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HEAVY METALS IN THE WATER AND SEDIMENT OF LAKES IN WESTERN MASSACHUSETTS
II. COPPER

Lawrence N. Kuzminski
James Grier

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UNIVERSITY OF MASSACHUSETTS
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PREFACE

This progress report is the second in a series of detailed progress reports prepared for the Division of Water Pollution Control, Massachusetts Water Resources Commission, Contract Number 15-51454, "Impact of Heavy Metals on the Aquatic Biota of Massachusetts Waters".

This report focuses on the levels of copper currently found in a number of water bodies in Western Massachusetts. The research presented herein was conducted by the authors from January to October, 1973. The authors are respectively, assistant Professor and graduate research assistant, Department of Civil Engineering, University of Massachusetts at Amherst.

This report will be brought to the attention of various agenices, organizations, companies, industries, and individuals interested in the preservation of our natural resources.

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ABSTRACT

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Although copper sulfate has been recognized for many years as an effective algicide, many of the long-range effects of its use remain undetermined. It was the purpose of this study to ascertain the ultimate fate of copper introduced into waters in the form of copper sulfate in order to assess any potential ecological dangers.

Water and sediment samples were collected from 17 lakes and ponds in western Massachusetts representing copper sulfate treatment ranging from extensive to non-existent. Following necessary sample preparation procedures, the waters and sediments collected were analyzed for copper by atomic absorption spectrophotometry.

The results showed that there is no significant difference in copper concentrations of waters which have received copper sulfate treatment and those which have not. Copper content in sediments of treated waters was found to be up to 500 times greater than untreated waters and the relative magnitude of this difference appears to be related to the extent and duration of copper sulfate treatment. Based on a comparison of this study's findings with previously published lethal copper concentrations, there was no evidence of immediate toxicological hazards to fish or bottom-dwelling biota as a consequence of properly applied copper sulfate treatment. However further studies are necessary to predict any long-term adverse physiological effects to these aquatic lifeforms.

INTRODUCTION

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Copper sulfate had been widespread use as an agent for the control of offensive algae in fresh waters since the turn of the century. The effectiveness of copper sulfate as an algicide has been repeatedly proven (1)*, however many questions regarding the environmental hazards associated with its use remain largely unresolved. Several studies have been conducted concerning the adsorption of copper by bottom sediments (2), toxicity to a variety of fish species (3) and benthic organisms (4), but most of these investigations were conducted in the laboratory over a relatively short period of time. The long-range, cumulative effects of repeated copper sulfate dosages, in particular the ultimate fate of copper in receiving waters and sediments,are areas of concern which deserve immediate attention.

It was the purpose of this study to ascertain a better understanding of the fate of copper and other long-term effects of copper sulfate treatment. Based upon information obtained from the Mass. Dept. of Public Health, the Toxic Element Survey (19) conducted by the Mass. Division of Water Pollution Control, and private companies engaged in the work of copper sulfate treatment, bodies of water were selected to exemplify low and high content of copper. Having confirmed that such a range of copper concentrations does exist through analysis of water and sediment samples collected at each location, the objectives of this study were:

1) A correlation of the determined copper concentrations in the field with the known amounts of copper introduced into the specific bodies of water over varying periods of time.

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*Numbers in parentheses refer to equivalent referenced article.

2) A comparison of the copper concentrations found in the water and sediment of lakes and ponds having a known history of copper sulfate treatment with those which have not received treatment.
3) An assessment of the possible environmental hazards which may exist within the lakes and ponds examined as a result of copper sulfate treatment.

LITERATURE REVIEW

The first large-scale use of copper sulfate to control algae was undertaken by the city of Madison, Wisconsin in 1918. Dosages were at first applied by dragging bags of copper sulfate crystals thorugh the water, but it was later found that spraying the chemical on surface waters was a much more effective distribution technique (6). Dosages are generally applied in amounts to yield an immediate copper concentration of about 0.3 ppm Cu to a depth of 6 feet (17). This concentration is effective in controlling anticipated algae blooms and is inexpensive to apply, only costing about $0.15 per acre -ft (24).

In regard to the chemistry of copper in water, Stiff (15) states that the concentration of free cupric ion, Cu^{2+}, represents only a small fraction of the total soluble copper present in a bicarbonate solution of the concentration and pH range of most natural fresh waters. The copper-carbonate complex $CuCO_3$ was found to be the predominant soluble carbonate complex species. Further study by Stiff (10) to determine the chemical states of copper in polluted fresh water revealed that besides the free cupric ion and its carbonate complexes, the most likely soluble forms of copper are its complexes with cyanide, amino acids and polypeptides, and humic acid (the sole oxidation state of copper in aqueous reactions is 2+). Analytical studies showed clearly that either suspended solids or copper precipitation reactions, or both, have a profound effect upon the physical state of copper in natural and polluted water.

No specific value for the background or naturally-occurring concentrations of copper in fresh water could be found in the literature surveyed. This can be attributed to the many factors which affect the naturally-occurring copper content of lake waters. Riley (11) states four of these factors: (1) precipitation which lowers Cu content by dilution; (2) sedimentation: removal from solution by adsorption on organic matter; (3) regeneration from mud; (4) liberation of Cu in autumn from decomposition of littoral vegetation.

Perhaps the most extensive study on the effects of copper sulfate treatment has been conducted by a number of investigators on several lakes in the Madison, Wisconsin area. The lakes under study represented copper sulfate applications for algae control which ranged from negligible doses to extensive.

Nichols et al (6) determined that untreated lakes contained natural copper concentrations on the order of 25 mg/kg of dried mud. Lake Monona, the Madison area lake which received the greatest amount of copper sulfate treatment, showed copper concentrations as high as 1093 mg/kg in dried sediment. Nichols also noted that the higest concentrations were found in the deeper parts of the lake and concluded that the natural grading process tends to carry the precipitated copper compounds to lower levels.

Antonie et al (7) conducted a study on Lake Monona four years after treatment with copper sulfate had ceased, to determine the concentration and distribution of copper in the bottom muds. The results of the investigation showed that the maximum copper concentrations occurred at sediment depths of about 1.5 feet, suggesting that the constant settling of silt into the deeper regions of the lake would in time cover up the heavy concentrations of copper that were deposited at the time of application. Antonie, like Nichols, found that the greatest concentration of copper is found in the lake muds of the profundal region.

Concerning the biological effects of copper sulfate treatment on the Madison area lakes, Mackenthum et al (8) surveyed the muds of heavily treated Lake Monona and three other lakes which underwent little or no copper sulfate treatment in order to assess and compare the population densities of bottom dwelling organisms. The results indicated that differences occurring in the population densities (proliferation) of bottom organisms in the four lakes studied are due to ecological variables within these separate bodies of water and not due to the degree of treatment with copper sulfate. Limited bioassay studies by Mackenthun obtained results which showed that the toxic limit of copper in sediment to bottom dwelling organisms is near 9000 mg/kg (dry weight basis). Results of the same study indicate that the accumulation of copper in bottom muds from copper sulfate treatment is considerably lower in concentration than the amounts experimentally determined to have a deleterious effect on the profundal-dwelling organisms studied.

Studies by Dykeman et al (9) reveal that organic matter plays an important role in the ultimate fate of aqueous copper. Chelation, or binding of copper ion with nitrogen, oxygen or sulfur ions of organic compounds, has the effect of making it unavailable for further reactions. These chelates are usually insoluble in water, and are very stable, requiring strong acid or complexing agents for their removal. Soil pH is very important in chelate formation. Dykeman's investigations revealed that copper toxicity was greatest in soils with least buffer capacity, and that toxic properties decreased with time after application.

In the efforts of Reimer et al (2) to determine the copper adsorption capacities of three clay minerals, humic acid, and three natural pond sediments, it was found that when four times the normal $CuSO_4$ dosage for algae control was applied, nearly complete adsorption occurred in all systems. It was determined that only 2.5% or less of the total copper applied remained water soluble over a five-week period, even though copper was applied weekly. Thus, high rates of copper removal can be expected from treated pond waters when sediments are high in clay or organic matter content and where circulation brings most of the water in contact with the sediment.

Copper toxicity studies have been conducted by a number of investigators on both aquatic and bottom-dwelling organisms. Mount et al (3,5) found that the 96-hour median tolerance limit (i.e. the concentration at which half the organisms survive after 96 hours exposure) of copper to fathead minnows was 430 μg/l in hard water but only 84 μg/l in soft water. Similar findings were borne out by Woodbury et al (12) who determined that the lethal concentration of copper sulfate to large-mouth bass in distilled water was 1.5 ppm and Nichols et al (6) who found that the lethal dosage of copper sulfate to the same species in lake water with an alkalinity of 170 mg/l was 200 ppm. Arthur et al (4) found the 96-hour median tolerance limits for three species of benthic organisms in relatively soft water to range from 20 to 1700 μg/l.

The effects of chelation on copper toxicity were underscored by Sprague (13) who determined that the trisodium salt of NTA was found to increase the tolerance of Atlantic salmon to copper by up to 33 times the lethal threshold value.

Lloyd et al (14) listed several environmental factors which affect the toxicity of copper: calcium content (hardness), temperature, dissolved oxygen, and activity rate. He also suggested that out of the total quantity of copper contained in water, only the ionic fraction was toxic. Stiff (15) stated that support for the theory of ionic copper toxicity could be gained by considering the effect of bicarbonate equilibrium on copper complexing, meaning that the toxicity would depend on alkalinity rather than on hardness.

EXPERIMENTAL METHODOLOGY

EXPERIMENTAL METHODOLOGY

Selection of Lakes

The initial point of procedure in meeting the objectives of this study was to obtain an adequate selection of lakes and poinds which have and have not been treated with copper sulfate. To this end the Mass. Dept. of Public Health (16), which maintains a record of the treatment histories of waters within the state, was solicited to provide the information required. In addition, two Massachusetts-based companies which engage in the work of copper sulfate treatment, i.e. Allied Biological Control Corporation of Wellesley Hills (17) and Northeast Weed and Brush Control of Spencer (18), were contacted for supportive data. As a result of these inquiries the following list of lakes and ponds in western Massachusetts and their treatment histories was obtained:

1. Stockbridge Bowl; Stockbridge, Mass.

   1966-2500 lbs.copper sulfate
   1969-2500 lbs.copper sulfate
   1970-2500 lbs. Malachite (55.8% copper)

2. Indian Lake; Worcester, Mass.

   1963 to 1972-5600 lbs copper sulfate per year (180).

3. Shaw Pond; Becket, Mass.

   1972-Multiple treatments with copper sulfate; amounts unspecified.

4. Pontoosuc Lake; Lanesborough, Mass.

   1972-2300 lbs. copper sulfate

5. Cheshire Reservoir; Cheshire, Mass.

   1972-2300 lbs. copper sulfate

6. Lake Metacomet; Belchertown, Mass.

   1970-50 lbs.copper sulfate

7. Cranberry Pond; Sunderland, Mass.

   1972-50 lbs. copper sulfate (21).

To provide a basis for comparison between treated and untreated waters, the following ten lakes and ponds in which copper algicides were not used were selected for sampling:

1. North Pond; Florida, Mass.
2. Pelham Lake; Rowe, Mass.
3. Prindle Lake; Charlton, Mass.
4. Borrow Pit Pond (91F); Whately, Mass.
5. Center Pond; Becket, Mass.
6. Guilder Pond; Mt. Washington, Mass.
7. West Lake; Sandisfield, Mass.
8. Upper Spectacle Pond; Sandisfield, Mass.
9. Big Benton Pond; Otis, Mass.
10. Silver Lake; Pittsfield, Mass.

(Note: A more detailed description of these lakes is provided in the Appendix).

Two of the bodies of water listed, i.e. Cranberry Pond and Silver Lake, were selected as one means to check the validity of the data determined in this study by comparison with the values found in the Toxic Element Survey (19) for the same locations.

Field Sampling Procedure

A map of each lake selected for sampling was obtained (25) and the approximate location of each individual sampling point was marked, as well as a brief word description to the nearest landmark recorded. Sampling points were chosen as to provide for a thorough coverage of the lake area, e.g. shoreline and profundal regions. The number of samples collected per lake was determined by consideration of the relative size(area) of the lake.

Water samples were taken just below the surface in 1-liter plastic sample bottles and acidified with 5 mls concentrated nitric acid to preserve the dissolution of metal ions (20). In instances where stratification was thought to exist, depth samples were also taken. Sediment samples, as well as depth water samples, were collected with an Ekman dredge, stored in 1-liter plastic sample bottles, and the depths recorded to the nearest foot.

Sample Preparation

Water samples required no preparation other than acidification in the field.

Sediment samples were prepared by the procedure used by Delaney and Isaac (19). Aliquots of each sediment sample were transferred to evaporating dishes and dried to constant weight in a hot air oven at 60-70°C. It was determined by means of a moisture loss vs. drying time curve analysis that a 48-hour drying time was sufficient to yield constant weights for all sediment samples. The analysis showed that after the 48 hour period, approximately 65% of the moisture was lost at the stated drying temperature (see Appendix; Fig. I). Each dried sample was then pulverized with mortar and pestle, shaken on a standard No. 30 seive, and 10.0 grams of sample which passed through the seive were weighed out into a 500 ml erlenmyer flask. Five mls of concentrated nitric acid and approximately 100 mls distilled deionized water were added and the sample digested to dryness on a hot plate. The digestion process was repeated once to yield a total of two digestions for the sediment. Following the second digestion, the residue was wetted with 2 mls concentrated nitric acid, 50 mls distilled deionized water, and filtered through a Whatman No. 42 filter. The erlenmyer flask and filter were rinsed several times with distilled deionized water to insure that the entire sample was quantitatively transferred through the filter. The filtrate was then brought up to 100 mls total volume in a 100 ml volumetric flask with distilled deionized water and stored in a clean screw-cap glass bottle numbered for identification. By this procedure the mg of copper per kilogram of dry weight sediment are calculated by multiplying the micrograms per milliliter found in analysis of the 100 ml extract by 10.

It should be noted that due to the sensitivity of trace metal analysis and the large measure of error which can be introduced by contamination, great care was taken to insure that all containers used for sample collection, storage, and preparation were treated in the following sequence as recommended in Standard Methods (20): washed in soap and water, rinsed with chromic acid, tap water, 1+1 nitric acid, tap water, and distilled deionized water.

Sample Analysis

Water and sediment samples were analyzed by atomic absorption spectrophotometry with a Perkin-Elmer Model 303 Atomic Absorption Spectrophotometer and HGA-70 Graphite Furnace. The graphite furnace permitscopper determinations in the µg/l or ppb range. This highly accurate method of analysis is ideally suited for use when a large number of determinations must be made and the element of interest is subject to few chemical and spectral interferences, as is copper.

To analyze a given sample, a 20 µl aliquot is injected into the graphite tube with an Eppendorf microliter pipet,and the programming sequence set into operation to yield a percent absorption value on the chart recorder attachment (see Appendix; Fig.II). Percent absorption values are next converted to absorbance values and the actual concentration is subsequently determined from the calibration curve for the metal being analyzed.

Calibration curves were made with standards prepared form 1000 mg/l stock atomic absorption copper standard solution diluted to concentrations of 10, 40, 100, 200, 300, and 400 µg/l copper with distilled deionized water and acidified with concentrated nitric acid for the purpose of maintaining, as far as possible, an equivalent matrix for water, sediment, and standard solution samples. It was found that the linear working range for Cu was approximately between 0 and 300 µg/l (see Fig. 1). Since all the sediments had copper concentrations well above this linear working range, each sample was diluted by a factor appropriate to yield a concentration within the linear range on the calibration curve. In almost all instances water samples required no dilution.

Other operating parameters were:

Wavelength Setting: 3247 A^o

Slit Setting: 4

Scale Expansion Setting: 1

Noise Suppression Setting: 1

Light Source: Cu Hollow Cathode Lamp

Fuel: Nitrogen at 38 psi

Cooling Water Flowrate: 3 liters/min

Chart Speed: 0.75 in/min

HGA Program Setting: 7

Drying Time: 40 sec
Thermal Destruction Time: 90 sec
Atomization Time: 20 sec at 9 volts

Statistical Methods

A) Accuracy of Copper Analysis by Atomic Absorption Spectrophotometry

It was necessary to determine how many analyses per sample were required to yield accurate results from analysis by the method of atomic absorption spectrophotometry. In order to ascertain this information, a method described by Holman (26) outlined below, was used.

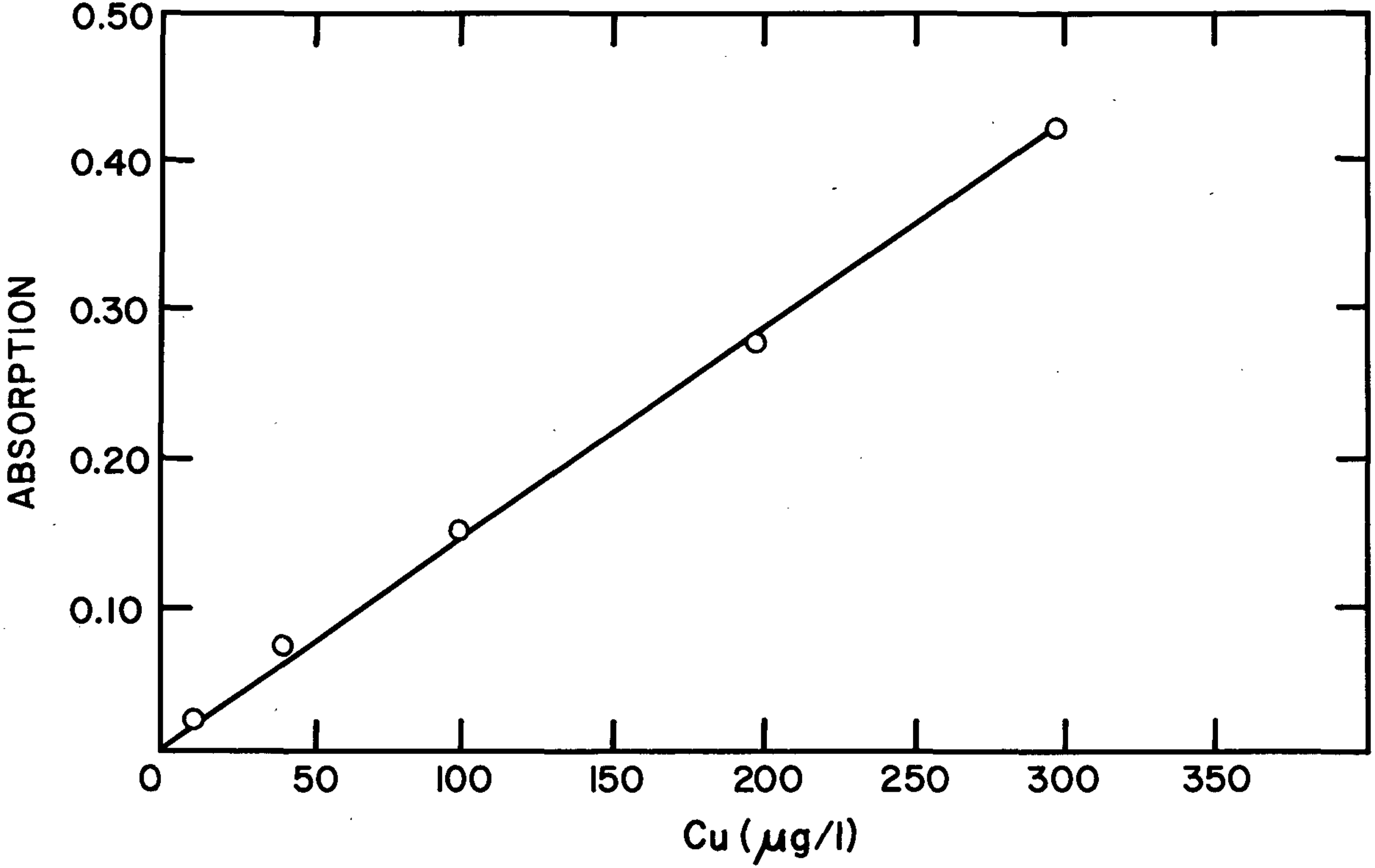

Figure 1: Calibration Curve for Determination of Copper by Atomic Absorption Spectrophotometry using an HG A-70 Graphite Furnace.

For a 95% confidence interval, i.e. the probability is .95 that the mean $\overline{X}$ of n observations lies within this interval,

$$95\%\ \text{C.I.} = \overline{X} \pm 1.96\,\frac{\sigma}{\sqrt{n}}\ ,\ \text{where}$$

$$\overline{X} = \text{mean} = \frac{\Sigma X}{n}\ ,\ \text{and}$$

$$\sigma = \text{standard deviation} = \left(\frac{\Sigma(X-\overline{X})^2}{n-1}\right)^{1/2}$$

It was decided subjectively that an error no greater than 20% of the true concentration would be acceptable. This constraint was met as follows

$$95\%\quad X + .2X = X \pm 1.96\,\frac{\sigma}{\sqrt{n}}\ ,\ \text{or}\ .2X = 1.96\,\frac{\sigma}{\sqrt{n}}$$

$$\text{and}\ \frac{\sigma}{X} = \frac{.2}{1.96}\sqrt{n}$$

Therefore, for $n = 1$, $\frac{\sigma}{X} = 0.104$

$n = 2$, $\frac{\sigma}{X} = 1.144$

$n = 3$, $\frac{\sigma}{X} = 1.178$, etc.

To determine the ratio $\frac{\sigma}{X}$, composite samples (1 ml each of all samples) of both water and sediment were prepared and 20 (the number recommended by Holman) analyses for copper performed on the Perkin-Elmer Model 303.

The results of the analyses were as follows:

Water Composite: $\frac{\sigma}{X} = 0.083$

Sediment Composite: $\frac{\sigma}{X} = 0.074$

Since both values of $\frac{\sigma}{\overline{X}}$ were less than 0.104, only one analysis per sample is required for 95% confidence that the value obtained is in error by 20% or less.

B) Other Statistical Calculations

For each lake and pond analyzed, the mean, $\overline{X}$, and standard deviation, σ, as defined previously, were calculated for water and sediment samples respectively, taken at all locations throughout a particular lake. The mean is a measure of the central tendency of a data set, while the standard deviation is a measure of its spread. For a normal distribution, 84.13% of the observations lie within ± one σ of the mean $\overline{X}$ (27).

The correlation coefficient, $r = \frac{(X-\overline{X})\ (Y-\overline{Y})}{(\Sigma(X-\overline{X})^2\Sigma(Y-\overline{Y})^2)^{1/2}}$ is a measure of the linear relationship which may exist between two sets of data, X and Y. A correlation coefficient greater than 0.7 in a large set of data is considered to indicate a high degree of relationship (27).

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

Copper Content of Waters

A summary of the copper content of the water samples taken is presented in Table 1. From Table 1 it is evident that there is no clear pattern with respect to copper concentrations in waters having been recipient to known sources of copper and those which have not. In all but two locations, i.e. Silver Lake and Cranberry Pond, the mean concentration of copper for each lake is in the vicinity of 0.1 mg/l Cu. The mean copper concentration of water samples from lakes not treated with copper sulfate is also approximately 0.1 mg/l Cu and it is assumed that this value represents the background or naturally-occurring amount of copper for the waters analyzed in this study. It may be noted that there is considerable variation in the copper content of waters from sampling point to sampling point, as is indicated by the relatively large standard deviations observed. This variation may be due to a number of factors such as water current movements, dilution by subsurface springs, localized leaching of copper from sediments and other unknown variables within the given body of water.

As stated previously, abnormally high copper concentrations were encountered at Silver Lake and Cranberry Pond. Silver Lake is situated within a heavily industrialized area and is used as an outfall for process wastes by the adjacent General Electric Co. plant. Thus in all probability there is a continuous feed of wastes high in copper content into Silver Lake which would explain the high copper concentration observed in this water.

Table 1. Summary of Copper Concentrations Found in Waters of Selected Lakes and Ponds in Western Massachusetts. [] denotes number of samples collected and analyzed at each location.

CuSO	Total Dosage (lbs/acre)	Cu (μg/l)	
		Mean	Standard Deviation
Indian Lake [9]	294.7	109.4	46.9
Shaw Pond [8]	unknown	109.3	63.6
Stockbridge Bowl [11]	20.2	152.6	99.5
Cheshire Res. [8]	5.05	57.0	29.4
Pontoosuc Lake [12]	4.80	95.9	43.2
Cranberry Pond [5]	2.08	282	146
Lake Metacomet [5]	0.67	63.6	25.5
No Treatment			
Silver Lake [5]		264	199
Pelham Lake [5]		45.2	26.6
Prindle Lake [8]		114.1	46.6
Center Pond [9]		86.9	64.3
Borrow Pit Pond [3]		123.7	6.1
North Pond [5]		75.4	20.6
Big Benton Pond [8]		154.6	90.8
West Lake [5]		147.6	46.1
Guilder Pond [5]		134.4	59.4
Upper Spectacle Pond [5]		94.0	60.4

Cranberry Pond, on the other hand, exhibits a high copper content in its waters which is not as readily explained. It was recently learned from Dr. Roger J. Reed (21) that approximately 50 lbs. copper sulfate had been used to destroy Pumpkinseed fish egg nests along the periphery of Cranberry Pond in late Spring 1972. It is possible that unspent copper sulfate associated with this action may have been introduced into the water as a consequence of the runoff due to heavy rains immediately preceeding the sampling of Cranberry Pond for this study. This is at best a tenuous explanation, but it is the only reasonable means of accounting for the high values of copper found in the waters of this pond. As a final note, there were a large number of recently killed fish seen along the shore of Cranberry Pond the day on which samples were collected. Whether this was a result of copper toxicity is unknown.

Where stratification was thought to be present, i.e. Stockbridge Bowl, Pontoosuc Lake, North Pond, and Big Benton Pond, both surface and depth water samples (taken just off the bottom) were collected in an attempt to note any difference in copper content. The data indicate that there is no demonstrable relationship of any type between copper concentration and depth.

As determined in a personal communication with Dr. J. Coleman (17) of Allied Biological Control Corporation, who is familiar with the procedure of copper sulfate treatment for algae control, the usual applied dosage is 0.8 lbs. $CuSO_4$ per acre-ft. This will typically result in an immediate copper concentration of about 0.3 ppm Cu to a depth of 6 feet, a value toxic to algae but harmless to other aquatic life. The concentration decreases with time and new dosing is required within a few weeks. This information is confirmed by Monie (1) who observed that the copper hydroxide suspension resulting from copper sulfate treatment disappears in 6 to 7 weeks and renewed dosing is necessary to control algae proliferation.

On the basis of this information it is apparent from the observed data that none of the lakes in this study were sampled at a time closely following copper sulfate treatment, with the possible exception of Cranberry Pond. The results of the water analysis for copper content in this study therefore indicate that copper sulfate treatment results in a temporary adjustment (increase) of Cu concentration in the water and that copper concentrations in the water return to background levels in a relatively short period of time. To better illustrate this point, Table 2 presents the mean copper concentrations found from analysis of water samples collected from lakes with known treatment histories vs. the total amounts of copper as $CuSO_4$ introduced into these waters.

An examination of Table 2 clearly reveals that even extensive treatment with copper sulfate (e.g. Indian Lake) does not result in any significant increase in the background levels (approximately 0.1 mg/l) of copper present in the water. This then suggests that the ultimate fate of copper introduced as $CuSo_4$ is its adsorption and chelation by sediments, as is indeed indicated by the data presented in the following section of this report.

Copper Content of Sediments

Referring to Table 3, a summary of the copper content of the sediment samples collected, there is clearly a wide range of copper concentrations among the sediments of the lakes and ponds sampled and analyzed in this study. The results generally indicate that the highest concentrations observed parallel the relative magnitude of copper quantities introduced into each lake and pond analyzed.

Indian Lake in Worcester has by far received the most extensive treatment with copper sulfate, i.e. 10 years treatment at 5600 lbs. $CuSO_4$ per year, and the mean concentration of its sediments is approximately 500 times those normally found in untreated waters (i.e. 25 mg/kg dry weight according to Nichols et al (6)).

Table 2. Present Mean Copper Concentrations in Water vs. Total Dosages of Copper Sulfate for Lakes with Known Known Treatment Histories.

		Total Amounts of Copper Introduced as $CuSO_4$ (mg/l)	
Lake	Cu (μg/l)	Top 6 ft	Fully Mixed
Indian	109.4	14490	10868
Stockbridge	152.6	988	220
Cheshire	57.0	271	232
Pontoosuc	95.9	235	94.1
Metacomet	63.6	33.0	19.8
Cranberry	282	102	68.1

between copper in water and copper in sediments of the lakes analyzed in this study.

The concentrations of copper found in the sediments agree quite well with those found in other studies. Nichols _et al_ (6) found that lakes contained natural copper concentrations on the order of 25 mg/kg of dried mud. This value is very close to the average amount found in the sediments of the untreated lakes and ponds selected for this study. Delaney and Isaac (19) analyzed core samples from Silver Lake and Cranberry Pond in their _Toxic Element Survey_ and reported mean copper concentrations of approximately 3000 and 28 mg/kg dry weight respectively (analysis was for sediments only). The corresponding values for these locations as determined in this study are 5550 and 25 mg/kg dry weight. These comparisons reinforce the validity of the determinations made here.

As was noted with the concentrations in water, copper content in sediments varied considerably from sampling point to sampling point within the same body of water. This is primarily due to the heterogeneity of bottom muds with respect to soil-type classification (e.g. organic vs. clay) and their ability to complex copper out of solution. One observation to be made is that in nearly all instances where sandy, silica-type sediments were collected and analyzed, their copper concentrations were on the average 2 to 4 times less than those of organic sediments taken from the same body of water. This supports the conclusion reached by several investigators concerning the ability of organic sediments to chelate copper (2).

Assessment of Environmental Hazards

It is now appropriate to assess the results of this study in terms of the environmental hazards possibly associated with the use of copper sulfate for the control of offensive algae in fresh waters.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

1. After a period of time following treatment, there is no significant difference in the concentrations of copper found in the waters of lakes and ponds which have received copper sulfate treatment and those which have not. If any differences do exist, they are indistinguishable from the background levels of 0.1 mg/l Cu.
2. There appears to be a significant difference in the concentrations of copper found in the sediments of lakes and ponds which have received copper sulfate treatment and those which have not. The concentrations in the sediments of copper sulfate treated waters, depending on the extent and duration of treatment, were found to be 1 to 3 orders of magnitude greater than naturally occurring amounts of 25 mg/kg Cu dry weight.
3. There is no correlation between copper content of waters and copper content of sediments in treated and untreated waters that could be demonstrated in this study.
4. The amounts of copper introduced into waters in the form of copper sulfate are in time removed from solution by precipitation and sediment-chelation and adsorption mechanisms.
5. There do not appear to be any immediate toxicological effects upon either fish or benthic organisms as a consequence of conscientiously-applied copper sulfate treatment.

Table 3. Summary of Copper Concentrations Found in Sediments of Selected Lakes and Ponds in Western Massachusetts. [] Denotes Number of Samples Collected and Analyzed at Each Location.

$CuSO_4$ Treatment	Total Dosage (lbs/acre)	Cu (mg/kg dry wt.) Mean	Cu (mg/kg dry wt.) Standard Deviation
Indian Lake [9]	294.7	1272	947
Shaw Pond [8]	unknown	669	505
Stockbridge Bowl [8]	20.2	298	209
Cheshire Res. [8]	5.50	76.3	38.4
Pontoosuc Lake [10]	4.80	58.7	35.2
Cranberry Pond [5]	2.08	25.0	11.6
Lake Metacomet [5]	0.67	27.6	12.7
No Treatment			
Silver Lake [5]		5548	2711
Pelham Lake [5]		67.2	50.4
Prindle Lake [8]		67.0	44.2
Center Pond [9]		28.4	26.3
Borrow Pit Pond [2]		12.0	8.0
North Pond [4]		20.5	8.4
Big Benton Pond [7]		20.6	12.4
West Lake [5]		10.2	3.2
Guilder Pond [5]		43.8	7.7
Upper Spectacle Pond [5]		24.2	9.2

Shaw Pond has received multiple treatments with unspecified amounts of copper sulfate and the data suggests that the quantities may have been considerable.

Stockbridge Bowl has undergone heavy copper sulfate treatment during three recent years and the copper content of its sediments reflect this fact.

The remaining lakes and ponds which are known to have been treated with copper sulfate do not show any distinct differences in sediment copper concentrations which can be positively distinguished from naturally occurring amounts (i.e. 25 mg/kg dry weight). This is primarily due to the relatively small amounts of copper sulfate which have been introduced into bodies of water of large surface area. For example, 50 lbs. of copper sulfate was applied to Lake Metacomet 3 years ago. This is certainly a small amount for a lake 74 acres in size. In addition, the copper sulfate applications may have been concentrated in one or more small areas, e.g. campsites, beaches etc., and quite possibly those points were not among those sampled in this study. Nevertheless the concept that copper does accumulate in the sediments as an aftereffect of copper sulfate treatment is definitely indicated in the data.

To verify this conclusion more quantitatively, a linear regression analysis of mean sediment copper concentrations vs. total dosages (over a period of time) of $CuSO_4$ was performed for the lakes and ponds with known treatment histories. Dosages were calculated in lbs. $CuSO_4$ per acre and lbs. $CuSO_4$ per acre-ft to consider the effects of both area and depth. Table 4 presents these calculations and the results of the linear regression analysis.

The results of the linear regression analysis yield correlation coefficients r and r' very close to unity or perfect correlation. This strongly suggests that a relationship between sediment copper concentration and the extent of copper sulfate treatment does in fact exist. As expected, there was no correlation

Table 4. Linear Regression Analysis of Mean Copper Concentrations in Sediments vs. Total Copper Sulfate Dosages for Lakes with Treatment Histories.

Lake	X Cu(mg/kg dry wt.)	Y (lb/acre)	Y' (lb/acre-ft)
Indian	1272	294.7	36.87
Stocbridge	298	20.2	0.746
Cheshire	76.3	5.50	0.786
Pontoosuc	58.7	4.80	0.319
Metacomet	27.6	0.67	0.067
Cranberry	25.0	2.08	0.231

Results: r (X vs. Y) = 0.988

r' (X vs. Y') = 0.980

where r = correlation coefficient

between copper in water and copper in sediments of the lakes analyzed in this study.

The concentrations of copper found in the sediments agree quite well with those found in other studies. Nichols et al (6) found that lakes contained natural copper concentrations on the order of 25 mg/kg of dried mud. This value is very close to the average amount found in the sediments of the untreated lakes and ponds selected for this study. Delaney and Isaac (19) analyzed core samples from Silver Lake and Cranberry Pond in their Toxic Element Survey and reported mean copper concentrations of approximately 3000 and 28 mg/kg dry weight respectively (analysis was for sediments only). The corresponding values for these locations as determined in this study are 5550 and 25 mg/kg dry weight. These comparisons reinforce the validity of the determinations made here.

As was noted with the concentrations in water, copper content in sediments varied considerably from sampling point to sampling point within the same body of water. This is primarily due to the heterogeneity of bottom muds with respect to soil-type classification (e.g. organic vs. clay) and their ability to complex copper out of solution. One observation to be made is that in nearly all instances where sandy, silica-type sediments were collected and analyzed, their copper concentrations were on the average 2 to 4 times less than those of organic sediments taken from the same body of water. This supports the conclusion reached by several investigators concerning the ability of organic sediments to chelate copper (2).

Assessment of Environmental Hazards

It is now appropriate to assess the results of this study in terms of the environmental hazards possibly associated with the use of copper sulfate for the control of offensive algae in fresh waters.

In no instance did the copper concentrations found in any of the waters analyzed closely approach the USPHS 1962 Drinking Water Standards limit of 1.0 mg/l Cu (22). Thus there is no reason to prohibit the correct use of copper sulfate in drinking water supplies from a public health standpoint, based on this standard.

As discussed at length in the literature review, the toxicity of copper in water is influenced by a great number of environmental factors. It is difficult then to state specifically the actual or potential threat to the well-being of various aquatic species on the basis of the data derived from this study. For instance, it has been shown that the degree of hardness of a given water has a pronounced effect on the toxicity of copper (5). Also, the deleterious effects of copper vary substantially from one fish species to another. Thus, although the long-range physiological effects of copper sulfate treatment require further study, the data obtained from this investigation indicates that the residual copper concentrations in treated waters are well below reported copper toxicity levels and as such do not pose a direct or immediate threat to common aquatic species. The greatest hazard is perhaps presented immediately after the application of copper sulfate when the concentration of copper in water is at its highest. Frost (23) reports a massive fish kill resulting from a miscalculation of volume and doubling dose of copper sulfate. With regard to bottom dwelling organisms, even the highest values found in the sediments analyzed in this study do not approach the toxic levels of copper cited in the literature.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

1. After a period of time following treatment, there is no significant difference in the concentrations of copper found in the waters of lakes and ponds which have received copper sulfate treatment and those which have not. If any differences do exist, they are indistinguishable from the background levels of 0.1 mg/l Cu.
2. There appears to be a significant difference in the concentrations of copper found in the sediments of lakes and ponds which have received copper sulfate treatment and those which have not. The concentrations in the sediments of copper sulfate treated waters, depending on the extent and duration of treatment, were found to be 1 to 3 orders of magnitude greater than naturally occurring amounts of 25 mg/kg Cu dry weight.
3. There is no correlation between copper content of waters and copper content of sediments in treated and untreated waters that could be demonstrated in this study.
4. The amounts of copper introduced into waters in the form of copper sulfate are in time removed from solution by precipitation and sediment-chelation and adsorption mechanisms.
5. There do not appear to be any immediate toxicological effects upon either fish or benthic organisms as a consequence of conscientiously-applied copper sulfate treatment.

RECOMMENDATIONS

1. Based on the findings of this study, lakes and ponds of known low and high copper content should be sampled for selected fish and benthic species and these organisms assayed for amounts of copper present.
2. Laboratory studies should be conducted on the possible uptake and release rates of copper by various aquatic species. All levels of the food chain should be considered.
3. A far more extensive sampling survey (water and sediment) of one or more of the lakes determined in this study to have low and high copper contents. This would enable the application of rigorous statistical methods to the data collected and permit more definitive statements regarding the conclusions proferred in this investigation.

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LITERATURE CITED

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APPENDIX

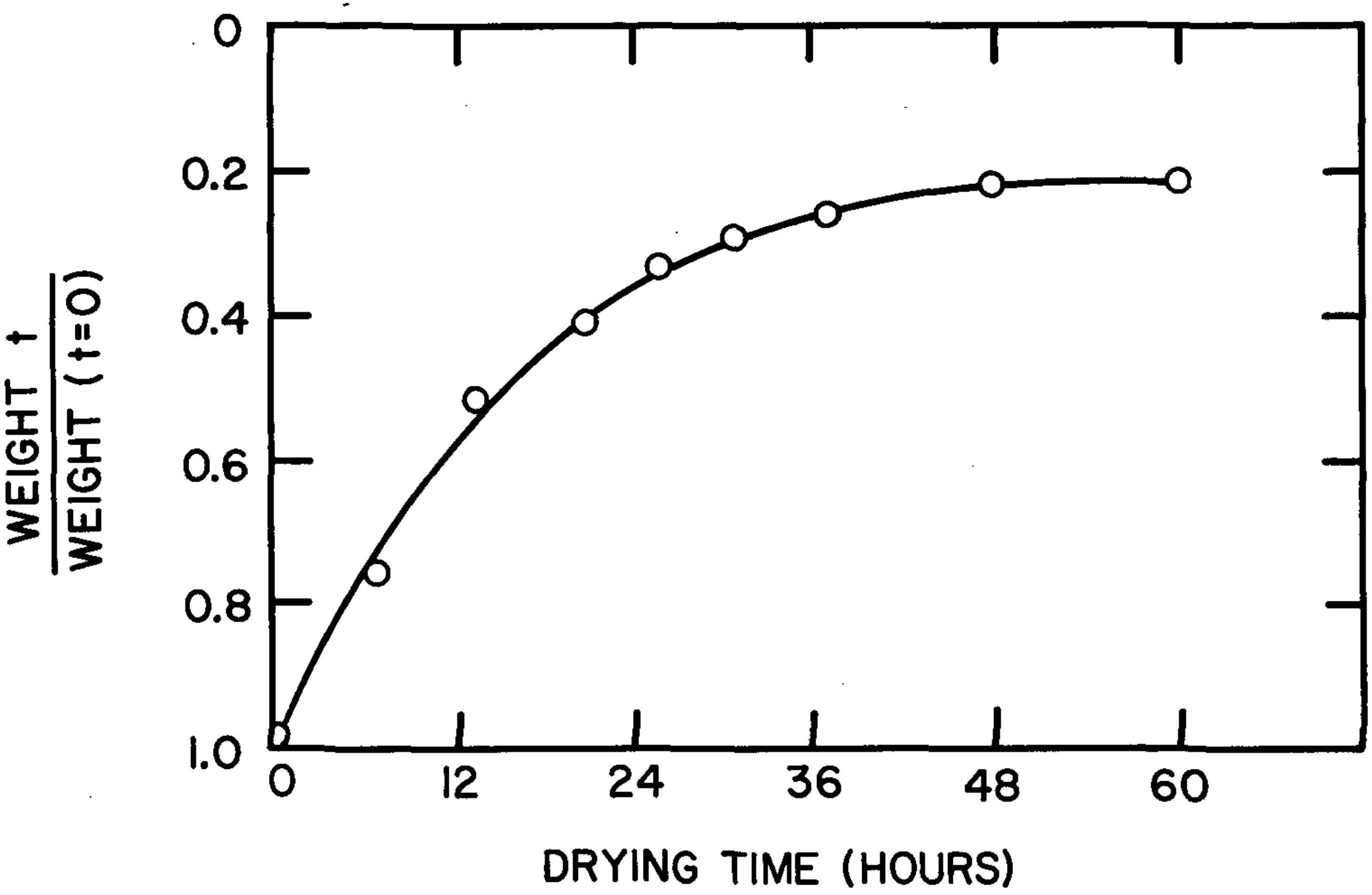


Figure I: Moisture Loss vs. Drying Time Curve *

*Note: The time of drying necessary to achieve constant weight was determined experimentally with 100 grams (wet) aliquots of a representative sediment (triplicate analyses).

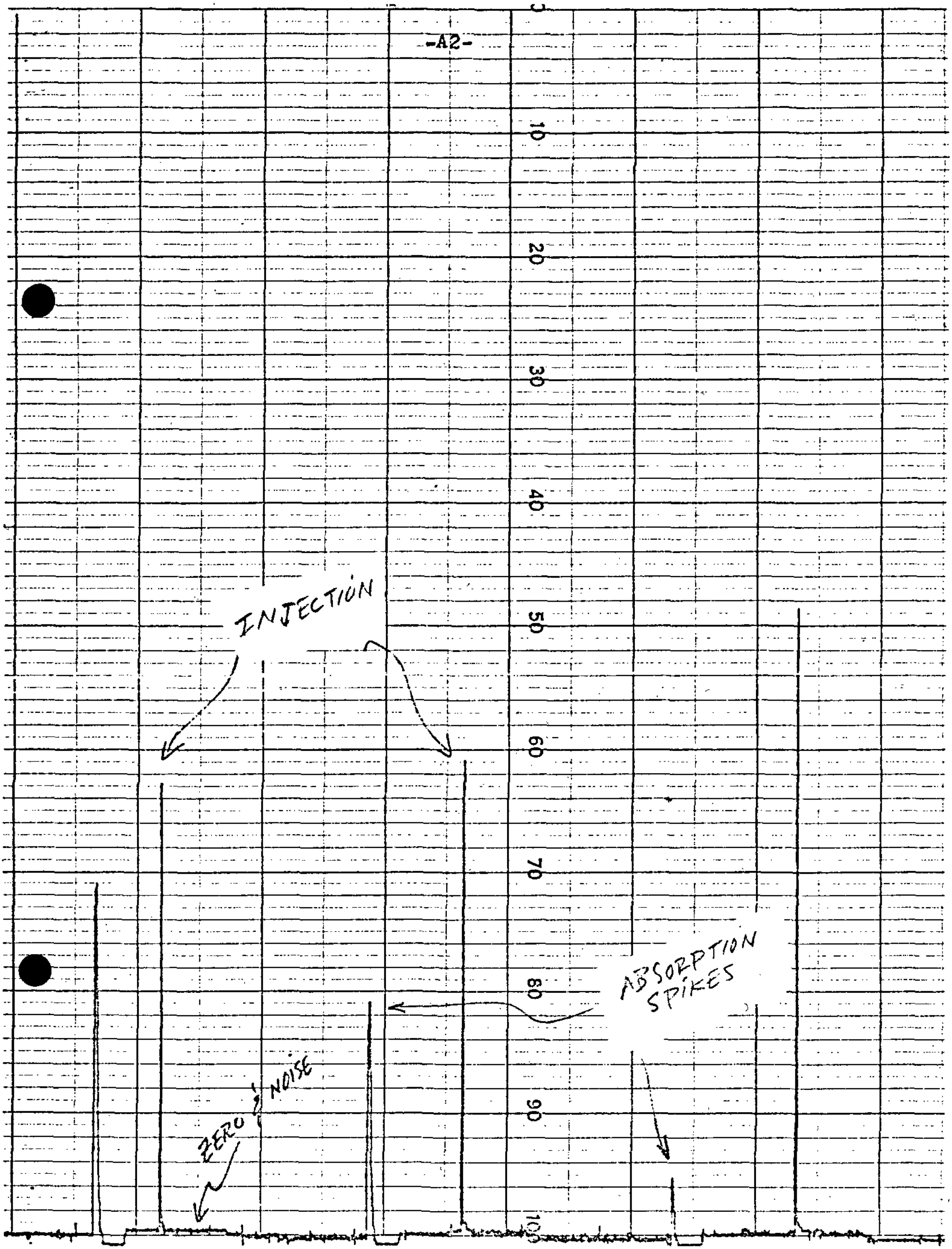


Figure II: Copper Analysis by Atomic Absorption Spectrophotometry; Chart Recorder Readout

Indian Lake

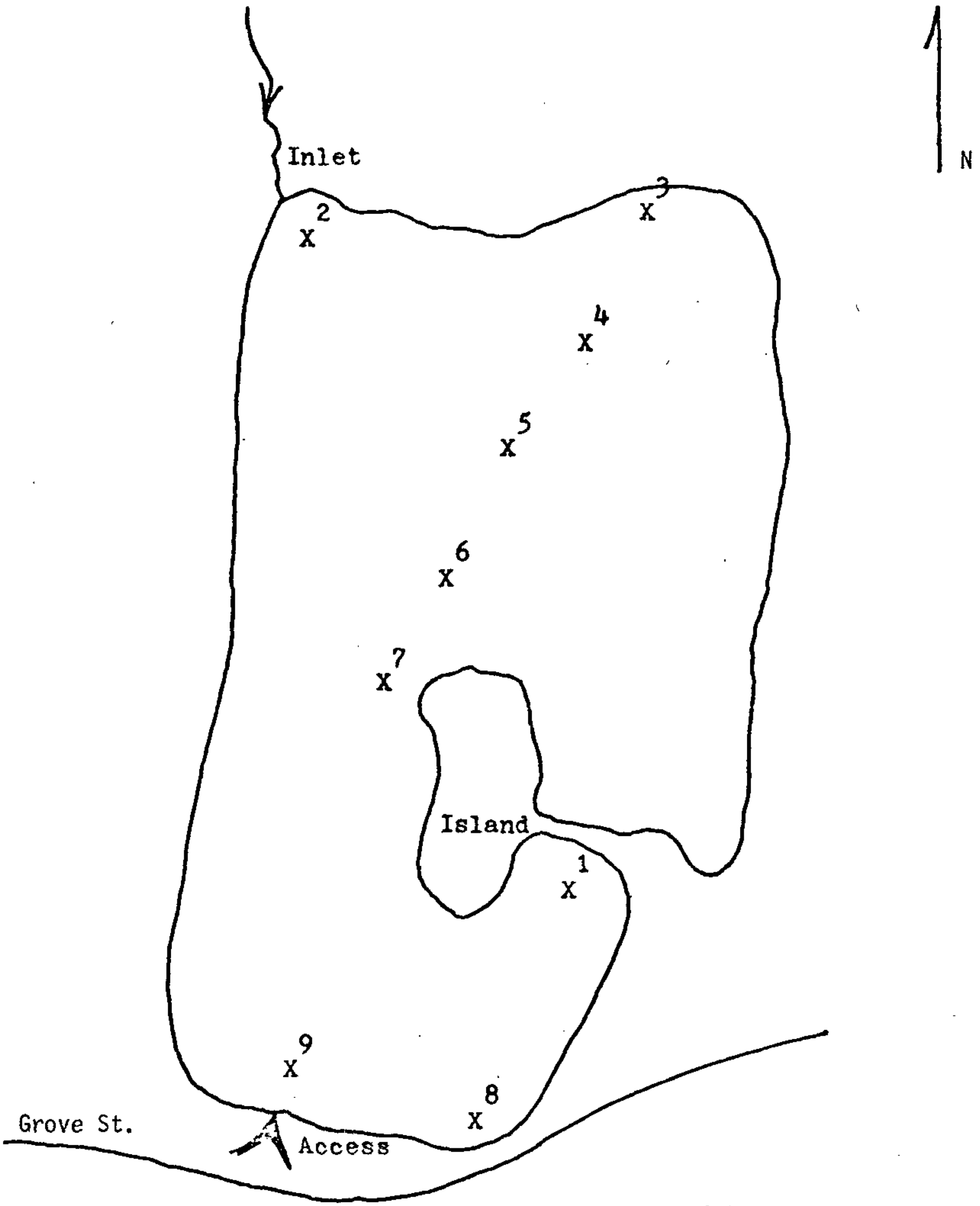
Location: Worcester, Mass.
Area: 190 acres
Mean Depth: 8'
Known Copper Source: 1963-1972 - 5600 lbs. copper sulfate per year

Sample #	Depth	Cu*	Location of Sampling Point**
W-1	Surface	112	50' from island
S-1	1'	480	
W-2	Surface	55	150' from bridge
S-2	4'	1700	
W-3	Surface	132	30' from shore in cove
S-3	6'	400	
W-4	Surface	210	100' from beach
S-4	7'	350	
W-5	Surface	116	Midway from cove to lighthouse
S-5	12'	3000	
W-6	Surface	148	300' from lighthouse
S-6	13'	2280	
W-7	Surface	65	30' from lighthouse
S-7	8'	1280	
W-8	Surface	82	20' fromhighway
S-8	5'	120	
W-9	Surface	65	30' from access ramp
S-9	6'	1840	

	Water	Sediment
Mean:	109.4	1272
Standard Deviation	46.9	947

*Water Conc. in µg/l; Sediment Conc. in mg/kg dry weight

**See accompanying map.



INDIAN LAKE
WORCESTER
190 ACRES

Shaw Pond

Location: Becket, Mass.
Area: 100 acres
Mean Depth: 13'
Known Copper Source: *1972 - Multiple treatments with copper sulfate; unspecified amounts*

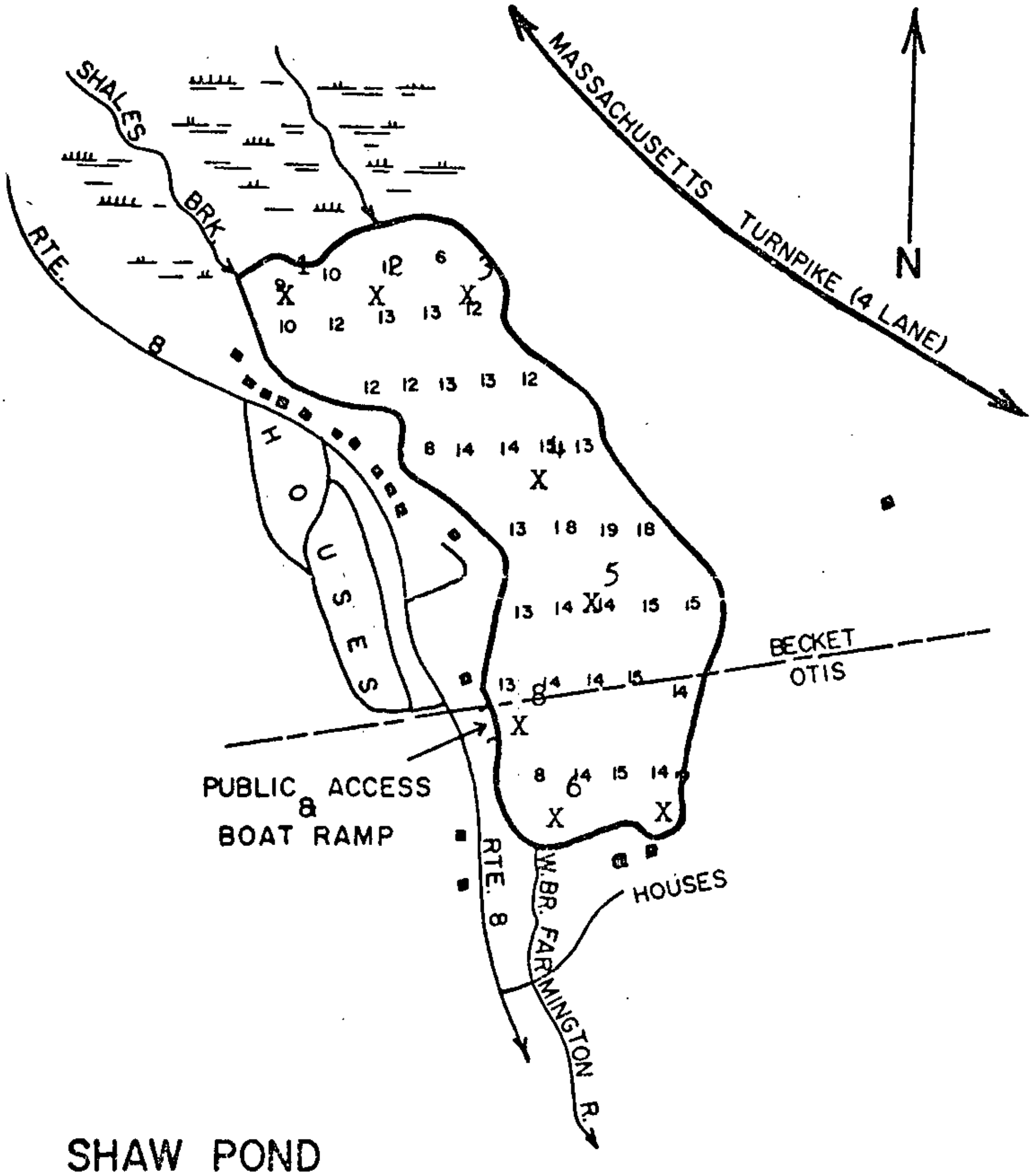
Sample #	Depth	Cu*	Location of Sampling Point**
W-1	Surface	40	10' from shore
S-1	3'	235	
W-2	Surface	210	Middle of pond
S-2	9'	1700	
W-3	Surface	72	50' from shore
S-3	9'	650	
W-4	Surface	13	Midlake
S-4	14'	800	
W-5	Surface	176	100' from north shore
S-5	15'	120	
W-6	Surface	124	30' from north shore
S-6	13'	650	
W-7	Surface	145	100' from outlet
S-7	4'	120	
W-8	Surface	94	50' from access
S-8	8'	1080	

	Water	Sediment
Mean:	109.3	669
Standard Deviation	63.6	505

---

[*] Water conc. in μg/l; Sediment conc. in mg/kg dry weight

[**] See accompanying map



SHAW POND

BECKET

100 ACRES

1/16 MILES

Stockbridge Bowl

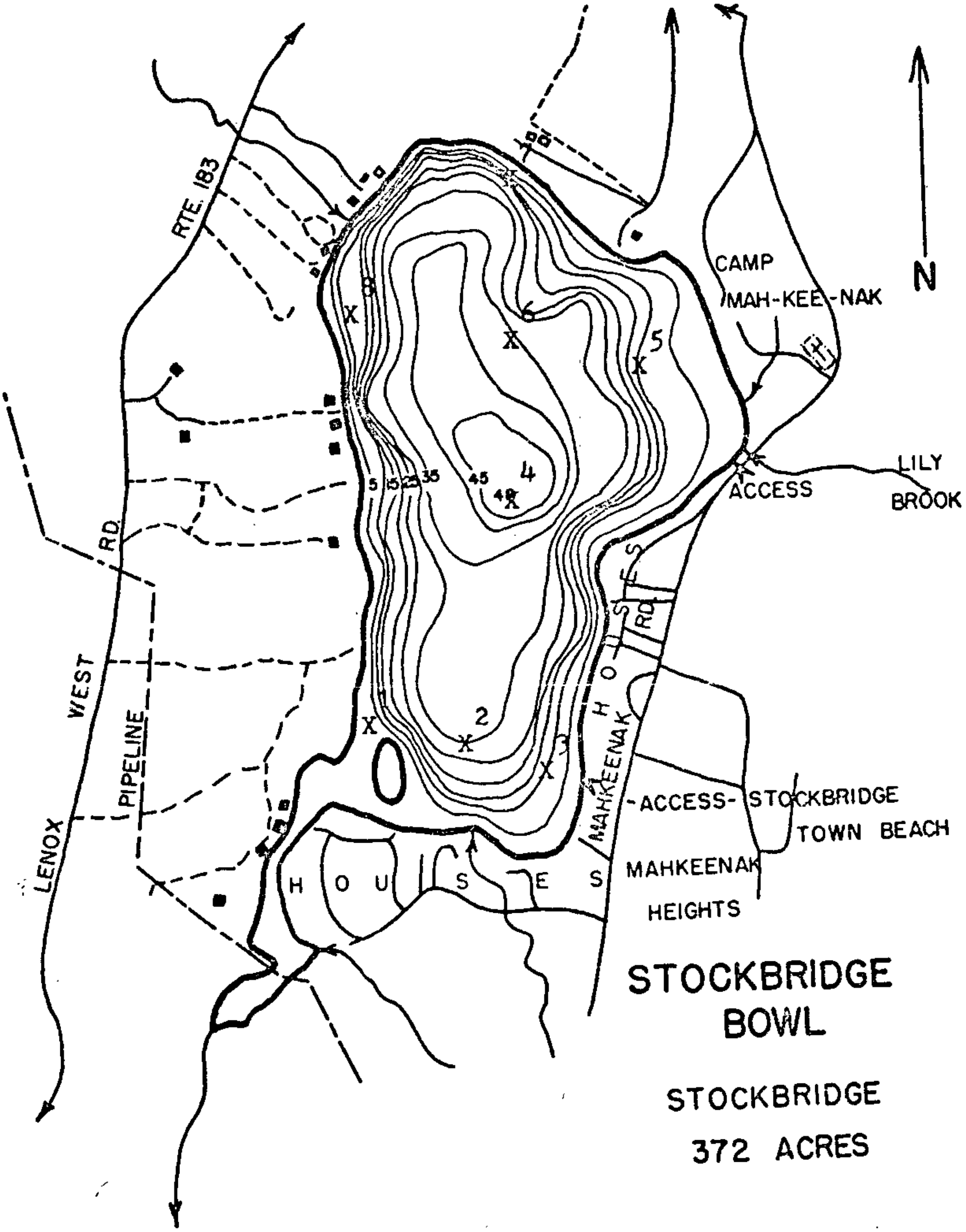
Location: Stockbridge, Mass.
Area: 372 acres
Mean depth: 27'
Known Copper Source: 1966 - 2500 lbs. copper sulfate
1969 - 2500 lbs. copper sulfate
1970 - 2500 lbs. Malachite (55.8% copper)

Sample #	Depth	Cu*	Location of Sampling Point**
W-1	Surface	94	20' from west shore
S-1	4'	100	
W-1	Surface	293	75' east of island
S-2'	25'	280	
S-2	28'	65	
W-3	Surface	50	40' from east shore
S-3	16'	235	
W-4	Surface	44	Midlake
W-4'	30'	210	
S-4	37'	710	
W-5	Surface	195	150' west of east shore
S-5	12'	340	
W-6	Surface	76	Midlake
W-6'	30'	300	
S-6	37'	100	
W-7	Surface	82	25' from shore
S-7	20'	330	
W-8	Surface	55	10' from access
S-8	3'	500	

	Water	Sediment
Mean:	152.6	298
Standard Deviation:	99.5	209

*Water conc. in µg/l; Sediment conc. in mg/kg dry weight

**See accompanying map



STOCKBRIDGE BOWL

STOCKBRIDGE

372 ACRES

Cheshire Reservoir
(Northern Section Only)

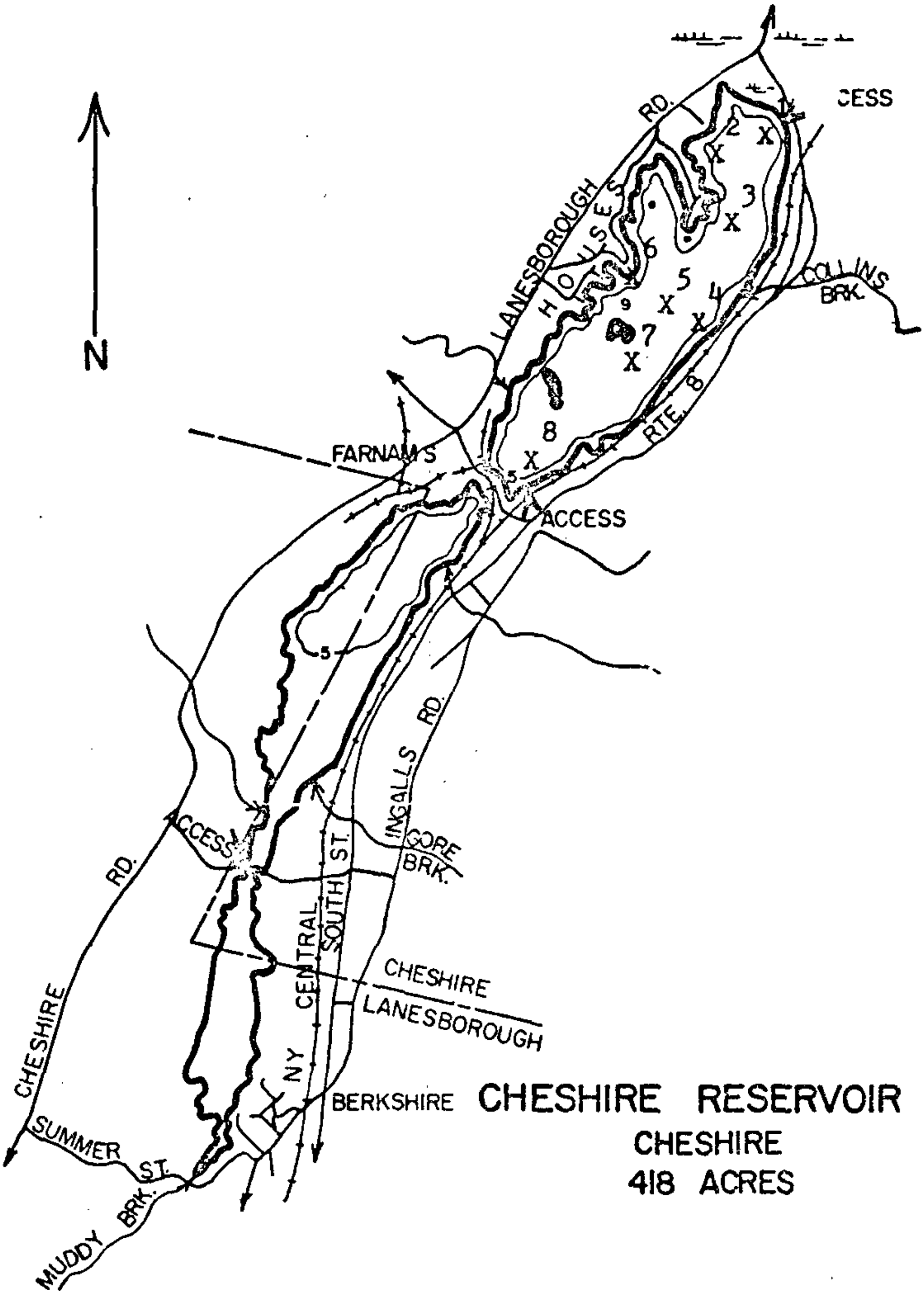
Location: Cheshire, Mass.
Area: 418
Mean Depth: 7'
Known Copper Source: 1972 - 2300 lbs. copper sulfate

Sample #	Depth	Cu*	Location of Sampling Point**
W-1	Surface	53	20' from railroad bridge
S-1	3'	--	
W-2	Surface	80	100' from twin willow trees
S-2	7'	68	
W-3	Surface	10	200' from boat house
S-3	10'	48	
W-4	Surface	72	20' from abandoned building
S-4	7'	68	
W-5	Surface	44	500' from abandoned building
S-5	10'	122	
W-6	Surface	80	100' from west shore
S-6	9'	46	
W-7	Surface	61	200' from large island
S-7	9'	138	
W-8	Surface	26	10' from access
S-8	2'	12	

	Water	Sediment
Mean:	57.0	76.3
Standard Deviation:	29.4	38.4

*Water conc. in μg/l; Sediment conc. in mg/kg dry weight

**See accompanying map



CHESHIRE RESERVOIR
CHESHIRE
418 ACRES

Pontoosuc Lake

Lo Lanesborough, Mass.
Area: 480 acres
Mean depth: 15'
Known Copper Source: 1972 - 2300 lbs copper sulfate

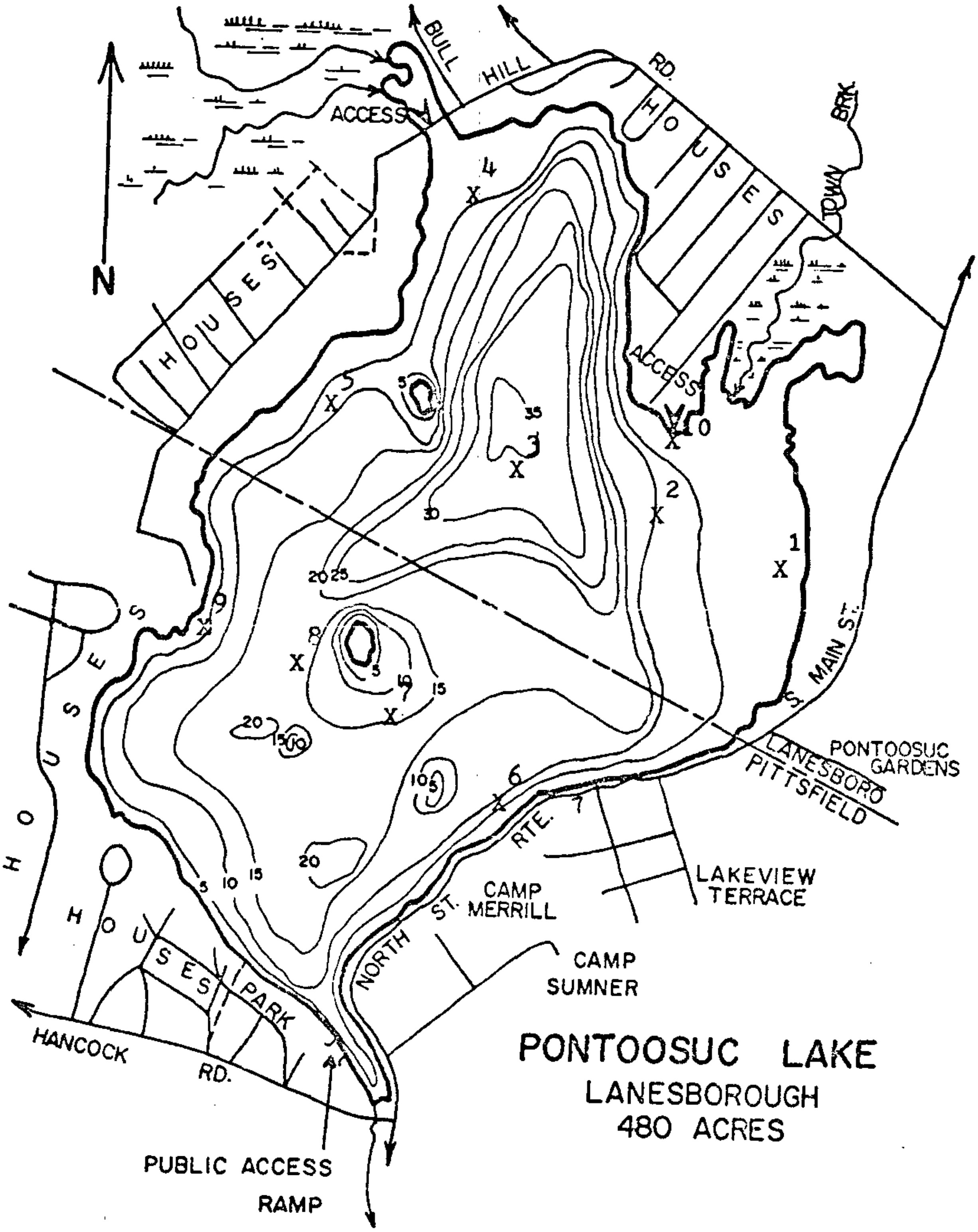
Sample #	Depth	Cu*	Location of Sampling Point**
W-1	Surface	28	150' from prominent white house
S-1	6'	11	
W-2	Surrace	76	200' from pont
S-2	8'	25	
W-3	Surface	107	500' from large island
W-3'	20'	112	
S-3	32'	68	
W-4	Surface	107	200' from highway culvert
S-4	6'	48	
W-5	Surface	61	150' from large island
S-5	12'	108	
W-6	Surface	163	20' from white house on east shore
S-6	8'	34	
W-7	Surface	65	15' from shoal marker
S-7	8'	60	
W-8	Surface	150	100' from small island
S-8	14'	122	
W-9	Surface	28	200' from barn on shore
W-9'	15'	148	
S-9	16'	85	
W-10	Surface	107	10' from access
S-12	2'	26	

	Water	Sediment
Mean:	95.9	58.7
Standard Deviation:	43.2	35.2

---

*Water conc. in µg/l; Sediment conc. in mg/kg dry weight

**See accompanying map



PONTOOSUC LAKE
LANESBOROUGH
480 ACRES

Cranberry Pond

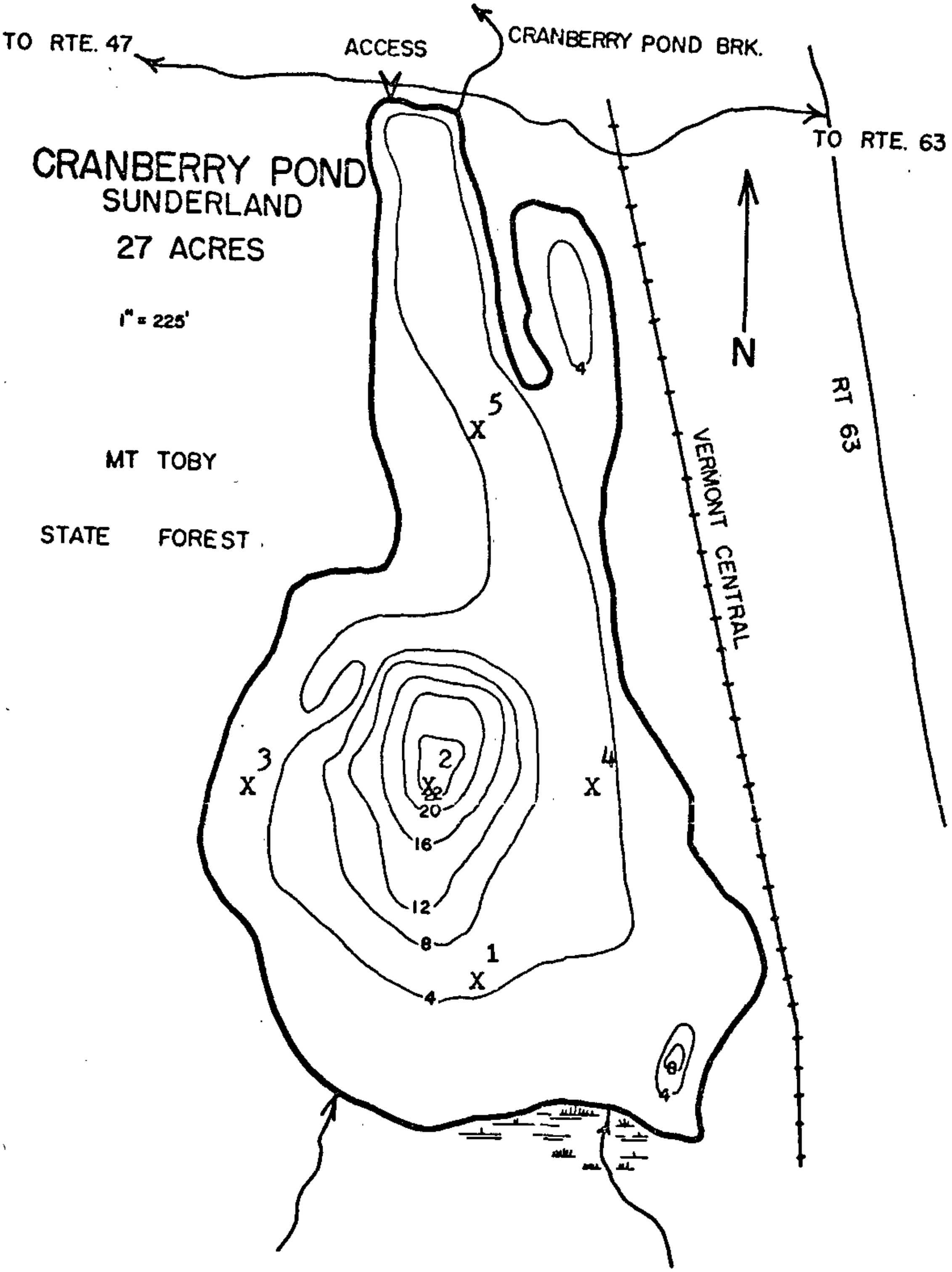
Lcoation: Sunderland, Mass.
Area: 24 acres
Mean Depth: 9'
Known Copper Source: 50 lbs. copper sulfate used to destroy Pumpkinseed fish eggs in 1972.

Sample #	Depth	Cu*	Location of Sampling Point**
W-1	Surface	392	10' from tree stump in water
S-1	4'	38	
W-2	Surface	112	Middle of pond
S-2	18'	11	
W-3	Surface	456	50' from west shore
S-3	5'	25	
W-4	Surface	346	30' from east shore
S-4	6'	13	
W-5	Surface	104	50' from shore
S-5	6'	38	

	Water	Sediment
Mean:	282	25.0
Standard Deviation:	146	11.6

---

*Water conc. in µg/l; Sediment conc. in mg/kg dry weight
**See accompanying map


TO RTE. 47
ACCESS
CRANBERRY POND BRK.
TO RTE. 63
CRANBERRY POND
SUNDERLAND
27 ACRES
1" = 225'
MT TOBY
STATE FOREST
N
RT 63
VERMONT CENTRAL
X 5
X 3
X 2
X 4
X 1
2
20
16
12
8
4
4
8
4

Lake Metacomet

Location: Belchertown, Mass.
Area: 74 acres
Mean Depth: 10'
Known Copper Source: 1970 - 50 lbs. copper sulfate

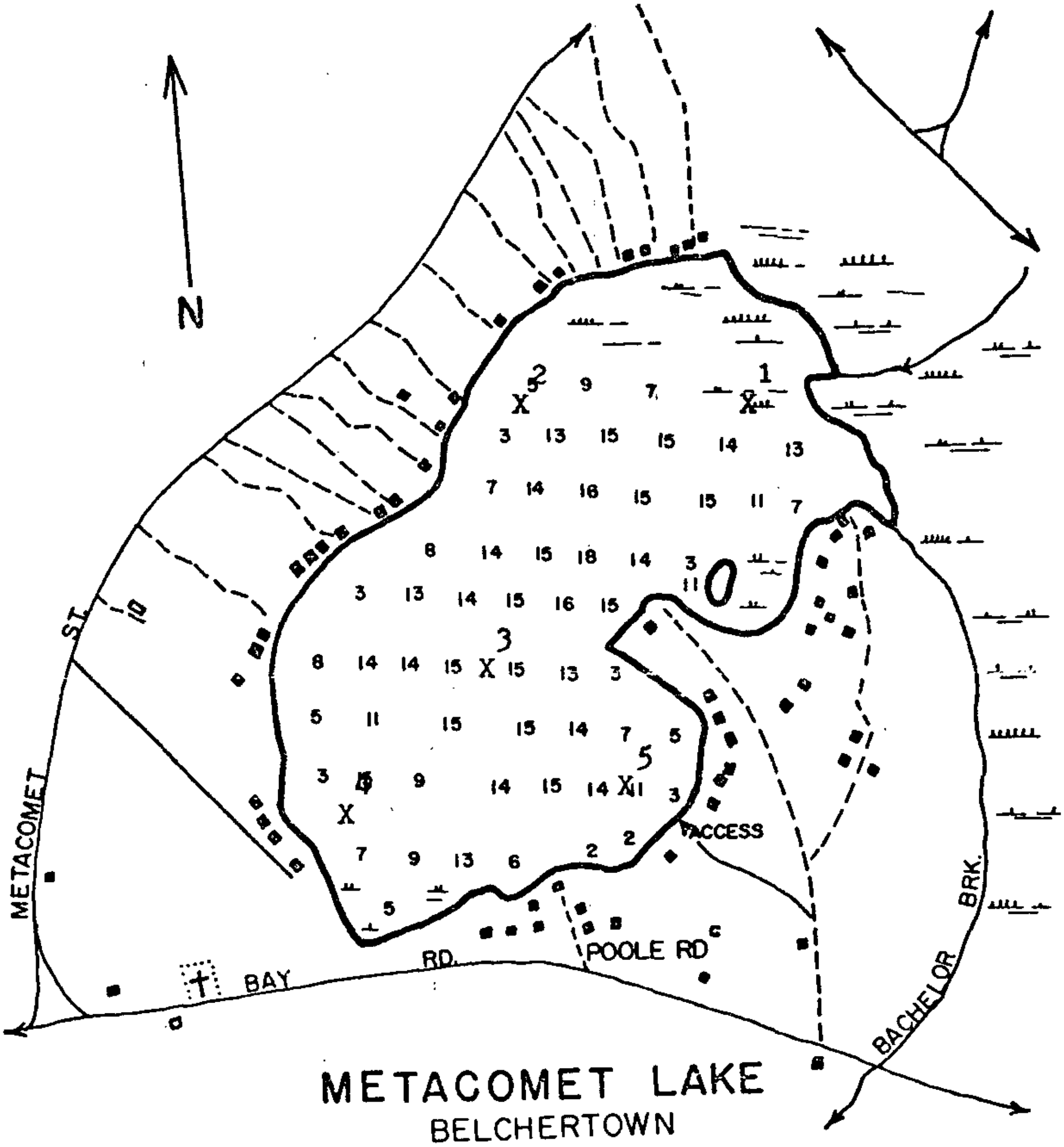
Sample #	Depth	Cu*	Location of Sampling Point**
W-1	Surface	50	100' from inlet
S-1	10'	52	
W-2	Surface	110	100' from large willow tree
S-2	5'	18	
W-3	Surface	55	150' from island
S-3	14'	20	
W-4	Surface	35	150' from promontory
S-4	13'	20	
W-5	Surface	68	50' from access
S-5	3'	28	

	Water	Sediment
Mean:	63.6	27.6
Standard Deviation:	25.5	12.7

---

*Water Conc. in µg/l; Sediment Conc. in mg/kg dry weight

**See accompanying map



METACOMET LAKE

BELCHERTOWN

74 ACRES

1/32 MILES

Silver Lake

Location: Pittsfield, Mass.
Area: 24 acres
Mean depth: 25'
Known Copper Source: Heavy use as an outfall for industrial process wastes

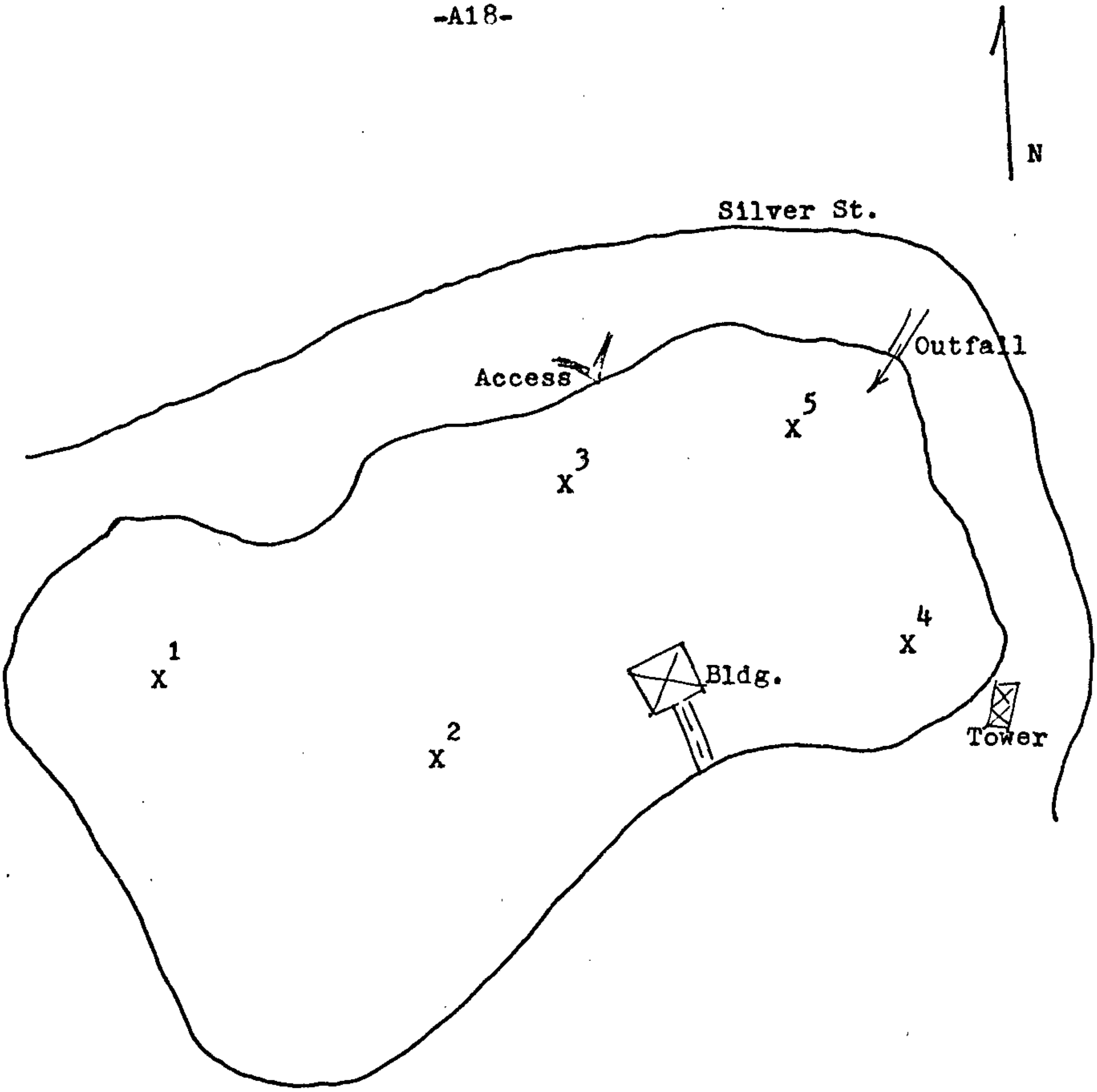
Sample #	Depth	Cu*	Location of Sampling Point**
W-1	5'	107	150' from smoke stack
S-1	20'	3000	
W-2	7'	195	Center of lake
S-2	17'	8000	
W-3	7'	100	75' from north shore
S-3	23'	9000	
W-4	7'	640	100' from high-tension tower
S-4	25'	5700	
W-5	7'	280	100' from visible outfall
S-5	15'	2040	

	Water	Sediment
Mean:	264	5548
Standard Deviation:	199	2711

---

[*] Water conc. in µg/l; Sediment conc. in mg/kg dry weight

[**] See accompanying map.



SILVER LAKE
PITTSFIELD
24 ACRES

Pelham Lake

Location: Rowe, Mass.
Area: 71 acres
Mean depth: 5'
Known Copper Source: None

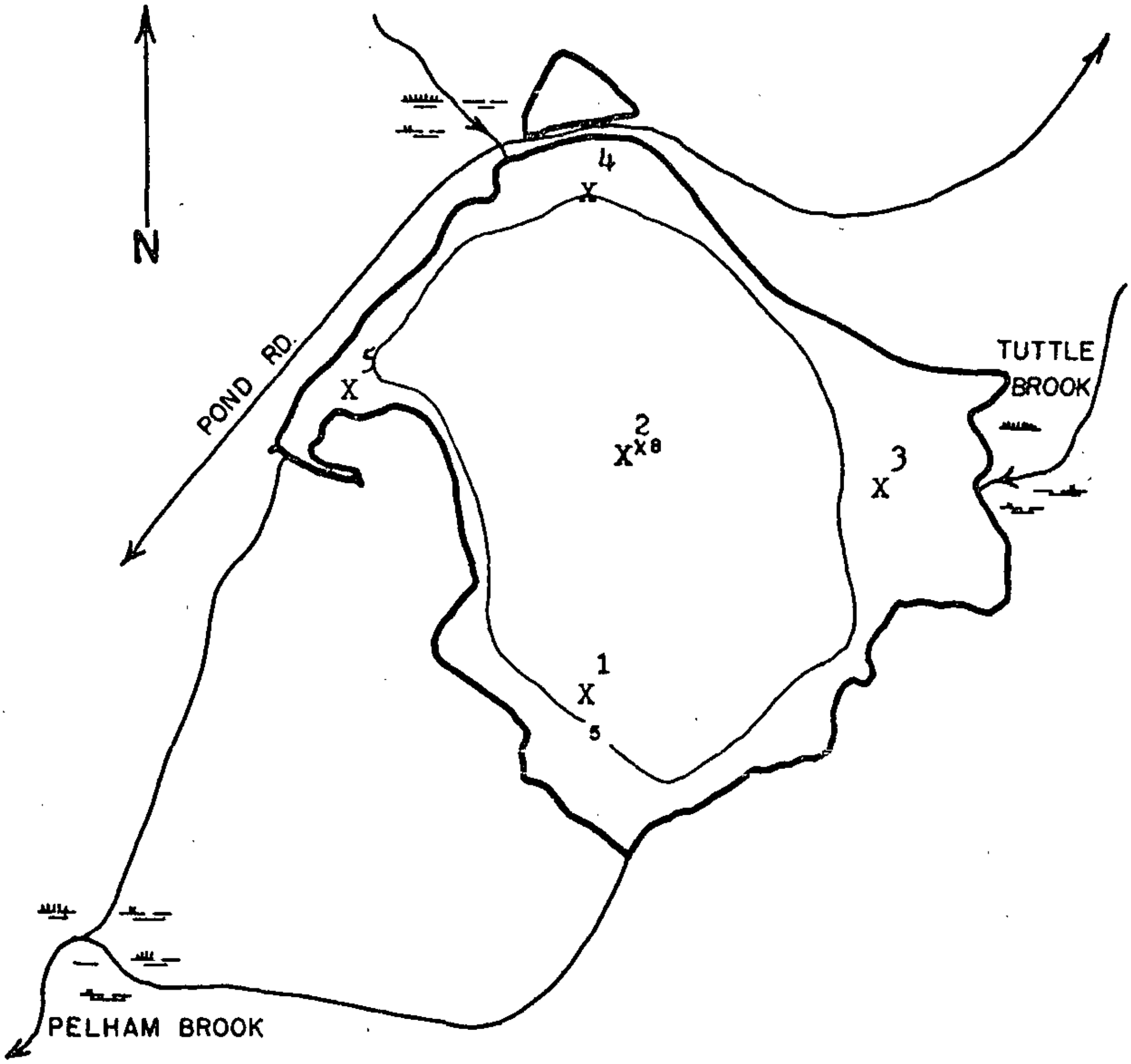
Sample #	Depth	Cu*	Location of Sampling Point**
W-1	Surface	90	50' from southeast shore
S-1	4'	136	
W-2	Surface	22	Center of lake
S-2	18'	20	
W-3	Surface	15	50' from southern point
S-3	5'	120	
W-4	Surface	55	50' from inlet
S-4	6'	20	
W-5	Surface	44	125' from dam
S-5	6'	40	

	Water	Sediment
Mean:	45.2	67.2
Standard Deviation:	26.6	50.4

---

*Water conc. in μg/l; Sediment conc. in mg/kg dry weight

**See accompanying map



PELHAM LAKE

ROWE

71 ACRES

1/24 MILES

Prindle Lake

Location: Charlton, Mass
Area: 71 acres
Mean Depth: 8'
Known Copper Source: None

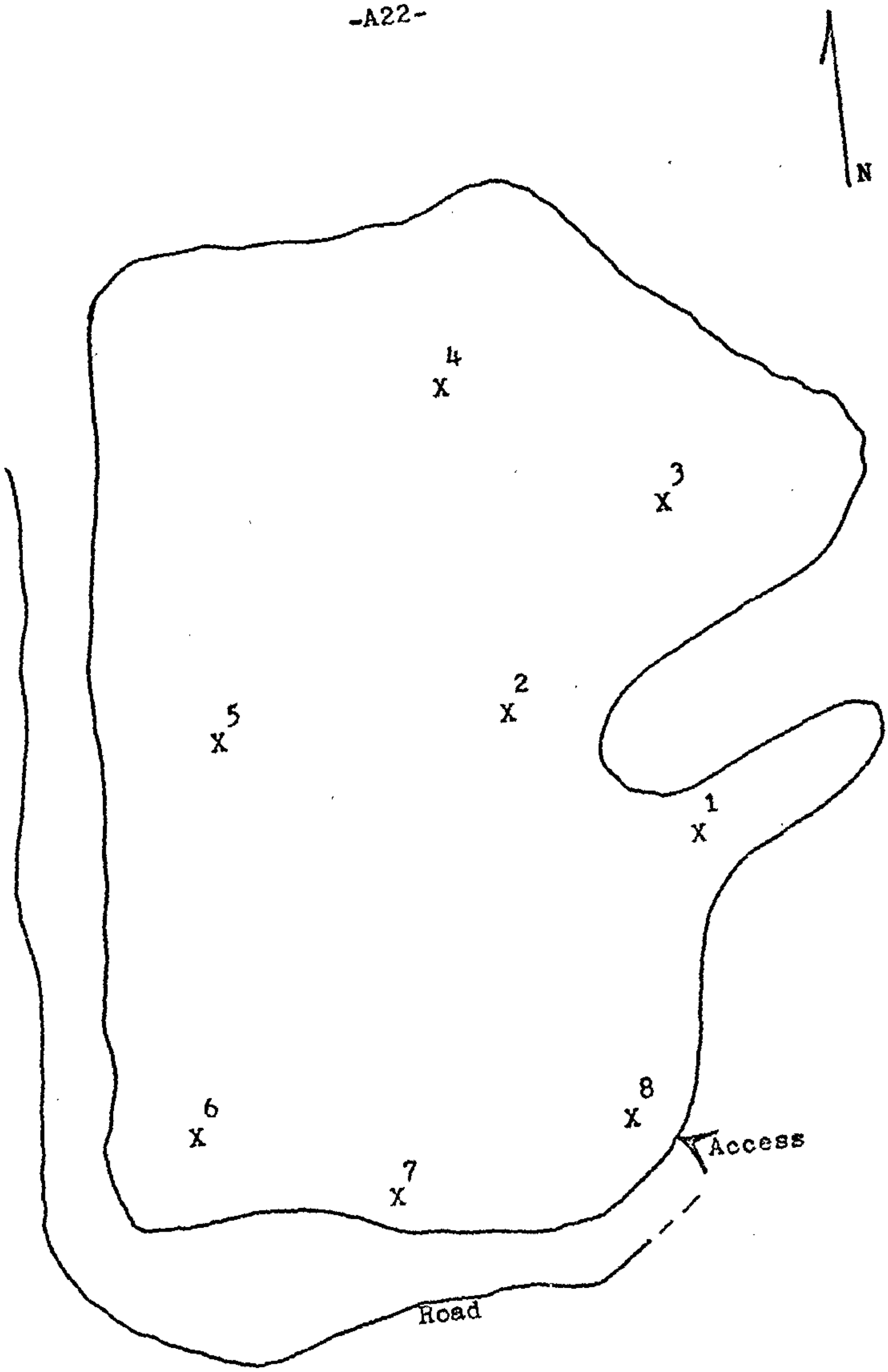
Sample #	Depth	Cu*	Location of Sampling Point**
W-1	Surface	176	Center of small cove
S-1	6'	66	
W-2	Surface	53	50' west of promontory
S-2	5'	44	
W-3	Surface	44	Center of large cove
S-3	5'	30	
W-4	Surface	150	Mouth of large cove
S-4	6'	115	
W-5	Surface	150	150' from shore opposite promontory
S-5	5'	20	
W-6	Surface	80	40' from shore
S-6	4'	51	
W-7	Surface	148	25' from shore
S-7	5'	50	
W-8	Surface	112	3' from access
S-8	1'	160	

	Water	Sediment
Mean:	114.1	67.0
Standard Deviation:	46.6	44.2

---

*Water conc. in μg/l; Sediment conc. in mg/kg dry weight

**See accompanying map



PRINDLE LAKE
CHARLTON
71 ACRES

Center Pond

Location: Becket, Mass.
Area: 125 acres
Mean Depth: 8'
Known Copper Source: None

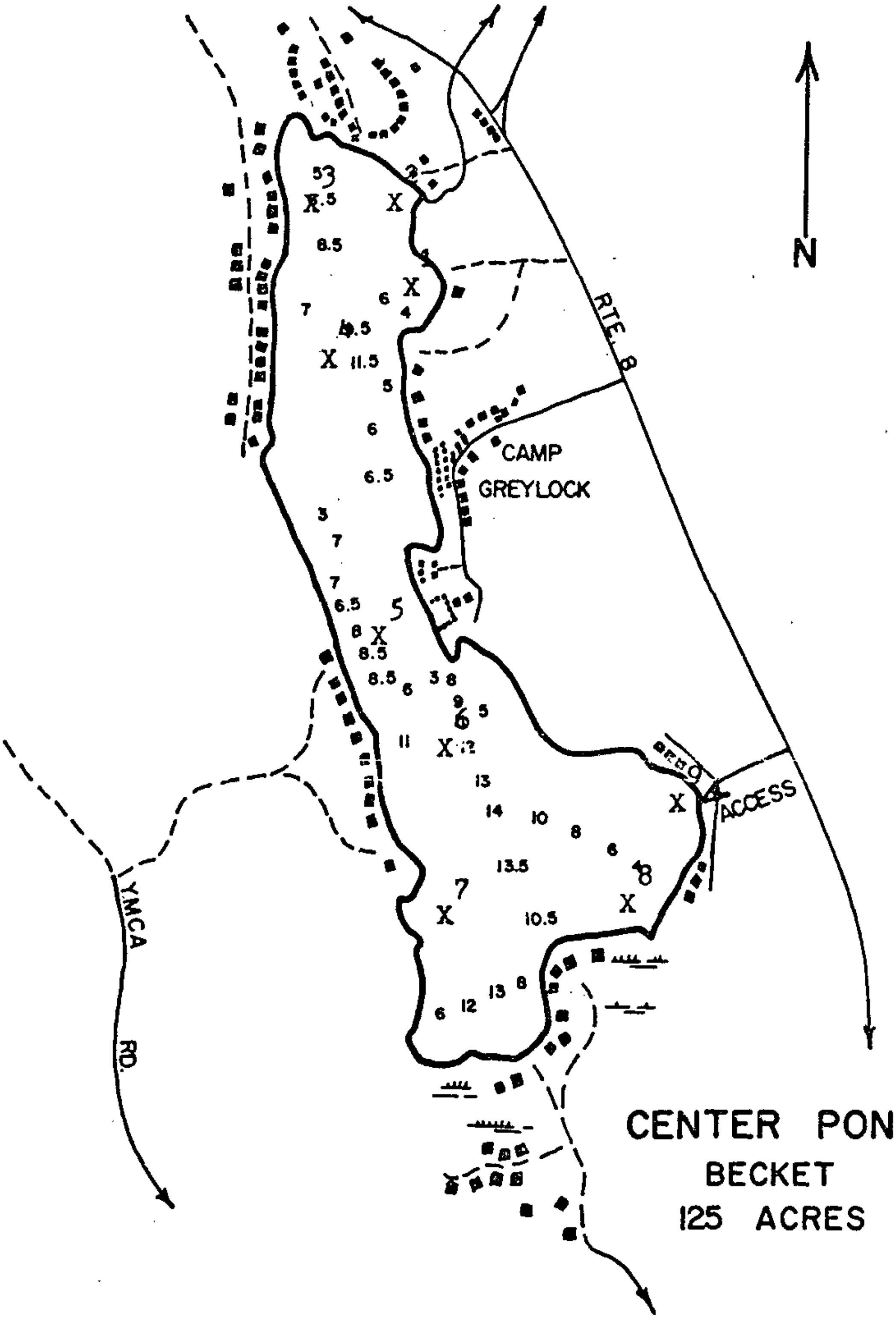
Sample #	Depth	Cu*	Location of Sampling Point**
W-1	Surface	180	Middle of cove
S-1	5'	7	
W-2	Surface	22	25' from outlet
S-2	5'	6	
W-3	Surface	90	Midlake
S-3	14'	34	
W-4	Surface	28	Midlake
S-4	11'	24	
W-5	Surface	210	Midlake
S-5	13'	90	
W-6	Surface	37	Midlake
S-7	13'	16	
W-7	Surface	40	30' from shore
S-7	10'	54	
W-8	Surface	65	25' from shore
S-8	4'	5	
W-9	Surface	110	50' from shore
S-9	8'	20	

	Water	Sediment
Mean:	86.9	28.4
Standard Deviation:	64.3	26.3

---

[*] Water conc. in μg/l; Sediment conc. in mg/kg dry weight

[**] See accompanying map



CENTER POND

BECKET

125 ACRES

Borrow Pit Pond (91F)

Location: Whately, Mass.
Area: 10 acres
Mean depth: 7'
Known Copper Source: None

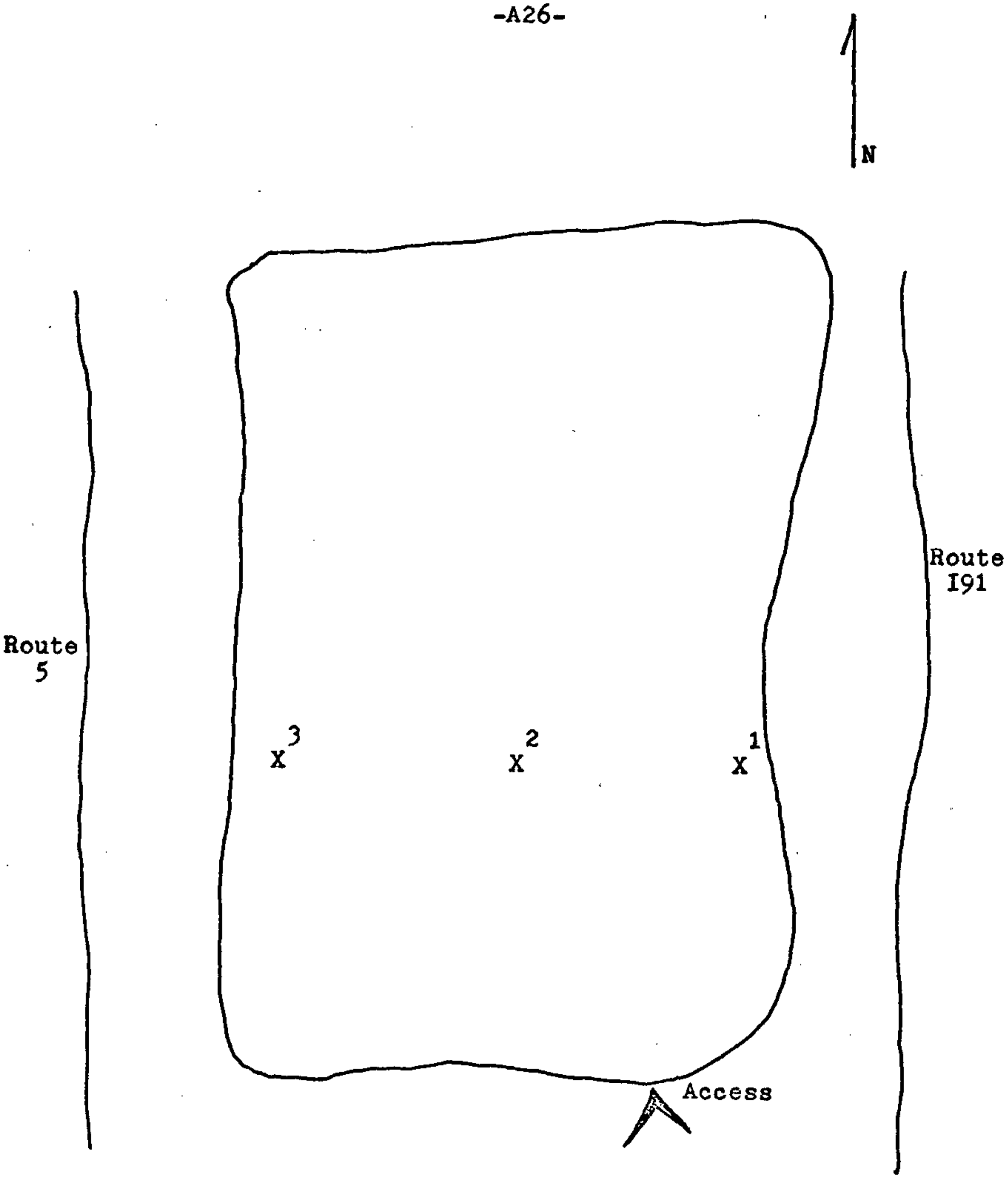
Sample #	Depth	Cu*	Location of Sampling Point**
W-1	Surface	115	50' from east shore
S-1	7'	--	
W-2	Surface	128	150' from east shore
S-2	7'	4	
W-3	Surface	128	300' from east shore
S-3	7'	20	

	Water	Sediment
Mean:	123.7	12.0
Standard Deviation:	6.1	8.0

---

* Water conc. in μg/l; Sediment conc. in mg/kg dry weight

** See accompanying map



BORROW PIT POND (91-F)
WHATELY
10 ACRES

North Pond

Location: Florida, Mass.
Area: 18 acres
Mean Depth: 13'
Known Copper Source: None

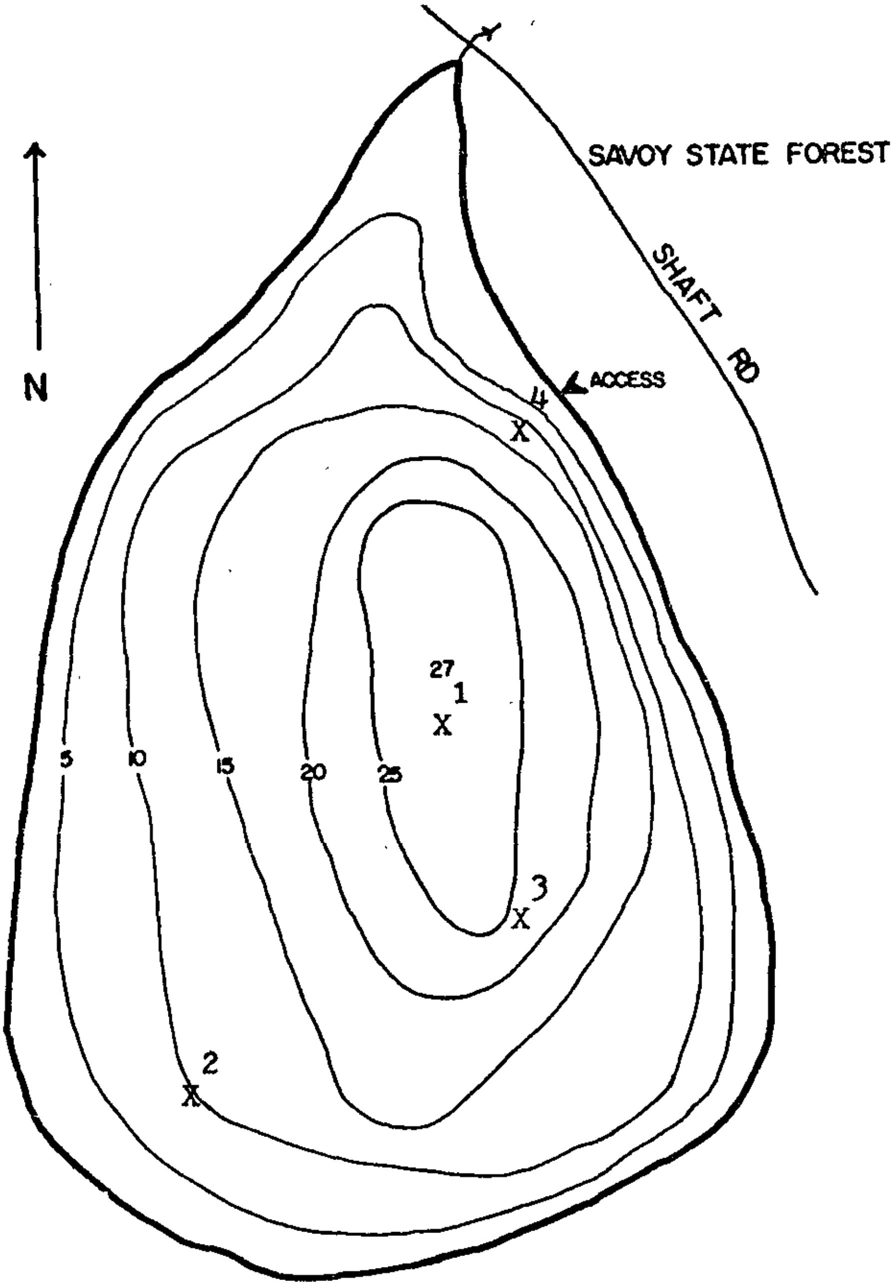
Sample #	Depth	Cu*	Location of Sampling Point**
W-1	Surface	90	100' from point south of beach
W-1'	22'	78	
S-1	27'	15	
W-2	Surface	110	75' from west shore
S-2	10'	16	
W-3	Surface	61	150' form large rock on east shore
W-3'	17'	53	
S-3	21'	16	
W-4	Surface	55	50' from access
S-4	8'	35	

	Water	Sediment
Mean:	75.4	20.5
Standard Deviation:	20.6	8.4

---

[*] Water conc. in μg/l; Sediment conc. in mg/kg dry weight

[**] See accompanying map



NORTH POND
FLORIDA
18 ACRES

Big Benton Pond

Location: Otis, Mass.
Area: 331 acres
Mean depth: 16'
Known Copper Source: None

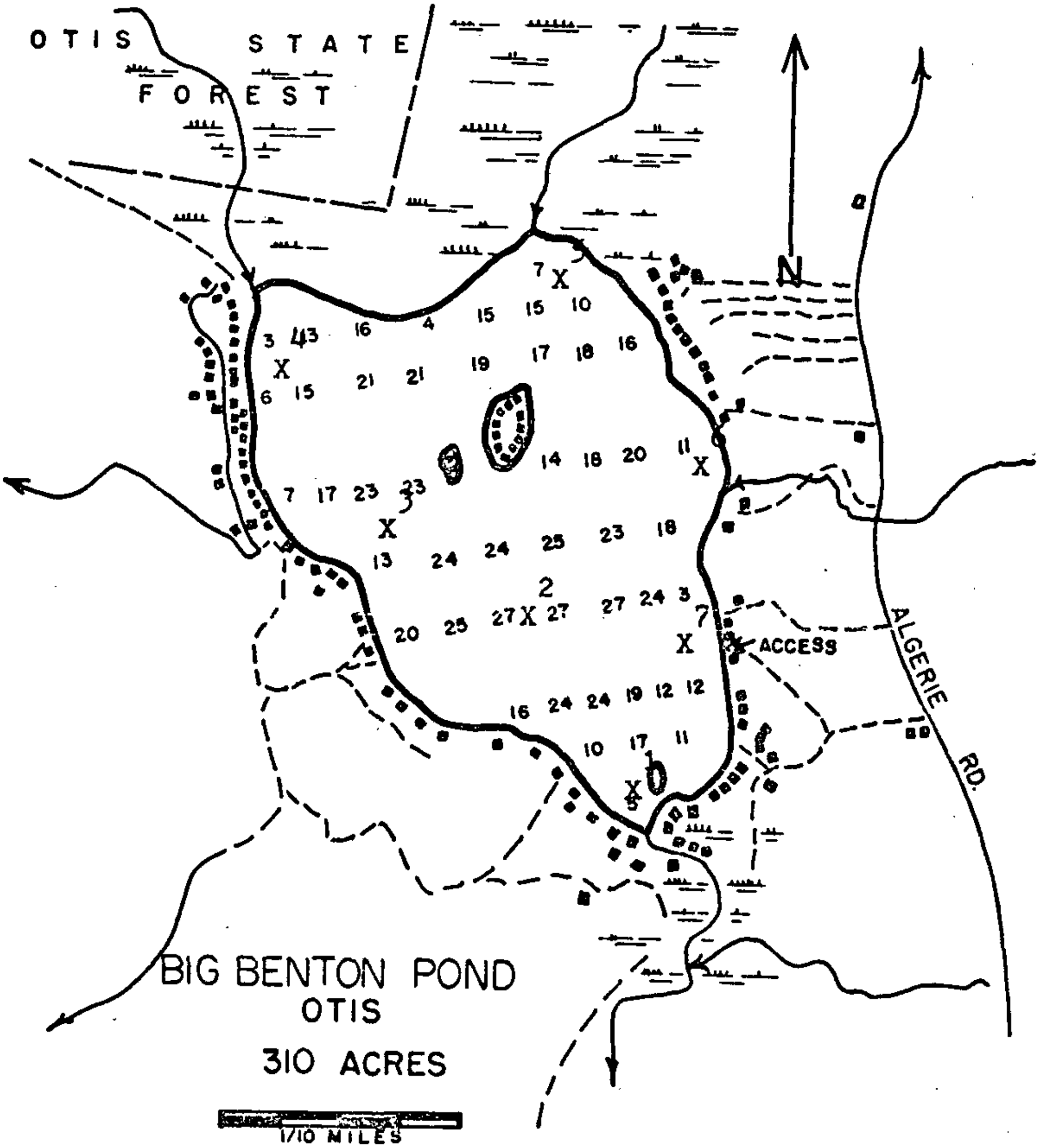
Sample #	Depth	Cu*	Location of Sampling Point**
W-1	Surface	167	25' from island near west shore
S-1	5'	4	
W-2	Surface	263	Midway between large and small islands
S-2		29	
W-3	Surface	72	75' west of large island
W-3'	18'	40	
S-3	21'	40	
W-4	Surface	293	10' from boat docks
S-4	3'	30	
W-5	Surface	167	25' from north shore, middle of bay
S-5	3'	21	
W-6	Surface	40	50' from shore
S-6	2'	14	
W-7	Surface	195	20' from access
S-7	2'	6	

	Water	Sediment
Mean:	154.6	20.6
Standard Deviation:	90.8	12.4

---

*Water conc. in μg/l; Sediment conc. in mg/kg dry weight

**See accompanying map



BIG BENTON POND
OTIS
310 ACRES

West Lake

Location: Sandisfield, Mass.
Area: 60 acres
Mean depth: 8'
Known Copper Source: None

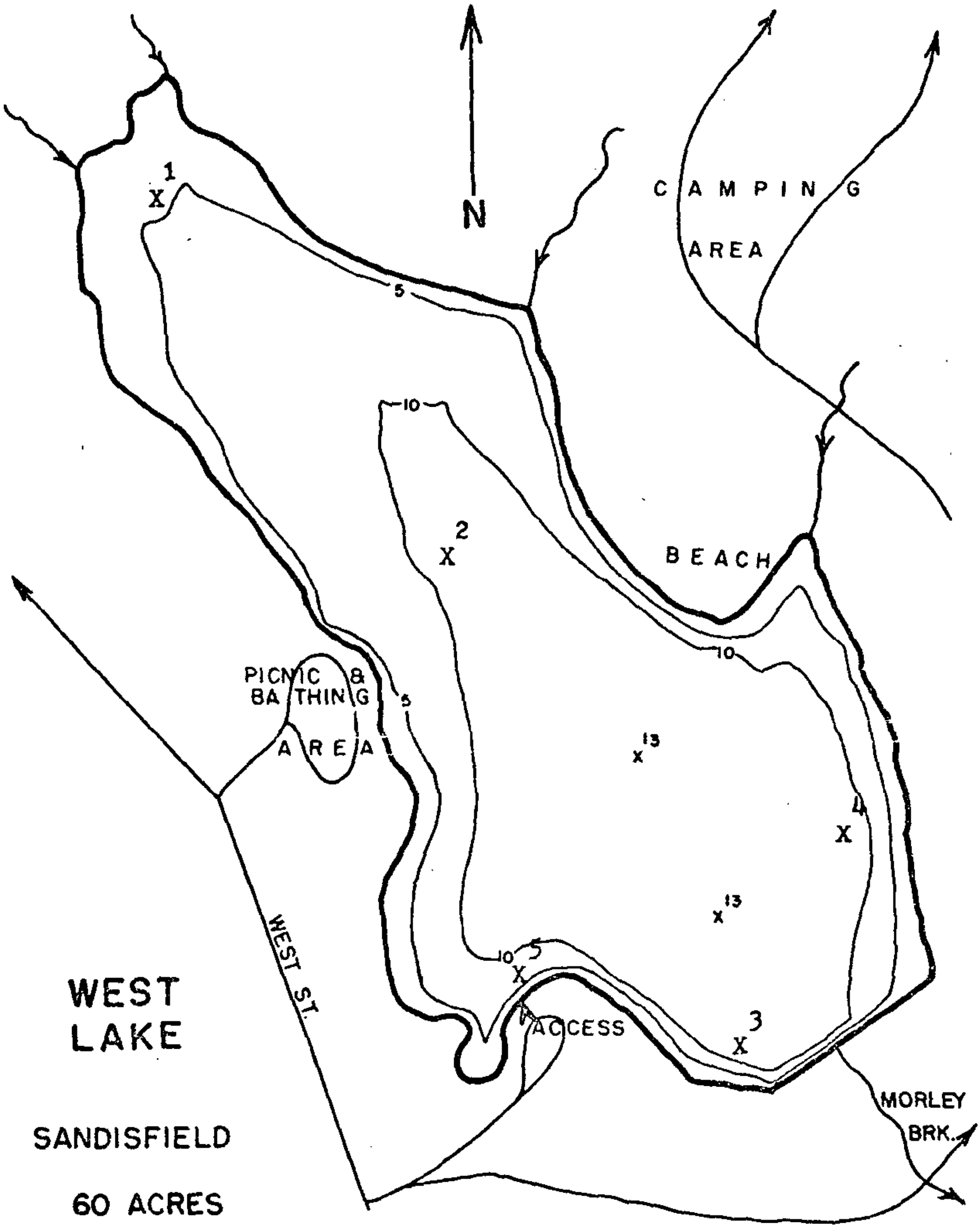
Sample #	Depth	Cu*	Location of Sampling Point**
W-1	Surface	107	100' from inlet
S-7	7'	14	
W-2	Surface	128	300' from fallen tree
S-2	15'	10	
W-3	Surface	195	40' from dam
S-3	14'	9	
W-4	Surface	98	30' from shore in large cove
S-4	9'	13	
W-5	Surface	210	20' from access
S-5	2'	5	

	Water	Sediment
Mean:	147.6	10.2
Standard Deviation:	46.1	3.2

---

*Water conc. in µg/l; Sediment conc. in mg/kg dry weight

**See accompanying map



WEST LAKE

SANDISFIELD

60 ACRES

Guilder Pond

Location: Mt. Washington, Mass.
Area: 15 acres
Mean Depth: 4'; K
Known Copper Source: None

Sample #	Depth	Cu*	Location of Sampling Point**
W-1	Surface	53	5' from access
S-1	4'	48	
W-2	Surface	195	Middle of cove
S-2	3'	35	
W-3	Surface	176	Middle of pond
S-3	4'	34	
W-4	Surface	176	25' from North shore
S-4	3'	51	
W-5	Surface	72	Middle of cove
S-5	3'	51	

	Water	Sediment
Mean:	134.4	43.8
Standard Deviation:	59.4	7.7

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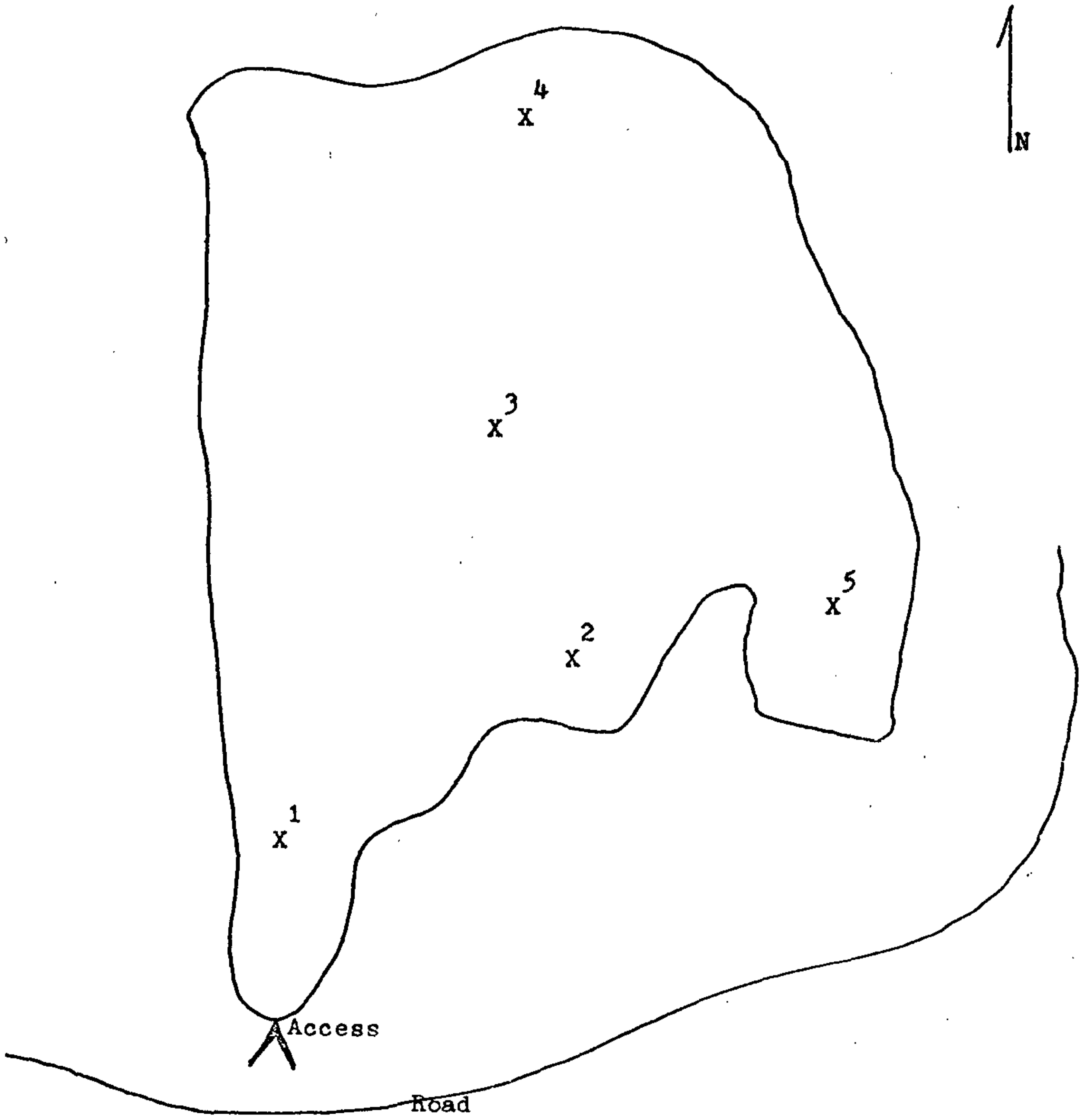
*Water conc. in μg/l; Sediment conc. in mg/kg dry weight

**See accompanying map



GUILDER POND
MT. WASHINGTON
15 ACRES

Upper Spectacle Pond

Location: Sandisfield, Mass.
Mean Depth: 11'
Area: 72 acres
Known Copper Source: None

Sample #	Depth	Cu*	Location of Sampling Point**
W-1	Surface	28	Midway between island and west shore
S-1	6'	14	
W-2	Surface	37	Middle of cove
S-2	3'	14	
W-3	Surface	65	Middle of pond
S-3	10'	24	
W-4	Surface	82	50' from large rock
W-4'	14'	176	
S-4	16'	34	
W-5	Surface	176	40' from outlet
S-5	13'	35	

	Water	Sediment
Mean:	94.0	24.2
Standard Deviation:	60.6	9.2

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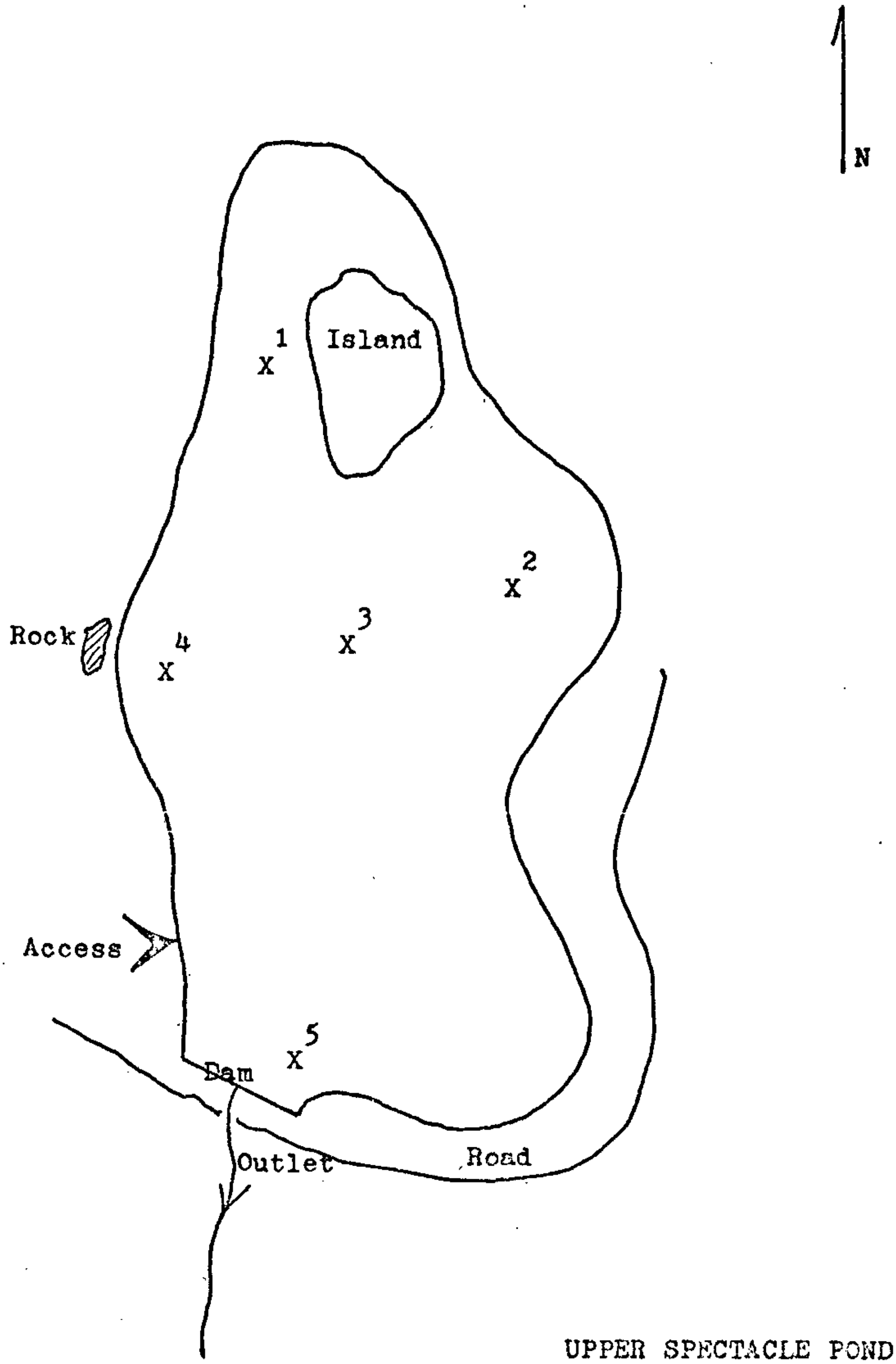
*Water conc. in µg/l; Sediment conc. in mg/kg dry weight

**See accompanying map



UPPER SPECTACLE POND
SANDISFIELD
72 ACRES

January, 1974

Report No. Env.E. 39-74-2

HEAVY METALS IN THE WATER AND SEDIMENT OF LAKES IN WESTERN MASSACHUSETTS

II. COPPER

by

Lawrence N. Kuzminski

James Grier

Progress Report for Division of Water Pollution Control
Massachusetts Water Resources Commission
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Environmental Engineering Program
Department of Civil Engineering
University of Massachusetts
Amherst, Massachusetts