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Project Summary

Lakes are conspicuous, ecologically-important, and socially-valued components of landscapes. Lakes collect water, energy, solutes and pollutants from the land and atmosphere, provide habitats and resources for organisms, and interact with diverse human activities. The North Temperate Lakes Long-Term Ecological Research program aims to understand the ecology of lakes in relation to relevant atmospheric, geochemical, landscape and human processes. Our overarching research question is "How do biophysical setting, climate, and changing land use and cover interact to shape lake characteristics and dynamics over time (past, present, future)?" We address this question through five inter-related goals:

1. Perceive long-term changes in the physical, chemical, and biological properties of lake districts

2. Understand the drivers of temporal variability in lakes and lake districts

3. Understand the interaction of spatial processes with long-term change

4. Understand the causes and predictability of rapid extensive change in ecosystems

5. Build a capacity to forecast the future ecology of lake districts

We examine patterns, processes, and interactions of lakes, landscapes and people at four spatial scales: individual lakes, small drainage systems with several lakes, entire lake districts, and the Western Great Lakes region of North America. Temporally, we consider scales from a fraction of a day to decades. We use multiple approaches of long-term observation, comparison across ecosystems, experimental manipulations, and process modeling. In this proposal, we specifically address decadal forecasts of ecosystem change, which become the hypotheses for future long-term research. Our interdisciplinary research group includes ecologists, hydrologists, climatologists, chemists, demographers, an economist, rural sociologists, and specialists in remote sensing and information management.

We expect our research to produce new conceptualizations of lake district dynamics. Among these are new insights on the dynamics and impacts of invasive species, understanding of the role of spatial location of lakes in landscape dynamics, the reflexive interactions of human and ecological processes, and the interactive effects of geomorphic setting, climate and human activity on long-term change in lake districts. The understanding of integrated landscape-lake-social systems developed through our LTER program will be useful in decisions of individuals and institutions concerned with the future of the Western Great Lakes region and the welfare of its residents.

Section 1. Results from Prior Support

Comparative Studies of a Suite of Lakes in Wisconsin

Grant # DEB9232863 Funding (1996-2002) = $6,000,000

The North Temperate Lakes Long-Term Ecological Research (NTL-LTER) program was established in 1981. Over the past 20 years we have designed and implemented a comprehensive study of seven lakes in a forested landscape within the Northern Highland Lake District in northern Wisconsin, and since 1994, an additional four lakes in the agricultural and urban catchments in southern Wisconsin. We have increased our understanding of long-term dynamics of lakes at spatial scales ranging from small sites within lakes to the northern hemisphere. We have published 243 peer-reviewed papers during the last six years (1996-2001, plus those in press; Fig. 1). A complete publication list is in the Supplementary Documentation section of this proposal.

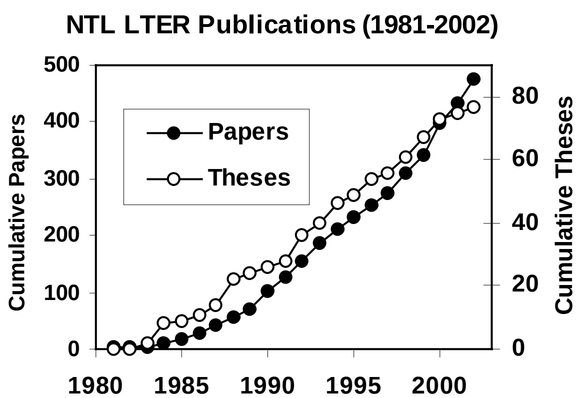

Fig. 1. Cumulative publications by year for the North Temperate Lakes LTER project from 1981 to present. Publications in press are counted as 2002. Popular articles and non-LTER related publications from the Center for Limnology are not included. Publication numbers are likely underestimated because we do not learn of every paper that uses our publicly-available data.

Below we describe some selected research, information management, and educational accomplishments of the past six years. For convenience we have grouped research results into four areas: in-lake dynamics, biotic invasions, regional analyses, and human-lake interactions. These four areas reflect the breadth of our program, but for brevity only a few representative research results are described. Each of these results relied on high-quality, well-managed, long-term data. Other examples can be found on our web page (http://www.limnology.wisc.edu/findings.html) or in our publications.

In-Lake Dynamics

Long-term patterns in water clarity. Analyses of long-term data for Lake Mendota show that food web dynamics, phosphorus runoff, and lake-mixing events interact in complex ways to determine water clarity (Lathrop et al. 1999). Food web dynamics that affect the grazing rate of *Daphnia* can dramatically influence algal densities, especially in the non-summer months when edible-sized algae dominate. Among-year variability in runoff events influences phosphorus loading which fuels algal blooms. Finally, fine-scale lake mixing events can influence nutrient distribution within the water column and alter water clarity (Soranno 1997). The combined effect of all of these processes is seen in the long-term data from NTL lakes.

Long-term dynamics of yellow perch in Crystal Lake. One of the most intriguing types of population fluctuation is that of regular cyclical change. Since 1981, we have observed three cases of cohort dominance of yellow perch in Crystal Lake in which two age-classes dominated the population for roughly 5 years (Fig. 2, Sanderson et al. 1999). Oscillations in young-of-the-year perch abundance were endogenously driven. Young-of-the-year fish were abundant primarily in years when reproductively mature fish were present, suggesting that the repeated oscillations are driven predominantly by pulses of abundant reproductive adult perch. As these young perch grow to juveniles, they exclude the possibility of survival by successive cohorts through cannibalistic and competitive interactions.

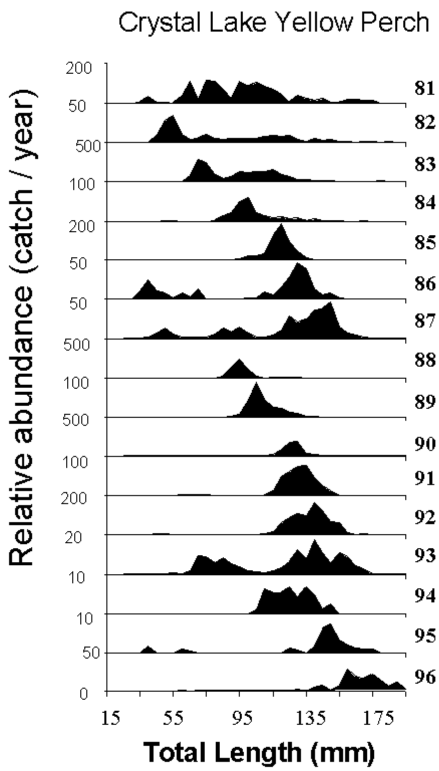

Fig. 2. Relative abundance (CPUE) of yellow perch (*Perca flavescens*) in Crystal Lake as a function of fish size for 1981-1996. Scales for each year differ and are indicated by the numbers on the left axis.

Instrumented buoys developed to measure lake metabolism. Whole-lake metabolism is an integrative process that is highly dynamic and difficult to measure. We developed a series of instrumented buoys and deployed them for several days on 32 lakes to measure diel dynamics of dissolved O_2 and CO_2 in the surface water of lakes. Changes in gas concentrations were used to calculate *in situ* rates of respiration (R), gross primary production (GPP) and net ecosystem production (NEP). O_2 was measured using a rapid pulse dissolved oxygen probe, and CO_2 was measured independently of O_2, using a custom-built gas equilibration chamber coupled with an infrared gas analyzer. R was positively correlated with dissolved organic carbon and chlorophyll concentrations, GPP was positively correlated with chlorophyll, and NEP was positively correlated with both chlorophyll and DOC. These short-term studies have laid the foundation for a more intensive long-term study of lake metabolism using instrumented buoys described in this proposal.

Biotic Invasions

Effects of introductions of exotic fish species. Long-term data revealed time lags in effects of invaders on lake communities. Rainbow smelt (*Osmerus mordax*) have invaded Crystal and Sparkling Lakes, two LTER primary lakes in northern Wisconsin. Each of these invasions has led to large shifts in fish community structure. Long-term data sets have been instrumental in allowing us to identify the mechanisms of inter-specific interaction, rates of decline, and extinctions of native species caused by the smelt invasions. Predation effects of smelt have led to the extinction of native cisco (*Coregonus artedi*) in Sparkling Lake over the span of approximately a decade and

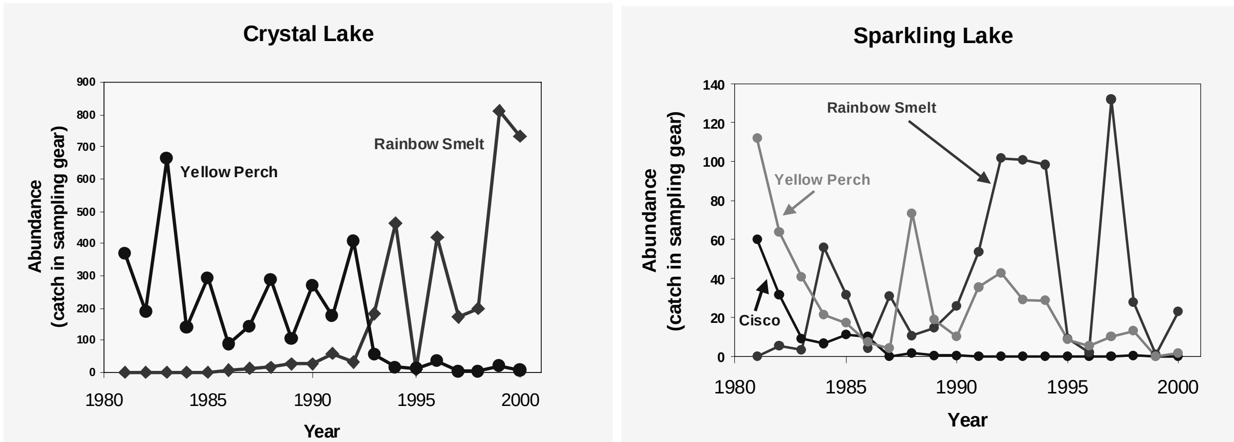

Fig. 3. Abundance of exotic Rainbow Smelt and native planktivorous fishes in Crystal and Sparkling Lakes.

competitive interactions have reduced a historically dominant yellow perch (*Perca flavescens*) population in Crystal Lake to a small component of the fish community (Fig. 3, Hrabik et al. 1998, Hrabik et al. 2001). Rainbow smelt is one of five invading species that NTL is studying. The others are rusty crayfish (*Orconectes rusticus*) which invaded many of the northern Wisconsin in the 1970s, zebra mussels which have recently been found in low numbers in the Madison area lakes, Eurasian milfoil which invaded the Madison area lakes in the 1960s, and *Cylindrospermopsis raciborskii*, an invasive and highly toxic cyanobacterium.

Lake District and Regional Analyses

Landscape Position, Groundwater, Lake Chemistry and Climate. The position of lakes within a hydrologic flow system determines many fundamental features of lakes. Lakes high in the flow system tend to be smaller, more dilute chemically, clearer, more susceptible to acidification, receive less groundwater input, have fewer fish species, and have less human use than lakes lower in the flow system (Kratz et al. 1997, Webster et al. 1996, Reed-Anderson et al. 2000a, Riera et al. 2000). Lake dynamics are also influenced by landscape position. Lake chemical responses to a prolonged drought were a function of a lake's landscape position (Fig. 4). Lakes moderately high in the landscape, where reversals in groundwater inflow are likely, lost cation mass during drought (Webster et al. 1996, 2000). Lakes low in the landscape, however, accumulated cations during the drought because their groundwater inputs are dominated by regional flowpaths, which are less responsive to climate shifts. Data from other lake districts such as the Experimental Lakes Area and the Dorset Research

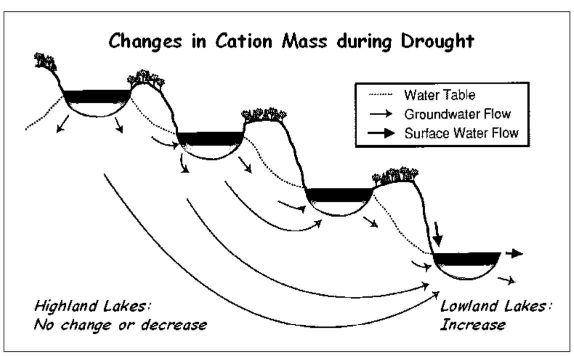

Fig. 4. Changes in cation mass of the NTL-LTER lakes during drought. Lakes are arranged along a landscape position gradient

Centre in Ontario suggest that landscape patterns of lake response to drought are complex but predictable across the Upper Midwest (Webster et al. 2000).

Ice phenology in the northern hemisphere. NTL researchers have led efforts to use changes in lake ice phenology as indicators of global climate change and variability. Duration of ice cover has decreased in the last 150 years in lakes throughout the Northern Hemisphere (Magnuson et al. 2000). El Niño influences (Robertson et al. 2002) and effects of interdecadal climatic shifts (Benson et al. 2002) are not uniformly distributed across the hemisphere. Interannual variation in freeze and thaw dates was larger from 1971-1990 than from 1951-1970 (Kratz et al. 2002a) but periods of high and low variation have occurred throughout the last 150 years.

Human/Lake Interactions

Predicting Blue-Green Algal Blooms in Lakes using Long-Term Data. Long-term records of phosphorus loading, in-lake P concentrations, and blue-green algal abundances were used to predict the probabilities that blue-green algae would exceed bloom thresholds of >2 and >5 mg L^{-1} as a function of P loading rate for Lake Mendota (Lathrop et al. 1998, Fig. 5). These analyses were used to set targets for P input reduction by the Lake Mendota Priority Watershed Project, which will commit over $16 million of state and local funds to improve water quality in the lake. The long-term P loading data were also used by Carpenter et al. (1999) to show that traditional deterministic lake models overestimated P input targets, if the goal of P management is to maximize the net economic benefits of all human activities using the lake and its watershed.

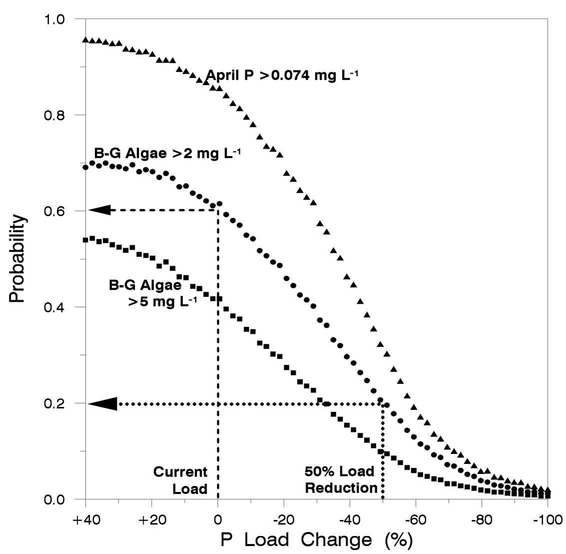

Fig. 5. Probabilities of summer blue-green algal bloom concentrations >2 and >5 mg L^{-1} and spring P concentrations >0.074 mg L^{-1} vs. change from current P loading rates. Arrows show current load and a proposed 50% reduction in P loading rates for Lake Mendota.

Ecological Economics of Lakes Subject to Regime Shifts. NTL interdisciplinary studies have calculated the net economic value of water quality, based on the economics of farming, value of housing near the lake, and the recreational economy derived from boating, fishing and so forth (Wilson and Carpenter 1999, Stumborg et al. 2001). These analyses suggest that the economically optimal loading of phosphorus to the lake (which maximizes net costs and benefits to society as a whole) is around one-third of the current loading rate. The long-term data also suggest that even the economically-optimal phosphorus loads may incur a high risk of shifting the lake into an irreversible eutrophic state (Carpenter et al. 1999, Carpenter 2001, Scheffer et al. 2001). This risk is related to the high variability in loading caused by variable climate. It also depends on the proportion of the watershed used for phosphorus-intensive agriculture such as dairy or meat production.

Cross-site science

We organized two large, international cross-site workshops: one on ice phenology across the Northern Hemisphere, which led to a special symposium at the SIL meeting in Dublin, Ireland, and the other on the ecological organization of lake districts, which led to a special issue of *Freshwater Biology*. In addition NTL scientists led or participated in a number workshops at the 2000 All-Scientists Meeting and NCEAS synthesis activities including workshops on Regional Comparison of Plankton Dynamics and Biodiversity and Productivity.

Long term, core data and their management

We collect and manage high-quality, comprehensive, long-term datasets on the physical, chemical, and biological properties and processes of the LTER lakes and the surrounding landscape (Magnuson and Bowser 1990, Kratz et al. 1986). All of these data are available electronically to LTER investigators and collaborators and data more than two years old are freely available to the public on the World Wide Web (Table 1, in Supplementary Documentation). The number of data requests and access history of our web page are summarized in Table 2 (in Supplementary Documentation). Data management at our site is described in Section 4: Information Management.

Development of Human Resources in Science and Engineering

Graduate education and graduate students have been direct and indirect beneficiaries of our LTER research. In a typical year we supported an average of eight graduate students fully or in part from the NTL LTER grant. In addition, about 20 graduate students were affiliated with our LTER project each year and received training and education benefits even though they were not directly supported. 14 MS and 14 Ph.D. theses based on LTER research were produced in the period 1996-2001.

Undergraduate education and undergraduate students were also both direct and indirect beneficiaries of LTER awards. In an average year 23 undergraduate students worked directly for our LTER project. Principal investigators routinely use recent results from LTER in their courses. We estimate that approximately 300 undergraduate students each year took classes taught by LTER PIs where LTER results were used to enrich the curriculum. In addition, NTL data available on the web were used by faculty at other institutions to enhance their classes.

As part of the Schoolyard LTER program, we have partnered with several local elementary and high schools. We have worked with 3rd grade, 7th grade, and high school teachers and students to develop a curriculum for winter limnology projects that culminated in a day-long field trip where observations were made and hypotheses tested. More information about outreach appears in Section 5.

I. CONCEPTUAL FRAMEWORK

Lakes are foci of ecological, economic and social processes on many landscapes throughout the world. Small, inland lakes, such as those prominent throughout the Great Lakes region of North America, play a central role in regional hydrologic and biogeochemical cycles, ecological processes, and a wide range of human activities. Over the past two centuries, deforestation, fire suppression, agriculture, industrialization, tourism, and urbanization have transformed landscapes within the region and fundamentally altered the interactions between lakes and their surroundings. For the next century and beyond, the quality of life and the economies of the region will depend upon the quality of the lakes.

The North Temperate Lakes Long-Term Ecological Research (NTL LTER) program seeks to understand the long-term ecology of lakes and their interactions with terrestrial, atmospheric, and human processes. Our overarching question is:

***How do biophysical setting, climate, and changing land use and cover interact to shape lake characteristics and dynamics over time (past, present, future)*?**

Our conceptual framework considers lakes as interactive components of their environment. As collectors of water, energy, and solutes from the landscape and atmosphere, as habitats for aquatic biota, and as attractors of human activities, lakes affect and are affected by natural and human-induced changes in the local and regional landscape and atmosphere. Our perspective extends from analyses of the past (especially the past 150 years of recorded history but also including paleoecological records), through the present, to forecasts of the next 50 years of change in the landscapes and the lakes. We employ a nested set of spatial scales including individual lakes, multiple neighboring lakes, entire lake districts, the Upper Great Lakes region, and lakes of the northern hemisphere. Within the context of this conceptual framework, our program has five inter-related goals.

(1) Perceive long-term changes in the physical, chemical, and biological properties of lakes. This goal includes the collection and management of our core datasets. Most of the research we describe depends on these continually evolving, long-term datasets. We propose to add three new long-term core datasets: (i) land use and land cover change in the watersheds of our primary study lakes; (ii) human populations and socio-economic characteristics in these core watersheds; and (iii) daily archives of MODIS satellite imagery covering Wisconsin.

(2) Understand the drivers of temporal variability in lakes and lake districts. The growth of our long-term database has created several unique opportunities for understanding long-term change in lakes. Five topics have emerged as particularly promising at this stage of the project: (i) dynamics of algal blooms, (ii) patterns in ecosystem production and respiration, (iii) the association of productivity and diversity in lake plankton, (iv) long-term change in the balance of littoral and pelagic processes in lakes, and (v) patterns of fish recruitment.

(3) Understand the interaction of spatial processes with long-term change. Lakes are connected dynamically to surrounding landscapes. Long-term change in lakes may depend upon the spatial arrangement of these landscape mosaics. We address three questions in this area. (i) Over what scales of space and time are spatial dependencies important in determining lake characteristics and dynamics? (ii) How do climate, geologic setting, and land use/cover change influence water and solute loading to lakes? (iii) How does spatial positioning of lakes influence their value to humans?

(4) Understand causes and predictability of rapid, extensive change in ecosystems. Some ecological changes are rapid and extensive. Such big changes can be difficult to understand or anticipate. Yet understanding the mechanisms underpinning thresholds or regime shifts is a key need for forecasting future change. Our data sets have grown to the point where we can carefully evaluate certain types of big changes. We have selected three for analysis during this grant cycle: (i) eutrophication, (ii) ecosystem consequences of species invasion, and (iii) changes in angler-fish interactions as lakeshores switch between public and private ownership.

(5) Build a capacity to forecast the future ecology of lake districts. In coming decades, landscapes and lakes will exhibit complex responses to changes in climate, land use and cover, biota, and human activities such as riparian development and fishing. We will develop methods for forecasting changes in temperate lake districts, as both an emerging research frontier and as a mechanism to generate hypotheses for future long-term research. This research, which is a new theme for NTL LTER, will address two questions. (i) How might climatic, geochemical, ecological, and socio-economic drivers of the lake districts change in the next 50 years? (ii) How could these changes affect hydrology, biogeochemistry, and ecology of the lakes?

In addressing these five goals we use a variety of approaches including long-term observations, small- and large-scale experiments, comparative studies, and process modeling. In the next five sections, we elaborate on each of the five goals. We follow this with a concluding section describing the synthetic nature and significance of our proposed research program.

II. PERCEPTION OF LONG-TERM CHANGE

One of the basic goals of the NTL LTER program is the collection and management of ecologically relevant data that allow investigators to observe and analyze long-term changes in physical, chemical, and biological features of lakes. Long-term observations and analyses are crucial to understanding lake ecology. Natural phenomena, such as strong year-classes of long-lived predators, a series of drought years, or an invasion by an exotic species, can cause multi-year to decadal effects in lakes, often with substantial time lags between cause and effect (Magnuson 1990, Magnuson et al. 1990, Carpenter and Leavitt 1991, Webster et al. 2000). In addition, many human-induced pressures influencing lakes, such as eutrophication and climate change, operate over time scales of years to decades or longer. The accumulation of these effects can cause changes that are difficult to understand without a long-term context (Likens 1989, Holling 1995, Likens 2001). To provide such a context for our research, we collect and maintain a series of ’core’ databases (Table 3). These datasets provide the basis for addressing most of our research questions and constitute one of the most comprehensive and accessible long-term limnological databases in the world.

Background. Over the past 21 years we have designed and implemented a balanced and integrated data collection program (e.g. Kratz et al. 1986, Magnuson and Bowser 1990; online data catalog at http://lter.limnology.wisc.edu/catalog.html). We selected lakes and measurements to address important interdisciplinary questions regarding the ecology and management of lakes from a long-term perspective at individual lake, multiple lake, lake-district and regional scales.

We focus our data collection on two sets of lakes and their surrounding landscapes. One set is in the forested and tourism-dominated Northern Highland Lake District in northern Wisconsin, the other is in the agricultural- and urban-dominated landscape in and near Madison in southern Wisconsin (Fig. 6). Both regions have a substantial history of ecological research dating back to about 1900 (Frey 1963).

In northern Wisconsin, beginning in 1981, we focused on a suite of seven primary lakes and surrounding terrestrial areas linked through a common groundwater and surface water flow system and sharing a common climatic, edaphic, and biogeographic regime (Figs. 6 and 25). The lake set includes oligotrophic, dystrophic, and mesotrophic lakes (Table 4) chosen to represent marked differences in size, morphometry, habitat diversity, thermal and chemical features, species richness and assemblies, and position in the groundwater flow system. In 1994, we added four primary study lakes in southern Wisconsin (Table 4, Fig. 6). These four eutrophic lakes were chosen in a 2x2 design of urban vs. agricultural setting and headwater vs. lower in the landscape. Substantial historical data are available on these lakes (Brock 1985, Kitchell 1992, Lathrop et al. 1992, Watson and Loucks 1979). In addition to the primary lakes we also have a set of secondary lakes for which less complete information is collected. These lakes are used for comparisons with primary lakes on specific research questions. We also collaborate with two Canadian groups with similar data on two other lake districts, the Experimental Lakes Area in western Ontario and the Dorset Research Centre in eastern Ontario. Collectively, the data and research programs at these four lake districts afford a unique opportunity for analyses of the Western Great Lakes region.

Our sampling program allows comparisons of parameters and processes among seasons, years, lakes, and lake districts. We sample most major physical, chemical and biological components (Table 3) with sampling frequencies tuned to the dynamics of individual parameters. We sample most intensively at four key times of the year: spring overturn, maximum stratification in summer, fall overturn, and winter stratification. Complete cation-anion balances are determined at these times. Nutrients, pH, inorganic and organic carbon are sampled every two or four weeks, depending on the lake and the nutrient. Temperature, dissolved oxygen, chlorophyll *a*, light penetration, and zooplankton abundance are sampled every two weeks during the open-water season

Table 3. North Temperate Lakes LTER core parameters. More details on measurement protocols available at <http://lter.limnology.wisc.edu/catalog.html>
(* = measured at both the Madison Lake Area and Trout Lake Area; otherwise, Trout Lake Area only)

PARAMETER	FREQUENCY	LOCATION	METHOD
LOCAL MEASUREMENTS			
Weather Air Temperature* Relative Humidity* Wind Speed* Precipitation* Solar Radiation* Wind Direction* Soil Temperature*	Hourly except half-hourly for Solar Radiation and 5 minute for rain gauge during rain events	Woodruff Airport, Sparkling Lake, Trout Lake and Madison NWS Woodruff Airport and Madison NWS	Thermistor Campbell HMP 35c probe 3-cup anemometer Tipping Bucket Gauge Eppley Pyranometer (long and short wave) Electronic Wind vane Thermistor probes
Evaporation Air Temperature Relative Humidity Wind Speed Water Temperature		Lake rafts on Sparkling Lake and Trout Lake	Thermistor Campbell HMP 35c probe 3-cup anemometers Thermistor array
Precipitation Chemistry	Weekly	Trout Lake NADP site	NADP protocols
Other Weather Data*	Daily	32 km radius	Weather Service Weather Stations
Hydrologic and Terrestrial Groundwater: Water Level Water Chemistry same as Chemical Limnology, except no total particulate matter	Monthly Annually in autumn	Selected wells near study lakes	Tape and popper; chemistry same as lake samples
Physical Limnology Water Temperature* Vertical Light Attenuation Secchi Disk Depth* Dissolved Oxygen* Ice Thickness* Snow Depth on Lake* Ice Duration*	Every two weeks during ice-free season Every six weeks during ice-covered season Annually	Deepest part of lake; Quarter meter to one meter depth intervals depending on lake NTL lakes	YSI 58, Campbell Dataloggers, LiCor Cosine Quantum Sensors, Meter Stick
Instrumented Buoys Water Temperature, Dissolved Oxygen, Chlorophyll, pH, PAR, Conductivity, Total Dissolved Gas	Profiles several times per day	Trout Lake at 1 meter intervals	Apprise Technology profiling buoy with YSI multiprobe sondes
Water Temperature, pCO2, Dissolved Oxygen, Chlorophyll	Hourly	Selected study lakes	Custom designed buoys using probes and equilibration chambers

Chemical Limnology Total Nitrogen* Total Dissolved Nitrogen Nitrate, Ammonia* Total Phosphorus* Total Dissolved Phosphorus* Total Silica Dissolved Reactive Silica* Field pH* Air Equilibrated pH* Total Alkalinity Total Inorganic Carbon Dissolved Inorganic Carbon* Total Organic Carbon Dissolved Organic Carbon* Total Particulate Matter* Chloride*, Sulfate*, Calcium*, Magnesium*, Sodium*, Potassium*, Iron*, Manganese*, Specific Conductance*	Every four weeks during ice-free season Every six weeks during ice-covered season Quarterly at spring and fall mixis, summer and winter stratification	Deepest part of lake; top and bottom of epilimnion, midthermocline and top middle,and bottom of hypolimnion	Samples collected with peristaltic pump and in-line filtration. N by $K_2S_2O_8$ digestion and copper cadmium digestion and diazo complex; P by $K_2S_2O_8$ digestion and phospho-molybdate complex; Si by $NaHCO_3$ digestion and silica-molybdate complex; pH with meter; Alkalinity by Gran Titration; C by persulfate digestion; Anions by ion chromatography; Cations by atomic absorption
Biological Limnology Chlorophyll a* Primary Production Sedimentation Rate	Same as Physical Limnology	Deep part of lake; Chl at 2-9 discrete depths; Prod by thermal strata for euphotic zone	Chl by spectroscopy; Prod by C14 incubation and analysis of diurnal oxygen and pCO2; sediment traps
Macrophyte Distribution and Biomass*	Annually in August in Trout Lake and in summer in Madison lakes	Selected shoreline locations	Permanent line transects
Zooplankton Biomass*	Same as Physical Limnology	Deep part of lake; 2-9 depths per lake	2 meter long Schindler-Patalas trap; Wisconsin net
Crayfish Abundance*	Annually in August	Selected shoreline locations	Cylindrical traps baited with beef liver
Other Benthic Invertebrates	Annually in August and September	Deep part of lake and selected shoreline locations	Conical net for Mysis and Chaorborus; "Dendy" samplers
Fish*	Annually in August	Deep part of lake and selected shoreline locations	Vertical gill nets; Fyke nets; Trammel nets; Seines; Electroshocker; Acoustic Transects
Human Demography Housing Density	Each decade since 1940	Northern Highlands Lake District; partial block groups	U.S. Census

SPATIAL DATA: VECTOR NAME / THEME	**SCALE**	**SITE (MLA = Madison Lake Area, TLA = Trout Lake Area)**	**SOURCE**
Hydrography	1:24,000	Wisconsin	Wisconsin DNR
Bathymetry	1:24,000	Lake Mendota	NTL-LTER
Watersheds	1:100,000 1:24,000	Wisconsin TLA	Wisconsin DNR NTL-LTER
Soils	1:250,000 1:24,000 1:24,000	Wisconsin Vilas Co. Dane Co.	USDA Vilas Co. Dane Co.
Original Vegetation	1:100,000	Wisconsin	Wisconsin DNR
Historical Land Use/Cover	1:20,000	MLA /TLA 1930-1990s	NTL-LTER
Riparian Vegetation	1:24,000	Mendota Watershed	NTL-LTER
Building Locations	1:30,000	Vilas Co.	Vilas Co.
Roads	1:31,680	Vilas Co.	Vilas Co.
Wetlands	1:24,000	Vilas Co	Wisconsin DNR

SPATIAL DATA: RASTER (THEMATIC) NAME / THEME	DATE	SITE	SOURCE
WISCLAND Land Cover	1992 -1994	Wisconsin	Wisconsin DNR
Elevation	Variable	Wisconsin	USGS 7.5-minute DEMs
Digital Raster Graphs	Variable	TLA	Scanned USGS maps
Land Economic Inventory	1930	TLA	Scanned LEI maps

SPATIAL DATA: AERIAL PHOTOGRAPHS DATE	SCALE	SITE	COMMENTS
1930's	1:20,000	MLA & TLA	Black / White from statewide
1960's	1:20,000	MLA	Black / White
1960's	1:15,840	TLA	Black / White infrared
1986	1:10,000	TLA	Color /color infrared, shorelines
1993	1:40,000	MLA	Black / White from statewide
1996	1:31,680	TLA	Black / White, digital orthophotos
1997	1:9,000	MLA	Color infrared, from NASA ATLAS
1998	1:9,800	MLA & TLA	Color infrared, from NASA ATLAS

SPATIAL DATA: RASTER (DIGITAL IMAGES) NAME / SENSOR	**TYPE**	**RESOLUTION (m)**	**DATE (n=number of images if multiple) (MLA = Madison Lake Area, TLA = Trout Lake Area)**
Landsat MSS	M	80	TLA: 1972, 1986, 1991; MLA: 1975, 1986, 1990
Landsat TM	M,T	30 – 120	TLA: 1984, 1988, 1989 (2), 1991, 1992, 1993 (2), 2000; MLA: 1984 (2), 1986, 1987, 1988, 1989, 1990, 1991 (2), 1992 (2), 1994, 1995 (4)
Landsat ETM+	M,P,T	15 – 60	TLA: 1999; MLA: 1999 (3), 2000(2), 2001
Terra ASTER	M,P,T	30 – 90	TLA: 2000 (2)
Terra MODIS	M,T	250 – 1000	WI: 2000 (various dates), 2001 - present (daily)
SPOT HRV	M,P	10 – 20	TLA: 1988; MLA: 1986, 1988 (4), 1989
IKONOS	M,P	1 – 4	TLA: 2000; MLA: 2000
EO-1 ALI	M,P,T	10 – 30	MLA: 2001
EO-1 Hyperion	H	30	MLA: 2001
ATLAS	A,M,T	3	TLA: 1998; MLA: 1997, 1998
SIR-C	R	25	TLA: 1994 (3)
ERS-1	R	25	TLA: 1992 (2); MLA: 1992

Type codes: A = airborne, H = hyperspectral, M = multispectral, P = panchromatic, R = radar, T = thermal

Table 4. Characteristics of the eleven primary LTER study lakes. For each region and land use type, the lakes are ordered by their landscape position in the hydrologic flow systems.

________________________________TROUT LAKE AREA____ ______MADISON LAKE AREA_______

~~~~~~ Forested ~~~~~~~~~~~~~~~~~~~~~~~~~ ~~~ Agricultural ~~~ ~~~~~ Urban ~~~~~~

Characteristic	Crystal Bog (27-2)	Trout Bog (12-15)	Crystal Lake	Big Muskellunge Lake	Sparkling Lake	Allequash Lake	Trout Lake	Fish Lake	Lake Mendota	Lake Wingra	Lake Monona
Landscape position	High	high	high	intermediate	intermediate	low	low	high	low	high	low
Area (ha)	0.5	1.1	36.7	396.3	64.0	168.4	1607.9	87.4	3937.7	139.6	1324
Mean Depth (m)	1.7	5.6	10.4	7.5	10.9	2.9	14.6	6.6	12.8	2.7	8.2
Maximum Depth (m)	2.5	7.9	20.4	21.3	20.0	8.0	35.7	18.9	25.3	6.7	22.5
Duration of ice cover (days)	156	157	142	143	141	149	138		119	120	107
Water Temperature (°C)	19.9	18.0	20.8	20.9	20.9	21.2	19.9	23.9	24.3	23	25.2
Secchi Depth (m)	1.6	1.2	7.3	6.7	6.1	3.1	4.6	2.1	3.4	0.7	2.5
pH	5.1	4.8	6.0	7.3	7.3	7.5	7.6	8.3	8.2	9.4	8.2
ANC (µeq/L)	10	5	16	366	612	795	829	2873	3714	3723	3500
Conductivity (µS)	11	23	14	49	80	88	93	280	412	500	434
Total P (µg/l)	19.2	40.0	8.6	22.5	15.2	29.3	16.9	47.8	118.0	331	89.2
Total N (µg/l)	629	873	207	489	375	364	235	860	1080	930	1080
SiO2 (µg/l)	366	806	20	145	3582	6486	4311	550	1100		660
Chlorophyll (µg/l)	8.5	14.0	1.8	3.0	2.2	8.3	3.3	8.2	8.6	12.0	11.9
Number of fish species	1	3	23	30	30	38	39	24	43	26	38
Development on shoreline	low	low	low (campground)	moderate	moderate	low	moderate	high	high	high	high

Water temperature (0-2m) and secchi from June 1 - August 31; pH, ANC, and conductivity from the average of spring and fall mixis sampling; total P, total N, and SiO2 from spring mixis; chlorophyll (surface) from open water season.
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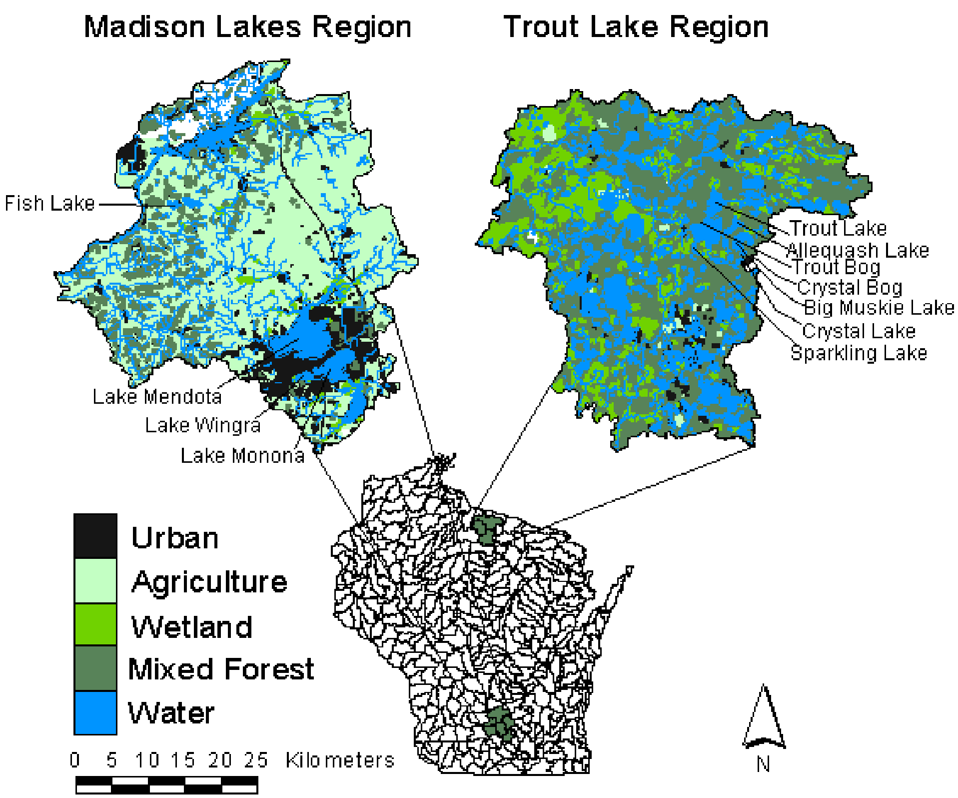


Figure 6. Hydrography and land use of the North Temperate Lakes LTER site. All data are copyright Wisconsin Department of Natural Resources. NTL-LTER core study lakes are labeled.

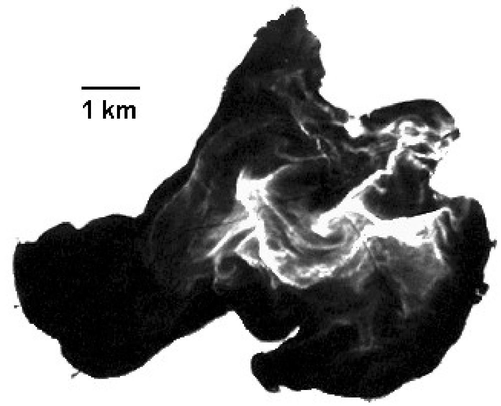


Figure 7. Landsat-7 near-infrared image showing swirling blue-green algal bloom in Lake Mendota, Wisconsin, 31 October 1999.

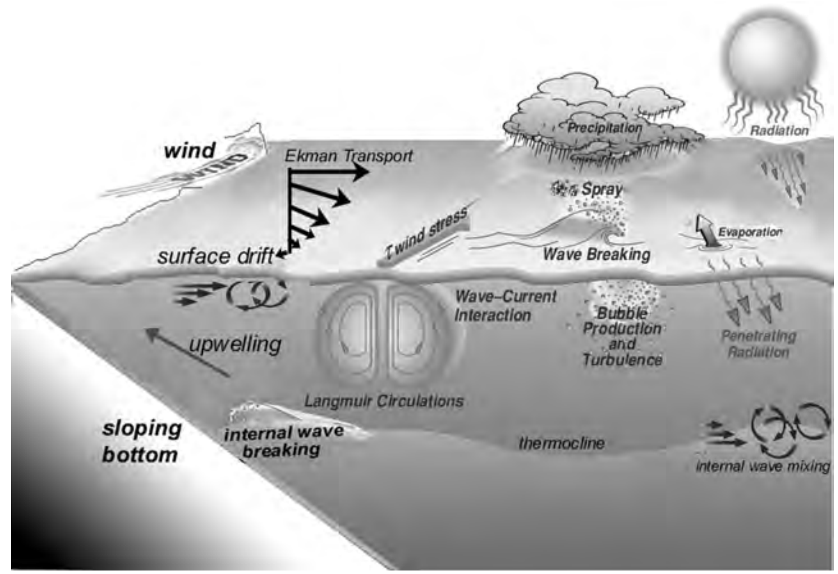


Figure 8. Hydrodynamic processes that affect the spatial pattern and movement of algal blooms.

and every five weeks under ice cover. Primary production rates are measured every two weeks from selected lakes and samples for phytoplankton community composition are collected six times throughout the year. Parameters that vary over longer time scales are measured annually in August. These include macrophyte distribution and abundance, fishes (abundance, biomass, and community structure), and benthic invertebrate abundance. Groundwater levels in selected wells are measured monthly and groundwater chemistry from a subset of these wells is measured annually.

We have a series of instrumented buoys on selected primary lakes, including a raft on Sparkling Lake for measurements of evaporation, wind stress, and high-resolution thermal structure, and an instrumented buoy on Trout Lake for vertical profiling. We plan to develop and deploy small buoys measuring pCO_2, oxygen, and water temperature for estimates of gross primary production, respiration, ecosystem productivity, and carbon flux to the atmosphere on each primary lake. In addition, we maintain an automated land-based weather station at the local airport 10 km from Trout Lake. We have access to National Weather Service data from the Madison airport.

In addition to providing comprehensive limnological data, this sampling program positions us to detect invading exotic species in our primary lakes. Potential new invaders include many European species that have reached the Laurentian Great Lakes (www.seagrant.umn.edu/exotics/index.html). These large lakes now act as a nearby source of colonists including fishes (ruffe, rainbow smelt, rudd, round goby, etc.), zooplankton (*Bythotrephes cederstroemi*, *Eurytemora affinis*, etc.), molluscs (zebra mussels, fingernail clams, and a variety of snails), a macrophyte (Eurasian watermilfoil), and a highly toxic cyanobacterium now invading North America (*Cylindrospermopsis raciborskii*). We have designed our sampling so that introductions of these or other invading species will be discovered early and we can implement specific research activities to understand consequences of these introductions (Turner et al. 2002).

To provide basic information about the terrestrial landscapes surrounding our study lakes, we have developed a geographic information system (Table 3) that includes data layers on land use/land cover, soils, topography, roads, and other landscape features. We have a particularly strong foundation of spatial data on land use and land cover, including a statewide pre-settlement vegetation database; detailed, large-scale historical land use/land cover databases from the 1930's, 1960's, and 1990's for watersheds or riparian zones of selected study lakes; and the statewide WISCLAND land cover database (Lillesand et al. 1998).

We maintain an extensive archive of airborne and satellite imagery for both the northern and southern lake regions (Table 3). The core of this archive consists of Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) images from 1984 to the present. Other image data sources available to researchers at the NTL site include the EO-1/Advanced Land Imager and Hyperion imaging spectrometer, high-resolution (1m to 4m) IKONOS images for the Madison and Trout Lake areas, daytime and nighttime thermal images from ASTER, the NASA ATLAS airborne multispectral and thermal scanner, and the Shuttle Imaging Radar-C (SIR-C) system (Table 3).

Proposed New Core Datasets. The core datasets listed in Table 3 provide the foundation for addressing most of the research questions presented in this proposal. We will continue to collect and maintain these datasets. In addition we propose to add three new datasets: (i) a time series of land use and land cover for NTL core watersheds, (ii) U.S. census data configured for NTL core watersheds, and (iii) additional satellite imagery including daily archives of MODIS data.

Land use and land cover (LULC) patterns integrate many human activities that influence aquatic ecosystems. For example, the amount of impervious surface in the watershed affects runoff, the extent and location of agriculture influence nutrient sources, and the amount and continuity of natural riparian vegetation may control nutrient delivery to streams and lakes. We initiated development of a new core dataset on our primary study lakes under current funding, and this database development will be continued in the next funding cycle. For the Madison Lakes region, we mapped LULC for three watersheds (Lake Wingra and two subwatersheds of Lake Mendota) for the 1930's, 1960's and 1990's; a third subwatershed of Lake Mendota was also completed under EPA funding. For the Northern Highland area, mapping of LULC around 50 lakes is in progress using LTER and other funding. We will continue to update LULC patterns along with related data on population and building density at regular intervals for both study areas. These data will allow us to quantify important changes in the watersheds and will provide the foundation for forecasting future scenarios of LULC change.

We propose to add new demographic data sets to the NTL core data. The first two of these will provide the number of housing units and, by extension, housing density for the Northern Highland Lake District (encompassing Vilas and Oneida Counties). One of these housing data sets was developed under current funding and provides estimates of housing density for each decade from 1940 to 1990 at the neighborhood/community level, U.S. Census partial block groups (Hammer et al. in review, a). We propose to update these estimates to include the 2000 Census and to make projections to 2050 using a stochastic model. In addition, we will prepare a set of spatially more detailed estimates of housing density at the block level for 1990 and 2000. This second dataset will enhance the assessment of recent lakeshore development. The demographic data set that will be added to the core, will provide detailed demographic profiles of each of the watersheds within the Northern Highland Lake District for 1990 and 2000 with an assessment of the changes that occurred during the decade. This data set will be constructed using the methodology that was developed during the last project period, which uses road nodes to interpolate demographic characteristics from census geographies to watersheds (Hammer et al. in review, b).

Satellite imagery is an important tool in our efforts to understand long-term change at regional scales. Beginning with the summer 2001 season, we began collecting and archiving all MODIS imagery for Wisconsin on a daily basis to permit regional-scale, multi-temporal monitoring of large lakes (>400 hectares). We will investigate the viability of MODIS-derived estimates of a variety of biophysical parameters, such as transparency, chlorophyll *a*, and total suspended matter. Through the Wisconsin Satellite Lake Observatory Initiative (Lillesand et al. 2001), we have nearly completed a statewide database of Landsat-derived lake clarity estimates for 1999-2001, with one or more observations for over 7000 lakes. During the next six years we will extend this backward in time using historical satellite imagery and field observations. The ongoing acquisition of Landsat and MODIS data will provide an increasingly valuable tool for assessment of regional changes in lakes and watersheds.

III. UNDERSTANDING TEMPORAL VARIABILITY

Understanding how multiple drivers interact to affect the long-term dynamics of ecosystems is a central goal of the LTER program (Hobbie et al. 2002, Likens 1989, Magnuson 1990). In limnology, internal drivers, such as nutrient cycling and trophic interactions, and external drivers, such as changes in land use and climate, are important in determining ecological dynamics of lakes (Kalff 2001, Turner et al. 2001,Cushing 1997, Trenberth 2000). The rich data sets available for our primary study lakes allow us to address many fundamental questions of how internal and external drivers influence processes, status, dynamics, and potential futures of freshwater ecosystems. For this grant cycle, we propose work on five topics for which we are well-positioned to make significant advances. These topics address fundamental issues of limnology related to blooms of cyanobacteria; carbon cycling; plankton diversity and productivity; cross-habitat interactions; and fish recruitment. Each proposed study depends on long-term data sets as well as other types of information.

Temporal and spatial dynamics of cyanobacterial blooms

Blooms of cyanobacteria (blue-green algae) are conspicuous but highly variable features of eutrophic lakes (Reynolds 1997). Because blue-green algae are often buoyant, hydrodynamic processes create spatial pattern in blooms within lakes (Fig. 7).

Physical, chemical, and biological factors that drive the growth and movement of different species of blue-green algae are still poorly understood. The interaction of physical hydrodynamic processes (Fig. 8) such as Ekman transport, wind-induced surface waves, Langmuir circulation, and internal breaking waves are responsible for algal spatial patchiness (Verhagen 1994, Bees 1998, Olsen et al. 2000, Azumaya et al. 2001, Franke et al. 1999, Ennet et al. 2000, Litchman and Klausmeier 2001, Huisman et al. 1999, Araujo et al. 2001, DeSilva et al. 1997, Etemad-Shahidi and Imberger 2001). Chemical drivers such as excessive nutrients can increase algal biomass and primary production (Paerl 1997, Pinckney et al. 1999), and blooms may develop in response to nutrient pulses into surface waters that arise from hydrodynamic processes linked to wind stress and temperature (Kononen et al. 1996, Soranno 1997, Stauffer 1987). Finally, grazing by zooplankton can suppress competitors of blue-green algae, recycle nutrients, and thereby contribute to blooms (Kasprzak et al. 1999).

How do physical, chemical, and biotic factors affect the timing and location of cyanobacterial blooms? This question will be addressed by intensive, spatially-detailed sampling of algal blooms and their drivers during summer. In addition to sampling for nutrients, phytoplankton and zooplankton, we will measure velocity and temperature profiles using acoustic Doppler profilers and thermistor chains to assess hydrodynamic processes. To detect community responses to chemical and physical changes, we will use molecular characterization of cyanobacterial taxa (Honda et al. 1999). We will examine archived and contemporary samples for the highly toxic *Cylindrospermopsis raciborskii*, an invasive cyanobacterium associated with climate change (Chorus et al. 2000, Baker et al. 2001).

This study will use several remote sensing technologies to quantify the spatial/temporal dynamics of bloom development. We will employ a remote controlled model aircraft with a high-precision CCD camera to sample individual lakes. At the lake district scale, we will employ remote sensing systems described in Table 3 to study blooms on lakes >1.5 ha in area. We will track bloom development on 100 large lakes (>400 ha) in Wisconsin on a daily basis using the UW's real-time reception facilities for MODIS data (Lillesand et al. 2001). Our aim is to compare bloom development across lakes and assess synchronicity of blooms among lakes within a region. High synchronicity would indicate the importance of regional processes in controlling bloom development.

Patterns and controls of temporal variability in lake metabolism

Lake metabolism, the balance between gross primary production (GPP) and respiration (R), integrates lake ecosystem processes, including influences of the surrounding landscape (Kling et al. 1991, 1992, del Giorgio and Peters 1993, Cole et al. 1994, Raymond et al. 1997, del Giorgio et al. 1997, Dillon and Molot 1997, Cole and Caraco 2001). R and GPP are closely coupled (Fig. 9). Some drivers of ecosystem metabolism, such as nutrient input, are expected to change R and GPP in the same direction. Other factors, such as dissolved organic carbon loading, are not. For example, R exceeds GPP in lakes with dissolved organic carbon concentrations above about 10 mg L^{-1}. Is this change in the R versus GPP relationship simply a result of external forcing by dissolved organic carbon, or are there also changes in a lake's microbial community that amplify ecosystem respiration? There is some evidence that pelagic microbial communities can change rapidly in response to allochthonous dissolved organic carbon inputs (Hessen 1992, Jones 1992, Triplett et al. unpublished).

We will test the hypothesis that shifts in the balance of R and GPP in lakes can be explained by changing dissolved organic carbon and microbial community structure. To determine the components of lake metabolism we will measure diel cycles of O_2, CO_2, pH, temperature, and wind speed using in situ buoys, which will provide estimates of GPP, R, and total CO_2 flux to the atmosphere. Examples of metabolism measurements by our buoy systems are presented on <144.92.62.239/buoy/results/metabolism.htm>. Zooplankton and phytoplankton communities are measured by our routine monitoring program. Microbial communities will be measured in collaboration with the Microbial Observatory project (<microbes.limnology.wisc.edu>). Bacterial communities will be determined by molecular methods (Bowman et al. 2000). Bacterial respiration and production will be measured directly (Roland and Cole 1999). Substrate specific utilization arrays (Bertilsson and Polz 2001) coupled with planktonic respiration

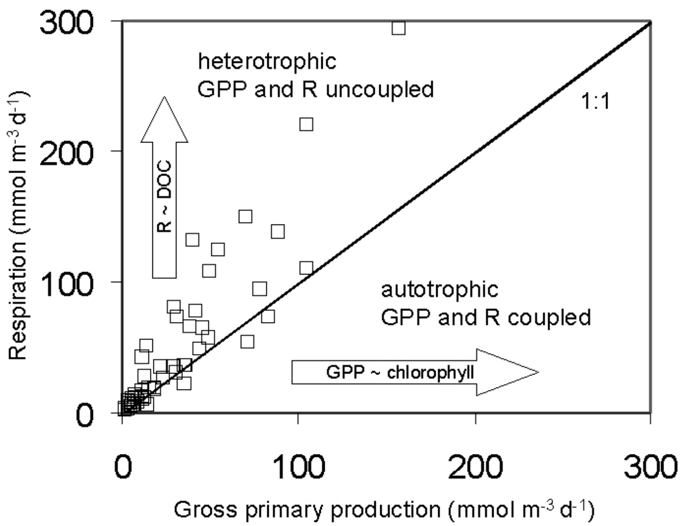


Figure 9. The heterotrophic status of 32 north temperate lakes surveyed in the summer of 2000. Lakes ranged in dissolved organic carbon (DOC) from 2-25 mg L^{-1} and in chlorophyll from 2-57 g L^{-1}. Most lakes fall above the 1:1 line, indicating that they are net heterotrophic. This is especially true for lakes with DOC above about 10 mg L^{-1}, consistent with the findings of Jansson et al. (2000)."

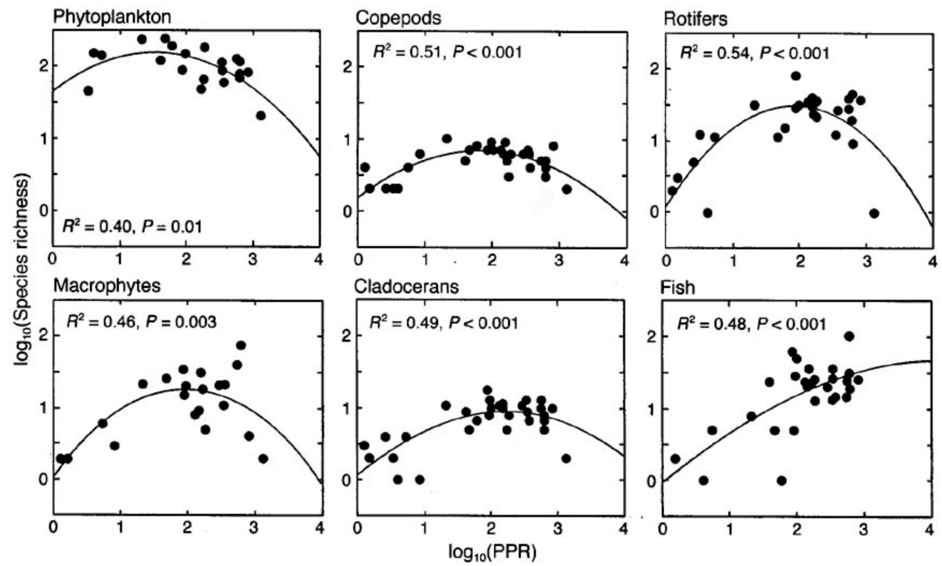
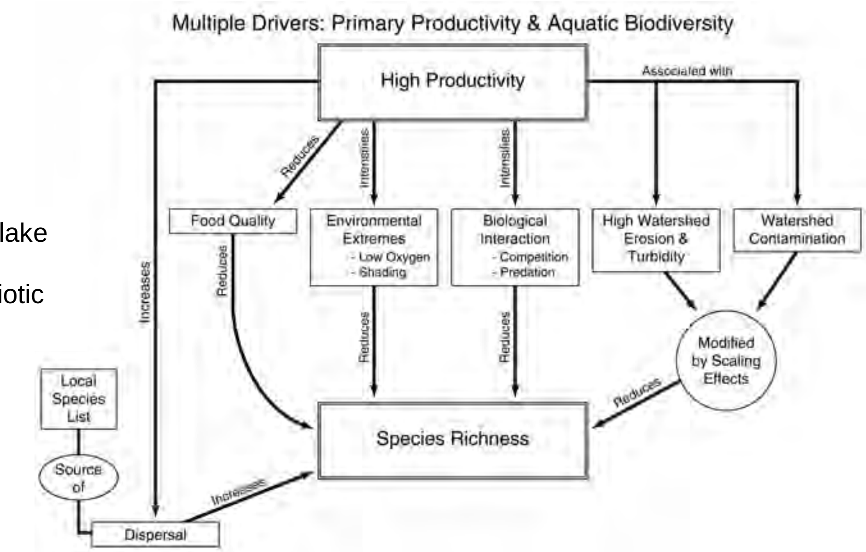


Figure 10. A regression analysis of log (species richness) as a function of log (PPR) for phytoplankton, copepods, rotifers, macrophytes, cladocerans and fish. (Dodson et al, 2001)

Figure 11. Linkages between lake productivity and biodiversity through multiple abiotic and biotic drivers.



measurements will allow us to connect allochthonous and autochthonous substrate dynamics to bacterial activity and whole lake metabolism.

Productivity – diversity relationships in lakes

Aquatic biodiversity is related to lake productivity (Fig. 10, Dodson et al. 2001). Multiple drivers (Fig. 11) have been suggested as being responsible for this observed relationship. Many of the hypotheses offered to explain aquatic diversity vs. productivity relationships invoke competitive and predator-prey interactions which reduce diversity at extreme levels of productivity (Leibold 1999, Dodson et al. 2001). Others invoke physical-chemical changes associated with eutrophication. Assessment of the various hypotheses is complicated by variability in measures of diversity related to the duration of a study (Arnott et al. 1998), apparent species turnover (Arnott et al. 1999) and time delays in biotic responses to changes in productivity (Dodson et al 2001). Resolution of this debate has been difficult because the drivers operate at different time scales and display varying degrees of correlation over time (Waide et al. 1999, Loreau et al. 2001).

We will characterize changes in the relationship between diversity and productivity in lakes as a function of the temporal scale of analysis. We hypothesize that the strength and direction of the relationship (i.e., positive or negative) may depend upon the time scale over which measurements are made and interpreted. Furthermore, factors contributing to lake condition, such as climate, land use and cover, lake size, physical mixing, and water chemistry, may also influence the diversity-productivity relationship. Therefore, our analysis will also consider these important covariates.

Littoral habitat: connections to fish community structure and dynamics

Macrophytes and coarse woody debris (CWD) are central components of the littoral zone structure, which provides habitat and refuge from predation for a variety of species (Persson et al. 1996). Furthermore, littoral and benthic habitats are highly productive, and provide a central food resource for a variety of fishes (Vander Zanden and Vadeboncoeur 2002). Changes in macrophytes occur seasonally and from year to year, while natural changes in CWD occurs at a multi-decadal time scale. We plan to examine how changes in littoral habitat structure affect benthic invertebrate community structure and productivity, and the implications for fish growth, fish recruitment dynamics, and community composition.

Past changes in littoral habitat of our core lakes have been driven by eutrophication, species invasion, and human removal of CWD. Lake eutrophication shifts primary and secondary production from benthic to pelagic habitats, potentially contributing to a decline in macrophyte cover due to shading by phytoplankton (Vadeboncoeur et al. 2001, 2002). Exotic species, particularly rusty crayfish and Eurasian milfoil, have driven many littoral changes in NTL core lakes, specifically the reduction of macrophyte diversity and abundance (Nichols et al. 1992, Lodge et al. 2000, Wilson 2001). In undisturbed lakes, rates of accumulation and degradation of CWD are much slower than for macrophytes, with processes of input and decay requiring centuries

(Christensen et al. 1996). However, humans can rapidly disrupt CWD dynamics, resulting, for example, in depletions of CWD in lakes surrounded by houses (Christensen et al. 1996, Kratz et al. 2002). We are engaged in two experimental whole-lake manipulations of CWD in a collaborative project with separate funding from NSF (http://biocomplexity.limnology.wisc.edu).

Long-term time-series data for fishes, invertebrates, and macrophyte cover will be used to test for changes in fish growth, recruitment, and community structure associated with the observed changes in littoral zone structure. Dietary and stable isotope analysis ($\delta^{13}C$ and $\delta^{15}N$) will be used to assess reliance on littoral resources. Cross-lake, comparative analyses and in-lake manipulations of CWD and macrophytes will be used to quantify the importance of CWD for zoobenthic productivity and fish growth and the consequences for recruitment.

Is variability in fish recruitment correlated among lakes?

Fish recruitment is among the most variable ecological phenomena (Forney 1980, Ricker 1954), and our lakes are no exception. The dynamic patterns of variation in fish year classes and assemblages within and among the Northern Wisconsin LTER lakes are likely related to both internal and external drivers (Magnuson et al. 1994, Hrabik et al. 1998, Sanderson et al. 1999). Between 1981 and 2001, large variations occurred in temperature (Trenberth 2000), ice cover (Magnuson 2002), and precipitation (Webster et al. 1996), and several species invasions were recorded (Hrabik et al. 2001, Wilson 2001). Air temperature, storms, and precipitation are external drivers of lake conditions that affect fish year class strength (Shuter and Post 1990, Van Winkle et al. 1997, King et al. 1999, Steinhart et al. 2001) (Fig. 12b,c). Internal factors include predation, cannibalism, and competition for resources (Hrabik et al. 1998, Sanderson et al. 1999, Jackson et al. 2001a, Hrabik et al. 2001, Wilson 2001). The introduction of an exotic species originates from outside the lake but can influence the internal dynamics for many years (Hrabik et al. 1998, Sanderson et al. 1999, Wilson 2001).

High correlation or coherence (Magnuson et al. 1990, Baines et al. 2000, Magnuson and Kratz 2000) in fish year-class dynamics between time series (Fig. 12a) would indicate that regional drivers such as climate have coordinated impacts on fish year classes. Low coherence, would suggest that internal lake-specific drivers might be more important. We hypothesize that changes in climatic factors and the invasion of exotics the largest drivers of variability in fish year classes and assemblages in the NTL LTER site. We will use the NTL database to address the following specific questions: (i) How coherent are fish year classes among the LTER lakes? (ii) How well do external and internal drivers explain fish year-class dynamics? and (iii) How general are the explanatory variables for species and guilds among lakes? Analyses will employ coherence measures for time series as well as multivariate methods.

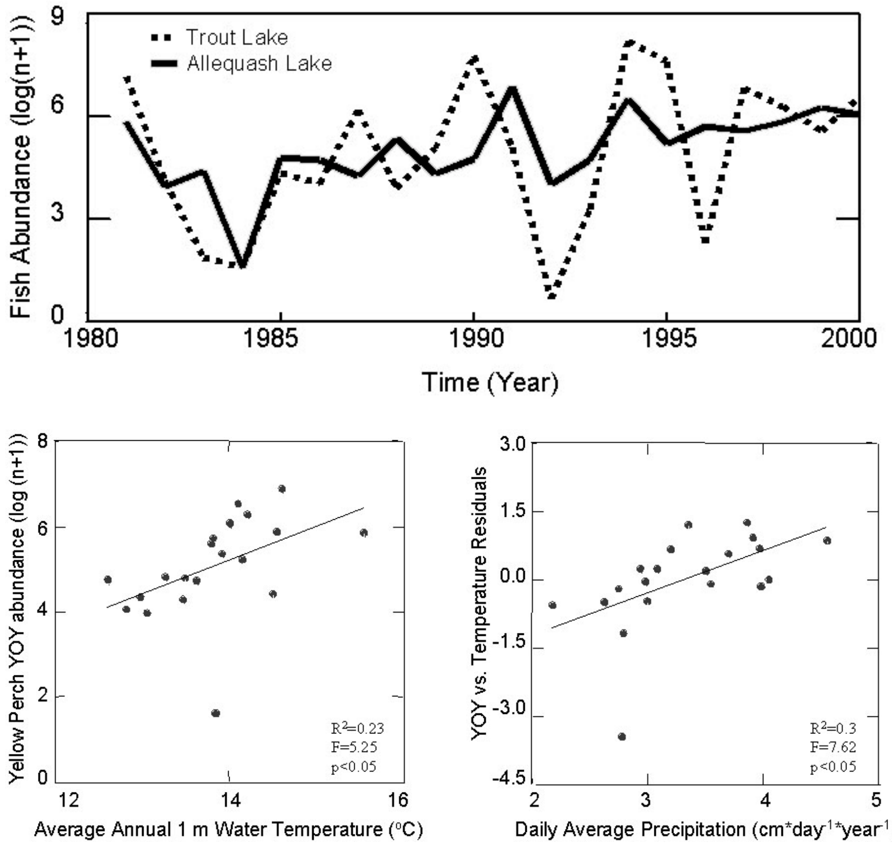


Figure 12. The coherence in year class strength for yellow perch between two NTL-LTER lakes, Trout and Allequash (a), are significant and positive ($r=0.56$, $p=0.01$). Explanatory models for yellow perch abundance in Allequash Lake were tested using stepwise linear regression. Water temperature accounted for 23% ($p<0.05$, $F=5.3$, $df=19$) of the annual variation in young-of-year yellow perch abundance (b), and precipitation accounted for 30% ($p<0.05$, $F=7.6$, $df=19$) of the remaining variation (c). The year 1984 is an outlier in both plots, and if removed the new regression explains 67% ($p<<0.001$, $F=15.9$, $df=18$) of the annual variation in young-of-year yellow perch abundance with the same two explanatory variables.

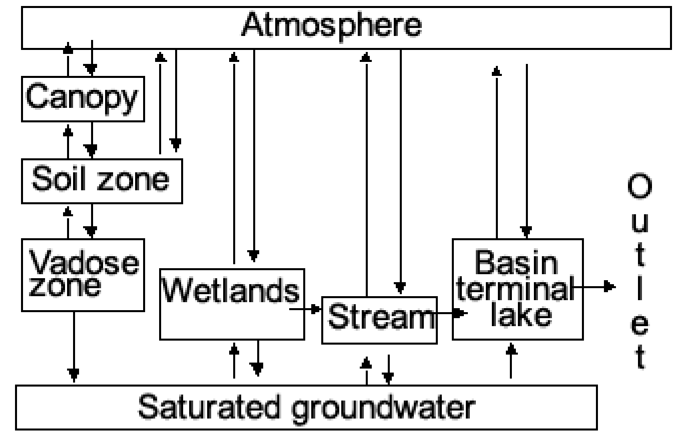


Figure 13. Hydrologic connections between lakes and their surroundings.

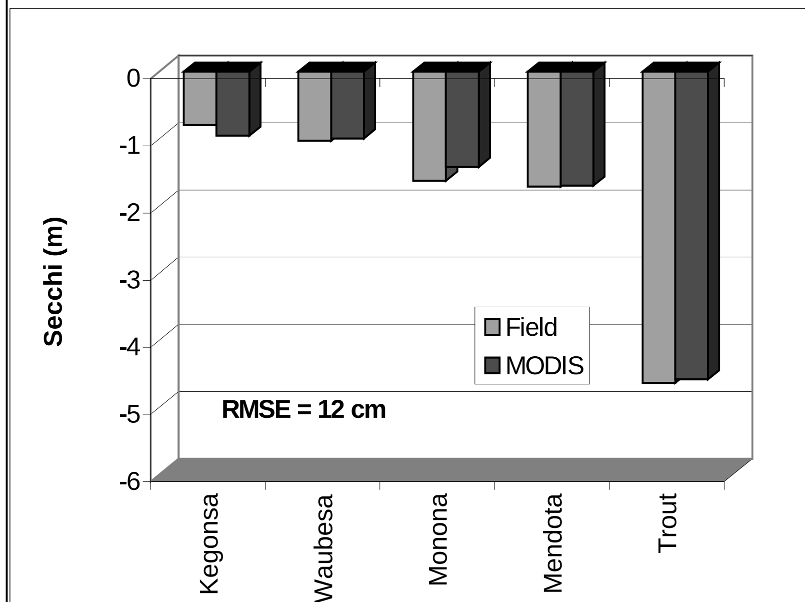


Fig 14. Accuracy of MODIS satellite-derived estimates of summer 2001 seasonal mean lake transparency, shown in comparison to NTL-LTER field observations.

IV. SPATIAL DEPENDENCIES AND LONG-TERM CHANGE

Lake ecosystems do not exist in isolation. They are connected spatially and functionally to streams, wetlands, and their watersheds (Wetzel 1983, Likens 1985, Soranno et al. 1999, Kling 2000, Kalff 2001, Fig. 13), and are affected by long-term change in their surrounding environment. Building on the foundation of our previous work, we propose to investigate spatial dependencies of lake ecosystems and the role of long-term changes in factors such as climate and land use/land cover. Spatial dependencies can be defined as situations in which the outcome of an ecological process or phenomenon is dependent upon the spatial arrangement of component parts. Thus, for example, we anticipate that the answer to the question of "How does land use change influence nutrient loading to a lake?" will depend upon how and where land conversions are occurring within the watershed. The specific studies that we are proposing are grouped into three general questions: (i) Over what scales of space and time are spatial dependencies important in determining lake characteristics and dynamics? (ii) How do climate, geologic setting, and land use and cover change influence water and solute loading to lakes? and (iii) How does spatial positioning of lakes influence their value to humans? The answers to these questions will provide new insights into the effects of spatial and temporal context on lake ecosystems.

Over what scales of space and time are spatial dependencies important in determining lake characteristic and dynamics?

Understanding the spatial and temporal scales at which spatial dependencies are important informs us about the relative roles that local and regional processes play in influencing lake dynamics (Magnuson and Kratz 2000). There is strong evidence that spatial dependencies can be important within lake districts (Baines et al. 2000, Kling et al. 2000, Kratz et al. 1997, Riera et al. 2000, Soranno et al. 1999), suggesting that processes occurring at that scale, such as hydrologic transport of solutes across the landscape, are important. For example, lakes that are positioned higher in the hydrologic flow system tend to be smaller, clearer, less diverse, more susceptible to acidification, and less used by humans than lakes positioned lower in the landscape (Riera et al. 2000). Similarly, spatial positioning of lakes within the landscape has been shown to be an important influence on the degree of among-year synchrony of a variety of limnological properties (Webster et al. 1996, 2000, Baines et al. 2000). Over the next six years we will examine spatial dependencies occurring across an expanded set of temporal and spatial scales, ranging from days to decades and from within-lakes to across continents. We will emphasize the following two topic areas.

How is the magnitude of temporal coherence of lakes affected by the temporal and spatial scale of analysis? Temporal coherence of lakes is the degree to which two or more lakes vary synchronously (Magnuson et al. 1990). Understanding how temporal coherence varies as a function of scale is crucial to developing a better understanding of the scales at which important drivers of lake dynamics operate. We will focus on time scales of hours to decades and spatial scales of individual lakes to continents. Four evolving datasets will be used for these analyses. (i) We will use the existing core physical, chemical, and biological data collected over the past 21 years (and counting) at biweekly to annual frequencies (Table 3). (ii) The new data on lake metabolism that we propose to measure using automated buoys on multiple lakes (see Section III. Understanding Temporal Variability) will provide important physical, chemical and biological data at sub-daily time scales. (iii) Data on ice phenology we assembled for 749 waterbodies across the Northern Hemisphere, covering more than 100 years in some cases, will allow analyses at continental and century scales. In particular, these data will allow us to analyze how interannual variability is related to large-scale climate dynamics such as the El Niño Southern Oscillation, the North Atlantic Oscillation, variations in the Aleutian Low, or volcanic eruptions (Robertson 1989, Anderson et al. 1996, Benson et al. 2001, Livingstone 2001, Robertson et al. 2001), and to a long-term warming trend apparent in ice phenology records (Magnuson et al. 2000). (iv) Satellite observations of lake conditions over large spatial extents, including Landsat-derived estimates of lake clarity for over 7000 lakes and daily MODIS imagery from which estimates of water transparency (Fig. 14), chlorophyll a, and total suspended matter can be made for all lakes in Wisconsin larger than 400 hectares, will allow analysis of water clarity patterns over extended spatial scales. Collectively, these data sets provide a rich resource for investigating the scales over which a variety of limnological drivers operate.

How does a lake's landscape position influence its biotic community composition and diversity? Preliminary work in the Northern Highland Lake District showed that diversity of fish, macroinvertebrates, and macrophytes was influenced more by lake position in the regional groundwater flow system than by the presence or absence of stream connections (http://www.limnology.wisc.edu/lppbite.html). We propose to extend this analysis to other lake districts in the western Great Lakes region such as the Experimental Lakes Area and the Dorset Research Centre, where the hydrology is more heavily influenced by surface water rather than groundwater and we expect stream connections to be a more important determinant of species richness.

How do climate, geologic setting, and land use/cover change influence water and solute loading to lakes?

Climate, geologic setting, and patterns of land use/land cover may all control the loading of water and solutes to lakes (Naiman and Turner 2000). At a regional scale, climatic variability has significant effects on the water budget of the central US (Lenters et al. 2000). The geologic setting and landscape position of lakes further influence water balance and solute loading, because lakes high in the landscape receive most of their water from precipitation, whereas lakes lower in the landscape receive significant amounts of water from ground or surface waters (Kratz et al. 1997). Finally, the distribution of land cover types within a watershed and their management are important determinants of water and solute loading because of their influences on surface runoff, evapotranspiration, groundwater recharge, and water quality (Detenbeck et al. 1993, Hunsaker and Levine 1995, Johnson et al. 1997, Wear et al. 1998). Long-term landscape changes occurring in the NTL LTER study region are correlated with significant alterations in lake level response to storms and nutrient loading (Wegener 2001, Soranno et al. 1996). These findings prompt us to investigate the linkages of geologic setting, climate, and land use/cover change that affect flux of water, C, N and P to our study lakes. Using a combination of long-term, comparative, and modeling approaches, we will address the following four topic areas.

What are the roles of landscape position and geologic setting in controlling loadings of water and solutes to lakes? To predict solute flux in a watershed (and hence inputs to lakes) it is important to understand the source of the water and the flowpath it takes through the watershed (Fig. 15). Even in the relatively simple geologic setting of the Trout Lake watershed, refining a groundwater flowpath can be quite challenging (Bullen et al. 1996, Kim et al. 1999). To improve our understanding of the geologic setting and its effects on water and solute loadings, we will use the results from recharge studies and coupled groundwater/surface-water models (Dripps in prep.), along with samples collected along various flowpaths for verification and refinement.

What are the functional roles of streams and wetlands in our watersheds, and how do they interact with lakes? Water may pass through wetlands and streams, where diverse biogeochemical reactions occur, before entering a lake (Fig. 13). For example, wetlands in the Allequash Creek system are important in methylation of mercury (Krabbenhoft et al. 1995) and can influence DOC export of stream systems that later drain into lakes (Elder et al. 2000). Similarly, the extent of wetland surrounding northern lakes is correlated with lake DOC concentration (Gergel et al. 1999). Thus, understanding how solutes are transported through a watershed to lakes requires knowledge of system hydrology, and how flow paths interact with reactive “hot spots” such as streams and wetlands. We will investigate the functional roles of streams and wetlands in shaping lake characteristics by examining biogeochemical dynamics of C, N and P and interannual fluctuations in chemistry within these systems. To address these questions we will combine a variety of approaches, including process-based measures of C, N and P dynamics in stream-wetland sites, continuation of a growing time series of chemistry of streams draining wetlands, examination of long-term lake chemistry and USGS flow records, and models linking hydrology and lake chemistry.

What is the role of climate variability in water and solute input to lakes? Our previous work has shown that the central US has strong seasonal and inter-annual variations in precipitation, evapotranspiration, and soil moisture (Lenters et al. 2000). There is a need to understand how this climate variability impacts water flow and solute delivery into lakes. For example, in recent decades the Upper Mississippi River basin has seen increased discharge, which has resulted in a large increase in nitrogen transport in addition to that caused by increased fertilizer application (Donner et al. 2002). We will investigate the extent to which both the magnitude and the timing of precipitation impact solute loading at scales ranging from individual rainfall events to inter-annual patterns of wet and dry years.

What is the role of land use/land cover in discharge and solute concentration of streams entering lakes, and how are long-term changes in land use/land cover affecting lakes? We have recently completed a time series of spatial databases covering 60 years of land use/land cover change for watersheds in the Madison Lakes region. During the

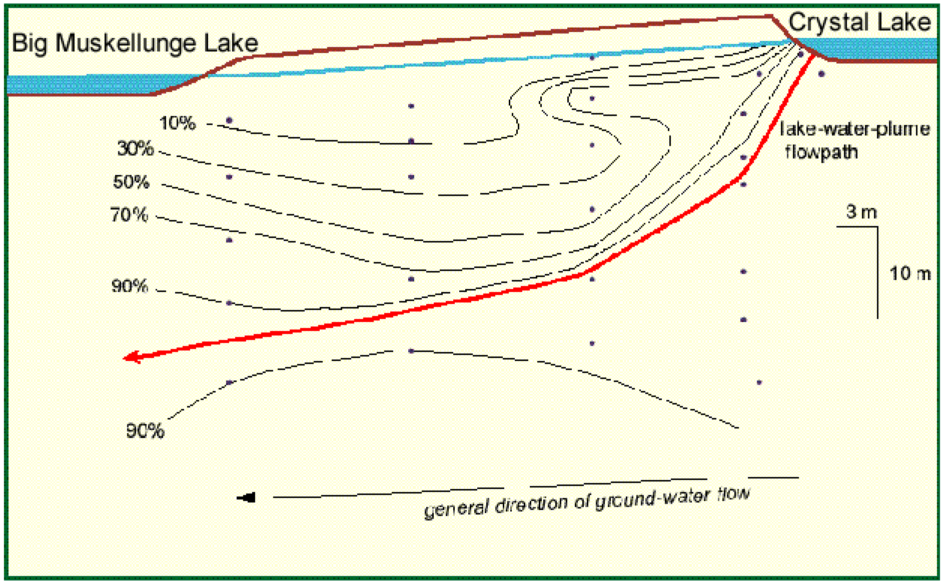


Figure 15. Groundwater flow between Crystal Lake and Big Muskellunge Lake, in the Trout Lake watershed. Groundwater beneath the isthmus between the two lakes is a mixture of Crystal Lake water and precipitation recharged through the isthmus. Contours shown represent percent lake water based on a simple mixing model using stable isotopes of water (^{18}O and ^{2}H). The flowpath shown is one likely flowpath of Crystal lakewater through the isthmus.

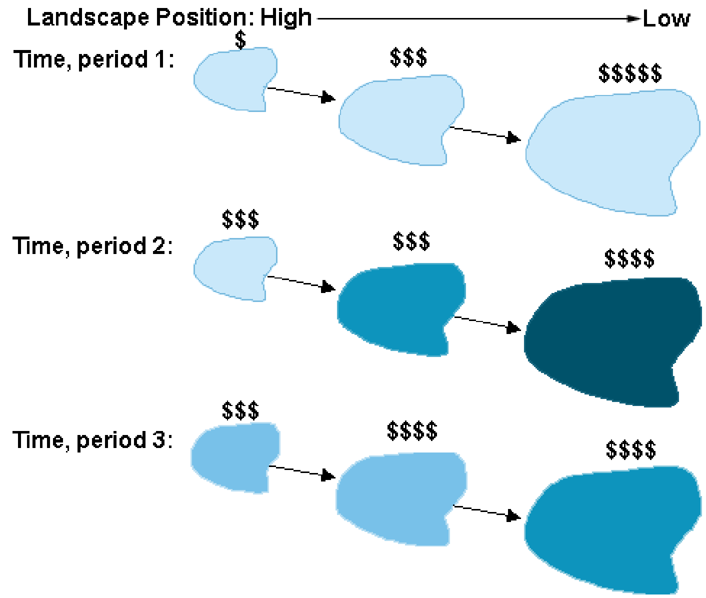


Figure 16. Hypothetical interaction between landscape position and change in lakeshore property value. The direction of hydrologic flow is indicated by the arrows; water moves from small lakes with a high landscape position to larger lakes with a low landscape position. The relative value of property along lakes is indicated by the number of dollar signs ($). Loss of environmental quality is indicated by the shades of blue; the darker the blue, the lower the environmental quality. In Period 1, all lakes are relatively undeveloped, and so environmental quality for all lakes is high. Property values on lakes with a low landscape position are relatively high, reflecting the hypothesis that people prefer the environmental goods and services associated with larger lakes to those associated with smaller lakes. In Period 2, heavier initial development on low-position lakes causes environmental quality on these lakes to diminish, thereby reducing the price differentials between lake types. Possibly this leads to action to preserve/recover environmental quality on low-position lakes, as shown in Period 3; this feedback alters again the price differentials among lakes.

next six years, we will complete development of a historical land cover database for riparian zones in the Trout Lake region. At the same time, we will examine the effects of agricultural practices and urbanization on the quantity and quality of water entering the lakes in the Madison region, and the role of long-term changes in these factors. We will use a coupled ecosystem and hydrologic model to answer questions such as: 1) how have historical changes in land use/land cover impacted the water and solute input to lakes in the last 60 years; 2) to what extent do individual land use types (urban, cropping, forest, fallow) contribute to the observed water and nutrient balance; and 3) how do individual crops (corn, wheat, soybean, and alfalfa), their respective management practices (fertilizer application amount and timing), and landscape position contribute to the total solute and water budget?

How does spatial positioning of lakes influence their value to humans?

In examining the relationships between socioeconomic and ecological systems, the focus is usually on how social systems affect ecology. The reverse question – how lake features affect social systems – has received less attention. We have documented variation in lakeshore building density based on lake attributes (Schnaiberg et al. 2002). We now turn to the effect lake characteristics have on lakefront property values (Wilson and Carpenter 1999, Spalatro and Provencher 2001, Poor et al. 2001). We hypothesize that lakefront property values are a function of a lake's landscape position (Fig. 16) and will use price differentials as indicators of preferences for some lakes over others. As the ecology of lakes change (in part due to human settlement), this price differential changes over time, and perhaps even changes direction (Fig. 16).

To examine this question, we propose a hedonic valuation study (Rosen 1974) in which lakefront property value is cast as a bundle of property and lake characteristics (such as the size of the property, lake water quality, the quality of fishing, and many other characteristics of the lake and property), and the market price of the property is regressed on these characteristics in a statistical analysis to determine the marginal contribution to the property price of each observed characteristic (see Palmquist 1991 for a description of hedonic valuation). Periodic estimation of the hedonic model will reveal how social preferences for different lake types change over time, with implications for feedbacks between social and lake systems.

V. THRESHOLDS AND REGIME SHIFTS

Ecological change need not be continuous in time. Many researchers, including NTL scientists, have documented periods of substantial change, in which ecosystems appear to cross thresholds from one dynamic regime to another (Peterson 2002, Carpenter 2001, Jackson et al. 2001b, Scheffer et al. 2001, Steele 1998). Assessments of rapid, extensive ecosystem change are crucial for understanding the past and anticipating the future. NTL long-term observations provide a strong foundation for the investigation of such change. Over the next six years, we will focus research effort on three types of massive, rapid change that are ecologically significant and well represented at our sites: eutrophication, species invasions, and change from public to private ownership of lakeshores.

Hysteresis in Eutrophication

When lake eutrophication is mitigated by pollution control, are the changes in ecosystem processes simply the reversal of those that occurred when eutrophication was created? Or is eutrophication hysteretic, i.e., changes during reversal of eutrophication are not just the opposite of those that occurred during its onset?

Eutrophication may be hysteretic, according to models based on many case studies (Carpenter et al. 1999, Dent et al. 2002). Relatively drastic reductions in P input are needed to control eutrophication, in comparison to P inputs that trigger eutrophication (Fig. 17). The causes of hysteresis may include individual farmers' decisions about fertilizer and manure application (Nowak and Korsching 1998, Nowak et al. 1998), excess P buildup in soils (Bennett et al. 1999, 2001), and effective recycling of P from sediments (Nürnberg 1984, Smith 1998, Carpenter et al. 1999).

The ongoing restoration of Lake Mendota is a long-term experimental test of the hysteresis hypothesis. Numerous long-term and retrospective studies have documented the changes that occurred during eutrophication of the lake beginning in the 1880s, and since restoration began about 1960. State and County officials are now engaged in aggressive control of nonpoint pollution aimed at reducing nonpoint P inputs to Lake Mendota 50% by 2008 (Betz et al. 1997). We will focus LTER research on three mechanisms that could create hysteresis in ecosystem response. (1) Does the interaction of management institutions with farmers achieve goals for soil P input rates in a smooth linear way as planned, or are changes in fertilizer and manure practices delayed? (2) Are the existing pools of soil P drawn down quickly, or do they persist and delay recovery of the lake? (3) Does recycling of P from sediment decrease, or does it persist and support algal blooms?

Species Invasions and Ecosystem Change

Introductions of invasive species are common in freshwater ecosystems (Kolar and Lodge 2000, 2001; Lodge 2001, Ricciardi and MacIsaac 2000) and the NTL primary lakes have experienced several such introductions. The common carp (*Cyprinus carpio*) was introduced to the Madison lakes in the 1880's and many other non-native fishes were stocked in the following century (Lathrop et al. 1992). Eurasian water milfoil (*Myriophyllum spicatum*) arrived in the Madison lakes in the early 1960s (Andrews 1986) and continues to dominate the macrophyte community (Nichols et al. 1992). Since the inception of the NTL LTER in 1981, lakes in northern Wisconsin have been invaded by both the rusty crayfish (*Orconectes rusticus*) (Lodge et al. 1986, Lodge and Lorman 1987, Wilson 2001), and the rainbow smelt (*Osmerus mordax*) (Hrabik et al. 1998), with impacts on many native species (Figs. 3 and 18).

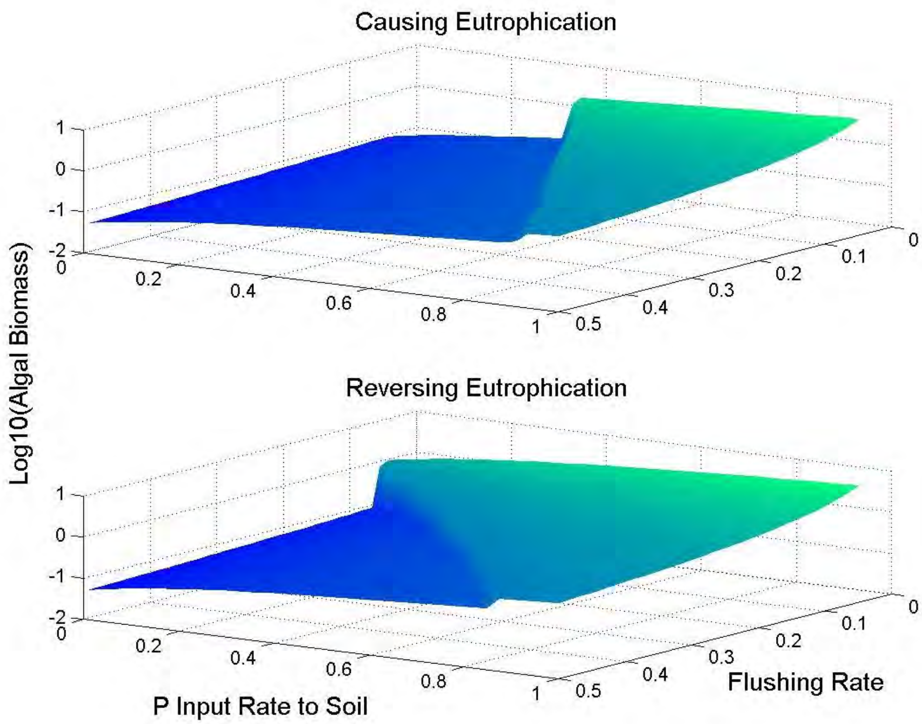


Figure 17. Hysteresis in eutrophication: Algal biomass (log10 scale) versus rate of P input to soil (from manure and inorganic fertilizers, g m^{-1} y^{-1}) and hydraulic flushing rate of the lake (y^{-1}) during the creation of eutrophic conditions (upper panel) and during the reversal of eutrophication (lower panel). For a given flushing rate, the onset of high algal biomass does not occur until P flux to soil is relatively high (upper panel). However, return to low algal biomass requires that P flux to soil be decreased to relatively low levels (lower panel). This difference between forward and backward pathways is hysteresis (Dent et al. 2002).

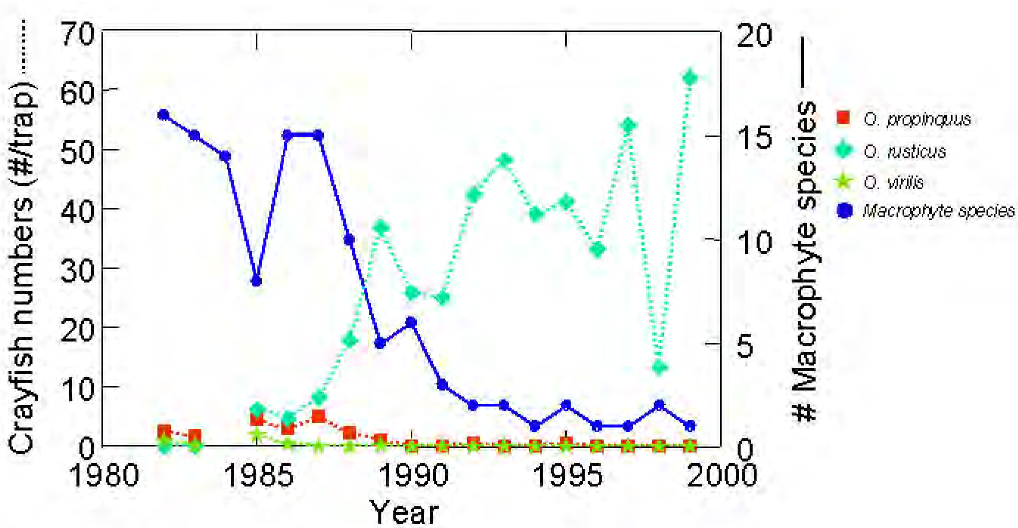


Figure 18. Invasion of rusty crayfish (*O. rusticus*) in one area of Trout Lake. Rusty crayfish have nearly eliminated the native crayfish, and reduced macrophyte species richness (Wilson 2001).

In 2001, adult zebra mussels (*Dreissena polymorpha*) were found in Lake Monona, heralding the arrival of yet another invader in NTL LTER lakes. Zebra mussels often exert dramatic and ecosystem-altering impacts on lakes and rivers (Ludyanskiy et al. 1993, MacIsaac 1996, Strayer et al. 1999). With a zebra mussel invasion on the horizon, the NTL database provides an opportunity to test model predictions for zebra mussel impacts in the Madison lakes (Reed-Anderson et al. 2000b). This invasion is predicted to drive Lake Mendota from a system dominated by pelagic production and processes, to one dominated by benthic production (Strayer et al. 1999, Rutherford et al. 1999, MacIsaac 1996). Such a shift may have tremendous consequences for species and community composition, energy flow through the food web, trophic dynamics, and fisheries (MacIsaac 1996). We are poised to determine the effects of zebra mussel invasion in the Madison lakes to assess ecosystem change, test model predictions, and evaluate changes in benthic and pelagic processes.

Private vs. Public Lakes: Angler Heterogeneity and Fish Community Change

Increasingly, public policy reflects the economic perspective that privatization of ecological goods and services assures their stewardship and beneficial allocation ("privatization" is defined as the replacement of an allocative regime by one in which benefits and costs of an action accrue directly to the decision maker). The future likely will bring an increase in environmental privatization, yet the ecological changes associated with changes in resource management regimes are poorly understood. This raises a number of important research questions about the impact of ownership (public versus private) on lake ecology and its interactions with human activity.

Potential differences in the ecology of public and private lakes have implications for human use (Fig. 19). The illustration emphasizes an important aspect of privatization: ecological variables (such as game fish) with economic value captured by lake "owners" become the drivers of the ecological system, in the sense that the levels of other ecological variables depend on their relationship to the "valuable" variables lake users manipulate. While a growing literature addresses questions of angler choice in open-access recreational fisheries (Beard et al. in review, Carpenter and Gunderson 2001, Cox et al. 2002, Hunt and Ditton 1997, Miranda and Freese 1991, Radomski et al. 2001), we do not have a good understanding of the potential impacts of privatization on freshwater fish communities.

We propose research to explore ecological implications of public vs. private ownership. The study will involve (1) comparisons of fish population structure on selected private and public lakes; and (2) analysis of behavioral and motivational heterogeneity among anglers using public and private lakes, with an emphasis on how angler behavior evolves over time in response to changing economic and ecological conditions (in particular, changes in the levels of lake privatization, and attendant changes in lake ecology). Recently developed econometric methods for modeling heterogeneity in consumer choice will be used to test for behavioral differences among anglers (Provencher et al. 2001, Provencher and Bishop 2001, Train 1999, Boxall and Adomowicz 1999, Chen and Coslett 1998).

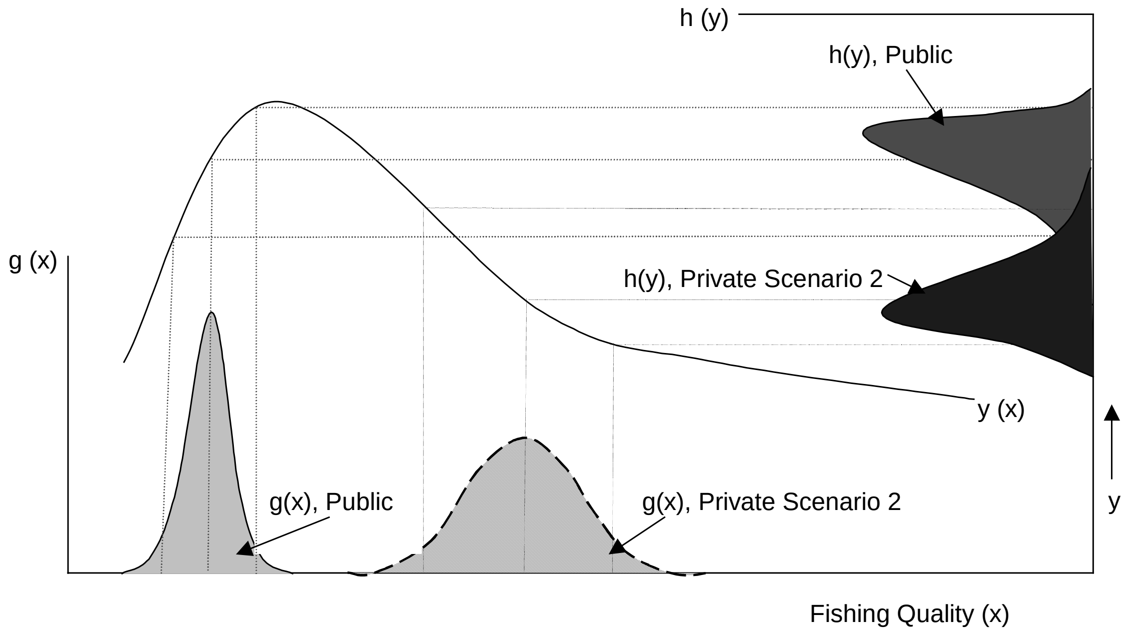


Figure 19. Hypothetical cross-sectional frequency distributions of fishing quality as perceived by anglers (x) and fish population density, public vs. private lakes. A mobile subset of expert, avid anglers effectively “flatten” fishing quality across lakes (Beard et al. 2001, Cox et al. 2001). This suggests an outcome in which the frequency distribution of fishing quality across lakes is lower and “tighter” for public lakes than for private lakes, because the subset of mobile, avid anglers more easily exploit public lakes than private lakes. Given a specified relationship between variables x and y, the frequency distribution of y for public and private lakes can be mapped from the frequency distributions for x.

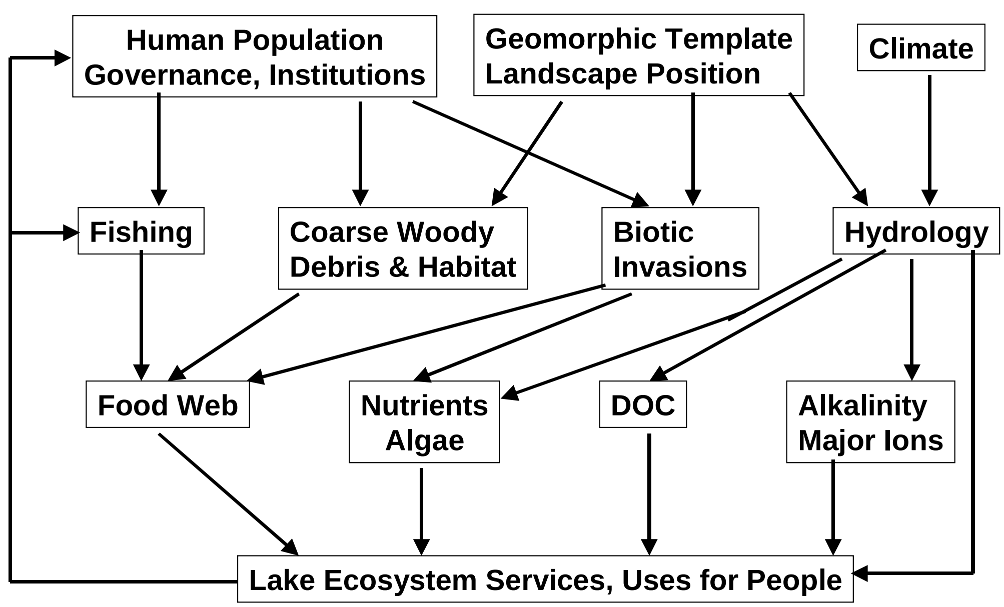


Figure 20. Major interactions hypothesized to affect long-term change in North Temperate Lake districts.

VI. FORECASTING LONG-TERM CHANGE

Multi-scale ecological observations, combined with emerging capabilities in coupled systems modeling, will rapidly accelerate our ability to forecast ecosystem change in the future. In addition to being an important research frontier, ecological forecasting offers managers and policymakers a capacity to anticipate potential environmental changes (Clark et al. 2001, Carpenter 2002). With this proposal, we introduce ecological forecasting as a new component of NTL LTER. It is natural for a program focused on long-term change to look forward as well as into the past. Conceptual frameworks and models developed to forecast will integrate and synthesize our long-term research, and the forecasts become hypotheses to be tested by future long-term research.

Over the next 50 years, the freshwater and terrestrial ecosystems of temperate lake districts may exhibit complex responses to several driving forces, including climatic variability, climate change, CO_2 fertilization (through the effects on C and water cycles), nutrient fertilization (through atmospheric deposition, and fertilizer input), land use and cover change, fishing, and lakeshore management. To some extent, we have already embedded forecasting in our research. We have developed forecasts of blue-green algal bloom frequency (Lathrop et al. 1998), dynamics of CWD (Turner 2002), impacts of invasive species (Reed-Anderson et al. 2000b, Hrabik and Magnuson 1999), and potential effects of climate change on lakes (DeStasio et al. 1996). All of these efforts have focused on selected, specific drivers and responses. However, no systematic, integrated evaluation of future change has yet been attempted for our lake districts.

We will develop and apply methods for forecasting changes in hydrological and biogeochemical processes of temperate lake districts. These changes derive from a complex web of interactions that involve both biogeophysical and socio-economic drivers and responses (Fig. 20). Over the next six years, we will focus on three objectives: (1) developing and testing integrated models for projecting hydrologic and biogeochemical changes; (2) creating scenarios for plausible future trajectories of important demographic and biogeophysical drivers; and (3) combining these to generate forecasts and hypotheses for long term change in our lake districts.

Integrated Models: Development and Testing

Forecasts involve synthesis of observations using models. We will build a new integrated regional environmental modeling system to evaluate large-scale changes in regional hydrological processes (including changes in terrestrial water balance, surface- and ground-water flows, and lake water budgets), and biogeochemical cycles (including regional-scale flows of carbon, nitrogen, and phosphorus). This system will link existing models of terrestrial ecosystems, surface hydrology, and groundwater transport and will include representations of human activity (e.g., land use, lake management practices) and changing environmental driving conditions (e.g., climate, climatic variability, atmospheric CO_2 concentration).

The modeling system (Fig. 21) will couple the IBIS terrestrial ecosystem model (Foley et al. 1996, Kucharik et al. 2000, Lenters et al. 2000), the HYDRA surface hydrology model (Coe 2000, Coe and Foley 2001, Donner et al. 2002, Fig. 26), and an analytic-element groundwater transport model (Hunt et al 1998, Walker and Krabbenhoft 1998, Fig 22) together with specific solute transport modules (Donner et al. 2002). These models will form the biophysical and ecological basis of the regional modeling system. Next, we will develop a human activity module to characterize management practices (e.g., lakeshore management, land cover change, fertilization and tillage practices, and crop and forest rotation practices). Finally, these sub-models will be linked through a common environmental change module, which will characterize changes in climate and atmospheric chemistry. We will use this modeling system to examine the sensitivity of lake districts to multiple environmental and social drivers, including changes in climate, climate variability, land cover and land use. Examples of results from preliminary model runs include monthly simulated water balance for the Trout Lake watershed (Fig. 23), crop yield and soil water balance for an agricultural field (Fig. 24), and simulated spatial dynamics of water recharge in the Trout Lake watershed from two models, a water balance model (Fig. 25 upper) and IBIS ecosystem model (Fig. 25 lower).

In order to test our regional modeling system, we will examine how human and environmental drivers have affected terrestrial and aquatic ecosystem processes during the last two decades recorded in NTL LTER data. Specifically, we will drive the integrated modeling system with historical data representing changes in climate, atmospheric CO_2 concentration, lake management practices, land cover, and land use practices (tillage practices, fertilizer use, irrigation, urbanization). This exercise will contribute to our understanding of these systems, and allow us to test our ability to meaningfully diagnose changes in hydrological and biogeochemical processes with available data.

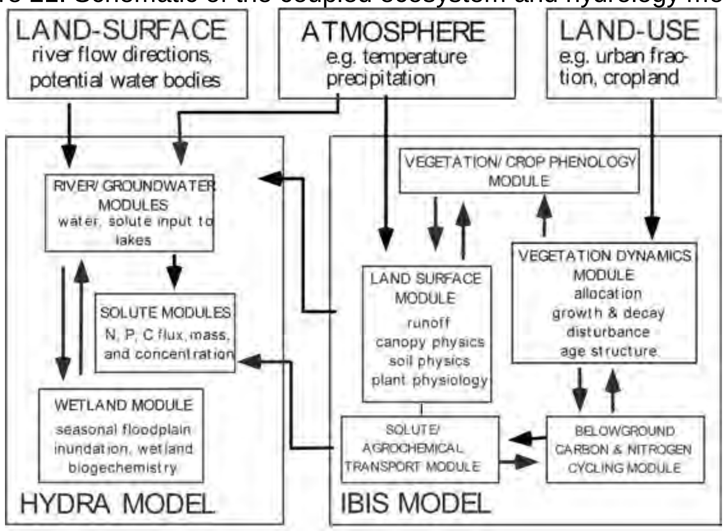
In order to improve our understanding of temperate lake districts, and how they may respond in the future, we must examine their sensitivity to various drivers. We will conduct a thorough sensitivity analysis with the regional modeling system. This analysis will consider effects of changing combinations of driving factors, nonlinearities, and threshold responses.

Scenarios for Demographic and Biogeophysical Drivers

We will focus on selected drivers for which quantitative scenarios can be constructed during the next six years: human population and settlement patterns, and changes in climate related to changes in atmospheric chemistry.

Past and future extent of residential development: For Madison-area watersheds, historical and current patterns of land development are available from our own core data and county land-use planners (Table 3, Bennett 2002). NTL researchers and county governments have developed projections of future development which will be used in scenario analyses (e.g. Soranno et al. 1996).

Figure 21. Schematic of the coupled ecosystem and hydrology models.



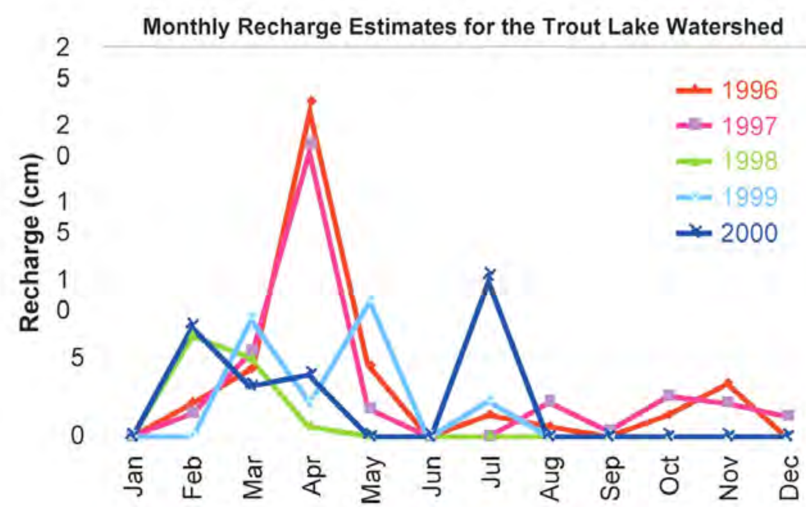


Figure 23. Monthly simulated soil water balance. Average recharge estimates for Trout Lake watershed (in cm).

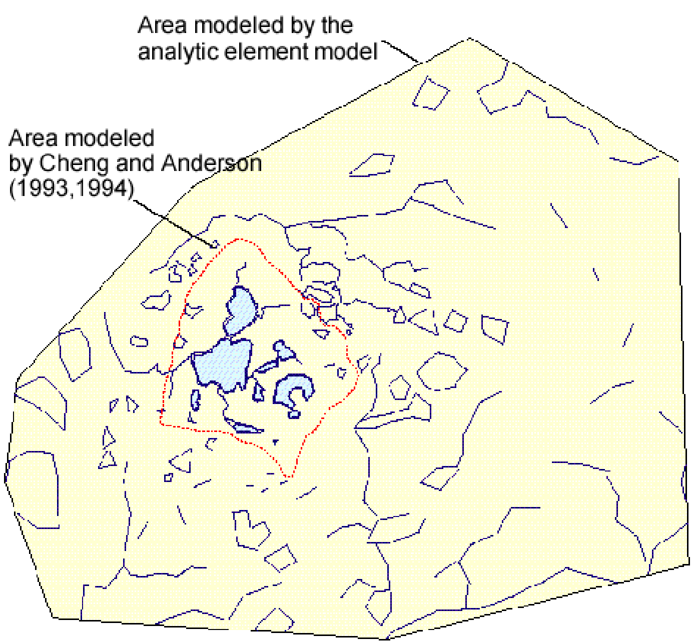


Figure 22. Example of the area analytic approach to groundwater modeling. The area of basin simulated with traditional groundwater model is shown in red dotted watershed (Cheng and Anderson 1993,1994). The efficient model architecture of the analytic model allows for much greater simulated area. This technique will be incorporated into our existing ecosystem/surface hydrology model.

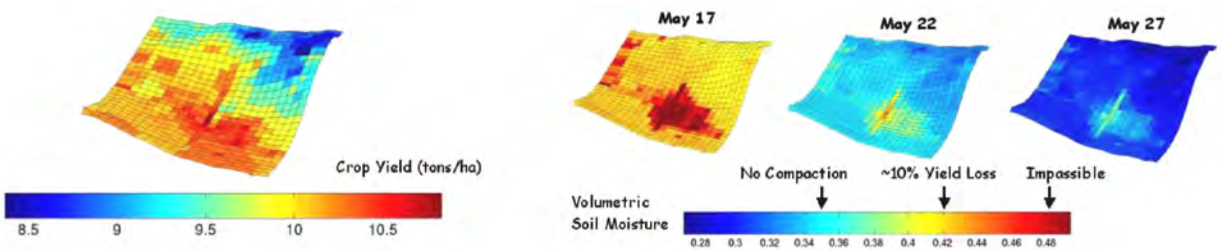
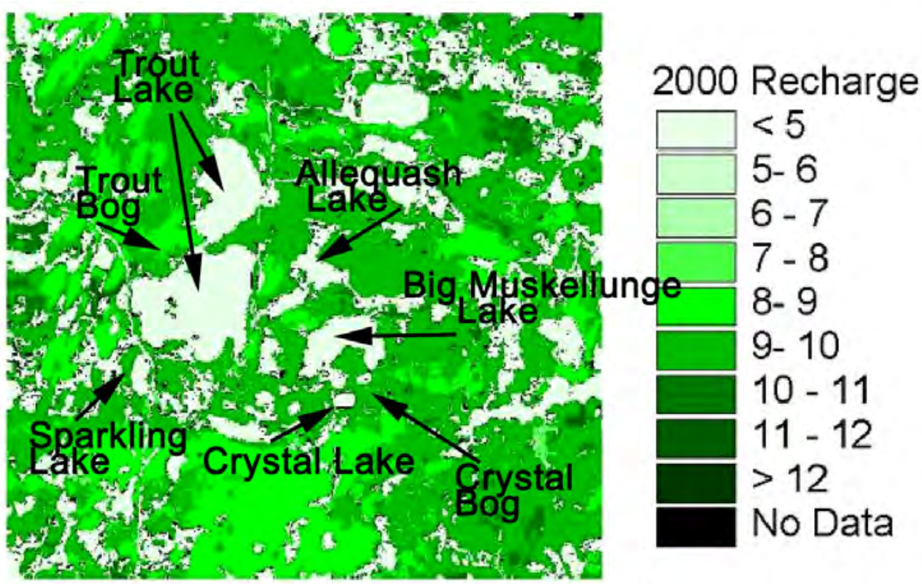


Figure 24. Illustration of IBIS simulations at very high resolution. IBIS simulated maize yield (left) and changes in May soil moisture (right figures) in 1999 for an individual field (125 m x 125 m) at the Arlington Agricultural Research Station in Arlington, Wisconsin. Each grid cell represents a 5 m x 5 m area. Gridded information such as texture, topography, and depth of a horizon were used as model inputs. Hourly micrometeorological data were used to drive the model.



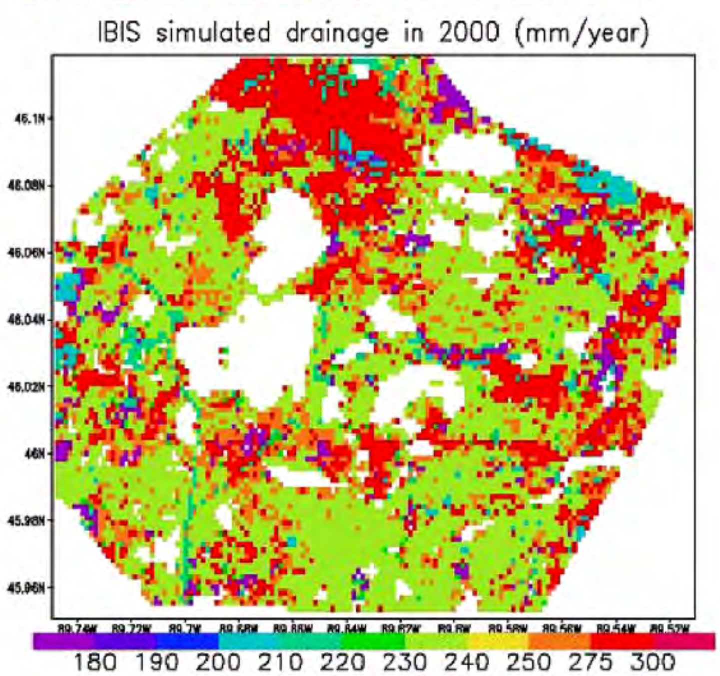


Figure 25. Example of simulated groundwater recharge from water balance model (top) and IBIS ecosystem model (bottom). The primary study lakes are labeled.

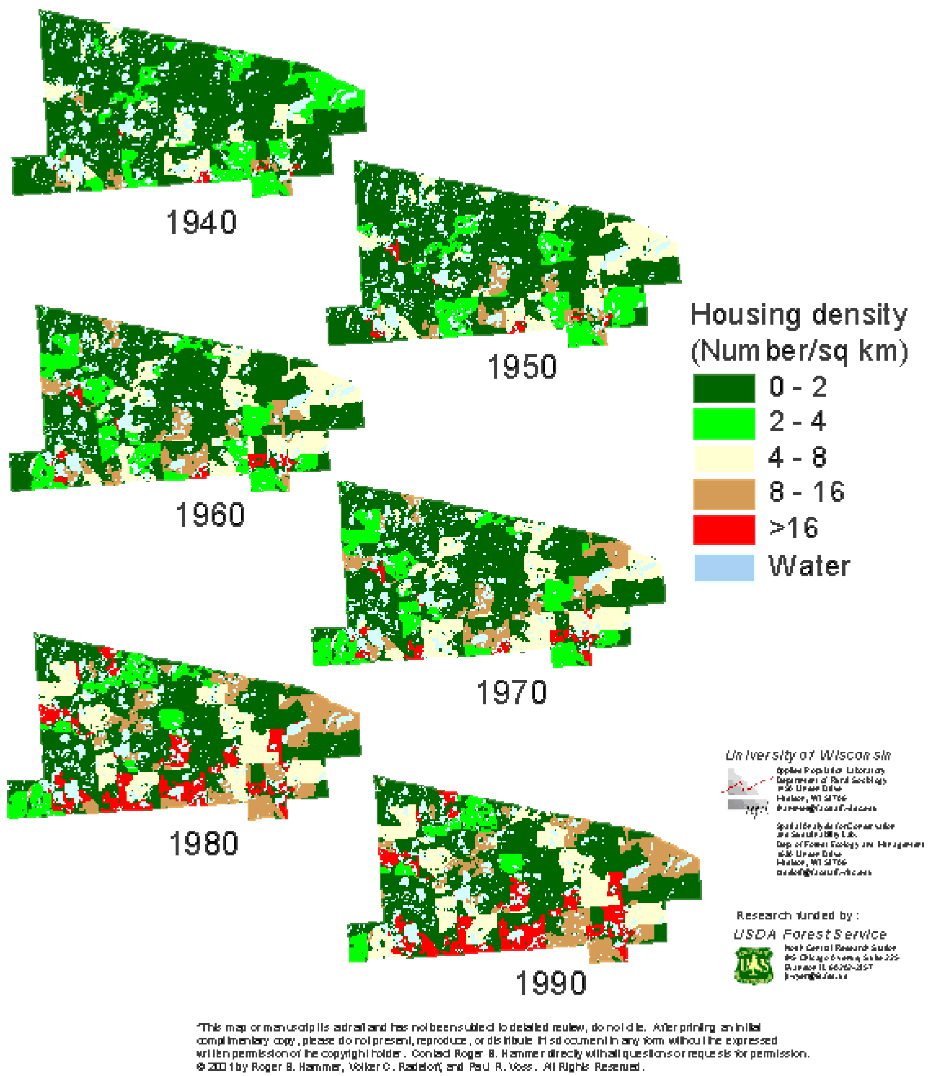


Figure 26. Housing density in Northern Highland Lake District, Vilas County, Wisconsin, 1940-1990. DO NOT CITE OR REPRODUCE.

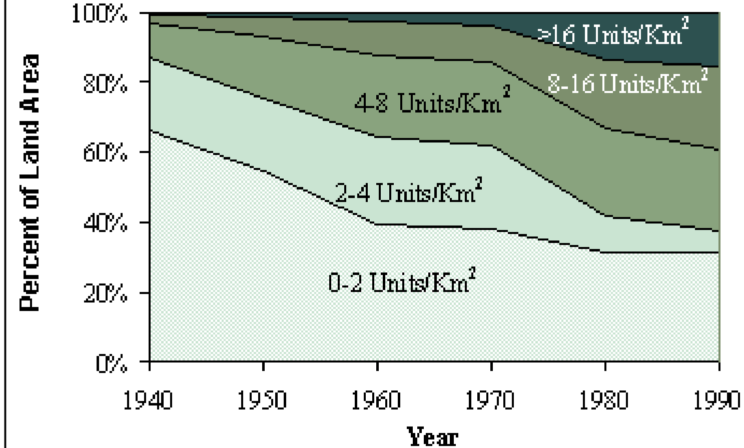


Figure 27. Percent of land area by housing density (units/square kilometer), 1940-1990 Vilas County, Wisconsin.

In the Trout Lake region, we will build on work of Schnaiberg et al. (2002) and Hammer et al. (in review,a). In 1990, the southern tier of Vilas County and the adjacent communities in Oneida County represented the largest consolidated cluster of high housing density (≥ 8 housing units km^{-2}) in the northern portion of the state. During the period from 1940 to the present, Vilas County experienced a distinctive pattern of growth, especially in areas proximate to large lakes and chains of lakes (Fig. 26). Between 1940 and 1990, the land area in Vilas County with eight to sixteen housing units per square kilometer increased nearly 10 fold, while the area with greater than 16 housing units per square kilometer increased nearly 20 fold (Fig. 27). In the next phase of this project, we will update these housing density estimates to include the 2000 Census and make projections of housing density to 2050. Projections will be a component of the integrated regional modeling system. We will also prepare finer-grained (i.e. Census Block Level) estimates of housing density for 1990 and 2000, to facilitate the assessment of lake-front development that occurred during the decade.

Past and Future Climate of the Lake Districts: We will generate future climate scenarios for temperate lake districts by combining the predictions of climate simulations by General Circulation Models (GCM) from the National Center for Atmospheric Research (NCAR) and the UK Hadley Center, along with historical climate data over our region. By blending historical climate data and GCM simulations, we will create a 50-year dataset of meteorological drivers (including temperature, precipitation, and solar radiation). The atmospheric concentration of CO_2 has a direct impact on plant physiology and ecosystem processes (in addition to its role as a greenhouse gas). Therefore, hypothesized increases in atmospheric CO_2 concentrations to 500-700 ppmv by 2050 will also be used.

A continued increase in the concentration of greenhouse gases in the atmosphere may result in an increase in frequency and severity of extreme weather events (IPCC 2001). A number of studies have noted that a substantial proportion of nitrate leaching from the terrestrial system occurs during heavy precipitation and flood events (e.g. Creed and Band 1998a,b). In our work, we will explore changes in climatic variability and extreme events such as prolonged droughts (Webster et al. 1996, 2000), on simulated hydrological and biogeochemical processes.

Forecasts and Hypotheses for Long-Term Change

We will use the regional modeling system to derive simple regional environmental indicators to diagnose and document large-scale changes in hydrologic and biogeochemical processes across temperate lake districts. For example, changes in the proportions of rainwater, groundwater, and surface water entering a lake are important clues to biogeochemical change (Webster et al. 2000). Such indicators will be used to diagnose locations where terrestrial and aquatic systems may be undergoing significant changes. In addition, we will conduct several more detailed case studies, where we will validate our modeling approaches with detailed datasets.

For our lake districts, we will develop a set of quantitative scenarios of future hydrologic conditions. The scenarios will be designed to span the range of possible outcomes based on plausible ranges of drivers and quantified uncertainties in the model. By formalizing these scenarios, we will be able to evaluate them against our database as it evolves. The forecasting component of NTL LTER is one of "learning by doing." Our capacity to forecast can be improved only by constructing forecasts, criticizing them rigorously in light of data, and then creating improved models and procedures for a new cycle of learning.

VII. SYNTHESIS AND SIGNIFICANCE

The research we propose will address key challenges in ecology that are of global importance. We focus especially on how four of the most important changes of global significance (climate, land use/land cover, introduction of species and biotic mixing, and movement of materials and solutes from terrestrial to aquatic ecosystems) will influence north temperate lake ecosystems. These drivers are ubiquitous. We address them at a variety of levels of organization, over a wide range of spatial and temporal scales, and in lakes in a rural, forested setting and in a rapidly changing agricultural/urban landscape (Fig. 28). Our basic understanding of how ecosystems respond to change will be integrated in forecasts of future ecosystem states. We also will consider key questions that represent important research frontiers in ecology—for example, understanding the linkage of community structure and biodiversity to ecosystem function, the complex dynamics of the integrated hydrosphere, the spatial and temporal scales over which spatial dependencies are important, and the ecological effects of species invasions.

In addition to generating new understanding about lake ecosystems, we will make innovative conceptual contributions that are of broad relevance to ecology. The National Academy of Sciences identified eight "Grand Challenges" for environmental science (NRC 2001). Research proposed here is directly relevant to six of the eight Grand Challenges: biogeochemical cycles; biodiversity and ecosystem functioning; climate variability and its consequences for ecosystems; hydrologic forecasting; institutions and resource use; and land use dynamics. Forecasting future scenarios is another innovative objective of our proposal (Clark et al. 2001). With our focus on understanding the conditions that may produce qualitative changes in lake districts, the proposed research will enhance understanding of threshold dynamics, feedbacks, spatial dependencies and disproportionalities at many scales. The potential for small changes to produce surprising and large responses is of particular importance for constructing and analyzing scenarios of future change.

High-quality, long-term datasets have been intimately connected to past scientific advances at our site, and are directly involved in our future plans (Fig. 29). The length and quality of the observational record affords new insights about lake dynamics at scales ranging from individual lakes to large regions. Ecosystems are complex systems in which change derives from multiple factors acting across a range of spatial and temporal scales. Disentangling cause and effect requires long-term data, and we will

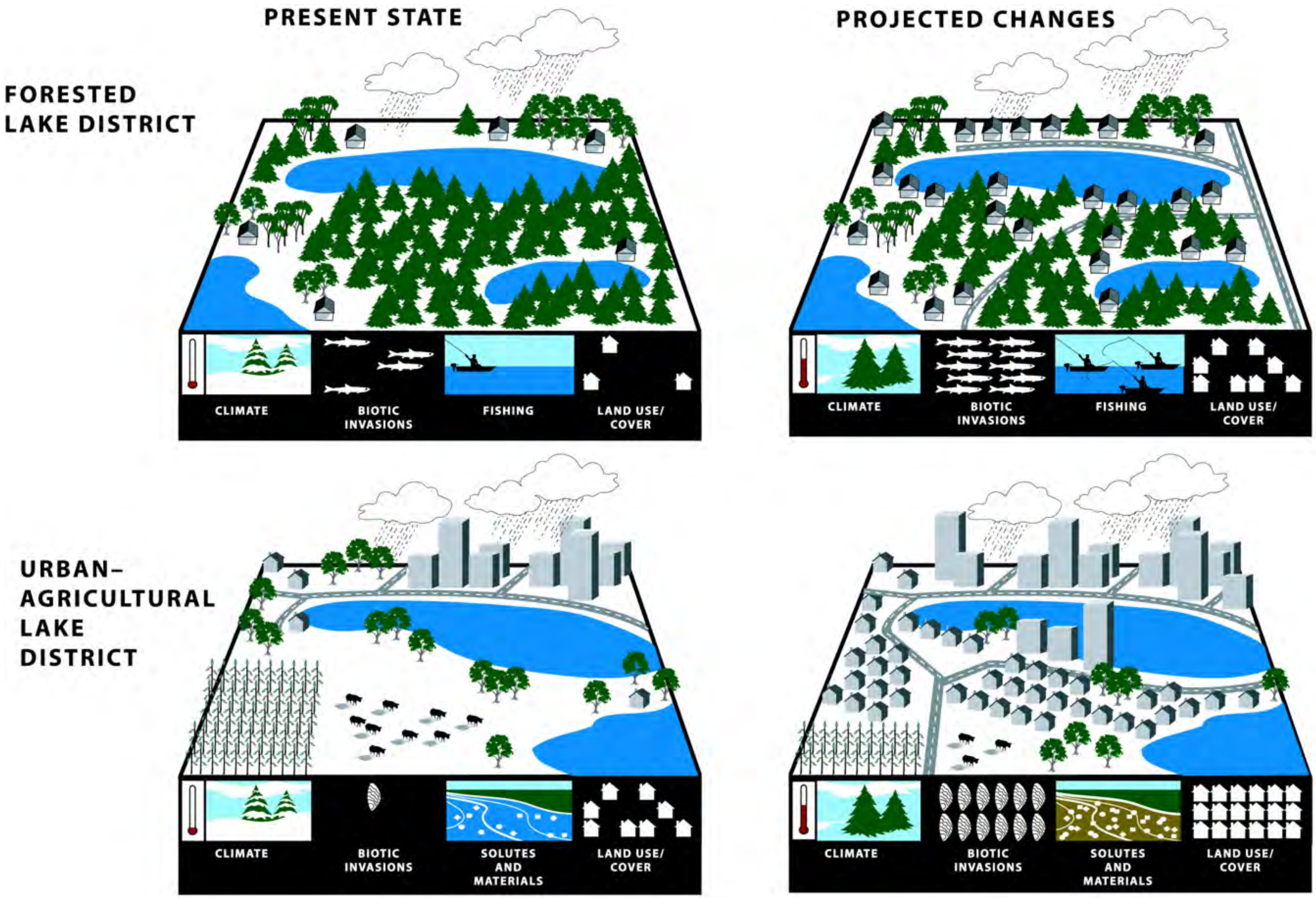


Figure 28. Present state and projected changes in the forested northern and agricultural/urban southern study landscapes.

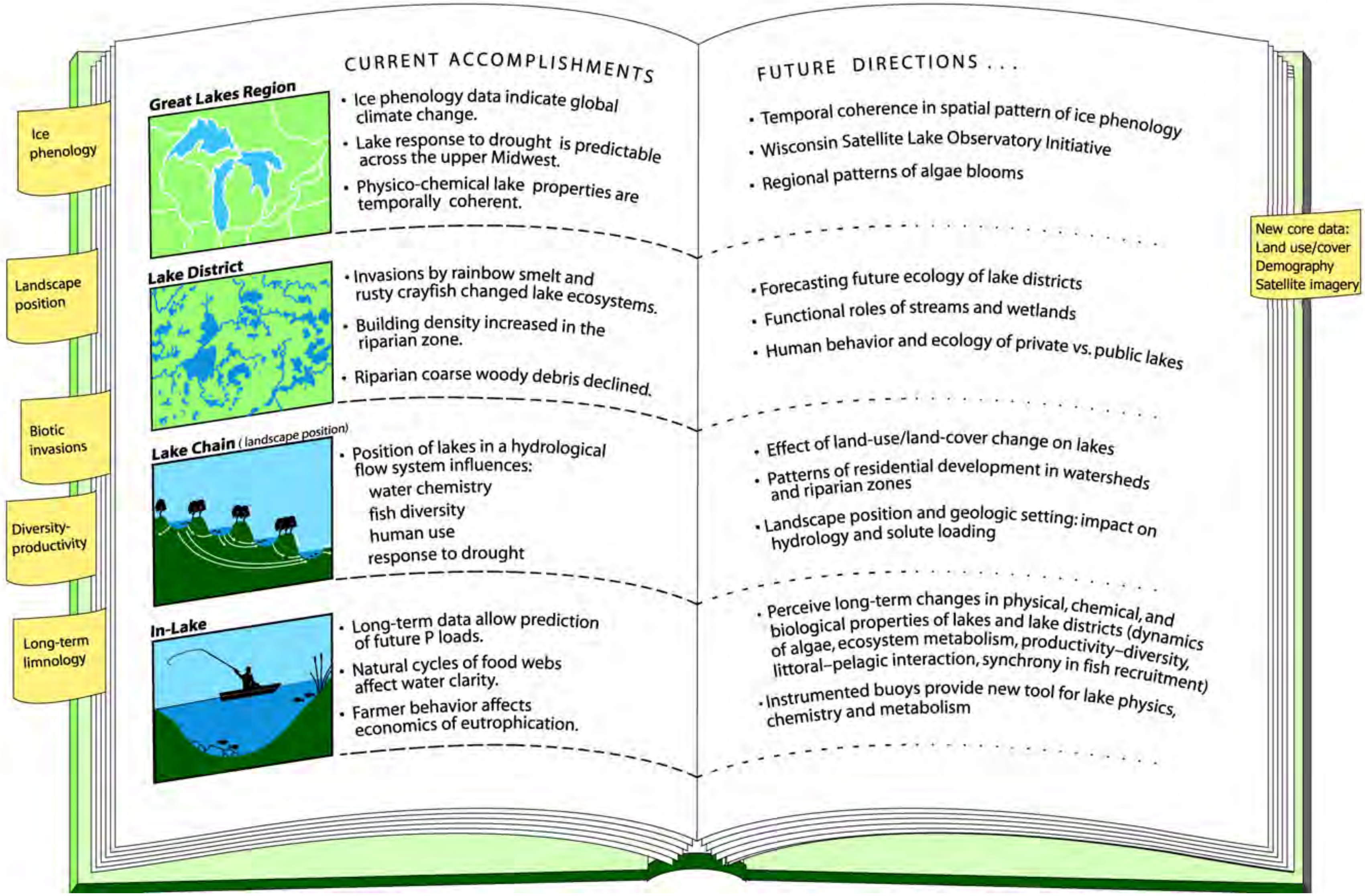


Fig. 29. Current and future chapters of the NTL-LTER program summarized for regional, lake-district, lake-chain, and in-lake spatial scales, with tabs denoting a few key data sets.

continue to build and use our long-term database. Our long-term research provides an opportunity for studying natural experiments through analysis of regional variability, historic data, and both episodic and chronic events. The core data sets will also be augmented to include new variables that reflect the interdisciplinary work we initiated during the current grant cycle. In addition, we will use new technologies (e.g., instrumented buoys and advances in remote sensing) to improve and expand measurements of key limnological variables.

The work at the NTL LTER site has been characterized by multiple approaches to question-driven science, including observational or comparative studies, experimental studies, modeling, and development of theory. Long-term observations and cross-system comparisons are a hallmark of LTER research. We are engaged in a major management experiment on eutrophication of Lake Mendota. We are also collaborating on three whole-lake manipulations under separate NSF funding. A core LTER lake, Sparkling Lake, is the site of a whole-ecosystem experiment on exotic species removal. We are also collaborating in whole-lake manipulations of littoral habitat in two lakes near Trout Lake Station. Finally, modeling for synthesis and ecosystem forecasting is a new major feature of this proposal.

Interdisciplinary studies are strongly developed at our site. We have a well-integrated approach that considers biophysical setting, climate, and land-cover change. In particular, we have effectively considered how humans interact with aquatic ecosystems at many scales. For example, understanding LULC patterns, changes and effects on aquatic ecosystems; community- and ecosystem-level effects of fishing; and forecasting future scenarios require fundamental contributions from both natural and social sciences. We will continue in this tradition, as we recognize the unique contributions of each approach and from different disciplines. Furthermore, we will continue to conduct our research across a range of temporal and spatial scales—from within-lake analyses to the Great Lakes region, and from short- to long-term dynamics (Fig. 29).

NTL research has been and will continue to be directly relevant to management and policy. Results from NTL LTER research have informed decisions that affect water quality made by the Wisconsin Department of Natural Resources (DNR) and the Dane County Lakes and Watersheds Commission. We actively collaborate with staff in state and federal agencies and participate in joint experiments (e.g., P reduction in Lake Mendota) and monitoring programs (e.g., USGS groundwater monitoring). In addition to these pragmatic activities, LTER research will continue to address fundamental issues in the theory of ecosystem management (e.g. www.consecol.org/vol3/iss2/art4).

NTL LTER research has produced new insights and has consistently contributed to fundamental knowledge of the long-term ecology of lakes and their interactions with important landscape, atmospheric and human processes (Fig. 29). As we begin a new chapter of LTER research, we will continue in the tradition of addressing fundamental scientific questions that demand a solid foundation of long-term, sustained research.

Section 3. Project Management

Project Governance: Direction of NTL-LTER is provided by Carpenter with the participation of the Principal Investigators, research staff, and students. We have no formal executive committee, although on certain issues Carpenter consults with a subgroup of relevant PIs. All PIs meet monthly for an hour to plan and advise on program, personnel, and budget decisions; minutes are taken. We normally operate by consensus with Carpenter acting on hard choices. The entire group of researchers meets monthly for two hours to discuss scientific results, concepts, and plans. In addition, subgroups of researchers meet frequently to work on projects, both on the Madison campus and at Trout Lake Station.

Our PIs are involved in LTER Network activities including the Executive Committee (Kratz 97-01), the Steering Committee for Information Management (Benson), and Committee on Scientific Initiatives (Carpenter, Magnuson). Many PIs have attended network meetings on various specialized topics. More than 25 NTL researchers participated in the LTER All-Scientists meeting in 2000.

Project Administration: The project is administered through the Center for Limnology (College of Letters and Sciences, University of Wisconsin-Madison). The Center has field stations at both primary sites (Trout Lake Station in northern Wisconsin, and the Laboratory of Limnology in Madison). Both sites have a LTER site manager (Kratz in the north, Lathrop in the south) and LTER field technicians. Information Management (led by Benson) is concentrated in Madison, at the Laboratory of Limnology. Spatial analyses and modeling also occur in Madison, in the Environmental Remote Sensing Center (directed by Lillesand), the Landscape Ecology Laboratory of Monica Turner, and the Center for Sustainability and the Global Environment (directed by Foley). Chemical analyses supervised by Stanley are conducted in the Laboratory of Limnology and adjacent Water Chemistry Laboratory. PIs (Table 5) are based at Trout Lake or around the Madison campus in three colleges and 11 departments. Two PIs are agency personnel based in Madison: Lathrop (Wisconsin Department of Natural Resources, the state management agency) and Walker (U.S. Geological Survey). Most graduate students receive degrees in Limnology and Marine Science, Zoology, Water Chemistry, Environmental Monitoring, or Rural Sociology, but degrees can come from any academic unit as our project evolves.

Project operations come from Carpenter, Sarah Carter (fiscal officer), Barbara Martinez (project officer) and secretarial staff in Madison and at Trout Lake.

The College of Letters and Sciences provides substantial direct costs annually for Center management, operations, and general building services which directly benefit LTER. Half of Carpenter’s academic year salary is covered by an endowment which represents a substantial subsidy to LTER. Additional college funding exercises provide support for capital equipment, remodeling, and facilities upgrades. When direct costs paid by the college, endowment funds, equipment and remodeling monies are accounted for, the actual overhead rate on the LTER grant was –6% (i.e. a net subsidy) from 1997-2001. This rate was calculated as 100 * (NSF indirect cost – total UW contribution) / NSF direct cost.

PI Additions: The PI roster (Table 5) has some new names. Emily Stanley (biogeochemistry) has assumed leadership of the NTL-LTER chemistry lab. We have added two social scientists, Roger Hammer (demography) and Bill Provencher (economics) to bolster our interdisciplinary capabilities. We have added a physical limnologist (Chin Wu). In May 2002, Dr. James Rusak will join the project, bringing his expertise in plankton ecology, paleolimnology, and multivariate statistics.

Coordination with other Projects: NTL-LTER is the central axis of a portfolio of grants with interlocking groups of PIs. These include NSF grants for IGERT on Integrated Social and Aquatic systems (lead PI Nowak), Microbial Observatory (lead PI Triplett), and BioComplexity (lead PI Carpenter); an EPA award for research on subwatersheds of Lake Mendota (lead PI Lathrop); and a USGS Water, Energy, and Biogeochemical Budgets project based at Trout Lake (led by Walker). We collaborate regularly with staff from the state management agency (Wisconsin Department of Natural Resources). We have maintained an active collaboration with other research groups focused on lake districts in Canada, Germany, and Japan.

We encourage others to use our LTER site by posters and talks at national and international meetings; an informative web page (lter.limnology.wisc.edu); an open policy of sharing data in collaborative research; and by helping to develop joint projects with other scientists. We often waive user fees at Trout Lake Station to encourage startup of pilot projects. We regularly write letters in support of researchers at other universities who wish to use our sites.

Table 5. Principal Investigators and senior staff involved in NTL-LTER.

PI	**Department**	**Specialty Area**
Timothy Allen	Botany	Complex systems, hierarchy theory
Mary Anderson	Geology and Geophysics	Hydrogeology
David Armstrong	Water Science & Engineering	Biogeochemistry
Barbara Benson	Limnology	Ecoinformatics
Carl Bowser	Geology & Geophysics	Geochemistry
Steve Carpenter	Zoology	Ecosystem studies, social-ecological modeling
Jonathan Chipman	Environmental Remote Sensing Center	Satellite remote sensing/landcover imaging
Stanley Dodson	Zoology	Community ecology, toxicology
Jonathan Foley	Atmospheric & Ocean Sciences	Regional hydrologic and biogeochemical models
Linda Graham	Botany	Eukaryotic aquatic microbiology
Paul Hanson	Limnology	Computing systems, wireless data acquisition
Roger Hammer	Rural Sociology	Population growth, residential development
Thomas Heberlein	Rural Sociology	Environmental attitudes, behaviors
Tim Kratz	Limnology	Lake landscape ecology
Dick Lathrop	Wisconsin Department of Natural Resources	Lake and watershed management
Tom Lillesand	Environmental Remote Sensing Center	Remote sensing
John Magnuson	Zoology	Fish ecology, Limnology
Pete Nowak	Rural Sociology	Agricultural systems
Robert (Bill) W. Provencher	Agricultural & Applied Economics	Economics
Emily Stanley	Zoology	Biogeochemistry, river ecology
Eric Triplett	Agronomy	Microbial ecology/function in lakes
Monica Turner	Zoology	Landscape ecology
Jake Vander Zanden	Zoology	Aquatic food web dynamics
Paul Voss	Rural Sociology	Demographic, migration modeling
John Walker	US Geological Survey	Hydrology
Chin Wu	Civil & Environmental Engineering	Physical limnology

Section 4. Information Management

Philosophy and Goals

Information management is an integral part of our research process. The NTL LTER data and information system is designed to facilitate interdisciplinary research. From the design of data collection, to incorporation in the centralized database, to analyses, we focus on linkages among the components of the ecosystems we study. Primary goals are to (1) maintain database integrity, (2) create a powerful and accessible environment for the retrieval of information, and (3) facilitate linkages among diverse data sets.

Information Management Infrastructure

NTL LTER has computer facilities at the Lake Mendota Laboratory, the Trout Lake Station, the Environmental Remote Sensing Center, and other associated laboratories. Specific details on networking, the web and database servers, backup protocols, and other components of the infrastructure are presented in Table 6 and the Facilities section of this proposal.

Personnel

Barbara Benson has been our information manager since 1983, providing stability and continuity to information management and its linkage to our science. With a Ph.D in ecology, she is directly engaged in design of research and frequently serves as lead or co-author of ecological papers in addition to papers on information management. She consults with students and other researchers on research data management. Our remote sensing/GIS specialist, Jonathan Chipman, has a Ph.D. in remote sensing and is appointed jointly at the Center for Limnology and the Environmental Remote Sensing Center (ERSC). A laboratory manager maintains the LAN and computers at the Center for Limnology. Two persons with backgrounds in computer science assist the information manager.

Data Sharing

Our longstanding policy is that all core data sets are available as soon as possible to all project PIs and staff. Core data sets are collected and managed centrally as opposed to being collected and managed by individual PIs. Thus, at our site, getting researchers to contribute data to the LTER database is not an issue. Meteorological and physical limnology data are available within a month, fish data within two months, and other data, including chemical limnology and other biological data, within a year but often sooner.

We encourage collaborative explorations of our data (Table 2, Supplementary Documents Section). Our policy is to provide all core data prior to the most recent two years on-line on the web. Meteorological data are placed on-line as soon as they have been incorporated into the LTER database (Table 1, Supplementary Documents Section, shows the status of data availability). Our data access policy is available on the

NTL home page. Researchers who wish to access additional data or information must contact Steve Carpenter directly.

NTL Database

Most of the core data collected by NTL (Table 3) reside in the Oracle database. Other data are maintained in text or spreadsheet format. NTL spatial data are stored on file systems at ERSC and the Center for Limnology and are fully accessible to NTL researchers. Core data are available to all NTL researchers as soon as the data are entered and quality screened. Non-core data of general interest such as regional limnological surveys are also maintained in Oracle as are data from associated projects (e.g., the NTL Microbial Observatory).

Data are entered, updated and maintained in the Oracle database using scripts and applications on the Sun Sparc Ultra2 workstation as well as through use of an application installed on networked Windows workstations. Some data are entered into the Oracle database directly through an application installed on the NTL web site. Data from the Oracle database are made available for viewing and/or downloading over a network connection by several methods (see Table 6). The Oracle database has broad functionality to maintain database integrity (e.g., passwords for access, privileges and roles to control read/write, recovery from system crashes, backup utilities).

Data Access and Analysis

The client/server environment provides researchers with the powerful search and linkage capabilities of a relational database together with an end-user query tool for simple, direct access. Currently, most researchers use an end-user query tool with a point-and-click interface. A researcher may retrieve information from the database to answer questions such as "What was the average epilimnetic chlorophyll concentration in Trout Lake during the ice-free season for each year since 1982?" The relational database supports the linking of the chlorophyll concentration table with the ice duration table, and the subsetting and aggregation that this request entails. An alternative way to access data is through text files available on the NTL web site (lter.limnology.wisc.edu) (Table 1). Links to on-line data are found within the on-line data catalog that also supplies the supporting metadata.

Information management staff provides support by developing data acquisition tools for technicians and data analysis for researchers. To speed data acquisition and reduce data entry errors, custom software has been written for recording fish field data, counting zooplankton, and analyzing fish scales. Numerous programs have been written to manipulate raw data into forms requested by researchers (e.g., hypsometric averages of depth profile data, estimation of mixed layer depth, histograms of fish lengths). Views are created within the Oracle database to provide researchers with useful joins of the Oracle tables.

Metadata

Metadata are a crucial part of our information system. Each on-line data set has associated header information including data set title, document update date, investigators, contact person, temporal and spatial resolution, descriptive abstract, study areas, variable description and units of measurement, variable codes, and file format. Metadata for spatial data include copyrights, map scale, thematic and map accuracy, and data lineage information. Field and lab methods are documented for each core data set and available on-line for most data sets.

We are restructuring the metadata associated with the NTL core data sets to be compliant with emerging standards, in particular, Ecological Metadata Language (EML), a metadata standard based on the emerging XML Schema specification. EML is the standard adopted by the LTER Network. The restructured NTL metadata will reside in Oracle and will be retrieved in conjunction with dynamic database access through the web.

Quality Control

A number of different quality-control mechanisms have been established. For example, the sampling and analysis protocol for physical and chemical parameters includes random blind samples and replicate analyses at about the ratio of 1:10 (replicate:sample). Quality control in the chemical results is checked by ion balances, calculation of critical parameters from a redundant data set, and visual verification. Error checking occurs in the data entry software and proofreading. Data sets have a system of flags to indicate quality conditions such as non-standard routine or equipment used.

Intersite Information Management Contributions

The NTL information manager is a member of IMExec, the steering committee for the LTER Information Managers, and the LTER Network Information System working group. For the 2000 LTER All Scientists Meeting, she was chair of the Organizing Committee for Information Management Workshops and co-organizer of a workshop entitled "Partnership between Long-term Ecological Research and Information Management: Successes and Challenges" and a follow-up working group, "Advancing the Sharing and Synthesis of Ecological Data: Guidelines for Data Sharing and Integration", (June 2001).

Future Directions and Challenges

We anticipate a long-term commitment to providing data sets on the NTL web site. The universal access of the web makes our web site the main entry point for external data distribution. We have constructed a prototype interface between the web and the Oracle database to add query functionality to data on the web site. This prototype also contains a form for users that will allow us to track data use. We propose a full implementation of this prototype.

Table 6. North Temperate Lakes LTER Information Management Infrastructure

Local Area Networks (LAN)	Windows NT LAN supporting Macintosh and Windows-based microcomputers at the Lake Mendota Laboratory and Trout Lake Station, Sun workstation, laser and color printers, slide maker, scanner *
Connection to WANs	Lake Mendota Laboratory LAN linked by a 10baseT connection to the campus-wide WAN; Trout Lake Station connected via a T1 land line
Web Server	Apache web server running on the Sun Sparc Ultra2 workstation (Solaris 7 operating system)
Database	Oracle 8.1.7 RDBMS installed on the Sun Sparc Ultra2 workstation
Data Retrieval	Oracle Browser application installed on networked Windows workstations; ODBC connections on networked workstations with installed Oracle Clients; text-formatted data on the NTL web site; dynamic query of the database through the NTL website (meteorological data).
System Backup	Daily backups of the Sun workstation to DAT tape; daily Oracle database exports; regular backups to tape of data on microcomputers; backups of spatial data to CD-ROM
Wireless Communication	Serial to field equipment/sensors; Ethernet for computers and some sensor systems
Video Conferencing Equipment	PC with Microsoft NetMeeting software, video camera, computer projector, document scanner, electronic tablet
Remote Sensing	Space Science and Engineering Center (SSEC) X-band satellite receiving antenna and ingest capability

* Computer facilities at the Center for Limnology are described at limnology.wisc.edu/Lake_Mendota_Lab/computerroom.htm

Section 5: Outreach

NTL-LTER personnel have engaged in many important outreach and professional service activities, and will continue to do so. In this section we describe our educational and public activities, media interactions, and implications of our research to policy and management.

The main focus of our educational activities is and will continue to be graduate student training. Graduate students are an intrinsic component of NTL-LTER research who figure prominently throughout our proposal. LTER funds supported 30 M.S. and Ph.D. students over the past six years who produced a total of 28 theses. These LTER-students have been highly successful in research productivity, in obtaining additional non-NTL-LTER support, and in obtaining post-graduate positions. The contribution of graduate students to NTL-LTER is highly valued and will always be encouraged.

Our program provides undergraduate students with extensive and rewarding first-hand research experiences. We involve 3-5 Research Experience for Undergraduate (REU) students every year in our summer LTER and related activities. We employ undergraduates as hourly workers to assist with summer field and laboratory work. We solicit applications for these positions from around the US and Canada. Our summer crews typically include an internationally diverse group. Many of our summer undergraduates continue on to graduate work in environmental science; we recruited several of these undergraduates to our own graduate programs. We encourage University of Wisconsin-Madison undergraduates to apply for university sponsored, summer environmental fellowships for independent research projects. Their projects often result in publishable papers. A large number of graduate students and recent Ph.D.'s trace their roots to early experiences with the NTL-LTER program. In addition to undergraduates involved directly with research, an additional 300 undergraduates each year take classes taught by NTL-LTER principal investigators and featuring NTL-LTER data. NTL-LTER data published on the web are also used by faculty at other universities in support of their teaching.

Our Schoolyard LTER program partners with six elementary and middle schools in the Trout Lake and Madison areas. Called "Limnology Explorers", the program provides hands-on lab and field experience for third and seventh graders as well as teacher training with an emphasis on winter limnology (Figure 30). These activities are led by NTL-LTER staff in partnership with the UW-Madison Center for Biology Education and the UW-Madison School of Education Outreach Saturday Enrichment Program. From participant evaluation surveys, we know that parents and students are enthusiastic about the program. Schoolyard LTER funds have been leveraged with a Dwight D. Eisenhower Professional Development Program grant awarded to Dr. Robert Bohanan at the Center for Biology Education to develop SchoolYard Science: Inquiry-Based Workshops and Research Experiences for Middle School Teachers (SYS). This program is closely allied with our Schoolyard LTER and has provided summer research experiences, curriculum development, and pedagogy workshops for practicing teachers as well as undergraduates majoring in Education.

We are also heavily involved in informal education activities. We participate annually in community activities such as leading popular nature walks; making public presentations on limnology and ecology to service organizations, lake associations and local governmental bodies; working with local to national print media to develop stories related to limnology; giving presentations to Elderhostel groups; and participating in a Northern-Highland-wide lake fair, where local residents and visitors are exposed to a variety of aquatic organisms and processes. We have open houses at the Trout Lake Station where homeowners from individual lakes are invited to discuss “their” lake and the research we are doing. NTL scientists appear on local and statewide radio and television shows to discuss water-related issues. NTL science has been featured prominently in each of the Madison Magazine’s monthly “Lake Effect” columns since its inaugural issue in January 2001. NTL research was highlighted on the Wisconsin Public Television show *Weekend*. The roughly six-minute clip showed LTER field sampling and discussed important research findings. These activities will continue.

We have deployed a sophisticated, state-of-the-art, instrumented buoy on Trout Lake. Real time data from this buoy (30 second updates) are available to the general public via the world wide web. In addition, almost all of our core data sets two years or older are publicly available via our web page.

NTL-LTER researchers participate in a wide range of professional activities such as service to National Research Council committees, the Millennium Ecosystem Assessment, State of Wisconsin Department of Natural Resources committees, the Nature Conservancy, and the Leopold Memorial Reserve. NTL-LTER personnel are active in national and international professional societies, particularly the Ecological Society of America, the American Society of Limnology and Oceanography, and the North American Lake Management Society. NTL scientists have briefed local, state, and federal elected officials on water-related issues. We are frequent reviewers of grant proposals to the National Science Foundation and other funding agencies and routine participants on review panels. Many other such activities could be listed.

Understanding the long-term dynamics of lakes allows us characterize the natural variability that lakes exhibit. Individuals and institutions can use this information to assess effects of existing or proposed changes in reference to the bounds of natural variability. Project scientists have interacted with various local, state, and federal policymakers to discuss how NTL-LTER results are useful in formulation of policy. Examples include interacting with the local County Board to explain the utility of our science to local resource management and the local economy, interacting with state agencies to develop sound policies towards exotic species, and communicating with congressional staff on issues of water resource management.

In the next six years we will continue and expand upon our education and outreach activities.

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Publications (out of 226):
Carpenter, S.R., N.F. Caraco, D.L. Correll, R.W. Howarth, A.N. Sharpley and V.H. Smith. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Applications 8: 559-568.
Carpenter, S.R., W.A. Brock and P.C. Hanson. 1999. Ecological and social dynamics in simple models of ecosystem management. Conservation Ecology 3(2): 4. Available on the internet: URL http://www.consecol.org/vol3/iss2/art4.
Carpenter, S.R., J.J. Cole, J.R. Hodgson, J.F. Kitchell, M.L. Pace,D. Bade, K.L. Cottingham, T.E. Essington, J.N. Houser and D.E. Schindler. 2001. Trophic cascades, nutrients and lake productivity: whole-lake experiments. Ecological Monographs 71: 163-186.
Bennett, E.M., S.R. Carpenter and N.F. Caraco. 2001. Human impact on erodable phosphorus and eutrophication: a global perspective. BioScience 51: 227-234.
Carpenter, S.R. 2001. Alternate states of ecosystems: Evidence and its implications. Pages 357-383 in M.C. Press, N. Huntly and S. Levin (eds), Ecology: Achievement and Challenge. Blackwell, London.

Timothy K. Kratz, Trout Lake Station, Center for Limnology, University of Wisconsin, 10810 County Highway N, Boulder Junction, WI 54512; telephone 715-356-9494; fax 715-356-6866; email tkkratz@facstaff.wisc.edu

Education:
B.S. Botany, University of Wisconsin-Madison, 1975; M.S., Ecology and Behavioral Biology, University of Minnesota-Twin Cities, 1977; Ph.D., Botany, University of Wisconsin-Madison, 1981.

Employment:
Director, Trout Lake Station, 2001-present
Assistant, Associate, Senior Scientist, Center for Limnology, University of Wisconsin-Madison, 1985-present:
Site Manager, North Temperate Lakes LTER Project, 1981-2001

Research Program:
Long-term, landscape ecology of lakes; the influence of landscape position on lake dynamics

Professional Activities:
- LTER Network Executive Committee, 1997-2000
- NSF Ecosystems Studies Review Panel, 1997-2000
- NAS National Research Council Committee on the Grand Canyon Monitoring and Research Center, 1998-1999
- NSF/EPA Decision Making and Valuation Review Panel, 1996
- NSF TECO Review Panel, 1995
- NAS National Research Council Committee on Environmental Monitoring and Assessment Project, 1991-1995
- Member: ESA, ASLO, SIL

Publications (out of 60):
Kratz, T. K., B. J. Benson, E. Blood, G. L. Cunningham, and R. A. Dahlgren. 1991. The influence of landscape position on temporal variability in four North American ecosystems. American Naturalist 138:355-378.
Kratz, T.K., P.A. Soranno, S.B. Baines, B.J. Benson, J.J. Magnuson, T.M. Frost, and R.C. Lathrop. 1998. Interannual synchronous dynamics in north temperate lakes in Wisconsin, USA. Pages 273-287 In George, D.G., J. G. Jones, P. Puncochar, C. S. Reynolds, and D. W. Sutcliffe (eds.) Management of Lakes and Reservoirs during Global Climate Change. Kluwer Academic.
Cole, J. J., N. F. Caraco, G. W. Kling, and T. K. Kratz. 1994. Carbon dioxide supersaturation in the surface waters of lakes. Science 265:1568-1570.
Kratz, Timothy K., Barbara J. Benson, Carl J. Bowser, John J. Magnuson, and Katherine E. Webster. 1997. The influence of landscape position on northern Wisconsin lakes. Freshwater Biology 37:209-217.
Baines, S. B., K. E. Webster, T. K. Kratz, S. R. Carpenter, and J. J. Magnuson. 2000. Synchronous behavior of temperature, calcium and chlorophyll in lakes of northern Wisconsin. Ecology 81:815-825.

Thomas M. Lillesand, Environmental Remote Sensing Center, University of Wisconsin, Madison, Wisconsin 53706; telephone 608.263.3251; fax 608.262.5964; email tmlilles@facstaff.wisc.edu; web site www.ersc.wisc.edu

Education:
B.S. (1969), M.S. (1970), Ph.D. (1973), Civil Engineering, University of Wisconsin, Madison.

Employment:
Professor of Environmental Studies, Forest Ecology and Management, and Civil and Environmental Engineering, University of Wisconsin-Madison 1982-present
Professor of Forest Resources and Civil and Mineral Engineering, University of Minnesota, 1978-1982
Professor of Forest Engineering, SUNY College of Environmental Science and Forestry, 1973-1978

Research Program:
Remote Sensing for natural resource management, environmental monitoring, and ecosystem understanding

Professional Activities:
Vice-President through Past-President, American Society for Photogrammetry and Remote Sensing, 1996-2000
Member, USGS/NASA Science Advisory Panel, EOS Archive, EROS Data Center
Member, Advisory Board, Mississippi Space Commerce Initiative, John C. Stennis Space Center, 2001-

Publications (out of more than 160):
Wynne, R.H, J.J. Magnuson, M.K. Clayton, T.M. Lillesand, and D.C. Rodman. 1996. Determinants of temporal coherence in the satellite-derived 1987-1994 ice breakup dates of lakes on the Laurentian Shield. Limnology and Oceanography, Vol. 41, No. 5, pp. 832-838.
Wynne, R.H., T.M. Lillesand, M.K. Clayton, and J.J. Magnuson. 1998. Satellite monitoring of lake ice breakup on the Laurentian Shield (1980-1994). Photogrammetric Engineering and Remote Sensing, Vol. 64, No. 6, pp. 607-617.
Lillesand, T.M. and R.W. Kiefer. 2000. Remote Sensing and Image Interpretation. 4th Edition. John Wiley and Sons, Inc., New York. 724 p.
Riera, J., P.R. Voss, S.R. Carpenter, T.K. Kratz, T.M. Lillesand, J.A. Schnaiberg, M.G. Turner, and M.W. Wegener. 2001. Nature, society, and history in two contrasting landscapes in Wisconsin, USA: interactions between lakes and humans during the twentieth century. Land Use Policy, Vol. 18, pp 41-51.
Lillesand, T.M., J.L. Riera Rey, J.W. Chipman, J.D. Gage, M. Janson, J. Panuska, and K. Webster. 2001. Integrating multi-resolution satellite imagery into a satellite lake observatory. Proceedings; Annual Meeting of American Society for Photogrammetry and Remote Sensing, St. Louis, Missouri, not paginated.

Bill Provencher, Department of Agricultural and Applied Economics, University of Wisconsin, Madison, WI 53706; tel. 608.262.9494. email: Provencher@aae.wisc.edu

Education:
B.S. 1981, Natural Resources, Cornell University; M.S. 1985, Forestry, Duke University; Ph.D., 1991, Agricultural Economics, University of California-Davis.

Employment:
Instructor, Department of Agricultural and Applied Economics, University of Wisconsin-Madison, 1990-1991; Assistant Professor to Associate Professor, Department of Agricultural and Applied Economics, University of Wisconsin-Madison, 1991-present.

Research Program:

Dynamic allocation of resources; structural estimation of dynamic decision problems; valuation of environmental goods and services when user preferences are heterogenous; the economics of open space preservation.

Professional Activities:
Editorial Board, *Land Economics*, 1997-present
Editorial Council, *Journal of Environmental Economics and Management*, 1997-present

Publications:

Spalatro, F. and B. Provencher. 2001. An analysis of minimum frontage zoning to preserve lakefront amenities. *Land Economics* 77: 282-297.

Provencher, B. 1997. Structural versus reduced-form estimation of optimal stopping problems, *American Journal of Agricultural Economics* 79, 357-368.

Provencher, B. and R.C. Bishop. 1997. An estimable dynamic model of recreation behavior with an application to Great Lakes angling, *Journal of Environmental Economics and Management*, 33, 107-127.

Provencher, B. 1995. An investigation of the harvest decisions of timber firms in the southeast United States, *Journal of Applied Econometrics* 10, 57-74.

Provencher, B, and O.R. Burt. 1994. A private property rights regime for the commons: the case of groundwater, *American Journal of Agricultural Economics* 76, 875-888.

Monica G. Turner, Department of Zoology, University of Wisconsin, Madison, Wisconsin 53706; telephone 608.262.2592; fax 608.265.63200; email mgt@mhub.zoology.wisc.edu; web site http://ravel.zoology.wisc.edu/mgt/

Education:
B.S. Biology, Fordham University, Bronx, NY, 1980; Ph.D. Ecology, University of Georgia, Athens, GA, 1985.

Employment:
Professor of Zoology, University of Wisconsin, 1994 – present
Research Scientist, Oak Ridge National Laboratory, 1987-1994
Postdoctoral Research Associate, University of Georgia, 1985-1987

Research Program:
Causes and consequences of spatial heterogeneity in ecological systems; dynamics of natural disturbances and their effects on ecosystems; fire ecology; ungulate foraging dynamics; ecological effects of land-use change; landscape and ecosystem ecology

Professional Activities:
NRC Committee on Ungulate Management in Yellowstone National Park, 1998-
Co-Editor in Chief, *Ecosystems*, 1997-
Editorial Board, *BioScience*, 1996-
NRC Ecosystems Advisory Panel, 1998-2000
Science Advisory Board, National Center for Ecological Analysis and Synthesis, University of California, Santa Barbara 1995 - 1997.
Editorial Board, *Ecological Applications*, 1992-

Publications (out of 129):
Turner, M. G., W. L. Baker, C. Peterson, and R. K. Peet. 1998. Factors influencing succession: lessons from large, infrequent natural disturbances. Ecosystems 1:511-523.
Gergel, S. E., M. G. Turner, and T. K. Kratz. 1999. Scale-dependent landscape effects on north temperate lakes and rivers. Ecological Applications 9:1377-1390.
Turner, M. G., R. H. Gardner and R. V. O’Neill. 2001. Landscape ecology in theory and practice. Springer-Verlag, New York.
Gergel, S. E. and M. G. Turner, editors. 2001. Learning landscape ecology: a practical guide to concepts and techniques. Springer-Verlag, New York.
Schnaiberg, J., J. Riera, M. G. Turner and P. R.Voss. Explaining human settlement patterns in a recreational lake district: Vilas County, Wisconsin, USA. Environmental Management (In press).

Timothy F. Allen, Professor of Botany, Department of Botany, University of Wisconsin-Madison, Madison, Wisconsin 53706. Telephone number (608) 262-2692, FAX (608) 262 7509, EMAIL tfallen@facstaff.wisc.edu

Education:
B.Sc., 1964; Ph.D., 1968, University College North Wales, University of Wales, Bangor, North Wales.

Employment:
Department of Botany, University of Wisconsin-Madison, Wisconsin, 1970 –present.
Faculty of Institute for Environmental Studies, and Inegrated Liberal Studies,
Editor of the Columbia University Press Series on *Complexity in Ecological Systems. 1990-present*
Visiting Professor, Cybernetic Systems, San Jose State 1988-89.
Lecturer Department of Biological Science, University of Ife, Nigeria, 1968-1970
Demonstrator (TA equivalent), University College North Wales, School of Plant Biology, 1964-1968.

Research Program:
Applying notions of complex systems and hierarchy theory to ecology
Community data analysis, agricultural systems, issues of scale, and sustainability.
Economic ecology, management of the whole ecosystem that makes resources renewable, not natural resources themselves.

Publications (out of 96):
Allen, T.F.H. and T.B. Starr. 1982. *Hierarchy: Perspectives for ecological complexity*. (University of Chicago Press, pp. 310).
O'Neill, R.B., D. DeAngelis, J.B. Waide and T.F.H. Allen. 1986. A hierarchical concept of ecosystems*.* *Monographs in population biology 23*. Pp. 272. Princeton.
Allen, T.F.H. and T.W. Hoekstra. 1992. *Towards a unified ecology*, Columbia Univ. Press.
T. F. H. Allen, J Tainter, C .Pires and T. Hoekstra. 2001 Dragnet ecology, “Just the facts Ma’am,”: privilege of science in a post-modern world. *Bioscience* 51: 475-485
Allen, T. F. H., J. Tainter and T. W. Hoekstra 1999. Supply-side sustainabiltiy *Systems Research and Behavioral Science* 16: 403-427

Mary P. Anderson, Dept. of Geology and Geophysics, University of Wisconsin-Madison, 1215 W. Dayton St., Madison, WI 53705; phone: 608-262-2396; fax: 608-262-0693; email: andy@geology.wisc.edu; web site: http://www.geology.wisc.edu/people/anderson.html

Education:
B.A. Geology, State University of New York at Buffalo, 1970: M.S. Geology, Stanford University, 1971; Ph.D. Hydrology, Stanford University, 1973.

Employment:
Adjunct Assistant Professor of Geology, Southampton College of Long Island University Sept. 1973 - June 1975; Visiting Lecturer in Geology at SUNY-Stony Brook (Spring 1974) Professor of Geology and Geophysics, UW-Madison, with appointments in the Institute for Environmental Studies (IES), the Water Resources Management Program, the Center for Limnology, and the Geological Engineering Program, Aug. 1985 – present.

Research Program:
Groundwater modeling with emphasis on groundwater-lake systems and recharge estimation; use of temperature measurements in hydrogeology.

Professional Activities:
Editor-in-Chief, *Ground Water Journal*, Jan. 2002- Dec. 2004
President, Hydrology Section, American Geophysical Union, 1996-98
Committee on Hydrologic Science (National Research Council), 1999-2002
Council, Geological Society of America, 1999-2002

Honors:
2000 C.V. Thesis Award, American Institute of Hydrology
1999 Fellow, American Geophysical Union
1998 O.E. Meinzer Award, Hydrogeology Division, Geological Society of America
1992 M.K. Hubbert, Association of Ground Water Scientists and Engineers/National Ground Water Association.

Publications (out of approximately 100):
Anderson, M.P. and W.W. Woessner, 1992, *Applied Groundwater Modeling: Simulation of Flow and Advective Transport*, Academic Press, 381 p. (also printed in Japanese and Chinese)
Anderson, M.P., 1997, Characterization of Geological Heterogeneity, in: *Subsurface Flow and Transport: A Stochastic Approach*, Cambridge Univ. Press, pp. 23-43.
Kim, K., Anderson, M. P., and Bowser, C. J. , 1999, Model Calibration using multiple targets: a case study from Northern Wisconsin, *Ground Water* 37(3), 345-351.
Kim, K., Anderson, M. P., & Bowser, C. J. , 2000, Enhanced dispersion in groundwater caused by temporal changes in recharge rate and lake levels, *Advances in Water Resources* 23, p. 625-635.
Anderson, M.P., R.J. Hunt, J. Krohelski, and K. Chung, 2001, Using High Hydraulic Conductivity Nodes to Simulate Seepage Lakes, *Ground Water*, in press.

David E. Armstrong, Water Science & Engineering Laboratory, University of Wisconsin, Madison, WI 53706; telephone 608.262.0768; email armstron@engr.wisc.edu; web site http://www.engr.wisc.edu/cee/faculty/armstrong_david.html

Education:
B.S., Agronomy, University of Nebraska, 1961; M.S., Soil Science, University of Wisconsin, 1963; Ph.D., Soil Science, University of Wisconsin, 1966.

Employment:
Assistant/Associate/Full Professor of Civil and Environmental Engineering, University of Wisconsin-Madison, 1967-present
Research Associate, Soil Science, University of Wisconsin, 1966-67

Research Program:
Aquatic environmental chemistry: Biogeochemical processes regulating forms and transport of trace metals in freshwaters and coastal waters; Sources, behavior, and fate of organic chemicals; Biogeochemical cycles of nutrient elements in freshwaters; Chemistry of the Great Lakes.

Professional Activities:
Director, Water Science & Engineering Laboratory, UW-Madison, 1988-present.
Chair, Environmental Chemistry & Technology (formerly Water Chemistry), UW-Madison, 1998-present
Professional Memberships: American Chemical Society, Society of Environmental Toxicology & Chemistry, American Society of Limnology and Oceanography, International Association for Great Lakes Research, Soil Science Society of America

Publications (selected):
Herrin, R.T., A.W. Andren, and D.E. Armstrong. 2001. Determination of silver speciation in natural waters I: Laboratory tests of Chelex-100 chelating resin as a competing ligand. Environ. Sci. Technol. 35:1953-1958

Herrin, R.T., A.W. Andren, M.M. Shafer, and D.E. Armstrong. 2001. Determination of silver speciation in natural waters II. Binding strength of silver ligands in surface waters. Environ. Sci. Technol. 35:1959-1966.

Zelewski, L.M., G. Benoit, and D.E. Armstrong. 2001. Mercury dynamics in Tivoli South Bay, a freshwater tidal mudflat wetland in the Hudson River. Biogeochem. 52:93-2001.

Hoffmann, S.R., M.M. Shafer, C.L. Babiarz, and D.E. Armstrong. 2000. A critical evaluation of tangential-flow ultrafiltration for trace metal studies in fresh water systems: I. Organic carbon. Environ. Sci. Techol. 34:3420-3427.

Poister, D., D.E. Armstrong, and J.P. Hurley. 1999. Influences of grazing on temporal patterns of algal pigments in suspended and sedimenting particulate matter in a north temperate lake. Canad J. Fish. Aquat. Sci. 56:60-69.

Barbara J. Benson, Center for Limnology, University of Wisconsin, Madison, Wisconsin 53706; telephone 608-262-2573; fax 608-265-2340; email bjbenson@facstaff.wisc.edu

Education:
B.A., Mathematics, University of Wisconsin-Madison, 1967; M.A., Mathematics, University of Wisconsin-Madison, 1969; Ph.D., Botany, University of Wisconsin-Madison, 1983.

Employment:
Information Manager for the North Temperate Lakes Long Term Ecological Research Project (1997-present: Associate Scientist, 1992-1997: Assistant Scientist, 1985-1992: Associate Researcher, 1983-1985: Specialist Life Science Research), Center for Limnology, University of Wisconsin-Madison, 1983 - present.

Research Program:
Ecoinformatics; ecosystem response to climate variability and change

Professional Activities (selected):
Chair of Organizing Committee for Information Management workshops at the 2000 LTER All Scientists Meeting; Member of the LTER Network Information System Working Group; Information Managers' Steering Committee, Long-Term Ecological Research Program, 1992-1996, 2001- ; Reviewer, Environmental Monitoring and Assessment; Reviewer, NSF proposals; NSF panelist KDI pre-proposals; NSF site review teams; Councilor for Long-Term Studies Section of ESA 1998-2000.

Publications (selected):
Baker, K. S., B. J. Benson, D.L.Henshaw, D. Blodgett, J.Porter, S.G.Stafford. 2000. Evolution of a multi-site network information system: the LTER information management paradigm. Bioscience 50: 963-978.

Benson, B. J. The World Wide Web as a tool for ecological research programs. 1998. In W.K. Michener, J.H. Porter, and S.G. Stafford, editors. Data and Information Management in the Ecological Sciences: A Resource Guide. Long-Term Ecological Research Network Office, Albuquerque, NM.

Benson, B. J., J. D. Lenters, J. J. Magnuson, M. Stubbs, T. K. Kratz, P. J. Dillon, R. E. Hecky, and R. C. Lathrop. 2000. Regional coherence of climatic and lake thermal variables of four lake districts in the Upper Great Lakes Region of North America. Freshwater Biology 43: 517-527.

Benson, B. J. and M. D. MacKenzie. 1995. Effects of sensor spatial resolution on landscape structure parameters. Landscape Ecology 10:113-120.

Benson, B. J., J. J. Magnuson, R. L. Jacob, and S. L. Fuenger. In press. Response of lake ice breakup in the Northern Hemisphere to the 1976 interdecadal shift in the North Pacific Ocean. Verh. Internat. Verein. Limnol. 27

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Education:
B.A., 1959, U.C., Riverside, Geology, Ph.D., 1965, U.C.L.A., Geology and Geochemistry

Employment:
1960, Instructor in Geology, U.C., Riverside,
1960-63, Research Assistant, Institute of Geophysics, U.C.L.A.,
1964-68, Assistant Professor of Geology, University of Wisconsin
1968-73, Associate Professor of Geology, University of Wisconsin
1973-2000, Professor of Geology, University of Wisconsin
2000-pres., Emeritus Professor of Geology, University of Wisconsin

Professional Affiliations:
Geological Society of America (fellow), Geochemical Society, Mineralogical Society (Fellow), American Association for the Advancement of Science, Sigma-Xi, American Geophysical Union, American Society for Limnology and Oceanography, Ecological Society of America.

Publications (selected):
Gat, J.R., C.J. Bowser, and C. Kendall (1994) The Contribution of Evaporation from the Great Lakes to the Continental Atmosphere: Estimate Based on Stable Isotope Data; Geophys. Research Lett., 21:557-560.
Hurley, J. P., Armstrong, D. E., Kenoyer, G. J., and Bowser, C. J. (1985) Silica in lake waters: Groundwater as a silica source for diatom production in a precipitation-dominated lake; Science, v. 227, pp. 1576-1578.
Kenoyer, G. and C.J. Bowser (1992) Groundwater Chemical Evolution in a Sandy Silicate Aquifer in Northern Wisconsin; 1: Patterns and Rates of Change; Water Resources Research, 28:579-589.
Kim, K., Anderson, M. P., and Bowser, C J., (2000) Enhanced Dispersion in Groundwater Caused by Temporal Changes in Recharge Rate and Lake Levels; Adv. Water Res., 23:625-635
Krabbenhoft, D.P., C.J. Bowser, C. Kendall, and J.R. Gat (1993) Use of Oxygen-18 and Deuterium to Assess the Hydrology of Groundwater-Lake Systems; in: Baker, L.A. (ed.) ENVIRONMENTAL CHEMISTRY OF LAKES AND RESERVOIRS; Amer. Chem. Soc. Adv. Chem. Ser. 237, pp. 67-90.

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Education:
A.B., Dartmouth College, Hanover, NH, 1990; M.S. Environmental Monitoring, University of Wisconsin-Madison, 1996; Ph.D. Environmental Monitoring, University of Wisconsin, 2001.

Employment:
Research Associate, University of Wisconsin, 2001 – present

Research Program:
Satellite remote sensing of lake and watershed characteristics at multiple spatial, temporal, and spectral resolutions; land use/land cover analysis and change detection

Professional Activities:
Membership in the American Geophysical Union (AGU), the American Society for Photogrammetry and Remote Sensing (ASPRS), the Alliance for Marine Remote Sensing (AMRS), and the Natural Areas Association (NAA)

Publications (selected):
Chipman, J. W. and T. M. Lillesand. 2001. Effects of forest stand characteristics on L-band interferometric radar elevation estimates. Submitted to Remote Sensing of Environment.

Chipman, J. W., T. M. Lillesand, F. L. Scarpace, and J. D. Gage. 2001. Dependence of L-Band interferometric elevation measurements on forest stand structural parameters. Proceedings, Annual Meeting of the American Society for Photogrammetry and Remote Sensing (ASPRS), April 2001, St. Louis, MO.

Chipman, J. W., T. M. Lillesand, J. D. Gage, and S. Radcliffe. 2000. Spaceborne imaging radar in support of forest resource management. Photogrammetric Engineering and Remote Sensing 66: 1357-1366.

Lillesand, T., J. Chipman, D. Nagel, H. Reese, M. Bobo, and R. Goldmann. 1998. Upper Midwest Gap Analysis Program Image Processing Protocol. Environmental Management Technical Center report EMTC-98-G001, US Geological Survey, Onalaska, WI.

Means, J. E., P. F. Hopkins, J. R. Jensen, S. R. Schill, J. W. Chipman, R. D. Ramsey, and D. A. Stow. 2001. ARC partnerships: industry and academia explore remote sensing applications. Journal of Forestry 99: 4-12.

Stanley I. Dodson, Zoology, Birge Hall, University of WI, Madison, WI. 53706-1381
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http://www.wisc.edu/zoology/faculty/fac/Dod/Dod.html

Education:
Ph.D. Department of Zoology. University of Washington, Seattle
B.A. Yale University

Employment:
Professor, Department of Zoology. UW-Madison (1982-present)
Chair, Department of Zoology. UW-Madison (1991-1993)
Associate Chair Department of Zoology. UW-Madison (1989-1991)

Research Program:
Community Ecology, with emphasis on zooplankton, aquatic macroinvertebrates, predator-prey interactions, chemical induction and phenotypic plasticity, toxicology, biomonitoring, population biology, biodiversity, taxonomy, aquatic conservation, and endocrine disruptors.

Professional Activities and Awards:
US Patent: *Daphnia* Reproductive Bioassay for Testing Toxicity of Aqueous Samples and Presence of an Endocrine Disruptor. P96080US (Awarded 1999)
Editorial Board: *Hydrobiologia* (1994-present)
Editorial board: Ecology (1999-present)

Publications (selected recent):
Peterson, J.K., D.R. Kashian, and S.I. Dodson. 2000. Methoprene and 20-OH-ecdysone affect male production in *Daphnia pulex*. Environmental Toxicology and Chemistry 20:582-588.
Dodson, S.I. and R.A. Lillie. 2001. Zooplankton communities of restored depressional wetlands in Wisconsin. Wetlands 21:292-300.
Dodson, S.I., S.E. Arnott, and C.L. Cottingham. 2000. The Relationship in Lake Communities between Primary Productivity and Species Richness. Ecology 81:2662-2679.
Weigel, B., J. Lyons, S.I. Dodson, L.K. Paine, and D.J. Undersander. 1999. Using stream arthropods to compare riparian land-use practices on cattle farms in southwestern Wisconsin. Journal of Freshwater Ecology 15:93-106.
Hanazato, T. and S.I. Dodson. 1995. Synergistic Effects of Low Oxygen Concentration, Predator Kairomone, and a Pesticide on the Cladoceran *Daphnia pulex*. Limnology and Oceanography. 40: 700-709.

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Education:
Ph.D., Atmospheric Sciences, University of Wisconsin, 1993

Employment:
University of Wisconsin, Madison -- Institute for Environmental Studies & Department of Atmospheric & Oceanic Sciences
2000-present: Director: Center for Sustainability and the Global Environment
1999-present: Associate Professor of Environmental Studies / Atmospheric Sciences
1993-1999: Assistant Professor of Environmental Studies / Atmospheric Sciences

Research Program:
Human/environment interactions; interactions between ecological, hydrological, & atmospheric processes; applications of modeling and remote sensing to ecology & natural resources

Professional Activities:
1993-2000: Reid A. Bryson Distinguished Professor of Climate People & Environment
1993-2000: Director: Climate, People and Environment Program
International Science Service--
USGCRP - Scientific Steering Committee, Interagency Carbon Cycle Science Program
AGU - Committee on Global Environmental Change
NASA - Terrestrial Ecology Program, Program Advisory Committee

Publications (selected):
Coe, M.T. and J.A. Foley, 2001: Human and natural impacts on the water resources of the Lake Chad basin, Journal of Geophysical Research (Atmospheres), 106 (D4), 3349-3356.
Foley, J.A., S. Levis, M.H. Costa, W. Cramer, and D. Pollard, 2000: Incorporating dynamic vegetation cover within global climate models, Ecological Applications, 10(6), 1620-1632.
Kucharik, C.J., J.A. Foley, C. Delire, V.A. Fisher, M.T. Coe, S.T. Gower, J. Lenters, C. Molling, J.M. Norman, N. Ramankutty, 2000: The IBIS-2 dynamic global biosphere model: Model formulation and evaluation, Global Biogeochemical Cycles., 14(3), 795-825.
Ramankutty, N., and J.A. Foley, 1999: Estimating historical changes in global land cover: croplands from 1700 to 1992. Global Biogeochemical Cycles 13(4), 997-1027.
Foley, J.A., S. Levis, I.C. Prentice, D. Pollard, and S.L. Thompson, 1998: Coupling dynamic models of climate and vegetation, Global Change Biology, 4, 561-579.

Linda K. E. Graham, Department of Botany, University of Wisconsin, Madison, Wisconsin 53706-1381; telephone 608.262.2640; fax 608.262.7509; email lkgraham@facstaff.wisc.edu; web site http://www.wisc.edu/botany-cryptogams/graham.html

Education:
B.A. Botany, Washington University, St. Louis, MO, 1967; M.A. Botany, University of Texas, Austin, TX 1969; Ph.D. University of Michigan, Ann Arbor, MI 1975.

Employment:
Professor of Botany, University of Wisconsin 1987-present (Chair 1988-1991); Associate Professor, UW 1982-1987; Assistant Professor, UW 1976-1982.

Research Program:
Microbial diversity, with a focus on freshwater algae and their bacterial epibionts; cyanobacteria and protozoa related to the ancestry of green and glaucophyte algae; and early-divergent fungi and their symbiotic associations. Evolutionary origin of land-adapted plants from aquatic green algal ancestors.

Professional Activities:
Member, Editorial Boards of *Microbial Ecology*, *American Journal of Botany*, *International Journal of Plant Sciences*, and *Critical Reviews in Plant Science*. Author of three books: Origin of Land Plants (1993), Algae (with L. Wilcox) (2000), and Plants in Today's World (with 2 other authors) (2002).

Publications (selected):

Arancibia-Avila, P., Coleman, J.R., Russin, W.A., Graham, J.M. and Graham, L.E. 2001 Carbonic anhydrase localization in charophycean green algae: Ecological and evolutionary significance. International Journal of Plant Sciences 162:127-135.

Graham, L.E., Cook, M.E., and Busse, J.S. 2000. The origin of plants: Body plan changes contributing to a major evolutionary radiation. PNAS 97:4535-4540.

Redeker, D., Kodner, R., and Graham, L.E. 2000. Glomalean fungi from the Ordovician. Science 289:1920-1921.

Fisher, M.M., Wilcox, L.W. and Graham, L.E. 1998. Molecular characterization of epiphytic bacterial communities on charophycean green algae. Applied and Environmental Microbiology 64:4384-4389.

Fisher, M.M., Graham, J.M., and Graham, L.E. 1998. Bacterial abundance and activity across sites within two northern Wisconsin *Sphagnum* bogs. Microbial Ecology 36:259-269.

Roger B. Hammer, Applied Population Laboratory, Department of Rural Sociology, University of Wisconsin, Madison, Wisconsin 53706; telephone 608.263.2898; fax 608.262.6022; email rhammer@facstaff.wisc.edu;

Education:
B.A. History, Rocky Mountain College, Billings, MT, 1985; M.R.P. City and Regional Planning, Cornell University, Ithaca, NY, 1987; M.S. Sociology, University of Wisconsin-Madison, 1997; Ph.D. Sociology, University of Wisconsin, 2001.

Employment:
Assistant Professor of Rural Sociology, University of Wisconsin, 2001 – present
Associate Director 2000-2001, Acting Director 1999-2000, Associate Consultant 1996-2001, Applied Population Laboratory, University of Wisconsin
Community Planning and Development Representative, U.S. Department of Housing and Urban Development, Milwaukee, WI 1991-1996

Research Program:
Modeling the social, economic, and environmental determinants of population growth and redistribution, especially as manifested by residential development, including spatial dynamics. Integrating human population components, that is demographic estimation and forecasting, into ecological models.

Publications:
Voss, Paul R., Roger B. Hammer, and Ann M. Meier. Forthcoming. "Putting migration data to work: A case study of a medium-sized metropolitan area." *Population Research and Policy Review.* Submitted 11/00.

Hammer, Roger B., Paul R. Voss, and Volker C. Radeloff. Forthcoming. "Approximating Geographic Patterns of Residential Development from 1940 to 1990 in Wisconsin's North Woods." *Rural Sociology.* Submitted 8/00, Resubmitted 6/01.

Radeloff, Volker C., Roger B. Hammer, Paul R. Voss, Alice E. Hagen, Donald R. Field, and David J. Mladenoff. 2001. "Human demographic trends and landscape level forest management in the Northwest Wisconsin Pine Barrens." *Forest Science.* 47(2):229-241.

Wilson, Franklin D. and Roger B. Hammer. 2001. "The causes and consequences of racial residential segregation." Forthcoming in *Urban inequality in the United States: Evidence from four cities*, Alice O'Connor, Chris Tilly, and Lawrence Bobo (eds.). New York: Russell Sage Foundation.

Green, Gary P., Roger B. Hammer, and Leann M. Tigges. 2000. "Someone to count on: informal support in Atlanta." Pp 244-63 in *The Atlanta paradox: Race, opportunity, and inequality in a new southern city*, David L. Sjoquist (ed.). New York: Russell Sage Foundation.

Hammer, Roger B. and Gary P. Green. 1996. "Local growth promotion: Policy adoption versus effort." *Economic Development Quarterly.* 10(4):331-341.

Paul C. Hanson, Center for Limnology, University of Wisconsin, Madison, Wisconsin 53706; telephone 608.262.5953; fax 608.265.2340; email pchanson@facstaff.wisc.edu; web site http://limnology.wisc.edu/personnel/hanson/hanson.html

Education:
B.S. Biology, University of Wisconsin - Whitewater, 1987; M.E.P.D. Physiology, University of Wisconsin-Whitewater, 1990.

Employment:
Information Processing Consultant, University of Wisconsin, 1992 – present
Coordinator Department of Physiology, The Boeing Company, 1991 – 1992

Research Program:
Ecosystem ecology with emphasis on lake metabolism; applying technology solutions to sensing, monitoring and communications problems in ecosystem monitoring.

Professional Activities:
2000 - Awarded a Technology and Teaching for Learning grant for implementing web-based fish identification in the course.
2000 - Organized and led a workshop entitled, "Wireless Communication - From Remote Sensing to the Internet" at the Long Term Ecological Research network's All Scientist Meeting. Snowbird, UT.
1999 to present - Long Term Ecological Research Technology Committee
1998 - Reviewer of Science 2001 textbook series

Publications:
Harvey, C.J., P.C. Hanson, T.E. Essington, P.B. Brown, and J.F. Kitchell. 2001. Using bioenergetics models to predict stable isotope ratios in fishes. Canadian Journal of Fisheries and Aquatic Sciences. (Accepted)
Carpenter, S., W. Brock, and P. Hanson. 1999. Ecological and social dynamics in simple models of ecosystem management. Conservation Ecology 3(2): 4. [online] URL: http://www.consecol.org/vol3/iss2/art4
Hanson, P.C., Johnson, T.B., Schindler, D.E., and Kitchell, J.F. 1997. Fish Bioenergetics 3.0. Technical Report WISCU-T-97-001. University of Wisconsin Sea Grant Institute, Madison, WI.

Thomas A. Heberlein, Department of Rural Sociology, University of Wisconsin, Madison, Wisconsin 53706; telephone 608.262.9531; fax 608.262.6022; email taheberl@facstaff.wisc.edu.

Education:
B.A. Sociology, University of Chicago, 1967; M.S. Sociology, University of Wisconsin-Madison, 1969; Ph.D. Sociology, University of Wisconsin, 1971.

Employment:
Professor Emeritus, Department of Rural Sociology, University of Wisconsin, 2001-Present
Assistant Professor to Professor of Rural Sociology, University of Wisconsin, 1972-2001
Assistant Professor of Sociology University of Colorado, 1971-1972

Research Program:
Human environmental relationships with particular reference to the development of environmental attitudes and their changes over time. Research on consumptive and non-consumptive outdoor recreation in various ecosystems.

Professional Activities:
Director, Center for Resource Policy Studies and Programs. School of Natural Resources University of Wisconsin-Madison. 1985-1991
Visiting Research Scientist. ETOUR-European Institute for Tourism Research Östersund, Sweden. 1997-Present
National Research Council. Committee on Environmental Issues in Forest Management in the Pacific Northwest 1993-1997. Report: Environmental Issues in Pacific Northwest Forest Management. 2000.
Presented the Award of Merit from the Natural Resources Research Group of the Rural Sociological Society. 2001.

Publications (out of 83):
Stedman, R. C. and T. A. Heberlein. 2001. Hunting and Rural Socialization. Rural Sociology: Forthcoming December.
Jorgensen, B.S., M. Wilson and T. A. Heberlein. 2001. Fairness in the Contingent Valuation of Environmental Public Goods: Attitude toward Paying for Environmental Improvements at Two Levels of Scope. Ecological Economics 36: 133-148.
Fredman, P., L. Emmelin, T. A. Heberlein and T. Vuorio. 2001. Tourism in the Swedish Mountain Region. pp. 123- 146 in Bengt Sahlberg (ed.) Going North: Peripheral Tourism in Canada and Sweden. European Tourism Research Institute Östersund Sweden R 2001:6 163pp.
Heberlein, T. A. and T. Willebrand. 1998. Attitudes Toward Hunting Across Time and Continents: the United States and Sweden. Game and Wildlife 15: 1071-1080.
Heberlein, T. A. 1996. Recreation and Tourism Management in Protected Areas pp. 203-209 in Breymeyer, Alicja and Reginald Nobel (eds.) Biodiversity Conservation in Transboundary Protected Areas. Washington D. C. National Academy Press.

Richard C. Lathrop, Aquatic Community Ecologist, Wisconsin Department of Natural Resources c/o UW Center for Limnology, Madison, WI 53706, Telephone: (608)-261-7593; Fax: (608)-265-2340; Email: rlathrop@facstaff.wisc.edu

Education:
Ph.D. Oceanography and Limnology, 1998, University of Wisconsin-Madison.
M.S. Natural Resources (Aquatic Ecology), 1975, University of Michigan, Ann Arbor.
B.A. Biology, 1971, Lehigh University, Bethlehem, PA.

Employment:
Wisconsin Department of Natural Resources, Bureau of Integrated Science Services,
Chief Limnologist, 1977-91; Research Scientist-Advanced, 1992-present
Dane County Regional Planning Commission, EPA-funded water quality study, 1975-77

Professional Affiliation:
Honorary Fellow appointment, University of Wisconsin Center for Limnology, 1998-present

Professional Societies:
American Society of Limnology & Oceanography
North American Lake Management Soc. (Program Chair 2001 Symposium, Madison, WI)
Societas Internationalis Limnologiae

Publications (out of 41):
Lathrop, R.C., B.M. Johnson, T.B. Johnson, M.T. Vogelsang, S.R. Carpenter, T.R. Hrabik, J.F. Kitchell, J.J. Magnuson, L.G. Rudstam, R.S. Stewart. Stocking piscivores to improve fishing and water clarity: a synthesis of the Lake Mendota biomanipulation project. Freshwat. Biol. (in press).
Reed-Andersen, T., S.R. Carpenter, R.C. Lathrop. 2000. Phosphorus flow in a watershed-lake ecosystem. Ecosystems 3:561-573.
Kasprzak P., R.C. Lathrop, and S.R. Carpenter. 1999. Influence of different-sized *Daphnia* species on chlorophyll concentration and summer phytoplankton community structure in eutrophic Wisconsin lakes. J. Plankton Res. 21:2161-2174.
Lathrop, R.C., S.R. Carpenter, and D.M. Robertson. 1999. Summer water clarity responses to phosphorus, *Daphnia* grazing, and internal mixing in Lake Mendota. Limnol. Oceanogr. 44:137-146.
Lathrop, R.C., S.R. Carpenter, C.A. Stow, P.A. Soranno, and J.C. Panuska. 1998. Phosphorus loading reductions needed to control blue-green algal blooms in Lake Mendota. Can. J. Fish. Aquat. Sci. 55:1169-1178.

John J. Magnuson, Center for Limnology, University of Wisconsin - Madison, Madison, Wisconsin 53706. Tel. 608-262-3010. Email: jmagnuson@mhub.limnology.wisc.edu. FAX: 608-265-2340.

Education
B.Sc. with distinction, 1956, Fish & Wildlife Management, University of Minnesota, M.Sc., 1958, Fish & Wildlife Management, University of Minnesota, Ph.D., 1961, Zoology/Oceanography, University of British Columbia, Vancouver B.C. Canada.

Employment:
Professor Emeritus in Zoology July 1, 2000-Present; Assistant to Full Professor of Zoology 1968-2000; Director of Center for Limnology 1983-2000 Chief Tuna Behavior & Physiology Program, US Bureau of Commercial Fisheries HA, 1961-7.

Professional Activities (selected):
Co-Chair the Wisconsin Academy Study on the Future of Our Aquatic Ecosystems and Resources 2001 -, Intergovernmental Panel on Climate Change, 2nd Assessment - a convening lead author of Hydrology and Freshwater Ecology –1995, 3rd Assessment a lead Author on Ecosystems – lakes and streams 2000. National Research Council, (Committee chair) Protection and Management of Pacific Northwest Anadromous Salmonids 1992-5; Assessment of Atlantic Bluefin Tuna 1994; Improving the Management of U.S. Marine Fisheries 1993-94; Sea Turtle Conservation 1989-90. International Joint Commission Great Lakes Water Quality-Science Advisory Board, 1990-95. National Science Foundation, Program Director for Ecology 1975-96. Ecological Society of America, Editorial Board for Ecological Applications, 1989-94. Freshwater Imperative, co-chair with Bob Naiman, 1992-95: NSF-sponsored workshop and Publication

Publications (out of >300 research papers and 5 books):

Magnuson, J.J., K.E. Webster, R. A. Assel, C.J. Bowser, P.J. Dillon, J.G. Eaton, H. E. Evans, D.J. Fee, R. I. Hall, L.R. Mortsch, D.W. Schindler, and F.H. Quinn. 1997. Potential effects of climate change on aquatic systems: Laurentian Great Lakes and Precambrian Shield Region. pp 7-53 in C.E. Cushing [ed] Freshwater Ecosystems and climate change in North America, A regional Assessment. Advances in Hydrological Processes. John Wiley& Sons viii. + 262pp. (Also as an Issue of the Journal Hydrological Processes 11(6) 1997.)

Magnuson, J.J., W.M. Tonn, A. Banerjee, J. Toivonen, O. Sanchez, and M. Rask. (1998). Isolation vs. extinction in the assembly of fishes in small northern lakes. Ecology 79(8): 2941-56.

Magnuson, J.J. & T.K. Kratz. 2000. Lakes in the landscape: approaches to regional limnology. Verh. Internat. Verein. Limnol. 27: 74-87.

Magnuson, J. J., Robertson, D. M., Benson, B. J., Wynne, R. H., Livingstone, D. M., Arai, T., Assel, R. A., Barry, R. G., Card, V., Kuusisto, E., Granin, N. G., Prowse, T. D., Stewart, K. M., Vuglinski, V. S. 2000 Historical Trends in lake and river ice cover in the Northern Hemisphere. Science 289: 1743- 1746.

Riera, J. L., Magnuson, J. J., Kratz, T. K. & Webster, K. E., 2000. A geomorphic template for the analysis of lake districts applied to the Northern Highland Lake District, Wisconsin, USA. Freshwater Biology. 43: 301-318.

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Education:
B.A., University of Minnesota-Duluth, 1972; Ph.D. University of Minnesota, 1977.

Employment:
Associate Professor & Professor, University of Wisconsin-Madison 1985-present; Assistant Professor & Associate Professor, Iowa State University, 1978-1985.

Research Program:
Diffusion of agricultural innovations that have natural resource management implications; spatial analysis of agronomic behaviors relative to environmental degradation

Professional Activities
Rural Sociological Society; Soil and Water Conservation Society; National Alliance of Independent Crop Consultants; American Society of Agronomy; Soil Science Society of America; Ecological Society of America; Editorial Board, Journal of Precision Agriculture Board of Directors, Board on Agricultural and Environmental Education Co-Director, Nutrient and Pest Management Program, UW-Madison; Advisor, Program on Agricultural Technology Studies, UW-Madison-CALS; Governance Faculty, Institute for Environmental Studies, UW-Madison; USDA-NRCS, Social Sciences Institute, Advisory Board; Water Environment Research Foundation

Publications (selected):
Nowak, P., F. Madison and R. Shepard 1998. Farmers and manure management: A critical analysis. Pp. 1-32 in J. Hatfield and B. Stewart (Eds.) Animal Waste Utilization: Effective Use of Manure as a Soil Resource, Ann Arbor Press, Chelesa, MI.

McCallister, R., and P. Nowak. 1999. Whole-soil knowledge and management: A foundation of soil quality. Pp 173-194 in R. Lal (ed.) Soil Quality and Soil Erosion. CRC Press, Boca Raton, FL

Pierce, F. and P. Nowak 1999. Aspects of precision agriculture. *Advances in Agronomy*, Vol. 67 Pp. 1-84. Academic Press, NY.

Wolf, S. and P. Nowak 1999. Institutional failure in agro-environmental management. *Research in Social Problems & Public Policy*, V. 7: 293-310 JAI Press, Stamford, CT.

Nowak, P., P. Cabot, L. Cutforth and B. Kahn. *In Press.* Nitrogen management by producers: a multiple scale perspective" Edited by R.Follett and J. Hatfield. Nitrogen Management in the Environment: Sources, Problems and Management. Elsevier Science Publications: Netherlands.

Emily H. Stanley, Center for Limnology, University of Wisconsin, Madison, Wisconsin 53706; telephone 608.263.2567; fax 608.265.2340; email ehstanley@facstaff.wisc.edu; web site http://limnology.wisc.edu/personnel/stanley/stanley.html

Education:
B.S. Biology, Yale University, 1984
M.S. Biology, Southwest Texas State University, 1986
Ph.D. Zoology, Arizona State University, 1993.

Employment:
Assistant Professor, Center for Limnology and Department of Zoology, University of Wisconsin Madison, 1998-present.
Assistant Professor, Department of Zoology, Oklahoma State University, 1995-1998
Post-Doctoral Research Associate, Department of Biological Sciences, University of Alabama, 1993-1995.

Research Program:
Ecosystem ecology of rivers, streams and wetlands; biogeochemistry of nitrogen, phosphorus, and carbon in lotic ecosystems; subsurface and riparian processes.

Professional Activities:
Aquatic Section Secretary, Ecological Society of America, 2001-2003.
Panelist, National Science Foundation Biocomplexity in the Environment: Coupled Biogeochemical Cycles Competition, 2001
Science Advisory Committee, The Nature Conservancy, Emiquon Reserve Restoration Project. 2001-2002.
Award of Excellence and Distinguished Service Award committee- North American Benthological Society, 2000-2001 (committee chair in 2001).

Publications (selected):
Stanley, E.H. and A.K. Ward. 1997. Inorganic nitrogen regimes in an Alabama wetland. Journal of the North American Benthological Society 16:820-832.
Boulton, A.J., S. Findlay, P. Marmonier, E.H. Stanley, and H.M. Valett. 1998. The functional significance of the hyporheic zone in streams and rivers. Annual Review of Ecology and Systematics 29:59-81.
Stanley, E.H. and J.B. Jones, Jr. 2000. Surface-subsurface interactions: past, present, and future. Pp. 405-417 in J.B. Jones, Jr. and P.J. Mulholland (eds.), Streams and Groundwater. Academic Press.
Haggard, B.E., D.E. Storm, and E.H. Stanley. Effect of a point source input on stream nutrient retention. Journal of American Water Resources Association: in press.
Stanley, E.H., M.A. Luebke, M.W. Doyle, and D.W. Marshall. Short-term changes in channel form and macroinvertebrate communities following low-head dam removal. Journal of the North American Benthological Society: in press.

Eric W. Triplett, Department of Agronomy, University of Wisconsin, Madison, Wisconsin 53706; telephone 608.262.9824; fax 608.262.5217; email triplett@facstaff.wisc.edu; web site http://agronomy.wisc.edu/~triplett/index.html

Education:
B.S. Biology, Cook College, Rutgers University, New Brunswick, NJ, 1976; M.S. Botany, University of Maryland, College Park, 1978; Ph.D. Agronomy, University of Missouri, Columbia, 1981

Employment:
Professor of Agronomy, University of Wisconsin-Madison, 1987 – present
Assistant Professor of Plant Pathology, University of California, Riverside, 1982 – 1987
Postdoctoral Associate, University of Wisconsin-Madison, 1981 - 1982

Research Program:
Symbiotic nitrogen fixation in legumes; association of endophytic nitrogen-fixing bacteria in grasses; microbial ecology and function in lakes.

Professional Activities:
Editorial Board, Applied and Environmental Microbiology
Service on grant review panels for NSF and USDA

Publications (out of 62):
Dong, Y., J.D. Glasner, F.R. Blattner, and E.W. Triplett. 2001. Genomic interspecies microarray hybridization: rapid discovery of three thousand genes in the maize endophyte, *Klebsiella pneumoniae* 342, by microarray hybridization with *Escherichia coli* K12 open reading frames. Appl. Environ. Microbiol. 67:1911-1921.

Chelius, M.K. and E.W. Triplett. 2001. The diversity of *Archaea* and *Bacteria* in the roots of *Zea mays* L. Microbial Ecology 41:252-263.

Fisher, M.M., J.L. Klug, G. Lauster, M. Newton, and E.W. Triplett. 2000. Effects of resources and trophic interactions on freshwater bacterioplankton. Microbial Ecology 40:125-138.

Fisher, M.M. and E.W. Triplett. 1999. Automated approach for ribosomal intergenic spacer analysis of microbial diversity and its application to freshwater bacterial communities. Appl. Environ. Microbiol. 65:4630-4636.

Robleto, E.A., J. Borneman, and E.W. Triplett. 1998. Effects of bacterial antibiotic production on rhizosphere microbial communities from a culture independent perspective. Appl. Environ. Microbiol. 64:5020-5022.

M. Jake Vander Zanden, Center for Limnology, University of Wisconsin, Madison, Wisconsin 53706; telephone (608) 262 - 9464; fax (608) 265 - 2340; email mjvanderzand@facstaff.wisc.edu

Education:
Ph.D., Biology, 1999, McGill University, Montreal, QC
B.A. Geography, 1994, McGill University, Montreal, QC

Employment:
David H. Smith Postdoctoral Fellow, The Nature Conservancy, 1999 - 2001
Assistant Professor, Center for Limnology, University of Wisconsin, 2001-present

Research Program:
Food web interactions in aquatic ecosystems, applications of stable isotopes and other ecological tracers, predicting the occurrence and impact of aquatic invasive species, dynamics of contaminants in aquatic ecosystems.

Publications:

Vander Zanden, M. J., B. J. Shuter, N. P. Lester, and J. B. Rasmussen. 2000. Within- and among-population variation in the trophic position of the pelagic top predator, lake trout. Canadian Journal of Fisheries and Aquatic Sciences 57:725-731.

Vander Zanden, J. M. Casselman, and J. B. Rasmussen. 1999. Stable isotope evidence for food web shifts following species invasions of lakes. Nature 401: 464-467.

Vander Zanden, M. J., N. P. Lester, B. J. Shuter, and J. B. Rasmussen. 1999. Patterns of food chain length in lakes: a stable isotope study. American Naturalist 154: 406-416.

Vander Zanden, M. J., and J. B. Rasmussen. 1999. Primary consumer $\delta^{15}N$ and $\delta^{13}C$ and the trophic position of aquatic consumers. Ecology 80:1395-1404.

Vander Zanden, M. J., and J. B. Rasmussen. 1996. A trophic position model of pelagic food webs: Impact on contaminant bioaccumulation in lake trout. Ecological Monographs 66:451-477.

Paul R. Voss, Applied Population Laboratory, Department of Rural Sociology, University of Wisconsin, Madison, Wisconsin 53706; telephone 608-262-9526; fax 608-262-6022; email voss@ssc.wisc.edu

Education:
B.A. Mathematics, Luther College, Decorah, IA, 1962; Graduate study, Operations Research and Systems Analysis, U.S. Naval Post Graduate School, Monterey, CA, 1966-67; M.S. Sociology/Demography, University of Michigan, 1971; Ph.D. Sociology/Demography University of Michigan, 1975.

Employment:
Professor of Rural Sociology, University of Wisconsin, 1990 – present
Researcher to Senior Scientist, Dept of Rural Sociology, Univ. of Wisconsin, 1976 -1990
Lecturer, Department of Sociology, Williams College, Williamstown, MA, 1973 – 1976

Research Program:
Small-area demographic modeling with emphasis on population estimation and forecasting; migration modeling; spatial regression modeling using demographic data at fine spatial resolution

Professional Activities:
Representative of Population Association of America to the U.S. Commerce Department Decennial Census Advisory Committee (1991 – present)
National Academy of Sciences, National Research Council Panel on Estimates of Poverty For Small Geographic Areas (1997 – 2000)
Member, UW-Madison Spatial Information and Analysis Consortium (1994 – present)
Research Scholar, Population Project, International Institute for Applied Systems Analysis (IIASA) (1999 – 2000)

Publications (selected):
Voss, P.R., R.B. Hammer and A.M. Meier. Forthcoming 2002. Putting Migration Data to Work. Population Research and Policy Review (in press).
Radeloff, V.C., R.B. Hammer, P.R. Voss, A.E. Hagen, D.R. Field and D.J. Mladenoff. 2001. Human Demographic Trends and Landscape Level Forest Management in the Northwest Wisconsin Pine Barrens. Forest Science 47(2):229-241.
J. Riera, P.R.Voss, S.R. Carpenter, T.K. Kratz, T.M. Lillesand, J.A. Schnaiberg, M.G. Turner and M.W. Wegener. 2001. Nature, Society and History in Two Contrasting Landscapes in Wisconsin, USA: Interactions between Lakes and Humans During the Twentieth Century. Land Use Policy 18:41-51.
Kuczenski, T.K., D.R. Field, P.R. Voss, V.C. Radeloff and A.C. Hagen. 2000. Integrating Demographic and LandSat Data at a Watershed Scale. Journal of the American Water Resources Association 36(1):215-228.
Radeloff, V.C., A.C. Hagen, P.R. Voss, D.R. Field and D.J. Mladenoff. 2000. Exploring the Relationship between Census and Land Cover Data. Society and Natural Resources 13:599-609.

John F. Walker, U.S. Geological Survey, Middleton, WI 53562; telephone 608.821.3853; fax 608.821.3817; email jfwalker@usgs.gov

Education:
B.S. Civil Engineering, University of Wisconsin, Madison, WI,1979; M.S. Hydrology,University of Wisconsin, Madison, WI, 1981; Ph.D. Hydrology, University of Wisconsin, Madison, WI,1985

Employment:
Research Hydrologist, U.S. Geological Survey, WRD March, 1985 - present
Adjunct Professor of Civil and Environmental Engineering, University of Wisconsin, September 2000 – present
Lecturer, Department of Civil and Environmental Engineering, University of Wisconsin - Madison, September 1983 - May 1984

Research Program:
Ground-water/surface-water interactions, including hydrology and geochemistry; assessing the effectiveness of nonpoint best-management practices; hydraulics of flow under ice; optimization of ground-water systems

Professional Activities:
American Geophysical Union, Member since 1982
American Society of Civil Engineers, Member since 1991; Chair, Technical Committee on Hydraulic Measurements and Experimental Uncertainty

Publications (out of 27):
Potter, K.W., and Walker, J.F., 1985, An empirical study of flood measurement error: Water Resources Research, v. 21, no. 3, p. 403-406.
Hirsch, R. M., Walker, J. F., Day, J. C. and Kallio, R., 1990, Chapter 13: The influence of man on hydrologic systems, in Wolman, M. G. and Riggs, H. C., eds., Surface water hydrology: Boulder, CO, Geological Society of America, The Geology of North America, v. O-1, p. 329-359.
Walker, John F., 1991, Accuracy of selected techniques for estimating ice-affected streamflow: Journal of Hydraulic Engineering, v. 117, no. 6, p. 697.
Walker, J.F., 1994, Statistical techniques for assessing water-quality effects of BMPs: ASCE Journal of Irrigation and Drainage Engineering, v. 120, no. 2, p. 334-347.
Walker, J.F., and Krabbenhoft, D.P., 1998, Groundwater and surface-water interactions in riparian and lake-dominated systems, in McDonnell, J.J., and Kendall, C., eds., Isotope tracers in catchment hydrology: Amsterdam, The Netherlands, Elsevier, p. 467-488.
Walker, J.F., Saad, D.A., and Krohelski, J.T., 1998, Optimization of Ground-Water Withdrawal in the Lower Fox River Communities, Wisconsin: U.S. Geological Survey Water-Resources Investigations Report 97-4218, 24 p.
Walker, J.F., and Bullen, T.D., 2000, Trout Lake, Wisconsin: A water, energy and biogeochemical budgets program site: U.S. Geological Survey Fact Sheet 134-99, 4 p.

Chin H. Wu, Civil and Environmental Engineering Department, University of Wisconsin, Madison, Wisconsin 53706; Telephone 608.263.3078; fax 608.262.5199; Email: chinwu@engr.wisc.edu; Web site: http://www.cae.wisc.edu/~chinwu

Education:
1989, B.S. Hydraulics, National Taiwan University
1991, M.S. Hydraulics/Water Resources, National Taiwan University
1999, Ph.D. Oceanography, Massachusetts Institute of Technology

Employment:
Assistant Professor, University of Wisconsin, 1999-present
Research Assistant, Massachusetts Institute of Technology, 1994-1999
Research Assistant, National Taiwan University, 1993-1994
Engineering Officer, Army Corps of Engineers, 1991-1993

Research Program:
Environmental fluid mechanics with emphasis on air-water CO_2 interactions, surface wave dynamics, coastal processes and shoreline erosion, contaminated sediment transports, and groundwater and surface water interactions

Scientific and Professional Societies:
American Geophysical Union
American Physical Society
American Society of Civil Engineers
Sigma Xi Scientific Research Society

Honors and Awards:
All-Star Hydraulic Association Fellow, 1989
Phi Tau Phi Scholastic Honor Fellow, 1989
Arthur T. Ippen Fellowship, 1998
Outstanding Instructor Award, Polygon Engineering Council, 2001
ASCE Student Chapter Outstanding Professor, 2001

Publications:
Nepf, H.M., Wu, C.H., Chan, E.S. 1998. A comparison of two- and three-dimensional wave breaking. J. Phys. Oceanogr. 28(7): 1496-1510.
Wu, C.H., Nepf, H.M. 1998. Turbulence and surface drift generated beneath a three-dimensional breaker. John Hopkins Conference in Environmental Fluid Mechanics: p.p.158, 1998.
Wu, C.H. and Nepf, H. M. In press. Breaking wave criteria and energy losses for three-dimensional breaking waves. J. Geophy. Res.
Wu, C.H., Nepf, H.M., Cowen, E.A. In press. Surface current and vorticity generated by three-dimensional breaking waves. J. Fluid Mech.

Facilities, Equipment & Other Resources

Laboratory:

Laboratory of Limnology (U.W. Madison campus)

The LTER Water Chemistry laboratory includes a 604 ft^2 lab in the Laboratory of Limnology and 248 ft^2 lab in the Water Science and Engineering building. Both labs contain fume hoods. Refrigerators, freezers, drying ovens, a muffle furnace, and balances are also available in one or both spaces.

The LTER wet lab is 502 ft^2 in the basement of the Laboratory of Limnology with 70 ft^2 of storage space. The wet lab is used for cleaning equipment and occasionally for processing samples. Laboratory 101 at the Laboratory of Limnology is a 538 ft^2 lab space which is used for storage, water sample processing, and zooplankton counting. There also is a 52 ft^2 chlorophyll lab space used to process chlorophyll samples on the fluorometer and for equipment storage.

Trout Lake Station

The Trout Lake Station has a complex of buildings located on the shore of Trout Lake in northern Wisconsin. Most are operated year-round. These include a main laboratory, Juday House, four year-round cabins and several service buildings. Although the actual physical property of the station is only 20 ha, we provide access to the more than 2500 lakes in our region.

Our all-season laboratory is a two-story structure with more than 7,500 ft^2 of space. The upper floor contains a chemistry laboratory and five well-equipped research laboratories. One laboratory is designed for super-clean conditions necessary for trace metal sample processing. The upper floor also contains a library/conference room, eight offices, a lunchroom and a computer room. The lower floor of the station provides space for field gear storage, sample processing, aquarium facilities, and a primary production incubation lab. Light and temperature conditions can be controlled in the three aquarium rooms and a set of five incubators. Specialized laboratories are available for microscopy, high performance liquid chromatography, gas chromatography, and radio-isotope work. Critical equipment at the laboratory is serviced by an auxiliary power plant. Five service buildings at the station provide facilities for equipment and vehicle storage.

Year-round housing at the station provides space for 29 people. During the period from May until October, non-winterized cabins provide an additional 12 spaces. Housing at the station is provided only for short-term stays (<1 year). Permanent employees provide their own housing off station.

Computer facilities include a central fileserver linked to computers in the main laboratory and the five all season residences via ethernet. Multiple general use computers are available for use by visiting scientists. The Trout Lake Station has a T1 connection to the internet. We are in the process of developing wireless internet connectivity to automated rafts and buoys located on key study lakes.

Environmental Remote Sensing Center (ERSC)
ERSC occupies approximately 4800 ft^2 on the 12th floor of the Atmospheric, Oceanic, and Space Sciences Building, 1225 W. Dayton Street, Madison, Wisconsin 53706. The LTER-ERSC Research Associate Office is located in Room 1201, and includes one dedicated Windows workstation. Other components of ERSC that are widely used for NTL-LTER research include the Integrated Remote Sensing Resource Center (IRSRC) and the Instructional Laboratory (Room 1253).

Established as part of a NASA Centers of Excellence grant in 1997, the purpose of the IRSRC is to provide UW with a state-of-the-art computing facility for high-end spatial research needs. The NTL-LTER site is one of the primary users of the Center. The IRSRC hardware environment consists of a high-speed network, a Terabyte file server, a central research facility at ERSC (Room 1249), and remote nodes at research venues scattered across the university campus. The network component of the IRSRC consists of Fast Ethernet networks linked via a campus Asynchronous Transfer Mode (ATM) backbone. Data storage consists of a 4-way Pentium Pro 200 file server with 62 - 18 Gigabyte hard drives configured as RAID 5 virtual disks. The formatted capacity of the data store is 985 Gigabytes. The central research facility consists of 5 high performance Windows workstations, support computers, and other peripheral hardware.

The facilities of the ERSC Instructional Laboratory are available for use by NTL-LTER researchers and graduate students. These include fifteen high performance Windows workstations and two Calcomp digitizing tables. Other computational resources at ERSC include three Linux servers, a slide scanner, several flatbed scanners (including one UMAX large-format scanner suitable for the creation of high-resolution digital orthophotos from aerial photographs), laser and color inkjet printers, a slide maker, a large format inkjet plotter, CD-ROM writers, and other peripherals.

Major image processing and analytical software packages at ERSC include ESRI products (ArcGIS and ArcView), ERDAS Imagine, IDL, and ENVI. A number of software products developed in-house for teaching have also been used in NTL-LTER projects, and they include WiscImg, Softcopy, and OrthoMapper.

Center for Sustainability and the Global Environment (SAGE)
Most of the new modeling proposed here will be conducted at SAGE on the U.W. Madison campus. SAGE has extensive computing and laboratory facilities for the analysis of environmental data, as well as developing complex simulation models of the Earth's climate system and biosphere. Currently, SAGE uses a combination of Unix and Macintosh computing equipment: 4 multiprocessor Silicon Graphics Origin 200 Unix servers; 5 G3 iMacs, 6 G4 Macs (1 AGPG4/450; 5 G4/400); 5 G3 Powerbooks; 4 G4 Titanium Powerbooks, a G4/450 Cube, 3 Beige G3 Macs, 15 iBook wireless computers on a powered, secured cart various laser printers and color inkjet printers; 4 Airport

802.11b wireless Base Stations; and 2 Epson Powerlite Projectors. Most of our research computing needs are being serviced by our Silicon Graphics clusters. However, we have also been experimenting with highly-parallel computing solutions over our network of Apple G3 and G4 Macintosh computers. G4 PowerPC (at 500+ MHz) processors are now capable of sustained gigaflop performance, and will be a highly cost-effective computing solution for our group. IBIS and HYDRA are currently being ported to this system.

In addition, for high-end climate simulations, SAGE has access to the supercomputing facilities of the National Center for Atmospheric Research (NCAR).

Clinical: NA
Animal:
Water Science and Engineering Laboratory (WSEL)
The Center for Limnology manages an aquarium facility in the Water Science and Engineering Laboratory (WSEL). This facility provides flow-through water systems that have automated light, water temperature, and water pressure controls. The facilities configuration can be adapted to suit various research needs, and can house several 5,000+ liter aquaria and dozens of 100-liter aquaria. Water sources include lake water, potable and non-potable city water, and tempered city water. The parameters for the tempered water are controlled by a series of six head tanks located on the ground floor of WSEL, and aquaria in the basement receive their water by gravity feed. Electromechanical controls prevent accidental water flow to aquaria when water temperatures are outside of specified ranges. Nearly all experimentation in the facility involves ectothermic species, such as fishes, amphibians, and crustaceans.

Trout Lake Station
The laboratory at Trout Lake Station has a series of large fiberglass holding tanks, four 75-gallon fiberglass aquaria and assorted small aquaria. Portable generators and pumps allow the use of holding tanks at remote sites.

Computer:
The Laboratory of Limnology runs a Windows NT 10/100 megabit local area network (LAN), with a 10 megabit connection to the campus wide area network (WAN). Two fileservers house a central repository of computer software and end-user data, and provide web services, administrative databases and connections with the Trout Lake Station. One SUN Ultra runs the LTER databases and GIS software. Available for student use are PC and Macintosh desktop and PC laptop computers, printers, slide shooters, slide and document scanners, fixed and portable computer projectors. The Center supports standard office software, graphics software, and a variety of modeling and statistics software, as well as access to major electronic journals. The Trout Lake Station runs a network analogous to that of the Madison laboratory, including a fileserver, T1 Internet connection, general use computers and the peripherals described above. In addition, the station provides wireless ethernet and serial communication.

Between the two facilities, there are nearly 75 computers, with about 1/3 of these being available for student use.

Instruments for data management include Windows NT local area network (LAN) supporting Windows-based microcomputers and a Sun Sparc Ultra2 workstation.

Additional computing capability is available at ERSC and at SAGE (see above).

Office:
The Center for Limnology provides substantial administrative, secretarial, computer, and building and equipment maintenance support that directly benefits the LTER program, in the form of 7.8 FTE funded by Center operational funds. Center personnel (4.8 FTE) manage and coordinate day-to-day operations of the center's research programs and oversee Center administration including all operational funds and research grants. Staff also assist with recruitment and appointment of research staff, maintain and administer accounting records for all operational and grant funds, including purchasing, travel arrangements and reimbursement, and compliance with University and federal requirements. Administrative, secretarial and receptionist services, and general computer hardware, software, and web support to all Center faculty and staff are also provided.

Other PIs are housed in departmental offices throughout campus or at Trout Lake Station. All offices are equipped with desktop computers and ethernet lines.

Other:
The Limnology Library in the Laboratory of Limnology houses a large collection of reprints and tracks reprints from LTER so that a publication list can be obtained. Pertinent LTER government documents are also collected and sorted by the various LTER sites.

MAJOR EQUIPMENT:

Laboratory of Limnology in Madison
Equipment used for LTER water chemistry analyses includes: O/I Model 700 TOC analyzer; Technicon Autoanalyzer II linked to a PC for automated data processing; Dionex DX-500 ion chromatograph equipped with an automated sampler, eluent generator, and gradient pump; Perkin-Elmer Optima 4300 DV Optical Emissions ICP spectrometer; a Beckman DU 640 spectrophotometer; and a Turner Designs TD-700 fluorometer. There are 2 Leica WILD MZ8 dissecting microscopes, 2 Leica WILD M5A dissecting microscopes, and 2 Nikon LABOPHOT compound microscopes.

The Laboratory of Limnology is well equipped for field sampling of the Madison area lakes. Lake Mendota and other lakes of the Madison chain are accessed from powerboats moored in the basement of the Laboratory of Limnology, and from the 31-foot R.V. *Limnos* on Lake Mendota. Other lakes are accessed by trailered boats. We maintain a snowmobile for winter access to the lakes. The Laboratory of Limnology operates a complete array of limnological sampling gear, including an electroshocking boat, nets, and water sampling equipment.

ERSC
Additional major equipment items at ERSC include an ASD FieldSpec hand-held spectroradiometer, several Trimble GPS units, a digital camera, and a videocamera.

Trout Lake Station
Trout Lake Station is well equipped to provide access for researchers to nearly any aquatic site in the region. Major field gear includes: two, four-wheel-drive trucks, eight boat trailers, a ski barge, 15 rowboats, eleven outboard motors, and two canoes. During the peak summer season, several additional vehicles are available for general field use. Scuba gear is also available. Two snowmobiles, ice drills, snowshoes, tents and insulated field boxes are available for winter limnology. We have most standard collecting gear for general limnological work including peristaltic pumps with in-line filtration, meters and probes to measure light (PAR and full spectral characteristics), temperature and oxygen meters including sondes that can be placed in lakes for extended periods, plankton samplers, trawls, fyke nets, gill nets, seines, two electroshocking boats, and a 120 kHZ hydroacoustic data collection system capable of estimating abundance of pelagic fishes.

Our laboratories are equipped with fume hoods, high quality water purification systems, drying ovens, a muffle furnace, dry sterilizers, balances (in a variety of ranges including a Cahn Electrobalance), pH meters, recorders, a Waters High Performance Liquid Chromatograph with a diode array detector, a Kontron Double-Beam Spectrophotometer, an electronic particle counter, a fluorometer, a Lachatt nutrient analysis system, a Beckman models LS 1801 liquid scintillation counter, and an OI Corporation organic carbon analyzer. A set of five, light-and temperature-controlled incubators are available for experimental projects and culture maintenance. Microscopes available at Trout Lake include: a Zeiss Inverted Microscope equipped for epifluorescence, a Nikon Labophot microscope, and 1 Leica and 3 Wild model M5A dissecting scopes. Detailed meteorological data are currently recorded at a nearby land-based station and on a fully-instrumented raft currently operated on Sparkling Lake, 3 km from the station. Chemical precipitation is sampled at an NADP site located at Trout Lake that is serviced by our laboratory.

OTHER RESOURCES:
In addition, Center staff (3.0 FTE) manage and maintain all Center facilities (laboratory and boat facilities, office and common space, and residential units) and equipment in the Laboratory of Limnology and at Trout Lake Station, including constructing and maintaining instruments, sampling gear and other research equipment. Staff also manage the experimental aquarium facilities in the Water Sciences and Engineering Laboratory, oversee construction and remodeling of all facilities, and are responsible for secure storage of all Center sampling equipment, boats, vehicles and limnological

samples. The Center machine, metal and woodworking shop facilities at the Madison Laboratory (1894 sq. ft) and Trout Lake Station (1132 sq. ft) contain many types of equipment available for LTER use, including welders, lathes, table, radial arm and band saws, drill presses, milling machines, and a large variety of hand tools. Staff also oversee all Center vehicle use, including deployment and maintenance of vehicles used for field research in Madison and at Trout Lake Station. Finally, staff provide logistical support for Center for Limnology outreach programs for students and teachers in the Madison and Boulder Junction areas.

Table 1:Electronic Availability of NTL-LTER Core Data.

Type of Data	Directly Accessible by NTL-LTER Researchers	Accessible (A) on the NTL web site
Physical Limnology		
Depth Profiles	ORACLE DATABASE	**A**
Ice Duration	ORACLE DATABASE	**A**
Ice Thickness/Snow Depth	ORACLE DATABASE	**A**
Secchi Disk Depth	ORACLE DATABASE	**A**
Lake Levels*	ORACLE DATABASE	**A**
Chemical Limnology		
Nutrients	ORACLE DATABASE	**A**
Major Ions	ORACLE DATABASE	**A**
Plankton		
Chlorophyll a	ORACLE DATABASE	**A**
Primary Production*	ORACLE DATABASE	**A**
Zooplankton (TLA)	ORACLE DATABASE	**A**
Zooplankton (MLA)	FILE SERVER	in process
Sediment Deposition*	FILE SERVER	**A**
Aquatic Macrophytes		
Macrophyte Biomass	ORACLE DATABASE	**A**
Macrophyte Transect	ORACLE DATABASE	**A**
Pelagic Macroinvertebrates*	FILE SERVER	**A**
Crayfish	ORACLE DATABASE	**A**
Benthic Macroinvertebrates*	FILE SERVER	**A**
Fish		
Fish Abundance	ORACLE DATABASE	**A**
Fish Length Frequency	ORACLE DATABASE	**A**
Groundwater*		
Groundwater Level	ORACLE DATABASE	**A**
Groundwater Chemistry	ORACLE DATABASE	**A**
Sparkling Lake Raft*		
Meteorological Data	ORACLE DATABASE	**A**
Water Temperature	ORACLE DATABASE	**A**
Meteorological*	ORACLE DATABASE	**A**
Historical land use/land cover data	FILE SERVER	in process
Spatial Data		
Hydrography	FILE SERVER	**A**
Elevation/DEM	FILE SERVER	**A**
Soils	FILE SERVER	**A**

* Trout Lake Area lakes only.   TLA = Trout Lake Area; MLA = Madison Lake Area

Table 2. NTL-LTER Data and Information Shared (outside of the project).

Requests received via email, mail and phone
during the period 1996 – 2001

For NTL-LTER Data
Investigators at the University of Wisconsin-Madison

Undergraduate	Graduates	Other Researchers
16	17	21

Investigators outside the University of Wisconsin-Madison

University	State/Local Government	Federal	Private	International
63	23	17	17	24

For Information and Data Collection Methods and Data Management
Investigators outside the University of Wisconsin-Madison

University	Other
28	15

Requests via Internet to NTL-LTER World Wide Web home page
compiled from entries in the web server log for January 2000 through December 2001

	Domain						
Information Type	wisc .edu	(other) .edu	.gov, .us	.net, .com	.ca	other countries	other*
General Site Information	410	368	80	531	43	153	1025
Lake Characteristics	161	198	46	501	40	97	651
Major Research Findings	121	144	25	202	19	37	305
Previous Proposals	34	81	18	226	8	20	322
Personnel Directory	206	299	54	213	37	82	537
Publications	137	339	77	586	97	267	995
Data Catalog / Data Sets	657	434	84	479	83	190	1571
Biodiversity Information	26	110	16	185	11	42	223
Education / Outreach	158	89	32	247	9	41	440
Calendar	50	17	1	276		18	180

*The “other” category represents requests from other domains or addresses not easily categorized into domains.

North Temperate Lakes LTER Publications 1996-2001 and in press

Journal Articles

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Publications resulting from Workshops organized and lead by NTL Scientists

The following list includes articles produced as a result of two workshops, one on Ice Phenology and the other on the Ecological Organization of Lake Districts, organized by NTL-LTER researchers and held at the University of Wisconsin Trout Lake Station. The publications listed here do not use NTL-LTER data. Publications from these workshops that use NTL data are listed in NTL publication list above.

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Assel, R.A. and L.R. Herche. (In Press). Coherence of long-term lake ice records. Verh. Internat. Verein. Limnol. 27
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