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ABSTRACT

We are proposing long-term ecological research on a suite of lake ecosystems. A balanced program of hydrologic, chemical, physical, and biological measurements are aimed at 1) perceiving and documenting long-term trends in physical, chemical and biological properties of lake ecosystems, 2) understanding the interrelationships among the physical, chemical, and biological properties of lakes and their relationships to the climatic and hydrologic environment, and 3) determining the stability and resiliency of lake ecosystems in the face of natural and anthropogenic disturbances. Six lakes are chosen for major research (Trout, Crystal, Helmet, Mary, and Mann in the Northern Highlands, and Mendota in the Madison area). Birge and Juday collected baseline limnological measurements on all these lakes in the early 1900s. For the northern lakes, plankton data are available as early as 1900, chemical and physical data from 1925 to 1942. Later records are intermittent. For Lake Mendota, baseline data were gathered beginning about 1890. Currently, there is an active and diverse research program on both the Northern Highlands lakes and Madison lakes.

The lakes span a range of trophic and edaphic conditions from oligotrophic to eutrophic to dystrophic, hard water to soft water, atmospheric dominated to watershed dominated. They also span a range in physical dimensions (i.e. fetch, depth) that produces a variety of heat budgets and stratification conditions. One is meromictic or permanently stratified. Even though the biotic communities among the lakes are diverse, we expect to find some species of bacteria, algae, zooplankton, benthic invertebrates, and perhaps fish, that are found across the entire spectrum. The lakes vary in anthropogenic influences. The northern lakes are moderately well protected and are in close proximity to similar lakes with even better protection. We propose a system for the storage and retrieval of numeric and sample data that utilizes the facilities of the Madison Academic Computing Center and the Zoology Museum, both on the Madison campus.

Principal investigators include a hydrogeologist, a physical limnologist, a geochemist, a chemical limnologist, and two biological limnologists. Modern lakeside research laboratories for this research exist at the Trout Lake Biological Station and at the Laboratory of Limnology and Water Chemistry Laboratory on the Madison campus.

INTRODUCTION

We propose long-term ecological research of lakes in the Northern Highlands Lake District of northern Wisconsin and the Madison area of southern Wisconsin. These lakes span a broad range of climatic, edaphic, geologic and anthropogenic influences. All have the benefits of an early data base from the Birge and Juday era. Both groups of lakes have modern aquatic research laboratories and facilities under a coordinated management by the University of Wisconsin-Madison.

Our major goals are to establish a data collection, management and analysis system that will 1) detect long-term changes in the physical, chemical, and biotic features of lakes, 2) help us understand the linkages among climate, hydrology, water and sediment chemistry, and biology, and 3) detect lake features which enhance stability and resiliency to natural and anthropogenic disturbances.

Our approach is to organize and make available limnological measurements collected over the past century, design a rational sampling scheme compatible with historic data, yet robust and adequate for future measurements on lake ecosystems, and promote and further develop the use of these measurements in ongoing research into the structure and function of lake ecosystems.

Below we propose a program of long-term research, point out the value of the lake ecosystem site in the Northern Highlands and in the Madison area, and describe the management of our lake ecosystem sites.

RESEARCH AND DATA MANAGEMENT

Rationale and Objectives

Ecological processes, cycles, and trends occur on different time scales. The turnover rate of dissolved reactive phosphorus in lake systems is of the order of minutes. The annual growth cycle of a submersed aquatic macrophyte has a period of about one year. The life cycle of fish takes several years. The senescence of lakes or climatic cycles are evident only over longer periods. What appears to be a trend from a short-term observation, may actually be a cycle or oscillation with a period longer than the term of observation. The frequencies and durations of observation must be consistent with the time scale of the processes of interest. For example, annual phytoplankton grab samples for 100 years would be worthless in a study of the short-term population dynamics of phytoplankton species, but would be valuable in studying long-term cycles or trends such as eutrophication. Similarly, weekly phytoplankton samples for one year would give detailed information about short-term dynamics, but give no information on longer-term trends. Thus, research strategies must be geared to the dynamics and time scales of events that influence and determine the structure and function of ecosystems.

Many ecological processes occur over time scales that are long relative to the term of most research projects or even individual scientific careers. Independent researchers tend to adopt different techniques, choose different systems, and ask different questions, thus scattering the available information and making comparisons difficult. As a result, gradual but long-term ecological changes go undetected. An appropriate, consistent, and reliable set of physical, chemical, and biological data archived over many years will be necessary to detect, understand and predict long-term trends and oscillations.

Lake systems provide ideal subjects for long-term ecological research. As discrete systems, similar lakes are often physically scattered over a relatively small area with each having somewhat different physical, chemical, and biological properties and influence. Thus, a set of lakes may be used as a natural experiment designed to at least partially isolate important factors. A long tradition of limnological work has laid the groundwork by suggesting which ecological variables are important and how often these need to be measured to minimize interference from short-term cycles.

Our research will consider three interrelated aspects of long-term processes in lacustrine systems.

(1) The perception and description of long-term trends in physical, chemical, and biological properties of lake ecosystems.

(2) Detection of linkages or interrelationships among the physical, chemical, and biological properties of lakes and their relationships to the climatic and hydrologic environment.

(3) Determination of lake features which influence long-term ecosystem stability and resiliency in face of natural and anthropogenic disturbances.

The most basic questions in long-term ecological research involve the perception and description of long-term trends and cycles. The description of periodicities for various physical, chemical and biological phenomena is crucial for determining linkages and interrelationships within the system. Most short-term studies with a lifetime of three years or less can only detect diel, lunar, seasonal and year-to-year changes. A set of lake ecosystems with a history of study would be of special value in detecting long-term trends. If the trend were gradual, the earlier in history that reliable data were collected, the more likely the trend will be detectable. Our major lakes already have intermittent records dating back to the early 1900s.

During the first years of the proposed long-term research, the principal investigators will examine variability, oscillation and trends in the early Birge and Juday data on file in the Archives of the University of Wisconsin-Madison. Much of the data, especially the biological data, has never been interpreted or published. Records of plankton, as well as physical-chemical conditions will be evaluated and compared with the early results from our proposed ecological measurements. We will focus on chemical limnology (Armstrong), phytoplankton generic composition and density (Brock), and zooplankton generic composition and density (Magnuson).

The detection of linkages among various physical, chemical, and biological phenomena in the lake ecosystem will be possible with the spatially and temporally coordinated set of measurements to be collected in this project. Various statistical tools (time series, correlation, regression) will be used to describe cyclical behavior and determine relatedness of phenomena. A description of the period associated with certain ecological changes may allow association of cause and effect even if time lags are present.

The detection of interrelationships can often be facilitated by the study of different systems each of which manifests the coupling among states and processes in its own unique way. An example of this would be the nutrient loading models of Vollenweider (Dillon 1974) and others. These models relate phosphorus concentrations to phosphorus loading in lakes with different properties. A relationship between nutrient input and phytoplankton production seems reasonable, but verification of this relationship requires data for a number of lakes spanning a broad range of trophic states. Thus, the ideal design for linkage determination would involve a wide variety of lakes.

Numerous important ecological questions concerning coupling of various aspects of the ecosystem can be addressed with long-term studies on a variety of lakes. Important linkages include:

Physical-Chemical

- relationship among drainage basin edaphic factors and water chemistry (Johnson and Swank 1973, Uttormark et al. 1974)
- relationship between ground and surface water inflow rates and chemical composition and lake water chemistry (Callender and Bowser 1976)
- relationship between climatological variation on several scales (storm events, year-to-year, little ice ages, etc.) and lake water chemistry (Mackereth 1966, Bortelson 1968, Stauffer 1974)
- sediment-water interactions influencing nutrient availability (Mortimer 1941, 1942, 1971, Moore and Silver 1975, Nriagu 1978, Holdren and Armstrong 1980)

Chemical-Biological

- relationship of benthic organisms to sediment-water interactions (Gallepp et al. 1978, Gallepp 1979)
- role of rooted aquatic plants as an autochthonous nutrient source to lake water and a nutrient sink from the sediments (Prentki et al. 1979)
- effect of internal biotic cycling (fish, zooplankton) on lake water chemistry (Peters 1975, Kitchell et al. 1979)

Physical-Biological

- effect of long-term climatic change (reflected in changes in a lake's energy budget) on composition and productivity of a lake's biota (McPhail and Lindsey 1970, Magnuson et al. 1979)
- effect of basin morphology on the distribution and abundance of a lake's biota (Magnuson 1976, Tonn MS)

Biological-Biological

- synergistic vs. antagonistic interactions between macrophytes and phytoplankton (Prentki et al. 1979)
- role of predation in determining species composition of lower trophic levels (fish-fish, fish-zooplankton, zooplankton-zooplankton, zooplankton-algae, crayfish-macrophytes and periphyton) (Brooks and Dodson 1965, Wells 1970, Dodson 1974, Lorman and Magnuson 1978)
- role of competitive and symbiotic interactions in determining species structure of lakes (Johannes and Larkin 1961, Nilsson 1967, Werner and Hall 1976)

By allowing adequate description of long-term cycles and trends in relatively undisturbed systems, long-term ecological monitoring will permit description and evaluation of specific natural and anthropogenic perturbations.

A strategy of monitoring a suite of several lakes will give more insight into the nature of the perturbation. Does it effect all lakes equally or are some more stable because of particular features? For example, a new species may invade one of two lakes leaving the second as a control. Or, a well-buffered lake will be more resistant to changes resulting from acid precipitation than an adjacent porrly buffered lake. The resulting changes in such lakes may be compared not only with each other and with their previous history, but also with the other lakes of similar character in a rich and diverse lake district.

Anthropogenic influences which can be expected to affect many lake systems, even the most protected, include acid precipitation (Cogbill and Likens 1974, Braekke 1976), introduction of non-native species (Magnuson 1976), and changes in watershed characteristics (Likens et al. 1970, Wright 1976). Long-term ecological research will be conducted in a manner to address questions involving the

- relationship between acid precipitation and the pH and chemical charcteristics of lake water (Wright and Gjessing 1976)
- effect of acid-rain induced changes in pH and water chemistry on the composition, abundance, and productivity of the biota (Hendrey et al. 1976)
- effect of introduced species (crayfish, fish, or macrophytes) on the native biota and the lake ecosystem (Zaret and Paine 1973, Magnuson et al. 1975, Carpenter in press)
- effect of catastrophic changes in a watershed (fire, wind, or logging) on water chemistry (Likens et al. 1970, McColl and Grigall 1975, Wright 1976)

Research Lakes

A major dilemma arises in choosing lakes for long-term ecological research from a lake district with hundreds of lakes of such diversity that they provided the major basis for comparative limnology of the Birge and Juday era (Frey 1963). A certain lake might be most appropriate for testing a hypothesis about predator control of community stability, another for anthropogenic influences such as acid precipitation, still another for relations between groundwater recharge and lake chemistry. Some of the most protected lakes have little historic data, while some of the most significant limnologically, such as Crystal Lake and Lake Mendota, are not independent of human alterations. With the fears and reality of acid precipitation and other atmospheric pollutants, it is impossible to find a lake to serve as a perfect reference site completely independent of human disturbance, however subtle.

We believe that maximum benefits to research will be achieved by intensively examining a suite of lakes that 1) span the variation among lake ecosystems, 2) have existing historic data which will allow immediate comparisons with the new data, and 3) are of direct interest to active researchers. The criteria used for our choice of lakes are 1) representation of major calcareous provinces in Wisconsin; 2) a range of trophic conditions, i.e. eutrophic, mesotrophic, oligotrophic, and dystrophic; 3) a range of lake sizes, and thermal regimes; 4) expected differences in the relative contribution of atmospheric and drainage inputs; 5) a range of intensity of human disturbance (no absolutely pristine lakes exist); 6) the availability of a historic data base; 7) the activity of ongoing research; 8) the accessibility to our research stations; and 9) technical feasibility of measuring particular parameters.

Major Lakes

Our initial selections are five lakes in the Northern Highlands (Crystal, Trout, Helmet, Mary and Mann Lakes) and one in the Madison area (Lake Mendota). A few chemical and morphometric features of these lakes are listed in Table 1. The locations of the Northern Highlands Lakes are given in Figure 1. One lake, Mendota, was chosen to represent the calcareous edaphic character of southern Wisconsin. The other five lakes and the major study area of this proposal are in the non-calcareous area of Vilas County, Wisconsin near the Trout Lake Biological Station. All lakes are accessible by automobile or boat from our major laboratory facilities at Trout Lake and Lake Mendota. All have a history of geochemical and biological research originating in the Birge and Juday era (Frey 1963). Historic data exist not only on chemical features, but also on zooplankton and phytoplankton, macrophytes and other groups. All but Mann are stratified lakes with varying degrees of hypolimnetic oxygen depletion. One (Mary) is meromictic.

The biological diversity is impressive. All (except Mary?) have a common planktivore fish, the yellow perch (Perca flavescens), several have another planktivore as well--the cisco (Coregonus artedii). Biomass estimates of these two species can be made acoustically owing to the differences in their behavior and the low species richness of the pelagic fish fauna. Trout and Mendota have high diversity fish faunas; the others have low diversity fish faunas. One, Trout Lake, contains a healthy population of Mysis relicta. Zooplankton and phytoplankton communities differ greatly among the lakes. Macrophytes cover a broad spectrum from deep water bryophytes in the most oligotrophic lake (Crystal), spahagnum bog communities in the dystrophic lake (Helmet) and meromictic lake (Mary), and an array of shallow water tracheophytes in mesotrophic (Trout) and eutrophic (Mendota, Mann) lakes.

Chemical gradients are large. Our classification was guided by the schemes of Birge and Juday. They recognized the importance of drainage (Trout, Mann, and Mendota) versus seepage (Crystal, Mary, and Helmet), high color lakes with high organic acid bogs (Helmet and Mary) versus low color clear water lakes (Crystal), and differences in calcium concentration (a range almost three orders of magnitude among these lakes). This set covers a gradient of lakes dominated by atmospheric inputs (Crystal) to those dominated by drainage basin influences (Mann and Mendota). Crystal Lake is a groundwater recharge lake--water leaves the lake on all sides and recharges the groundwater system. Mann Lake appears to be a groundwater discharge lake and will probably be the lake in which groundwater-surface water interactions will receive the most intensive study. Another lake chosen farther from this groundwater divide but still in the Northern Highlands Lake District will be chosen to contrast even fuller the influence of groundwater versus atmospheric chemical inputs. As much as possible the Northern Highlands Lakes were chosen to simplify the groundwater regime and connectedness to other lakes, by choosing a connected hydrographic series of lakes.

New information on the thermal behavior of lakes and the use of these lakes as climate indicators (Ragotzkie 1978) is enhanced by the variations in lake size (fetch, volume) and mixing or stratification regimes. Thus, lakes that are permanently (Mary) or seasonally stratified (i.e. Trout, Crystal) or unstratified (Mann) were selected.

Each of the lakes is of direct interest to at least two active university researchers and the long-term research lakes will not simply become part of an archived data set. Rather, they will provide a complete data set on important

Table 1. Characteristics of Lakes for Long-Term Research Data from Various Sources.

LAKE NAME	TYPE	WATER SOURCE	AREA (ha)	MAXIMUM DEPTH (m)	CONDUCTIVITY μmhos/cm at 25°C	ALKALINITY mg/ℓ $CaCO_3$	pH	SECCHI DISC DEPTH (m)
<u>Major Lakes</u>								
Northern Highlands								
Trout Lake	Mesotrophic	Drainage	1,570	35.1	76	41	7.6	6.1
Crystal Lake	Oligotrophic	Seepage	6.4	21.0	10	4	6.1	8.9
Helmet Lake	Dystrophic	Seepage	2.8	11.0	19	5.5	6.6	1.2
Mary Lake	Dystrophic and Meromictic	Seepage	1.2	20.4	21	13	6.0	2.0
Mann Lake	Eutrophic	Drainage	101	12.5	100	58	8.5	2.4
Madison Area Lakes								
Lake Mendota	Futrophic	Drainage	3,940	25	300	165	8.7	3.0
<u>Secondary Reference Lakes</u>								
Northern Highlands								
Allequash Lake	Mesotrophic	Drainage	164	10	67	38	7.9	4.1
Blueberry Lake	Dystrophic	Seepage	4.9	4.7	15	0.8	5.5	3.4
Deerpath Lake	Dystrophic	Seepage	2.4	5.0	17	0	4.5	1.5
Firefly (Weber) Lake	Oligotrophic	Seepage	10.9	7.9	9	3	6.1	10.4
Day Lake	Oligotrophic	Seepage	47.3	14.6	12	3	5.9	8.7
Pallette Lake	Oligotrophic	Seepage	70.0	19.8	19	9	6.8	4.9

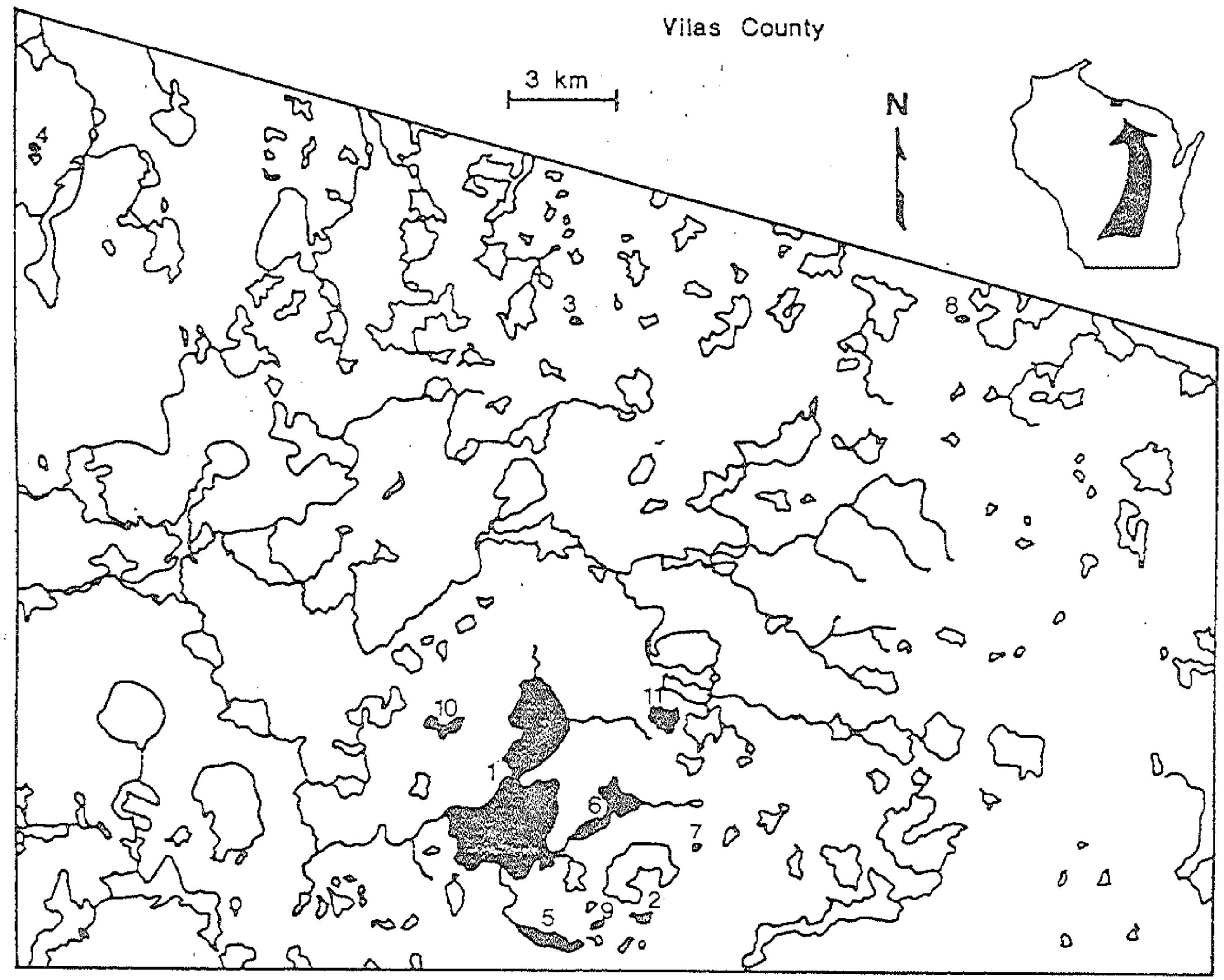


Figure 1. Map of a portion of Vilas County, Wisconsin, showing the major lakes with the lakes suggested for study highlighted and numbered. 1. Trout, 2. Crystal, 3. Helmet, 4. Mary, 5. Mann, 6. Allequash, 7. Blueberry, 8. Deerpath, 9. Firefly, 10. Day, 11. Pallette

scientific resources to active limnologists and ecologists. The lakes are representative of important classes of lakes. They are outstanding choices for long-term research at a national level.

Secondary-Reference Lakes

Those lakes with the best historical records, past research, and current interest to researchers have the disadvantage of being more accessible to humans and thus more affected by them. In the near future, it will be important to initiate at a lower level of intensity, ecological measurements on a group of reference lakes (Table 1) which are more isolated and less used by humans for recreation. This would be especially valuable in sorting out anthropogenic induced changes from more endogenous changes in the ecosystems. Useful contrasts could be made for bog lakes, the ultra oligotrophic lakes, and lakes of intermediate alkalinity in the Northern Highlands Lake District. Bog lakes such as Blueberry and Deerpath provide a range of possible human effects. Blueberry is in the Trout Lake drainage, Deerpath is an extremely isolated lake in the center of a large sphagnum bog mat which inhibits almost all human use. Its pH is 4.5, it contains only two species of fish. Firefly (Weber), Day, and Pallette Lakes are ultra oligotrophic and have a lower intensity of recreational uses than does Crystal Lake. Pallette is utilized the least and is part of the Wisconsin Department's Five Lakes Experimental Area. The groundwater regime of both Crystal and its neighbor, Firefly (Weber), were studied by Fries (1938). For intermediate fertility, Allequash, which drains into Trout Lake, is better protected from shoreline development than Mann Lake and is one of the State of Wisconsin's "Bench Mark Lakes."

Many other extremely interesting and valuable lakes along the gradients discussed above are present among the thousands of lakes in the Northern Highlands. Many would be useful for testing the validity of specific hypotheses or generalizations arising in our proposed long-term research. Several could be manipulated especially in regard to predator introduction by the fishery management division of Wisconsin's Department of Natural Resources. We presently have four studies initiated or developing that examine larger suites of lakes in regard to particular hypotheses. These hypotheses involve early signs of acid precipitation (61 lakes) (Lehner et al. 1979), the principles governing the distribution and dispersal of crayfish (Orconectes sp.) (70 lakes) (Capelli and Magnuson MS), the role of habitat severity as a community structuring mechanism (38 lakes) (Magnuson, NSF Proposal # DEB7912337), and the role of predators in structuring plankton communities as judged from sediment cores (8 lakes) (Kitchell, NSF Proposal # DEB7911781). Dr. Michael S. Adams is proposing to examine another group of lakes in regard to eutrophication and chlorophyll pigments in the sediment. The Wisconsin Department of Natural Resources has a rich program of lake surveys across the state for more comparisons among regions. The point is that intensive ecological research on the more restricted set of lakes proposed here will provide an invaluable asset to many regional studies of specific hypotheses conducted over shorter time periods.

Measurements

The parameters and criteria for selection of measurements for the site are consistent with the conference reports on long-term ecological measurements (NSF 1978, Loucks 1979). The core measurements will be made at the major lake sites according to the sampling program described below. A system of measurements will be developed and standardized first on Trout Lake and Lake Mendota and then tested and applied regularly to the other major lakes in the Northern Highlands.

The core chemical measurements and the sampling plan for aquatic and atmospheric samples are summarized in Table 2. The aquatic parameters selected and the sampling plan will provide a basis for following long-term trends in important major elements, nutrient elements, and associated parameters (alkalinity, pH, conductance, POC, DOC). Surface and groundwater measurements will provide data on inputs to the lake and changes over time. Atmospheric samples will provide data on inputs to the system, including acidity and associated factors related to acid precipitation.

Chemical measurements will be made according to standard procedures (see for example Strickland and Parsons 1968, Golterman 1969, APHA 1975, EPA 1979). Separation of dissolved and particulate fractions will be accomplished by membrane filtration. Metals (Ca, Mg, Na, K, Fe, Al, Mn) will be measured by atomic absorption spectrometry. Dissolved reactive P (PO_4) will be measured spectrophotometrically (Murphy and Riley 1962). Total P will be measured after digestion (Menzel and Corwin 1965). Inorganic N (NH_4, NO_3) will be measured by conversion to NH_4, distillation and titration or spectrophotometrically using automated procedures. Total N will be measured by Kjeldahl digestion (Bremner 1965). Analysis of POC and DOC will involve measurement of CO_2 released by digestion (Menzel and Vaccaro 1964). SO_4 will be analyzed as described by Mackereth (1955), and Cl and alkalinity will be measured by titration. Because of the low alkalinity in the Trout Lake district, alkalinity will also be measured by gas chromatographic analysis of total CO_2. This is of importance because of the need to accurately measure possible changes in alkalinity due to lake acidification. Particulate samples and atmospheric dry fall samples will be analyzed after digestion.

Details of analytical methods are not presented here. An important initial phase of the program will be the development of a manual of analytical methods. During this phase, alternative methods to some of those suggested above may be selected as the investigators review the analytical procedures and as methods are standardized with other sites. Where appropriate, automated procedures will be used.

The planned physical measurements are outlined in Table 3. Most of the meteorological data will be from Rhinelander Airport or gathered at Lakeland Airport near Trout Lake or taken from the Dane County Airport near Lake Mendota. The Dane County Airport is a first order weather station. Other measurements (e.g. water temperature, precipitation, groundwater level) would be made at the site.

Biological measurements and sampling plans will generally follow guidelines established by the NSF-sponsored conferences on long-term measurements (NSF 1978, Loucks 1979), and are outlined in Table 4. Sample handling and preservation will also follow NSF guidelines.

Specific measurements and sampling plans are expected to evolve, but changes will be based on considerations of 1) standardization among long-term ecological research sites, 2) quality control, and 3) information required to meet specific research goals.

Standardization of methods and quality control are of major importance to long-term research. Procedures must provide comparable results for data collected over a period of years and among different sites. Procedures will be standardized by analysis of "standard" samples composed of a matrix similar to the actual samples. NBS standards will be used when available. In addition,

Table 2. Chemical Measurements

Measurement	Sampling Plan
Aquatic Samples	
Major elements (Ca, Mg, Na, K, Fe, Mn, Si, Cl, SO_4) Nutrients (total P, dissolved reactive P, total N, NH_4, NO_3) Alkalinity, pH, specific conductance POC, DOC Total suspended material Dissolved oxygen	Lake inlet and outlet, if present - monthly samples, volume integrated for the inlet Lake waters - minimum of a vertical profile just after spring overturn and just before fall overturn; minim of one station per basin Groundwater - seasonally
Sediment Samples	
Total elemental analysis for major elements Organic and carbonate - carbon; total and organic P; total N; sedimentation rate	Lakes - several stations to give integrated measurement; every 5 years
Atmospheric Samples	
Wet Fall Acidity, alkalinity, pH conductance, SO_4, NO_3, NH_4, Cl, Na, K, Ca, Mg, total C, total P, total N	Monthly samples; Volchok sampler or equivalent; consistent with NADP network
Dry Fall Total P, total N, Ca, Mg, Na, K, Fe, Al, total C, SO_4, Cl, acid and base neutralizing capacity	Same

Table 3. Physical Measurements

Measurement	Sampling Plan
1. Temperature-air	National Weather Stations at Rhinelander, Wisconsin, continuous
2. Short-wave insolation	Same
3. Dewpoint	Same
4. Windspeed	Same
5. Wind direction	Same
6. Precipitation	Recording rain guage; continuous event time, duration, intensity at Trout Lake
7. Total radiation	% cloud cover from weather station
8. Groundwater level	Weekly; cased well
9. Temperature	
a. water	Lakes - profile at weekly intervals in the spring and fall; seasonally for other periods. Accuracy to 0.1°C. Inlet streams and outlet - seasonall
b. sediment	Frequency: twice each year, preferably just before freeze up and after breakup Location: deepest water in region of soft sediments if present, surface, one meter and one deeper point if soft sediments are deep Accuracy: 0.1°C
c. ice cover	Date 90 percent covered, date 90 percent open, thickness of ice, five points away from shore or shallow regions, monthly Accuracy: 0.5 cm
d. snow cover	Ten locations at random, not near shore or sheltered bays, monthly, same date as ice measurements Accuracy: 0.5 cm
10. Water Transparency	Secchi disk and spectrophotometric and absorbence at 320-350 nm (on filtered samples), two week intervals

Table 4. Biological Measurements

Measurement	Sampling Plan
Phytoplankton, chlorophyll a, zooplankton	replicated integrated epilimnion tube and Kemmerer sampler; Schindler Patalas trap from zooplankton spring and fall overturn, summer and winter stratification
Periphyton species composition, chlorophyll a	colonization of artificial substrates scrapings of natural substrates: spring, summer, fall, and winter at selected sites
Macrophyte species composition, cover, biomass	above- and below-surface photo-mapping, where appropriate, quadrat biomass harvest: every 2 years
Benthos, numerical density and species composition	multiple cores in profundal, diver-obtained cores and scrapings of natural substrate in littoral: colonization of artificial substrates: for crayfish quadrat counts for large clams; small-scale sampling twice a year, intensive every 3 years
Fish species composition, size frequency	acoustic estimate of pelagic fishes, gill net, fyke net, boom shocker, minnow traps, and diver survey, yearly, midsummer
Birds, mammals, amphibians	species identification: activity counts: yearly, midsummer
Humans	boat counts, swimmer counts, fisherman census: seasonally

standard and unknown samples will be interchanged with other Long-Term Ecological Research sites. A program of regular analysis of standard and unknown samples will be incorporated into the sampling and analysis program to maintain a record of procedure performance capable of detecting possible problems occurring in analytical methods. For biological samples of zooplankton and phytoplankton comparisons will be made between techniques of Birge and Juday and current research standards to insure comparability with early records.

Development of an adequate sampling program is of major importance. If the temporal or spatial frequency is inadequate, the data may not allow short-term or spatial variations to be distinguished from long-term trends. Conversely, excessive sampling and analysis will lead to inefficient use of program resources.

Because of the importance of sampling to a program of this nature, an initial phase of our research will be devoted to evaluation of sampling strategy for the various samples and parameters. For example, changes of pH are of major interest because of the possible acidification of lakes in the region. However, changes in pH due to acid precipitation will occur slowly, and may be detected only by collection of data over several years. These changes may be small compared to diurnal or seasonal changes. Consequently, an understanding of short-term changes is required to develop a sampling program for detecting long-term trends.

A proposed sampling plan is outlined in Tables 2, 3, and 4. But this plan will be modified as sampling strategy is evaluated as part of the program. Variations with time and station location will be investigated, especially for sensitive parameters such as pH, alkalinity, and nutrients, phytoplankton and zooplankton. Development of a documented sampling strategy should be one of the important early contributions of the investigation.

Data Management and Storage of Data and Samples

Data from this long-term research must be archived with greater long-term planning for its preservation and use than normally characterizes research projects of shorter duration. Data will consist of numbers, photographs, and frozen, dried, or chemically preserved biological (or water) samples. All numeric data will be stored in duplicate in the University of Wisconsin Archives and Trout Lake Station and on the tape storage system of the University of Wisconsin-Madison Computing Center. Frozen materials will initially be preserved in a commercial freezer rented in Madison; other biological samples will be stored at the University of Wisconsin-Madison. We are negotiating with the University of Wisconsin Zoological Museum to develop a flexible and practical system of lasting value and safety. Subsamples will be cataloged in the museum but most samples will be held as a data bank by the Museum which would function as a repository for the national program.

The Madison Academic Computing Center (MACC) will be used to acquire, process and store data. The facility is based on a Sperry Univac 1100/80 computer simultaneously available to as many as 70 remote terminals throughout the U.S. using the Telenet data network. Magnetic tape and mass storage file security prevents unauthorized access to files and saves files in case of system malfunctions. MACC maintains a library for the long-term storage of data files under controlled conditions. Software includes ASCII FORTRAN, BASIC, ALGOL, COBOL, PASCAL, APL, LISP, PL/1 etc. Software is available for statistical, analytical, graphic and mathematical processing. MACC provides manuals, updates and newsletters, and a complete consulting service. MACC is part of a consortium of 22 universities which share computing resources and is also used by state and

Federal facilities. The MACC Terminal Maintenance Facility offers preventive and emergency maintenance to remote terminals. Where necessary because of large output or for long-term storage, data can be placed on microfiche by command.

The Laboratory of Limnology on Lake Mendota has a microcomputer and hard copy unit which is connected to MACC whenever any of the above facilities are required. The Water Chemistry Laboratory on Lake Mendota also has a remote terminal to MACC.

Use of an on site microcomputer greatly simplifies the problem of transcribing and validating the data to a computer compatible form. Moreover, it has the advantage of allowing simple statistical tests and analysis to be performed on-site.

We propose to use a similar system for the station on Trout Lake. The microcomputer will provide for input, storage and verification of data before transmission to MACC. Data will be entered and computer checks made for values outside an expected range, thereby catching gross errors immediately. Data will be entered a second time by a different person and compared against the first set to minimize transcription errors. The data will be saved on magnetic tape or disk and a listing made. The data will be transmitted to the MACC computer along with row and column check sums to insure that no errors are made in transmission. A listing of the data will be made and stored on microfiche. Use of MACC insures that the data will be available indefinitely in a form that is accessible by computer. Also the data file can be modified and added to the data base of other agencies such as the EPA data network. The data sets can be immediately available to personnel at network sampling sites equipped with remote terminals.

Selection of data processing equipment is specified and justified in the Budget Justification.

CHARACTERISTICS OF THE RESEARCH SITE

General Description

Northern Highlands Lake District

The Northern Highlands Lake District includes all of Vilas and parts of Iron, Price, and Oneida Counties in Wisconsin, and Gogebic County, Michigan. This area encompasses 10,000 km^2 and contains thousands of lakes. Within a 10-km radius of the biological station on Trout Lake, there are 68 named lakes, 28 unnamed lakes, and 60 km of stream length. Vilas County has 17% of its area covered by open water and another 21% covered by marshes or muskeg. The Vilas County lakes (Black et al. 1963) range in pH from 4.5 to 9.3 and in methyl orange alkalinity from 0 to 121 mg/l as $CaCO_3$. This area is one of the most concentrated areas of lakes in the world, comparable only to a complex on the Minnesota-Ontario border and to areas within Canada and Finland.

Located at some of the highest elevations in the state, the Northern Highlands Lake District is the source of major river systems flowing north into Lake Superior, east into Lake Michigan, and south and southwest into the Mississippi River. Much of the area is glacial pitted outwash, a region of low relief. The soil is sandy and thin. The Lake District was covered by conifer hardwood forest with small sections of pine savannah and boreal forest. An active program of research is conducted at the site. The investigators and their research are listed in Appendix I.

Topographic maps, aerial photographs, and a complete bibliography are available for aquatic sites in the Northern Highlands area. In addition, there are species lists, geologic maps, and soil maps for specific sites where individual investigators carried on intensive research. Climatological data is available from at least five stations within 45 km of the biological station on Trout Lake. The baseline data for the area is best appreciated by examining the enclosed bibliography (Appendix II). These papers and theses reflect a broad background of aquatic sciences.

The earliest and most complete set of aquatic data were collected by the Birge and Juday group from 1924 through 1942. These data cover over 500 lakes, many of which were sampled frequently during this period. Most data were collected during summer months. Cards with this information are stored in the University of Wisconsin Archives. The data include temperature, pH, Secchi disc, conductivity, color, free and fixed CO_2, dissolved oxygen, nitrogen (NH_3-N, organic nitrate, nitrite and total), phosphorus (soluble, organic and total), silica, calcium, magnesium, total iron, manganese, carbon, C:N ratio, chloride, chlorophyll, plankton (net loss on ignition), Eh, bottom mud chemical analysis and groundwater residues and percent carbon. In addition the UW Archives hold field notes and calculations which contain phytoplankton and zooplankton counts by genus (collected as early as 1900) and a little data on fish. We have begun to make the data more available for research. For example, we have placed the surface water chemistry data for 61 lakes into the computer for analysis of long-term changes in pH (Lehner et al. 1979).

From 1960-1962 the Wisconsin Department of Natural Resources surveyed the surface waters in this region (Black et al. 1963). This extensive survey of all lakes and streams, assembled by County also, includes many small unnamed bodies of water.

The Scientific Areas Preservation Council of the Wisconsin Department of Natural Resources controls over 140 scientific areas in the State of Wisconsin. Nine of these areas, a mixture of aquatic and terrestrial sites, are located within a 20-km radius of the Trout Lake Biological Station. Each area has a site description and map. Certain areas have detailed lists of plant species and surveys of the breeding birds. The natural area report for the Trout Lake conifer swamp is included as an example (Appendix VI).

Additional aquatic research has been conducted by the Wisconsin DNR, particularly on five lakes located just east of Trout Lake. In the past 15 years they have manipulated the size limits on top carnivores (e.g., northern pike in Escanaba Lake from 1964 to 1972), simplified species community structure from about 14 to 2 species in Nebish Lake, introduced coho salmon to Pallette Lake, and changed bag limits and the fishing season. Such manipulations have important ties to current ecological theory on the role of predators in regulating community structure. In conjunction with these studies DNR personnel collect important environmental data. Since 1967, for example, they have been monitoring water quality and zooplankton in Nebish Lake.

In addition, the DNR began a state-wide monitoring program of Bench Mark Lakes in 1978 which includes four lakes in the Northern Highlands. The samples include 18 water chemistry parameters, temperature, Secchi disc, phytoplankton, zooplankton, and macrophytes.

Madison Area Lakes

Lake Mendota has been the site of extensive limnological work for nearly a century. As a result of this, and the commercial and social importance of this area to the State of Wisconsin, there exists extensive baseline data. These include geological, topographic and soil maps; climatological data from Dane County Airport (located one mile east of the lake); aerial photographs; and species lists of fish, benthos, zooplankton, phytoplankton, and macrophytes. In many cases censuses of species have been made periodically. For example, macrophyte surveys were completed five times from 1912 to 1966 (Denniston 1922, Rickett 1922, Andrews and Hasler 1943, Threinen and Helm 1952, Lind and Cottam 1969). Such records have already allowed investigators, such as Stewart (1976), to evaluate long-term changes in water transparency.

A bibliography developed by the late Professor Elizabeth McCoy (Appendix III) contains over 600 references to research on Lake Mendota. The bibliography is only a draft and needs to be revised. But the scope of this research is truly impressive, and the data contained in these publications represents our greatest source of baseline data on Lake Mendota.

In recent years the lake has been most intensively studied by water chemists G. Fred Lee and David E. Armstrong, and bacteriologist Thomas Brock, and their respective students. These studies have emphasized the chemistry of lake water, nutrient inputs and cycles, and the development and degradation of blue-green algae blooms. The Wisconsin Department of Natural Resources and Dane County have also made major investments in research aimed at minimizing human effects on the lake. A five-year program (1976-1980) monitoring Lake Mendota and its tributaries has been sponsored by the Dane County Regional Planning Commission and executed under the guidance of Richard C. Lathrop, a DNR research limnologist. This program has included monitoring flow, nutrient, and sediment load in all tributaries (with special emphasis on storm events), and also following water chemistry, phytoplankton, and zooplankton in the lake itself.

Current research at the site is listed in Appendix IV.

Site Integrity

Northern Highlands Lakes

Nearly all lakes in the immediate area of the station have near natural water quality because the state forest controls about 80% of the land area and two-thirds of the lake frontage. Moreover, this state forest has the directive of continuing to purchase private lands. Forestry guidelines include leaving a buffer zone 33 m from the shore of each lake and stream. There is no agriculture or heavy industry and only a sparse population density in the area. During summer the Northern Highlands are utilized as a recreation area by tourists. However, Baker and Magnuson's (1976) study showed little impact to date even of intensive recreational use.

Where greater site control is necessary, we have worked with private individuals and with the University of Notre Dame whose property in nearby Gogebic County, Michigan encloses 23 km^2 and 16 named lakes. We also have identified a group of secondary reference lakes (Table 1) and have the DNR's Bench Mark Lakes and the Five Lakes Experimental Site as resources.

All navigable waters in Wisconsin are considered part of the public domain and the Wisconsin DNR has a policy of maintaining public access to all lakes. Only lakes which are surrounded by private property present access difficulties. Because most of the land in the Northern Highlands is state-owned, limited access is rarely a problem. We anticipate no problems in the long-term availability of these resources for our research. The larger lakes with sport fish populations will be used for recreation by tourists and some local residents. This use is concentrated during the summer vacation months and minimal during the other nine months of the year (Bubul et al. 1978). Therefore, there is little conflict in use of these Northern Highlands lakes.

Madison Area Lakes

Lake Mendota, unlike the lakes of the Northern Highlands, is situated in a drainage basin that is intensively farmed and has a major urban area along its southern perimeter. Anthropogenic influences have and will continue to have a strong impact on environmental conditions in this system, although Dane County and state agencies are trying to minimize human impact. All sewerage inputs have been diverted from Lake Mendota and its water quality appears to be improving. The lake is used extensively for recreation by residents of Madison and Dane County. Though fish (carp) and macrophyte removal has occurred in the past and may be reinstituted in the future, we feel that because of human influence, Lake Mendota is an important contrast to the Northern Highlands lakes and will reflect the localized effects of human impact characteristics of lakes in a mixed agricultural-urban setting. We believe that understanding the historical responses of lakes of this set of common local conditions is equally as important as following remote lakes which are likely to respond, in most cases, more slowly to human impact. Because of Lake Mendota's widespread recreational use, we anticipate some degree of conflict with other users. However, our research laboratories on the lake shore insure ease of access and will facilitate the frequent checks of research equipment necessary to minimize loss of data. Because the site owner is the State of Wisconsin, long-term access to the site will not be a problem.

Lake Wingra, adjacent to Lake Mendota, is located in a more protected drainage and provides a somewhat more controlled reference lake to Mendota. Wingra is the site of active research (Loucks et al. 1977), but we do not propose to make measurements there as part of the present program.

Research Facilities

Modern facilities for aquatic research are available under the management of the University of Wisconsin-Madison both on Trout Lake and on Lake Mendota. These facilities are briefly described in Appendix V.

MANAGEMENT

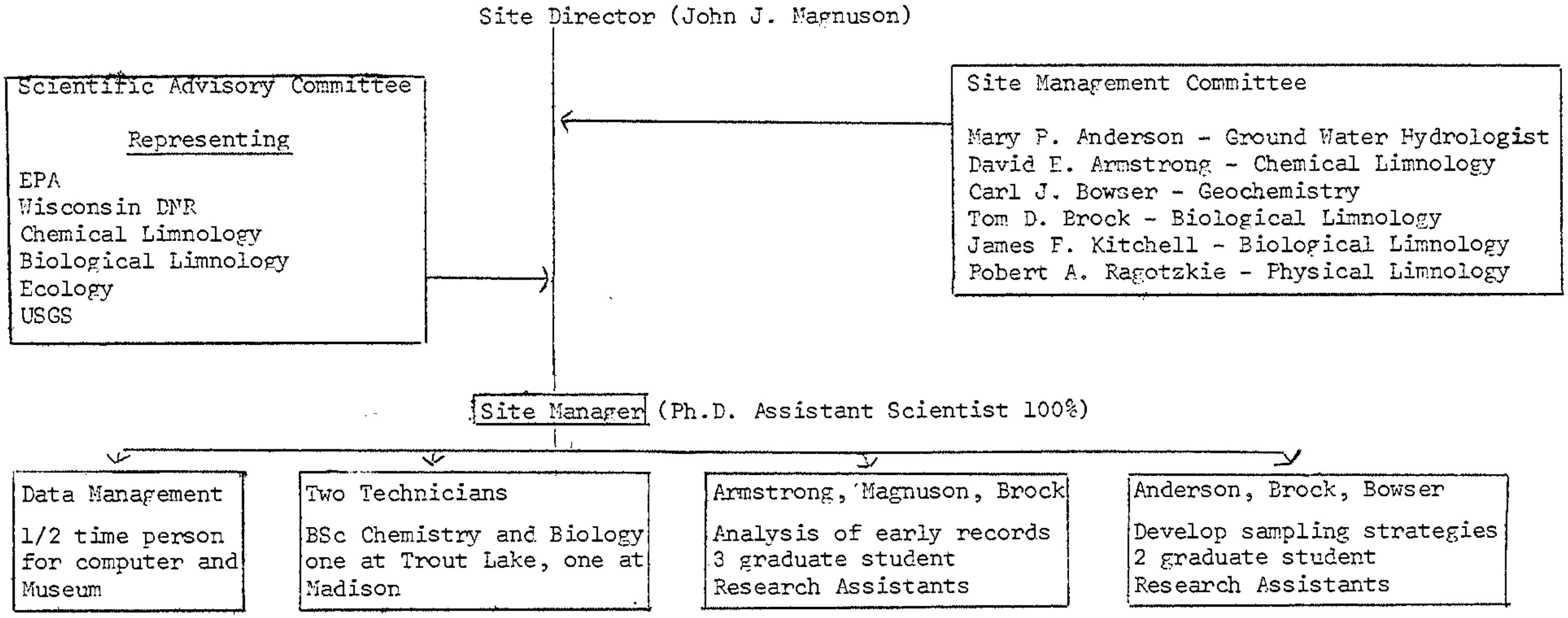
The organization of the site is diagrammed in Table 5. John J. Magnuson (vita in Appendix I) who is Director of the Trout Lake Research Station and the professor in charge of the Laboratory of Limnology on Lake Mendota, will direct the project. He is prepared to make a long-term commitment to the program and has an active research program in the Northern Highlands lakes. (See Current Research, Appendix IV.)

The conduction and management of the program will be assisted by an on-campus advisory committee (Table 5) composed primarily of the principal investigators on this project. They represent the range of disciplines included in the proposal and have a long-term commitment to the project. Their vitae are attached (Appendix I). All are tenure track faculty members well established in their fields and are comfortable with collaborative work.

A Scientific Advisory Committee (Table 5) representing interested state and Federal agencies as well as aquatic ecologists will also advise the site director and principal investigators on priorities and problems at the site and review the progress. We would call them together in the first, third and fifth years of the research. We would seek persons such as David Schindler, George Lauff, Sumner Richman, Henry Regier, and Gene Likens as well as interested agency people from EPA, Wisconsin DNR, or U.S. Geological Survey. We recommend a group of three to five persons. Funds are budgeted for their participation.

The site manager would be directly responsible to John Magnuson. The person would be a Ph.D. level professional in biological or chemical limnology. Residence would be in the Northern Highlands but frequent interaction with and travel to the Madison campus would prevent isolation. The manager would be assisted by two technicians, one with a permanent residence in the Northern Highlands, the other in Madison. Both technicians would assist with intensive field work at both sites. The Madison technician would be responsible for the more time-consuming chemical and biological sample processing; the site manager and northern technician would be responsible for field and laboratory work at the Trout Lake Biological Station and with much of the biological sample processing. A one-half time data manager would assist with curating biological samples at the Museum and with computer storage and retrieval of data.

Table 5. Organization of the Long-Term Ecological Research on Lake Ecosystems at Wisconsin



The graduate students would work with individual or groups of principal investigators to conduct research on the historic data sets or develop sampling strategies from the first year's measurements.

Participation of additional researchers will be encouraged especially in regard to incorporating these data into their ongoing research. These should include researchers from other universities interested in the region, the unique data set, or new ventures. In addition, data and research findings will be available to responsible researchers and agencies upon request to the principal investigators.

We are especially interested in developing closely correlated data sets with a wider array of lake ecosystems in different geochemical and climatic regions. The site director and manager and principal investigators will aggressively work toward developing these ties and shared data systems.

A brochure will be prepared outlining the facilities and research opportunities to maximize the use and value of the data and the associated field stations.

COMMITMENT OF THE UNIVERSITY

Statement of Administration Support

We at the University of Wisconsin are justly proud of the history and current activities of our limnologically oriented faculty. Since the earliest work of E.A. Birge in the last century, our University has maintained a strong commitment to freshwater ecology. Our state lies between two of the largest freshwater lakes of the world and contains thousands of smaller inland lakes. Research by our limnologists has been invaluable in understanding and maintaining these treasured resources. In studying our lakes, we serve the people of Wisconsin by communicating our results to the public and resource managers.

Our commitment has included maintaining aquatic ecologists in several departments on campus. The University has matched Federal funding for building the Laboratory of Limnology and the Trout Lake Biological Laboratory. In the past five years the University alone has allotted over $43,000 for service buildings at Trout Lake and has set aside an additional $31,250 for partial construction of a housing unit, again as match for Federal funds. These funds are supplemental to the annual Trout Lake Biological Station operating budget of about $60,000. Annual operating budget provided by the University for the Laboratory of Limnology is currently $75,000.

Today the University of Wisconsin-Madison offers an integrated research program in limnology; we are the primary Wisconsin university producing Ph.D. freshwater ecologists and limnologists. Programs at the Trout Lake Biological Station are strengthened and stimulated by association with the Laboratory of Limnology and Department of Zoology, as well as the Water Chemistry Department, the Marine Studies Center and faculty participating in the Oceanography and Limnology Graduate Program. Three colleges are involved in our programs: Agriculture and Life Sciences, Engineering and Letters and Science.

We assure University of Wisconsin resources essential to the continued program operation, including time commitments by the directors and continuation of operating budgets.

E. David Cronon, Dean
College of Letters and Science
University of Wisconsin-Madison

Irving Shain, Chancellor
University of Wisconsin-Madison

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