Water Resources Research Center
Annual Technical Report
FY 2002

Introduction

Research Program

Linking Lakes with the Landscape: The Fate of Terrestrial Organic Matter in Planktonic Food Webs

Basic Information

Title:	Linking Lakes with the Landscape: The Fate of Terrestrial Organic Matter in Planktonic Food Webs
Project Number:	2002NH1B
Start Date:	3/1/2002
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	
Research Category:	None
Focus Category:	Ecology, Models, Surface Water
Descriptors:	None
Principal Investigators:	Kathryn L. Cottingham, Jay Terrence Lennon

Publication

1. Lennon, J.T. Terrestrial carbon input drives CO2 output from lake ecosystems. In review, Oecologia.
2. Lennon, J.T. Sources of terrestrial-derived subsidies affects aquatic bacterial metabolism. In preparation for submission to Microbial Ecology.

WRRC FY 2002 Annual Progress Report

LINKING LAKES WITH THE LANDSCAPE: THE FATE OF TERRESTRIAL ORGANIC MATTER IN PLANKTONIC FOOD WEBS

Jay T. Lennon and Kathryn L. Cottingham
Department of Biological Sciences, Dartmouth College
6044 Gilman Laboratory, Hanover, NH 03755
Phone: (603) 646-0591 Fax: (603) 646-1347
Jay.Lennon@dartmouth.edu or cottingham@dartmouth.edu

PROBLEMS AND OBJECTIVES

We are evaluating how terrestrially-derived dissolved organic matter (DOM) influences the functioning of lake ecosystems. Terrestrially-derived DOM is commonly the largest carbon pool in lakes. As such, terrestrial DOM represents a major source of potential energy for aquatic food webs that may subsidize higher trophic levels (including zooplankton and fish) and determine whether lake ecosystems act as sources or sinks of CO_2. Our project addresses three main factors that influence terrestrial carbon flow in lakes.

Objective 1: Determine whether the energetic importance of terrestrial DOM in lakes is ultimately determined by bacterial metabolism. In this study, we define bacterial metabolism as biomass production and respiration. We hypothesized that bacterial biomass production and respiration are affected by the quantity and quality of terrestrial DOM. Specifically, we predicted that bacterial metabolism is higher on DOM sources with low C:N and C:P ratios.

Objective 2: Quantify the extent to which carbon flow in lakes is influenced by food web structure. One important feature of lake food webs is that not all members of the plankton community are capable of consuming DOM-subsidized bacteria. We hypothesized that food web structure affects whether higher trophic levels benefit from inputs of terrestrial DOM. We predicted that food webs dominated by cladoceran zooplankton, which are capable of feeding on bacteria, would be more efficient at transferring terrestrial carbon to higher trophic levels.

Objective 3: Use carbon stable isotopes ($\delta^{13}C$) in particulate organic matter (POM) and zooplankton to elucidate patterns of carbon and nutrient cycling along a terrestrial DOM gradient in New England lakes. We predicted that carbon stable isotope ratios in zooplankton and particulate organic matter would become more negative along the DOM gradient, reflecting a terrestrial $\delta^{13}C$ signal. We also predicted that cladoceran zooplankton would have lower $\delta^{13}C$ values than copepod zooplankton because they can feed on terrestrial subsidized bacteria.

METHODS

Objective 1*: DOM characteristics and bacterial metabolism*— We measured bacterial productivity (BP) and bacterial respiration (BR) on six different sources of terrestrial-derived DOM. We collected soils from the organic (Oa/A) horizons in near-monoculture stands of six of the most common trees in New England forests (pine, maple, hemlock, beech, oak, birch). We dried these soil samples and then extracted the organic matter in 1L 0.1N NaOH. We removed particulate material (>0.7 μm) from the leachates via serial filtration, dialyzed each leachate (500

D) in a distilled water buffer to reduce concentrations of salts and inorganic nutrients, and then gamma-irradiated the leachates to kill soil-associated microbes.

We then characterized a suite of chemical properties in each leachate: dissolved organic carbon (DOC), total phosphorus (TP), total nitrogen (TN), polyphenolic compounds, humic acids, protein content, and high molecular weight DOC fractions. In addition, we determined the concentrations of 15 major elements using inductively coupled plasma (ICP) atomic emission spectroscopy (AES).

We used regrowth experiments to quantify bacterial production and bacterial respiration in response to different leachates along a DOC gradient (3-17 mg/L). Each experimental unit was filled with 450 mL of 0.22 µm-filtered lake water and 50 mL of 2.7 µm-filtered (Whatman GF/D filtered) lake water containing bacteria, then concentrated terrestrial leachate was added to create the target DOC concentration. We estimated bacterial productivity (BP) at 36 h by measuring the uptake and incorporation of ^{3}H radiolabeled leucine into bacterial protein. Bacterial respiration (BR) was estimated as the changes in dissolved oxygen concentrations in dark bottles between 24 and 48 h.

Objective 2: ***Food web structure and terrestrial carbon flow*****—** We are using simulation models to address Objective 2. We are currently constructing a nonlinear deterministic simulation model in MatLab to assess how terrestrially-derived DOM could influence the energetics of lake food webs. Differential equations for state variables have been chosen from the primary literature and compartment sizes will be tracked using carbon as the currency. Bacteria and phytoplankton have logistic growth and all consumer-resource interactions are described with Type II ratio-dependent functional responses. Dynamics of the state variables will be solved using adaptive step size Runge-Kutta integration. Once the model is constructed, we conduct two types of sensitivity analyses: (1) independently manipulating the model parameters and (2) conducting Monte Carlo cross-factor simulations using parameter distributions estimated from the literature. After we establish that the model is well-behaved, we will run the model over a range of realistic DOM loading rates for two different food webs (daphniid- vs. copepod-dominated) across a gradient of lake trophic states.

Objective 3: ***Carbon stable isotope ratios along DOM gradients***— During summer 2002, we sampled 37 lakes in VT, NH, CT, and ME for $\delta^{13}C$ in POM and crustacean zooplankton. At each lake, we recorded physical-chemical features of the lake water (i.e., pH, O_2, conductivity), then took depth-integrated water samples from the epilimnion of each lake. Samples for POM were filtered onto precombusted glass fiber filters in the field, and samples for DOC, TN,TP, and chlorophyll *a* were brought back to the laboratory. We also took depth integrated zooplankton samples (>80 µm) and separated animals into two functional groups (large cladocerans and large copepods) before filtering them onto precombusted glass fiber filters. $^{13}C/^{12}C$ ratios were obtained with a Finnigan MAT 252 Isotope Ratio Mass Spectrometer at the UC Davis Stable Isotope Facility. We measured DOC on a Tekmar-Dohrmann TIC/TOC analyzer after H_2SO_4 digestion. We measured TN and TP spectrophotometrically after persulfate digestion and determined chlorophyll *a* with methanol extraction on a Turner Designs TD700 fluorometer outfitted for Welshmeyer’s method.

PRINCIPAL FINDINGS AND SIGNIFICANCE

Objective 1*: DOM characteristics and bacterial metabolism*— The chemical composition of the DOM sources (leachates) were significantly different from one another. One-way ANOVA revealed that there were significant differences among the leachates for all chemical attributes. Multivariate principal components analysis (PCA) also indicated that the DOM sources had different chemical compositions.

BP and BR responded strongly to the DOM treatments. A multiple regression model (using DOC and indicator variables for leachate type as the predictors) explained 87% of the variation in BP ($R^2 = 0.88$, $R^2adj = 0.85$, $F_{11,71} = 37.8$, $P < 0.0001$). This analysis revealed that differences in DOM sources explained much of the variability in BP. BP was highest when bacteria were grown on beech and oak DOM. Multiple regression explained 67% percent of the variation in BR ($R^2 = 0.67$, $R^2adj = 0.61$, $F_{11,70} = 10.9$, $P < 0.0001$), but was less affected by the different DOM sources as evidenced by overlapping confidence intervals for the slopes provided by the indicator variables (see Fig. 1).

As predicted, carbon:nutrient ratios were important in explaining variation in bacterial metabolism. Carbon specific rates of BP (i.e., the slope of the DOC-BP relationships) increased exponentially with the phosphorus content of the DOM source.

Together, these results suggest that sources of DOM vary in their chemical composition and that this variability can have a large effect on bacterial metabolism. These differences may influence the degree to which higher trophic levels are subsidized by terrestrial DOM. Work completed as part of this Objective is currently being written up for submission to *Microbial Ecology* during summer 2003.

Objective 2: *Food web structure and terrestrial carbon flow*— We have nearly completed our literature search for parameters needed in the food web model, and have programmed the microbial portion of the food web (bacterial carbon uptake and growth). Analyses of this sub-model indicate that the rate and magnitude at which carbon becomes available to bacteria have considerable effects on bacterial biomass, and that further simulations will need to take the temporal dynamics of carbon inputs into account. Our next step is to integrate the microbial part of this model into a more traditional plankton food web.

Objective 3: *Carbon stable isotope ratios along DOC gradients*—We obtained isotope samples from 37 of the 50 lakes visited in 2002. DOC concentrations in the lakes ranged from 3–15 mg/L. δ^{13}C-POM declined over the DOC gradient from -24 to -36 ‰. Similarly, δ^{13}C-zooplankton declined over the DOC gradient from -27 to -40 ‰ (see Fig. 2). A multiple regression model explained 63% of the variation in plankton $\delta^{13}C$ ($R^2 = 0.63$, $P < 0.0001$, n = 73). A paired t-test revealed that cladoceran vs. copepod zooplankton had similar $\delta^{13}C$ values ($P > 0.05$).

Published isotopic values of the POM and zooplankton are commonly less than terrestrial organic matter (-28‰). This observation, together with the relationship in Fig. 2, suggests that there is a progressively larger input of isotopically light carbon along the DOM gradient. We hypothesize that methane (CH_4) becomes more important for lake carbon cycling as terrestrial DOM inputs increase. Terrestrial DOM colors lake water and attenuates solar radiation, promoting anoxic conditions in the hypolimnia, which in turn favor methanogenic bacterial communities. Methanogenic bacteria convert H_2 and CO_2 to CH_4 and H_2O. CH_4 is then used by methanotrophic bacteria, creating isotopically light CO_2. This summer we plan to continue our lake survey, adding some new measurements to test the importance of CH_4 cycling in terrestrially subsidized lakes. We will analyze hypolimnetic CH_4 concentration, hypolimnetic δ^{13}C-DIC, and bacterial community structure using fluorescence in-situ hybridization (FISH). If CH_4 cycling becomes more important in DOM-rich lakes, and is responsible for the pattern in Fig. 2, then we should see the following: 1) hypolimnetic CH_4 increases with DOC, 2) ^{13}C-DIC becomes more negative with DOC, and 3) methanogenic and methanotrophic bacterial increase with DOC.

OTHER ACCOMPLISHMENTS

Students involved— To date, three students have been involved in this project. Jay Lennon is a Ph.D. student. This grant funds his dissertation research. Liza Pfaff and Nira Salant were Dartmouth undergraduate students employed by this grant; Pfaff worked on the project from April to December, 2002, and Salant worked from October to December, 2002.

Papers—

Lennon, J.T. Terrestrial carbon input drives CO2 output from lake ecosystems. In review. Oecologia.

Lennon, J.T. Sources of terrestrial-derived subsidies affects aquatic bacterial metabolism. In preparation for submission to Microbial Ecology in July 2003.

Presentations—

Lennon, J.T. June 10-14, 2002. Experimental evidence that terrestrial organic matter modifies plankton metabolism. American Society of Limnology and Oceanography, Victoria, British Columbia, oral presentation.

Lennon, J.T. October 16, 2002. Ecology of subsidies: role of terrestrial carbon in aquatic ecosystems. Colby-Sawyer College. Invited seminar.

Lennon, J.T. April 29, 2003. Terrestrial subsidies in aquatic ecosystems: is carbon flow to higher trophic levels regulated by microbial metabolism? Cary Conference, Institute of Ecosystem Studies, poster presentation.

Lennon, J.T. and Pfaff, L.E. August 3-8, 2003. Microbial constraints on the flow of terrestrial subsidies in lake ecosystems. Ecological Society of America, Savannah, GA, oral presentation.

Lennon, J.T. November 4-7, 2003. Trophic state and plankton nutrition along a terrestrial DOM gradient in New England lakes. North American Lake Management Society. Mashantucket, Connecticut, oral presentation.

Special session organizer—

Lennon co-organized a special session on "Ecological implications of terrestrial inputs into lakes and ponds" for the 2002 American Society of Limnology and Oceanography national meeting.

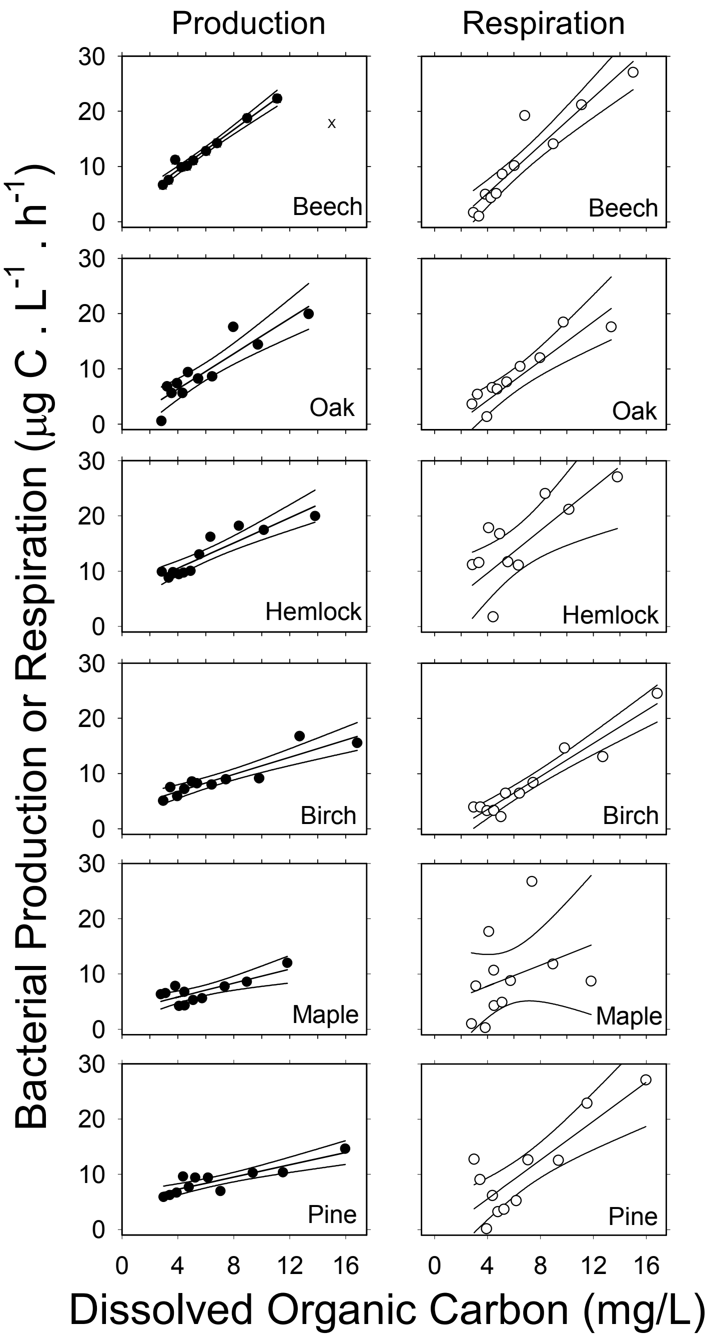


Figure 1. Bacterial production (●) and bacterial respiration (○) in response to varying quantities and sources of terrestrial-derived DOM. Bacterial production and bacterial respiration increased with dissolved organic carbon (DOC). Bacterial production was affected by different DOM sources (slopes are ranked highest to lowest along the vertical panels); bacterial production was greatest on beech and oak DOM sources. Bacterial respiration was not affected by DOM source.

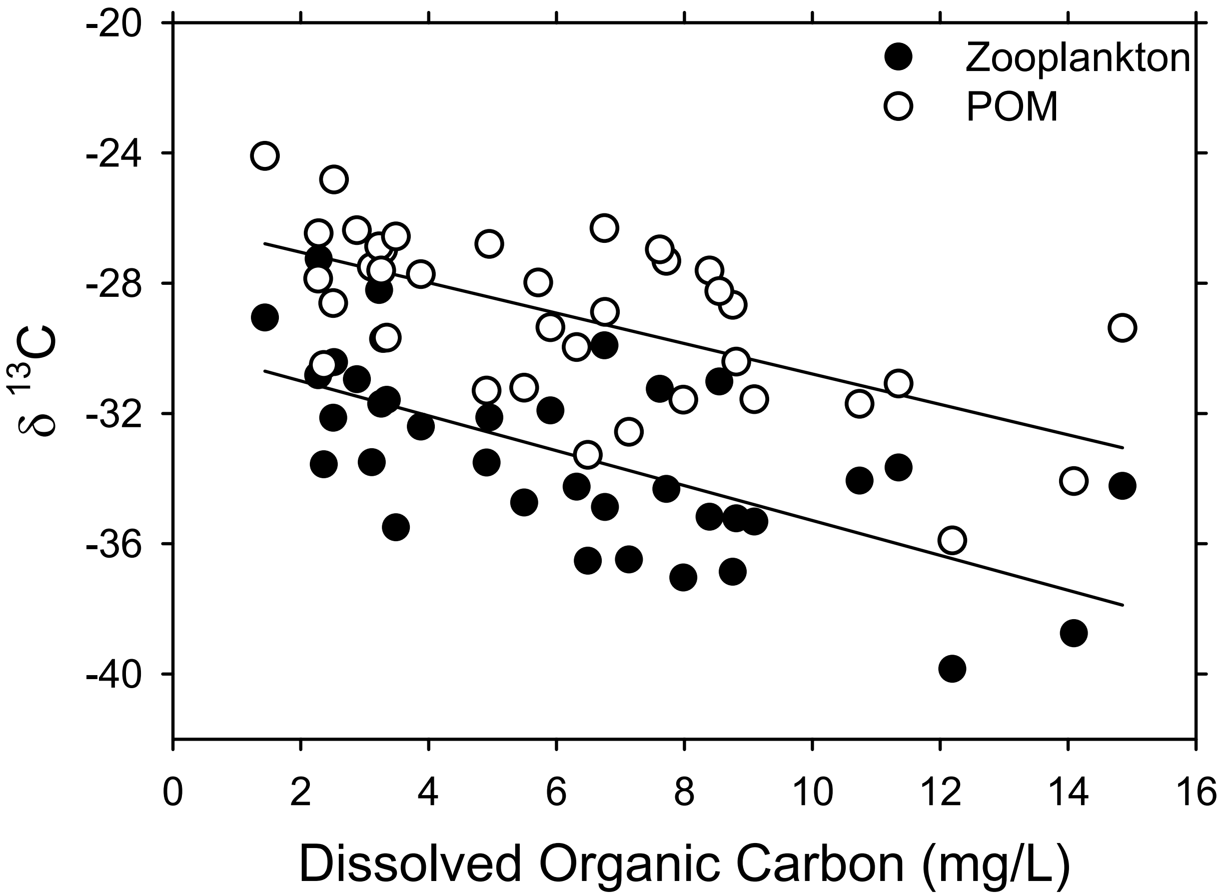


Figure 2. $\delta^{13}C$ of zooplankton (●) and POM (○) along a DOC gradient in 37 New England lakes. Multiple regression revealed that $\delta^{13}C$ of zooplankton and POM decreased at the same rate along the DOM gradient. However, the zooplankton intercept is significantly less than the POM source suggesting that POM does not perfectly reflect zooplankton diets.

Dynamics of Groundwater Inflows to the Lamprey River, New Hampshire

Basic Information

Title:	Dynamics of Groundwater Inflows to the Lamprey River, New Hampshire
Project Number:	2002NH2B
Start Date:	3/1/2002
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	
Research Category:	None
Focus Category:	Groundwater, Surface Water, Water Quantity
Descriptors:	None
Principal Investigators:	J. Matthew Davis

Publication

Progress Report for

Dynamics of Groundwater Inflows to the Lamprey River, New Hampshire

Funded by:
Water Resources Research Center
University of New Hampshire

July 7, 2003

1.0 Problem Statement and Research Objectives

The Lamprey River Watershed is an important component of the water resources of the seacoast region of New Hampshire and is similar in climatology and hydrogeology to many watersheds in New England. The Lamprey serves as a water supply for municipalities including Deerfield, Raymond, Epping, and Newmarket, as well as serving as an auxiliary water supply for Durham and the University of New Hampshire. Current activities within the watershed, including a proposed bottled water plant near Northwood, may result in changes to the aquifer system. Forecasting and potentially mediating late-summer low flow conditions in the Lamprey (and other similar rivers in the region) are critical to effectively managing these resources. In addition to the Lamprey's importance as a water resource, an 11.5-mile stretch of the Lamprey River from Newmarket to Lee was declared a National Wild and Scenic River. With this declaration, several restrictions were initiated, including policies against new dam and water transfers; water quality; channel alterations; new solid-waste facilities; and protected in-stream flows. These restrictions protect both the stream and surrounding ecology from future effects of population growth in the region. An important factor in protecting stream ecology is the dynamics of the river during reduced flows.

During reduced flow periods, a large percentage of surface water flow is derived from groundwater inputs (Perkins and Sophocleous, 1999; Harvey and Bencala, 1993; Cey et al., 1998). However, little research has been conducted to quantify inputs to the Lamprey River discharge from sources such as stratified drift aquifers, bedrock aquifers, and springs. Previous work on low flow systems in New England (Dingman and Lawlor, 1995; Risley, 1994; Barnes, 1986; and Kliever, 1996) have focused on the statistical methods of determining low flows rather than the source of water during these periods.

The principal objective of this research is to test the hypothesis that the stream flow in the Lamprey River during the late summer to early fall is controlled by the gravity drainage of both the bedrock and stratified drift aquifers. Ideally, we would be able to quantify the relative amounts of water from sources such as stratified drift aquifers and bedrock aquifers to determine the temporal hydrologic controls of surface water. Over the past year, we have collected groundwater and surface water data and collated historical groundwater and surface water data to help determine relationships between the aquifer and stream systems. The research is on-going, and this document will describe work that has been completed to date and describe future work.

2.0 Research Methods

2.1 GIS Analysis

GIS databases were obtained from GRANIT to compile data from the Lamprey River Basin. Particular data layers of interest that will be used later in the modeling phase of this proposal (see Section 2.4 for further discussion on the model phase) include the hydrography layer, surficial material layer, and the DEM data layer. Data layers were merged for the watershed, and cut based on a layer that contained the watershed boundary. This will allow for the production of maps on the watershed for the final research paper for this proposal.

2.2 Groundwater Data

Groundwater data collection was undertaken in July of 2002 with the assistance of personnel from the New Hampshire Department of Environmental Service (NHDES). Wells from a 1984 survey on water resources that were not decommissioned or destroyed were located throughout the watershed. Two wells were installed with a data-logging system that recorded levels at hourly intervals, and 5 additional wells (including USGS monitoring wells located in Deerfield and Lee) were monitored on a weekly basis. The data will be used to calibrate and verify the groundwater model (see Section 2.4 for further discussion on the model).

All monitored wells were advanced into the stratified drift aquifer. No wells were located to be monitored within the bedrock aquifer. Therefore, incomplete data exists for the bedrock aquifer. However, this should not be an issue since the model being developed will assume that the initial piezometric surface is a representation of the DEM data file (topography).

We will continue to work with NHDES and the NHGS to identify strategic locations for additional long-term monitoring wells in both the stratified drift and bedrock aquifers.

2.3 Surface Water Data

Historical data was collected from the USGS gage located on the Lamprey River near Packers Falls. This data was analyzed with basic hydrologic models to determine basic properties of the aquifer and the stream. This was completed by isolating data from 10 years of the lowest recorded flow. This data was further isolated by collecting precipitation and weather data from both Epping and Concord for the same time period. By combining this data, 10 hydrographs were analyzed and fitted with mathematical models to arrive at basic properties of the system. This data will be used as initial input into the groundwater model.

During this brief study, we were unable to identify optimal paired cross sections for determining gaining or losing conditions during low flow. However, this remains a critically important measurement and we will continue to search for an appropriate pair of stations.

Watershed Model

Our initial hypothesis focused on the superposition of outflows in two lumped-parameter models with different time constants. While we continue to pursue this as a viable hypothesis, limited data in the bedrock system severely limits our ability to assess the characteristics of the bedrock aquifer.

We are also developing a spatially distributed model to account for the significant topographic variability and its relation to surface water discharge characteristics. The model will be a single layer subdivided into stratified drift and bedrock components. The initial water table will be a function of the topography. The surface of the model will be coded either as a hydrographic feature (from GIS coverage) or a drain cell with a drain elevation equal to the surface elevation. A small amount of recharge will be applied to the entire model surface and the sensitivity of the recharged will be evaluated.

Results from the transient simulation will be analyzed in two ways. First, a map of the fluxes to the drains will be made for each time step. This will help understand how the drainage of the Lamprey River Watershed evolves over the course of a May-Sept season. Second, the drain fluxes will be integrated along the reaches above the Packers Falls gaging station to compare how well this simple model matches observed stream flow patterns.

Modeling Specifications. Argus ONE will be to work with GIS layers to form grids that were readable into MODFLOW. The model will be built to run with MODFLOW96.

The following steps have been completed to set-up the model:

1) GIS database layers were read into Argus ONE and exported in a format for MODFLOW. In particular, the hydrography layer, which will outline the location of the river, lakes, and ponds, was exported. The DEM files were combined, rasterized, and brought into Surfer for additional analysis. ArcView allowed the files to be generated to resolutions that matched the proposed grid size of the model (300 m x 300 m). The DEM file is important for this model because it will determine the initial head of the system, locations of surface drains and elevations of surface water bodies as determined in the hydrography layer.
2) Argus ONE was used to set up the grid for the model. The initial cell size was set to be 300 m by 300 m. This initial size was chosen to maximize model output while retaining model resolution. The size of the cells may change depending on model results, model run-time, and resolution issues.
3) Because 3 various programs are being used to work with the data (Surfer, Excel, and MODFLOW), a FORTRAN program that will allow for data manipulation was written. The program will change the formats from each output to a form that can be read by the various programs. This will allow for maximum efficiency in data analysis. For instance, recorded model heads for each particular time step can be visually monitored in Surfer to watch as the head changes with time. If problems are noted in particular areas, more efforts can be focused on what physical or model issues are occurring.

Students Supported

Brian Thomas, M.S. Hydrology candidate, Department of Earth Sciences

Papers and Presentations

None to date.

Characterization of Groundwater Discharge to Hampton Harbor

Basic Information

Title:	Characterization of Groundwater Discharge to Hampton Harbor
Project Number:	2002NH3B
Start Date:	3/1/2002
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	
Research Category:	Not Applicable
Focus Category:	Groundwater, Non Point Pollution, Nutrients
Descriptors:	
Principal Investigators:	Thomas P. Ballestero, Robert Roseen

Publication

A. Scheduled Tasks

The primary efforts during this reporting period were the final review of intertidal groundwater discharge zones, the preparation of the research findings for presentation at an upcoming conference, and final water quality analyses.

B. Progress on Tasks

The final review of intertidal groundwater discharge zones suggest that intertidal groundwater discharge is extremely limited in Hampton Harbor due to the presence of a large impermeable salt marsh. A single groundwater discharge zone was found within the study area. Numerous sites were located, and all but one had salinities greater than 21 ppt. With salinities that high, these sites were deemed locations of saltwater pumping rather groundwater discharge. A single site was located which had a salinity of 5 ppt. The strict hydrogeologic control limited all potential sites to coarse sands, likely the location of historic deposition of coastal barrier features. No potential sites were located within the salt marsh.

The unique project results will be presented at the *Technology Transfer Conference, Emerging Technologies, Tools, and Techniques, To Manage Our Coasts in the 21st Century,* sponsored by the U.S. EPA Office of Water, Office of Wetlands, Oceans, and Watersheds, Oceans and Coastal Protection Division. The title of the presentation will be *Limitations of the Use of Thermal Infrared Imagery for the Assessment of Inter-Tidal Groundwater Discharge based on Land Use, Land Cover, and Hydrogeology,* by Robert M. Roseen, Thomas P. Ballestero, Gabriel Bacca-Cortez, and William G. McDowell.

Following completion of water quality analyses, final loading calculations will be performed. However, as groundwater discharge is extremely limited, loading is expected to be very minimal.

C. Difficulties Encountered

None to report.

D. Anticipated Success in Meeting Project Objectives in Scheduled Project Period

The project is on schedule and project objectives will be met on time.

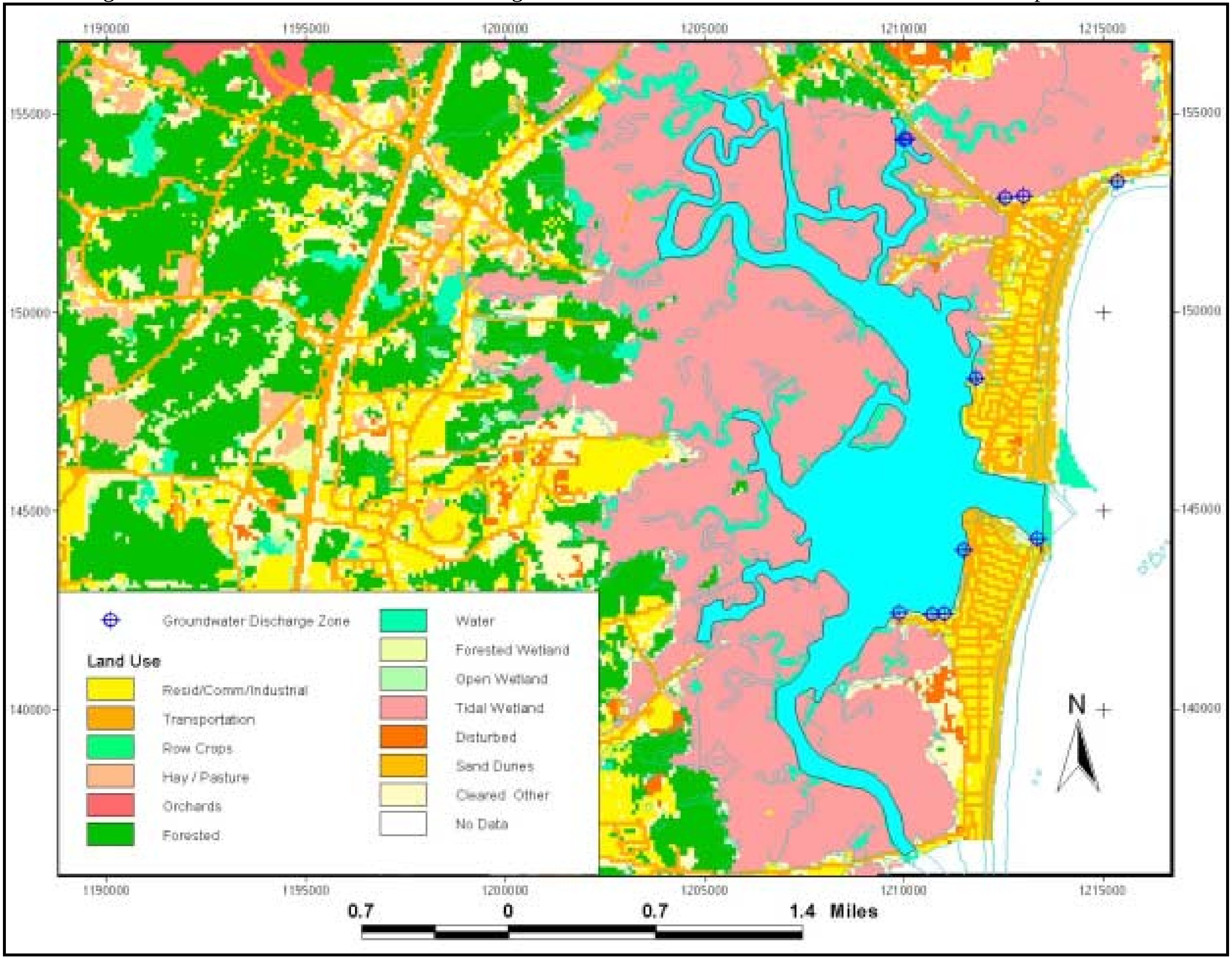
Schedule of Reporting Periods:

Report	Reporting Period	Submission Date
Progress Report #3	July 02 through Sept. 02	End of Oct. 02
Final Progress Report #4	Sept. 02 through Dec. 02	End of Jan. 03
Final Report	Jan. 02 through Dec. 02	End of June 03

E. Preliminary data

Preliminary results suggest a distinct lack of intertidal groundwater discharge zones within the salt marsh areas. This trend is consistent for nearly every site, with few exceptions. Figure 1 illustrates the location of groundwater discharge zones within transmissive materials. The correlation of discharge zones with upgradient land use is clear. Undisturbed upland marsh locations appear to yield little or no groundwater discharge at the marsh intertidal zone, whereas disturbed upland areas, with large permeable surfaces, seem to be correlated with groundwater discharge. It is anticipated that following water quality analyses, very little attendant loading from groundwater discharge will be present.

Figure 1: TIR Detected Groundwater Discharge Zones and the Correlation with Land Cover for Hampton Harbor



Effects of Land Use on Water Quality in a Changing Landscape

Basic Information

Title:	Effects of Land Use on Water Quality in a Changing Landscape
Project Number:	2002NH4B
Start Date:	3/1/2002
End Date:	2/28/2003
Funding Source:	104B
Congressional District:	
Research Category:	Not Applicable
Focus Category:	Water Quality, Non Point Pollution, Nutrients
Descriptors:	
Principal Investigators:	Jeffrey Schloss, William H. McDowell

Publication

1. J. Schloss, N. Lambert and F. Rubin. 2002. GIS Outreach and Training for Decision-makers and Educators to Ensure Data to Action in Local Watersheds. National Water Quality Monitoring Conference. Madison, Wisconsin , May 2002. (On web and CD).
2. J. Schloss 2002 Squam Lakes Watershed Study- Water and Nutrient Budget. UNH Center for Freshwater Biology/ UNH WRRC/ UNH Cooperative Extension.
3. R. Craycraft and J. Schloss. 2002. Lakes Lay Monitoring Program Annual Report for 2001. A series of more than 50 individual lake reports distributed to lake associations, towns, conservation and planning commissions, and state agencies.
4. Protecting a Postcard-Perfect Lake (Chocorua) Volunteer Monitor newsletter co-wrote with Eleanor Ely.

Objectives:

1- The continued collection and analysis of long-term water quality data in selected watersheds.
2- The dissemination of the results of the analysis to cooperating agencies, water managers, educators and the public on a local, statewide and regional basis.
3- To offer undergraduate and graduate students the opportunity to gain hands-on experience in water quality sampling, laboratory analysis, data management and interpretation.
4- To further document the changing water quality in the College Brook Watershed (at UNH) in the face of land use changes and management efforts.
5- To document the effectiveness of constructed BMPs in the Chocorua Lake Watershed
6- To finalize the data analysis of the Squam Lakes Water Nutrient Budget.
7- To determine the next steps for further analysis of long-term data sets.

Methodology

Ongoing sampling of College Brook has been done on a monthly basis and during storm events. Parameters measured include: dissolved oxygen, pH, temperature, specific conductivity, total suspended solids, total dissolved nitrogen, nitrate, phosphate, sulfate, chloride, silica, dissolved organic carbon, and base cations (Ca, Mg, Na, and K).
Lake and stream monitoring through the LLMP generally involved a minimum of monthly sampling from spring runoff through lake stratification, and weekly to bi-weekly sampling from stratification until fall overturn. Water clarity, chlorophyll a, acid neutralizing capacity, disoolved organic color, dissolved oxygen and nutrients (total N, total P and nitrate) was the default suite of parameters measured for lakes while nutrients, turbidity, color and flow were the parameters of choice for the lake tributary work. On occasion, student field teams traveled to join the volunteer monitors to perform quality assurance checks and do more in-depth analysis and lake profiling. Land cover changes to study subwatersheds were documented on our established GIS data base and new management practices or conservation efforts were also documented. Particular emphasis was placed in the Chocorua, Ossippee River and on the Squam Lakes watersheds this year.
This project was coordinated from the University of New Hampshire, which supplied the office and laboratory space (analytical and computer). The Center for Freshwater Biology Analytical Water Quality Laboratory has a Quality Assurance Project Plan for surface water analysis on file with the US Environmental Protection Agency Region 1 Office (EPA New England). Besides nutrient analysis (Total Phosphorus, Total Nitrogen, Nitrate), other water quality measurements included chlorophyll a, dissolved oxygen, dissolved CO_2, acid neutralizing capacity, specific conductivity, pH, ORP, turbidity, water clarity, iron and E.coli. The Water Quality Analysis Laboratory of the NH WRRC uses automated flow injection analysis, ion chromatography, and high temperature combustion techniques for water quality analysis.
UNH Cooperative Extension and the Natural Resource Department provided vehicles for travel for PI's, students and interns at a cost (mileage) basis. A dedicated GIS PC NT workstation was provided for use including Arc/Info and ArcView Software, ArcView Extensions: Spatial Analyst, 3D Analyst, Image Analysis and ArcPress. This was used in addition to other data input PC stations, laser printers and a large format (36" wide) ink jet plotter that was made available for the project.
The project utilized an extensive GIS database for the study subwatersheds created through previous WRRC funding to the PI. Updated and additional GIS data including a new land cover dataset for 2000 as well as an index of impervious surface cover was made available through the UNH Complex Systems Research Center which manages the NH GRANIT statewide GIS data depository. The extensive data directory contains statewide GIS data layers (usually at 1:24,000 scale) including hydrology, geology, soils, National Wetlands Inventory, land-use, land cover, and digital elevation models. Also available are Landsat Thematic Mapper, SPOT Panchromatic and digital orthophoto imagery.

Principal Findings and Significance

Comparisons between data collected in 1991 and 2000-present have indicated that overall water quality has improved in College Brook with the closing of the UNH incinerator and greater ecological awareness on campus. Recent water quality analysis (2000-2003) indicates that the drought of 2001 has a significant effect on water quality. It was the third driest year for the state of New Hampshire for 1895-2003 and water chemistry indicated that the health of the stream was at its lowest for some parameters (TDN, nitrate, ammonium, BOD, etc…). Construction on campus has also likely had an impact on stream quality and in 2001 construction occurred in close proximity to the stream in the watershed. Construction accidents (i.e. - water main break) caused large runoff discharges into College Brook and likely had effects on the stream, which further complicates the picture. Further analysis of the data and continued monitoring of College Brook is scheduled to continue. The College Brook web site can be viewed at http://www.wrrc.unh.edu/collegebrook/college_brook.htm

Ongoing collection of ambient water quality data across the state continues. We added new sites for our statewide lake study.). In 2002 we saw an additional 309 samples collected, a 12% increase over 2001 (in chlorophyll and color samples which all participants measure) with a greater than 36% increase occurring in the Lakes Region. In addition, as this year's project goals also including an increase in tributary sampling in particular, we added an additional 293 Total Phosphorus samples in 2002 over 2001. All but 18 of these were from Lakes Region participants. This is particularly impressive given that dry summer conditions did not allow for many tributary sampling opportunities on smaller streams for the addition of 4 new lakes and a river watershed, and the expansion of programs on 12 other lakes with the addition of 21 new or reactivated lake sampling sites and 32 tributary sites (Table 1). It also facilitated the training of 22 new volunteer monitors.

TABLE 1: Program Expansion

Lake/River	Association/Sponsors	Town(s)
New Programs Initiated in 2002:		
Burns Pond	UNH Cooperative Extension and Coos Cons. District	Whitefield
Cherry Pond	UNH Cooperative Extension and Coos Cons. District	Jeffreson
Durand Pond	UNH Cooperative Extension and Coos Cons. District	Randolph
Martin Meadow Pond	UNH Cooperative Extension and Coos Cons. District	Lancaster
Saco River**	Green Mountain Conservation Group	Ossipee, Freedom, Tamworth, Sandwich
Existing Programs Expanded (new monitoring sites) in 2002:		
Big Dan Hole Pond	Dan Hole Pond Watershed Assn.	Tuftonboro, Ossipee
Bow Lake**	Bow Lake Campowners Assn.	Strafford, Northwood
Lake Chocorua**	Lake Chocorua Ass'n.	Tamworth, Albany
Great East Lake**	Great East Lake Association	Wakefield
Lake Kanasatka**	Lake Kanasatka Watershed Assn.	Moultonboro
Little Dan Hole Pond	Dan Hole Pond Watershed Assn.	Ossipee
Newfound Lake**	Newfound Lake Region Assn.	Alexandria, Bristol, Bridgewater, Hebron
Ossipee Lake, Broad Bay	Broad Bay Association	Ossipee, Freedom
Squam Lakes**	Squam Lakes Association	Ashland, Holderness, Sandwich, Center Harbor
Lake Winnipesaukee, Moultonboro Bay	LWA* and Tuftonboro Assn	Tuftonboro, Moultonboro
Lake Winnipesaukee, Meredith Bay	LWA and Meredith Rotary Club	Meredith
Lake Winnipesaukee, Wolfeboro Bay	LWA and Town of Wolfeboro	Wolfeboro
Lake Winnipesaukee, Green's Basin	LWA and Town of Wolfeboro	Moultonboro
Lake Winnipesaukee, Broads	LWA	Guilford, Alton

* LWA= Lake Winnipesaukee Association
** Tributary monitoring expanded or initiated

The Lake Chocorua BMP Evaluation Study continued to disclose that a significant reduction in the phosphous loading was due to the road drainage mitigation techniques. The combination of the use of plunge pools, diversions to settling areas and a large collecting swale reduced loadings during storm events by 82-94% while control sites only varied by plus or minus 10%. The P concentration range from the runoff was again reduced significantly (pre-range of 34 to 281ppb post range of 13 to 32 ppb). Further monitoring was initiated to capture spring runoff and additional storm events but draught conditions limited the additional data collection. It is expected that the upcoming spring melt of 2003 will exhibit more “typical” spring runoff conditions. Preliminary testing of periphyton samplers with corresponding miniature data loggers for compensating for temperature and light conditions as part of this prject was used as the basis to secure EPA NPS program funding to continue investigating the wetland effects on water and nutrient flux as part of our landscape level analysis.

Analysis of the Squam Lake Watershed nutrient budget disclosed that subwatersheds with construction activity or active agriculture were the largest contributor of phosphorous on an aerial (load per hectare) basis. Highest loadings on a volumetric basis were typical of beaver flows and wetland or ponded drainage during certain times of the year (although many wetlands shunyed nutrients until the end of the growing season. Also, unlike Lake Chocorua, septic systems played a significant role in nutrient loading during the summer season. An analysis of landscape features and nutrient loadings is currently underway as a dissertation research study.

<u>Students involved or funded (#, undergrad, Masters, and PhD)</u>

Shane Bradt- -	Zoology	Grad student (PhD)	Summer/Fall/Winter
Autumn Carlson	Environmental Conservation	Senior	Summer/Fall
William Clark	Environmental Conservation	Senior	Summer/Fall
Robert Craycraft	Water Resources	Grad Student (MS)	Summer/Fall/Winter
Gregg Decelles	Marine & Freshwater Bio	Sophomore	Summer
Melissa McCartney	Forestry	Senior	Fall/Winter
Juliette Nowak	Zoology	Grad student	Summer
Lydia Pitkin	History	Sophomore	Fall/Winter
Kirsten Pulkkinen	Environmental Conservation	Senior	Summer
Santhana Souksamrane	Undeclared	Freshman	Fall/Winter
Amy Surprenant	Business	Sophomore	Fall/Winter

Total of 8 undergraduate, 2 masters and 1 doctoral student(s) directly supported. Indirect support (equipment loan, analytical services, field support) given to an additional 6 undergraduates and 3 MS students.

In addition: water quality and GIS data were used in:
WARM 604- Watershed Hydrology -11 students
Zoology/Botany 719/819- Field Limnology- 18 students
Biology/Zoology 896- Multidisciplinary Lake Management- 5 students
WARM 721-Ecology of Polluted Waters- 16 students
NSF Funded: Project Lake Watch

Presentations by Jeff Schloss covering all or parts of study or data base:

North American Lake Management Society/EPA/ NC Lake Management Society.	Southeastern Lake Management Conference	March 2002 Winston-Salem, NC	Invited plenary: "Successful Watershed Stewardship-Volunteers make it happen." and technical presentation: "In-vivo Chlorophyll Fluorescence: The good, the bad and the algae".
University of Maine Water Resources Research Center	Maine Water Conference	May 2002 Augusta, ME	Invited Plenary: "GIS Applications for Inland Watershed Management"
National Water Quality Monitoring Council	Third Annual Water Quality Monitoring Conference	May 2002 Madison, WI	Presented: GIS Outreach and Training for Decision-makers and Educators to Ensure Data to Action in Local Watersheds".
New England Chapter-North American Lake Management Society (NALMS)	2002-New England Lakes Conference	June 2002 Springfield, MA	Presented Workshop: "GIS Watershed Inventories- A guided Tour". Presented NALMS welcome for opening plenary.
New Hampshire Lakes Association	Annual Lakes Congress	June 2002 Manchester, NH	Invited panel speaker: "Carrying Capacity of NH Lakes".
Mount Washington Hotel	Centennial Celebration	August 2002	Invited to present: "Global Change in Climate, Water and Population. What it may mean for New England".
Alberta Lake Management Society	2002 Annual Meeting/Workshop	September 2002 Red Deer, Alberta, Canada	Invited to present plenary: "Successful Watershed Stewardship-Volunteers make it happen."

North American Lake Management Society/EPA/.	International Lake Management Symposium	November 2002 Anchorage, AK	Invited plenary speaker and technical presentation: “In-vivo Chlorophyll Fluorescence: The good, the bad and the algae”.
USDA CSREES Regional Water Quality Working Group	2002 Annual Meeting	December 2002 Warwick, RI	Invited presenter: “Spatial Technology Training for Water Resources Protection”

Information Transfer Program

USGS Summer Intern Program

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 RCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	10	0	0	0	10
Masters	3	0	0	0	3
Ph.D.	2	0	0	0	2
Post-Doc.	0	0	0	0	0
Total	15	0	0	0	15

Notable Awards and Achievements

Publications from Prior Projects

None