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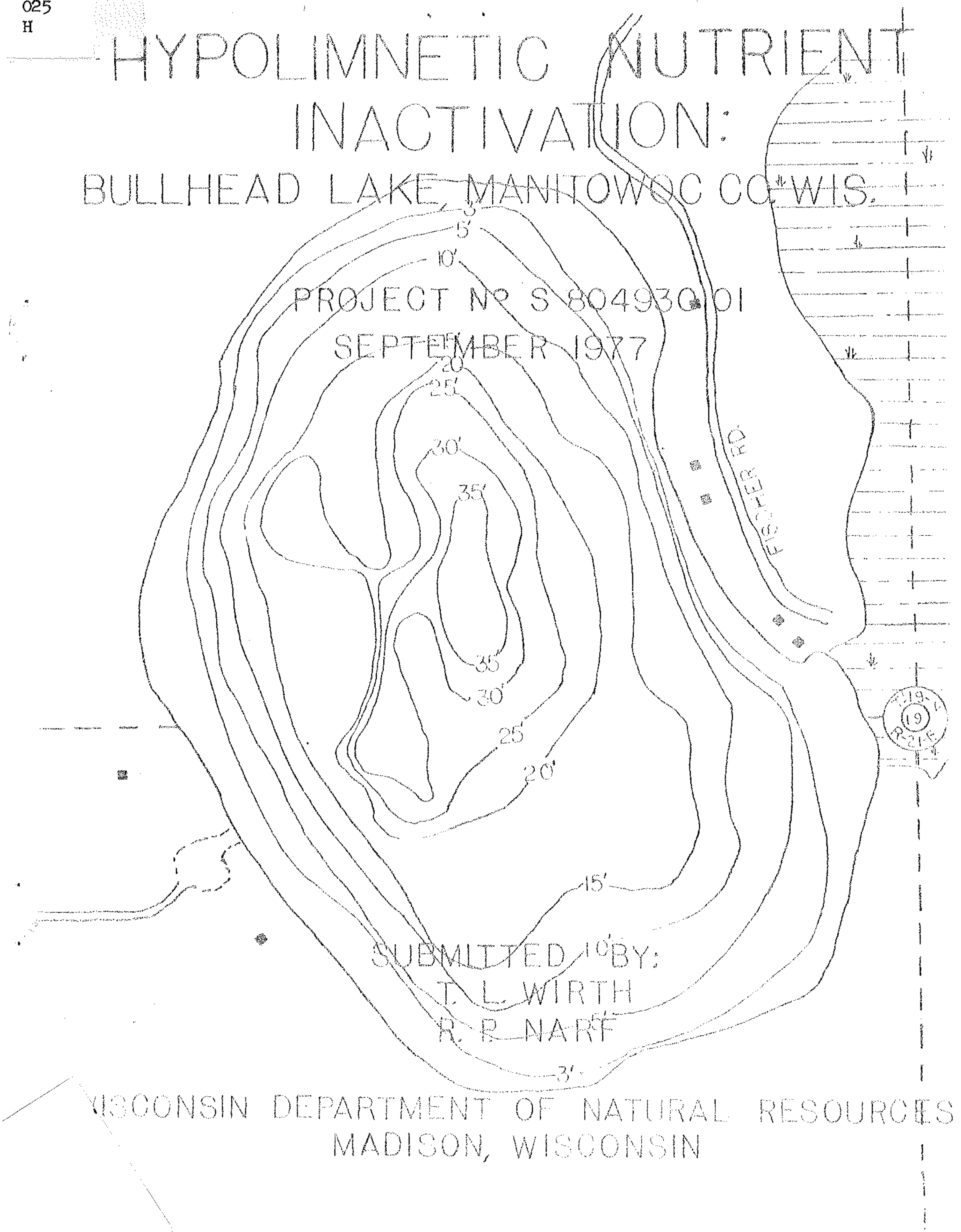
HYPOLIMNETIC NUTRIENT INACTIVATION:

BULLHEAD LAKE, MANITOWOC CO. WIS.

PROJECT Nº S 804930 01

SEPTEMBER 1977



SUBMITTED BY:
T. L. WIRTH
R. P. NARF

WISCONSIN DEPARTMENT OF NATURAL RESOURCES
MADISON, WISCONSIN

Form Approved
OMB No. 158-R0110

APPLICATION FOR FEDERAL ASSISTANCE
(Nonconstruction Programs)

PART I

1. State Clearinghouse Identifier: Wisconsin Department of Administration

2. Applicant's Application No.:

3. Federal Grantor Agency: U.S. Environmental Protection Agency
   Organizational Unit: Region V
   Administrative Office: ~~Grants Administration~~ Branch
   Street Address – P.O. Box: 230 So. Dearborn St.
   City: Chicago, State: IL, Zip Code: 60604

4. Applicant Name: Wisc. Dept. of Nat. Resources
   Department Division: Bureau of Research, Water Resources Res.
   Street Address – P.O. Box: P. O. Box 7921
   City: Madison, County: Dane
   State: Wisconsin, Zip Code: 53707

5. Descriptive Name of the Project: A demonstration and evaluation of hypolimnetic nutrient flocculation at Bullhead Lake, Manitowoc County, Wisconsin.

6. Federal Catalog No.:

7. Federal Funding Requested: $101557.00

8. Grantee Type: X State, ____ County, ____ City, ____ Other *(Specify)*

9. Type of Application or Request: X New Grant, ____ Continuation, ____ Supplement, ____ Other Changes *(Specify)*

10. Type of Assistance: X Grant, ____ Loan, ____ Other *(Specify)*

11. Population Directly Benefiting from the Project: 80,000

12. Congressional District: a. 2nd b. 6th

13. Length of Project: 3 years

14. Beginning Date: 1 January 1978

15. Date of Application: 1 September 1977 (original application 14 April 1976)

16. The applicant certifies that to the best of his knowledge and belief the data in this application are true and correct, and that he will comply with the attached assurances if he receives the grant. The applicant agrees that if a grant is awarded on the basis of the application or any revision or amendment thereof, he will comply with all applicable statutory provisions and with the applicable terms, conditions and procedures of the Environmental Protection Agency grant regulations (40 CFR Chapter I, Subchapter B) and of the grant agreement.

TYPED NAME	TITLE	TELEPHONE NUMBER AREA CODE	NUMBER	EXT.
Anthony S. Earl	Secretary	608	266-2121	

SIGNATURE OF AUTHORIZED REPRESENTATIVE: Anthony S. Earl

FOR FEDERAL USE ONLY

EPA Application Identification Number ____________ Date received in EPA ____________

PART II

PROJECT APPROVAL INFORMATION

Item 1.
Does this assistance request State, local, regional, or other priority rating?

___X___ Yes _______ No

Name of Governing Body ____________
Priority Rating ____________

Item 2.
Does this assistance request require State, or local advisory, educational or health clearances?

_______ Yes ___X___ No

Name of Agency or Board ____________
(Attach Documentation)

Item 3.
Does this assistance request require clearinghouse review in accordance with OMB Circular A-95?

___X___ Yes _______ No

(Attach Comments)

Item 4.
Does this assistance request require State, local, regional or other planning approval?

_______ Yes ___X___ No

Name of Approving Agency ____________
Date ____________

Item 5.
Is the proposed project covered by an approved comprehensive plan?

_______ Yes ___X___ No

Check one: State ☐
Local ☐
Regional ☐
Location of Plan ____________

Item 6.
Will the assistance requested serve a Federal installation?

_______ Yes ___X___ No

Name of Federal Installation ____________
Federal Population benefiting from Project ____________

Item 7.
Will the assistance requested be on Federal land or installation?

_______ Yes ___X___ No

Name of Federal Installation ____________
Location of Federal Land ____________
Percent of Project ____________

Item 8.
Will the assistance requested have an impact or effect on the environment?

_______ Yes ___X___ No

See instructions for additional information to be provided.

Item 9.
Has the project for which assistance is requested caused, since January 1, 1971, or will it cause, the displacement of any individual, family, business, or farm?

_______ Yes ___X___ No

Number of:
Individuals ____________
Families ____________
Businesses ____________
Farms ____________

Item 10.
Is there other related assistance on this project previous, pending, or anticipated?

_______ Yes ___X___ No

See instructions for additional information to be provided.

PART III—BUDGET INFORMATION

SECTION A—BUDGET SUMMARY

GRANT PROGRAM, FUNCTION OR ACTIVITY (a)	FEDERAL CATALOG NO. (b)	ESTIMATED UNOBLIGATED FUNDS		NEW OR REVISED BUDGET		
		FEDERAL (c)	NON-FEDERAL (d)	FEDERAL (e)	NON-FEDERAL (f)	TOTAL (g)
1. U.S. EPA Sec. 104		$	$	$101557	$	$101557
2.						
3. Wis. Dept. of Nat. Res.					101406	101406
4.						
5. TOTALS		$	$	$101557	$101406	$202963

SECTION B—SCHEDULE A BUDGET CATEGORIES

6. Object Class Categories	GRANT PROGRAM, FUNCTION OR ACTIVITY				TOTAL (5)
	(1) U.S. EPA	(2)	(3) WIS. DNR	(4)	
a. Personnel	$ 43242	$	$ 31780	$	$ 75022
b. Fringe Benefits 23%	9945		7309		17254
c. Travel	15766				15766
d. Equipment	1400				1400
e. Supplies	4750		1000		5750
f. ~~XXXXXXXX~~ Water Chem. Analysis			23633		23633
g. ~~XXXXXXXXX~~ Primary Prod. & Plankton Analysis	11254				11254
h. ~~XXXXX~~ Macrobenthos Analysis			22508		22508
i. Total Direct Charges	86357		86230		172587
j. Indirect Charges 17.6% overhead	15199		15176		30375
k. TOTALS	$101556	$	$101406	$	$ 202962
7. Program Income	$	$	$	$	$

SECTION B—SCHEDULE B—BUDGET CATEGORIES

6. Program Elements	FUNDING		(3) MAN-YEARS
	(1) FEDERAL	(2) NON-FEDERAL	
a. Operation and Maintenance	$ 101557	$ 101406	4.65
b. Permits			
c. Planning *(include Compliance Monitoring)*			
d. Monitoring			
e. Enforcement			
f. Training			
g. Administration			
h. Other			
i. Total Program Elements	$ 101557	$ 101406	
j. STATE TOTAL	$	$ 101406	4.65

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SECTION C—NON-FEDERAL RESOURCES

(a) GRANT PROGRAM	(b) APPLICANT	(c) STATE	(d) OTHER SOURCES	(e) TOTALS
8. Wis. Dept. of Natural Resources	$	$101406	$	$ 101406
9.				
10.				
11.				
12. TOTALS	$	$101406	$	$ 101406

SECTION D—FORECASTED CASH NEEDS

	TOTAL FOR 1st YEAR	1st QUARTER	2nd QUARTER	3rd QUARTER	4th QUARTER
13. Federal	$33497	$ 12299	$ 7067	$ 7065	$ 7067
14. Non-Federal	30508	7626	7628	7626	7628
15. TOTALS	$64005	$ 19925	$14695	$14691	$ 14695

SECTION E—BUDGET ESTIMATES OF FEDERAL FUNDS NEEDED FOR BALANCE OF THE PROJECT

(a) GRANT PROGRAM	FUTURE FUNDING PERIODS (YEARS)			
	(b) FIRST	(c) SECOND	(d) THIRD	(e) FOURTH
16. Federal	$ 33548	$ 34511	$	$
17.				
18. State	33273	37626		
19.				
20. TOTALS	$ 66821	$ 72137	$	$

SECTION F—OTHER BUDGET INFORMATION

(Attach Additional Sheets If Necessary)

21. Direct Charges:

22. Indirect Charges:

23. Remarks:

PART IV—PROGRAM NARRATIVE *(Attach per instruction)*

BUDGET ANALYSIS

Pay Schedule:

	1977	1978	1979
NRS-4	$8.53($17,742.40)	$9.21($19,156.80)	$10.04($20,883.20)
NRS-P	$6.52($12,625.60)	$7.04($14,643.00)	$7.68($15,974.40)

Travel:

I. Routine Sample Trips:

2 day trips based upon: 2 - breakfasts, 3 - lunches, 3 - dinners,

2 - lodgings = $76.50/person.

2 people/trip = $153.00

17 trips (1 every 3 weeks) per year = $2,601.00/year

II. Special Trips

A. Storm Events: 1/month: 1 person: 1 overnite:

4 meals + = $36.50 x 12 = $438.00/year

B. Alum Application: 9 people: 1 overnite: 4 meals:

1 overnite = $36.50 x 9 = $328.50

III. Vehicle Costs

A. Routine Trips (3 days) 350 miles/trip: 15.5/mile: 17 trips = $925.00

B. Storm Events 350 x 15.5 x 12 = $650.00

C. Alum Application: 3 vehicles, 1 trip, 350 miles: 15.5 = $163.00

Total Auto = $1,738.00

Water Analysis:

A. Complete Analysis - Lake

Quarterly and Alum Treatment

14 samples (central and 4 shoreline) x 6 trips x $25.00 = $2,100.00

B. Nutrient Analysis - Lake

Normal tri-weekly schedule

(17-4) = 13 trips x 14 samples x $10.00 = $1,820.00

C. Seepage Meters

Bi-monthly x 8 months

14 meters x 4 trips x $25.00 = $1,400.00

D. Wells

Bi-monthly x 8 months for nutrients (meter depth measured every trip)

8 wells x 4 trips x $10.00 $320.00

E. Storm Events

1 per month

5 sites possible x 12 x $25.00 $1,500.00

Total $7,140.00

Phytoplankton Analysis:

1 sample/trip x 17 trips x $50/sample = $850.00

Zooplankton Analysis:

1 sample/trip x 17 trips x $50.00/sample = $850.00

Benthic Analysis:

4 samples/trip x 17 trips x 100.00/sample = $6,800.00

Primary Production:

A. Plankton
\+ 17 trips x $100.00 (6 hrs @ $15./hr. + misc. equipment
B. Macrophytes plus set up time) $1,700.00

Chlorophyl-a

17 trips (14 samples each) (labor, filters, supplies) x $50./trip = $850.00

Supplies:

Aluminum Sulfate - $2,500.00

Filters for Chl-a and Dis P (average $30./100 over 3 years) = $250.00

General Purpose $3,000.00

Equipment:

Kemmerer Water Bottle, $200.11 @ $200.00

Millipore Filter Apparatus, $65.00 @ $190.00

Equipment (Cont.)

Ekmann Dredge (6 x 6)	$170.00
B.O.D. Probe and Analyser ($350.00 + $500.00)	$850.00
Plankton Nets $50.00 @ x 2	$100.00
Total	$1,505.00

Title: A Demonstration and Evaluation of Hypolimnetic Nutrient Flocculation at Bullhead Lake, Manitowoc County, Wisconsin

Submitted To: United States Environmental Protection Agency, Washington, D.C.

Submitted By: Wisconsin Department of Natural Resources
Bureau of Research
Water Resources Research Section

Administrative Director: Cyril Kabat, Director, Bureau of Research, Wisconsin Department of Natural Resources, 4610 University Avenue, Madison, Wisconsin 53707

Assistant Administrative Director: Thomas L. Wirth, Chief, Water Resources Research Section, Bureau of Research, Wisconsin Department of Natural Resources, 3911 Fish Hatchery Road, Madison, Wisconsin 53711

Principal Investigator: Richard P. Narf, Limnologist, Water Resources Research Section, Bureau of Research, Wisconsin Department of Natural Resources, 3911 Fish Hatchery Road, Madison, Wisconsin 53711

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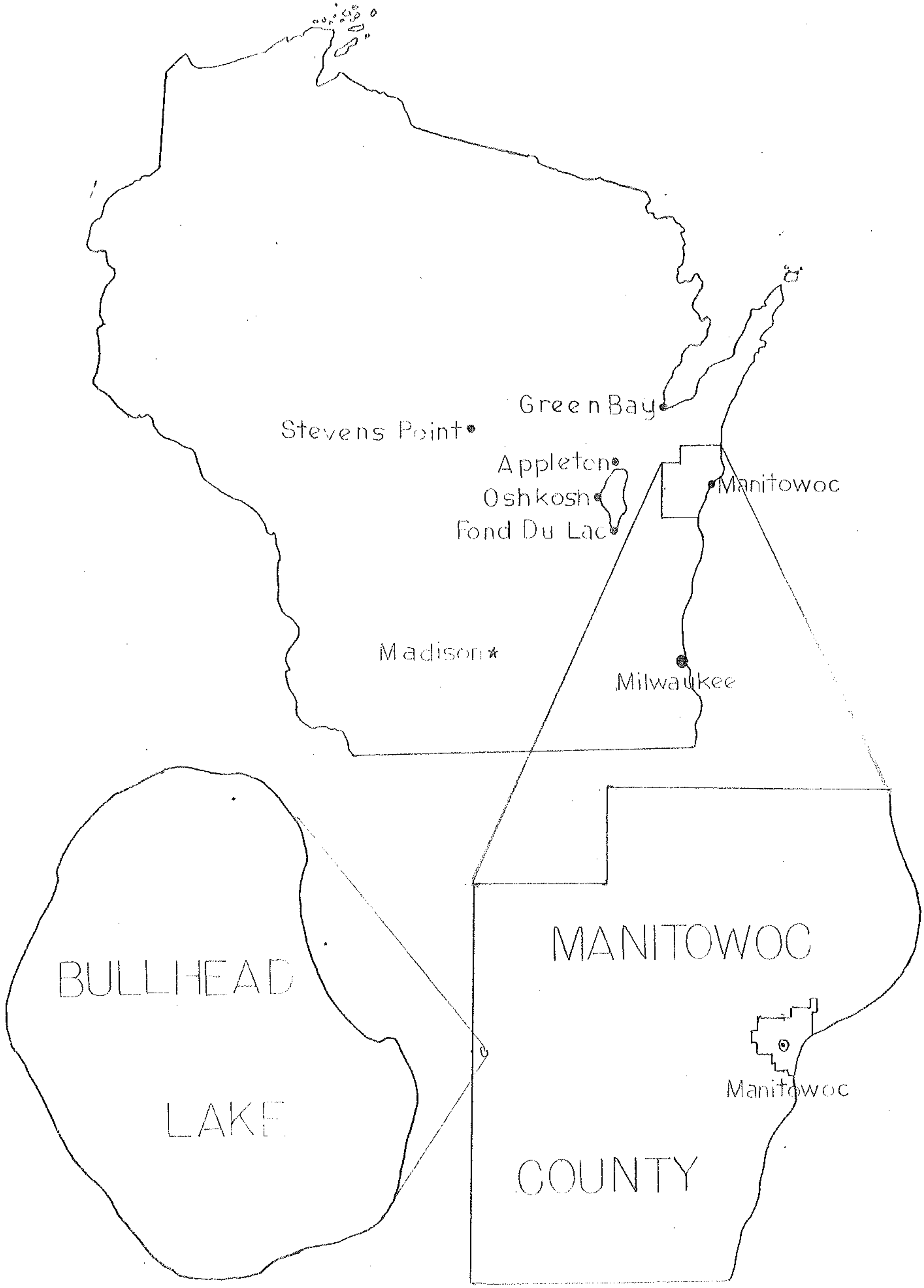
Fig: 1

Bullhead Lake Demonstration Site



INTRODUCTION

Phosphorus management (rather than nitrogen or carbon) is generally regarded as the primary goal in lake rehabilitation and protection schemes. Reducing phosphorus inputs from external and or internal sources is the usual form of management. When phosphorus input from external sources are minimal or have been greatly reduced, internal recycling assumes dominance and is often of such magnitude what undersirable eutrophic conditions persist. Therefore, internal phosphorus source management is critical if control of such a lakes' trophic status is desirable.

Internal phosphorus source reduction with the use of chemical inactivation is presently the only practical and potentially successful method, especially for stratified lakes that have algae as the dominant primary producer. Dredging is considered a means of phosphorus removal, but costs are very high, and effectiveness is dependent on the practical possibility of removing most of the phosphorus rich sediments. Dilution or flushing a lake is only practical where great sources of phosphorus poor water and equally large disposal areas for phosphorus rich water are available. Even then phorphorus rich sediments may not become sufficiently flushed.

Harvesting the biota to exhaust the supply of one or more critical plant nutrients in a lake is an ideal ecological method, however, present technology has not developed even close to a point of demonstrating such a method in most eutrophic lakes.

Selective discharge, like dilution or flushing, has potential if inflow quantity of nutrient poor water is available and a lake has a suitable outlet structure, (either an impoundment or a raised lake).

Lake bottom sealing with physical barrier sheeting is not generally practical from a physical and an economic standpoint. The use of other materials such as flyash, nutrient poor soils, gels, or combinations have either not demonstrated success, are impractical, or are not as economic as chemical inactivators.

These alternatives can be assessed in more detail as potential rehabilitation methods by referring to Dunst et al. (1974).

Precipitation of phosphorus and continued uptake by application of aluminium has been chosen as the best practical means of rehabilitating Bullhead Lake. Reasonably long term improvement is expected as a benefit while permanent improvement is possible if all potential future nutrient sources are detected and controlled. As will be brought out in this proposal, internal recycling of phosphorus is the principal source of nutrients in Bullhead Lake. As a result it is an ideal candidate for substantial trophic status improvement and evaluation of the method.

Review of Experiences

Aluminum sulfate inactivation has been employed by waste water treatment plants for the removal of phosphorus and organic particles and has recently been used for the removal of phosphorus in lakes. Reports of its use in lakes for total water treatment have shown its effectiveness as a phosphorus removal agent. The Wisconsin Department of Natural Resources has employed aluminum salts for total water column treatments on four lakes (Horseshoe, Long, Snake and Pickerel) to inactivate phosphorus. Aluminum sulfate was used exclusively in Horseshoe and Pickerel Lakes and sodium aluminate was added at the Long and Snake Lake projects to prevent a lowered pH due to a reduced buffer capacity. This method of phosphorus removal has proven effective. Inorganic phosphorus concentrations at Snake Lake, Vilas County (Knauer, in preparation) were reduced from 0.28 mg/l to 0.13 mg/l the following year (1973). Previously subject to recurring winter fish kills the lake has experienced none since the treatment. Aluminum sulfate was applied to Horseshoe Lake, Manitowoc County (Peterson, et al. 1973) where excessive algal blooms and winter fish kills were caused by excessive fertility from agricultural and dairy processing plant waste runoff. This treatment in 1970 decreased the total phosphorus for the two year duration of the study.

The phosphorus in the hypolimnion has remained at these lower levels until 1976, when a small increase was noted which was tied to agricultural runoff (Knauer report in progress). Six years after treatment Horseshoe Lake has not approached pretreatment phosporous concentrations (J. O. Peterson, Pers. Comm.). Long Lake, Langlade County was treated in 1972 to demonstrate phosphorus reduction to reduce periodic winter oxygen depletion that caused fish kills. Lake residents and observations by Department personnel reported these fish kills occurred in years of severe summer algae blooms. This demonstration has been effective to date as concerns the lack of fish kills. The use of sodium aluminate with aluminum sulfate to offset a toxic low pH was used for the first time at Long Lake. Phosphorus precipitation was also used in Pickerel Lake, Portage County where nuisance algal blooms occurred. Primary production was decreased due to a shift in algal species, however, the phosphorus concentrations were not appreciably reduced apparently due to a continuous source of phosphorus in the ground water and an unusually high ground water flow rate (Knauer, in preparation). Kennedy and Cook (report in preparation) have shown a reduction in phosphorus concentrations by injection of aluminum sulfate to _in situ_ isolated water columns. Phosphorus was reduced by 88% (total) and 98% (ortho), and remained low during the 104 days of the experiment. The floc layer on the sediments reduced the phosphorus release rate by 98%. Bowman and Harris (1973) have shown through laboratory testing that the aluminum floc can prevent release of sediment phosphorous for more than 400 days.

Advantages of Hypolimnetic Injection

The ability of aluminum salts to remove phosphorous from the water column and the continued uptake of phosphoruous by the aluminum floc on the bottom has been demonstrated. It follows, then, that the application of the alum to that part of the lake (the hypolimnion) containing the greatest concentrations of phosphorous is a logical progression and application technique. The advantages of this application technique include:

1. The placement of alum where the dissolved phosphorus concentration is highest.
2. The use of less alum than a total lake treatment to reduce dissolved phosphorus.
3. The injection of alum in a manner most likely to reduce possible biotic toxicity.
4. The capability of using higher concentrations of alum safely if needed.

Bullhead Lake Phosphorus

The greatest concentration of phosphorus in Bullhead Lake is located in the hypolumnion at depths greater than 6.0 m (Table 1). The dissolved form of phosphorus is the major constituent. The concentration of dissolved phosphorus in the lake during August stagnation; based upon an average of six samples, is 83 Kg. Of this 28 Kg. and 55 Kg. are located above and below the 6 m. depth, respectively. The expected reduction of hypolimnetic phosphorus using 150 mg. $Al_2(SO_4)_3$/l is 60%. This would reduce the total lake concentration of dissolved phosphorus from 83 Kg. to 60 Kg. Additionally, potential phosphorous from epilimnetic seston subsequently reaching the sediments is expected to be at least partially tied up by the floc on the sediment.

The cost of hypolimnetic treatment would be far less than a total water column treatment. There are 12.3 x $10^4 m^3$ of water below the 6 m. depth and 95.6 x $10^4 m^3$ water above this depth. The cost of aluminum sulfate would be 88% less than a total water treatment or about $2,500 based upon the use of 150 mg/l of 17% aluminum sulfate.

Table 1. Dissolved Phosphorus Concentrations in Bullhead Lake during summer stratification.

Depth(m)	Ave.[1] P.dis.	Range P.dis.	Cubic Meters	P.dis. Kg.
0.5	0.02 mg/l	.01-.04 mg/l	2.46×10^5	4.9
1.5	0.035	.01-.05	2.46	8.6
2.5	0.025	.01-.05	1.5	3.9
3.5	0.025	.01-.05	1.8	4.6
4.5	0.02	.01-.03	0.9	1.8
5.5	0.068	.01-.12	0.6	4.2
6.5	0.28	.19-.47	0.3	8.6
7.5	0.65	.48-.93	0.3	20.0
8.5	0.86	.53-1.17	0.12	10.6
9.5	0.89	.52-1.12	0.12	11.0
10.5	0.88	.49-1.07	0.06	5.4
		Total	10.6×10^5	83.6

[1] Based upon 6 samples.

Demonstration Site

Bullhead Lake (STORET No. 363064) is located along County Highway "JJ" in the western most part of Manitowoc County (T-19N, R-21E, S-19). It is a landlocked lake of 27 hectares and has a maximum depth of 10.5 meters (Figure 1). The drainage area comprises 259 hectares (1 square mile).

Lake Morphology and Biota

The lake basin (Figure 2 and Table 2) slopes gradually to 6 meters and then rapidly to the 10.5 meter depth. The substrate consists of muck that supports a border of macrophytes and a benthic community of *Chironomus spp.*, *Chaoborus spp.*, Ostracoda and Copepoda. The macrophyte community consists of *Nuphar advena* Ait., *Potamogeton pectinatus* L., *P. richardsoni* (Benn.) Rydb, *Scirpus americanus* Pers., and Typha latifolia L. These growths are moderate to sparse and restricted to the shallow shoreline area less than 2 m. deep. The plankton population has not been assessed to date, however, Oscillatoria rubescens de Condolle and Daphnia parvula Fordyce are common members of the biota. Dense algal blooms in spring and early summer are common as shown by productivity studies. Net production exceeded 150 mg C/m^3/hr in 1976 and was greater than 50 throughout the growth season. The principal sport fish population consists of yellow perch (Perca flavescans), large mouth bass (Micropterus salmoides salmoides), hybrid Muskellunge (Esox lucius-masquinongy) and bluegills (Lepomis machrochirus).

Table 2. Bullhead Lake - Morphology and Hydrography[1]

Area	27 hectares
Shore Length	1979 meters
Ratio of area to shore length	0.8:1
Depth - Maximum	10.5 m
Mean	2.3 m
Present area less than 1 meter	16%
Present area more than 6 meters	19%
Volume	$10.6 \times 10^5 m^3$
Maximum length	756 m
Maximum width	483 m
Lake Condition Index Value	17
Hydraulic Retention Time	2+ yrs.

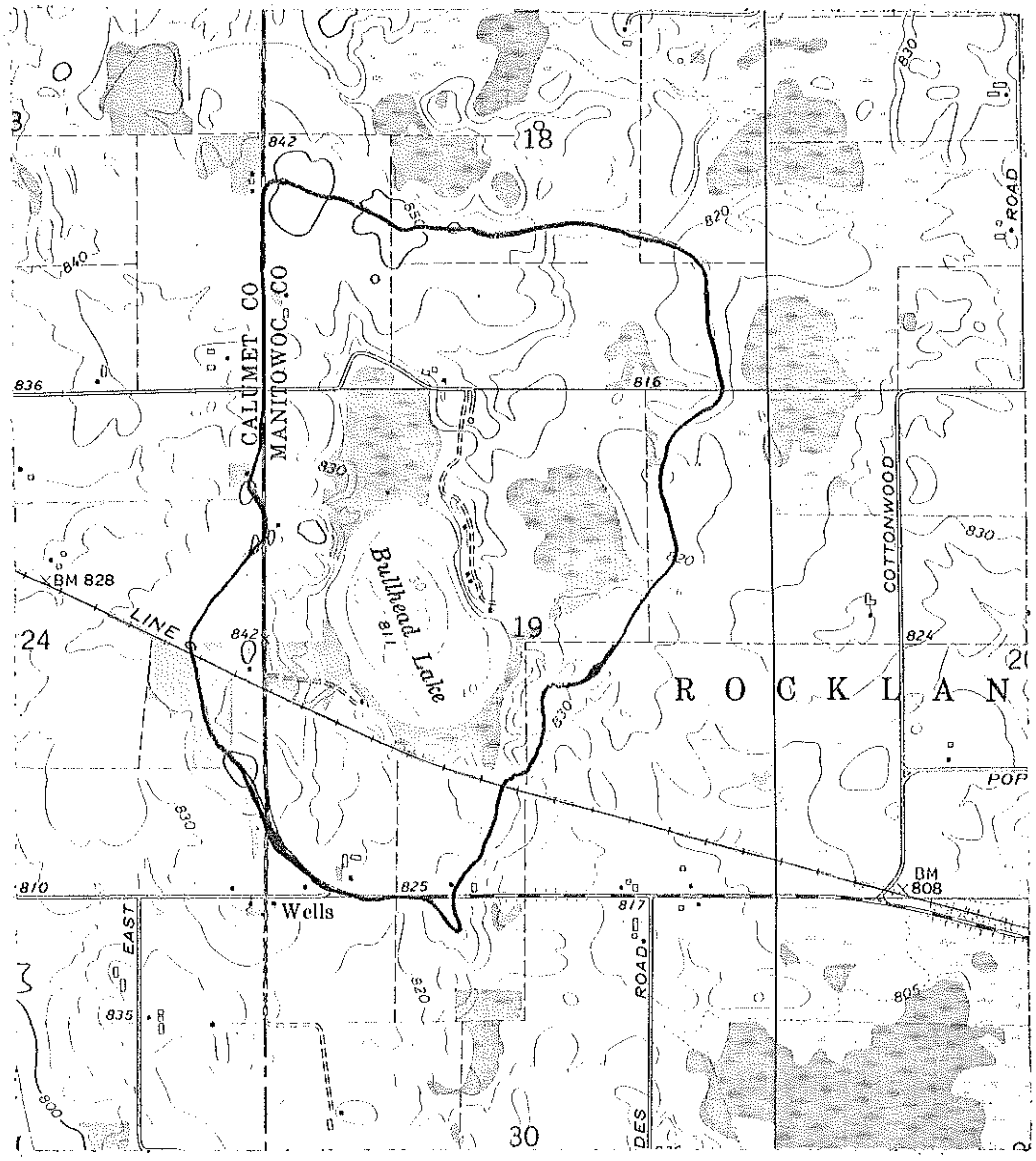
[1]Source: Wisconsin Department Natural Resources

Topography

The surface of Manitowoc County adjacent to the study area is a moderately undulating plain consisting of perched wetlands that slope towards Lake Michigan. The typical mature soil of the county is developed from glacial-till (Kewaunee

Fig: 2

Bullhead Lake Drainage Area



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Silty Clay Loam) characterized by a consistent profile which shows a gray-brown fragile surface soil, a rather heavy brown-red gravelly clay subsoil, and a brown-red glacial till parent material. This soil type is predominant in the drainage basin except for the presence of Carlisle Muck in the three wetlands (total of 58 hectares) adjoining Bullhead Lake. The Kewaunee topsoil and subsurface layers have been leached and the lime carbonate removed. The organic matter present is moderate to low as indicated by the light color of the soil (Anderson, 1926).

Land Use

Lumbering in the watershed produced pine and hemlock material before agriculture assumed importance about 1865. Presently mixed farming is practiced with dairy products most important. The major crops are hay, oats and corn used mainly as livestock feed. Approximately 70% of the watershed consists of pastures and row crops with the balance in woodlots and wetlands. Farmers of the watershed have an active land treatment program through the Manitowoc (and Calumet) County Soil and Water Conservation Districts. Soil conservation practices are employed on over 93% of the land in these districts. These practices consist of contour plowing and grassed waterways (USDA, SCS, 1975). Cultivation is separated from Bullhead Lake by lakeshore development of six homes along the east shore, the marsh areas, and a narrow buffer zone along the west shore. The wetlands (Fig. 2) adjoining the lake on the north, west and south shores are wooded and comprise an area of about 20 hectares. The wetland bordering the southeast shore is composed mainly of cattails (*Typha* sp.) and extends northeast to the edge of the drainage basin. This marsh comprises about 38 hectares.

Land Use - Bullhead Lake Drainage Area

	Area	Percent
Forest (upland)	12 ha.	5
Agricultural	162 ha.	70
Wetlands	58 ha.	25

Lake Use

The closest major populated area is the city of Manitowoc (34,000 population) 27 km to the east. The lake is used by fishermen and duck hunters through public access provided by a county park with 80 m of frontage and a boat landing. The number of people using the park is unknown (pers. comm. Manitowoc Parks Dept.); however, there are 80,000 potential users in the county and the metropolitan Milwaukee area is 125 km to the south. Observations by members of the Water Resources Research Section, WDNR, indicate the presence of five to six persons on the lake during each visit of the past years. This would indicate that about 2,000 people use the lake for recreational purposes, usually angling, each year.

Nutrient and Hydrologic Budget

Ground Water

The ground water moving through Bullhead Lake was assessed by two methods: observation wells and seepage meters.

Observation wells were placed in eight sites around Bullhead Lake (Fig. 3). Well depths varied from 2 to 9 meters and all terminated in a clay soil of low permeability. Samples were obtained by using a bailer. The low porosity of the soil would not permit continued pumping. The samples obtained were then filtered through a 0.45μ filter. Chemical analysis for phosphorus was conducted by the Wisconsin Department of Natural Resources water quality laboratory at Delafield. Results of these samples are presented below:

Observation Wells

	Range	Average
Tot.-P (filtered)	.01 - .46 mg/l	.07 mg/l
PO_4-P (filtered)	.004 - .132 mg/l	.03 mg/l

A theoretical assessment of ground water movement and discharge was made based upon typical values of permiability, gradient and porosity for the brown-red clay subsoil typical of this region. Using the formula:

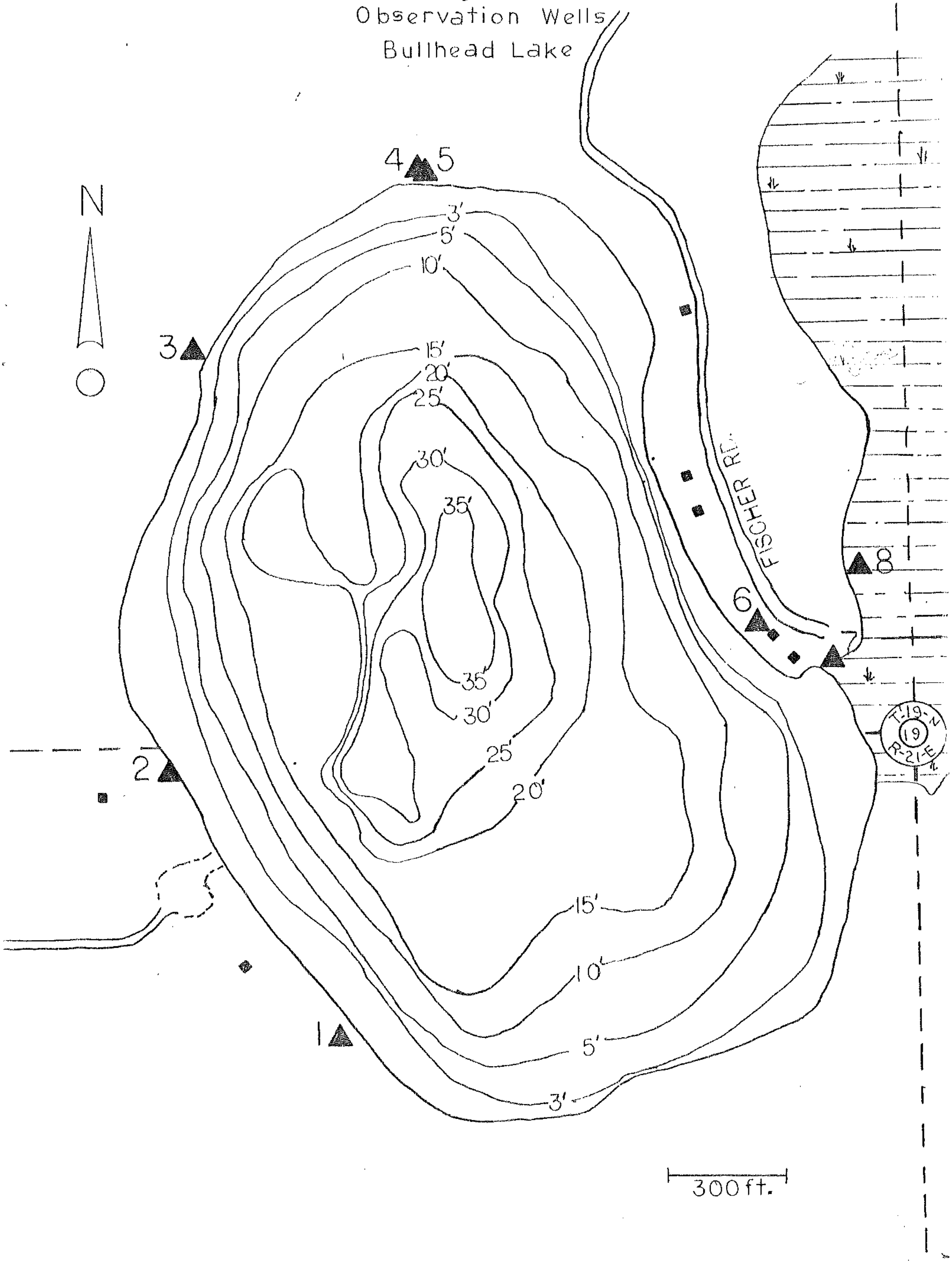
$$\text{Velocity} = \frac{K\ i}{n\ (7.48\ \text{gal./ft.}^3)}$$

$$\text{and if } K = .5\text{-}2\ \text{gpd./ft.}$$

$$i = .2\ \text{ft./ft.}$$

$$n = .4$$

Fig.: 3
Observation Wells
Bullhead Lake



the ground water velocity becomes .04-.13 ft./day (.01 - .039 M/day). It is apparent that lateral movement of water into or out of the wells will be very slow and water elevations could not be relied upon for the determination of movement.

To determine the movement of water in and out of the lake, seepage meters were constructed as described by Lee (1977). Fourteen of these meters were placed at 30 different positions to produce 53 measurements of water flow and phosphorous concentrations. The location of the meter sites is shown in figure 4. The ground water discharge into Bullhead Lake based on the average of 53 measurements is 36.17 M^3/day (24.0 M^3/day above the 6 M depth and 12.17 M^3/day below the 6M depth). There is no known area of ground water movement out of the lake. Theoretical ground water discharge (Q) was computed using the equation.

$$Q = Ki\ A$$

were $K = .5\text{-}2$ gpd/ft.

$i = .2$ ft./ft.

$A = 77{,}000$ ft.^{2}

$Q = 7700\text{-}3080$ gpd (29 - 116 M^3/day)

This would indicate that the flow data of the seepage meters (36 M^3/day) is relatively accurate. The water collected by the seepage meters was analysed for total phosphorus and dissolved phosphorous. Results are shown below.

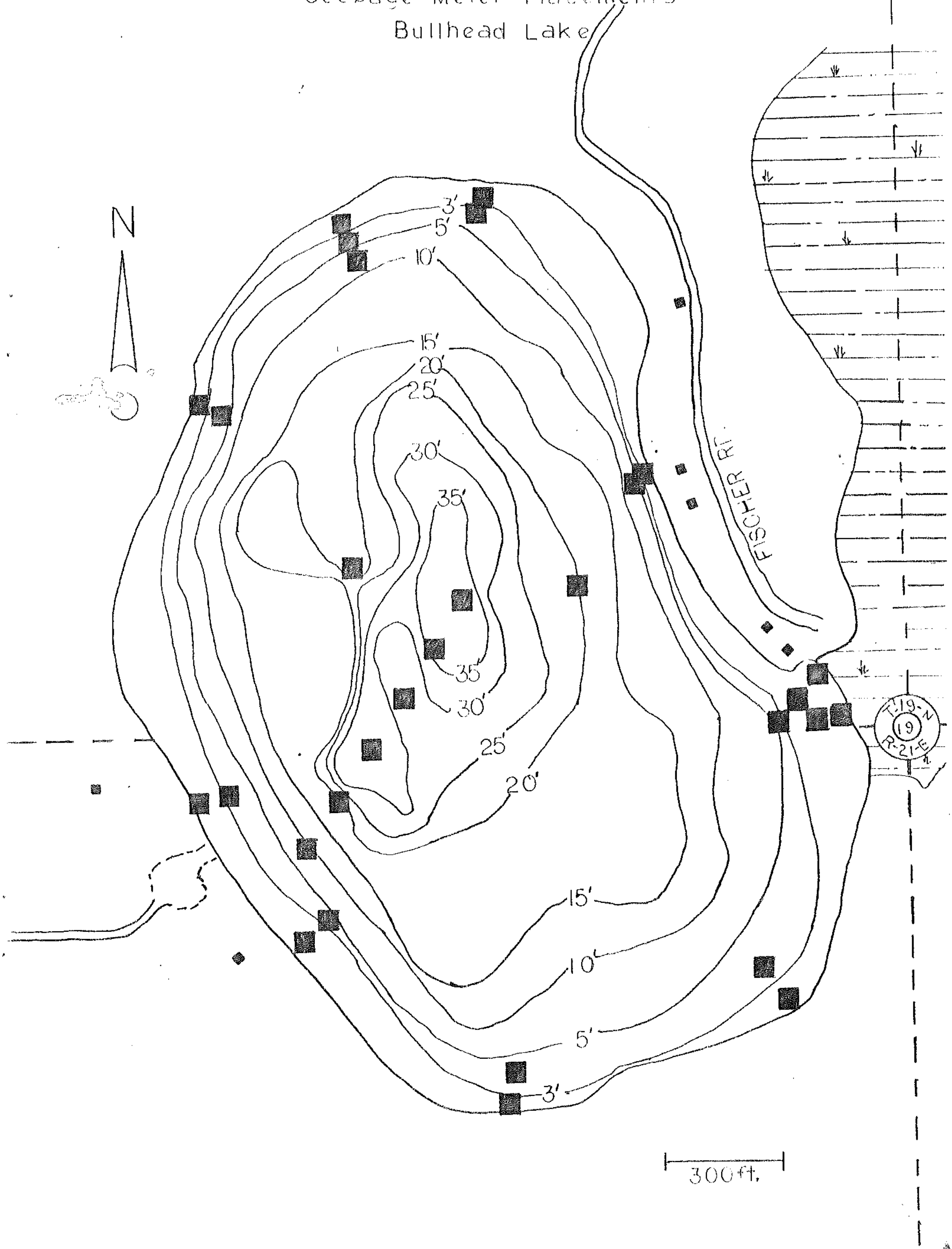
Ground Water Phosphorus Concentrations

for

Seepage Meters

		Range ($x10^{-3}$Kg/M^3)	Average ($x10^{-3}$Kg/M^3)
Above 6M depth:	Tot.P	.01 - .45	.078
	Dis.P	.01 - .63	.037
Below 6M depth:	Tot.P	.27 - 2.46	1.47
	Dis.P	.08- 1.95	1.14

Fig.: 4
Seepage Meter Placements
Bullhead Lake



The concentrations of phosphorus in the meters below the 6 meter depth is appreciably higher. We suspect that these higher concentrations are the result of influence from interstitial waters and do not reflect true ground water concentrations. The amount of interstitial influence is not completely understood at this time.

A ground water influence upon Bullhead Lake can be calculated using the average flow rate of the seepage meters and the concentration of phosphorus based upon the seepage meter data (which agrees with the concentrations found in the test wells) the total phosphorus yearly input would be:

$$.078 \times 10^{-3} Kg/M^3 \quad x \quad 36\ M^3/day \quad x \quad 365 \quad = \quad 1.02\ kg\ Tot.P/yr.$$

Runoff

The drainage area of Bullhead Lake (Fig. 2) comprises 232 hectares (approx. 1 sq. mile) of gently rolling poorly drained land. Surface water drainage has never been observed flowing directly into the lake since the preliminary data gathering began in May 1975. The drainage flows into the wetlands at a distance from the lake. The water apparently proceeds through the overlying humus soil towards the lake. Channeled flow through the wetlands has not been found to occur during repeated surveys including periods during storm events. We conclude, then, that surface water runoff is represented by only negligable quantities with minimal areas of diffuse surface runoff adjacent to the lake. Therefore, we assume the input of nutrients be less than 1% of the total nutrient budget.

To support this reasoning a comparison of primary production (Table 5) and annual precipitation (Table 3) is made. The rainfall of 1975 was above normal (79 cm.) and conversly 1976 was a drought (58 cm.) year. The annual primary production for both years did not vary significantly indicating that surface runoff plays a minor role in the nutrient budget.

Table 3. Annual Precipitation - Chilton, Wisconsin

Year	Rainfall (cm)	Year	Rainfall (cm)
1960	80.7	1969	78.3
1961	80.8	1970	78.8
1962	70.9	1971	98.8
1963	60.0	1972	91.6
1964	76.4	1973	88.1
1965	100.4	1974	75.9
1966	75.1	1975	79.3
1967	82.7	1976	57.6
1968	92.3		

Precipitation

The Bullhead Lake area receives an average annual rainfall of about 76 cm (30 inches). Actual amounts are presented in Table 3 for the weather station at Chilton located 14.5 Km (8 miles) southwest of the lake. Bullhead Lake would typically receive rainfall totalling 20 x $10^4 M^3$/yr. Based on data from two major storm events at Bullhead Lake this past summer total phosphorus and dissolved phosphorus concentrations in rain water are .055 mg/l and .025 mg/l, respectively. These concentrations would indicate that Bullhead Lake receives the following phosphorus loading:

Rainfall Phosphorus Loading

	Concentration	Direct Rainfall	Kg/yr.
Total P	.055 x 10^{-3}Kg/M^3	20 x $10^4 M^3$/yr.	11.0
Dissolved P	.025 x 10^{-3}Kg/M^3		5.0

Precipitation samples taken for the feasibility study at Big Cedar Lake, Washington County, 7 Km (2.6 miles) south, found the annual rainfall to contribute .19 Kg Tot.P/ha/yr. This would indicate a yearly input of 5.3 Kg Tot.P/hr. for Bullhead Lake.

Hydraulic Retention Time

The hydraulic retention time for Bullhead Lake can be calculated based upon 76 cm rainfall, 2.59 x $10^6 M^2$ drainage area and a .25 runoff coefficent. Runoff would amount to 5 x $10^5 M^3$ (400 acre feet). The lake has a volume of 10.6 x $10^5 M^3$ (850 acre-feet) which would give a retention time of 2.1 years under these assumptions. A single major storm event of this summer produced rainfall of 2.3 cm (.9 in.) on August 4 and raised the lake level 1.2 cm (.05 in.) or 3 x $10^3 M^3$ (2.64 acre-ft.). Given this information, another runoff coefficent and retention time can be computed by substituting the rainfall amount and the lake volume increase into the water volume equation, thus:

Rainfall	x	Area	x	Runoff Coefficient	=	M^3
.012M		$2.59x10^6M^2$		X	=	$3.2x10^3$
				X	=	.10

Using this new coefficient a hydraulic retention period of 5 years (.25/.10 x 2.1) is found. By comparison, Horseshoe Lake located 22 Km (14 mi) south east (Fig. 5) in similar terrain has a calculated residence time of 0.35 years (Peterson, Wall, Wirth, Born 1973). The drainage basin is composed of 700 ha..(1730 acres) with one major inlet and outlet. The inlet stream receives runoff from field tile drains and other agricultural activities.

Septic Systems

Seven houses are located adjacent to Bullhead Lake. Three are permanent homes, two are summer homes and two are used for weekend trips. All septic systems were built between 1969 and 1975 and meet or exceed the minimum set-back of 50 ft. and associated requirements (pers. comm. Manitowoc County).

Dudley and Stephenson (1973) studied nutrient enrichment of ground water by septic systems at eleven areas in Wisconsin. Their study showed that phosphorus concentrations in ground water fell off rapidly within short distances of the on site treatment system (Fig. 6). Assuming all systems at Bullhead Lake are only 50 feet from the shore, actual set-backs are 75-150 feet, the ground water phosphorous levels would be less than .1 mg/l Tot.P.

A lake rehabilitation feasibility study, in similar soil types is being conducted at Big Cedar Lake, Washington County, by the Wisconsin Department of Natural Resources, analysed 540 samples for septic tank influence. The highest concentration of Tot.P. discharged to the lake was .07 mg/l. This would indicate that the findings of Dudley and Stephenson are excessive for Bullhead Lake, probably because of the clay soil that is present. The maximum annual input of phosphorous from septic systems would be:

7 houses x 4 people/house x .4 M^3 H_2O/person/day x 365 days x .07 x 10^{-3}

= .29 Kg Tot.P/yr.

Fig: 5
Horseshoe Lake Study Location

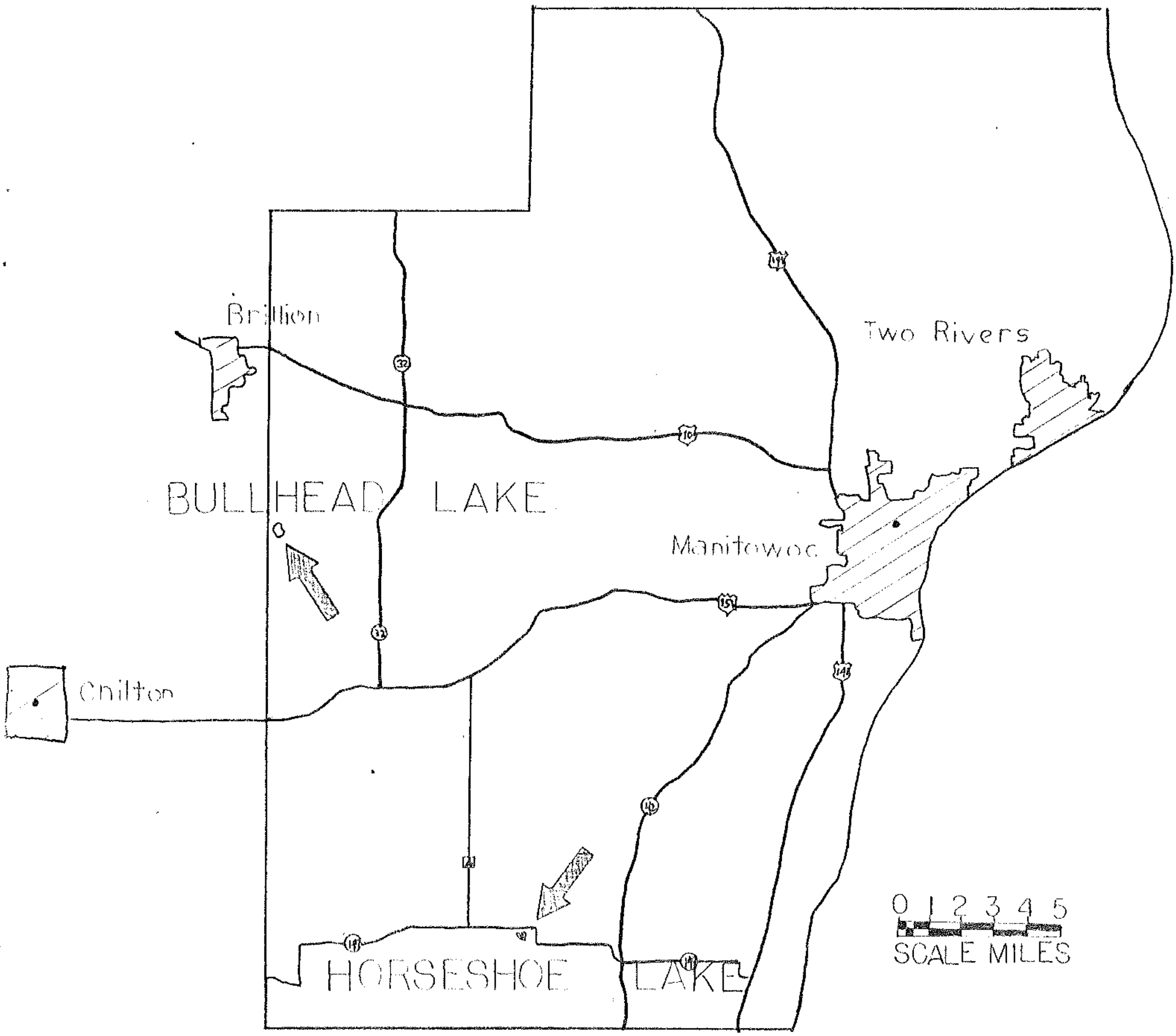
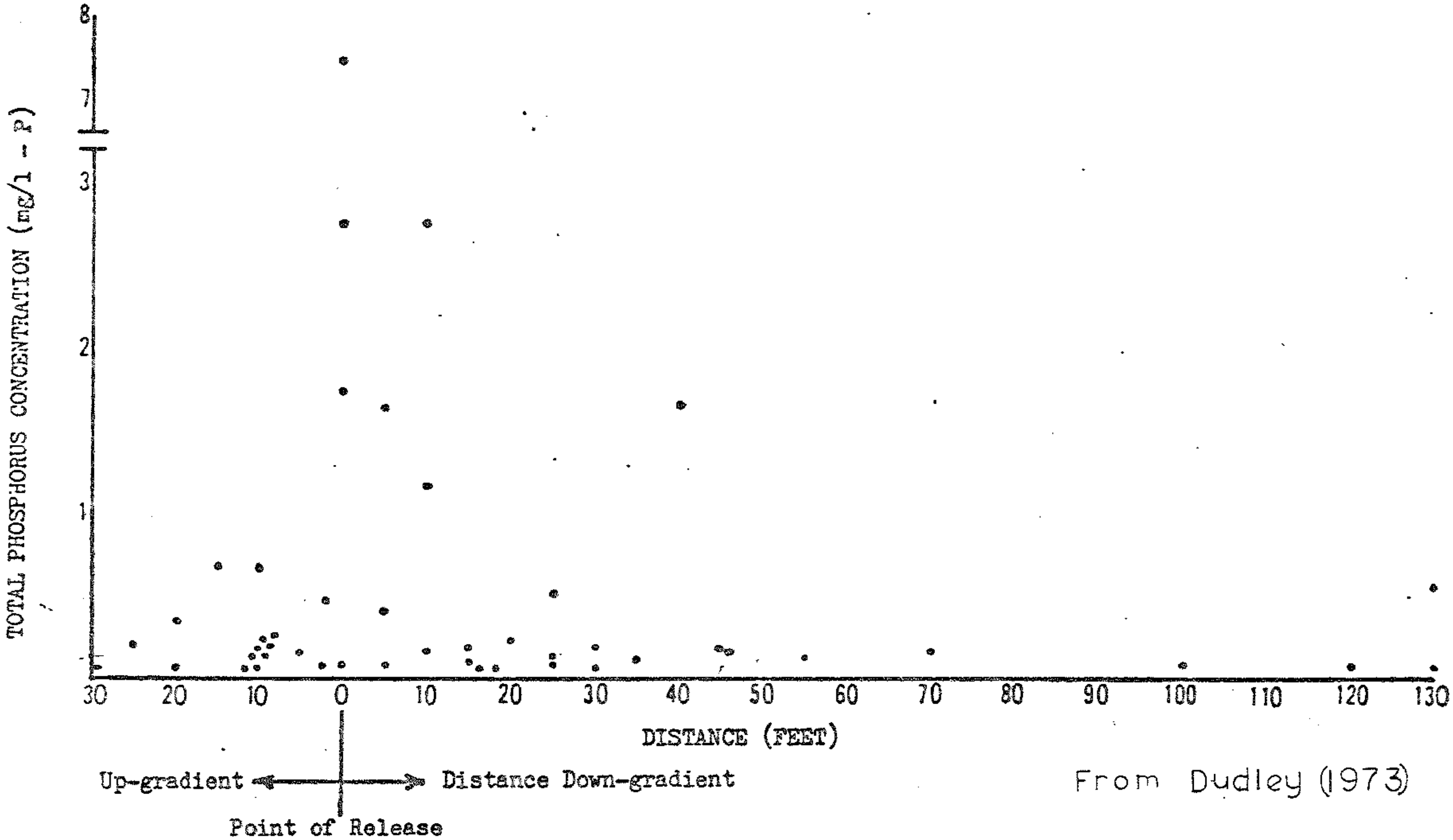


Fig: 6

DISTRIBUTION OF TOTAL PHOSPHORUS IN GROUND WATER ADJACENT TO THE ELEVEN MONITORED SYSTEMS
(DATA POINTS REPRESENT THE MEAN CONCENTRATION FROM EACH WELL)



From Dudley (1973)

Table 4. External Phosphorous Loading

Source	Kg. Tot. P/yr.	Percent
Rainfall	11.00	8%
Ground Water	1.02	8
Septic Systems	.29	2
Surface Runoff	.12	1
Wet Lands	0	
Total	12.43 Kg Tot.P/yr.	

Internal Phosphorus Loading

It is apparent that all the external phosphorus sources are of minor significance. This indicates that the major source of nutrients is from internal recycling. The amount of sediment phosphorus release can be derived from the amount of annual primary production (Table 5) comparied to the primary production - phosphorus release rates of similar lakes; i.e., Lakes Fureso and Esrom(Kamp-Neilson,1974). These two lakes are similar to Bullhead in trophic status and bottom type. Kamp-Neilson found the following primary production to phosphorus release relationship:

	Primary Production ($gC/M^3/yr.$)	Phosphorus Release ($P\text{-}PO_4/M^2/day$)
Lake Esrom	260	12.3
Fureso Lake	310	17.3

The primary production for Bullhead Lake for 1975 and 1976 was 559 and 584 $gC/M^3/yr.$, respectively. These numbers are considered to be only 90% of the total annual production since the tests were not conducted during the winter season. The production of Bullhead Lake far exceeds that of Lakes Esron and Fureso and it follows that Bullhead Lake's sediment phosphorus release will also be equal or greater. The minimum amount of phosphorus released into the water column of Bullhead Lake can be computed from the average of the phosphorus

Table 5. Net Production Bullhead Lake
(oxygen Method: 0.5 - 3.5 M depth)

1975	g.C/m³/day
5/15	2.0[1]
5/15	2.1[1]
7/10	1.4
7/20	1.8
8/5	1.8
8/20	1.8
9/5	1.5
9/15	1.6
10/1	2.1
10/15	1.2
	Ave. 1.7 x 329= 559g.C/m³/.9yr.
1976	
5/28	2.0
6/11	3.0
7/9	1.5
7/21	3.1
8/4	1.8
8/18	1.1
9/9	1.1
9/21	1.7
10/14	.7
	Ave. 1.6 x 365 = 584g.C/m³/.9yr.

[1]based on average of 1976-77 samples for these months

release in Lakes Esrom and Fureso, and the duration of anoxia in Bullhead Lake:

$$\frac{(12.3 + 17.3)}{2} \times \frac{130}{365} \times 6.9 \times 10^4 M^2 = 364$$

Kg. C/M^2/yr.

This large amount of phosphorus supports the lake's large algal population and the magnitude of this population can be shown by the high chlorophyl-a concentration. These concentrations are commonly greater than 10 mg/M^3 and often exceed 20 mg/M^3 during midsummer months.

The method of phosphorus transport across the metalimnion is not throughly understood at this time; but it does occur as experienced in the Shagawa Lake Eutrophication Project where the reduction of the major point source of phosphorus did not reduce concentrations to the expected level. Stauffer and Lee (1974), as one explanation, suggest that winds create metalimnetic seiches which act alone or in combination with the downward migration of the thermocline producing a nutrient pump.

Project Longevity

The phosphorus budget of Bullhead Lake shows that internal recycling is the major source of nutrients. This is a phenomenon typical of naturally eutrophic lakes. The introduction of alum to form a floc will short circuit this cycle by preventing the movement of sediment phosphorus into the water column. The breaking of this cycle will reduce phytoplankton growth which will in turn retard the buildup of sediments and improve the oxygen concentrations at lower lake depths.

The longevity of this project is expected to exceed ten years. This is based upon our experiences at Horseshoe Lake which was treated with aluminum sulfate in 1970. After six years the total phosphorus concentrations have not approached pretreatment levels (J. O. Peterson, pers. comm.). Hydraulic retention time for Horseshoe Lake is 0.35 years compaired to 2+ years for Bullhead Lake. The absence of direct runoff, an inlet and outlet will further inhance the ten year life expectency of this project.

Objectives

1. To inactivate phosphorus by hypolimnetic aluminum sulfate injection in a lake.
2. To evaluate the longevity of phosphorus reduction.
3. To continue monitoring sources of phosphorus.

Project Justification

There are eight counties (including Manitowoc County) that have all or a major part of their land surface within an 80 km radius from Bullhead Lake (Table 3). Within these counties are 159 lakes of which only 9 have surface area and depth equal to or greater than Bullhead Lake, the largest of which is Lake Winnebago. These provide the present major recreational facilities for this region. The balance of the lakes are predominately shallow and very small.

Table 6. Surface Waters Summary - Counties within 80 km of Demonstration Site

County	Total No. Lakes	Total Lake Surface Area h	Lake Number: Area ≥24 h	Lake Number: Depth ≥10.5 m
Brown	4	38	0	0
Calumet	7	37	0	2
Fond du Lac	30	655	6	3
Kewaunee	14	100	0	0
Manitowoc	52	527	5	2
Outagamie	3	31	1	0
Sheboygan	38	782	5	3
Winnebago	10	66761	6	0

Bullhead lake provides a suitable setting for the treatment proposed. The lake is large enough for demonstration purposes but not so large as to make the costs prohibitive. The results obtained will be equitable to other lakes of equal proportions. The drainage basin will minimally effect longevity due to its small size (259 hectares), the absence of point discharges, the soil conservation practices employed and marsh areas around the lake. Present information on the lake provides a very good database for comparison after nutrient inactivation. The public will be provided with an improved aquatic habitat in an area lacking recreational lakes.

Methods

Sample Stations:

Sampling for the past two years (June 1975 to present) has been confined to a single site at the lake's deepest point. Water column profiles were taken bi-weekly during open water and monthly in winter (data provided with original proposal). For the duration of this study and beginning April 1977, four additional sites were established and sampled tri-weekly. These are located in approximately one meter of water at the edge of the macrophyte beds along the North, South, East, and West shores. These additional sites will be sampled at mid-depth for selected chemical and biological parameters (Table 7). The addition of these four sites will provide a better assessment of plankton biomass, productivity, and chlorophyll *a* by offsetting shifts of plankton due to wind conditions. Chemical analysis of water will provide an indication of nutrient input from the decomposition of organic material present in the littoral zone. Macrophyte biomass determinations will be carried out at these points.

Water Chemistry:

Chemical analysis will be carried out on a tri-weekly basis. Parameters to be assessed are shown in Table 7 and are designed to ascertain the action of the aluminum floc upon the phosphorus and upon algae production and biomass. Samples will be taken at one meter intervals beginning at the 0.5 meter level and analyzed according to Standard Methods, 13th Edition. Emphasis will be

Fig: 7
Sampling Site Locations
Bullhead Lake

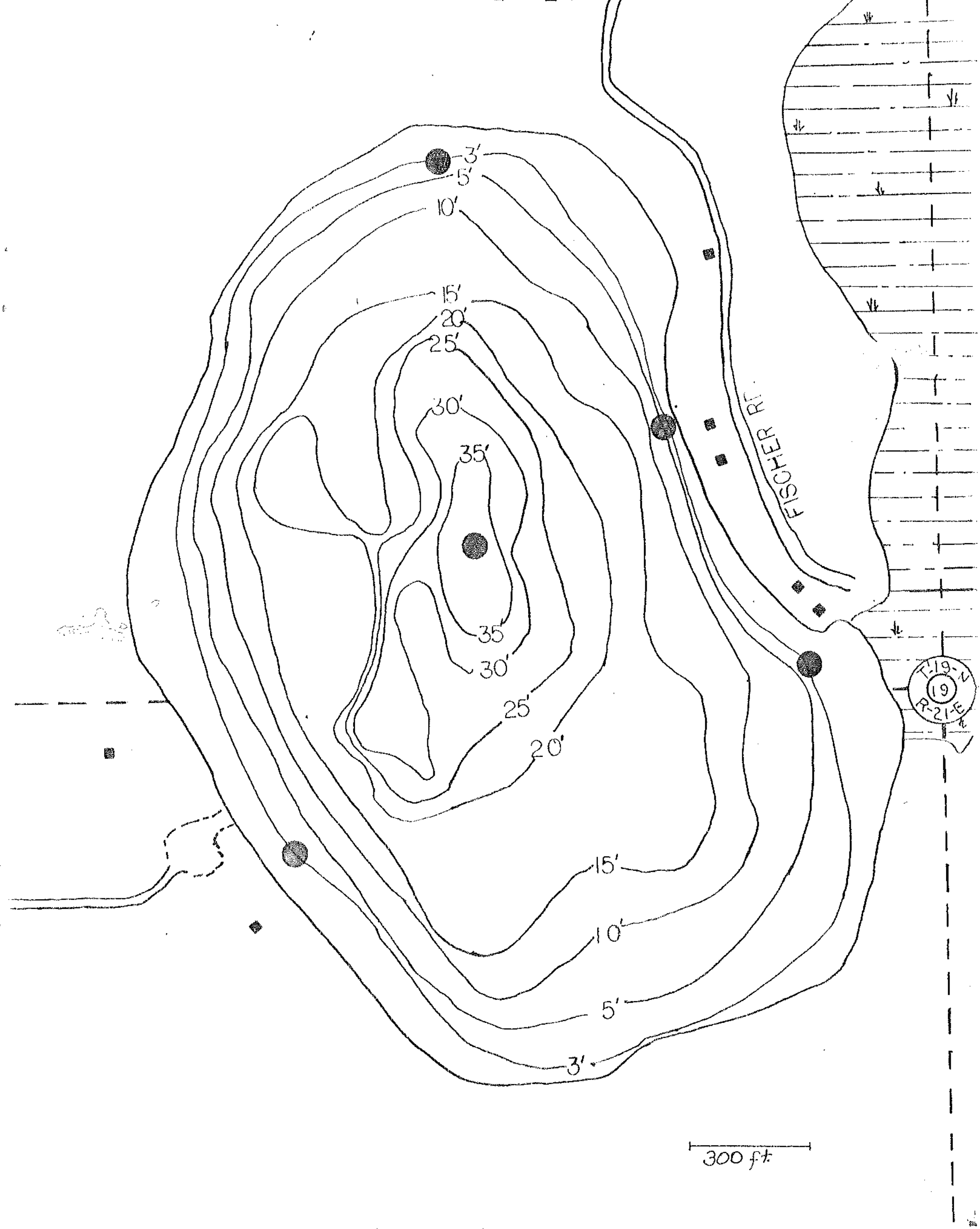


Table 7. Limnological Parameters to be Evaluated

Parameter	Sites	Duration	Frequency
Temperature	1 - 5	Entire Year	Triweekly
Dissolved Oxygen (Electronic)	"	"	"
pH (Electronic)	"	"	"
Secchi Disk	"	"	"
BOD_5	"	"	"
COD	"	"	"
Total Phosphorus	"	"	"
Ortho Phosphorus	"	"	"
Total Dissolved-P. (Filtered)	"	"	"
Dissolved-P (Filtered Ortho-P)	"	"	"
Kjeldahl Nitrogen	"	"	"
Ammonia Nitrogen	"	"	"
Nitrate+Nitrite Nitrogen	"	"	"
Alkalinity (Carbonate)	"	"	"
Specific Conductance	"	"	"
Turbidity	"	"	Quarterly
Al	"	"	"
SO_4	"	"	"
Fe	"	"	"
Primary Production (O_2 Method)	"	"	Triweekly
Chlorophyl a (Phenophytin Corrected)	"	"	"
Benthos (Species Composition)	1	"	"
Plankton (Species Composition)	"	"	"
Macrophyte Biomass (Dry Weight: 3 co-dominate species)	2 - 5	Apr. - Nov.	"

placed upon the dissolved and organic phosphorus concentrations and their genesis. Additional sampling will be conducted prior to and following the aluminum application.

Benthic Sampling:

Benthic sampling will be carried out to ascertain species composition and shifts in populations. Four Ekman (6x6) dredge samples will be collected tri-weekly from the lake's deepest point. Special attention will be given to the period just before and after the application of alum. All samples will be sieved through a 60 mesh sieve which will allow assessment of the Copepods, Ostracoda and Cladocera populations associated with the bottom muds and early insect larval instars.

Aluminum Sulfate Application:

The application of $Al_2(SO_4)_3$ will take place in August during the period of maximum summer stagnation and dissolved phosphorus concentration. The alum slurry will be injected via manifold into the lower level of the metalimnion at about the 6 m. depth. This will allow the floc to settle through the hypolimnion removing the phosphorus that is present. The amount of alum used will depend upon the metalimnion location and tests on lake water prior to treatment. The final dosage should range from 14-20 mg/l of aluminum (148-215 mg/l of $Al_2(SO_4)_3$) in the hypolimnion volume.

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