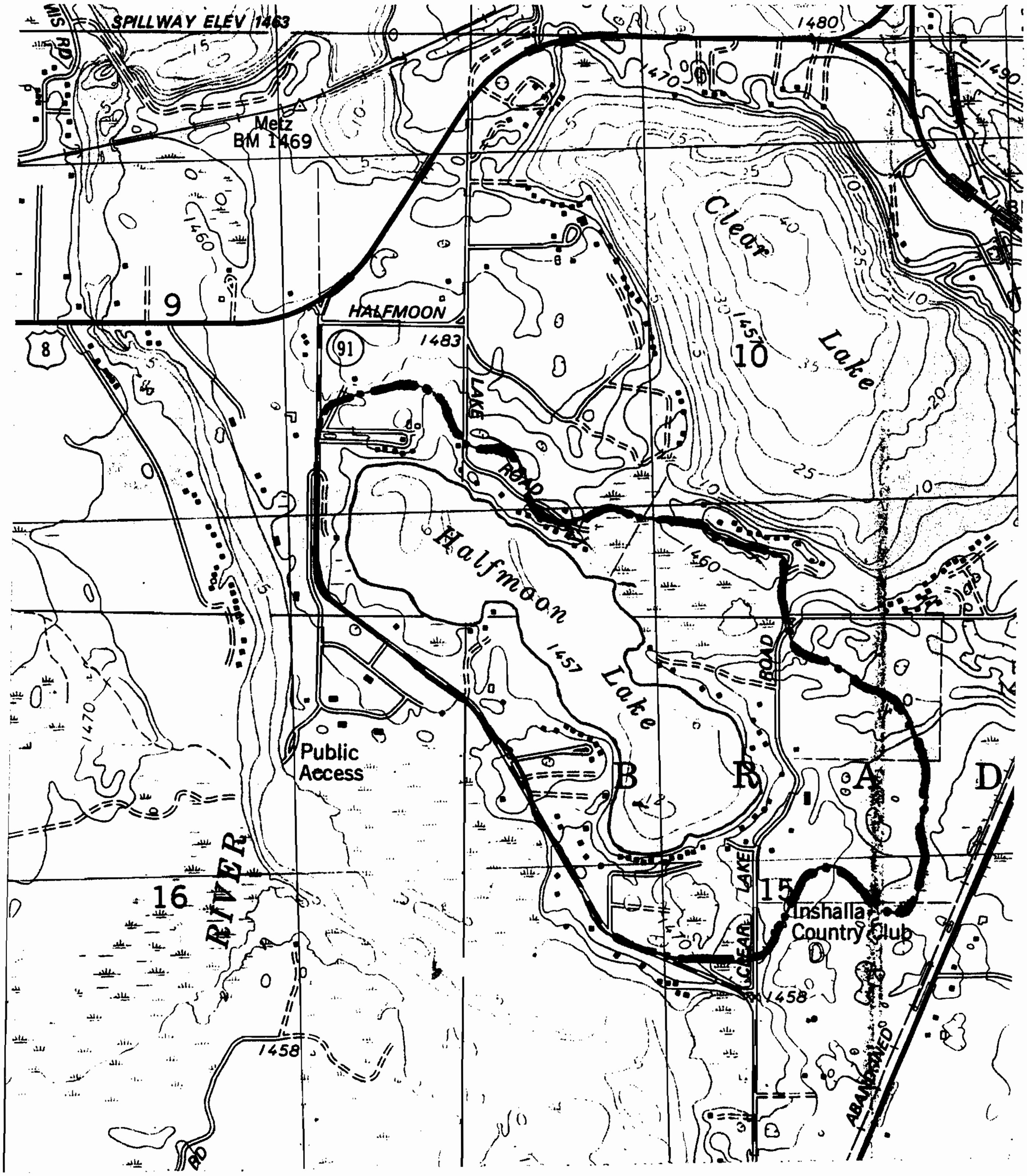

Figure 4. Half Moon Lake watershed.

5. Lake Characteristics

Lake Sediments

Half Moon Lake sediments are dominated by sand in the nearshore areas and are mucky in the deeper water. A sediment survey was conducted in 1992 by Northern Lake Service (shown in Appendix A) and soft sediment depths were determined (Figure 6).

Soft sediments probably reflect sedimentation that has occurred after the retreat of the glaciers. Soft sediment depths in Half Moon Lake ranged from 5 to 15 feet (Figure 6). This is not a very high accumulation rate. Other lakes in this area have soft sediment thickness of 40 feet or more.

The relatively low sediment accumulation in the original Half Moon Lake basin also tells us that the original lake basin was never very deep. This finding may give some support to the idea that the shallow lake basin is isolated from the regional groundwater because its bottom does not penetrate into the aquifer. Isolation from regional groundwater would imply that surface inflows and rain are the major inputs. Because rain apparently dominates, and has a low pH, it may be at least, partly responsible for the low pH in Half Moon Lake.

Water Depth (feet) **Sediment Thickness (feet)** **Original Basin Depth (feet)**

Figure 6. **Contours of lake depths, sediment depths and original basin depths (Northern Lake Service, 1992).**

Physical/Chemical Data Emphasizing Dissolved Oxygen, Temperature, and Secchi Disc

Half Moon Lake is 86 acres in size, with a watershed of 222 acres. The average depth of Half Moon Lake is about 5 feet with a maximum depth of 14 feet (Table 2). A lake contour map is shown in Figure 1. Half Moon Lake is located in an area of Wisconsin that is dominated by wetlands and forests. The Half Moon Lake watershed is 45% forest (100 acres), 28% residential (63 acres) and 26% wetlands (59 acres) (Table 2).

The secchi disc transparency had an average summer depth of 12.3 feet in 1994.

The summer dissolved oxygen (DO) and temperature profiles are shown in Figure 7.

A concern for Half Moon Lake is the decrease in oxygen in the hypolimnion.

Table 2. Half Moon Lake Characteristics

Area (Lake): 86 acres (34.8 ha)
Mean depth: 5 feet (1.5 m)
Maximum depth: 14 feet (4.3 m)
Volume: 430 acre-feet (52.2 Ha-M)

Watershed area: 222 acres (89.8 ha)
Watershed: Lake surface ratio 3:1
Estimated average water residence time 1.7 years
Public accesses (#):
Inlets: 0 Outlets: 1

Land Use (percentage/area):

	Forest	Wetlands	Urban-Res
Percentage	45	26	28
Acres	100	59	63

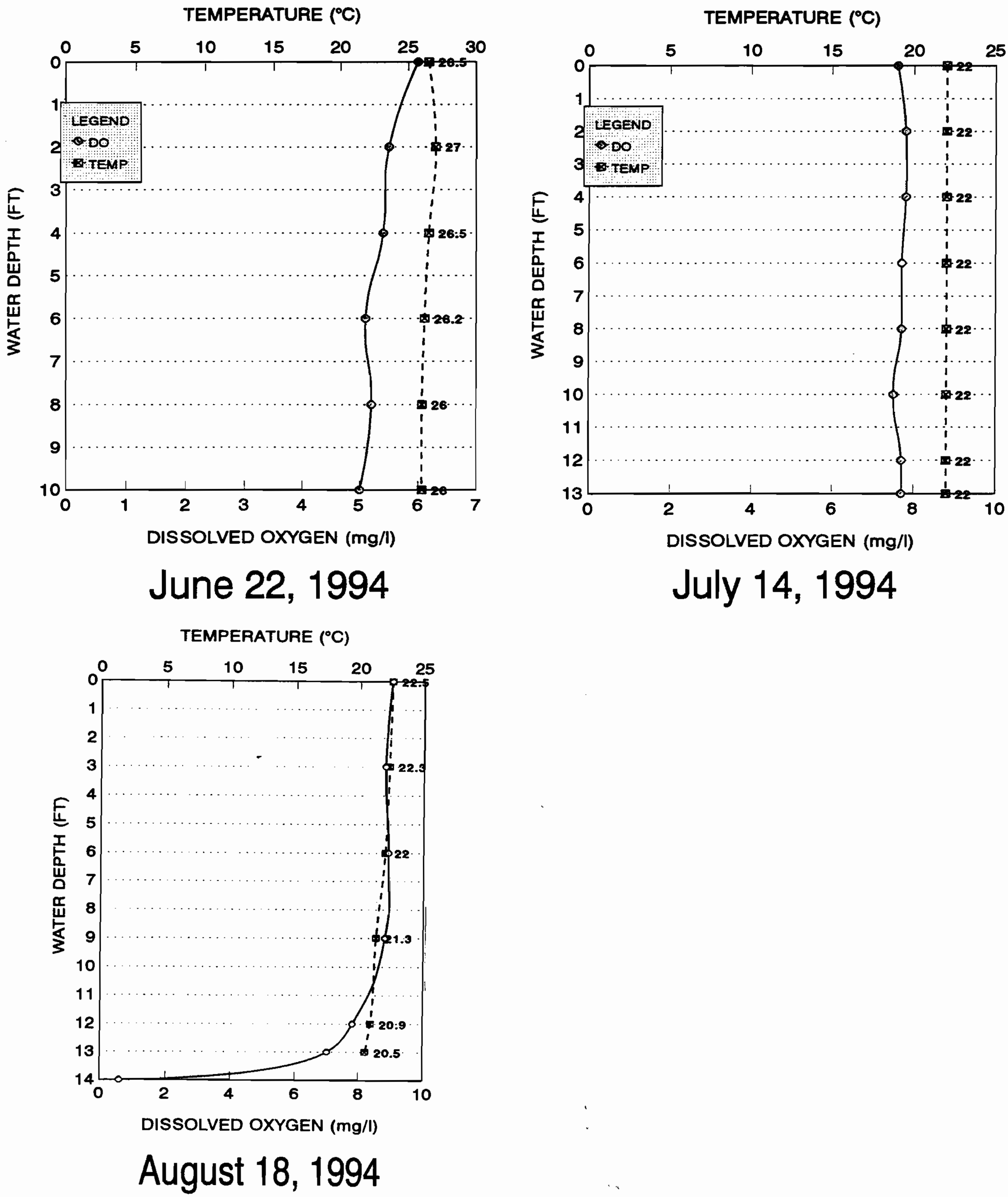

Figure 7. Dissolved oxygen and Temperature profiles for Half Moon Lake.

Physical/Chemistry Data: Phosphorus, Nitrogen
Summer water chemistry data collected during 1994 included secchi disc, total phosphorus (TP), chlorophyll a (Chl a), total kjeldahl nitrogen (TKN), ammonia (NH_3), nitrate (NO_3), and conductivity (Cond) (Table 3). Samples were collected at the surface and two feet off the bottom in the deepest area of Half Moon Lake.

Table 3. Half Moon Lake water chemistry data for 1994.

Location	Date	TKN (mg/l)	NO3 (ug/l)	TP (ug/l)	Calcium (mg/l)	Chl a (ug/l)	Conductivity (umhos/cm)	pH	Alk (mg/l)	Iron (mg/l)
Top	6.22	0.4	3850	8	1.6	1.1	22	5.38	2	<0.05
Bottom	6.22	--	--	11	1.7	--	22	5.70	3	0.06
Top	7.14	0.39	<7	8	1.5	2.5	22	5.25	2	<0.05
Bottom	7.14	--	<7	14	1.6	--	22	5.88	3	0.05
Top	8.18	0.3	<7	26	1.4	0.7	22	5.26	2	0.12
Bottom	8.18	--	<7	9	1.5	--	22	5.37	2	0.11
Summer Averages (surface)		0.36	<7	14	1.5	1.4	22	5.30	2	<73

Algae: Algae samples were taken three times during the 1994 sampling summer. Phytoplankton are microscopic plants that are indicators of the amount of nutrients, mostly phosphorus, that are in the water column.

Overall numbers of algae were low. The analysis indicate that blue-green algae are the dominant algae during the sample year of 1994 (Table 4).

Zooplankton: Zooplankton samples were collected three times during the summer of 1994.

Copepods were the dominant zooplankton in Half Moon Lake throughout the summer of 1994. Results of the zooplankton analysis is shown in Table 4.

Table 4. Zooplankton and phytoplankton counts for Half Moon Lake.

Half Moon Lake zooplankton counts

	Daphnids						Copepods				Rotifers
Date	Big	Little	Ceriodaphnia	Bosmina	Chydorus	Total	Calanoids	Cyclopoids	Nauplii	Total	
6.22.94	7	16	0	0	0	17	4	21	61	86	0
7.14.94	1	3	0	1	1	6	23	1	18	42	12
8.18.94	3	2	0	1	0	6	7	5	16	28	36

Half Moon Lake phytoplankton counts.

Date	Species	Number/ml of water
6.22.94	Microcystis	17
	Chlofococcales	311
7.14.94	Microcystis	157
	Staurastrum	17
8.18.94	Microcystis	2,123
	Chroococcus	766
	Chlorella	592
	Chlorococcales	661

Macrophytes
An aquatic plant survey was conducted on Half Moon Lake in 1994 and results are shown below.

Three transects were run with sample points at different locations around Half Moon Lake. Rooted plants were found over most of Half Moon Lake. Plant coverage is shown in Figure 7. Plant coverage on the bottom is roughly 85% of the bottom area. Two plant groups are represented, with no group dominating (Table 5).

Table 5. Species list of the aquatic plants found in Half Moon Lake.

Common Name	Scientific Name
moss	*Drepanocladus*
turf	*Myriophyllum tenellum* (identified in 1989)

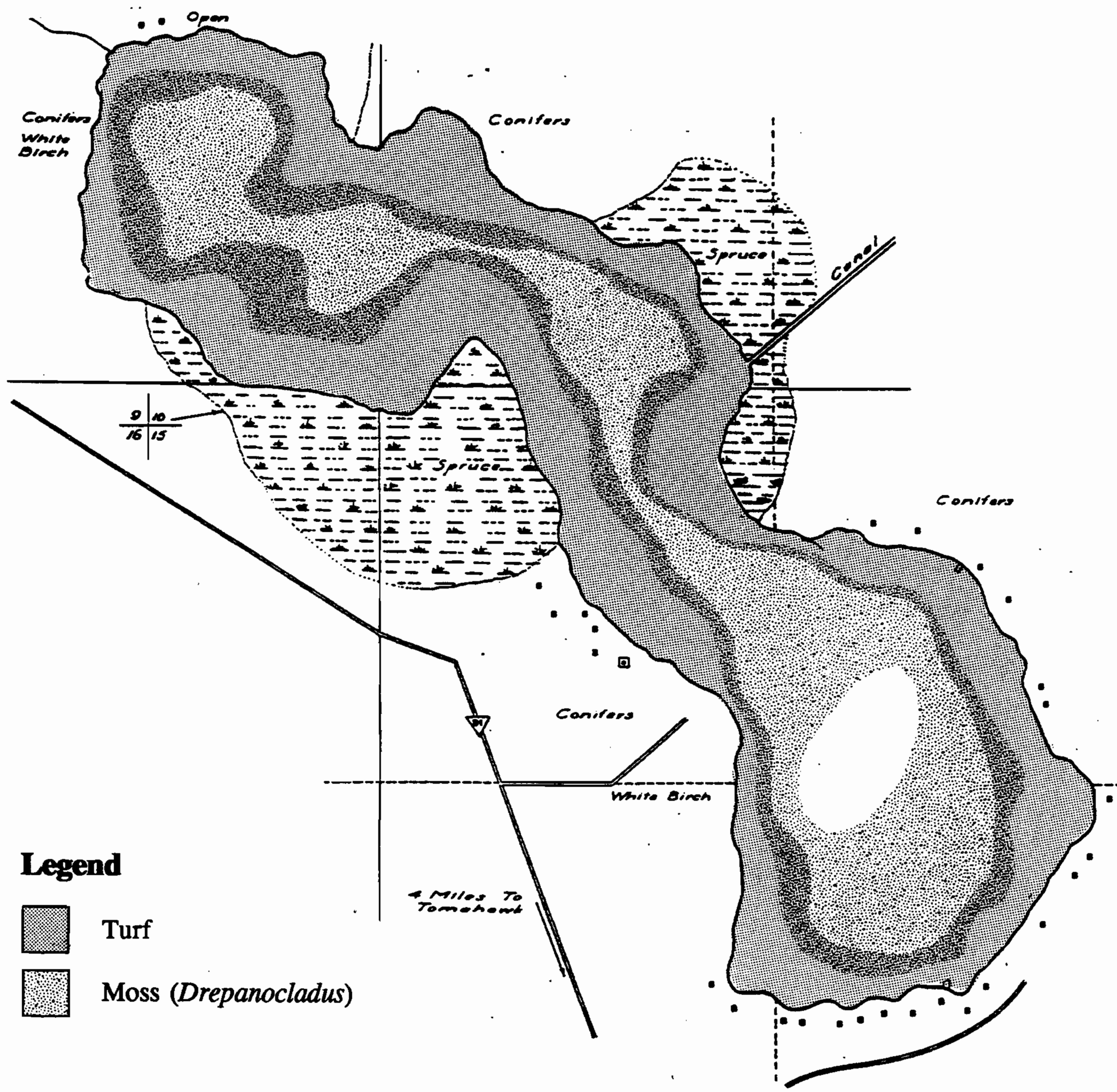

Figure 8. Aquatic plant map for Half Moon Lake, 7.14.94.

Conductivity Survey
A conductivity survey was preformed on Half Moon Lake during July 1994. A conductivity survey uses a Yellow Springs Inc. specific conductance meter with the probe secured to the end of a pole. A boat moves slowly around the shoreline and he meter is watched to spot changes in specific conductance. The objective of the conductivity survey is to find possible groundwater inflows (springs) or faulty on-site wastewater treatment systems. A conductivity less than the background conductivity of the open lake indicates areas of groundwater inflow, whereas a higher conductivity, could indicate a faulty septic system.

There are a few locations around Half Moon Lake that need to be looked at more closely in regard to potential failing on-site systems (Figure 9). Conductivity that is different than open lake background (16 umhos/cm^2) by about 10% should be looked at more closely. There appears to be three locations around Half Moon Lake that could be groundwater inflows, and one location that could be a faulty septic system or a point source of pollution to the lake.

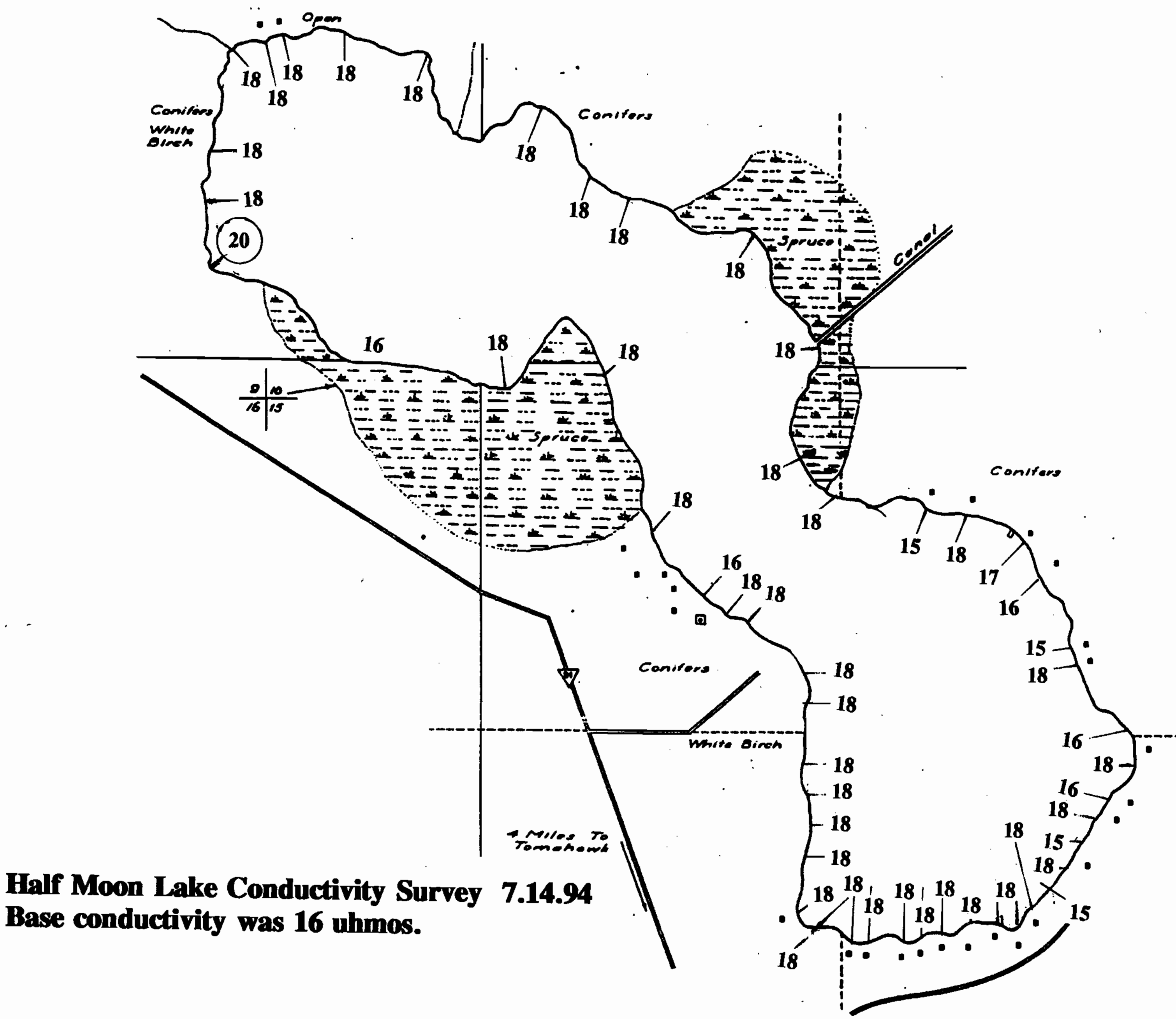

Figure 10. Half Moon Lake conductivity survey, 7.14.94.

Fish

The last fish survey we found in the files was from 1972. Excerpts from the report of April 18, 1973 are shown below. Fish survey results, conducted by WDNR

Fishes

The only game fish in this survey were northern pike. The panfish population consists of yellow perch, bluegill, pumpkinseed, black crappie, black bullhead, and brown bullhead. Half Moon Lake suffered a partial winterkill in 1971. After the ice went out, a few large dead walleye (23-28) were observed. It appears as if the walleye population was not significant before the kill and may not exist now.

The fish population appears to be heavily influenced by partial winterkill and critical winter D.O. levels. No particular species is very abundant and the population is dominated by low oxygen tolerant panfish such as bullhead, yellow perch, and pumpkinseed. Of the game fish, northern pike tolerate low oxygen quite well and only they were found in our survey. It was interesting to note that young of the year bluegill were found during the survey but no adults, while adult crappie were found but no young of the year crappie were found. This would seem to indicate that the success of each species is quite variable.

Aquatic Vegetation

Nuisance algae blooms develop frequently in the summer months. Chemical treatments have been carried out. Sparse stands of yellow water lily and pickerel weed were the only macrophyte vegetation found.

Past Investigations

A perch removal investigation was initiated in 1949 and species found were yellow perch, bluegill, crappie, sunfish, a few largemouth bass, one rockbass, and one walleye. A seine haul in 1954 yielded a total of twelve smallmouth bass. Winter oxygen levels were tested in 1961 and 1970 and were found to be critically low.

Past Management

A variety of fish including bluegill, crappie, yellow perch, sunfish, largemouth bass and northern pike were stocked from 1938 to 1956. During the past ten years, stocking has consisted of northern pike in 1965 and 1971 and an isolated planting of 408 musky fingerlings in 1962.

Proposed Management Measures

The findings of this survey indicate that little fish management can take place until winter oxygen problems can be alleviated. This lake appears to be a good candidate for experimentation with the Crisafalli pump. If this method proves feasible, perhaps a group of the resort and cottage owners could purchase and operate a pump. Until this becomes a reality, I am recommending northern pike fry plants after winterkill and periodic plantings of adult northern pike when available.

6. Half Moon Lake Phosphorus Model

Lake modeling is a tool that aids in predicting what phosphorus concentrations should be in a lake based on the amount of nutrients that comes into a lake on an annual basis. A lake model can also be used to predict what future conditions could be if changes occur in the watershed that bring in more phosphorus.

Many lake models have been written. In this report we used the Wisconsin Lake Model Spreadsheet (WLMS) which will run 10 different lake models at the same time. An example of an equation used in a lake model is the Canfield and Bachmann Model (1981). The model format is shown in Table 6.

Before the WLMS models could be run, nutrient and water budget for Half Moon Lake was needed. To estimate the nutrient budget, phosphorus concentrations were assigned for various land use delineations and then assuming a certain amount of runoff per year we estimated phosphorus inputs from various land uses. A summary of phosphorus export coefficients for each land use and then the total estimated phosphorus input to Half Moon Lake is shown in Table 7. The nutrient input table shows that agricultural land is the major nutrient contributor to Half Moon Lake. The variables with high uncertainty are groundwater inputs as well as septic tank inputs. Our estimates are that septic tanks inputs are relatively low.

The phosphorus model predictions and the actual observed phosphorus load are shown in Table 7 as well.

Table 6. Phosphorus models used for Half Moon Lake.

Canfield and Bachmann Phosphorus Model (1981)

$$TP = \frac{L}{z(0.162\ (L/z)^{0.458} + p)}$$

where:

TP (mg/m^3) = concentration of total phosphorus in the lake water
L ($mg/m^2/yr$) = annual phosphorus loading per unit of lake surface area
z (m) = mean depth of the lake
p (yr^{-1}) = hydraulic flushing rate

Model Results: The nutrient loading from on-site wastewater treatment systems was estimated based on the number of people living around Half Moon Lake. We assumed 50 cabins with a combination of permanent and seasonal residences. A total of 50 capita - year was used in the model. This results in about 4 kilograms of phosphorus coming into Half Moon Lake per year from on-site systems.

The 10 models all used the same input data, but the predicted lake phosphorus concentration ranged from 9 to 58 ppb. The observed phosphorus concentration was 14 ppb. The models bracketed the lake phosphorus concentration. The oxic lake model by Reckhow was the closest fit to what we observed in the lake, but model number 10 was also close.

Table 7. Phosphorus model for Half Moon Lake.

```
*******************************************************************
*                WISCONSIN LAKE MODEL SPREADSHEET                 *
*                   VERSION 1.01 - JULY 1994                      *
*            WISCONSIN DEPARTMENT OF NATURAL RESOURCES            *
* Although this model has been tested by WDNR, no warranty is     *
* expressed or implied.  See users manual prior to using model.   *
*******************************************************************
* LAKE IDHalf Moon Lake                                           *
* TO AUTO LOAD WTRSHD.   DATA ENTER COUNTY ID, HOLD ALT & TYPE  L *
* WATERSHED COUNTY IDENT. NUMBER    =       35 CO. NAME:Lincoln   *
*******************************************************************
*              HYDROLOGIC AND MORPHOMETRIC MODULE                 *
* ============================================================== *
*                             ENGLISH            METRIC           *
* TRIB. DRAINAGE AREA     =     220.0 Ac.       8.90E+05 m^2      *
* TOTAL UNIT RUNOFF       =      11.7 In.          0.297 m        *
* ANNUAL RUNOFF VOLUME    =     214.5 Ac-Ft.    2.65E+05 m^3      *
* LAKE SURFACE AREA <As> =      86.0 Ac.       3.48E+05 m^2      *
* L. VOLUME <V>           =     430.0 Ac-ft.    5.30E+05 m^3      *
* L. MEAN DEPTH <z>       =      5.00 Ft.           1.52 m        *
* L. NET ANNUAL PRECIP.   =       5.2 In.           0.13 m        *
* HYDRAULIC LOADING       =     251.8 Ac-Ft/Yr 3.11E+05 m^3/Yr   *
* AREAL WATER LOAD <qs>   = 2.93E+00 Ft/Yr.    8.92E-01 m/Yr     *
* L. FLUSHING RATE <p>    =      0.59 /Yr  Tw =     1.71 Yr       *
*******************************************************************
*                   PHOSPHORUS LOADING MODULE                     *
* ============================================================== *
*                            --LOADING (Kg/Ha-Yr)--               *
* LAND USE              AREA           MOST             LOADING   *
*                       (Ac)    LOW    LIKELY    HIGH   PERCENT   *
* AGRICULTURE            0.0   0.30     0.50     2.00      0.0    *
* FOREST                50.0   0.05     0.10     0.20      6.2    *
* URBAN                 15.0   0.50     1.00     1.50     18.5    *
* OPEN GRASSLAND        50.0   0.10     0.30     0.50     18.5    *
* WETLAND              105.0   0.10     0.10     0.10     12.9    *
* PRECIPITATION         86.0   0.10     0.30     1.00     31.8    *
* -------------------------------------------------------------- *
* POINT SOURCE WATER LOADING (m^3/Yr)          0.00E+00           *
* POINT SOURCE PHOS.(Kg/Yr)    0.00     0.00     0.00      0.0    *
* SEP.TANK OUTPUT(kg/cp-yr)    0.70     0.80     2.10     ----    *
* # capita-years        50.00  ----    -----     ----     ----    *
* % P. RETAINED BY SOIL          98       90       80     ----    *
* SEP. TANK LOADING (Kg/Yr)    0.70     4.00    21.00     12.2    *
* -------------------------------------------------------------- *
* TOTAL LOADINGS (Lb)      3.20E+01 7.24E+01 1.84E+02    100.0    *
* TOTAL LOADINGS (Kg)      1.45E+01 3.29E+01 8.33E+01    100.0    *
* ------------------------------------------------------------   *
* AREAL LOADING(Lb/Ac-Yr) =3.72E-01 8.42E-01 2.14E+00             *
* AREAL LOADING(mg/m^2-yr)=4.17E+01 9.44E+01 2.39E+02             *
*    %  TOTAL PHOSPHORUS REDUCTION =         0                    *
*******************************************************************
```

Table 7. Continued.

```
**********************************************************************
*                  PHOSPHORUS PREDICTION MODULE                      *
* ================================================================== *
* OBSERVED SPRING TOTAL PHOSPHORUS          =       14     mg/m^3    *
* ------------------------------------------------------------------ *
*                                                         PREDICTED  *
*   LAKE PHOSPHORUS MODELS                        TOTAL PHOSPHORUS *
*                                                        (mg/m^3)    *
*                                                 ---------------- *
*                                                                    *
* 1. WALKER, 1987  RESERVOIR MODEL                           54      *
*               24        54        136                              *
* 2. CANFIELD-BACHMANN, 1981, NATURAL LAKE MODEL             44      *
*                                                                    *
* 3. CANFIELD-BACHMANN, 1981, ARTIFICAL LAKE MODEL           36      *
*                                                                    *
* 4. RECKHOW, 1979, NATURAL LAKE MODEL                        7      *
*            0.003     0.007     0.019                               *
* 5. RECKHOW, 1977, ANOXIC LAKE MODEL                        74      *
*               33        74        189                              *
* 6. RECKHOW, 1977 OXIC LAKES  qs < 50 m/yr                  58      *
*               25        58        146                              *
* 7. RECKHOW, 1977 OXIC LAKES  qs > 50 m/yr                  18      *
*                8        18         46                              *
* 8. WALKER 1977, GENERAL LAKE MODEL                         50      *
*               50        50         50                              *
* 9. VOLLENWEIDER, 1975  LAKE MODEL                           9      *
*                                                                    *
* 10. DILLON-RIGLER-KIRCHNER, 1975 LAKE MODEL                10      *
*      P. RETENTION  COEFFICIENT <R>    0.90                         *
**********************************************************************
*                   UNCERTAINTY ANALYSIS MODULE                      *
* ================================================================== *
*                          PREDICTED                                 *
*                          MINUS                  95 PERCENT         *
*                          OBSERVED    PERCENT    CONFIDENCE         *
* LAKE RESPONSE MODEL      (mg/m^3)    DIFF.      LIMITS(mg/m^3)     *
* ------------------------------------------------------------------ *
* 1.WALKER, 1987 RESERVOIR      40       286        0      185       *
* 2.CANFIELD-BACHMANN, 1981     30       214       14      127 <=    *
* 3.CANFIELD-BACHMANN, 1981     22       157       11      103 <=    *
* 4.RECKHOW, 1979 GENERAL       -7       -50        0       26       *
* 5.RECKHOW, 1977 ANOXIC        60       429       74      256       *
* 6.RECKHOW, 1977 qs<50 m/y     44       314        0      201       *
* 7.RECKHOW, 1977 qs>50 m/y      4        29        0       60       *
* 8.WALKER,  1977 GENERAL       36       257       18      123       *
* 9.VOLLENWEIDER, 1975          -5       -36       --       --       *
* 10.DILLON-RIGLER-KIRCHNER     -4       -29       --       --       *
* <= Range within which 95% of the observations should fall.         *
* See users manual discussion on the use of these models.            *
**********************************************************************
```

Table 7. Continued.

```
********************************************************************
*                   PARAMETER RANGE MODULE                         *
*     Model input values MUST be within the range listed below.   *
* ============================================================== *
*                          PARAMETERS                              *
********************************************************************
* AREAL WATER LOADING <qs=z/Tw>   =  8.92E-01 m/yr                 *
* INFLOW PHOSPHORUS CONC.<LTw/z> =  1.06E-01 mg/l                  *
* MEAN DEPTH <z>                  =  1.52E+00 m                    *
* FLUSHING RATE <p>               =      0.59 /yr                  *
* HYDRAULIC RETENTION TIME <Tw>   =      1.71 yr                   *
* AREAL PHOSPHORUS LOADING <L>    =     94.40 mg/m^2-yr            *
* P = PREDICTED IN-LAKE PHOSPHORUS CONC.  mg/m^3                   *
* ============================================================== *
*                                              Lakes in data base *
* 1. WALKER, 1985 RESERVOIR MODEL                          (41)    *
*  1.5 < z < 58 m    0.13 < Tw < 1.91 yr                           *
*  0.014 < LTw/z < 1.047 mg/l                     P=        54     *
* -------------------------------------------------------------- *
* 2. CANFIELD-BACHMANN, 1981 NATURAL LAKE MODEL           (704)    *
*  4< P < 2600 mg/m^3  30< L < 7600 mg/m^2-yr                      *
*  0.2< z <307 m       0.001< p <183/yr           P=        44     *
* -------------------------------------------------------------- *
* 3. CANFIELD-BACHMANN, 1981 ARTIFICIAL LAKE MODEL        (704)    *
*  6< P <1500 mg/m^3   40< L <820,000 mg/m^2/yr                    *
*  0.6< z <59 m        0.019< p <1800/Yr          P=        36     *
* -------------------------------------------------------------- *
* 4. RECKHOW, 1979 NATURAL LAKE MODEL                      (47)    *
*  4 < P < 135 mg/m^3    70 < L <31,400 mg/m^2-yr                  *
*  0.75< qs <187 m/yr                             P=         7     *
* -------------------------------------------------------------- *
* 5. RECKHOW, 1977 ANOXIC LAKE MODEL                       (21)    *
*  17< P < 610 mg/m^3 0.024< LTw/z< 0.621mg/l     P=        74     *
* -------------------------------------------------------------- *
* 6. RECKHOW, 1977 OXIC LAKES  qs < 50 m/yr                (33)    *
*  P < 60 mg/m^3    LTw/z < .298 mg/l             P=        58     *
* -------------------------------------------------------------- *
* 7. RECKHOW, 1977 LAKES WITH  qs > 50 m/yr                (28)    *
*  P < 135 mg/m^3    LTw/z < 0.178 mg/l                            *
*  Tw < 0.25 yr      z < 13 m                     P=        18     *
* -------------------------------------------------------------- *
* 8. WALKER, 1977 GENERAL LAKE MODEL                      (105)    *
*  P< 900 mg/m^3     LTw/z < 1.0 mg/l             P=        50     *
* -------------------------------------------------------------- *
* 9. VOLLENWEIDER, 1975  GENERAL LAKE MODEL                        *
*    NOT AVAILABLE                                P=         9     *
* -------------------------------------------------------------- *
* 10. DILLON, RIGLER, KIRCHNER, 1975 GENERAL LAKE MODE     (15)    *
*  P < 15 mg/m^3     107 < L < 2210 mg/m^2-yr     P=        10     *
*  1.5< qs <223 m/yr   0.21<  p < 63/yr                            *
********************************************************************
```

Table 7. Concluded.

```
*****************************************************************
*                     LAKE CONDITION MODULE                     *
*                                                               *
* ============================================================= *
* ENTER THE AVE. SPRING MIXED T. PHOSPHORUS =      14     mg/m^3 *
* ------------------------------------------------------------- *
* THE GROWING SEASON CHLOROPHYLL a =       7 mg/m^3              *
* ------------------------------------------------------------- *
* ENTER THE AVE. GROWING SEASON CHLOROPHYLL a       2 mg/m^3     *
* ------------------------------------------------------------- *
* THE MIXED NATURAL LAKE SECCHI DEPTH      =     3.51 m          *
* THE STRATIFIED NATURAL LAKE SECCHI DEPTH =     4.24 m          *
* ------------------------------------------------------------- *
* THE MIXED IMPOUNDMENT SECCHI DEPTH       =     2.26 m          *
* THE STRATIFIED IMPOUNDMENT SECCHI DEPTH  =     2.94 m          *
* ------------------------------------------------------------- *
* Regressions from:  (Lillie, Graham and Rasmussen, 1993)       *
* ------------------------------------------------------------- *
*                    TROPHIC STATE INDICIES                     *
* ------------------------------------------------------------- *
* ENTER TOTAL PHOSPHORUS  =      14 mg/m^3    T.S.I  =      49  *
* ENTER CHLOROPHYLL a     =       2 mg/m^3    T.S.I  =      40  *
* ENTER SECCHI DISC DEPTH =     3.6 meters    T.S.I  =      42  *
*****************************************************************
*                WATER AND NUTRIENT OUTFLOW MODULE              *
*                                                               *
* ============================================================= *
* THE AVE. ANNUAL INLAKE TOTAL PHOSPHORUS  =       14 mg/m^3    *
*                                                               *
* ANNUAL DISCHARGE        = 2.52E+02 AF      3.11E+05 m^3       *
*                                                               *
* ANNUAL OUTFLOW LOADING =      1.9 LB            4.2 Kg        *
*****************************************************************
```

7. Lake Status

The status of Half Moon Lake is good. Values for phosphorus, chlorophyll and secchi depth are within ecoregion values (Table 8).

Table 8. Summer average water quality characteristics for lakes in the Northern Lakes and Forest ecoregion, as noted in Descriptive Characteristics of the Seven Ecoregions in Minnesota, by G. Fandrei, S. Heiskary, and S. McCollar. 1988. Minnesota Pollution Control Agency.

Parameter	Northern Lakes & Forests	North Central Hardwood Forests	Half Moon Lake
Total phosphorus (µg/l)	14-27	23-50	14
Chlorophyll a			
mean	<10	5-22	1.4
maximum	<15	7-37	2.5
Secchi disc (feet)	8-15	4.9-10.5	12.3
(meters)	2.4-4.6	1.5-3.2	3.7
Total Kjeldahl Nitrogen (mg/l)	<0.75	<0.60-1.2	0.36
Nitrite & Nitrate N (mg/l)	<0.75	<0.01	<0.007
Alkalinity (mg/l)	40-140	75-150	2
Color (Pt-Co units)	10-35	10-20	--
pH (SU)	7.2-8.3	8.6-8.8	5.3
Chloride (mg/l)	<2	4-10	--
Total Suspended Solids (mg/l)	<1-2	2-6	--
Total Suspended Inorganic Solids (mg/l)	<1-2	1-2	--
Turbidity (NTU)	<2	1-2	--
Conductivity (umhos/cm)	50-250	300-400	22
TN:TP Ratio	25:1-35:1	25:1-35:1	26:1

A map showing the ecoregion area and the Half Moon Lake location is displayed in Figure 11. Phosphorus concentrations ranged from 8-26 ppb. Half Moon Lake had a summer phosphorus concentrations of 14 ppb.

These comparisons indicate that in 1994 Half Moon Lake was within Ecoregion values and was in good shape.

Trophic State Index
The Trophic State Index (TSI) was calculated for water chemistry results and is shown in Table 9. Results indicate Half Moon Lake is a mesotrophic to eutrophic lake.

Table 9. Summary of Trophic State Index Values for Half Moon Lake

TSIP (TP)	45
TSIC (Chl a)	39
TSIS (Secchi disc)	41
TSI (mean)	42

TSI = Trophic State Index

TSI(Chl a)(ppb or ug/L) = $36.25 + 15.5 \log_{10}$ [Chl a]
TSI(TP)(ppb or ug/L) = $60 - 33.2 \log_{10} (40.5/TP)$
TSI(Secchi)(meters) = $60-(SD \log_{10} \times 33.2)$

8. Conclusions

Several compounding factors make lake management recommendations difficult. The current fishery does not appear to be very good. It seems this is a result of winterkill rather than of acidic conditions. The last official fish survey was conducted in 1972 and an updated survey is needed.

One way to improve the fishery is by installing winter aeration. Currently, the lake has low productivity (chlorophyll a is less than 2 ppb), so the lake may not support high numbers of fish anyway, but aeration would help maintain the fish community.

Raising the pH by adding limestone may help increase the fertility, but this could cause nuisance algae blooms and is not a desirable outcome.

I would recommend monitoring dissolved oxygen over the winter of 1995-1996, and if low, consider installing a winter aeration system for the 1996-1997 season.

Also, I would recommend continued monitoring of pH. If it drops below 5.0 and averages less than 5.0 over a summer, I would add lime in the form of limestone in low doses over a 2 to 3 year period to bring the pH up.

Dredging the soft sediments of Half Moon Lake would not improve the overall quality of the lake. I do not believe it would be a cost-effective measure. Some spot dredging using a backhoe may increase depths in some nearshore areas, and this would be a project for individual homeowners.

9. Management Plan for Half Moon Lake

A list of projects has been prepared that are intended to protect the water quality of the Half Moon Lakes. Projects are listed below:

1. Continue a lake monitoring program, to monitor winter oxygen levels as well as pH, phosphorus, and algae. Consider a fish survey as part of a Lake Management Planning grant program.
2. If winter oxygen levels are low, a winter aeration system should be considered.
3. Landscaping for wildlife on lake resident lots.
4. On-site system maintenance program.
5. If a pH adjustment is needed, liming with limestone would be recommended over groundwater augmentation.

Details of these projects are given in the following pages.

1. Continue a Lake Monitoring Program.
To evaluate Half Moon Lake, a monitoring program should be ongoing. This program will address the issues of:

- Effectiveness of watershed projects in regard to phosphorus in runoff
- Changes in lake quality as measured by total phosphorus, secchi disc, algae and macrophyte distribution.

Lake Monitoring Details
Secchi Disc transparencies should be taken through the summer monthly.

2. Winter Aeration System
Examples of some aeration systems are shown on the next couple of pages. The information is from the book "Lake Smarts".

Pump and Baffle Aeration

The goal of a winter aeration project is not to aerate the entire lake but to set up an oxygen-rich refuge to allow game fish to get through the remaining ice-covered days until breakup. With ice breakup, the wind-mixing action will quickly reaerate an entire lake.

3. Landscaping for Wildlife.
The careful planting of selected land plants and aquatic plants can improve water quality by reducing nutrients that run into the lake (land plants) and by taking up nutrients and by stabilizing bottom sediments (aquatic plants). Examples of typical plants are shown in the fact sheets that will be available to lake association members. Another benefit is planned landscaping can enhance wildlife by creating refuges and food sources for water fowl and aquatic animals. The combination of landscaping and aquascaping is appropriate for wetlands, streams, and lakes. For this project we are encouraging the use of vegetative buffers to help reduce erosion and nutrient inputs to the lakes.

Some benefits of this approach are:

- Erosion can be a problem nearly anywhere in the watershed. It is especially critical adjacent to a water body because sediment delivery rates are so high. Landscaping upland areas may not only reduce soil erosion, but may reduce the use of fertilizer as well. Aquascaping is a form of erosion control in the nearshore areas of lakes, and can be used on stream banks as well. Aquatic vegetation can stabilize nearshore areas.
- In some cases, it has been found that aquatic plants can transfer oxygen from the water column down to the roots and aerate the surrounding sediments. This can help reduce phosphorous release from the sediments and improving water quality. To be effective this "natural aeration" effect should be done on a broad scale.
- Transplanting native terrestrial and aquatic plants also aids in reestablishing native plants that have disappeared from the area. One of the objectives of this project is to see if homeowners can reestablish native vegetation in their nearshore areas.

Several Fact Sheets have been prepared that give instructions on planting upland plants.

4. On-site System Maintenance Program.
The septic tank/soil absorption field has been one of the most popular forms of on-site wastewater treatment for years. When soil conditions are proper and the system is well maintained, this is a very good system for wastewater treatment. The on-site is the dominant type of wastewater treatment found around Half Moon Lake today.

However, problems can develop if the on-site system has not been designed properly or well-maintained. Around Half Moon Lake there are on-site systems that need maintenance and upgrades. At the same time, it is good practice to ensure that systems that are functioning adequately now will continue to do so in the future.

This project calls for an organized program to be developed that makes homeowners aware of all they can do to maintain their on-site systems.

A description of activities associated with the on-site maintenance program are described below:

- SEPTIC TANK PUMPING CAMPAIGN
  Lincoln County could work with the Half Moon Lake Association in a coordinated campaign effort to get every septic tank associated with a permanent residence pumped 2-3 years and seasonal systems pumped 4-6 years in the Shoreland area to help reduce phosphorous loading to the septic system drainfield.

- ORDINANCE IMPLEMENTATION
  Work to implement a County Ordinance, where septic systems must be "evaluated" at the time a property is transferred. The seller would obtain a septic system evaluation from Lincoln County at the time of property transfer. The evaluation would determine if the septic system was "failing", "non-conforming", or "conforming". A "failing" septic system includes septic systems that discharge onto the ground surface, discharges into tiles and surface waters, and systems found to be contaminating a well. The County would require a "failing" system to be brought into compliance with the Lincoln County Ordinance within 90 days of property transfer. A dry well, leaching pit, cesspool, or a septic system drainfield with less than 3-foot vertical

separation instance from the bottom of the drainfield to the seasonal high water table or saturated soil conditions would be "non-conforming", but not required to be upgraded at property transfer under the Lincoln County Ordinance.

Through these County property transfer requirements a percentage of the septic systems that are not failing but are "non-conforming" would be upgraded to "conforming" if a prospective buyer was applying for a mortgage because the potential buyer's lending institution in some cases will not approve the buyer's loan request because the property to be purchased does not have a conforming septic system. The County's evaluation report would state whether or not the evaluated septic system is "conforming" or "non-conforming".

5. Liming with Limestone

An option for increasing the pH in Half Moon Lake would be to treat the lake with limestone. Limestone, or calcite, is made up of primarily calcium carbonate ($CaCO_3$) which neutralizes acid water and buffers the water from rapid fluctuations in pH.

By raising the pH of the water, liming reduces the toxic effects of metals such as aluminum, cadmium, lead, cooper, nickel, and zinc, which can go into solution as ions when the pH is low. Lakes which are very acidic ($pH < 4$) are virtually devoid of aquatic life. Though not all this extreme, Half Moon Lake did have an average summer pH of 5.3, which puts it in the danger zone for toxic effects.

When the calcium carbonate dissolves in the water column, the carbonate reacts with free hydrogen ions to reduce the acidity of the lake (i.e. raise the pH).

Elevating the lake's pH should increase the productivity of the lake. As the pH goes up, phosphorus could be released from the lake sediments. This nutrient is essential to phytoplankton growth, and can trigger a chain reaction up the food chain to ultimately result in a larger and more diverse fish community. This increase in productivity will likely lead to a decline in water clarity because of increased phytoplankton densities, so residents should be prepared for this tradeoff if limestone is going to be added to the lake.

Half Moon Lake's low pH and low alkalinity make it a potential candidate for limestone addition.

<u>Recommendation</u>
Adding 80 tons of anything to a lake is no small decision. I would not add limestone until the summer average pH dropped to 5.0 or below. If limestone is to be added, a winter aeration system will probably be necessary due to increased productivity and an increase in winter oxygen consumption. A permit from the WDNR will be needed also.

<u>Treatment Methods</u>
Finely ground (pulverized) agricultural lime (aglime) is recommended for liming lakes and ponds. Aglime is relatively inexpensive, widely available, easy to handle, natural and non toxic.

The calcium content should be at least 70% and preferably 90-100% calcium carbonate by weight. Pure calcium has acid neutralizing capacity of 100% and aglime ranges from 85-100%. To calculate the amount of limestone needed, divide the estimated lime required by its neutralizing value (%).

For the initial dosing, an application rate of one tone per surface acre is reasonable. After the treatment, changes in pH and alkalinity should be monitored throughout the summer at the same time each day. Inexpensive kits can be purchased for the weekly pH and alkalinity monitoring. The one ton/acre initial dosage should give a good reference for any future liming which may be desired. If there is no noticeable increase in pH, the treatment should be repeated.

The aglime can be applied as a dry powder, or mixed with water as a wet slurry. A well-mixed slurry of lake water and fine-sized limestone particles is more soluble than a dry powder. Limestone should be spread over the entire lake surface. Areas of deep water will require proportionally greater amounts of limestone.

<u>Costs</u>
Aglime costs are between $10-50/ton, so for Half Moon Lake, which has a surface area of 86 acres, the cost of a one ton/acre treatment will range from $860-4300 for the limestone. Finely

ground limestone is more expensive then coarse limestone, and bagged limestone is more expensive than bulk purchases. This variably accounts for the wide-ranging estimate. Cost associated with the application (labor, boats, etc.) are additional.

The ideal time to apply the limestone is in the fall of the year when the lake is well-mixed, and when liming efforts won't interfere with summer activities on the lake.

<u>Side Effects</u>
Initially there will be cloudiness and turbidity resulting from suspension of the limestone in the water column. Also residents should be prepared to see increased aquatic plant growth as phosphorus is released from the sediments.

Immediate effects on the fish and other aquatic life will be subtle. However, if pH and alkalinity are elevated, improvements should be seen.